GEOLOGISCHE BUNDESANSTALT

MAGYAR ÁLLAMI FÖLDTANI INTÉZET
1869
GEOLOGICAL INSTITUTE OF HUNGARY

ADVANCES
in
Austrian—Hungarian Joint Geological Research

1000 YEARS AUSTRIA & 1100 YEARS HUNGARY

ADVANCES

in

Austrian—Hungarian Joint Geological Research

Detail of the page "Hungaria" of the Mercator—Hondius' Atlas, published 1607

Marsigli, Luis Ferdinand: Carte Partculière de La Hongrie et de le Danube. La Haye, 1741

Budapest, 1996

ADVANCES

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GEOCHEMISTRY, PETROLOGY & APPLIED GEOLOGY

Directors' Preface

A formal cooperation agreement between the Geological Survey of Austria (Geologische Bundesanstalt, GBA) and the Hungarian Central Office of Geology (Központi Földtani Hivatal, KFH) was signed in 1968.

In 1988, on the 20th anniversary of this agreement, it was decided to present the achievements of joint research in jubilee publications.

Due to technical and organisational problems encountered in both countries the publication suffered considerable delay. However, two parts of the jubilee volume (Jubiläumsschrift 20 Jahre Geologische Zusammenarbeit Österreich–Ungarn — A 20 éves magyar–osztrák földtani együttműködés jubileumi kötete) were issued in 1991 and 1994, respectively.

Teil 1.–1. rész, S. 1–400 old., eds. H. LOBITZER & G. CSÁSZÁR, Wien–Bécs, Sept. 1991

Teil 2.–2. rész, S. 1–520 old., eds. H. LOBITZER, G. CSÁSZÁR & A. DAURER, Wien–Bécs, Nov. 1994

Part 1 contained 21, Part 2 27 scientific papers from the fields of Stratigraphy and Facies, Tectonics and Palaeogeography, Environmental, Engineering and Hydrogeology, Raw material Geology (Mineral Resources), Geophysics and Museum Collections.

In the Directors' Preface, the historical background has been briefly reviewed, so there is no need to elaborate on this here.

Furthermore, a special issue of "Geophysical Transactions" was also published by ELGI in 1991.

Joint research has been going on ever since, in spite of the reorganisation and severe budget cuts which affected in particular MÁFI and ELGI in 1993–1994.

The double state anniversary occurring in 1996 (1100 years of the Hungarian state and 1000 years of the Austrian one) provides us with an excellent opportunity to continue our reporting on the advances of joint Austrian–Hungarian geological research. The much shorter time span concerned and the very considerable reduction of MÁFI's scientific staff are the main reasons for the much shorter extent of the present volume as compared to the two previous ones. Nevertheless it offers a certain insight into the variety and the results of joint research, which hopefully will go on successfully in the future, too.

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GAÁL GÁBOR
Magyar Állami Földtani Intézet

Editors' Introduction

The language of this volume, in contrast to the preceding two geological jubilee publications, is uniformly English. However, Abstracts are presented also in German and Hungarian. In all other aspects the same format and setting have been adopted. Technical editing was done this time not in the GBA, but in the MÁFI in Budapest.

The co-editors take advantage of this opportunity to express their sincere thanks to all the responsible authors of the present volume for their cooperative spirit and kind understanding, as well as to those members of MÁFI's staff who were involved in the cumbersome procedure of technical editing, in particular: M. Csongrádi, D. Szilágyi, A. Pentelényi, D. Simonyi and I. Tiefenbacher.

HARALD LOBITZER
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HISTORY OF GEOLOGY

Ups and Downs — the Hungarians in the Austrian Empire from 1740 through 1869

ENDRE DUDICH*

Keywords: history of geological science, Austria, Hungary

Motto: *Unless we study the past, we misunderstand the present, and shall spoil the future.*

Abstract

The widely changing Austrian–Hungarian relations are reviewed from MARIA THERESA to FRANZ JOSEPH I, in the context of economic, social and political events. Special attention is paid to the development in the field of geological sciences, from the creation of the Mining Academy at Selmecbánya (Schemnitz, Banská Štiavnica) in 1763 to the founding of the Royal Hungarian Geological Institute in 1869.

Zusammenfassung

Die ziemlich wechselhaften österreichisch–ungarischen Beziehungen werden kurz besprochen, von MARIA THERESIA bis FRANZ JOSEF I, im Zusammenhang mit den wirtschaftlichen, gesellschaftlichen und politischen Ereignissen. Besondere Aufmerksamkeit wird der Entwicklung auf dem Gebiet der geologischen Wissenschaften gewidmet, von der Rangerhöhung der Schemnitzer (Selmecbánya, Banská Štiavnica) Bergschule zur Bergakademie im Jahre 1763 bis zur Gründung der Ungarischen Geologischen Anstalt im Jahre 1869.

Összefoglalás

A változékony osztrák–magyar viszony alakulását mutatja be röviden a dolgozat, MÁRIA TERÉZIÁtól I. FERENC JÓZSEFig, a gazdasági, társadalmi és politikai eseményekkel összefüggésben. Különös figyelmet szentel a földtani tudományok területén bekövetkezett fejlődésnek, a selmecbányai (Schemnitz, Banská Štiavnica) Bányászati Iskola akadémiai rangra emelésétől (1763) a Magyar Királyi Földtani Intézet megalapításáig (1869).

Introduction

The present historical review aims at providing the reader of this volume with a —however sketchy— social, economical and political background prior to the founding of the Royal Hungarian Geological Institute in 1869.

Such an undertaking has to be, by its very nature, selecitve. For this reason, it is, to some degree, inevitably subjective. The author, who beside being a geologist by profession, was involved in studies on the history of geological sciences for twenty years, did his best to avoid extremist views and possibly not to offend anybody. If he failed in this point, the reader is asked to kindly accept his sincere apologies.

"Our life and blood — yes, our privileges — no!" (1740–1780)

As it had been duly prepared by the Pragmatica Sanctio (1713, 1723), His Majesty the German–Roman Emperor CHARLES VI (as King of Hungary, CHARLES III) was succeeded on the Hungarian throne by his daughter MARIA THERESA in 1740. In the same year, FRIEDRICH II (later surnamed the Great) became King of Prussia.

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The stage was set for the Seven year War of Austrian succession (1741–1748 — a struggle for hegemony between the Hapsburg and the Hohenzollern dynasties.

The young Empress of Austria and King of Hungary badly needed the support of the Hungarian nation, i.e. the clergy and the noblemen. She was the "King" and not the "Queen" of Hungary: the traditionalist Hungarians insisted on her being their " Rex" and not "Regina". At the 1741 "Dieta" (National Assembly) MARIA THERESA asked them for support.

A historical anecdote characterises well the attitude of the Hungarian deputees. When their sovereign appeared with her little son (who was to become King JOSEPH II), they enthusiastically aclaimed her (in Latin):

"Vitam et sanguinem pro rege nostro Maria Theresia!" (Our life and blood for our King Maria Theresa!)

But, in order to avoid possible embarrassing misunderstandings, they hastily added:

"Sed avenam non!" (But our crops not!)

They were jealous on their income and even more jealous on their privileges dating back to dynasties that had preceded the Hapsburgs on the Hungarian throne.

Some of these fundamental rights, however, represented serious obstacles to social and economic progress.

The Seven year War ended with the Aachen Peace Treaty in 1748. FRANZ STEFAN OF LOTHARINGIA, MARIA THERESA's husband, was acknowledged Emperor of the Holy German–Roman Empire.

MARIA THERESA did not forget the military assistance she had been given by the Hungarians. She initiated a policy fostering the development of industries in Hungary. This was of considerable economic importance.

It had a deep psychological impact that in 1751 she —for the first time during the Hapsburg domination over Hungary, i.e. since 1526— addressed the Hungarian National Assembly in Hungarian.

The euphory did not last long. As soon as in 1754, a new Customs Law made Hungary very much dependent from Austrian industry and trade.

The Hungarians did not react promptly this time. During the renewed hostilities with Prussia, general A. HADIK with his Hungarian light cavalry (the famous Hussars) eventually entered Berlin. Young Hungarian noblemen felt deeply honoured to be accepted to serve in the Hungarian Noble Guards which MARIA THERESA set up in 1760. Some of these young officers contributed considerably to the intellectual renewal in Hungary.

The opening of an Imperial Stock Exchange House in Vienna (1761) marked the beginning of a new stage in the economic development of Austria.

Two years later the Hubertusburg Peace Treaty reestablished the Status quo between the Austrian Empire and the Prussian Kingdom.

In the same year 1763, MARIA THERESA promoted the Mining School (Bergschule) of Selmecbánya (Schemnitz, Banská Štiavnica), in operation since 1735, to the status of Mining Academy (Bergakademie), the first one of this kind in Europe.

This had an almost incredible impact on the further development of fundamental and applied earth sciences, chemistry and metallurgy, until the final disintegration of the Empire in 1920, as a consequence of the Trianon Peace Treaty. The Academy then moved to Sopron (Ödenburg), and in the 1950-ies it was step by step transferred to Miskolc in NE Hungary. Only the Faculty of Forestry, founded in 1809, has been left in Sopron, and is functioning as the University of Forestry and Timber Industry, recently gradually expanding.

An early fruit was Italian-born G. A. SCOPOLI's „Crystallographia hungarica" published in Prague in 1776.

MARIA THERESA put in practice a rather flexible policy concerning Hungary. She insisted on essential social reforms, but tried to assure the goodwill of the Hungarian nobility and clergy by organisational and administrative measures favourable to them. Just a few examples should be mentioned here.

1765 MARIA THERESA tries to diminish the economic burden of the serfs. The Hungarian nobility displays a furious resistance. Nevertheless they accept crown-prince JOSEPH as a co-ruler.

1766 the feudal counties (comitates) of Hungary are obliged to establish orphan homes for abandoned children.

1767 The freedom of displacement of serfs is restituted.

1769 Transylvania is elevated to the status of Grand Duchy (Grossfürstentum).

1770 A Faculty of Medicine is established at the University of Nagyszombat (Tirnau, Trnava), founded by the jesuit Cardinal P. PÁZMÁNY, archbishop of Esztergom, in 1635.

1771 MARIA THERESA orders to transfer St. STEPHEN's relic (his preserved right hand) from Raguza (Dubrovnik) to Buda. She declares the 20th of August St. STEPHEN's day — a national holiday up to present.

1773 After the division of Poland in 1772, the 13 Szepes (Zipser) towns come back to Hungary.

— MARIA THERESA issues the Ratio Educationis, a full-fledged educational system for the Empire. The draft had been produced by three Hungarians.

1777 The university moves from Nagyszombat to Buda (Ofen) and in 1784 to Pest. This is the present-day L. Eötvös University (named after the inventor of the torsion balance), two faculties of which —Theology and Medicine— have become independent in the meantime. (These are the Semmelweis University of Medicine and the P. Pázmány Theological Academy).

1778 The military frontier zone of Bánság is reintegrated into Hungary.

MARIA THERESA, who —in spite of "family quarrels"— was held in great esteem by the Hungarians, passed away in 1780.

From enlightened absolutism to prevention by execution (1780–1795)

MARIA THERESA'S co-ruler and now successor, JOSEPH II, was deeply convinced that the Empire has to be radically reformed "from above", but conserving and even strengthening its unity. He was also firmly decided to avoid the trap of searching compromise with the nationalist, but at the same time ultra-conservative nobility and clergy of Hungary. Declining to oblige himself with a solemn oath to respect the "Hungarian Constitution", which he considered an obsolate list of fossilised privileges, he refused to be crowned with St. STEPHAN's Holy Crown. That is why the Hungarians dubbed him "the King with the hat".

During the ten years of his rule, JOSEPH II proceeded to quite a number of drastic reforms, partly inspired by his idea(l)s of free-masonry.

1783 Serfdom is abolished in Transylvania.

1784

— Full freedom of commerce is declared within the Empire, complemented by a strict prohibition to import any wares.
— All monastic orders are dissolved. Many of their cloisters are converted into factories.
— St. Stephan's crown is transported to the Hofburg (Imperial Castle) in Vienna. (This was ressented as a major offense by the Hungarians.)

1785

— The system of feudal counties (comitates, the fiefs of traditionalist opposition) is abolished.
— *German is introduced as the common and unique official language of the Empire,* replacing the still surviving medieval Latin in Hungary.

There was such an uproar that Joseph II, with his death approaching (1790) had to retract all his reforms, except the Act of Tolerance.

LEOPOLD II mounted the throne of the Empire right after the French Revolution. He ruled only for two years, but his successor FRANZ II (for Hungary, FRANZ I) was just like him decided to prevent a similar disaster in the Austrian Empire. He succeeded in bringing together, readily supported by Britain, a *Great Coalition* against the revolutionary France in 1793 (dividing, by the way, Poland for the second time.)

In 1794, he prohibited the activity of freemasons.

Spirits were deeply divided in Hungary at that time. The traditionalists were relieved by the anti-revolutionary and even in most cases anti-reformist attitude of LEOPOLD II and FRANZ I.

However, there were also intellectuals who cherished liberal, reformist and progressive ideas. The freemason IGNAZ VON BORN (the living model of MOZART's Sarastro) had succeeded in organising the *First Congress of Naturalists* at Szklenófürdő (Sklené Teplice) in 1786. On this occasion the first international professional society was founded: the *Mining Society*, which acquired members even in France and America.

Even the revolutionary ideas found enthusiastic adepts in Hungary: a clandestine *Club of Hungarian Jacobins* was formed in 1792.

This was one step too far. After the execution of King LOUIS XVI and his Queen MARIE ANTOINETTE — a Hapsburg princess — in 1793 the leaders of the Club were arrested and accused with conspiration. Five of them, including the ex-abbot and chemist IGNÁC MARTINOVICS, were publicly executed in Buda, in 1795. The site of their execution, at the foot of the Royal Castle of Buda, is called Vérmező (Blood Field) up to the present day.

The shadow of Napoleon and the Holy Alliance (1795–1820)

For twenty years, the history of Europe was determined by the breath-taking rise and double fall of a Corsican star: NAPOLEON(E) B(U)ONAPARTE, lieutenant of the artillery, brilliant young general of the French Republican Army, First Consul of the French Republic (1799), self-crowned Emperor of France (1804), husband of MARIA LUISA, Emperor FRANZ's daughter (1810), exiled first to the island of Elba, and after a remarkable l00-days return definitively to St. Helena (1815).

NAPOLEON endangered Vienna as early as 1797 and defeated the Austrian army at Marengo in 1800. His marshall MURAT entered triumphantly Vienna in 1805. After the battle of Austerlitz at the end of that year, the Pressburg Peace Treaty slightly relieved the dangerous pressure on Austria. Nevertheless, FRANZ II resigned from the throne of the German–Roman Empire — an event that marked the end of a 844-year old Empire.

The Tilsitt Peace Treaty of NAPOLEON with Tsar NICOLAS I produced a new political division of Europe in 1807.

In the same year, the Hungarian National Assembly was convened not to Pozsony (Pressburg), but —for the first time— to Buda.

This peace was nothing more than kind of an interact. A new French-Austrian war broke out in 1809, which resulted in a genuine disaster for the Austrian Empire. The French Army occupied Vienna. Moving farther, it defeated the Austrian and Hungarian joint forces at Győr (Raab) in Hungary, and other Austrian ones at Wagram.

Count STADION was replaced by Prince K. L. von METTERNICH. On 14 October a peace treaty was signed at Schönbrunn Castle. Austria lost the Adriatic region (becoming the Illyrian Provinces) and Galicia.

In 1810 NAPOLEON even married MARIA LUISA, a daughter of Emperor FRANZ II.

The rest of NAPOLEON'S trajectory is well-known. The disastrous campaign of the Grande Armée against Russia in late 1812, the Battle of Peoples at Leipzig in 1813, resignation at Fontainebleau, exile on the island of Elba, return and the fatal battle at Waterloo in 1815, exile on St. Helena and death (1821).

The *Congress of Vienna* reorganized Europe once more, this time under the auspices of the *Holy Alliance*, so dear to the heart and mind of Prince METTERNICH. In 1820 it was confirmed at Trappau, with a declaration that all kinds of liberal movements have to be suppressed.

"Inter arma silent musae." Nevertheless, sciences in general and earth sciences in particular were not entirely silent during those movemented years.

In Jena, Saxony, a *Mineralogical Society* (Mineralogische Societät) was founded in 1796, which counted several active members from Austria and Hungary. Even its first President was a young Hungarian aristocrat, traveller and mineral collector, Count DOMOKOS TELEKI. He was in office for one year only; he untimely passed away in 1798.

In 1802, Count FERENC SZÉCHENYI created the Hungarian National Museum in Pest.

The Selmec Academy continued to be very active (see ZSÁMBOKI's paper in the present volume). F. MOHS was charged by the Viennese Court in 1804 to supervise it, along with all mines in Hungary and Transylvania. (See in the paper of SCHEDL & SCHERMAN, this volume.)

JÓZSEF JÓNÁS founded a *Mineralogical Society* (Montangesellschaft) at Selmecbánya in 1811.

K. A. ZIPSER published an important book in Sopron (Ödenburg) in 1817: *"Versuch eines topographisch-mineralogischen Handbuchs in Ungarn",* listing 258 (!) mineral localities.

The year 1818 was marked by the travel in Hungary of F. P. BEUDANT from France (see BREZSNYÁNSZKY's paper in this volume.)

In 1820 J. JÓNÁS, already in charge of the Natural History Collection of the Hungarian National Museum, launched in Pest a publication entitled *"Physiotechnographisches Magazin über die anorganische Natur des oesterreichischen Kaiserstaates,"* which might have become the first scientific journal of the Empire. Unfortunately enough, his untimely death next year (February 1821) cut short this very promising initiative.

Cultural and political revival (1820–1848)

Since MARIA THERESA's times, a relatively small but extremely enthusiastic group of Hungarian intellectuals were stubbornly working on the renewal of Hungarian culture. They adopted and tried hard to adapt new ideas, coined new words for them, revised the grammar and the vocabulary of the Hungarian language.

This movement produced an interesting work also in the field of geological sciences. In 1822, MIHÁLY KOVÁCS published a nine-language Mineralogical Dictionary (*Lexicon mineralogicum enneaglottum.* Pestini, 4 partes.) The nine languages were: English, Danish, French, German, Hungarian, Italian, Latin, Russian and Swedish.

This movement was not confined to language problems. Its adepts were very active in literature —specially in poetry— and fostered all kinds of economic and scientific activity. Most of them were sons of the "middle" and "lower" nobility (including MARIA THERESA'S "guard poets"), but some high-class aristocrats also revealed themselves as true patriots. One of these was Count ISTVÁN SZÉCHENYI, a gallant cavalry captain ("Steffl"), a veteran of the Napoleonic wars, who travelled extensively in Western Europe. His economic and political views were based on his experience of and sympathy to Britain. (His adversaries even accused him of anglomania.) Back to Hungary, he unfolded an almost incredible activity. In 1825, he proposed to found a *Hungarian Academy of Sciences* (which, in fact, became operational in 1830). During the 30-ies and 40-ies, he introduced in Hungary, or helped to create, a great number of institutions and activities of extraordinary variety. Such were e.g., in finances: savings banks, credit transactions, in social life: clubs, casinos, horse racing and yachting, in the field of practical innovations: steamships, railways, steam mills, regulation of the rivers Danube and Tisza, and the first permanent bridge connecting Buda with Pest. This bridge, the Chain Bridge, now bears his name.

By far not all Hungarian patriots focussed their efforts on such practical and profitable aspects of the reform activities. Many of them got deeply involved in politics, characterised by a large spectrum ranging from (rare) loyalism to openly anti-Hapsburg independentism.

One of these was LAJOS KOSSUTH who founded his fame and popularity with his *"Reportages"* from the 1832–36 National Assembly.

In 1835, Emperor FRANZ II was succeeded by FERDINAND V. The real power, however, was in the hands of Chancellor Prince METTERNICH, who, no wonder, was far from being happy with the growth of Hungarian nationalism. Whether labelled reactionary or liberal, it undoubtedly represented a potential danger to the monolithic unity of the Empire. Its "left wing" was rather suspect even from the point of view of the Holy Alliance.

Due to the remarkably efficient network of his secret police, METTERNICH was very well informed. He did not hesitate to take the measures he considered appropriate. L. KOSSUTH, BARON M. WESSELÉNYI and other leaders of the radical opposition were arrested in 1837. Thanks to a reasonable compromise worked out by F. DEÁK, they were set free in 1840.

The following years were very productive indeed.

1840

— At the Selmec Mining Academy, an independent Department of Mineralogy and Geognosy is created.

— The Union of Hungarian Physicians and Naturalists is founded. (It still exists under the name "Natural Sciences Society").

1841

— L. KOSSUTH becomes the (first) editor of the newspaper *"Pesti Hírlap".*

— The periodical *Természettudományi Közlöny* is started. (Its present name is *Természet Világa*, World of Nature).

1843

— The Selmec graduate Á. KUBINYI is appointed Director of the Hungarian National Museum.

1844

— The National Assembly passes the so-called *Language Act*, declaring that the official language of Hungary is henceforward Hungarian. (It replaces Latin, a medieval heritage and a most convenient tool of resistance against German.)

— The principle of general sharing of taxation is accepted. This is the first great victory of the reformers over the stubborn and short-sighted conservatives.

1847

— In Sopron (Ödenburg) the idea of creating a Hungarian Geological Society is brought up at a meeting of the Union of Hungarian Physicians and Naturalists.

— A Mining Academy is founded in *Leoben*, Austria — in case anything would negatively affect the Selmec one.

1848

— On 5 January, in the mansion of the KUBINYI family at Videfalva (now Vidina in Slovakia) the Hungarian Geological Society is formally founded.

The Spring of Peoples in 1848 brought about revolutionary upheavals in Western and Central Europe.

The example of Paris was followed by Vienna on 13 March, and METTERNICH had to leave in a considerable hurry (to Britain).

15 March is the long-expected great day for the Hungarians, with the 12 points of Revendications of the Hungarian Nation. (A national holiday even at present — after the years of interruption during the communist rule). A responsible, democratic Hungarian government is set up, headed by Count LAJOS BATTHYÁNY as the Prime Minister.

The whole Empire is in effervescence. End of March RAJAŠIĆ Serb patriarch claims autonomy for the Serbs. On 21 May the Romanians claim their rights at Balázsfalva, protesting against the union of Transylvania with Hungary. On 15 May, there is a second uprising in Vienna and the Imperial Court leaves the capital. On 11–17 June the wave of demonstrations attains Prague, but this uprising is oppressed by military power.

Behind the scene, however, serious counter-moves are being made. On behalf of the Emperor, the young crownprince FRANZ JOSEPH and the Tsar of Russia NICOLAS II agree to join forces against Prussia on one hand, and against Hungary striving for independence on the other.

The armed confrontation is obviously inevitable. On the 11 July L. KOSSUTH proclaims: "Our mother country is in danger!"

SZÉCHENYI's beautiful dream of peaceful progress by joined forces became cruelly dissipated by macchiavellic reality.

The Emperor FERDINAND V on September 9 signs a decree abolishing all feudal burdens and serfdom.

A glorious disaster and a disastrous victory (September 1848–October 1849)

These thirteen months weigh as many years.

They comprise what is called by patriotic Hungarians "the War for Freedom", while by the partisans of the Hapsburg dynasty — a most disloyal revolt against His Majesty the Emperor and King.

It began in a rather odd way.

The Court and the Chancellery had succeeded in persuading Baron I. JELAČIĆ (JELLASCHITSCH, JELLASICS) who was nominated Ban (Governor) of Croatia on 22 March 1848 to marsh with his troops against the "Hungarian rebels".

The battle of Pákozd on 29 Szeptember ended with the crushing victory of the newly-born Hungarian army of "Honvéds (Defendants of the Mother-country".)

A complicated series of campaigns followed, Prince WINDISCHGRÄTZ being the Commander-in-Chief of the Austrian army (who succeeded in crushing revolutionary resistance in Prague and Vienna) and general ARTUR GÖRGEY that of the Hungarian one.

The *"divide et impera"* strategy of the Imperial Court and the nationalist intransigence of the Hungarian noblemen combined resulted in a kind of "neutrality" of the majority of the other ethnies of the Empire (northern and southern Slavs, Romanians etc.)

It is worth of mention that Count LÁSZLÓ TELEKI, the Ambassador of the Hungarian Government in the revolutionary Paris, almost succeeded in establishing a *"Danube Confederation"* consisting of the non-Austrian parts of the Empire. Full agreement had been reached by the negotiating partners — but L. KOSSUTH declined it. TELEKI, deeply disappointed and as a manifest sign of protest, resigned from his post. (It is the irony of history that two years later, in 1851, when it was no more feasible, KOSSUTH came back to the idea, and the plan became public as late as 1862. This is why he is often credited for it.)

The BATTHYÁNY government demissioned and Kossuth's Commission of National Defense seized the power on the 16 September.

The Hungarian National Assembly refused to accept the change on the throne that occurred in Olmütz (Olomouc) on 2 December 1848, FERDINAND V resigning in favour of FRANZ JOSEPH I (aged 18 at that time). They even undertook an irrevocable and fatal step: in the Calvinist Great Church of Debrecen in Eastern Hungary the *destitution of the House of Hapsburg from the Hungarian throne* was solemnly declared on the 14 April 1849. L. KOSSUTH was elected Governor of Hungary.

The reaction was logical, predictable and inevitable. The young Emperor called for the military intervention of the tsar, as stipulated by the Warsaw Agreement. It was granted, and the Russian troops came, under the command of Marshal T. F. PASKEVICH, the "hero of Yerevan", oppressor of the Warsaw insurrection of the Polish in 1831.

The decisive battle was fought at Temesvár (Timişoara) on 9 August. The overwhelming Russian force defeated the Hungarian army. General GÖRGEY surrendered to Paskevich at Világos on the 11 August 1849.

The Empire was saved — but it never became again what it had been.

The Governor, L. KOSSUTH, left Hungary at Orsova to Turkey.

From hard repression to soft compromise (1849–1867)

The former Prime Minister Count BATTHYÁNY did not flee. He was arrested and summarily executed on the 6 October 1848. So were also, at Arad, on the same day, 13 generals of the Hungarian army. Four of them were shot, but nine were hanged —the greatest dishonour for an officer. L. KOSSUTH and L. TELEKI were later also hanged— "in effigie", since they had emigrated.

After a hard year the bloody military repression exerted by Field Marshal Baron J. J. HAYNAU was replaced by the apparently less brutal rule of Minister of the Interior A. BACH, and in 1851 by the Governorship of Archduke ALBRECHT. The secret police took over from the patrools and pelotons of execution.

The Hungarian nation lost most of its best intellectuals: emigrated, executed, sentenced to many years of heavy jail.

It was only in 1852 that the vigour of Austrian Civil Law was extended to Hungary — a first step of restoring legality.

It was under such circumstances, when only "passive resistance" was possible, that the Hungarian Geological Society started operating in 1850 (after the establishment of the k. k. Geologische Reichsanstalt, the Imperial Geological Survey of Austria in late 1849). Professor JÓZSEF SZABÓ, who was to become its most active and successful president, was for some years "persona non grata" because his expertise had contributed to supplying the Hungarian army with home-made gunpowder.

At the end of the fifties, the French–Austrian confrontation gave rise to dangerous illusions and adventurous plans both in the emigration headed by KOSSUTH (who had passed from Turkey to Torino in northern Italy, trying to find support in Britain and in the United States) and among his fervent devotees in Hungary. But NAPOLEON III signed a treaty with FRANZ JOSEPH I in 1859, and there was no hope left for any help coming from abroad.

Count I. SZÉCHENYI committed suicide — in a lunatic asylum at Döbling near Vienna in 1860. (He had been surnamed by L. KOSSUTH, his political adversary, "the greatest of Hungarians".)

Soon both sides began to realise that the status of "frozen confrontation" (kind of a past-century version of cold war) can not and should not last for ever.

The first step was undertaken by FRANZ JOSEPH I — the "October Diploma" of 1860 to which the way was patiently prepared by F. DEÁK who has become the leader of the "moderate opposition" in Hungary.

Other troubles came: the birth of the unified Italian Kingdom in 1861, a Meeting of the Pan-Slavic Movement in Northern Hungary (now Slovakia) claiming the creation of an autonomous Slovak province within the Empire, and a war against Denmark, strangely enough in alliance with Prussia which, of course, could not be enduring.

The Hungarian National Assembly of 1865–66 paved the way to what was called *later "the Historical Compromise"* (Ausgleich, Kiegyezés). This was delayed in time but considerably promoted as to emphasising its necessity by the 1866 war of Austria against Prussia and Italy.

The defeat of the Austrian army at Königgrätz (3 July) led to the Peace Treaty of Prague (23 August 1866). Austria lost Schleswig-Holstein in the North and Venice in the South. It was high time indeed to pacify Hungary in the East...

Accordingly, 1867 became the *Year of the Compromise.*

- In February, Count GYULA ANDRÁSSY is appointed Prime minister of Hungary. The ancient Hungarian Constitution is re-established.
- In May, the Parliament ratifies the Compromise.
- In June, FRANZ JOSEPH and his wife ELISABETH ("SISSY", a Bavarian princess by birth, who has been very popular with the Hungarians) are crowned in the Holy Virgin's Church (Matthias Church) in Buda castle by St. STEPHEN's Holy Crown.

A new start (1867–1869)

The dualistic Austro–Hungarian Monarchy was born.

The Jews obtained full emancipation in Hungary in 1867. (It is to note, however, that the independent Hungarian National Assembly already in 1849 had accepted, as its last move before its dissolution, the emancipation of the Jews.) But the problems of other ethnies went on being completely disregarded. (It was the year when the *First Congress of Pan-Slavism* took place in Moscow!)

The only successful exception was a compromise reached between Hungary and Croatia in 1868. Relations have been rather troubled since the unsuccessful military adventure of Baron J. JELAČIĆ in September 1848 mentioned above. (His services were acknowledged by the Court by promoting him to Count in 1854.)

King FRANZ JOSEPH I signed the Founding Charter of the independent *Royal Hungarian Geological Institute* (Königliche Ungarische Geologische Anstalt, Magyar Királyi Földtani Intézet) on the 18 June 1869. (In Hungarian!)

This act marked the beginning of a new epoch in the history of geological sciences in Hungary. (See in *EPISODES*, by E. DUDICH, 1994).

During the last third of the past century the Monarchy in general and Hungary in particular enjoyed vigorous prosperity as far as the finances, the industry, the agriculture, and even the sciences are concerned.

However, the problem of ethnics remained a built-in bomb which went on ticking. The "big bang" came at the end of the last (and lost) war of the Empire, World War I. As a result, from the good old *"divide et impera"* only the "divide" was left. The "impera" was gone.

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ADVANCES
in
Austrian—Hungarian Joint Geological Research
Budapest, 1996

The first hundred years of teaching geological sciences at the Selmecbánya (Schemnitz) School (later Academy) of Mining

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Keywords: education, history of geological sciences, Selmecbánya School of Mining

Abstract

The Selmecbánya (Schemnitz, Banská Štiavnica) School of Mining, founded in 1735, was promoted to a Mining Academy in 1763. The development of the teaching of geological sciences is reviewed, from the beginning until 1841 and prominent 19-century Austrian and Hungarian graduates of the Academy are enumerated.

Zusammenfassung

Die Bergschule von Schemnitz (Selmecbánya, Banská Štiavnica), begründet im Jahre 1735, wurde im Jahre 1763 zur Bergakademie erhoben. Die Entwickung des Unterrichts der Geowissenschaften wird besprochen, vom Anfang bis 1841, und prominente österreichische und ungarische Absolventen der Bergakademie (XIX Jh) werden vorgestelltt.

Összefoglalás

Az 1735-ben alapított selmecbányai (Schemnitz, Banská Štiavnica) Bányászati Iskola 1763-ban lépett elő Bányászati Akadémiává. A dolgozat áttekintést ad a földtani tudományok oktatásának fejlődéséről a kezdettől 1841-ig és bemutatja a XIX. sz.-ban Selmecen végzett legnevesebb osztrák és magyar szakembereket.

Introduction

The roots of higher technical education can be found in the schools of mining and metallurgy, and in those of military engineering. It is only the organization of the army and the mining and metallurgy of the Treasury (including its enormous system of estates and forest management system covering the entire empire) that was capable of establishing the education of leading technical experts at a time when no true knowledge of natural sciences was taught in any other educational institution and technical sciences were not instructed at all.

The first educational institution of mining and metallurgy in the world was set up in the Hapsburg Empire at Joachimsthal/Jachimov in 1716. However, it only existed for a short lime. The second one organized at Selmecbánya (Schemnitz) (1735) proved to be viable. In 1920, it moved to Sopron, its successor named Miskolc University is operating even today in Miskolc, Hungary, as the oldest institute of technology in the world (ZSÁMBOKI L. 1985). The Faculty of Forestry has been left in Sopron.

The system of education at Selmecbánya School of Mining at the beginning was as follows.

In the first year, general knowledge of all branches of "mining" and mathematics was provided, whereas in the second year, each student had to study a branch he had chosen. The branches included: mine exploitation and mining legislation, mine surveying and land surveying, ore processing, metallurgy/assay of ores, mintage, separation of gold.

According to a detailed Curriculum of Studies of 1735, the geological knowledge (rocks inside and outside mines, ore bodies veins and veinlets) had to be taught within the branch of mine exploitation and mining legislation. Owing to the general education provided during the first year, every Selmec graduate had been

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taught also geology. During the walk surveys in mines which was mandatory for students of each branch, the task of the students was "to get to know and to distinguish the stretching thin veinlets and full ore bodies, the precious and common ore veins, and all kinds of ores and barren rocks" (ZSÁMBOKI, L. 1984).

However, a much more detailed idea can be formed about how geology was taught at the Selmecbánya Academy by reviewing the chapter devoted to geology in "Speculum metallurgiae politissimum" by RÖSSLER (Dresden, 1700). This was a mandatory study-book of "mining" in the curriculum of studies of the "Bergschule" (mining school).

At that time, there was no vocational education in the field of mining and metallurgy either within the Hapsburg Empire, or elsewhere in the world. Consequently, there was no teaching of geology either. (It is in 1765 that a two-year Bergakademie was established in Freiberg at which the education began in 1766.)

The re-organization of the educational institute of mining and metallurgy at Selmecbánya

It began in 1763 when N. J. JACQUIN was appointed Professor of Mineralogy, Chemistry and Metallurgy by the Vienna Court Chamber. In 1765, a Professor of Mathematics, Physics and Mechanical engineering was appointed, whereas in 1770 the appointment of a Professor of "Mining" was performed. This meant the completion of the organization of "Academica Metallurgica", a 3-department, 3-year Academy of Mining and Metallurgy. At the same time, a detailed curriculum of studies was also supplied by the Court Chamber.

During the six years that elapsed from 1764, the time when JACQUIN started giving lectures, to 1770, the time a summarizing Curriculum of Studies was prepared, there was no sign of a regular teaching of geology. JACQUIN lectured, as evidenced by a manuscript that has been preserved, on minerals and mineral chemistry, and particularly, on the knowledge and examination of ores, as well as the chemical properties of metals, etc ("metallurgy"). Obviously, the professor of the second department did not deal with geology related issues. Nonetheless, the students could not be left without geological knowledge. During the "vocational practices", walk surveys in mines, etc amounting to nearly half the educational period, the students got to know, on the site, the structure of mountains, the properties and setting of rocks, the types and positions of veins, veinlets, etc.

The reform of 1770 and its consequences until 1805

With a new summarizing Curriculum of Studies in 1770, a new chapter began in the history of not only the university teaching of mining and metallurgy — but of geology as well.

The new order of education

An organizatory structure was set up featured by a 3-year education and 3 departments each with a professor. It became operative from autumn, 1770, according to the following:

Year I: "Mathematics" (mathematics proper, geodesy, physics, experimental physics and mechanics)

Year II: Mineralogy, chemistry and "metallurgy"

Year III: Geology, mine exploitation, mining engineering, forestry and mining legislation.

As shown above, geoscience was lectured for students of two different classes (years), by two different professors. Mineralogy was lectured for the second-year students whereas geology was lectured for students of the third year. This situation ended only as late as 1840 when the lecturing of mineralogy and geology was taken away from both the professor of chemistry and the professor of geology, and a new Department of "Mineralogie, Geognosie und Paläontologie" (Mineralogy, Geognosy and Palaeontology) was established.

According to the Curriculum of Studies, the guideline for teaching geology was as follows:

1. In the practical part of Year II, during visits to plants and walk surveys in mines, the students "had to be familiarized with the structure of the earth and its mountains, the properties of various rocks, ore bodies, dykes, etc. included therein, the features of waters originating from them, consequently, the entire underground geography and hydrography".

2. For the theoretical part of Year III, the following geological curriculum of studies was specified:

a) For the students of this year the basic theorems of underground geography and hydrography lectured in Class Two should be briefly repeated, then, depending on the time available, the various kinds of middle and high mountains (in the language of miners — the downs, and the hilly, or steep mountains), their main and side valleys, rock types and ore bodies included in them, the steep, floating, or flat dykes, seams, localities and stocks, outcrops, crossing, intersection of dykes, their mineral content, and the surface features referring to minerals and metals should be lectured.

b) Although in the previous class (Class Two) the students more or less got to know the various assumptions of natural science about the way how minerals develop, increase, decrease, or weather in the bowels of the earth, nevertheless, a brief explanation to, or a description of the reasons why ores on the surface of mountains, or in the bowels thereof, become more precious or less precious, should be given to them.

c) Considering that an intelligent miner attending the second class should focus on mine waters in accordance with those lectured within the framework of theoretical hydrography, the professor should give the students an explanation to the origin of underground water springs, the path the water takes through gaps, dykes and rocks in the mine and on the surface, and should describe its hydrostatic and hydraulic basic theorems and justify them through examples.

Lecturing geology was a duty of the acting professor of mining. It was always the actual professor of mining exploitation that was responsible for lecturing geology, or when this Department had no professor (1777–1809), in such cases the professors of the other two departments performed this job alternatively.

The Professors are listed and commented on

1770–72: Chr. T. DELIUS. He wrote a book about geology.

1772–77: J. T. A. PEITHNER. He published a book. The material of his lecture matter has been preserved.

1779–88: J. SZELECZKY, an mining engineer. He had graduated from the Selmecbánya School, wrote no curriculum.

1789–90: M. PATZIER, an engineer who had graduated from the Selmecbánya School wrote a 4-volume book concerning metallurgical chemistry. It has only a few mineralogical implications.

1791–92: K. HAIDINGER, professor of mathematics at Selmec, was the author of several books on mineralogy and petrology.

1792–98: A. PRYBILLA, an engineer who graduated from the Selmecbánya School, a miner with high reputation. He wrote no curriculum.

1798–1805: J. MÖHLING, an engineer who had graduated from the Selmecbánya School, wrote a book about mining surveying.

Since the treatise on mining written by DELIUS was used at the Academy for teaching till the 20's and 30's of the 19th century, the curriculum for teaching geology was actually given. Nevertheless, on one hand, the freedom in the education and the development of sciences on the other, obviously led to changes in the teaching of geology as well. PEITHNER —directly after DELIUS— lectured according to his own conceptions! The same can be assumed about the intelligent KARL HAIDINGER who was well known all over Europe. After 1805, FRANZ REICHETZER —at the greatest astonishment of the international mining society– started following the path of WERNER'S Neptunist conception, at the time when this could not be done any more even at Freiberg. In addition, after REICHETZER had left, it continued to be the basis of teaching geology during the period LANG VON HANSTADT was the professor. LANG was an excellent mining expert with a great knowledge: his work about mine surveying obtained international reputation as proved by the matter of his lectures about mining exploitation, mining engineering, salt mining, etc. Apparently, he did not take too much care of teaching geognosy (Geognosie). Till 1840, he lectured REICHETZER'S book published in 1812, almost word by word.

The way how DELIUS taught geology

DELIUS, before getting to the Selmecbánya Academy, was already a well-established authority in not only geology but also metallurgy.

His geological papers, published in one volume, are: "A study on the development of mountains. A study on the development of ores encountered in mountains, that is, the so-called dykes and veinlets. A study on the probable way of development of ores occurring in dykes and veinlets. A study on the mineralization of metals, particularly, gold". They were published in Vienna in 1764, then in Leipzig in 1770.

During his stay at Selmecbánya, on the basis of his obligations as professor, he wrote a book of mining exploitation (1773) which was later published again, in 1778 in Paris in French, and in 1806 in Vienna in German (ZSÁMBOKI L. 1981).

He published his previous studies as a geological introduction to his book about mining exploitation. (Anl. zu der Bergbaukunst. Wien 1773. 1–113. p. *Note:* For an easier reading, the wording of the edition of 1806 issued in Roman letters will be included here. The text is idential in both editions).

The chapter devoted to geology in DELIUS' book is as follows:

"Unterirdische Berggeographie

1. Kap. Von dem (theoretischen) Theile der unterirdischen Berggeographie, oder von der innern Kenntniss der Gebirge und der Lagerstätte der Mineralien

2. Kap. Von Ihrem praktischen Theile: oder von Schürfen and Anlegung neuer Bergwerke."

Analyzing Delius's' geological views and ideas with regard to its importance for the history of science represents a special task.

PEITHNER's lecturing on geology

Unlike DELIUS who, despite his extraordinary theoretical knowledge always considered himself as a practical "miner" and also achieved similar outstanding results in practice (Resica, Szomolnok etc.), PEITHNER was at no time either a practising miner-metallurgist, geologist, or mineralogist. As a matter of fact he was linked with mining and metallurgy through his classical interest of an archivist, at least in the beginning. His major fields of interest included mining legislation and history of mining. (His main work is devoted to the history of mining and metallurgy in Bohemia). That is why he refused, in the years 1762–63, to accept his appointment at Selmec: he ought have to organize a laboratory, walk in mines and collect minerals. PEITHNER, who was a man of extraordinarily wide reading, was featured by an extremely wide knowledge of the relevant literature. His library exceeding 1000 volumes forms the basis of the present-day Historical Library at Selmecbánya. It is a fact typical of him that in regard to the shape and genesis of the Earth he referred to Newton even as early as in 1770 of which there was hardly any example in the community of proper mining experts — geologists.

Manuscript lecture notes prepared in 1774 about his lectures about mine exploitation have been preserved (Miskolc University, Archives).

HAIDINGER's lecturing on geology, and his geological activities

K. HAIDINGER only spent two years at the Selmecbánya Academy. As a peculiar irony of fate, he was appointed professor of mathematics instead of mining and geology. As an assistant, he gave lectures about mining and geology. After leaving Selmec, he worked as a mining councillor at the Court Chamber in Vienna till his death (1797). His petrology and rock systematics were published also in St. Petersburg.

In the introduction to his systematics, the conceptual definition of rocks, the classification applied, the theories related with the types and way of development of rocks are dealt with and attempts are made to describe the features of "original rocks" etc.

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The "classical age" of teaching geology ended at the Selmecbánya Academy in the year 1805. The professors having a comprehensive and independent knowledge and conception concerning geology were replaced, over a period of 3.5 decades, by professors of mining who did not deal —in the necessary degree— with geology. This was due not only to their outstanding activities in other fields, but to the fact that they had acquired their geological knowledge from books not reaching the level of the age and transferred it to their students. As a result of this conservatism, the natural scientists surrounding W. HAIDINGER (the son of K. HAIDINGER) established the Geological School (courses as well) in Vienna which achieved an internal reputation later, and they organized the independent Department of Geology at Selmec.

The teaching of geology according to the Curriculum of the Academy in the early 19th century

During the introductory studies of general natural sciences of the course of philosophy, the basic terms and concepts of natural sciences needed to form a systematic world concept. Geology was taught for students in a network of great relationships of natural sciences.

"Oryktognosie" (oryctognosy) was taught to the student of the second year. This was, in fact, mineralogy based upon the aforesaid foundation concerning natural sciences. General geological knowledge taken in present-day sense is likely to have been taught as an introduction. However, no mineralogical work, or a manuscript document of a lecture on mineralogy remained from the professors of this age (M. PATZIER — till 1811, M. HÖRING, 1811–1820, and ALOIS WEHRLE, 1820–1835). At least we have no information on them. PATZIER published a 4-volume book about metallurgical chemistry (Buda, 1805), and WEHRLE published a book of metallurgy and assay of ores (Vienna, 1841) but no book of mineralogy.

Geology taken in present-day sense was lectured for students attending Class III (Year Three) by the so-called "professor of mining". This department had the following professors: FRANZ REICHETZER (1805–1812) and JOHANN NEPOMUK LANG von HANSTADT (1812–1840). What remained from them are a book about geology (geognosy) by REICHETZER, and a manuscript of LANG's lectures.

Curriculum of geology at the Academy

The curriculum lectured by REICHETZER

The material lectured by REICHETZER is known to us from two editions of his study book (Anleitung zur Geognosie, REICHETZER F., Wien 1812, then 1821). Both the cover page and the introductory part proudly show ABRAHAM WERNER as an ideal to follow. Based thereupon, both the contemporaries and the succeding generations drew the rather unilateral conclusion that the work by REICHETZER is partly a simple adaptation, and partly, a "warming up" of WERNERS' theories that could still be considered to be up-to-date at that time.

However, this is not fully correct. REICHETZER was an expert of wide reading who assembled his own curriculum and work on the basis of his knowledge of the content of relevant special literature of that age, and in the knowledge of the systematics and activities of F. MOHS, and by using the experience he had obtained during a long period of his own professional work. He can not be blamed for his honour to WERNER, even though WERNER was beaten in the great scientific dispute of that age.

According to REICHETZER, the concept of geognosy can be outlined as follows:

Geognosy is part of mineralogy which gives us a systematic description of the typical features of the solid earth body (Erdkörper), particularly, the localities of "fossils" encountered therein, including their genesis and interrelationships.

According to his systematics, geognosy is separated from "orography", that is, the description of individual hills, mountains, "orognosy" (lithology, Gebirgskunde), "orology" (development and layout of mountains, etc), "geogony" (the genesis of the earth), and "geology" (the physical, etc description of the earth). According to him, the order heading from the widest concept is as follows:

MINERALOGY — GEOLOGY — GEOGNOSY — OROGNOSY

The latter two are of greatest importance for a mining expert.

His curriculum of studies was divided into four chapters:

(1) The external conditions of the solid earth body

(2) The internal structure of the Earth

(3) About the general localities (occurrences) of fossils (minerals)

(4) About the special localities

LANG's lectures

LANG's curriculum is known to us from a student's notes taken of LANG's lecture which has remained from 1820 (Library of the Geological Institute of Hungary).

Apart from the differences in the introductory systematics of sciences, his lecture matches almost word by word with the book written by REICHETZER.

LANG who was otherwise a highly educated man whose theoretical and practical work concerning mine surveying, mechanical engineering for mining, and ore preparation was prominent and widely recognized seems not to have paid too much attention to lecturing geology. He completely took over the curriculum worked out by REICHETZER which had actually become outdated by that time (according to notes from that time, the senescent LANG lectured REICHETZER's book).

A decisive step

Finally, probably due to the fact outlined above, the Vienna Court Chamber including the scientific circles that are likely not to have been satisfied with such an operation of the single university level educating of geology within the Hapsburg Empire, decided to undertake a major step:

(1) To set up an independent department of mineralogy, geology and palaeontology at the Selmecbánya Academy (1841);

(2) To start courses of geology in the Museum of Natural Sciences in Vienna, under the direction of WILHELM HAIDINGER who had established a well known school from which a number of experts graduated becoming responsible mining geologists later, such as J. PETTKÓ, G. FALLER, (GYULAY Z. 1974).

Engineers who had graduated from Selmec and were involved in the geological activities

In the Royal Hungarian Geological Institute

Four out of the five-head staff of the Section of Geology established at Ministry of Agriculture etc. in 1868 were mining engineeers: the head, M. HANTKEN as well as J. BÖCKH and B. WINKLER had graduated from Selmecbánya, whereas K. HOFFMANN had graduated from Freiberg as a miner. The fifth member was A. KOCH.

The first Director of the Royal Hungarian Geological Institute was M. HANTKEN (1869–1882), followed by J. BÖCKH (1882–1908).

The outstanding activities during the first years —as shown by the present-day relevant special literature— linked with the names of HANTKEN, HOFFMAN, BÖCKH, KOCH, and two other mining engineers who had graduated from Selmec (F. HERBICH and E. PÁVAY-VAJNA).

In the 1880's, other mining engineers elerting by outstanding activities in the field of geology are found within the framework of the Institute. They are as follows: S. GESELL and GY. HALAVÁTS who graduated from Selmec, and B. INKEY, T. POSCHEWITZ and L. TELEGDI RÓTH who attended the Freiberg Academy.

In the 1900's, mining engineers who had graduated from the Selmec School, working for the Institute were as follows: K. ADDA, F. BÖHM, V. ILLÉS, D. PANTÓ and P. ROZLOZSNIK. Out of these, ADDA, ILLÉS and PANTÓ got into the geological service from the Department of Mineralogy and Geology of the Selmec Academy.

In addition, the names of GY. BOJTÁR, F. HERBITZ, I. MARTINY, F. PELACHY and T. WEISS can also be encountered in the year books of the Institute.

At the Geologische Reichsanstalt in Vienna

The development of geological research and science in Austria and Hungary started from the sphere of activities of the Museum of Natural Sciences in Vienna. It was linked, in the beginning, with the name of F. MOHS, then intensively with the name of W. HAIDINGER. It was this core from which the Imperial Geological Institute in Vienna (the Geological Survey) relying on its methodology developed. It was W. HAIDINGER, who himself also graduated from the Freiberg Academy as a mining expert, who organized post-graduate courses for geologists in Vienna in the 1840's. Nearly 250 participants, part of them sent for training, part of them participating on their own, attended these courses. Included in them were 75 experts of mining and metallurgy who had graduated from the Selmec School. Of them, those that have already been mentioned are as follows: J. PETTKÓ, V. BRUIMANN, L. LITSCHAUER, E. PÁVAY-VAJNA, E. PÖSCHL etc.

The following names represent the first geologist generation of Vienna and Prague: J. CZJEK, A. LÖWE, F. HAUER, J. KUDERNATSCH, M. V. LIPOLD, D. ŠTUR, F. FOETTERLE, V. ZEPHAROVICH, K. KORISTKA, V. MRAZEK etc.

The first director of the K.K. Geologische Reichsanstalt formally established in 1849 was W. HAIDINGER. He was followed by F. HAUER, then DIONYS ŠTUR, both graduates from Selmec.

Members of the Academy of Sciences (19th century) owing to their geological activities

In Budapest (in Pest)

1858	SZABÓ, JÓZSEF
1861	PETTKÓ, JÁNOS
1864	HANTKEN, MIKSA (1874)
1865	HAUER, FRANZ RITTER VON
1868	ZSIGMONDY, VILMOS
1876	BÖCKH, JÁNOS

In Vienna

1851	FUCHS, WILHELM
1860	HAUER, FRANZ RITTER VON
1865	KORISTKA, KAREL
1872	ZEPHAROVICH, VIKTOR

In the university level training

Mining engineers who had graduated from Selmec and played a major role in the university education in Hungary are as follows:

— J. SZABÓ, professor at the Department of Mineralogy and Geology at the Pest University (1862–1894), first President of the Hungarian Geological Society

— M. HANTKEN, professor at the Department of Palaeontology at the Budapest University (1882–1893)

— F. HERBICH, professor of the Kolozsvár (Klausenberg) University in Transylvania.

Professor K. KORISTKA played a leading role in the education at the Prague University and in the organization of the Czech Geological Society, whereas Prof. W. ZEPHAROVICH played a major role in the education at the Cracow, Graz and Prague universities in the field of mineralogy and geology.

At the Leoben and Přibram Academies of Mining and Metallurgy (both of which had separated from the Selmecbánya Academy), the education of geology was under the direction of mining experts from Selmec, over a long period of years.

At Leoben — A. MILLER (1848–72), then F. ROCHELT (1873–92)

At Přibram — J. GRIMM (1850–74)

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ADVANCES
in
Austrian—Hungarian Joint Geological Research
Budapest, 1996

Austro–Hungarian geological mapping before 1869

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Keywords: history of geological sciences, Austro–Hungarian Monarchy, mapping

Abstract

At the end of the 18th century and during the first half of the 19th century the Austrian and Hungarian knowledge of mining and geology evolved from common roots. At the same time, till the middle of the 19th century, geologists developed their own map representation techniques being most suitable to the purpose. The development of the geological mapping in the Austrian, later on Austro–Hungarian Monarchy is marked by the publishing of two outstanding cartographic works, namely of W. HAIDINGER's geognostic (1845) and F. HAUER'S geologic (1867) maps.

The founding of the Geological Institute of the Empire, Vienna (1849) and of the Royal Hungarian Geological Institute (1869) represent two milestones in the history of geological sciences in this period.

Zusammenfassung

Am Ende des XVIII. und während der ersten Hälfte des XIX. Jahrhunderts entwickelten sich die österreichischen und ungarischen Kenntnisse auf dem Gebiete des Bergwesens und der Geologie aus gemeinsamen Wurzeln. Zur selben Zeit, bis zur Mitte des XIX. Jahrhunderts, entwickelten die Geologen eine eigenständige zweckorientierte kartographische Dastellungstechnik. Die Entwicklung der geologischen Kartierung in der Österreichischen (später Österreich–Ungarischen) Monarchie ist durch die Veröffentlichung von zwei hervorragenden Kartenwerken besonders gekennzeichnet. Das sind W. HAIDINGERS Geognostische Karte (1845) und F. RITTER VON HAUERS Geologische Karte (1867). Die Gründung der Geologischen Reichanstalt in Wien (1849) und der Königlichen Ungarischen Geologischen Anstalt (1869) sind die zwei Meilensteine in der Geschichte der geologischen Wissenschaften während dieser Periode.

Összefoglalás

A XVIII. század végén és a XIX. század első felében közös gyökerekből fejlődött az osztrák és a magyar bányászati, földtani ismeret. Ezzel párhuzamosan, a XIX. század közepéig a földtan, hasonlóan más tudományágakhoz, kialakította saját, a célnak legjobban megfelelő térképi ábrázolási módszereit. Az Osztrák, később Osztrák–Magyar Monarchiában a földtani térképezés fejlődését két kiemelkedő kartográfiai mű, a W. HAIDINGER-féle (1845) geognóziai és a F. HAUER-féle (1867) geológiai térkép kiadása fémjelzi.

A korszak geológiai tudományának történetében mérföldkövet jelent a k.k. Geologische Reichsanstalt, Wien (1849) és a Magyar Királyi Földtani Intézet (1869) megalapítása.

Introduction

At the end of the 18th and in the beginning of the 19th century, the Austrian and Hungarian knowledge of mining and geology evolved from common roots. One of the first scenes of this common development was the Academy of Mining (Bergakademie) established by the Empress and Queen Maria Theresa by promoting the School of Mining founded in 1735 and established at Selmecbánya (Schemnitz) located in the mining region in

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North Hungary (now Slovakia). Sons of both nations were included in both the international staff of professors of this Academy and its students.

The growth and improvement of geological knowledge was due to the experience obtained during the mining operations. The institutions of mining and metallurgy had been owned by the state since the Middle Ages. Their considerable financial funds allowed Mineralogy, Crystallography and Geology to develop into independent disciplines. By the end of the 18th century, ABRAHAM GOTTLOB WERNER, a professor at the Freiberg Academy of Mining in Saxony, with his monumental oeuvre, established the science of Geognosy, a descriptive kind of geoscience based on direct experience, which is considered a forerunner of modern geology, although it only covered a very narrow field thereof. At the Selmecbánya Academy of Mining, one of the most prestigious educational institutions of the Hapsburg Empire, WERNER'S geognosy was lectured (see L. ZSÁMBOKI's paper in the present volume).

The first half of the 19th century was the "classical age" of geology. At that time, WILLIAM SMITH (1769–1839) established Stratigraphy, GEORGE CUVIER (1769–1832) and JEAN BAPTISTE DE LAMARCK (1744–1829) provided a sound basis for Palaeontology. As a result of their parallel development, the activities of ALEXANDER VON HUMBOLDT (1769–1859), LEOPOLD VON BUCH (1774–1852) and KARL ERNST ADOLF VON HOFF (1771–1837) led to the birth of geohistory proper, that is, Geology.

The first "geological" maps

Until the middle of the 19th century, geology, just as several other disciplines, developed its own map representation techniques being most suitable to the purpose. Particularly, the mine maps from the 18th century, as well as the topographic maps containing geology related data and showing the occurrences of the mineral resources most important at that time (gold, silver, copper, iron, salt) have been considered as forerunners of the early geological maps.

The first map covering, for the most part, the territory of Hungary and also showing the geological setting of each region was an annex to a book titled "Travels in Hungary with a short account of Vienna in the year 1793" by ROBERT TOWNSON, a globetrotter from England [1].

A map compiled by the Polish priest STANISLAW STASZIC [2] shows the geological setting of the NE part of the Hapsburg Empire.

The foreign travellers were attracted by the advanced level of mining and the abundance in mineral resources in the region, as well as by the diversity in the geological and geographic setting featuring the region.

The first genuine geological map covering nearly the entire territory of the Hungarian Kingdom was prepared in 1818 by a French geologist named FRANÇOIS SULPICE BEUDANT, on the basis of a journey he had undertaken in the country. This journey was initiated by the Austrian Chancellery. Upon its request the French government launched a mission to study the geology and geography of Hungary. The French King and his Government, the Academy of Sciences, the Paris University and the Institute of Natural Sciences charged Professor BEUDANT with the mission. During his trip, BEUDANT paid particular attention to the regions of Selmecbánya (Schemnitz) and Körmöcbánya (Kremnitz) because as he said he wanted to study the problematic rocks most of which were referred to, with an uncertainty, as "saxum metaliferum" (BÖCKH J. 1896). The great four-volume work by BEUDANT (Voyage minéralogique et géologique en Hongrie, Paris 1822) was of essential importance at that time, concerning the geology of Hungary in general, and its volcanic rocks in particular. A geological map on scale 1:1,000,000 was annexed to this work in which 24 geological formations divided into four groups were shown [3]. His work was greatly appreciated over a long period (FÜLÖP J. 1969).

The Selmec phenomenon

The mine maps remaining in manuscript form and already reflecting in their content the considerable advances in the field of geology were drafted in the years following BEUDANT's journey. At the Selmecbánya Academy of Mining, the progress was manifested in a thorough reorganisation of training. In the year 1840, a Department of Mineralogy–Geology–Palaeontology was set up at the Academy.

Linking theory with practice represented a strong feature of the education. As specified in the curriculum of studies, the techniques of applying the theoretical knowledge in practice were taught in the third, or, later, fourth year of studies. The surveying of mines and the drafting of mine maps and sections also formed part of this practical education. So did the six months or one year vocational practice that each student had to go through. After the practice, each apprentice had to submit a summarising report, on the experience collected during the vocational practice (ZSÁMBOKI L. 1985).

The manuscript maps made with great care and stored in the Archives of the Geologische Bundesanstalt in Vienna, among the compilers of which were several individuals involved later in great mapping activities (for instance, VAJDA, F. [4], LOLLOK, C. M. [5], LEUTNER, K. [6], VOLNY, J. [7] GÖTTMAN, C. [8], FOETTERLE F. & KIRNBAUER, PH. [9], ZENOVITZ, J. [10], ZEMLINSZKY, R. [11]) beyond doubt form part of these periods spent in practice and of the completed reports.

As far the above-mentioned authors are concerned particularly noteworthy are the mine maps compiled by FOETTERLE, F. and KIRNBAUER, PH. [9], and by ZENOVITZ, J. [10], using a technique of superimposing translucent foils, as a special representation in space, to show working levels, entries and dykes concerning the Selmecbánya mine area. This representation technique is considered as a forerunner of the Geographic Information System (GIS).

The modernisation of the teaching of geology at the

Selmecbánya Academy is inseparably linked with the name of JÁNOS PETTKÓ (fig. 1.). PETTKÓ graduated in mining and metallurgy from the Selmecbánya Academy (1836–1839). Then, he studied geology with Wilhelm HAIDINGER in Vienna. From 1843, he was teaching at the Selmecbánya Academy of Mining. In 1847, he was appointed Professor and Head of Department at the Selmec Mining Academy. Some of his students such as JÓZSEF SZABÓ, JÁNOS BÖCKH, MIKSA HANTKEN, SÁNDOR GESELL etc. later became outstanding personalities of the classical age of Hungarian geology (ZSÁMBOKI, L. 1983). PETTKÓ, making use of his own experience in mining and geology, published a geological map of the Körmöcbánya area [12] in 1847, and about the Selmecbánya area [13] in 1852 which was considered by JÓZSEF SZABÓ as the first map —after BEUDANT— that showed a considerable progress in geology.

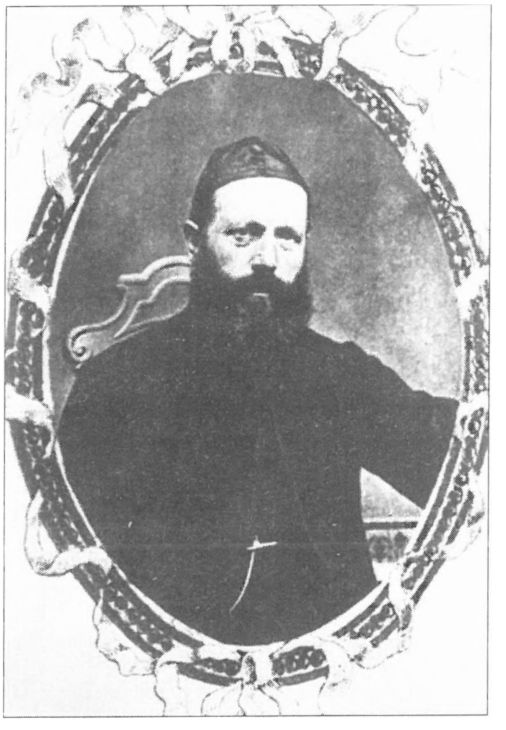

Fig. 1. JÁNOS PETTKÓ

W. HAIDINGER's Geognostic Map

The first geognostic or geological map showing the entire territory of the Austrian Monarchy, linked with the name of WILHELM HAIDINGER, a member of the Mining Board, was published in 1845 [14]. At that time, HAIDINGER was the attendant of the mineralogical-geological collections of the Sammlung der k. k. Hofkammer im Münz- und Bergwesen, or briefly, k. k. Montanistisches Museum in Vienna. It was Prince FERDINAND JOSEF LOBKOWITZ, Chairman of the Court Chamber, himself, who charged HAIDINGER to prepare the map.

The map was plotted on scale 1:864,000. Its topographic basis was provided by map sheets based on the second up-to-date military survey supplied by the k. k. Militärisch-geographisches Institut that had recently been established. This map was published in nine sheets which —when fitted together— resulted in a total size of 1.26 x 1.77 m.

Under the direct guidance of HAIDINGER and the supervision of FRANZ VON HAUER, also the selected students who —after graduating from the Selmecbánya Academy of Mining— were attending a post-graduate course of mineralogy-geology in the k. k. Montanistisches Museum in Vienna, participated in assembling the geological content of the map. As concerns the participants of three courses held between 1842 and 1844, maps were compiled by KÁROLY FOITH, about Transylvania (Désakna), by ADOLF HROBONY, about North Hungary (Diósgyőr), by FERENC KOLOSVÁRY, about South Hungary (Oravica), by GUSZTÁV FALLER, about Croatia-Slavonia including the military frontier guard zone (Selmecbánya), by TÓDOR KARAFIÁTH, about Bohemia-Moravia and Inner Austria (Vienna), by FRANZ WEINECK about the Alps (Weyer), and by PASQUAL FERRO about Tyrol (Kleinboden) (HAIDINGER, W. 1847).

In addition to the map compilers' personal knowledge of the specific area, also the data and maps supplied by the Mine Directorates of the Treasury provided a basic evidence for the compilation of the maps. Data from former references as well as maps relating to each specific partial area of Hungary, maps prepared by French travellers AMI BOUÉ [15] and FRANÇOIS SULPICE BEUDANT [3], and by KARL LILL VON LILIENBACH [16], LUDWIG ZEUSCHNER [17] and others were also used (GYULAI Z. 1974).

On the map, 20 different colours and alphabetical symbols were used to distinguish 22 kinds of rock and stratigraphic units. Several terms are in use even to date. This map in which the structural units of the Bohemian Massif and the Alps-Carpathians are clearly distinguished can also be considered up-to-date also from the aspect of megatectonics.

F. VON HAUER's Geological Map

The 10-year activity of the Montanistisches Museum, in fact, was a preliminary work for the founding of the Geological Institute of the Empire namely, the k. k. Geologische Reichsanstalt, in Vienna (1849).

For the Institute and its first director, WILHELM HAIDINGER (fig. 2.), geological mapping represented a priority task. After a brief period of preparatory work, a detailed systematic surveying performed on a sheet-by-sheet basis began in summer, 1851 (HAIDINGER, W. 1859).

In the beginning, the work covered the vicinity of Vienna, and later the area W thereof, the region of Lower Austria.

Fig. 2. Wilhelm Haidinger

In the third year, 1853 the first surveys were carried out on the territory of the Hungarian Kingdom: in the direct vicinity of the Austrian border, in the region of Pozsony (Pressburg) and Sopron (Ödenburg). The mapping was done by Franz von Hauer and Hans Foetterle.

In the following two years, the detailed surveying continued towards the North — in Bohemia, and towards the South — in Styria. (fig. 3.).

In the year 1856, a new phase of mapping activities began. In addition to the detailed surveying performed on the scale 1:144,000, a surveying for overall mapping on scale 1:288,000 was also started. Thanks to the application of this method the mapping of the southern and western provinces of the Hapsburg Empire could be completed by 1857. In the meantime, a detailed mapping concerning Bohemia was also going on. At the same time, Karl Peters, a mineralogist and palaeontologist of Bohemian origin who had been working as Associate Professor at the Pest University within the framework of a cultural mission in Hungary since 1859, performed a mapping activity, first in Buda, then in its wider region, the region of Visegrád, Esztergom, Tata and Zsámbék.

In 1858, the up-to-date topographic map sheets —on the scales 1:288,000 and 1:144,000, respectively— of the second military survey about the territories of Hungary and Transylvania were still not available. For this reason, the mapping work that had begun in North Hungary as a continuation of mapping of the Empire was performed on an overall scale of 1:288,000.

The work was directed from two regional centers, one in Pozsony and the other in Kassa. The mapping was performed by Franz Foetterle, Dionys Štur, Heinrich Wolf and Ferdinand Andrian from the western border region to the river Hernád, and by Franz von Hauer and Ferdinand Richthofen on the eastern part, as far as the border of Bukovina and Transylvania. They all were working for the Geologische Reichsanstalt. Professor Gustav Andreas Kornhuber from Pozsony also participated in the western part, whereas Otto Hingenau and Arthur Glós from Szalóc were also involved in mapping done in the eastern part.

In 1859, in addition to detailed surveys done in Bohemia, a mapping on overall scale was performed also N of Hungary, in the territory of the Austrian Empire — in the surroundings of Cracow, as well as in Galicia and Bukovina.

Upon the request of the "Verein für siebenbürgische Landeskunde", Transylvania was classified as a province of major importance for mapping. In the same year, Franz Hauer and Ferdinand Richthofen began to map the eastern part of Transylvania, with the participation of Albert Bielz, and professor József Meschendörfer, from Brassó.

Albert Bielz, a Saxon zoologist and natural scientist from Transylvania performed geographic and geological observations and assembled remarkable collections (bug, plant, molluscan and vertebrate faunas) during his journeys in Transylvania, and published maps summarizing the results from his geological observations. One of these maps [18] supplies geological information on each region in Transylvania. Another map published in 1854 represents, in addition to the distribution of each kind of rocks and formations, also the location of salt occurrences and saline springs [19]. After the completion of the mapping of Transylvania, Franz von Hauer (fig. 4.) published a geological map of Transylvania including a related monography, on scale 1:576,000 in 1861 [20], then, with the involvement of co-authors, on scale 1:288,000 [21] in 1863. In the development of a key to colours used in the map and of its content the authors used a map by Karl Peters [22] that had been published as a result of a scientific expedition launched to explore the Bihar Mountains. This map, in regard to its conception and up-to-date features, considerably exceeds the level of the previous ones.

In the following years, the mapping activities focused on the territory of Hungary. A detailed mapping of the surveys that had formerly been done on an overall scale was performed, and new areas were also attacked.

Of those working for the Geologische Reichsanstalt, Franz Foetterle, Dionys Štur, Heinrich Wolf, Guido Stache, Ferdinand Andrian, Ferdinand Stoliczka and Karl Paul participated in the mapping operation in 1860 and 1861.

Franz von Hauer presented the geological map of the SW part of Hungary, the area between the rivers Danube and Dráva, at a session of the Geologische Reichsanstalt, in December 1861. This map includes the Buda Hills, the Pilis Mountains, the Vértes Mountains, the Bakony Mountains, the Balaton Uplands (Balatonfelvidék) and the region of the Mecsek Mts. At that time, Miksa Hantken who lectured geology and natural history at the Pest Academy of Commerce in those years, and Professor József Szabó who lectured at the Department of Mineralogy of the Pest University, also joined the mapping operation. They continued and completed the mapping formerly commenced by Karl Peters in the regions of Buda and Esztergom [23], [24]. József Szabó (fig. 5.) who was appointed ordinary professor at the Department of Mineralogy of the University in 1862, extended and intensified his scientific work after his appointment. In addition to his theoretical studies, his

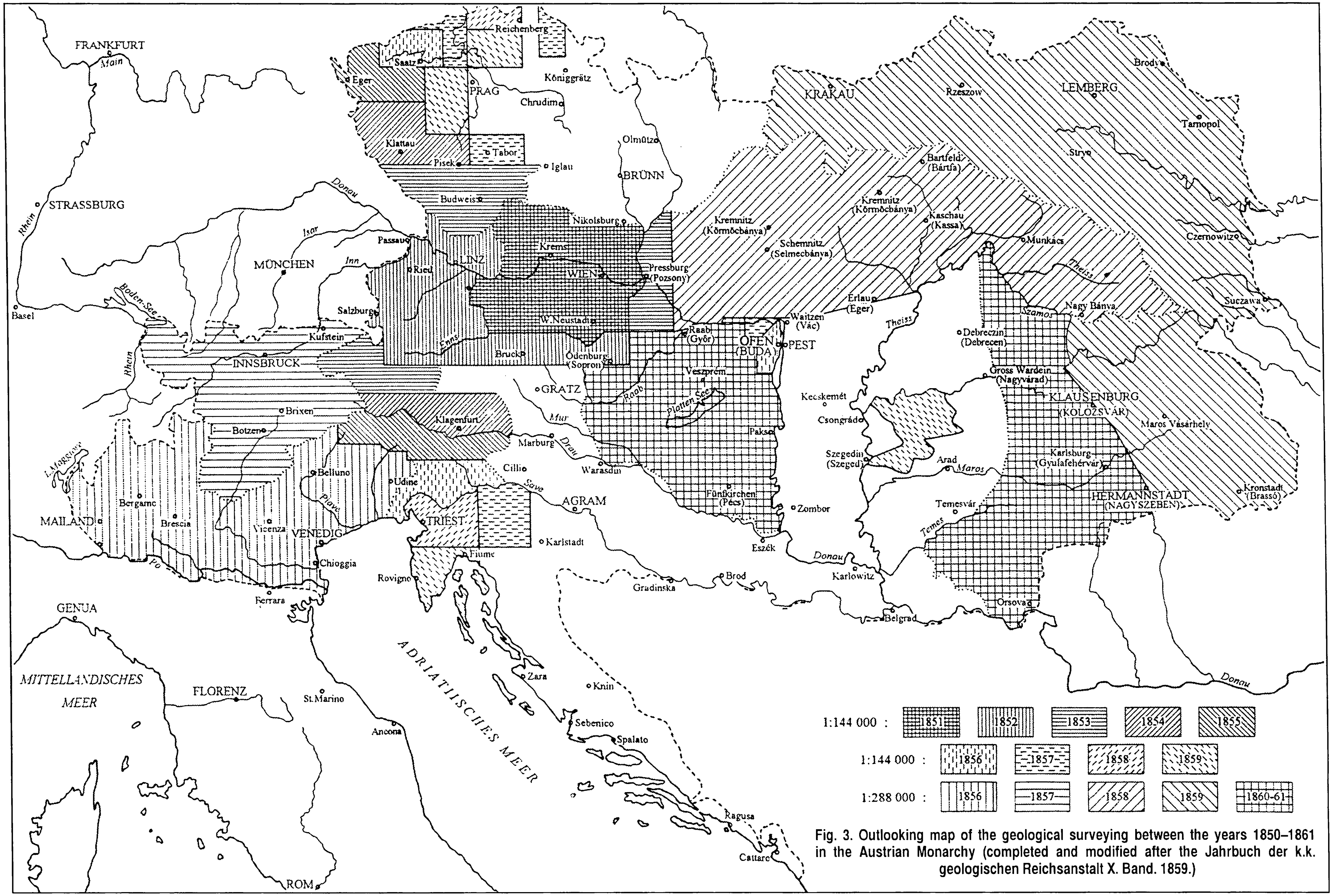

Fig. 3. Outlooking map of the geological surveying between the years 1850–1861 in the Austrian Monarchy (completed and modified after the Jahrbuch der k.k. geologischen Reichsanstalt X. Band. 1859.)

Fig. 4. FRANZ VON HAUER

Fig. 5. JÓZSEF SZABÓ

geological maps about Békés-Csanád County [25], Heves-Szolnok County [26] and Tokaj-Hegyalja [27] are also noteworthy. JÓZSEF SZABÓ is considered the founder of independent Hungarian geology.

In addition to the systematic, sheet-by-sheet mapping of the Empire, also local mapping was carried out, particularly in mine areas. Out of these, the geological maps remaining in manuscript form, stored in the Archives of the Geologische Bundesanstalt in Vienna and showing mine areas which are documents concerning the activities of the Austrian Railways Co. (k. k. priv. Österreichische Staats-Eisenbahn-Gesellschaft) are also definitely noteworthy. Between 1856 and 1867, the Railways Co. built the Szeged–Temesvár–Báziás railway line and used its own mines to supply mineral resources required for the railway line. The geological maps indicating neither the author, nor the year when they were plotted might have originated from this period. These maps show the region of iron ore and coal occurrences in the Southern Carpathians (Oravica, Dognácska, Resicabánya, etc), in many cases at a rather high standard, exceeding the average level. The representation of tectonic elements such as folds and faults [28–33] is particularly striking.

In the year 1862, a decision was reached to publish a new overall map showing the entire Austrian Monarchy. This map was based on the manuscript map documents resulting from the detailed as well as the overall mapping done during the previous period of over a decade. This map, the compilation of which was in progress, was first presented at a scientific session of the Geologische Reichsanstalt, on 19th April, 1864. Other presentations were made in 1865 in Köln, and in 1866 in Vienna, at the Agricultural Exhibition (HAUER, F. RITTER V. 1867). In the meantime, the coordination of matters to be included in the map continued. Mining engineers ADOLF OTT, JÁNOS BÖCKH, SÁNDOR GESELL and WILHELM GÖBL were also requested to make comments. The lithographic operations were also performed with a printing house in Vienna (HAUER, F. RITTER V. 1870). The colourful printed map was published in 1867, due to the political changes already as the geological map of the Austro–Hungarian Monarchy, on scale 1:567,000, in 12 sheets. It was republished several times [34].

The legend used in this map is more detailed than any others a map had ever before, showing 102 kinds of geological formations. It is based on the stratigraphic time scale classification system within which the lithostratigraphic units and kinds of rocks referred to in a present-day sense are distinguished. An explanatory booklet was also printed. The authors of which included, in addition to a number of geologists working for the Geological Institute in Vienna, also ALBERT BIELZ, KÁROLY HOFFMAN, JÁNOS PETTKÓ and JÓZSEF SZABÓ.

The completion of this great oeuvre and the involvement of Hungarian experts in the work were of major importance both for the development of independent Hungarian geology and for the establishment (1869) and subsequent operation of its most important institution, the Royal Hungarian Geological Institute.

List of Maps

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[5] LOLLOK C. M. 1841: Geognostische Hauptkarte über den Nagy Bányer und Marmaroscher Bergdistrict. — (Scale 1:288,000). Manuscript.

[6] LEUTNER K. 1843: Hodritscher Segengottesstollner Bergbau. — (Scale=?). Manuscript.

[7] VOLNY J. 1844: Schemnitzer Grubenbau in seinen Lehen in Karten von Schemnitz Grubenbau. — (Scale=?) Selmecbánya (?). Manuscript.

[8] GÖTTMANN C. 1846: Geognostisch–Bergmaennische Karte über die Gebirge zwischen der Theiss und Szamos nebst den Bergbau Verhaltnissen bei Turcz und N. Tárna im Ugocsaer Comitat. — (Scale 1:247,400). Manuscript.

[9] FOETTERLE, F. & KIRNBAUER, PH. 1846: Uebersichtskarte der Central Section des Schemnitzer Grubenbaues. Karten des Schemnitzer Grubenbaues. — (Scale approx.: 1:760). Selmecbánya. Manuscript.

[10] ZENOVITZ J. 1846: Schemnitzer Bergbau mit seinen Lehen. — (Scale 1:20,000) Selmecbánya. Manuscript.

[11] ZEMLINSZKY R. 1847: Karten von Schemnitz Grubenbau. — (Scale=?). Manuscript.

[12] PETTKÓ J. 1847: Geognostische Karte der Gegend von Kremnitz. — (Scale 1:72,000) In: Naturwissenschaftliche Abhandlungen, Wien 1847. I. Band. Wien.

[13] PETTKÓ J. 1852: Geognostische Karte der Umgegend von Schemnitz. — Scale 1:144,000) In: Abhandlungen der k. k. Geologischen Reichsanstalt, 1855. II. Band. Wien.

[14] HAIDINGER, W. 1845: Geognostische Uebersichts-Karte der Oesterreichischen Monarchie. — (Scale 1:864,000). Wien.

[15] BOUÉ, A. 1834: Carte Géologique de la Transylvanie. — Scale approx. 1:1,900,000). In: Mémoires de la Société Géologique de France. — Tome premier. Deuxičme partie. Paris.

[16] LILL VON LILIENBACH, K. 1834(?): Geognostische Karte der Karpathen. — (Scale 1:2,078,000).

[17] ZEUSCHNER, L. 1844: Carte géologique de la chaîne du Tatra et des soulčvemens parallčlles. — (Scale=?). Berlin.

[18] BIELZ E. A. 1854: Karte der geognostischen Verhältnisse des Grossfürstenthums Siebenbürgen. — (Scale 1:864,000).

[19] BIELZ E. A. 1854: Karte der Verbreitung der Salzquellen und des Steinsalzes in Siebenbürgen mit Rücksicht auf die geognostischen Verhältnisse dieses Landes. — (Scale 1:864,000).

[20] HAUER, F. V. 1861: Geologische Übersichts-Karte von Siebenbürgen. — (Scale 1:576,000). Hermannstadt (Nagyszeben).

[21] HAUER, F. V., ŠTUR, D. & STACHE, G. 1863: General-Karte des Grossfürstenthums Siebenbürgen und der im Jahre 1861 mit dem Königreiche Ungarn vereinigten Theile. — (Scale 1:288,000). Wien.

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ADVANCES
in
Austrian—Hungarian Joint Geological Research
Budapest, 1996

Austria's contribution to the mineralogical exploration of Hungary until 1869

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Keywords: history, mineral collections, Selmec Mining School, Imperial Geological Survey, minerals

Abstract

With a short glance at the antecedents, the period between 1763 (the promotion of the Selmec Mining School to the rank of Mining College) and 1869 (the founding of the Royal Hungarian Geological Institute) is dealt with in detail Particular attention is paid to the various mineral collections, the early scientific societies and the resulting publications. Two major milestones were the establishment of the Montanistic Museum in Vienna (1835) and that of the Imperial Geological Survey (1849). The 21 mineral species discovered in and described from historical Hungary are listed in Table 1.

Zusammenfassung

Nach einem kurzen Blick auf die Antezedenzen ist die Periode von 1763 (Promovierung der Schemnitzer Bergschule zu Bergakademie) bis 1869 (Gründung der Königlichen Ungarischen Geologischen Anstalt) eingehend besprochen. Besondere Aufmerksamkeit ist gewidmet den verschiedenen Mineraliensammlungen, den frühen wissenschaftlichen Vereinen/Societäten und den Veröffentlichungen. Zwei wichtige Meilensteine waren die Gründung des Montanistischen Museums in Wien (1835) und die der Geologischen Reichsanstalt (1849). Die im (historischen) Ungarn entdeckten und beschriebenen 21 Mineralarten sind in Tafel 1 dargestellt.

Összefoglalás

Az előzményekre vetett rövid pillantás után a dolgozat az 1763 és 1869 (a selmecbányai Bányászati Iskola akadémiai rangra emelése és a Magyar Királyi Földtani Intézet alapítása) közötti időszakot tárgyalja, különös figyelmet szentelve a különféle ásványgyűjteményeknek, a korai tudós társaságoknak és az ekkor született publikációknak. Két jeles mérföldkő volt a bécsi Montanisztikai Múzeum és a Birodalmi Földtani Intézet megalapítása (1835, illetve 1849). A történelmi Magyarországon felfedezett és leírt 21 ásványfajt az 1. táblázat mutatja be.

Introduction

The contribution of Austria to the development of the geosciences in Hungary in general and the mineralogical exploration in particular can best be analysed on the basis of the intensive historical and socio-economic interlaces of both countries. As there are no thorough scientific historical investigations known — particularly from the Austrian point of view— a short survey is presented here, not least based on a series of Hungarian monographic investigations of the history of geosciences in Hungary which consider international aspects as well (DUDICH, 1984; HÁLA, 1985; CSÍKY & VITÁLIS, 1989; CSÍKY & KECSKEMÉTI, 1991).

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Hungary in this survey is understood in the boundaries before 1918. Consequently all the classical mining districts of Upper and Lower Hungary, Transylvania and Banat are included and scientists, scholars and collectors are considered, regardless of their place of birth as long as an essential part of their scientific output is connected directly with their service in the Austrian government or some Austrian scientific institution.

The Austrian contribution to the mineralogical exploration of Hungary occurred in phases of varying intensity which can more or less directly be connected to mining activities. Highs in mining are always accompanied by increased interest in minerals as objects of collecting as well as objects of systematic scientific research. Of greatest importance from the point of view of science and history is the establishment of mineralogy as an autonomous branch of science and its institution at universities. The latest phase in the joint Austrian–Hungarian development in the mineralogical science is the foundation of geoscientific research institutions and Academies (Montanistic Museum, Academy of Sciences, Imperial Geological Survey) with differently accentuated research interests.

At the first climax of the Central European mining and smelting industry in the 16th century "minerals" were mainly seen as sources of raw material production. But in the sense of humanistic attitude there was a change towards considering minerals as objects of collecting as well as research. In the 16th century imperial and princely "chambers of artifacts and miracles" were established in Vienna, Innsbruck and Prague, where rich collections of minerals and gems were developed.

Already at that time representative samples from the mines of the empire were collected. Among the richest and most valuable collections of this time was the famous mineral collection of Emperor RUDOLF II (1552–1612) in Prague, which after his death was liquidated completely. According to the eminent importance of the Hungarian silver, gold and copper mining at that time specimens of these classical mines could be found in the collections of Prague and Vienna as well as in the collection of the Amras Castle of Archduke FERDINAND OF TYROL (1529–1595).

With the decline of the mining and smelting industry in Austria-Hungary at the end of the 16th and especially in the 17th century, the immediate interest in minerals waned as well. While the growing interest in scientific journeys led to some visits to Hungary by scientific explorers (BROWN, TOLLIUS, MARSIGLI) who were engaged to varying degrees in the exploration of Hungarian mineral resources, there is nothing similar known from Austrian travellers and scholars from that time. The more remarkable is the fact that in this early stage of mineral research a series of Hungarian scholars (CSOMBOR, KÖLESÉRI, CSIBA) were occupied with studying Hungarian mines and the minerals occurring there.

A decisive break in the evolution of the mineralogical exploration in Hungary occurred in the middle of the 18th century which finally led to the classic pioneering treatises on this subject in Hungary. A strong new stimulation to the recovery of mining in the 2nd half of the 18th century was caused by economic measures taken under MARIA THERESA and her son JOSEPH II. The Hungarian mining industry, rich in tradition, has in the meantime lost its all-European significance, but was still by then of great importance to the Hapsburgian countries. The progressive exhaustion of known sections of the mining districts led to the exploration of deeper levels of these deposits (the first time ever blasting was introduced to heading) and to intensified prospecting on the surface. This development led to geoscientific questions which aimed at the recognition of regularities in the geological setting and the mineralogical composition of the mountains and deposits. The investigation based on empirical methods was seen as the main task of the natural sciences in the 18th century, which in the individual branches of science led to descriptive and systematizing approaches.

From the scientific sight the most important achievement was, without doubt, the institutionalisation of mining and of the related disciplines. In particular the development of montanistic teaching and the establishment of mineralogical subjects at the universities led to an increased mineralogical exploration of the Austro–Hungarian Empire. A prominent center for the training in mining related branches of science was created by establishment the Mining Academy in Selmec (Schemnitz) in 1770 (since 1735 Mining School, since 1763 Mining College). Mineralogical knowledge has been seen since its start as an essential element in the education of mine officers. With the foundation of Mining Academies in all these institutions chairs of mineralogy were established. As first professor of mineralogy and chemistry in Selmec the well known NIKOLAUS JOSEF JACQUIN (1750–1808) was appointed, who after his departure to the University of Vienna was succeeded by the company physician of the Idria mine, JOHANN SCOPOLI (1723–1788). SCOPOLI'S contribution to the mineralogical exploration of Hungary is expressed in a series of important publications on mineral history. In 1779 ANTON RUPPRECHT (1750–1808) took over the chair of mineralogy and chemistry and was active here until his call as successor of BORN to the Viennese Chamber of the Court in 1791.

Knowledge of minerals was among others also an element of bourgeois education. An essential effect on the mineralogical sciences had FRANZ STEPHAN VON LOTHRINGEN, husband of Empress MARIA THERESA, who was reputed as a great promotor of mercantilistic endeavours and natural sciences. In 1748 he founded the Imperial and Royal Mineral Cabinet, which became the basis of the mineral collection of the Museum of Natural History. Connected with the activity of collecting minerals there was already from the beginning the acquisition of minerals from various parts of the empire. Besides others the mathematician and physicist JOSEPH ANTON NAGEL was charged to travel to Hungary on imperial expenses and to collect minerals from the Carpathian Mountains (FITZINGER, 1856).

The general rise in the interests in natural sciences from the middle of the 18th century led learned circles increasingly to deal with mineralogy and to found private mineral collections. Responding to this demand MARIA THERESA transferred the imperial collection after the death of FRANZ STEPHAN into the national property and shortly afterwards it was made accessible to the public. At the same time she promoted the expansion of a new natural history collection for reference and educational purposes. The new arrangement had to follow strictly scientific principles.

To achieve these objectives MARIA THERESA and her son JOSEPH II ordered the systematic collection of domestic minerals from all mines of the Austro–Hungarian Empire. Eminent contributions from the Hungarian part of the empire were made by A. v. RUPPRECHT, mining counselor from Selmec, the Privy council and vice-president F. J. MÜLLER v. REICHENSTEIN as well as by the administrative counselor FICHTEL from Transylvania. With the new arrangement and scientific treatment of the natural history collection the famous metallurgist IGNAZ VON BORN was appointed in 1776. He was considered the pioneer of the geologic, montanistic and mineralogical research in the Monarchy and was one of the leading scientists in Austria in the second half of the 18th century.

Essential factors which also influenced the mineralogical research in Hungary towards the end of the 18th century were the increasing numbers of scientific journeys to the mining districts, the sharp increase in montanistic publications as well as the establishment of the Society of Mining (1786–1790) which from an all-European sight stimulated the further development of mining. Important personalities responsible for these developments were the mining officers IGNAZ V. BORN (1742–1791), JOHANN EHRENREICH VON FICHTEL (1732–1795) and FRANZ JOSEPH MÜLLER v. REICHENSTEIN (1742–1825). The activities of these scientists, of great importance for the mineralogical research in Hungary, are already documented in detailed treatises (CSÍKY, 1985; MOLNÁR & WEISS, 1986; FETTWEIS & HAMANN, 1989; S. & P. HUBER, 1992).

BORN founded the "Abhandlungen einer Privatgesellschaft in Böhmen" (Treatises of a Private Society in Bohemia) (1775–1784) and "Physikalische Arbeiten der einträchtigen Freunde in Wien" (Physical Treatises of Harmonious Friends in Vienna) (1783–1788). With these publications he provided an extensive platform for a remarkably large circle of people interested in mineralogy and mining and he provided new standards for a rich scientific activity in Vienna and Prague. The two journals had a very stimulating effect on the development of mineralogy in the Austro–Hungarian Empire. Of particular relevance for the Hungarian area were the contributions of RUPPRECHT and MÜLLER v. REICHENSTEIN, published in 1783–1785, on the occurrence of the "supposedly native Spießglanzkönig" (native Tellurium). The further examination of this material by KLAPROTH led in 1798 to the discovery of the chemical element Tellurium.

During the presentation of the amalgamation process, developed by BORN in 1786 in Glashütten near Selmec, BORN founded together with the mining officer TREBRA the "Society of Mining", an international society, which can be assumed to be the climax of his organisational activity. In the two volumes of the journals of this society, published in 1789 and 1790, some papers deal with mineralogical observations in Hungary and Transylvania.

After BORN's death a noticeable stagnation in the mineralogical sciences in Austria occurred. From an all-European viewpoint the development of mineralogy, towards the end of the 18th and in the beginning of the 19th century was determined by the progress in knowledge of crystallography and mineral chemistry. Particularly these fields of mineralogical research in Austria stood in the shade of the great European mineralogists.

One of the few Austrian mineralogists of this time with a reference to Hungary was Abbé ANDREAS STÜTZ (1747–1806) who succeeded KARL HAIDINGER at the imperial natural history collection, and was responsible for the new arrangement of the mineralogical, geological and palaeontological collections. Beside this occupation STÜTZ was of eminent importance in the history of acquisitions of this collection. On his journeys he personally performed industrious collecting activity. One of these journeys took him in 1795 to Transylvania its Ore Mountains (Erzgebirge). The most important results of this journey were published in 1802 as a book with the title "Physical-Mineralogical Description of the Gold and Silvermine at Szekerembe near Nagyág Including an Addition about some Problematic Minerals of Transylvania".

Towards the end of the 18th century a series of significant mineral collections were established, which were revised scientifically at this time. The "Mineralogische Taschenbuch" (Mineralogical Pocketbook) of STÜTZ, published 1807 after his death, gives an interesting insight into Viennese mineral collections around 1800. The diversity and special quality of many Hungarian mineral occurrences find their equivalent in the relative importance of the specimens. This became evident in the collections of Archduke RAINER, Count MORITZ v. FRIES, ELEONORE OF RAAB (Collection catalogue BORN, 1790), VAN DER NÜLL. All the classical mineral occurrences in Upper and Lower Hungary as well as Transylvania are represented, particularly gold, silver and antimony ores.

The stagnation in the Austrian and Hungarian mining industry in the first decades of the 19th century had indirectly an effect on the development of the mineralogical research. While the mineralogical sciences in France, Germany and England made fast progress, they were restricted in Austria to the systematic museal field.

In Hungary an autonomous mineralogical research developed on a relatively broad basis with in some cases exemplary mineralogic-topographic synopses. In this context the papers of BENKÖ (1786), SCHÖNBAUER (1806–1810), ZIPSER (1817) and JÓNÁS (1820) give a more or less comprehensive survey of the mineral occurrences of Hungary.

In the beginning of the 19th century the most prominent individual with greatest importance for the development of mineralogy in Austria was FRIEDRICH MOHS (1773–1838) who came from the Harz Mountains. Altogether he spent 30 years of his scientific career with different Austrian institutions.

MOHS with his endeavours to quantify mineral properties and to mathematize mineralogy brought a very modern onset of research for Austrian standards. MOHS gained great merits through the discovery of minerals and in the field of mineral systematics as well as in the application of mineralogy in the research of mineral deposits.

MOHS in 1802 followed an invitation of the banker VAN DER NÜLL for a systematic arrangement of his famous mineral collection. Based on this task MOHS developed a "natural historical system for the classification of minerals". As a consequence of his stay in Vienna MOHS made various study trips which led him, together with FRIEDRICH Count STADION in 1808, among others, to the Mining Academy of Selmec and to other parts of Hungary and to Transylvania. He had been professor of mineralogy in Vienna since 1826. He re-arranged the mineral collection of the COURT under inclusion of VAN DER NÜLL's collection according to his new system. 1835 MOHS was appointed with the Chamber of Mint and Mining Affairs. His task now was to establish a mineral collection for educational purposes in the newly founded Montanistic Museum. This museum also acted as a post-graduate school for the students of the Selmec Mining Academy, as well as students from Hungary who were trained here in special courses in mineralogy, geognosy and chemistry.

Logistic support for the establishment of the collections was provided to MOHS by the Imperial Chamber of Mint and Mining Affairs, which ordered all subordinated offices to submit rock and mineral specimens from their areas of competence. To prepare the requisition of such specimens MOHS was authorized to collect samples himself in all parts of the empire (HAIDINGER, 1843, 1869). In 1835 MOHS travelled to the Lower Hungarian mining district. His excursions and mine visits had the purpose on one hand to describe thoroughly the mining and geognostic conditions and to collect and investigate minerals and raw materials.

With the unexpected death of MOHS in 1839 the fruitful development of the mineralogical sciences for the whole Austro-Hungarian Empire stopped abruptly.

At the same time with MOHS P. PARTSCH, a Viennese (1791–1856) was active in the Natural-History Collection of the COURT. He can be regarded as one of the most important pioneers of geo-scientific research in Austria. In 1826 the Chamber of COURT put him in charge of geological investigations in Transylvania and Upper Hungary. The results and experiences of his 10 months stay are documented in monthly reports to the Chamber and in two special investigation reports: on the ore deposits of Offenbánya, in the mountains Szászvári and on the occurrencies of salt in Transylvania (SCHÖLLER, 1956). A remarkable by-product of these investigations is the draft of an early geological map of Transylvania, which unfortunately, as the above mentioned investigations, remained unfinished. To the collection of demonstration samples of the Mineral Collection PARTSCH added a large number of ore samples from the mines he visited.

W. HAIDINGER (1795–1871) was without doubt the most prominent researcher in the 19th century after MOHS. He was a disciple and successor of MOHS. In 1840 he was appointed to the Chamber for Mint and Mining Affairs, later called the Montanistic Museum. HAIDINGER gained an international reputation through a number of crystallographic and mineralogic publications. In 1827 he retired in for the porcelain (china) factory of his family in Ellenbogen as an entrepreneur.

Due to his return to Vienna in 1840, this city ows him a new impetus in natural sciences, in particular in mineralogy and geology. During his service in the Montanistic Museum, besides dealing with the mineral collection, he made a number of research trips which brought him, among others 1841 to various parts of Hungary. His mineralogical lectures held 1843–1849 at the Montanistic Museum, were attended by mining probation-students and graduated mining engineers from Selmec and became a refuge of mineralogical education, also for numerous Hungarian participants who later were to hold important positions in montanistic affairs and partly also in the geo-scientific research of Hungary. To support his lectures HAIDINGER wrote a "Handbook on determinative mineralogy" in 1845, a milestone in this time. It contained a number of first namings of minerals, which occurred in Hungarian type localities (see table 1).

Towards the middle of the 19th century a new climax in the organisation of sciences in Austria was reached by the union of representatives of various special fields in scientific societies. In these HAIDINGER held a pioneering position as a geo-scientist. His activity was the beginning of a centralisation and institutionalisation of the scientific research of the empire. A group of younger scholars joined the "Association of friends of the Natural Sciences" founded by HAIDINGER, ETTINGSHAUSEN and SCHRÖTTER. Publication organs were the so-called "Berichte der Freunde der Naturwissenschaften" (Reports of the Friends of Natural Sciences) (1846–1850) and the "Naturwissenschaftliche Abhandlungen" (Natural-Scientific Treatises) (1847–1851), with outstanding monographs. Among the numerous scientific papers and items are the results of investigations of Hungarian mineral occurrences and first descriptions of minerals (hauerite / HAIDINGER, 1846, and schreibersite / HAIDINGER & PATERA, 1847). Of the mineralogists and mineral chemists working in Austria HAIDINGER, KENNGOTT, LÖWE, LEYDOLT, PATERA and SCHRÖTTER published on topics related to Hungary.

Since 1847 the Imperial Academy of Sciences in Vienna had been the central organisation of the Austrian sciences. Many scientific results in the field of mineralogy are included in the publications of the Academy until 1869. Papers and mineralogical topics in relation to Hungary were written by HAIDINGER, KENNGOTT, ZIPPE, HOERNES as well as ZEPHAROVICH.

An important pace-step for the geo-scientific research in the empire was set with the establishment of the Imperial Geological Survey. Although mapping dominated the activity in the early years of the Imperial Survey, the investigation of mineral deposits in the empire and the setting up of a museum provided wide space for mineralogical research. The Imperial Geological Survey began its activity on Dec. 1st, 1849 and owned already at that time a mineral collection inherited from its predecessor, the Montanistic Museum. With the establishment of the Survey arose a busy acquisition activity of minerals, by the mapping geologists as well as by contributions from the mining companies of the empire. Among the regularily published lists of minerals in the Yearbook samples from Hungary are conspicuous.

Scientific contributions in the fields of mineralogy as well as investigation of mineral deposits of various extent can be found in the publications of the Geological Survey. Among the papers in the Yearbook of the Imperial Geological Survey from 1850 to 1859 referring to Hungary there are some famous monographic works on the deposits of Nagyág (HINGENAU, HOCHEDER, 1857), Vöröspatak (HAUER, 1851; GRIMM, 1852); Selmec (LIPOLD, 1867), several papers of HAIDINGER on the linarite of Rézbánya (1851), native copper of Récs (1850) as well as a series of smaller mineralogical papers by KENNGOTT, ZEPHAROVICH, HÖFER V. HEIMHALT, PATERA, POSEPNY (1865–1869), TSCHERMAK (1865–1868) and VIVENOT (1869).

Table 1

Minerals of Hungarian type localities named by geoscientists working in Austria (1830–1878; valid names in bold letters)

Name	Formula	Named by	Named for	Type Locality
Alloklas	$(Co, Fe)AsS$	Tschermak (1866) Sb. Akad. Wiss. Wien, 53, p. 220	αλλοσ κλαω	Oravicza
Argentit	Ag_2S	Haidinger (1845) Handb. bestimm. Min., p. 565	argentum	Hungary, not specified
Biharit	Mg-Ca-K-Alumosilikat	Peters (1861) Sb. Akad. Wiss. Wien, 44, Abt. 1, p. 132	Bihar (TL)	Biharberg, Rézbánya
Dillnit	$Al_{15}S_6O_{25}(OH,F)_{18}Cl$	Haidinger (1849) Pogg. Ann. Phys. Chem, 77, p. 577	Dilln (TL)	Dilln, Selmec
Eukamptit	Mg-K-Alumosilikat	Kenngott (1853) Übers. min Forsch. p. 581	ευκαμπτος	Preßburg
Felsőbányit	$Al_4SO_4(OH)_{10} \cdot 5H_2O$	Haidinger (1852) Sb. Akad. Wiss. Wien, 12, p. 183	Felsőbánya (TL)	Kapnik, Felsőbánya
Hauerit	MnS_2	Haidinger (1846,1847) Ber. Mitt. Freund. Naturwiss. Wien, 2, p. 2; Naturw. Abh.,1, 101, 107,	J. und F. v. Hauer	Kalinka, Neusohl
Hemimorphit	$Zn_4Si_2O_7 (OH)_2 \cdot H_2O$	Kenngott (1853) Das Mohs'sche Mineralsyst., p. 67	εμι μορφηος	Rézbánya
Hörnesit	$Mg_3(AsO_4)_2 \cdot 8H_2O$	Haidinger (1860) Jb. geol. R.-A.,10–11; Sb. Akad. Wiss. Wien, 11, p. 18	M. Hoernes	Bánát
Kenngottit	Syn. Miargyrit	Haidinger (1856) Sb. Akad. Wiss. Wien, math. nat. Kl. 22, p. 236	A. Kenngott	Felsőbánya
Ludwigit	$Mg_2Fe^{3+}BO_5$	Tschermak (1874) TMPM, 1874, p. 59	E. Ludwig	Morawicza, Bánát
Nagyágit	$Pb_5Au(Te,Sb)_4S_{5\text{-}8}$	Haidinger (1845) Handb. bestimm. Min., p. 566	Nagyág (TL)	Nagyág
Partschinit	$(Fe,Mn)_3Al_2Si_3O_{12}$	Haidinger (1848) Ber. Mitt. Freund. Naturwiss. Wien, 3, p. 440	P. Partsch	Oláhpian
Petzit	Ag_3AuTe_2	Haidinger (1845) Handb. bestimm. Min., p. 556	Petz	Nagyág
Pilsenit	Bi_4Te_3	Kenngott (1853) Das Mohs'sche Mineralsyst., p. 121	Deutsch-Pilsen (TL)	Börzsöny
Schreibersit	$(Fe,Ni)_3P$	Patera, Haidinger (1847) Ber. Mitt. Freund. Naturwiss. Wien, 3, p. 69	F. A. v. Schreibers	Árva
Stützit	$Ag_{5-x}Te_3$	Schrauf (1878) Zs. Kryst. Min., 2, p. 209	A. Stütz	Zalathna
Száibelyit	$MgBO_2(OH)$	Peters (1861) Sb. Akad. Wiss. Wien, 44, p. 143	Szájbelyi	Rézbánya
Tellurit	TeO_2	Haidinger (1845) Handb. bestimm. Min., p. 506	tellurium	Siebenbürgen
Tetradymit	Bi_2Te_2S	Haidinger (1831) Pogg. Ann. Phys. Chem., 25, p. 597	τετραδυμος	Schubkau, Selmec
Veszelyit	$(Cu,Zn)_3PO_4(OH)_3 \cdot 2H_2O$	Schrauf (1874) Anz. Akad. Wiss. Wien, p. 135	A. Veszelyi	Moravicza

On the occasion of the general agricultural and industrial exhibition in Paris 1855 an outline of the mineral deposits of the Austro-Hungarian Empire was compiled by HAUER and FOETTERLE on order of the Geological Survey. This compilation contains a comprehensive survey also of the mineral deposits of Hungary and Transylvania. From a mineralogical point of view this outline gives only little information on details but as consequence a profound revision by COTTA & FELLENBERG (1862) of mineral deposits and ore mineralogy in Hungary and Transylvania took place .

In the time until 1869 a last climax was reached in the joint Austro-Hungarian mineralogical research. The publication of the book "Mineralogisches Lexicon für das Kaiserthum Österreich" (Mineralogical Encyclopedia of the Austrian Empire) in three volumes (1858, 1873, 1893) by ZEPHAROVICH (1830–1890) served as a model for all further descriptions of the member countries of the empire with its methodological approach. This work compiled systematically the entire information on the places of ocurrence in the empire and consequently is a fundamental work on the mineral occurrences of Hungary and Transylvania.

In this short survey of the contribution of Austrian geo-scientists to the mineralogical investigation in Hungary has to be mentioned their part in the nomenclature of minerals of Hungarian type localities. The intensive occupation with the samples from Hungarian deposits led inevitably to a series of new discoveries or new naming of minerals. From more than 3000 known mineral species worldwide some were discovered by Austrian mineralogists working on deposits of Hungary (as defined in the borders before 1918). These minerals are quoted in Table 1 with their type locality and the naming/first describing mineralogist. Minerals with still valid names are printed in bold letters. The names of all the other minerals are synonymes in the international nomenclature.

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ADVANCES
in
Austrian—Hungarian Joint Geological Research
Budapest, 1996

Austria's contribution to the palaeontological research in Hungary until the founding of the Royal Hungarian Geological Survey in 1869

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Keywords: palaeontology, Mesozoic floras, ammonitic faunas, Neogene, mollusca, insects, foraminifera, flora, Hungary

Abstract

The present short review deals essentially with the time span 1800–1869, in more detail with 1847–1869. During this period, main palaeontological research activity concerned the Mesozoic floras, (mostly ammonitic) faunas and the Neogene molluscs, insects, foraminifers and floras. From the Pleistocene, one single mammal find is mentioned.

Zusammenfassung

In der vorliegenden kurzen Übersicht wird im wesentlichen die Zeitspanne 1800–1869 behandelt; eingehend nur die Periode 1847–1869. Die meisten paläontologischen Untersuchungen dieser Zeit befassten sich mit den Floren und Faunen (vor allem Ammoniten) des Mesozoikums, sowie mit den Neogenen Mollusken, Insekten, Foraminiferen und Pflanzen. Aus dem Pleistozän wird nur ein einziger Mammalienfund erwähnt.

Összefoglalás

A jelen rövid áttekintés lényegében az 1800–1869, részletesebben az 1847–1869 közötti időszakkal foglalkozik. Akkoriban a kutatások a mezozóos flórákra és (jórészt Ammonitesz) faunákra, valamint a neogén puhatestűekre, rovarokra, foraminiferákra és növényekre irányultak. A negyedkorból mindössze egyetlen emlőslelet van megemlítve.

Introduction

"Hungary" should be understood within her largest historical boundaries and therefore encloses the following territories:

— The kingdom of Hungary including Upper Hungary, (Slovakia) and western Hungary (Burgenland),
— the kingdoms of Croatia and Slavonia,
— the grand duchy of Transylvania.

The kingdom of Dalmatia has been disregarded.

As "Austrians" all scientists from the cisleithanian part of the Empire have been considered, who have been sent to Hungary by a central office or were charged to work on Hungarian fossil material.

Due to the centralistic structure of the Empire, most of the universities, museums, collections and learned societies as well as the Academy of Sciences and the Geological Survey were concentrated in the capital Vienna, so that at most Viennese scholars had to do the work. People, who were living or working in the Hungarian part of the Empire will not be considered, even if they were not ethnic Magyars, such as KARL BERNHARD BÜHL or JOHANN NEUGEBOREN.

At the very beginning of geological research in Hungary Hungarian scientists naturally were occupied with palaeontological collecting, determination and research (VITÁLIS & KECSKEMÉTI 1991).

Nevertheless, some of the first records of Hungarian fossils came from Austrians, such as from FRANZ KARL SARTORI, official of the "Bücher-Revisionsamt" in Vienna, who described in his book "Naturwunder" (Miracles of Nature, 1806–1809) the so called "Ziegenklauen" (goat's claws) from Lake Balaton, but also remains of bones from

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Pleistocene cave fillings in Upper Hungary and an "excavated skeleton of an elephant in Hungary" (ZAPFE 1987, p. 193, f. 221).

It also should be remarked that the very first reference of a fossil from present-day Austria has relation to former Hungarian territory. It is a silicified piece of wood ("Lithoxylon") from the Upper Pannonian freshwater opal from the Csat mountains near Kohfidisch in Burgenland, which has been identified by CAROLUS CLUSIUS as a remain of an oak tree, *Quercus cerris*, in 1601 (ZAPFE 1987, p. 213).

From August 11. to 18., 1847 the VIII. Meeting of Hungarian Physicians and Naturalists took place at Ödenburg (Sopron). Austria was represented by MORIZ HÖRNES and FRANZ V. HAUER, the latter (HAMMERSCHMIDT 1848) being chairman of the section of mineralogy, geognosy, chemistry and pharmacy and reporting on several Hungarian fossils, such as those from the Miocene of Ritzing and the Pleistocene bone cave of Beremend in the county Baranya.

The assembly agreed on two topics as priorities until the next meeting, planned to take place in Pest 1848:

1. Comparison of Pannonian Basin fossils with those of the Vienna Basin.

2. Comparison of the "cephalopods from the red limestone of the Hungarian mountains" with those of the Eastern Alps.

Surely nobody knew at this time, what would happen next year. However, this may be considered as the first written down project of Austro–Hungarian geoscientific cooperation.

ANTON V. KUBINY, director of the National Museum in Pest, and CHRISTIAN ANDREAS ZIPSER even at that time proposed the foundation of a Hungarian Geological Society ("Ungarländische Geologische Gesellschaft") for the purpose of geological research in Hungary. This society became reality in January 1848.

The year after MORIZ HÖRNES travelled to Pest to promote the effective establishement of the Geological Society.

The Imperial and Royal Geological Survey ("K.u.k. Geologische Reichsanstalt") has been founded in December 1849 under the aegis of WILHELM HAIDINGER with the aim of geological exploration of the whole Austro–Hungarian Empire.

The new Geological Survey of Austria considered itself only "after a series of years" capable to begin the geological investigations in the countries of Saint STEPHEN's Holy Crown. HÖRNES offered his willingness to represent the interests of the Hungarian Geological Society in Vienna. On the occasion of his visit to Pest he studied the palaeontological collections of the National Museum and those of the "Hofkammersekretär" ANDREAS MIKECZ.

Palaeontology in those days was no independent science; palaeontological findings often were by-products of geological surveying and mapping. Most of them were published in geological papers — it is impossible to quote them all.

So we intend to deal only with some priorities of general palaeontological interest, i.e. publications which exclusively or nearly exclusively deal with Hungarian sites and have been published by "Austrians" in the sense mentioned above. We can not deal with those monographs which, covering a large scientific area, also consider Hungarian material, such as most of the papers on palaeobotany by FRANZ UNGER.

Due to the geological setting of the countries of Saint STEPHEN's Holy Crown there were two main topics of palaeontological investigation: the Mesozoic of the Carpathians and the Neogene of the Pannonian Basin; in addition to them some smaller occurrences and the Pleistocene caves.

Palaeontology of the Mesozoic

In 1848 JOHANN KUDERNATSCH, "Bergverwalters-Adjunkt" at Steierdorf (Anina) in the Banat, later geologist at the Geological Survey in Vienna since 1850, discovered a calcareous sequence forming the hanging wall of the Steierdorf coal, which contains a rich ammonite fauna of Middle Jurassic age. Three years later he described this fauna in a monograph. The fauna of Swinitza (Svinica, today Romania) comprises 12 species and is equivalent to the alpine Klaus limestone (KUDERNATSCH 1851). He also discovered the Liassic flora of Steierdorf, which he first considered to belong to the Buntsandstein Formation. Swinitza and Steierdorf are localities to which often has been referred later.

Beside these there are several more notices on fossils from Hungary, partly determined only provisionally. HAUER reported about another finding of Liassic plants from the surroundings of Kronstadt (Brasov), collected by the high school professor JOSEF MESCHENDÖRFER, correspondent of the Geological Survey in Vienna (Hauer 1860). He also checked the petrefact collection of the Hofrat ANTON V. SCHWABENAU at Ödenburg (Sopron), which mainly contained Mesozoic fossils from the neighbourhood of Zircz and Bakonybél in Veszprém county.

In 1866 FRANZ HERBICH, curator of the National Museum in Kolozsvár (Cluj) sent "a series of most interesting petrefacts" to HAUER, who reported on it in the same year (HAUER 1866):

The rich fauna of the Middle Jurassic from the brown oolitic limestone of the Nagyhagymás (Haghimaşul Mare) mountains is also important.

The ammonite fauna of the Dachschiefer from Mariathal (Marianka) in the Little Carpathians has always been of great stratigraphic interest. First thought to be Palaeozoic, later it turned out to be of Liassic age. Among the scientist dealing with its fossils were DIONYS ŠTUR, ANDREAS KORNHUBER — at this time high school professor in Preßburg (Bratislava) and FRANZ V. HAUER (HAUER 1869a).

Palaeontology of the Tertiary

The richest field of early palaeontological investigation was offered by the great intracarpathic basins.

As a classic example of a very early scientific work we have to consider a short paper on the so called "petrified goats' claws" from lake Balaton by PAUL MARIA PARTSCH, who worked at the k.k. Hof-Mineralien-Cabinet in Vienna. PARTSCH identified them as the polished umbonal regions of a bivalve genus not yet described, which he called ***Congeria*** (lat. congerere = gather), because it seemed to combine features of different other genera. The very "goats' claws" from Tihany he named *Congeria triangularis*.

More and more reports on the occurrence of Tertiary fossils were published, mainly on molluscs from the Neogene. So e.g. the faunas from Szob (HÖRNES 1847), Kórod (Corod) in Transylvania (HAUER 1847, with 28 species, among them *Cardium kuebecki*, Königsberg (Kralowa) in Upper Hungary (HAUER 1848) and Ritzing in Western Hungary (HÖRNES 1848) were described.

In both of his large monographs on the molluscan fauna of the Vienna Basin (HÖRNES 1851–1857, HÖRNES 1859–1870) MORIZ HÖRNES mentioned localities from Western Hungary such as Ödenburg (Sopron), Eisenstadt, Groß Höflein, St. Margarethen, Mattersdorf (Mattersburg) and Forchtenau.

The same is true for AUGUST EMANUEL REUSS, who quoted "polyparians" (i.e. Anthozoa and Bryozoa) from Eisenstadt, Rust, Mörbisch, Rohrbach, Kroisbach, Neudörfl (Devinska Nova Ves) and Ipolyság (Šahy) (REUSS 1848), resp. "entomostraceans" (i.e. Ostracoda) among others from Rust, Ödenburg (Sopron) and Felső-Lapugy (Lăpugiul-de-Sus) (REUSS 1850).

In the field of micropalaeontology there are also no special treatises on Hungarian material. Similarly to the systematic categories mentioned above in the larger monographs sporadic Hungarian localities occur, such as again Ödenburg (Sopron), Rohrbach, Marz and Forchtenau in Western Hungary by FELIX KARRER in his monograph on marine Miocene Foraminifera (KARRER 1862). He also described the foraminiferal fauna from Kostej (Coşteiul-de-Sus) in the Banat with an astonishing number of 268 species, among them 50 new (KARRER 1868).

A peculiarity is the occurrence of Miocene insects from Radoboj in Croatia. GUSTAV MAYR, secondary school teacher in Vienna and entomologist, worked specially on the ants. He distinguished 50 species, of them 3 hitherto not described.

Palaeobotany of the Upper Tertiary

The most discussed Miocene flora is that of Radoboj. Already in the middle of the last century ADOLF v. MORLOT brought a large collection of fossils to Vienna, containing 500 rock pieces with plants, 610 with insects and 70 with fishes. At that time it was thought that in the Radoboj material there are 200 different species of plants, 231 of insects and a dozen of fishes. Nearly at the same time CONSTANTIN v. ETTINGSHAUSEN in Vienna and FRANZ UNGER in Graz studied the rich flora which soon lead to a embittered quarrel between them. In 1850 UNGER succeeded in temporarity forbidding ETTINGSHAUSEN to use the collections of the Joanneum in Graz. Both of them in their important monographs dealt again and again with the Radoboj material: a detailed list of the references therefore is unnecessary. As an example should be mentioned the paper by UNGER 1861, covering 61 species, nearly all of them new.

1850 LUDWIG V. KOVÁTS and FRANZ V. KUBINYI discovered the Sarmatian flora from Erdőbénye near Tokaj. KUBINYI took 2000 prints of leaves to Vienna to be examined. ETTINGSHAUSEN (1854) described 68 species from the shales, many of them new. From a "stagnigena silicea" (fresh water opal) from Ilia near Schemnitz (Banská Štiavnica) UNGER (1853) cited the remains of a fern stem which he called *Osmundites schemnicensis*.

Pleistocene

Pleistocene findings scarcely have been determined or described. The scientific value of such short notes therefore is rather poor. As a curiosity mention should be made of a "giant skull of *Bos priscus* BOJ.", which fishermen on April 21, 1858 pulled up with their net out from the river Raab (Raba) near the town of Raab (Győr). It measured 940 millimetres between the tips of the horns and was bought by EDUARD SUESS (SUESS 1858).

In 1869 the Royal Hungarian Geological Survey has been founded. Geological mapping and scientific exploration from this time were taken over by the young institution. Though old friendly connections continued to exist on this and the other side of the river Leitha, this short outline should end with this remarkable date.

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STRATIGRAPHY

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PALAEONTOLOGY

ADVANCES
in
Austrian—Hungarian Joint Geological Research
Budapest, 1996

Palynology of the middle Upper Pannonian lignite occurrences in the area of Torony–Höll–Deutsch-Schützen–Bildein (Hungary/Austria)

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Keywords: Palynology, Upper Pannonian, Lignite, Burgenland

Abstract

In cores from the middle Upper Pannonian lignite sequence (Zone F) at the western part of the Pannonian Basin on the Hungarian–Austrian border in the area of Torony–Höll–Deutsch-Schützen–Bildein a rich microflora with 142 floral elements could be documented mainly in the botanical relation. It gave a good result about the different types of vegetation forming the peat and growing on the drier soil, almost without any influence of salt water.

Zusammenfassung

Aus Bohrkernen von braunkohleführenden Schichten des mittleren Oberpannon (Zone F) am Westrand des Pannonischen Beckens bei Torony (Ungarn)–Höll–Deutsch-Schützen–Bildein (Burgenland–Österreich) wurde eine sehr formenreiche Mikroflora bearbeitet und 142 Taxa vorwiegend botanisch bestimmt. Daraus kann man auf verschiedene Pflanzengemeinschaften auf Feucht- und Trockenstandorten nahezu ohne Salzwassereinfluß schließen.

Összefoglalás

Torony–Höll–Deutsch-Schützen–Bildein községek vidékén, az osztrák–magyar határ vidékén (a Pannon-medence nyugati peremén), a felső-pannóniai összlet (F zóna) fúrómagjaiból 142 flóraelemet tartalmazó gazdag mikroflórát sikerült kimutatni. Ez jó képet ad az egykori különféle, mocsári, illetve szárazabb talajon élt növénytársulásokról, szinte teljesen sósvízi hatás nélkül.

Introduction

For the present work the Upper Miocene lignite sequence around the Hungarian/Austrian border was selected. Boreholes in the lignite sequence in both countries made it possible to afford enough pollen bearing material for more detailed palynological studies. The great advantage of this deposit is that by previous and recent investigations in both countries the age and geology of the whole area is known.

Geology

Höll-Deutsch-Schützen–Bildein—Southern Burgenland (G. PASCHER)

Mapsheet of GÖK 168 Eberau

Geological setting, historical review

In the area for the first time coal was mentioned by WINKLER-HERMADEN & W. RITTLER (1949), according to the results of boreholes. The cores showed an Upper Pannonian sequence of 100 meter thickness (middle Upper Pannonian, zone F) with a considerable amount of coal. The area of Höll–Deutsch-Schützen was investigated by the Graz Köflacher Browncoal Company in the seventies.

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Boreholes were made also on the Hungarian side of the Pannonian Basin in the area of Torony–Ják. The lignite sequence is the same as on the Austrian side. Sauerzopf (1950, 1952, 1954) could subdivide the Pannonian sequence in the same way like it was done by Papp (1951) for the Vienna Basin. The best information about the geology of this area could be found in the excursion guide-book (Bernstein, F. Koller 1990) of the Austrian Geological Society.

Regional geology of the investigated area

The investigated area is situated in the area of the "Südburgenländische Schwelle". The "Südburgenländische Schwelle" separates the Pannonian from the Styrian Basin. This swell in the geological sense is a buried neck of the Palaeozoic basement. It started to subside in the Late Pannonian and was an island in a slightly brackish lake, which came into being because of the breaking down of the Paratethys.

The presence of mostly only small lignite layers intercalated between clay and sand point to not continuous subsidence. This swell consists of several segments. During the Neogene each of the segments developed in a different way. One of these segments is bordered to the north and northwest by the so called "Eisenberger Schieferinsel" (Segment of Eisenberg). The segment of Eisenberg of the "Südburgenländische Schwelle" is adjacent to the West-Hungarian borderland of the Pannonian Basin. To the latter belongs at the Austrian side the alluvial plain of Pinka and as East of the villages Oberbildein and Unterbildein the forest of Bildein—Eberau.

Sequence of strata

In that part of the Pannonian Basin the Neogene sequence consists of Lower and Upper Pannonian. There was no evidence for Lower Pannonian in boreholes. The lower Upper Pannonian is a clay-sand sequence (200 meters), the middle Upper Pannonian is a lignite sequence (150 meters) and the upper Upper Pannonian is a sand sequence (200 meters), discordantly overlain by "Levantin" of 30 meters thickness [Nebert (1977)].

The Pleistocene deposits have a thickness of 10—15 meters. The youngest alluvial layers are along the Pinka-river (more than 10 meters thick).

The flatly SE dipping sequence is of Late Pannonian age. The thickness of the "lignite sequence" amounts up to 150 meters. Within the 150 meter thick lignite sequence the number of coal seams being more than 1 meter thick is not more than 6—8. Their average thickness is about two meters. The interbeds of clay and marl can amount up to 12 meters. The upper edge of this lignite sequence could be recognized near Badersdorf in an outcrop and furnished a well preserved rich microflora (Zetter 1988). The outcrop is 1.5 meters thick and shows alternating clay layers in various colours and two coal seams of 20 cm each. On top of this profile there is a reddish gravel layer, which is the base gravel of the Upper Pannonian (up_3) sequence. The browncoal was detected in boreholes and is soft and laminated. Due to the plain dipping towards the south, the coal bearing sequence of Hungary is cropping out on the Austrian side.

Origin and formation of the lignite

The detailed mapping by Nebert (1977) and others and the available documents make the palaeogeographical reconstruction possible.

The "Südburgenländische Schwelle" was an emerged land or a bigger island during the Late Pannonian. In the calcareous basement rocks a karst-landscape was developed under humid climate. Later on, in the Late Pannonian (up_3), sand covered this karst landscape.

A fossil flora at the base of the Upper Pannonian includes subtropical elements (Nebert 1977). The investigation of a well preserved microflora from Badersdorf,

VIENNA BASIN		EISENBERGER SEGMENT OF SÜDBURGENLÄNDISCHE SCHWELLE	WESTHUNGARIAN MARGINAL REGION OF THE PANNONIAN BASIN JASKÓ (1975)
LOWER PLEISTOCENE (q)			
COLOURED CLAY AND SAND UPPER LIGNITE-SEQUENCE	H	SAND-SEQUENCE (up_3) Gastropod fauna BASIC GRAVELS	SAND-SEQUENCE (up_3) LIGNITE-SEAMS *Unio wetzleri* and *Viviparus*
BLUE CLAY *Viviparus*	G	KARST LANDSCAPE	LIGNITE-SEQUENCE (up_2) *Prosodacna vutskitsi* *Congeria balatonica*
CLAY AND SAND LIGNITE (Zillingsdorf a. Neufeld) *Congeria neumayri* *Congeria croatica*	F	mammal fauna of Kohfidisch	CLAY–SAND-SEQUENCE (up_1) *Congeria neumayri*
CLAY OF INZERSDORF	E	UPPER PANNONIAN (UP)	

Ev: K. NEBERT, 1977. tab. 1, p. 5

Fig. 1. Pannonian stratigraphy showing the level of the lignite sequence (up_2)

Bonisdorf, Rechnitz brought an extended knowledge about the palaeovegetation of the southern part of Burgenland (ZETTER 1987).

The development of the Late Pannonian lignite can be reconstructed as follows. During that period of develepement, the "Südburgenländische Schwelle" was dry land and formed the edge of the West Hungarian basin. Along this swell a swamp was extending several kilometers towards southwest.

The gradual subsidence of the "Südburgenländische Schwelle" started during the Late Pannonian.

The clastic sediments at the base of the Upper-Pannonian in the boreholes (clay-sand, up_1) point to a sudden subsidence of the "Südburgenländische Schwelle" at the Eisenberger Segment.

Later on in the middle Late Pannonian the rate of sedimentation became slower, so that there was a balance between the sedimentation and the vertical movement of groundwater (NEBERT 1977). From that time on the conditions for the accumulation of organic material of brown coal were optimal. The results of this process was what NEBERT described as the lignite sequence (up_2).

The conservation of the organic matter occurred in the uppermost Upper Pannonian by the deposition of the so-called sand sequence (up_3).

Tectonics

In general, the deposition of the Upper Pannonian strata was quiet in the area of the west Hungarian border of the Pannonian Basin. A dip of 1—2° towards SE of the Upper Pannonian strata could be determined in the borehole profiles.

In the area of the Holocene plain of Pinka the dip of the Upper Pannonian sequence was 5—6° towards the same direction.

The West Hungarian edge of the Pannonian Basin is bordered against the sand-sequence of the Eisenberger Segment by a north—south running fault. After the deposition of the sand sequence (up_3) the Eisenberg Segment was turned against southeast. The NW edge of the swell became higher and was therefore eroded.

This turn may have happened during Late Pliocene. The turn originated dislocations up to 2 m within the sand sequence (up_3). It caused minor displacements. In the area of the Eisenberger Schieferinsel the layers of the Upper Pannonian (up_3) were lifted up and eroded . Therefore, the up_3-layers are dipping rather steeply towards NW at the NW border of the Eisenberger Schieferinsel and towards SE and E at its SW edge. The thickness of the Pannonian amounts to more or less 600 m in the area of the Südburgenländische Schwelle.

The downwards movement of the Eisenberger Segment was not uniform, but oscillating. Therefore there is not a single thick coal layer, but a partition into several coal seams. This is the result of rhythmic sedimentation. The individual seams are facies members of sedimentation-cycles or series. A single cycle consists of the following facies members: sand, clayish sand, clay, clayish coal, lignite. The duration of the different cycles was irregular and the individual cycles are not of the same thickness. NEBERT described 4–5 cycles from the West Hungarian border of the Pannonian Basin.

Torony

On the basis of JASKÓ's articles (1975) with respect of stratigraphy, the beds occurring on the territory of Torony belong to the horizon of *Congeria balatonica* and *Prosodacna vutskitsi*. The lignite layers are of paralic type and are repeatedly intercalated with dead rocks. This type of rock formation is present at the margin of the Pannonian Basin. Although the Pannonian beds are folded in the area to the south and to the west of Hungary, they rest undisturbed on the piedmont of the Alps at the western rim of the Pannonian Basin. The lignite-bearing territory of Rechnitz–Deutsch-Schützen extends across the Austrian border to the area of Torony–Nárai in Hungary along the strike toward north–northeast. In the Torony area the lignite layers are dipping 2–3° in southeast direction. This means that in 6 km distance the layers are at 120–140 m below the surface. The total thickness of the lignite layers including the dead rocks is 100 meters in Torony–Nárai territory. There are no carbonate and coarse clastic rocks present.

JASKÓ (1975), p. 311, considers the irregular lignite seams to form rhythms in the territory of Torony. Namely in the sequences: clayey sand–clay–clay with lignite (lignite clay)–lignite.

In the hanging wall, however sand follows without transition. JASKÓ interprets this phenomenon in that way that the swamp was suddenly covered by sand deposited by rivers. Later on a swamp developed again. The duration of individual cycles is largely varying.

From the investigated two boreholes, one (Torony 76, situated 1 kilometer to the northeast of Torony) intersected two lignite seams, whereas the other one (Torony 71, situated 3.5 kilometers to the southeast of Torony) met four lignite seams. According to JASKÓ (1964) the reason for this difference is that the upper part of the sediments with two lignite beds was eroded north of Torony, whereas in the south all the four lignite beds have been preserved. This feature characterizes the territory as found in the borehole Torony 71.

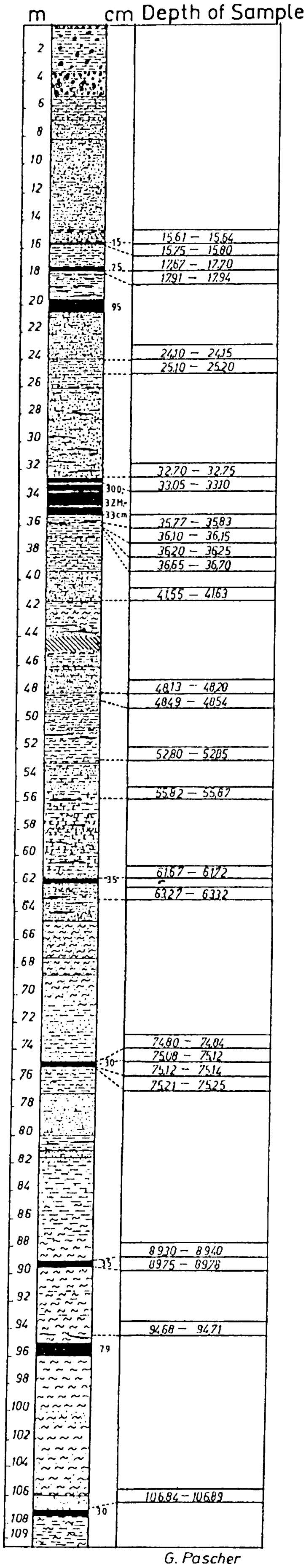
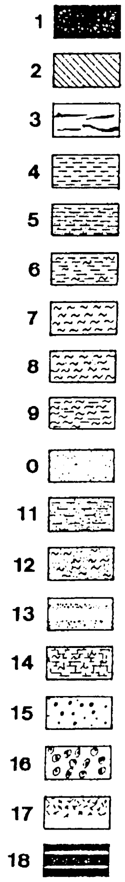


Fig. 2. Lithology of Höll—Deutsch-Schützen borehole 2 and position of the analyzed samples
1 Brown-coal; 2 Coaly clay; 3 Interbedded with lignite; 4 Clay, grey; 5 Clay with sand; 6 Clay with marl; 7 Claymarl, grey-green; 8 Claymarl, sandy; 9 Claymarl, clayey; 10 Sand, grey, partly with muscovite; 11 Sand clay; 12 Sand, marl; 13 Interbedded with sand; 14 Clay, claymarl; *Quaternary deposits* (15, 16, 17): 15 Gravel, 16 Quartz gravel, 17 Humus; 18 Interbeds



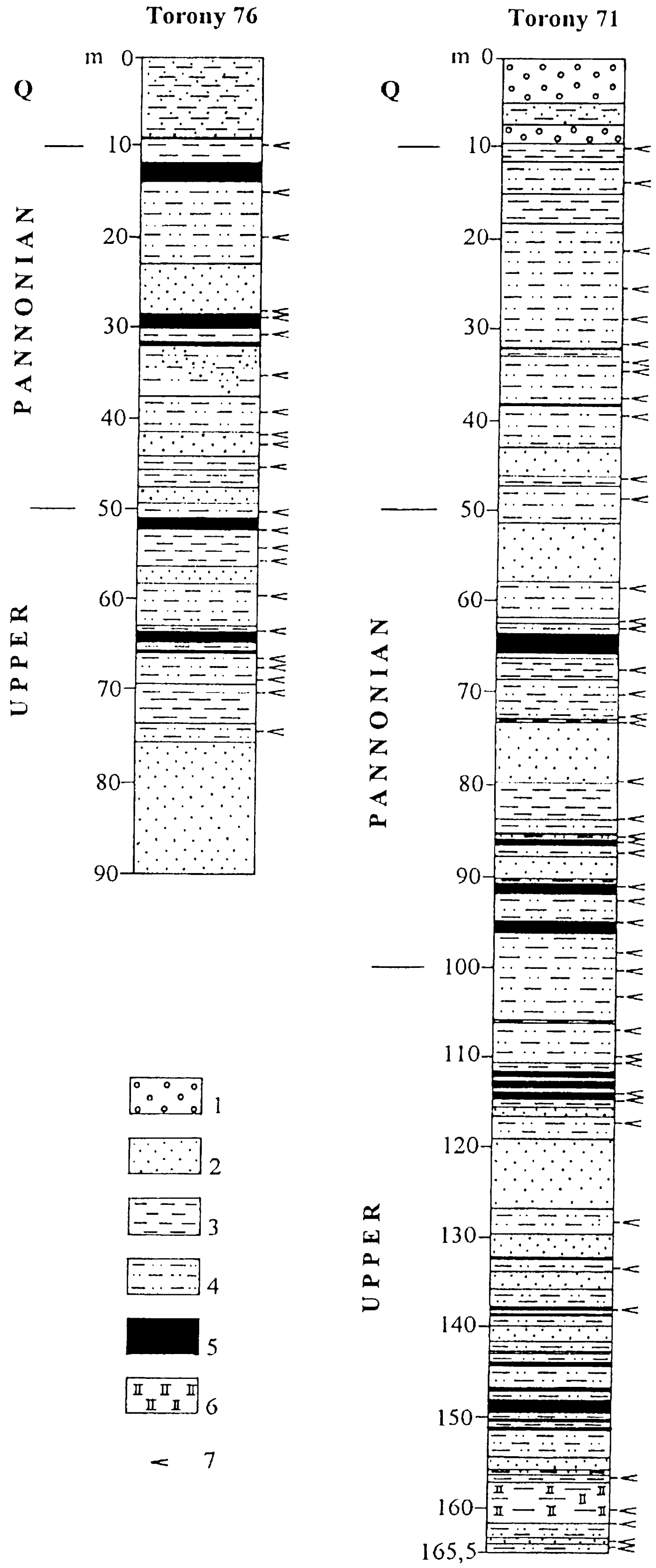


Fig. 3. Lithology of Torony borehole 71 and 76 and the position of the analyzed samples
1 Gravel; 2 Sand; 3 Clay; 4 Silt; 5 Lignite; 6 Limestone; 7 Sample

Mapsheet of GÖK 168 EBERAU

GIS-based preliminary map

Mapped by: R. GRATZER 1985, K. NEBERT 1977 and W. POLLAK 1962
GIS-performance: G.A. PASCHER 1995

Austrian-Bundesmeldenetz No. 7707
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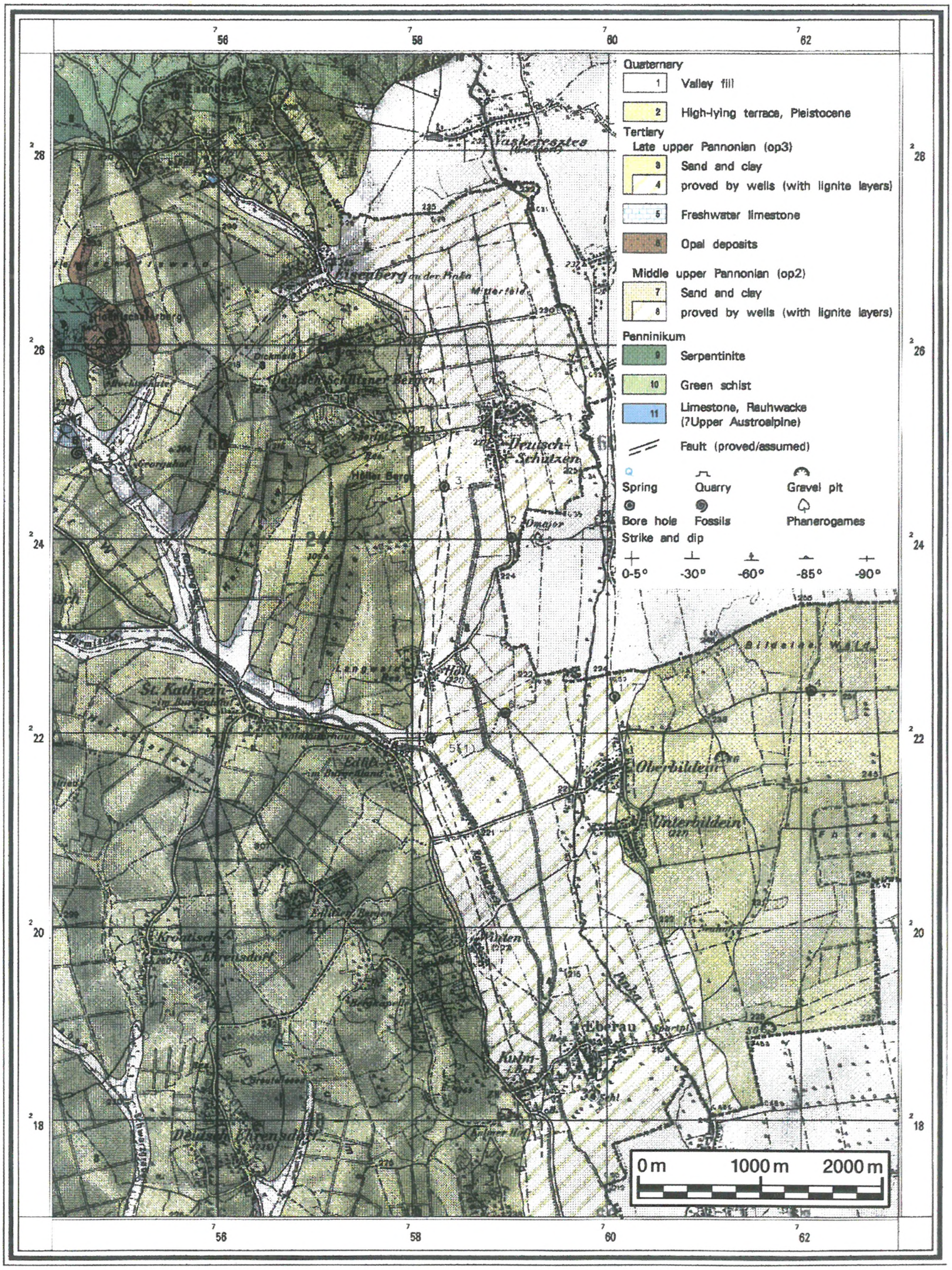


Palynological results

Material and methods

The investigated samples at the Austrian side originate from three boreholes (1, 2, 4) in the middle Upper Pannonian lignite sequence from Höll—Deutsch-Schützen—Bildein at the Austrian side and from two boreholes (nr. 71 and 76) in the same sequence near Torony (Hungary). The microflora occurred fairly frequently and was well preserved in some layers. So the investigation in LM and SEM provided more information about its position in the botanical system.

After examiniation of pollen grains under the light microscope selected specimens were transferred to a SEM stub according the method of ZETTER (1989).

The preservation of pollen and spores varies considerably in this sequence. So the state of preservation was important for selecting samples for the closer study by SEM.

Microfloral assemblage (recorded in a list and diagrams)

Spore and pollen taxa from the middle Upper Pannonian lignite deposit
Höll–Deutsch-Schützen–Bildein–Torony

Algae:

Dinophyceae
- *Spiniferites* sp.

Desmidiaceae
- *Closterium* sp.

Zygnemataceae
- *Spirogyra* sp.
- *Mougeotia* sp.

Botryococcaceae
- *Botryococcus braunii*
- *Cooksonella* sp.
- *Monogemmites* sp.
- *Micrhystridium* sp.

Sporites:

Anthocerotaceae
- *Rudolphisporites rudolphi [(*KRUTZSCH *1959)* KRUTZSCH & PACLTOVÁ 1963]

Sphagnaceae
- Sphagnaceae (*Stereisporites* sp.)

Lycopodiaceae
- *Lycopodium* sp.
- *Huperzia selago* (*Selagosporis selagoides* KRUTZSCH 1963)
- *Lusatisporis* sp.

Osmundaceae
- *Osmunda* sp.
- *Osmundacidites primarius primarius*
- *Osmundacidites primarius crassiprimarius*

?Schiceazeae
- *Lygodium* sp.

Pteridaceae
- *Pteris* sp.

Polypodiaceae
- *Laevigatosporites haardti* (POTONIÉ 1931) THOMSON & PFLUG 1953
- *Laevigatosporites* sp.
- *Verrucatosporites alienus* (POTONIÉ 1931) THOMSON & PFLUG 1953
- *Pteridium* sp.

Salviniaceae
- *Azolla* sp.

Pollenites:

Ginkgoaceae
- *Ginkgo* sp.

Pinaceae
- *Abies* sp.
- *Cedrus* sp.
- *Keteleeria* sp.
- *Picea* sp.
- *Pinus* Diploxylon-type
- *Pinus* Haploxylon-type
- *Cathaya* sp.
- *Tsuga* sp. (5 formspecies in Torony)

Taxodiaceae, Cupressaceae
- Taxodiaceae, Cupressaceae (*Inaperturo pollenites hiatus* (POTONIÉ & VENITZ 1934) THOMSON & PFLUG 1953]
- *Taxodium*, Glyptostrobus sp. [*Inaperturopollenites concedipites* (WODEHOUSE 1933) KRUTZSCH 1971]
- *Sciadopitys* sp.

Ephedraceae
- *Ephedra* sp.

Nelumbonaceae
- *Nelumbo* sp.

Nymphaeaceae
- *Nymphaea* sp.

Ranunculaceae

Hamamelidaceae
- *Liquidambar* sp.

Eucommiaceae
- *Eucommia* sp.

Rosaceae
- Rosaceae (2 genera)

Lythraceae
- Decodon (2 species)

Onagraceae
- Onagraceae (2 genera or species)

Elaeagnaceae
- *Elaeagnus* sp.

Nyssaceae
- *Nyssa* sp.

Trapaceae
- *Trapa* sp.

Haloragaceae
- Myriophyllum (2 species)

Rutaceae
- *Toddalia* sp.

Aceraceae
- Acer sp. (3 species)

Aquifoliaceae
- *Ilex* sp.

Vitaceae
- Vitaceae, *Partonecissus* sp.

Araliaceae
- *Hedera* sp.

Cornaceae

Mastixiaceae
- Mastixiaceae

Apiaceae
- Apiaceae (4 genera)

Rubiaceae
- *Galium* sp.

Valerianaceae
Patrinia sp.
Valeriana sp.
Dipsacaceae
Succisa sp.
Scabiosa sp.
Tiliaceae
Tilia sp. [*Intratriporopollenites cordataeformis* (WOLFF 1934) MAI 1961]
Craigia sp. [*Intratriporopollenites instructus* (POTONIÉ 1931) THOMSON & PFLUG 1953]
Sterculiaceae
Reevesia sp.
Buxaceae
Buxus sp.
Oleaceae
Fraxinus sp.
Ligustrum sp.
?Asclepidiaceae, Periplocoideae
Convolvulaceae
Calystegia sp.

Lamiaceae
Phlomis sp.
Asteraceae
Asteroideae (6 genera)
Cichorioideae
Artemisia sp.
Ericaceae
Erica sp.
Rhododendron sp.
Caryophyllaceae
Caryophyllaceae (3 genera)
Chenopodiaceae
Chenopodiaceae (4 genera)
Iteaceae
Itea sp.
Sapotaceae
Sapotaceae
Ebenaceae
Diospyros sp.
Polygonaceae
Polygonum sp.

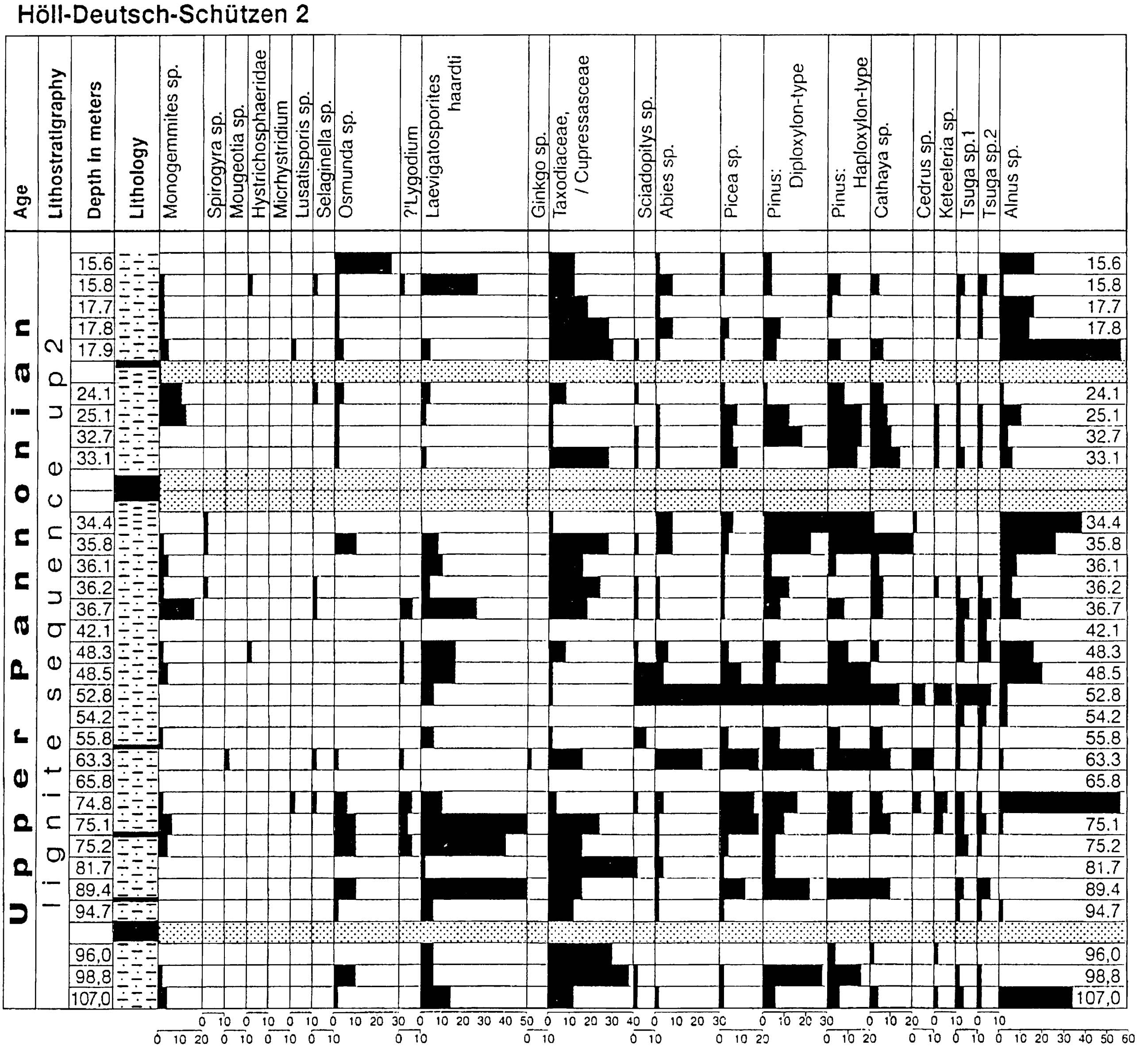
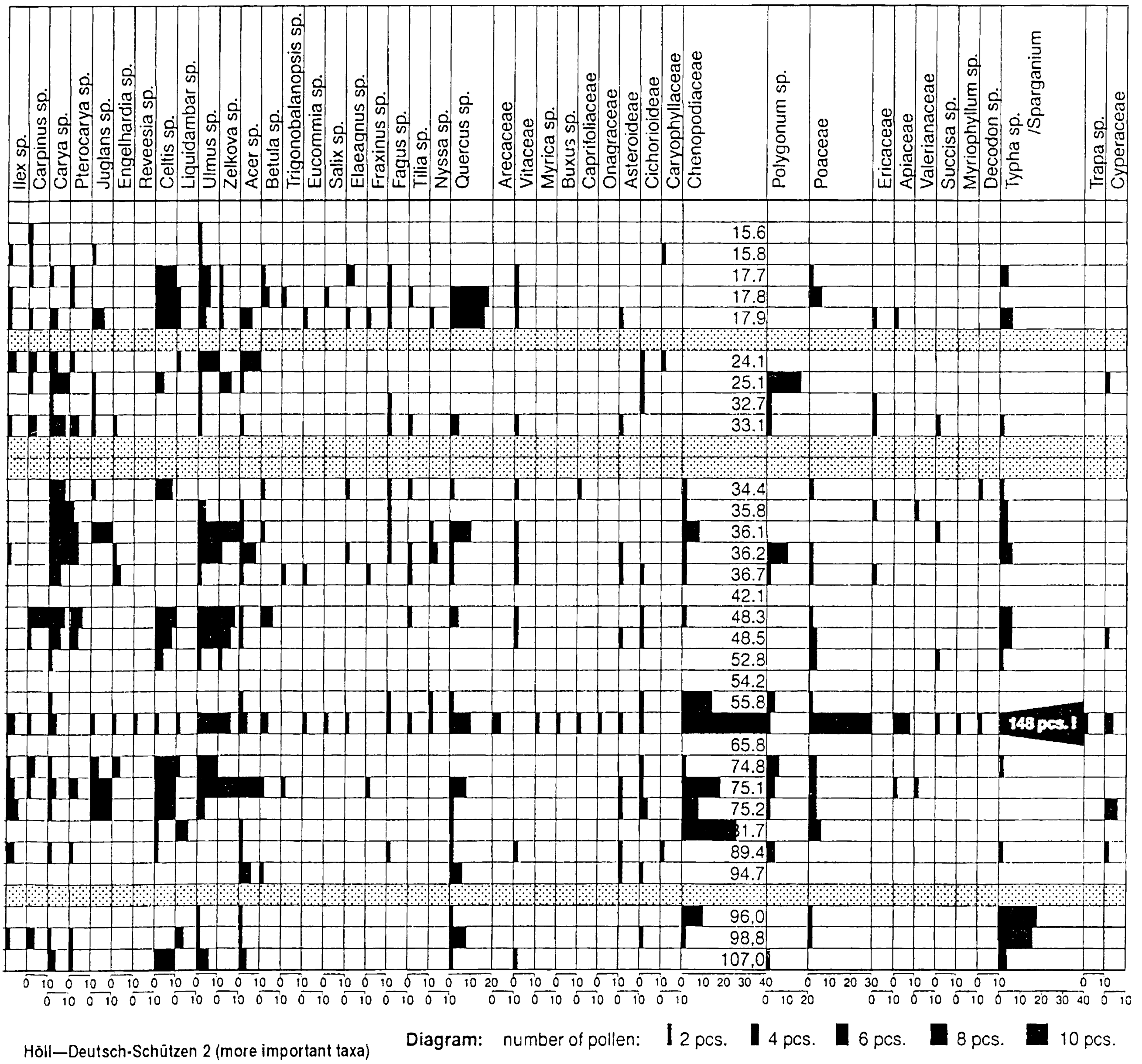


Fig. 4. Pollen diagram of borehole

Urticaceae
 Urticaceae
Ulmaceae
 Celtis sp.
 Ulmus sp.
 Zelkova sp.
Betulaceae
 Alnus sp.
 Betula sp.
 Caroinus sp.
 Corylus sp.
Fagaceae
 Trigonobalanopsis sp. [*Castaneoiideaepopllis pusillus* (POTONIÉ 1934) GRABOWSKA 1994]
 Castanea sp.
 Fagus sp.
 Quercus sp. (6 species)
Juglandaceae
 Carya sp.
 Engelhardia sp.
 Juglans sp.
 Pterocarya sp.
Myricaceae
 Myrica sp.
Salicaceae
 Salix sp.
Alismataceae
 Alisma sp.
Hydrocharitaceae
 Stratiotes sp.
Potamogetonaceae
 Potamogeton sp.
Cyperaceae
 Cyperaceae
Poaceae
 Poaceae (5 genera)
Sparganiaceae
 Sparganium sp.
Typhaceae
 Typha sp.
Palmae
 Sabal sp.



Höll—Deutsch-Schützen 2 (more important taxa)

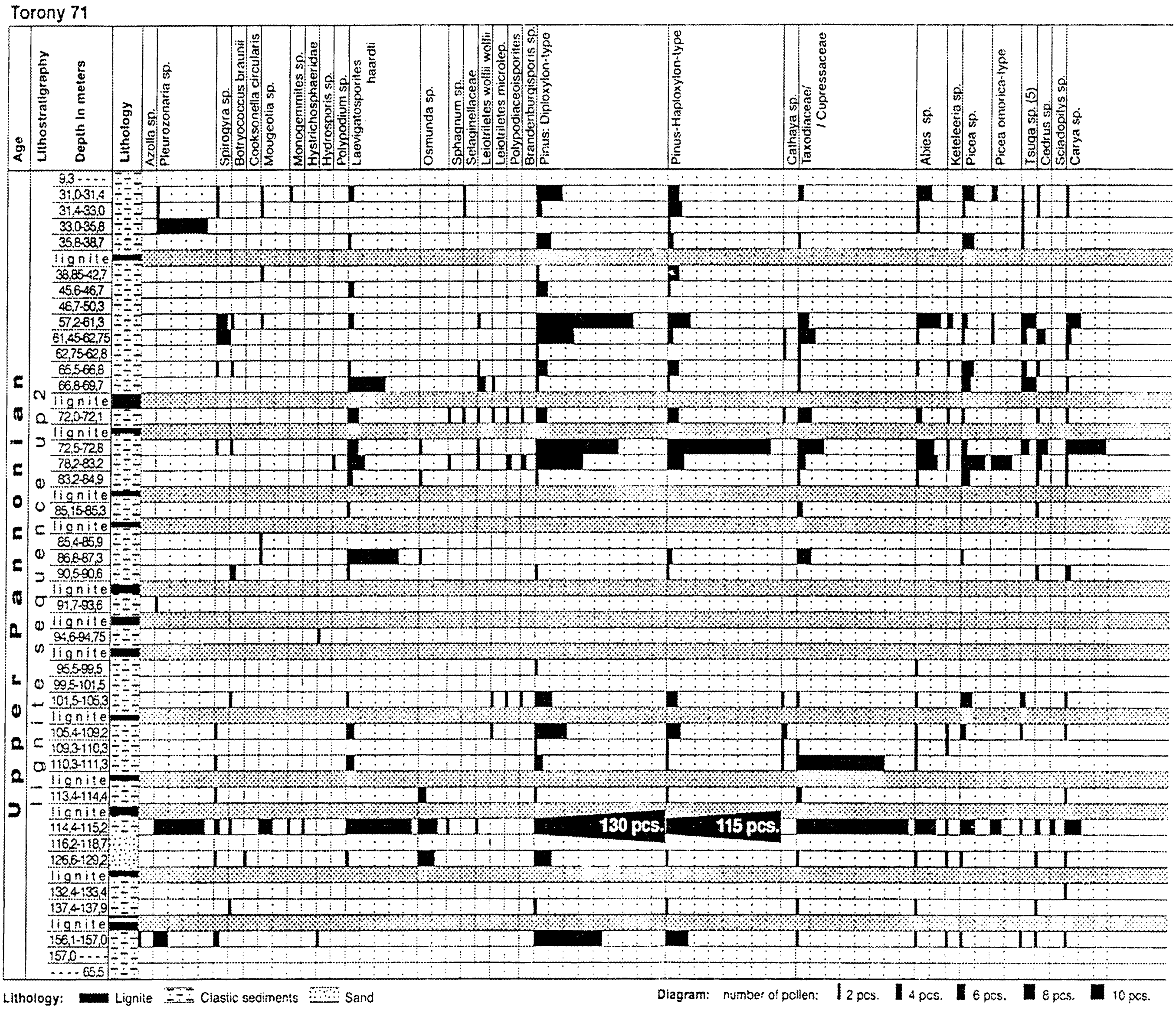


Fig. 5. Pollen diagram of borehole

Discussion

Palaeovegetation represented by the pollen and spore assemblage

The following plant communities could be reconstructed.

There are planctonic organisms which originate from freshwater: *Spirogyra*, *Mougeotia*, *Cooksonella*, *Botryococcus*. Dinoflagellates are extremely rare. They are not present in the Austrian part but a few specimens occur in the Hungarian part of the investigated area.

The floral elements could be grouped in the following categories of vegetation:

1. Open freshwater with freshwater plankton (*Monogemmites*, *Spirogyra*, Zygnemataceae, *Botryococcus*) and fresh water plants like *Myriophyllum* (two species), *Trapa* sp., *Potamogeton*, *Nymphea*, *Nuphar*, *Nelumbo*, *Alisma*, *Stratiotes*.

2. Lakeshore vegetation with *Typha*, *Sparganium*, perhaps *Phragmites*, Cyperaceaeae.

3. Sandbanks and salty soil with Chenopodiaceae and *Ephedra*.

4. Tree-dominated bog environment:

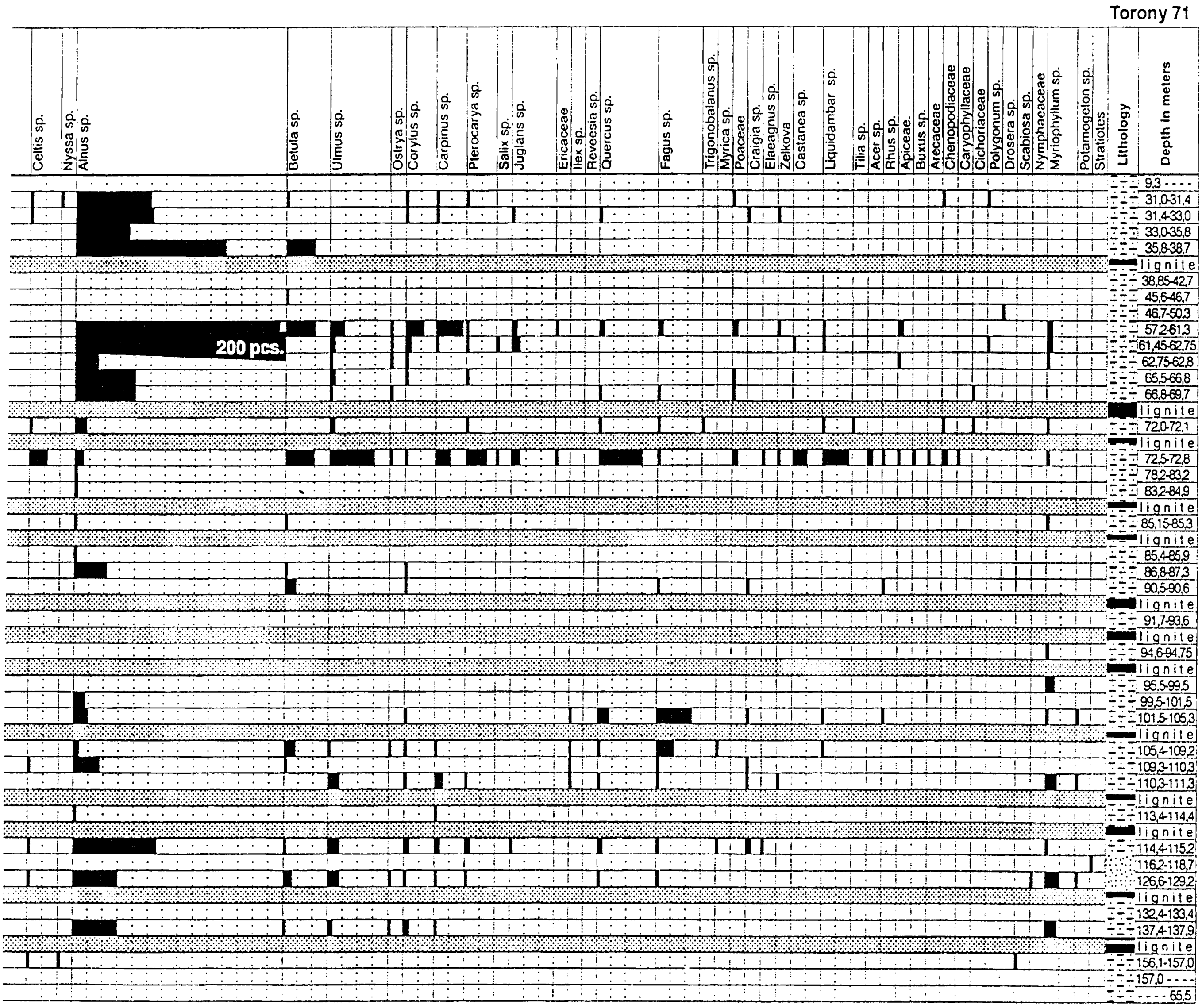
A swamp-forest is documented by Taxodiaceae, *Nyssa*, *Decodon*, Vitaceae, *Fraxinus* and probably with *Rhododendron*, *Palmae* and *Osmunda* species in the undergrowth.

A riparian forest could be distinguished by *Alnus*, *Carya*, *Betula*, *Salix*, *Ilex*, *Quercus*, *Liquidambar*.

5. Swampy meadows with *Succisa*, *Polygonum*, Apiaceae, Valerianaceae, Caryophyllaceae, Poaceae.

6. "Mixed mesophytic forest" behind the peat forming vegetation with Pine species, *Ginkgo*, *Picea*, *Abies*, *Sciadopitys*, *Quercus*, *Fagus*, *Tilia*, *Craigia*, *Reveesia*, *Lonicera*, *Viburnum*, *Eucommia*, *Engelhardtia*, *Acer*, Fagaceae, *Elaeagnus*, Rutaceae, *Buxus*, *Carpinus*, *Erica*.

7. Hillside-piedmont forest with conifers, *Pinus*, *Abies*, *Picea*, *Tsuga*, *Larix*, *Cedrus*, *Keteleeria*.



Torony 71 (more important taxa)

Palaeoclimatic character of the flora

From the flora it could be concluded that the climatic conditions were warmer than today.

Subtropical elements like *Reevesia* (Sterculiaceae), *Sabal* and *Engelhardia* perhaps could survive locally in the undergrowth of the swamp forest. These elements are present in the middle Upper Pannonian sequence but are much more dominating in the warm periods of the earlier older Miocene periods. *Engelhardia* is very rare and also the other palaeotropical floral elements like Mastixioideae, Sapotaceae and *Reevesia* are retreating in the middle Upper Pannonian from zone D/E to F remarkably. It should be mentioned that the characteristic element *Tricolporopollenites sibiricum* (LUBOMIROV 1972) NAGY 1992 (*Tricolporopollenites wackersdorfensis* THIELE-PFEIFFER 1980) Fabaceae are therefore not present in this lignite sequence. This element disappeared in this region in the Zone E of the Pannonian.

Reevesia and *Engelhardia* live today in the zone with high humidity only in the Himalaya and other regions of southeast Asia.

A climatic cooling within the middle Late Pannonian could be proved by the increase of coniferes (*Abies*, *Picea*, Pine species, *Tsuga* species) in the pollen spectra of the lignite sequence in the Hungarian and Austrian part (Fig. 4, 5) .

Gramineae, Compositae, Chenopodiaceae, *Acer*, *Alnus*, *Betula*, *Carya*, *Pterocarya*, *Ulmus*, *Pinus*, *Abies*, *Picea*, *Sciadopitys* and *Tsuga* became important or even dominant.

Sciadopitys and *Cathaya* are extremely endemic today and therefore it is not relevant to transfer the present day climatic conditions directly to the fossil occurrence.

There are also warm temperate plant elements like *Liquidambar*, *Carya*, *Pterocarya*, *Buxus*, *Rhus*, *Ostrya*, *Ilex* present.

The most numerous are temperate plants (e.g. *Fagus*, *Ulmus*, *Quercus*, *Tilia*). *Alnus* is a typical azonal element.

The expansion of the decidous hardwood forest, typical for Late Pannonian is clearly visible by the high number of *Quercus* species in the upper part of the lignite sequence, which were distinguished by SEM (obviously deciduous)

In the pollen spectra of the Upper Pannonian lignite sequence there is also a remarkable tendency of increasing number of non-arboretic pollen-types from herbs like Chenopodiaceae Asteraceae, *Succisa*, *Scabiosa*, *Valeriana*, *Patrinia*, Apiaceae, Caryophyllaceae, Rubiaceae, Lamiaceae etc. This seems to be an indication of larger non-forested areas probably locally caused by the retreat of the sea and (or an effect by the cooling) the development of non forested peat and reed meadows.

Acknowledgements

The authors thank very much the Geological Institute of Hungary for promoting their work as well as Dr. A. W. RUTTNER for his help in translating the geological part into English. They are indebted to Mr. K. BAUER for preparing the samples so carefully and to Mr. J. RUTHNER for drawing the diagrams (all of them Geol. Survey, Vienna).

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PLATE 1

Fig. 1–3: Fig. 1 *Lycopodium* sp.; 850 x LM.
Fig. 2 *Lycopodium* sp.; 1500 x SEM.
Fig. 3 *Lycopodium* sp.; Detail of the exine surface; 8500 x SEM.

Fig. 4–6: Fig. 4 *Huperzia* sp.; 850 x LM.
Fig. 5 *Huperzia* sp.; 1200 x SEM.
Fig. 6 *Huperzia* sp.; Detail of the exine surface; 9500 x SEM.

Fig. 7–9: Fig. 7 *Sciadopitys* sp.; 850 x LM.
Fig. 8 *Sciadopitys* sp.; 1400 x SEM.
Fig. 9 *Sciadopitys* sp.; Detail of the exine surface; 6000 x SEM.

Fig. 10–13: Fig. 10 *Tsuga* sp.; 600 x LM.
Fig. 11 *Tsuga* sp.; 700 x SEM.
Fig. 12 *Tsuga* sp.; Detail of the exine surface of the corpus; 7000 x SEM.
Fig. 13 *Tsuga* sp.; Detail of the exine surface of the saccus; 8000 x SEM.

Fig. 14–16: Fig. 14 *Cathaya* sp.; 800 x LM.
Fig. 15 *Cathaya* sp.; 900 x SEM.
Fig. 16 *Cathaya* sp.; Detail of the exine surface; 7000 x SEM.

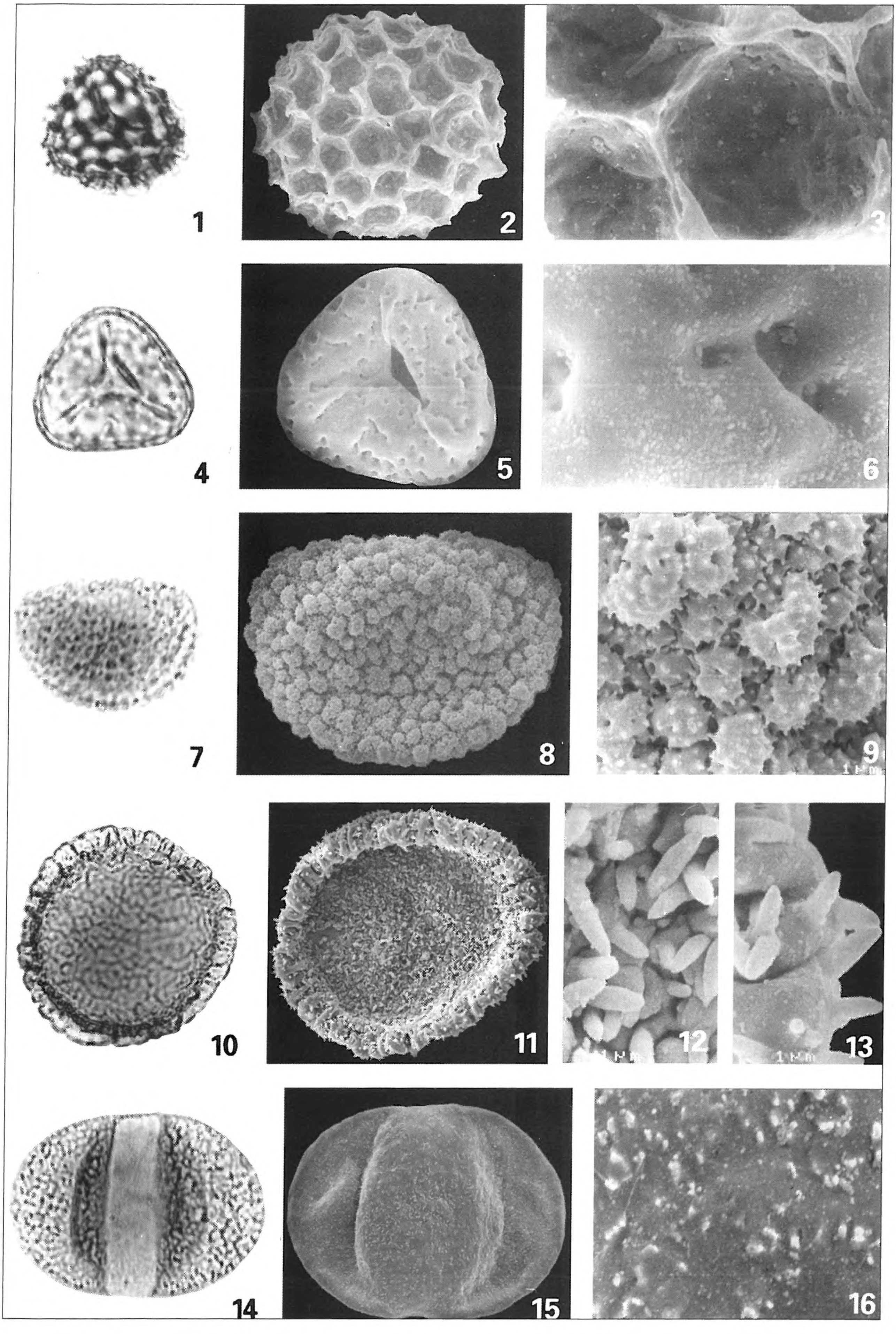
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PLATE 2

Fig. 1–3: Fig. 1 Arecaceae; 850 x LM.
Fig. 2 Arecaceae; 1600 x SEM.
Fig. 3 Arecaceae; Detail of the exine surface; 8000 x SEM.

Fig. 4–6: Fig. 4 *Typha* sp.; 850 x LM.
Fig. 5 *Typha* sp.; 1800 x SEM.
Fig. 6 *Typha* sp.; Detail of the exine surface; 8000 x SEM.

Fig. 7–9: Fig. 7 *Patrinia* sp.; 850 x LM.
Fig. 8 *Patrinia* sp.; 1500 x SEM.
Fig. 9 *Patrinia* sp.; Detail of the exine surface; 6000 x SEM.

Fig. 10–12: Fig. 10 *Phlomis* sp.; 850 x LM.
Fig. 11 *Phlomis* sp.; 2000 x SEM.
Fig. 12 *Phlomis* sp.; Detail of the exine surface; 14000 x SEM.

Fig. 13–15: Fig. 13 Poaceae; 850 x LM.
Fig. 14 Poaceae; 2200 x SEM.
Fig. 15 Poaceae; Detail of the exine surface; 13000 x SEM.

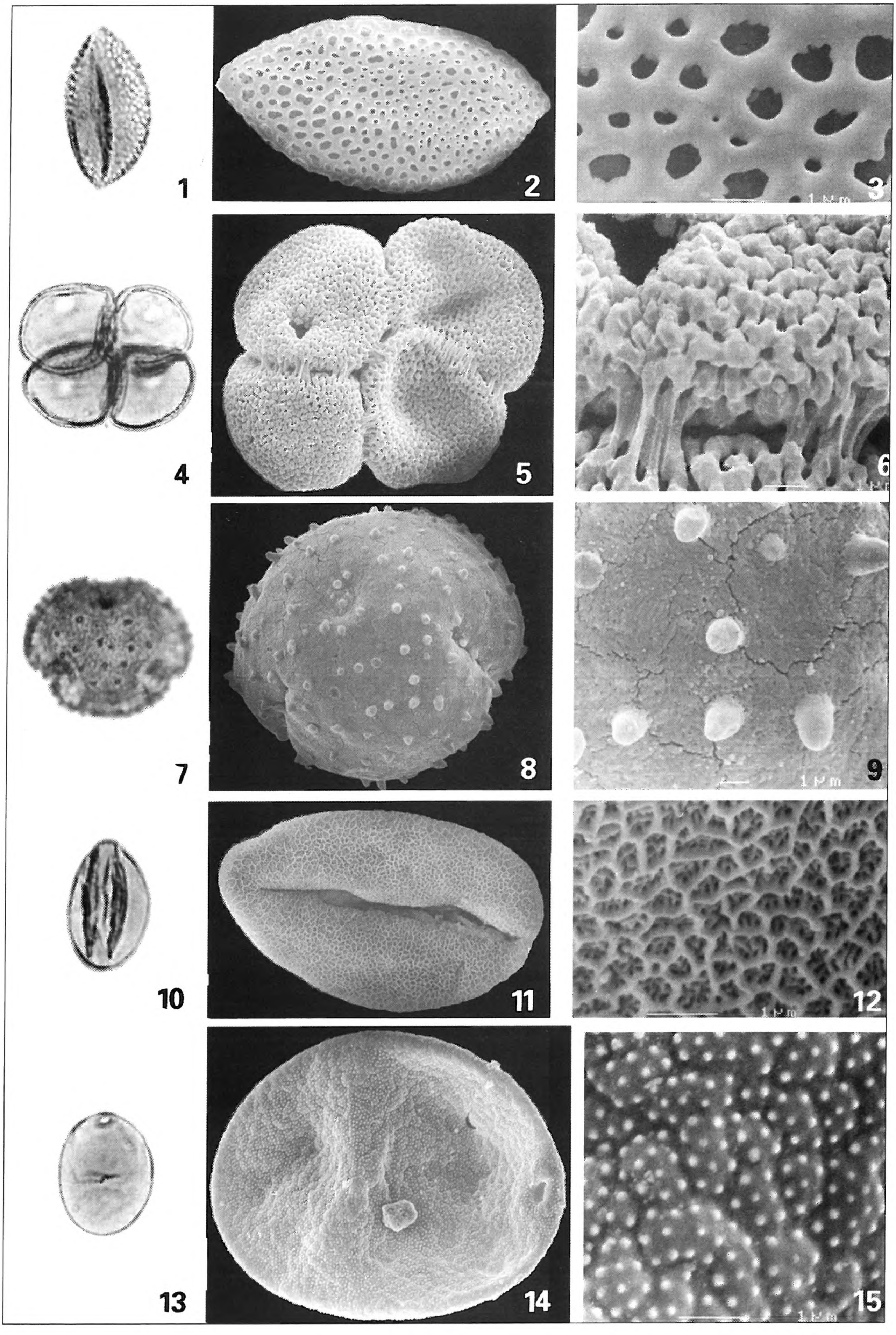
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PLATE 3

Fig. 1–3: Fig. 1 *Trapa* sp.; 850 x LM.
Fig. 2 *Trapa* sp.; 850 x SEM.
Fig. 3 *Trapa* sp.; Detail of the exine surface; 6000 x SEM.

Fig. 4–6: Fig. 4 *Polygonum* sp.; 850 x LM.
Fig. 5 *Polygonum* sp.; 1000 x SEM.
Fig. 6 *Polygonum* sp.; Detail of the exine surface; 6000 x SEM.

Fig. 7–9: Fig. 7 *Myriophyllum* sp.; 850 x LM.
Fig. 8 *Myriophyllum* sp.; 1900 x SEM.
Fig. 9 *Myriophyllum* sp.; Detail of the exine surface; 11000 x SEM.

Fig. 10–12: Fig. 10 Apiaceae – Gen. 1; 850 x LM.
Fig. 11 Apiaceae – Gen. 1; 4000 x SEM.
Fig. 12 Apiaceae – Gen. 1; Detail of the exine surface; 8000 x SEM.

Fig. 13–15: Fig. 13 Apiaceae – Gen. 2; 850 x LM.
Fig. 14 Apiaceae – Gen. 2; 4000 x SEM.
Fig. 15 Apiaceae – Gen. 2; Detail of the exine surface; 12000 x SEM.

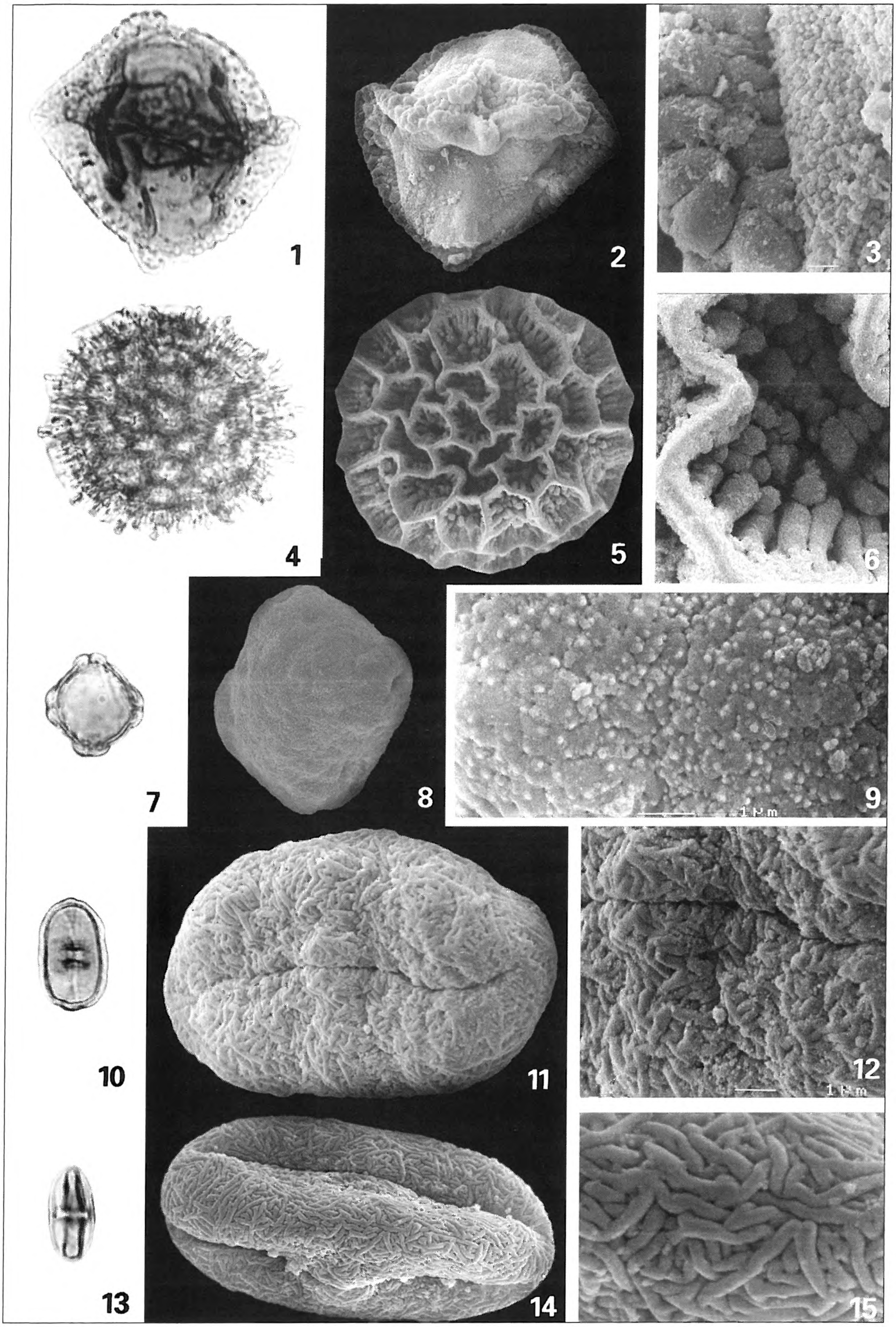
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Fig. 1–3: Fig. 1 *Acer* sp.; 850 x LM.
Fig. 2 *Acer* sp.; 3000 x SEM.
Fig. 3 *Acer* sp.; Detail of the exine surface; 10000 x SEM.

Fig. 4–6: Fig. 4 Rosaceae – Gen. 1; 850 x LM.
Fig. 5 Rosaceae – Gen. 1; 2700 x SEM.
Fig. 6 Rosaceae – Gen. 1; Detail of the exine surface; 7000 x SEM.

Fig. 7–9: Fig. 7 Rosaceae – Gen. 2; 850 x LM.
Fig. 8 Rosaceae – Gen. 2; 4000 x SEM.
Fig. 9 Rosaceae – Gen. 2; Detail of the exine surface; 11000 x SEM.

Fig. 10–12: Fig. 10 Cichorioideae; 850 x LM.
Fig. 11 Cichorioideae; 1200 x SEM.
Fig. 12 Cichorioideae; Detail of the exine surface; 6000 x SEM.

Fig. 13–15: Fig. 13 Dipsaceae; 850 x LM.
Fig. 14 Dipsaceae; 900 x SEM.
Fig. 15 Dipsaceae; Detail of the exine surface; 8000 x SEM.

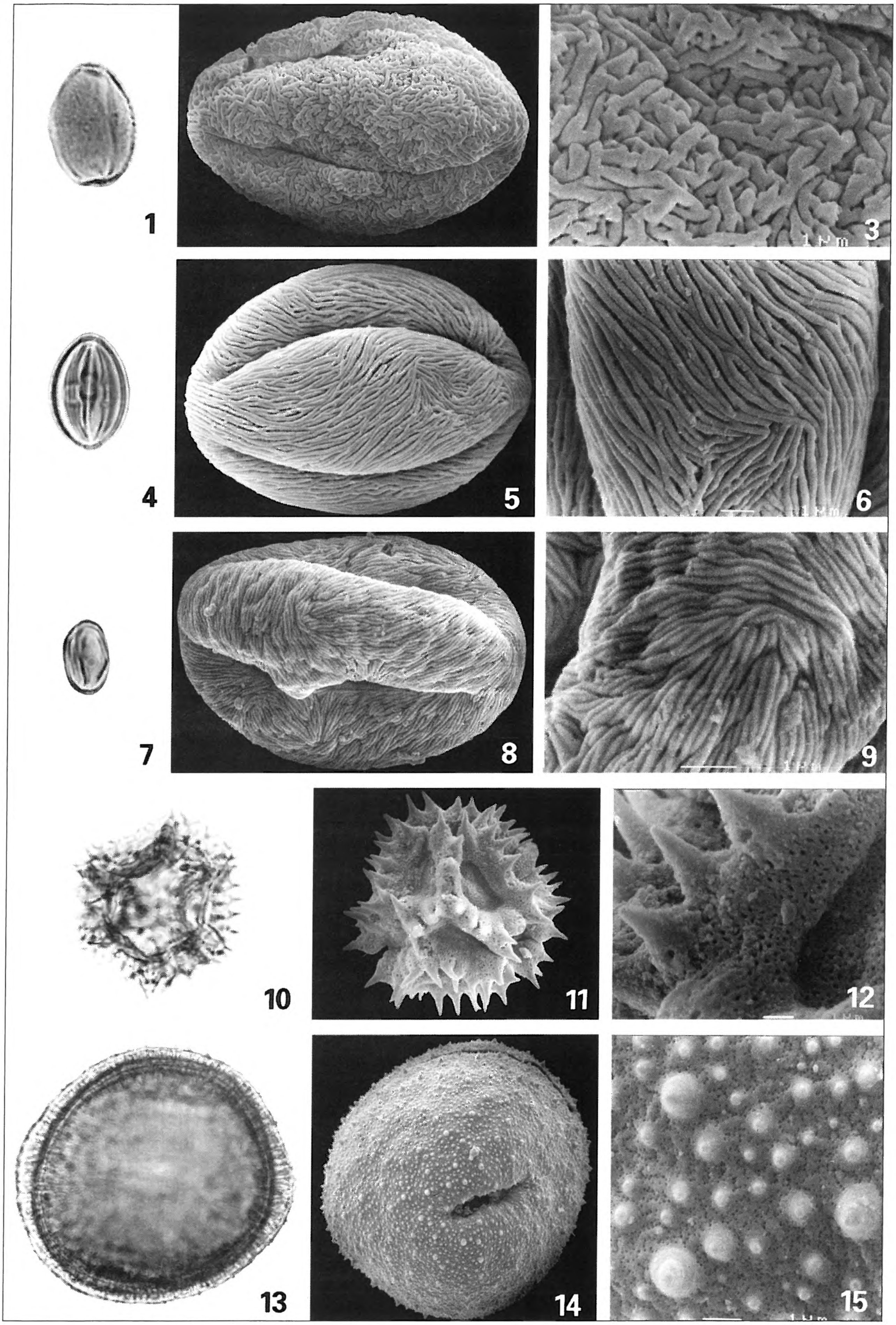
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PLATE 5

Fig. 1–3: Fig. 1 *Quercus* sp. 1; 850 x LM.
Fig. 2 *Quercus* sp. 1; 2000 x SEM.
Fig. 3 *Quercus* sp. 1; Detail of the exine surface; 11000 x SEM.

Fig. 4–6: Fig. 4 *Quercus* sp. 2; 850 x LM.
Fig. 5 *Quercus* sp. 2; 2000 x SEM.
Fig. 6 *Quercus* sp. 2; Detail of the exine surface; 11000 x SEM.

Fig. 7–9: Fig. 7 *Quercus* sp. 3; 850 x LM.
Fig. 8 *Quercus* sp. 3; 2500 x SEM.
Fig. 9 *Quercus* sp. 3; Detail of the exine surface; 11000 x SEM.

Fig. 10–12: Fig. 10 *Quercus* sp. 4; 850 x LM.
Fig. 11 *Quercus* sp. 4; 1200 x SEM.
Fig. 12 *Quercus* sp. 4; Detail of the exine surface; 11000 x SEM.

Fig. 13–15: Fig. 13 *Quercus* sp. 5; 850 x LM.
Fig. 14 *Quercus* sp. 5; 2200 x SEM.
Fig. 15 *Quercus* sp. 5; Detail of the exine surface; 11000 x SEM.

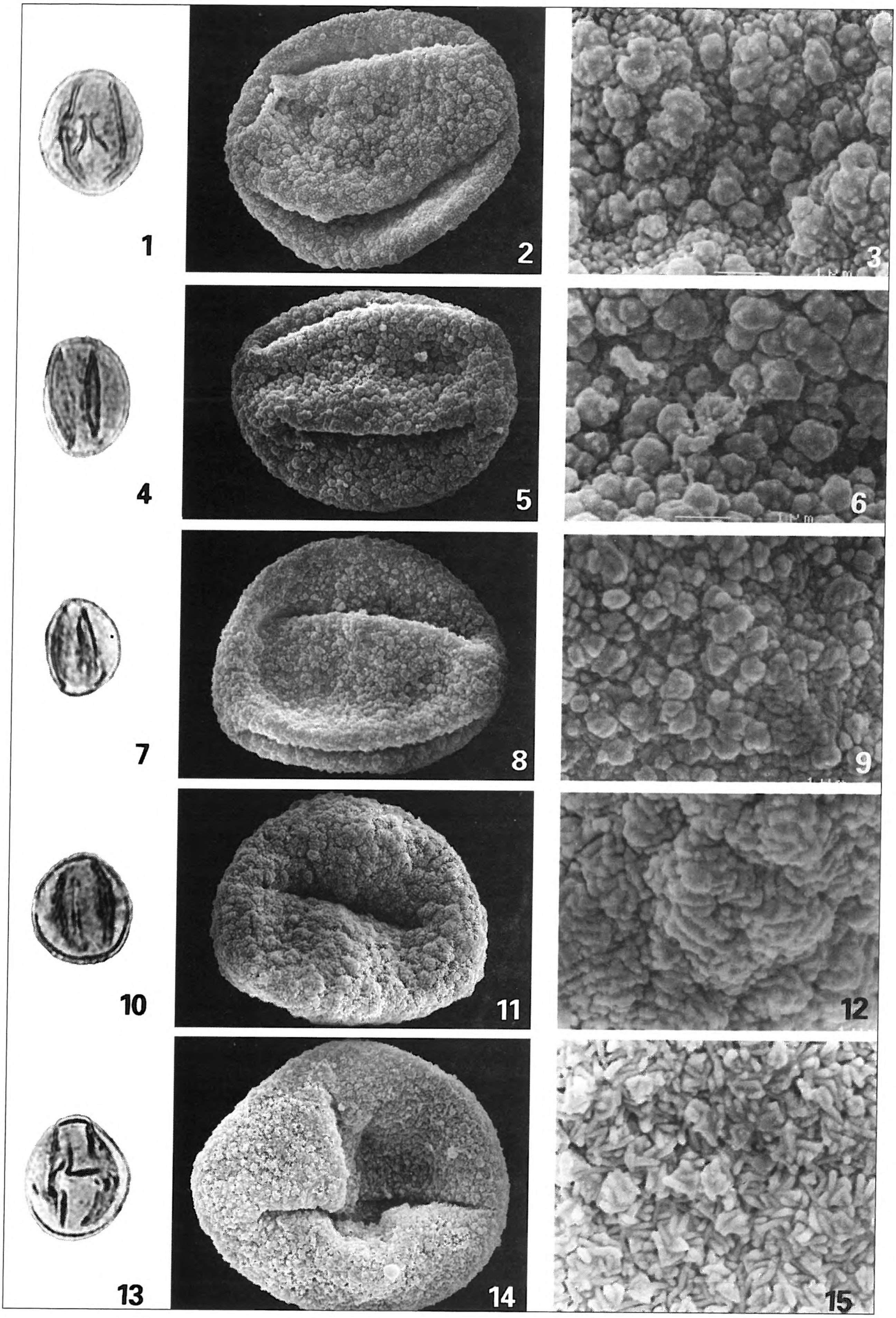
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PLATE 6

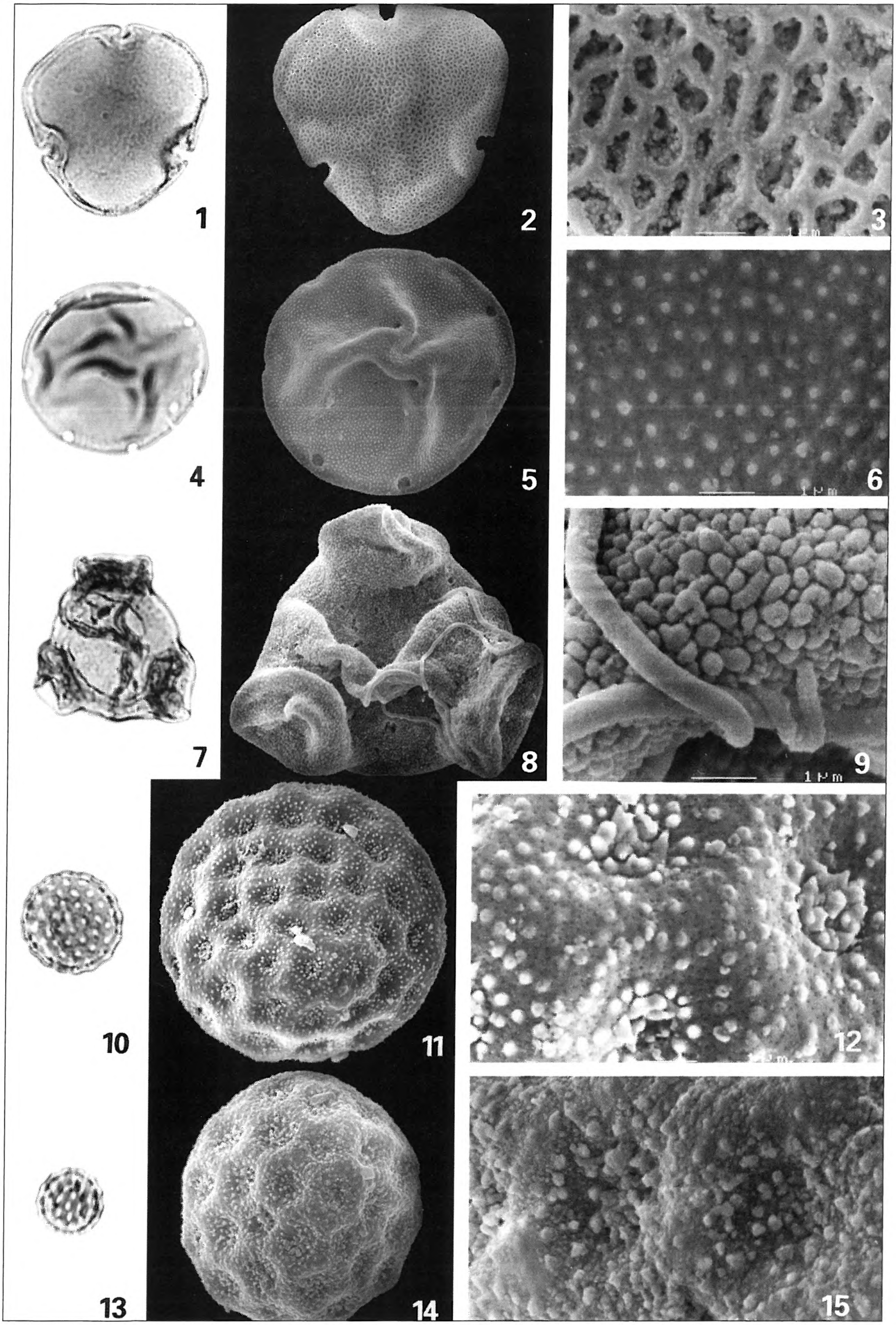
Fig. 1–3: Fig. 1 *Tilia* sp.; 850 x LM.
Fig. 2 *Tilia* sp.; 1000 x SEM.
Fig. 3 *Tilia* sp.; Detail of the exine surface; 10000 x SEM.

Fig. 4–6: Fig. 4 *Juglans* sp.; 850 x LM.
Fig. 5 *Juglans* sp.; 1400 x SEM.
Fig. 6 *Juglans* sp.; Detail of the exine surface; 11000 x SEM.

Fig. 7–9: Fig. 7 Onagraceae; 850 x LM.
Fig. 8 Onagraceae; 1700 x SEM.
Fig. 9 Onagraceae; Detail of the exine surface; 12500 x SEM.

Fig. 10–12: Fig. 10 Chenopodiaceae – Gen. 1; 850 x LM.
Fig. 11 Chenopodiaceae – Gen. 1; 2500 x SEM.
Fig. 12 Chenopodiaceae – Gen. 1; Detail of the exine surface; 12000 x SEM.

Fig. 13–15: Fig. 13 Chenopodiaceae – Gen. 2; 850 x LM.
Fig. 14 Chenopodiaceae – Gen. 2; 3000 x SEM.
Fig. 15 Chenopodiaceae – Gen. 2; Detail of the exine surface; 11000 x SEM.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ADVANCES
in
Austrian—Hungarian Joint Geological Research
Budapest, 1996

A representative leaf assemblage of the Pannonian Lake from Dozmat near Szombathely (Western Hungary), Upper Pannonian, Upper Miocene

LILLA HABLY & JOHANNA KOVAR-EDER*

Keywords: palaeobotany, palaeoenvironment, swamp vegatation, Dozmat (West-Hungary), Pannonian

Abstract

Near Dozmat village in Western Hungary a palaeobotanical locality has become known. It contains a taphocoenosis widespread in the Pannonian region during Late Pannonian time. Floral finds of this type are known from the hangingwall of lignites at several localities of the Pannonian Basin, but their detailed description and interpretation is missing so far. The assemblage consists of three dominant species: *Glyptostrobus europaeus* (BRONGNIART) UNGER, *Alnus cecropiifolia* (ETTINGSHAUSEN) BERGER and *Byttneriophyllum tiliifolium* (AL. BRAUN) KNOBLOCH & KVACEK. Along these, which constitute more than 90 percent of the flora, there are only a few rare accessory elements present. The relatively intact leaves, male catkins and female cones of *Alnus*, the cones and seeds of *Glyptostrobus*, as well as the frequent occurrence of branched twigs indicate autochtonous fossilisation.

Zusammenfassung

Die Lokalität beim Dorf Dozmat in Westungarn ist durch einen in der pannonischen Region während des Oberpannons weitverbreiteten Vergesellschaftungstyp gekennzeichnet. Dieser ist von zahlreichen Fundorten des Pannonischen Beckens im Hangenden von Ligniten bekannt, wurde aber bisher noch nicht gründlich beschrieben. Die Vergesellschaftung besteht aus drei dominanten Arten: *Glyptostrobus europaeus* (BROGNIART) UNGER, *Alnus cecropiifolia* (ETTINGSHAUSEN) BERGER und *Byttneriophyllum tiliifolium* (AL. BRAUN) KNOBLOCH & KVACEK. Neben diesen, die mehr als 90% der Fossilreste ausmachen, treten nur einige akzessorische Elemente auf. Die relativ gut erhaltenen Blätter, die männlichen Kätzchen und weiblichen Zapfen von *Alnus*, die Samen und Zapfen von *Glyptostrobus* sowie auch das häufige Vorkommen von verzweigten Sprossen deuten auf weitgehend autochtone Fossilisationsverhältnisse hin.

Összefoglalás

A Nyugat-Magyarországon, Dozmat község határában feltárt ősnövénylelőhely a felső-pannonban uralkodó mocsári társulásra jellemző taphocoenozist tartalmaz. Ilyen típusú flórák a Pannon-medence lignit lelőhelyeinek fedőjéből számos lelőhelyről ismertek, azonban részletes leírásuk és értékelésük mindeddig nem történt meg. A flórát három uralkodó faj alkotja: *Glyptostrobus europaeus* (BRONGNIART) UNGER, *Alnus cecropiifolia* (ETTINGSHAUSEN) BERGER valamint a *Byttneriophyllum tiliifolium* (AL. BRAUN) KNOBLOCH & KVACEK. Az uralkodó fajokon kívül, amelyek a flóra több, mint 90 százalékát teszik ki, csak néhány ritka járulékos elem fordul elő. A viszonylag ép levelek, az éger barkái, áltobozkái, a Glyptostrobus toboza, magja, valamint az elágazó hajtások gyakori előfordulása is autochton fosszilizációra utal.

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Introduction

In the Savaria Museum in Szombathely (Western Hungary) a rich collection of plant fossils from Dozmat is kept. It was collected in the sixties by ERNŐ HORVÁTH, curator of the Natural History Collection at that time and comprises more than three thousand specimens. More than 1500 of them have been studied by the present authors. The most informative ones are treated and listed in the present paper.

Although this type of taphocoenosis was described in former times by STUR (1867:100f) from Zillingsdorf (Lower Austria), Iharosberény (Western Hungary, HABLY 1992) and Romania (GIVULESCU 1992) an up-to-date documentation in the whole area of the Pannonian Basin is still missing. Most of the earlier exposures arose by lignite mining and do not exist anymore. We are not aware of any recent exposures giving opportunity to study this type of fossil assemblage in the field.

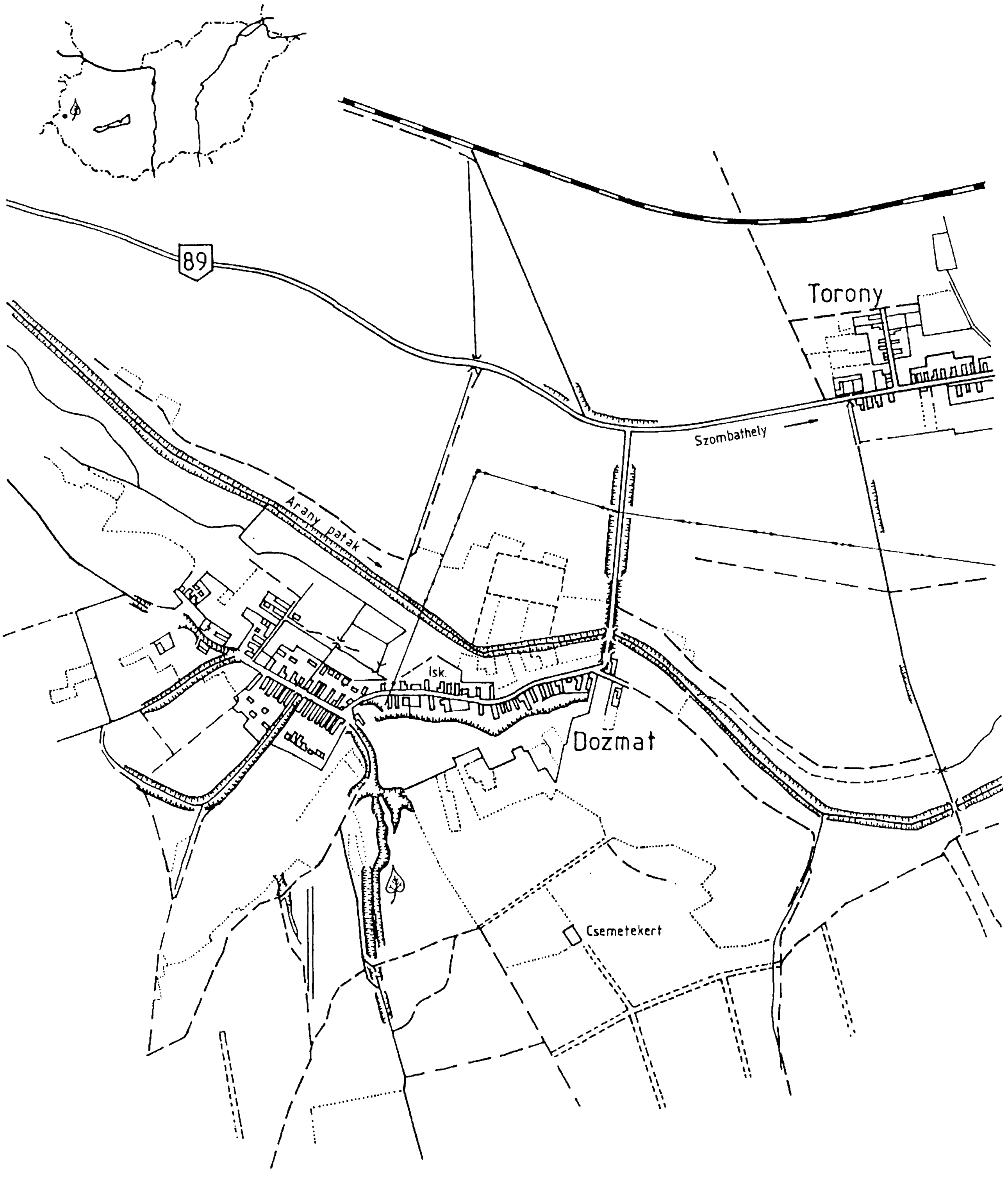

Fig. 1. Location of the palaeobotanical site near Dozmat

Geographic situation

The small village of Dozmat is situated about 6 km West from Szombathely in Western Hungary, 6 km from the Austrian border. Exact information about the site where the material was collected is not available.

During a visit of the area we found an overgrown section of sediments similar to the collection specimens and a lignite horizon in a narrow valley south of Dozmat (fig. 1). We suspect that this place or very close nearby was the locality where E. HORVÁTH collected his material.

The notices and slides made by ERNŐ HORVÁTH kept in the Savaria Museum show a very schematic profile of the section. On some slides the outcrop and the section can be seen. The schematic profile shows at least one lignite seam intercalated in clay and silty layers. It is not marked in which layers the plants have been collected. Based on this drawing and the slides a schematic section has been reconstructed (fig. 2).

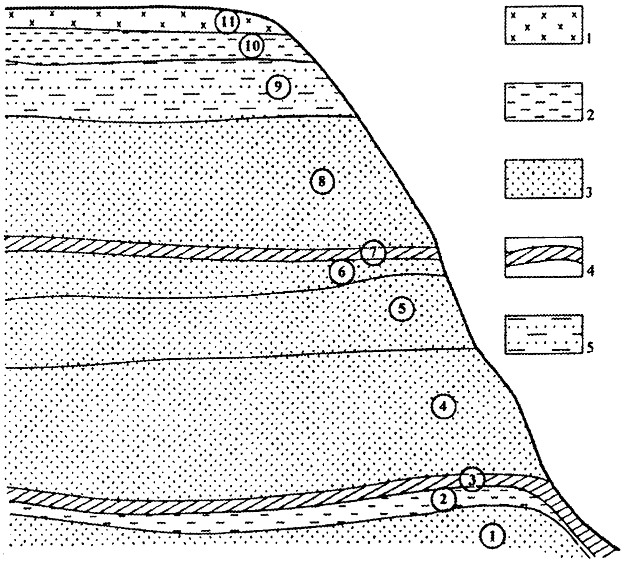

Fig. 2. Geological section of the locality
1 Soil, 2 Clay, 3 Sand, 4 Lignite, 5 Clayey sand

Geological setting

The late Tertiary clays, clayey sands, sands are widely distributed in the Little Hungarian Plain. Their age was doubtful. Some palaeobotanical sites near Dozmat (Sótony, Sé, etc.) were described as Pliocene or Upper Pliocene by HORVÁTH (1961, 1963, 1964, 1971–72). However, none of these outcroups yielded other fossils indicative of age. The age of the famous Baltavár mammal fauna which is situated nearby, is Messinian (Upper Miocene), and the fossil-bearing beds are overlain by Holocene sediments. Palaeomagnetic measurements were performed on core samples of two drillings in this area: Szombathely-II and Duka-II (LANTOS et al. in press.). The total thickness of the sediments younger than 6 Ma proved to be less than 24 m. In the Szombathely-II borehole, a very thin sequence was assumed to be of Pliocene age. The top of the Pannonian sensu LŐRENTHEY probably is also older than 8 Ma there i.e. the latest Miocene. It seems that Pliocene sediments did not develop, or, rather, they have been removed in this area. Therefore, the age of the fossil plant-bearing fluvio-lacustrine sediments, including Dozmat, is estimated to be Late Miocene (MAGYAR & HABLY 1994). In this publication the problem of dating of these plant-bearing layers is explained in detail.

Systematic part

Osmunda parschlugiana **(UNGER) ANDREÁNSZKY**
Pl. 1. figs. 3, 5; Pl. 3. fig. 2.

Description — Fragments of pinnae, the longest one 45 mm (incomplete), up to 22 mm wide, base cordate, in one case the acute apex preserved, leaf margins parallel and fine serrate; main vein straight but in the very apical part bifurcating several times; further venation forked once directly at the midvein, then the branches commonly bifurcate again once in a short distance and occasionally once more closer to the leaf margin.

Discussion — The fragmented remains of this fern are very rare in this flora. Among the 1500 specimens only five have been found.

Material — 66.5.197, 66.5.784, 66.5.830, 66.5.955, 66.6.40

Glyptostrobus europaeus (BRONGNIART) UNGER
Pl. 2. figs. 2–4, 6.

Description — Branched twigs, uneroded cones either connected with twigs or detached, and isolated seeds.

Discussion — The branched twigs of this Taxodiaceae occur most frequently. Cones and seeds are less common. As this conifer is well known we have only selected a few specimens for documentation. The collection numbers below do not indicate the real abundance.

Material — 66.5.390, 66.5.422, 66.5.427, 66.5.603, 66.5.641, 66.5.1210. (plus more than 1000 fragmentary specimens)

Alnus cecropiifolia (Ettingshausen) Berger

Pl. 3. figs. 1, 3–6, Pl. 4. figs. 2–6.

Description — Large leaves, to at least 140 mm in length, most common size about 80 to 120 mm, the smallest leaf 46 mm in length; width 40–110 mm, lamina usually broad elliptic, more rarely slightly ovate or obovate; leaf base rounded, obtuse, truncate, sometimes slightly cordate, symmetric or little asymmetric; petiole slender, up to 42 mm in length, straight (only one specimen with complete petiole); leaf apex short acute or short acuminate.

Leaf margin double serrate, teeth variable in size and shape, large leaves sometimes bearing prominent teeth, more common are small-sized ones. Tooth apex and sinus acute.

Venation craspedodromous, secondary veins subparallel to slightly divergent towards the leaf margin, 7–11 pairs of secondaries; basal secondary veins slightly sinuous originating from the mid vein. Secondary veins may terminate distinctly in primary marginal teeth; sometimes only fine veins arising from the secondaries directly enter the marginal teeth; dense tertiary venation originating approximately perpendicular from the secondaries;. marginal tertiaries forming loops that send small veins towards the leaf margin to supply secondary teeth; occasionally distinct tertiaries arise from the basal side of the secondaries going in the marginal area; they run slightly curved to enter marginal teeth; the veins may end in the tooth apices or in the sinuses.

Only very few small leaves 26 to 63 mm in length and 17 to 34 mm in width have been found. The shape of their lamina and the venation type (number of secondaries, tertiary venation) coincide with those of the large leaves. At the first view they look distinct because the venation is more closely spaced due to their smaller-sized lamina.

Discussion — No other fossil *Alnus* species is characterized by leaves of such large size. The broad leaves may indicate uniformly humid habitat conditions. *A. cecropiifolia* grew prevailingly in late Miocene swamp assemblages. *Alnus ducalis* is a common element in diversified taphocoenoses of fluviatile origin in the late Miocene. We are not aware of fossil assemblages containing both species. This may be due to their different ecological needs.

The notices of E. Horváth concerning Dozmat contain two drawings of this species (specimen nr.66.5.271 and 66.5.378). The first specimen is missing in the collection. The drawing of the second specimen is not exact enough. Therefore, they are not figured herein.

Material — 66.5.17, 66.5.52, 66.5.70, 66.5.79, 66.5.80, 66.5.115, 66.5.155, 66.5.205, 66.5.207, 66.5.216, 66.5.225, 66.5.227, 66.5.236, 66.5.241, 66.5.254, 66.5.300, 66.5.307, 66.5.311, 66.5.332, 66.5.363, 66.5.376, 66.5.388, 66.5.406, 66.5.480, 66.5.507, 66.5.541, 66.5.552, 66.5.560, 66.5.603, 66.5.667, 66.5.672, 66.5.681, 66.5.682, 66.5.705, 66.5.718, 66.5.728, 66.5.749, 66.5.754, 66.5.766, 66.5.785, 66.5.875, 66.5.895, 66.5.937, 66.5.940, 66.5.949, 66.5.975, 66.5.1041, 66.5.1042, 66.5.1069, 66.5.1098, 66.5.1117, 66.5.1210, 66.5.1222, 66.5.1389, 66.5.1414, 66.5.1417, 66.6.64, (plus more than 1000 specimens).

Small sized leaves: 66.5.194, 66.5.288, 66.5.420, 66.5.422, 66.5.468, 66.5.566, 66.5.578, 66.5.620.

Alnus sp. — cones

Pl. 4. figs. 7, 8.

Description — Imprints of pedunculate female cones, cone length 13–19 mm, width 8–10 mm; length of pedunculus 13 and 16 mm, (present on two cones only); some of the cones still closed, some of them with widely opened cone scales but almost undamaged by transport.

Discussion — The cones are most chracteristic of alders. It may be assumed that they derive from the same species as the leaves of *A. cecropiifolia*.

Material — 66.6.56 one open cone, 66.5.225 one open cone, 66.5.567 one closed cone, on the same slab a catkin fallen apart, 66.5.641 two open cones, 66.5.686 two open cones, 66.5.831 three closed cones, 66.6.65 young female cone.

Alnus sp. — male catkins

Pl. 4. fig. 9.

Description — Length at least up to 50 mm; some catkins with closed bracts some catkins partly fallen appart, the isolated cone scales surrounding the axis.

Discussion — The taphonomic record —closed uneroded catkins, several of them on one slab as well as scattered bracts around the axis— indicates almost no transport. We assume that these catkins belong to the same species as the leaves of *Alnus cecropiifolia* and the female cones. The fossil state of the oxidized imprints was not suitable to isolate pollens in situ.

Material — 66.5.197, 66.5.225, 66.5.567, 66.5.641, 66.5.784, 66.5.798, 66.5.837, 66.5.1007

Byttneriophyllum tiliifolium (Al. Braun) Knobloch & Kvacek

Pl. 1. figs. 1, 2, 4, 6, Pl. 2. figs. 1, 5.

Description — Large leaves, therefore mostly incomplete, length up to 180 mm, width at least up to 130 mm, distinctly asymmetric lamina, petiole extremely thick, about 5 mm, at least 35 mm long and straight. Leaf base clearly asymmetric, sometimes distinctly cordate, sometimes rounded, leaf margin entire, leaf apex acute or acuminate.

Venation palinactinodromous, clearly camptodromous, 5 to 9 primary veins originating directly from the base of the lamina, the midvein of them is stronger than the lateral ones and may be straight or slightly curved due to the asymmetric shape of the lamina; the lateral primary veins are always bent; secondary veins arising from the main veins in long intervals forming distinct marginal loops. Tertiary venation forming a perpendicular network between the primary and secondary veins.

Discussion — The systematic affinity to the Sterculiaceae was described by KNOBLOCH & KVACEK (1965) and the interpretation as floating leaves still is up to discussion. The fossil record from Dozmat coincides with what is already known. We lack further information to settle it. Byttneriophyllum is known from several Sarmatian floras of Hungary (ANDREÁNSZKY 1959) as a rare accessory element.

It is dominant during the Pannonian age, especially in the Upper Pannonian plant record connected with lignitic facies.

Material — 66.5.98, 66.5.294, 66.5.340, 66.5.482, 66.5.489, 66.5.508, 66.5.723, 66.5.757, 66.5.784, 66.5.906, 66.5.919, 66.5.1210, 66.5.1378, 66.6.28, 66.6.45, 69.10.71 (plus more than 1000 specimens).

Alnus gaudinii **(HEER) KNOBLOCH & KVAÇEK**
Pl. 4. fig. 1.

Description — Leaves oblong to elliptic up to 82 mm long, leaf base slightly asymmetric in one specimen preserved only, cordate; apex acute to attenuate, leaf margin fine and dense simple serrate. Venation: midvein straight, 8–10 pairs of secondary veins. Distance between secondaries up to 8–9 mm, at the base: 3 mm, craspedodromous. Tertiary veins not very distinct, percurrent. Venation of higher order reticulate.

Discussion — *Alnus gaudinii* occurs in the European Neogene record, especially in the Miocene. It is bound to lignitic and fluviatile facies. The oblong shape of the lamina is not very characteristic for *Alnus*.

Material — 69.10.112., 69.10.124., 69.10.238., 69.10.245., 69.10.254.

Dicotylophyllum **sp.**
Pl. 1. fig. 7.

Description — One fragment of a leaf without apex and base, incomplete length 70 mm (complete length 75 mm), incomplete width 50 mm (completed about 54 mm); lamina asymmetric, of ovate or elliptic shape, leaf margin most finely simple serrate, tooth apices acute, sinus rounded; venation semicraspedodromous(?), mid vein straight, three pairs of secondaries arising in different distances from one another (from base to apex: 13 mm, 21 mm), secondaries bent running through the lamina towards the leaf apex; because of the missing leaf apex we do not know whether the secondaries reach the leaf apex; intersecondaries present; tertiaries forming a distinct perpendicular to oblique network; at the margin the tertiaries form loops from which finest veins arise to support the marginal teeth.

Discussion — The incomplete, not well preserved single leaf is indeterminable. The serrate margin and the curved secondary veins running towards the apex, show similarities with some species of *Rhamnus*.

Material — 66.5.1102.

Taphonomic observations and discussion

The plant remains are closely packed in a light grey-yellowish clay (in dry state), embedded parallel to the bedding. They are preserved as oxidized imprints. Very common are remains of fungi. Wood and remains of leafless axes have been observed occasionally crossing the clay layers. Roots are rarely present. Leaf remains of monocotyledoneous affinity have not been observed.

Most of the leaves are incomplete. Damage is rather due to their large size and the method of collecting (splitting the sediment layers) than a result of transport. Almost no heavily fragmented leaves have been found. The co-occurrence of most numerous leaves of *Alnus cecropiifolia*, female cones of *Alnus* and male inflorescences in different stages of maturity indicate authochtonous fossilisation. In addition most numerous are branched twigs, cones, and occasionally seeds of *Glyptostrobus europaeus*. They confirm this interpretation as well. Neither the cones of *Glyptostrobus* nor those of *Alnus* exhibit traces of erosion.

The monotonous clay sediment, which is apparent on the fossiliferous matrix, indicates quiet sedimentation.

In many sites *Byttneriophyllum tiliifolium* is associated with *Banisteriaecarpum*. In the collection studied not one single remain of *Banisteriaecarpum* has been recovered. Only a drawing of E. HORVÁTH (fig. 3) showing two winged fruits indicates the presence of this taxon in this fossil assemblage. The drawing bears no collection number.

The stratigraphic and palaeogeographic distribution of *Byttneriophyllum tiliifolium* has been revealed in KOVAR-EDER & al. (in press). According to these results

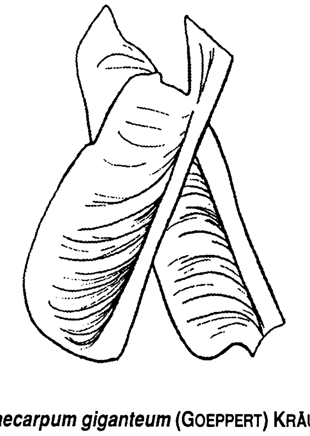

Fig. 3. *Banisteriaecarpum giganteum* (GOEPPERT) KRÄUSEL. Drawing of ERNŐ HORVÁTH from the Dozmat collection as *Acer*

B. tiliifolium was already occasionally present in more eastern regions of Europe during the early Middle Miocene. But there the composition of plant assemblages yielding *B. tiliifolium* were richer in species. In addition *B. tiliifolium* remains were nowhere as numerous as in the Late Pannonian assemblages. This may be due to changing facies conditions and requirements. The characteristic Late Pannonian assemblages in the Pannonian lake area include: *Glyptostrobus europaeus*, *Alnus cecropiifolia, Byttneriophyllum tiliifolium* with few accessory elements (Givulescu 1992) as does the association of Dozmat.

Acknowledgements

The studies have been enabled by the bilateral Austrian–Hungarian cooperation between the Magyar Állami Földtani Intézet Budapest and the Geologische Bundesanstalt Wien. The Savaria Museum in Szombathely and the museologist L. Balogh offered us all possibilities to work in the collection there. Z. Kvacek critically went through the manuscript and gave us important comments. M. Barbacka prepared the fotographs. This work was supported by OTKA grant T 4154.

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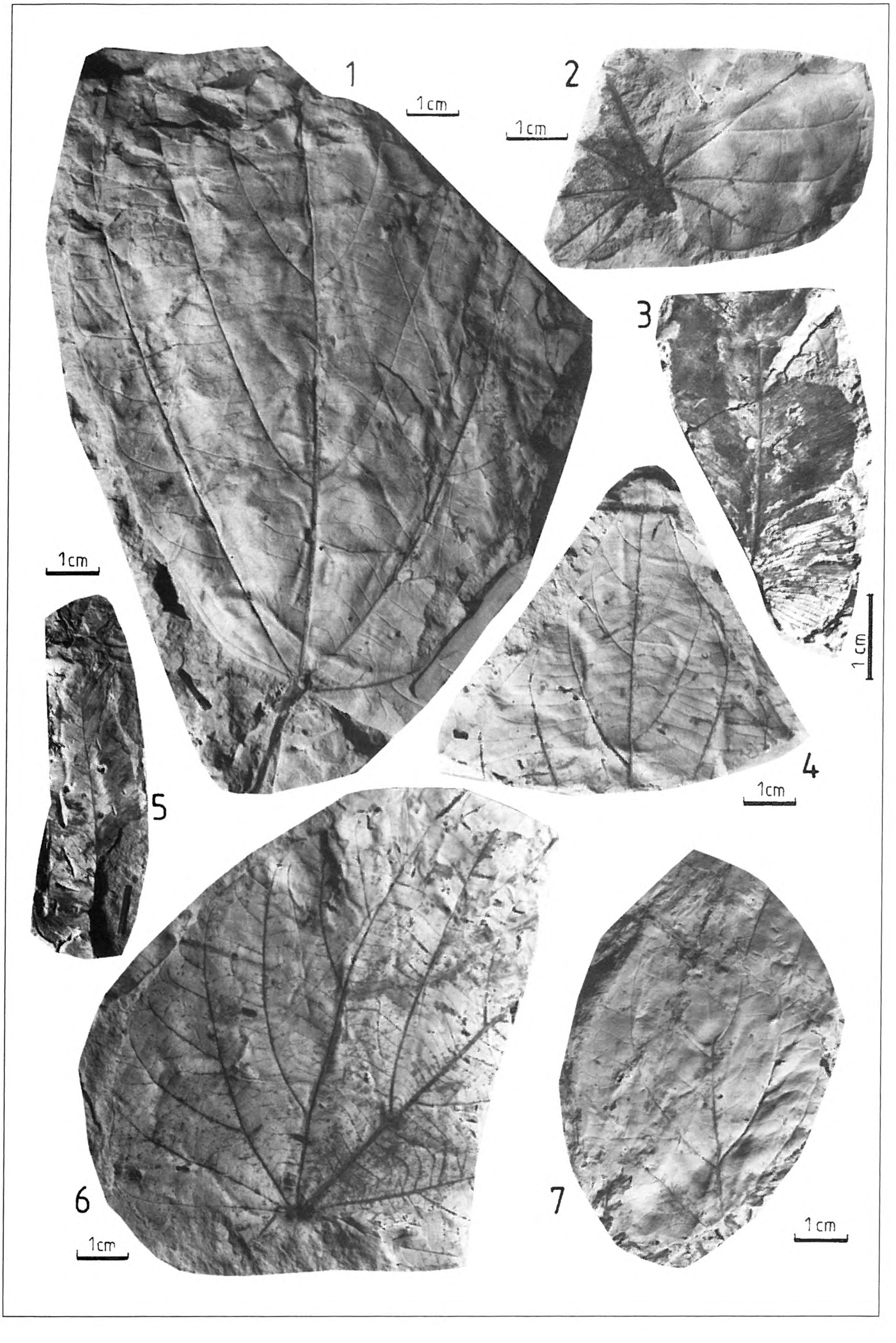
Plate 1

1 *Byttneriophyllum tiliifolium* (Al. Braun) Knobloch & Kvacek, 66.5.1210. x1
2 *Byttneriophyllum tiliifolium* (Al. Braun) Knobloch & Kvacek, petiole, 66.5.98. x1.2
3 *Osmunda parschlugiana* (Unger) Andreánszky, 66.5.830. x1.6
4 *Byttneriophyllum tiliifolium* (Al. Braun) Knobloch & Kvacek, apex, 66.5.1378. x1
5 *Osmunda parschlugiana* (Unger) Andreánszky, 66.5.784. x1
6 *Byttneriophyllum tiliifolium* (Al. Braun) Knobloch & Kvacek, 69.10.71. x1
7 *Dicotylophyllum* sp., 66.5.1102. x1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1 *Byttneriophyllum tiliifolium* (AL. BRAUN) KNOBLOCH & KVACEK, 66.6.45. x1
2 *Glyptostrobus europaeus* (BRONGNIART) UNGER, cones, 66.5.422. x2
3 *Glyptostrobus europaeus* (BRONGNIART) UNGER, seed, 66.5.641. x2.5
4 *Glyptostrobus europaeus* (BRONGNIART) UNGER, twigs, 66.5.427. x1
5 *Byttneriophyllum tiliifolium* (AL. BRAUN) KNOBLOCH & KVACEK, apex, 66.5.482. x1
6 *Glyptostrobus europaeus* (BRONGNIART) UNGER, cone, 66.5.1210. x2.2

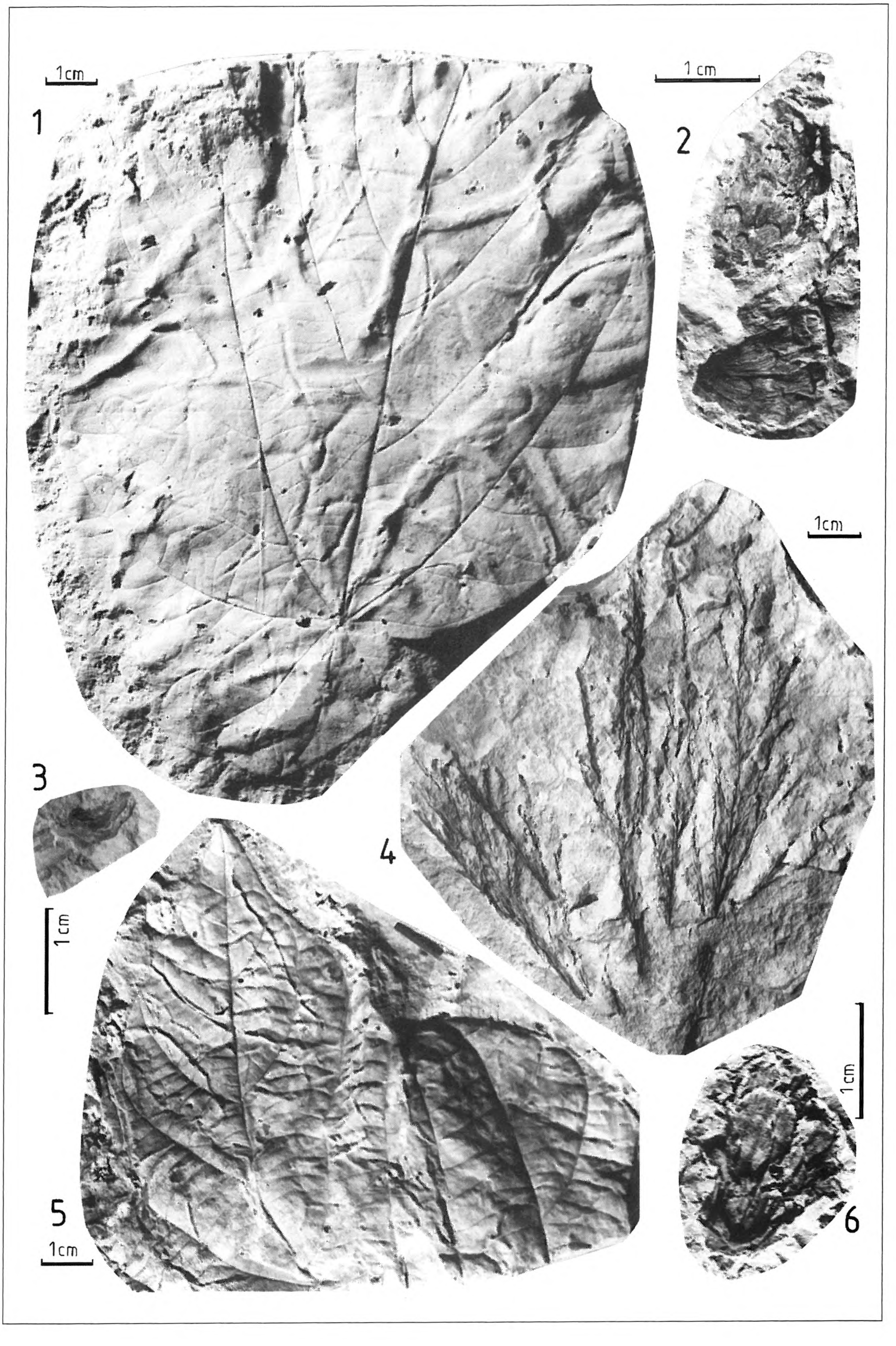
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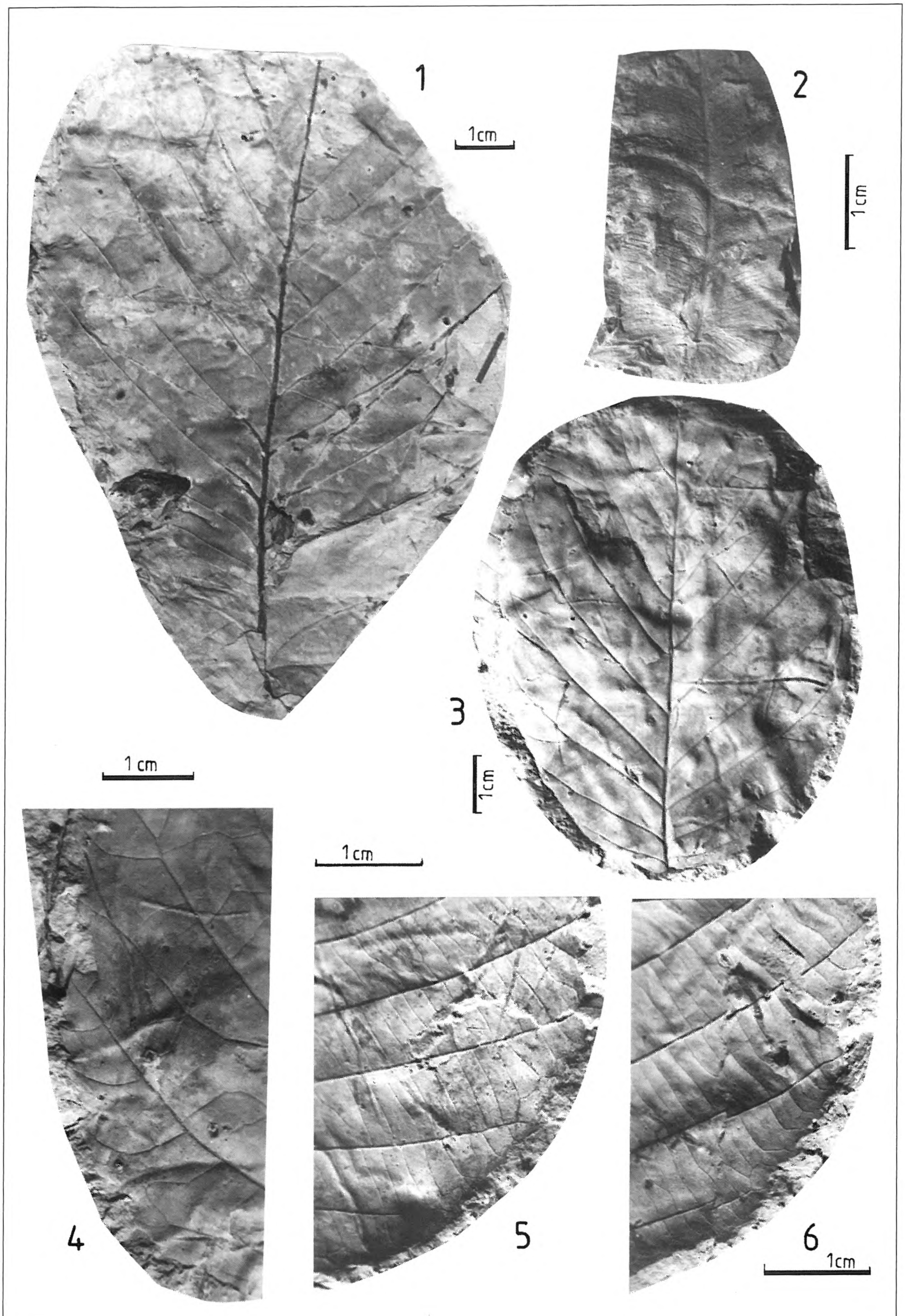
Plate 3

1 *Alnus cecropiifolia* (Ettingshausen) Berger, 66.5.603. x1.1
2 *Osmunda parschlugiana* (Unger) Andreánszky 66.5.955. x1.7
3 *Alnus cecropiifolia* (Ettingshausen) Berger, 66.5.115. x1.1
4 *Alnus cecropiifolia* (Ettingshausen) Berger, 66.5.322. x1.7
5 *Alnus cecropiifolia* (Ettingshausen) Berger, 66.5.227. x 2
6 *Alnus cecropiifolia* (Ettingshausen) Berger, 66.5.940. x 2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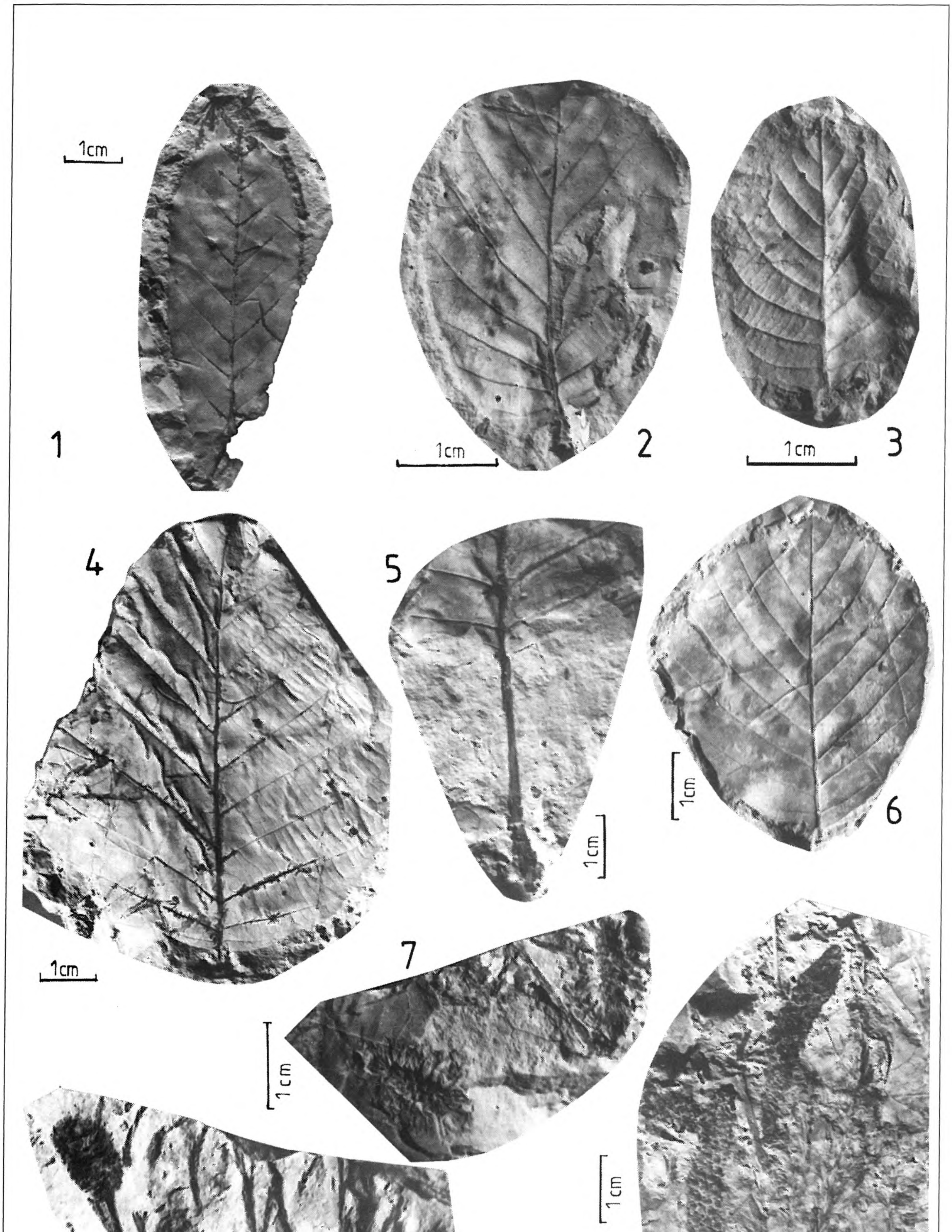
1 *Alnus gaudini* (HEER) KNOBLOCH & KVACEK, 69.10.124. x1
2 *Alnus cecropiifolia* (ETTINGSHAUSEN) BERGER, 66.5.468. x1.8
3 *Alnus cecropiifolia* (ETTINGSHAUSEN) BERGER, small type, 66.5.194. x1.9
4 *Alnus cecropiifolia* (ETTINGSHAUSEN) BERGER, 66.5.940. x1
5 *Alnus cecropiifolia* (ETTINGSHAUSEN) BERGER, 66.5.507. x1.1
6 *Alnus cecropiifolia* (ETTINGSHAUSEN) BERGER, 66.5.1389. x1.2
7 *Alnus* sp., cones, 66.5.686. x1.7
8 *Alnus* sp., cones, 66.5.831. x1.1
9 *Alnus* sp., male catkins, 66.5.225. x1.2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ADVANCES
in
Austrian—Hungarian Joint Geological Research
Budapest, 1996

Revision of Hungarian Tertiary holoplanktonic gastropods housed in the collections of the Hungarian Museum of Natural History in Budapest

IRENE ZORN & MARGIT BOHN-HAVAS *

Keywords: holoplanktonic gastropods, pteropods, Central Paratethys, Hungary, Oligocene, Miocene

Abstract

The Hungarian Tertiary holoplanktonic gastropods housed in the collections of the Hungarian Museum of Natural History in Budapest are revised. They originate from Oligocene (Kiscellian, Egerian) and Middle Miocene (Badenian) deposits of the Hungarian part of the Central Paratethys. The following species are present in the collections: *Vaginella austriaca* KITTL 1886 (Badenian); *Vaginella tricuspidata* ZORN & JANSSEN 1993 (Egerian); *Creseis* ? sp. A, *Praehyalocylis raricostata* (NOSZKY 1940), *Ireneia tenuistriata* (SEMPER 1861), *Clio* aff. *triplicata* AUDENINO 1897, *Clio* sp. A, *Clio* sp. B, *Clio* sp. indet. and Cavoliniidae gen. et sp. indet. (Kiscellian).

A lectotype is designated for *Praehyalocylis raricostata*. The occurrence of *Ireneia tenuistriata* in the Central Paratethys represents a further possibility for interregional correlation by means of pteropods in Europe.

Zusammenfassung

Die ungarischen tertiären holoplanktonischen Gastropoden in den Sammlungen des Ungarischen Naturhistorischen Museums in Budapest werden revidiert. Die Proben stammen aus oligozänen (Kiscellium, Egerium) und mittelmiozänen (Badenium) Ablagerungen des ungarischen Anteils der Zentralen Paratethys. Folgende Arten konnten in der Sammlung festgestellt werden: *Vaginella austriaca* KITTL 1886 (Badenium); *Vaginella tricuspidata* ZORN & JANSSEN 1993 (Egerium); *Creseis* ? sp. A, *Praehyalocylis raricostata* (NOSZKY 1940), *Ireneia tenuistriata* (SEMPER 1861), *Clio* aff. *triplicata* AUDENINO 1897, *Clio* sp. A, *Clio* sp. B, *Clio* sp. indet. und Cavoliniidae gen. et sp. indet. (Kiscellium).

Für *Praehyalocylis raricostata* wird ein Lectotypus gewählt. Durch das Vorkommen von *Ireneia tenuistriata* in der Zentralen Paratethys ergibt sich eine weitere Möglichkeit für interregionale Korrelationen mit Hilfe von Pteropoden in Europa.

Összefoglalás

Revíziót végeztünk a budapesti Magyar Természettudományi Múzeum gyűjteményeiben levő harmadidőszaki magyar planktoncsigákon. A példányok a Középső Paratétisz magyarországi részéből, oligocén (kiscelli, egri) és középsőmiocén (bádeni) képződményekből származnak. A következő fajokat sikerült azonosítani: *Vaginella austriaca* KITTL 1886 (bádeni), *Vaginella tricupidata* ZORN & JANSSEN 1993 (egri), *Creseis* ? sp. A, *Praehyalocylis raricostata* (NOSZKY 1940), *Ireneia tenuistriata* (SEMPER 1861), *Clio* aff. *triplicata* AUDENINO 1897, *Clio* sp. A., *Clio* sp. B., *Clio* sp. indet. és Cavoliniidae gen. et sp. indet (kiscelli).

A *Praehyalocylis raricostata* fajnak lektotípust jelöltünk ki. Az *Ireneia tenuistriata* jelenléte a Középső Paratétiszben további régióközi párhuzamosításra nyújt lehetőséget Európában a pteropodák révén.

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Introduction

In the palaeontological collections of the Hungarian Museum of Natural History in Budapest (Magyar Természettudományi Múzeum) Tertiary holoplanktonic gastropods (euthecosomatous pteropods) from the Oligocene (Kiscellian, Egerian) and Miocene (Badenian) are housed, originating from Hungarian localities of the Paratethys realm. They were collected by the Hungarian geologists T. Báldi, J. Noszky and L. Strausz and by I. Harmat, T. Kázmér and R. Streda between 1920 and 1960. The main part of these pteropods was already published earlier (Báldi 1960a, 1960b, 1973, 1986; Báldi & Radócz 1965, 1971; Bohn-Havas & Zorn 1994; Noszky 1940; Strausz 1924, 1928, 1966; Zorn & Janssen 1993).

Because of the rare occurrence of some of these species in the Paratethys and new results of pteropod systematics in the last decades, a revision of these pteropods is of importance.

Samples with pteropods are available from the following Hungarian localities in the collections of the museum:

- Budapest–Kiscell, Újlak brickyard, Oligocene, Kiscellian, Kiscell Clay (reg. no. M60/4374, M61/7242–M61/7247)
- Borehole Mucsony-136, 430 m, Borsod Basin, Oligocene, Egerian, Eger Formation, Molluscan Clay (reg. no. M95/11)
- Nógrádszakál, Cserhát Mountains, Miocene, Badenian, Lagenid Zone, Nannoplankton Zone NN 5 (reg. no. M61/8340)
- Romhány, West Cserhát Mountains, Oligocene, Kiscellian, Kiscell Clay (reg. no. M59/4988)
- Sámsonháza, Budahegy, Cserhát Mountains, Miocene, Badenian, Lagenid Zone (reg. no. M68/6730)
- Szokolya, Börzsöny Mountains, Miocene, Badenian, Upper Lagenid Zone (reg. no. M60/306–309, M60/311–312)
- Zebegény, Börzsöny Mountains, Miocene, Badenian, Upper Lagenid Zone (reg. no. M62/2538–M62/2545, M62/2590, M62/2592)

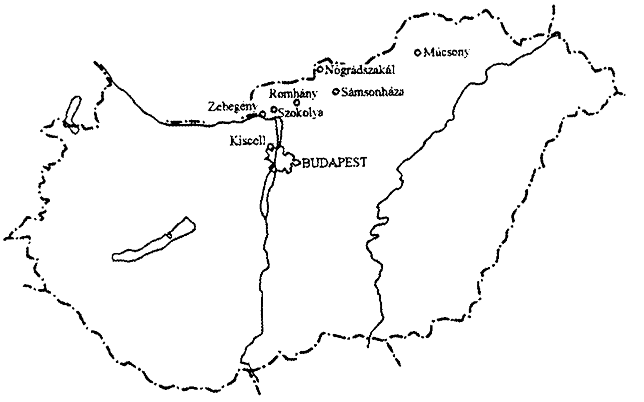

Fig. 1. Schematic map of Hungary showing localities mentioned in this paper

The geographical position of these localities is shown in figure 1. In the next chapter some notes are given on the samples from the various localities with respect to their history of research, their state of preservation and the revised identifications. The order of the localities is based on their geographic position from W towards E. Table 1 gives a short summary of the revision.

Table 1

List of pteropod samples in the collection of the Hungarian Museum of Natural History in Budapest with revised identifications

Reg. no.	Number	Label	Revision	Locality
M59/4988	c.* 11	*Vaginella* sp.	*Ireneia tenustriata*	Romhány
M60/306	c. 7	*Vaginella austriaca*	*Vaginella austriaca*	Szokolya
M60/307	1	*Vaginella austriaca*	*Vaginella austriaca*	Szokolya
M60/308	1	*Vaginella austriaca*	*Vaginella austriaca*	Szokolya
M60/309	1	*Vaginella rzehaki*	*Vaginella austriaca*	Szokolya
M60/311	c. 4	*Vaginella austriaca*	*Vaginella austriaca*	Szokolya
M60/312	2	*Vaginella* sp.	*Vaginella austriaca*	Szokolya
M60/4374	c. 5	*Styliola maxima*	*Praehyalocylis raricostata*	Budapest–Kiscell
M61/7242	c. 7	*Vaginella gibbosa*	*Creseis* ? sp. A	Budapest–Kiscell
M61/7243	0	*Balantium* cf. *calix*	material missing	Budapest–Kiscell
M61/7244	1	*Cleodora* cf. *triplicata*	*Clio* aff. *triplicata*	Budapest–Kiscell
M61/7245	1	*Vaginella* cf. *expressa*	*Clio* sp. B	Budapest–Kiscell
M61/7246	1	*Vaginella calandrellii*	Cavoliniidae gen. et sp. indet.	Budapest–Kiscell
M61/7247	1	*Balantium multicostatum*	Clio sp. A	Budapest–Kiscell
M61/7247	2	*Balantium multicostatum*	*Clio* sp. indet.	Budapest–Kiscell
M61/8340	1	*Vaginella* sp.	*Vaginella austriaca*	Nógrádszakál
M62/2538	3	*Vaginella depressa*	*Vaginella austriaca*	Zebegény
M62/2539	1	*Vaginella acutissima*	*Vaginella austriaca*	Zebegény
M62/2540	1	*Vaginella austriaca*	*Vaginella austriaca*	Zebegény
M62/2541	1	*Vaginella* sp.	*Vaginella austriaca*	Zebegény
M62/2542	c. 25	*Vaginella*	*Vaginella austriaca*	Zebegény
M62/2543	6	*Vaginella*	*Vaginella austriaca*	Zebegény
M62/2544	c. 27	*Vaginella*	*Vaginella austriaca*	Zebegény
M62/2545	1	*Vaginella*	scaphopod + frag. of *V. austriaca*	Zebegény
M62/2590	pl.	*Vaginella*	*Vaginella austriaca*	Zebegény
M62/2592	c. 15	*Vaginella*	*Vaginella austriaca*	Zebegény
M68/6730	1	*Vaginella* sp.	*Vaginella austriaca*	Sámsonháza
M95/11	c. 25	*Vaginella tricuspidata*	*Vaginella tricuspidata*	Mucsony-136

* c. = circa (about)

Miocene Localities

Zebegény

The pteropods from Zebegény were donated to the museum by L. STRAUSZ in 1925 (M62/2538–M62/2541) and by NOSZKY in 1935 (M62/2592) and in 1938 (M62/2542–M62/2545, M62/2590).

STRAUSZ published his material in 1924, 1928 and 1966. In his first two publications he identified the pteropods as *Vaginella depressa* DAUDIN 1800, *V. acutissima* AUDENINO 1897, *V. gibbosa* AUDENINO 1897 and *V.* sp. In 1966 STRAUSZ revised *V. depressa* to *V. austriaca* KITTL 1886 and figured *V. acutissima* (p. 490, fig. 220) schematically. In the collection, however, the pteropods are labelled as *V. austriaca* (M62/2540, on an older label *V. gibbosa*), *V. acutissima* (M62/2539), *V. depressa* (M62/2538) and *V.* sp. (M62/2541).

The material was recently mentioned by BOHN-HAVAS & ZORN (1994). They came to the conclusion that all specimens belong to *Vaginella austriaca*.

NOSZKY identified his samples as *Vaginella*. These specimens also belong to *Vaginella austriaca*, except one specimen (M62/2545), which turned out to be a scaphopod. This sample yields only fragments of *V. austriaca*.

The pteropods are partly in shell preservation and partly preserved as moulds.

Szokolya

The pteropod material from Szokolya was mainly collected by BÁLDI (M60/308, M60/309, M60/311, M60/312) and was added to the collection in 1959. BÁLDI published it in 1960 (a, b). Two samples (M60/306, M60/307) were bought by I. GAÁL and were identified as *Vaginella austriaca* by NOSZKY in 1937. They were included in the revision of BÁLDI (1960a, b), who identified the pteropods as *Vaginella austriaca* (M60/306–M60/308, M60/311), *V. rzehaki* KITTL 1886 (M60/309) and *V.* sp. (M60/312). He figured one specimen of *V. austriaca* (1960b, pl. 3, fig. 12; M60/306). It was reidentified by A. LÁNYI in 1937 as *V. acutissima*. All specimens at hand belong to *V. austriaca*. They are mainly preserved as moulds with parts of the shell.

BÁLDI-BEKE et al. (1980) also recorded *Vaginella austriaca* in the Badenian of the borehole Szokolya-2.

Nógrádszakál

A single specimen of *Vaginella* sp., collected by STREDA in Nógrádszakál, is preserved as a mould. Its revised identification is *V. austriaca*. There are no literature data on pteropods from this locality.

Sámsonháza

The collection contains one sample from Sámsonháza labelled as *Vaginella* sp. It was donated by I. HARMAT in 1931. It contains one specimen of *Vaginella austriaca*, preserved as a mould. NOSZKY (1925) mentioned *Cavolinia (Hyalaea)* sp. from Sámsonháza–Márkháza.

Oligocene Localities

Budapest–Kiscell

Most of the pteropods from Budapest–Kiscell (Újlak brickyard) were collected and donated by I. HARMAT in 1935 and were identified by NOSZKY in 1939. NOSZKY published his identifications in 1940 and distinguished seven pteropod species in the Kiscell Clay: *Cleodora* cf. *triplicata* (AUDENINO 1897) (M61/7244), *Balantium* cf. *calix* BELLARDI 1873 (M61/7243, material missing), *Balantium multicostatum* BELLARDI 1873 (M61/7247), *Vaginella calandrellii* (MICHELOTTI 1847) (M61/7246), *Vaginella* cf. *depressa* DAUDIN 1800 (M61/7245), *Vaginella gibbosa* AUDENINO 1897 (M61/7242) and *Styliola maxima* nov. var. *raricostata*. He illustrated one specimen of the last mentioned species (pl. 2, fig. 32). This sample is probably the one registered under the reg. no. M60/4374. It is labelled *Styliola maxima*, but there is neither a reference to the HARMAT collection nor to the publication of NOSZKY. The original label is missing. In NOSZKY's figure captions we find the remark that the specimens are stored in the "Magyar Nemzeti Múzeum", which is an older name of the museum. We consider the specimens to be syntypes of NOSZKY's variety. Lectotype designation see below in the next chapter.

The collection of HARMAT was revised by BÁLDI (1986). Concerning the pteropods he gave no specific identifications and just referred to *Vaginella* sp. I and *V.* sp. II, and *Clio* sp. I and *C.* sp. II. We reidentified the pteropods as *Creseis* ? sp. A, *Praehyalocylis raricostata*, *Clio* aff. *triplicata*, *Clio* sp. A, *Clio* sp. B and Cavoliniidae gen. et sp. indet. State of preservation see the next chapter.

Romhány

One pteropod sample from Romhány is present which was donated by T. KÁZMÉR in 1931. It is labelled *Vaginella*. The specimens are preserved as pyritic internal casts. They belong to *Ireneia tenuistriata* (SEMPER 1861).

Mucsony-136

Concerning the sample from the borehole Mucsony-136 (430 m) the reader is referred to ZORN & JANSSEN (1993). They erected the species *Vaginella tricuspidata* on this sample from the Egerian and specimens from coeval strata of St. Etienne-d'Orthe (SW France, Aquitanian Basin). The Hungarian specimens are paratypes.

Systematic part

In the lists of synonyms we apply RICHTER's (1943, p. 41) symbols:

1881 (year in italics) name cited without description or illustration;
1881 (year in roman) the cited reference contributes to the knowledge of the taxon;
* first valid introduction of the taxon;
· responsibility for the identification is accepted by the present authors;
(no symbol) responsibility for the identification is not accepted by the present authors, but there is no reason for doubt;
? in the opinion of the present authors there is reason to doubt the identification;
v the original material of this reference was studied by the present authors.

Phylum: MOLLUSCA
Classis: GASTROPODA
Ordo: THECOSOMATA
Subordo: EUTHECOSOMATA
Familia: CAVOLINIIDAE FISCHER, 1883

Subfamilia: CRESEINAE RAMPAL, 1973

Genus: *Creseis* RANG, 1828
Type species: *Creseis virgula* RANG, 1828

***Creseis* ? sp. A**
(Pl. 1, fig. 1, textfig. 2a, b)

v. 1940 *Vaginella gibbosa* AUD. — NOSZKY, p. 51 (non *Vaginella gibbosa* AUDENINO, 1897).

Material — C. seven specimens (M61/7242) from Budapest–Kiscell, Oligocene, Kiscellian, Kiscell Clay, pyritic internal casts.

Description — The teleoconch is slender and conical. The transverse section is circular over the entire length of the teleoconch, but in one specimen the anterior part is flattened dorsoventrally, which is caused by rock pressure. No sculpture or lateral carinae are developed. The apertural parts are not preserved. The largest specimen measures 0.6 mm in height.

The protoconch (fig. 2a, b) is separated from the teleoconch by a distinct constriction. The protoconch axis does not deviate from that of the teleoconch. Protoconch-II is elongated and inflated and measures 0.23–0.25 mm in height and 0.14 mm in width. It is clearly separated from protoconch-I by a constriction. Protoconch-I is small (0.14 mm in height, 0.07 mm in width) and elongate and has a rounded tip.

Remarks — The protoconch in some respect reminds of that of *Vaginella*. The constrictions between teleoconch and protoconch-II and between protococh-II and protoconch-I are also present in *Vaginella*, but the protoconch-I of *Vaginella* is more inflated and is provided with a posterior spine. The earliest part of the teleoconch of *Vaginella* is flattened dorsoventrally in most of the species (except *Vaginella tricuspidata Zom & Janssen, 1993*) and not circular as in *Creseis* and the examined specimens. Additionally the teleoconch of *Vaginella* has lateral carinae.

The general shape of the teleoconch of the present specimens is similar to *Creseis*, but the protoconchs of the known *Creseis* species do not show a constriction between protoconch-I and -II. Because of these differences and similarities we assign the Hungarian specimens to *Creseis* with a question mark.

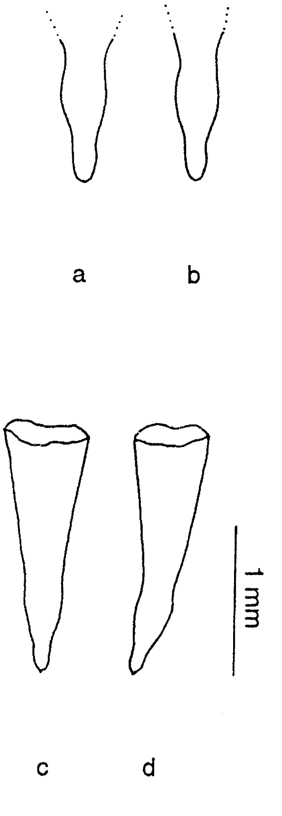

Fig. 2. Protoconchs of a, b) *Creseis* ? sp. A, M61/7242 and c, d) *Ireneia tenuistriata* (SEMPER, 1861), M59/4988; c) frontal, d) lateral

Genus: *Praehyalocylis* KOROBKOV in KOROBKOV & MAKAROVA, 1962
Type species: *Styliola annulata* TATE, 1887

Praehyalocylis raricostata **(NOSZKY, 1940)**
(Pl. 1, fig. 3–4)

v* 1940 *Styliola maxima* (LUDWIG) ZITTEL, nov. var. *raricostata* — NOSZKY, p. 51, 73, pl. 2, fig. 32.
? *1986* *Creseis maxima* LUDWIG–BÁLDI, tab. 2.

Type material — C. seven syntypes (M60/4374), preserved as pyritic internal casts. The most complete specimen is here designated to be the lectotype (pl. 1, fig. 3, the specimen on the right). All other specimens are paralectotypes.

Type locality — Budapest–Kiscell, Újlak brickyard, Hungary.

Type level — Oligocene, Kiscellian, Kiscell Clay.

Description — The shell is slender, straight and conical. The shell width increases very slowly and gradually from posterior to anterior. The transverse section is circular. The entire surface is covered with transverse ribs with relatively wide interspaces. They are slightly oblique with respect to the shell axis. The number of transverse ribs is 10 per 3 mm in the lectotype (at midheight of the shell). In the juvenile part of the shell the ribs are more close-set and more numerous (9 ribs per 1 mm). The apertural part and the protoconch are not preserved. The lectotype measures 6.3 mm in height and 1.4 mm in width.

Remarks — At present a discrimination of the various *Praehyalocylis* species is difficult without a greater number of individuals from the different deposits and without a possibility of comparison (see JANSSEN 1989). The species and "varieties" have mainly been differentiated on the basis of differences in density of the transversal ribs but we know little about the variability of these densities. Although we cannot clearly separate the different species of *Praehyalocylis* there is obviously a trend to a decrease in number of ribs from Eocene to Oligocene.

The main part of the Eocene specimens used to be identified *P. annulata* (TATE 1887) and *P. chivensis* KOROBKOV & MAKAROVA, 1962. The latter taxon turned out to be a junior synonym of *P. annulata* (see JANSSEN, 1989). Therefore the name of the type species of *Praehyalocylis* changes to *P. annulata*. JANSSEN (1989) also points to the fact that "some members of the *P. maxima*-complex resemble *P. annulata* closely".

The Oligocene specimens of *Praehyalocylis*, earlier assigned to *Tentaculites*, *Styliola* or *Creseis*, used to be included in the "*P. maxima*-group" with three "varieties", viz. *denseannulata* (LUDWIG, 1864) (= *densecostata* in BLANCKENHORN 1889), *laxeannulata* (LUDWIG, 1864) and *raricostata* (NOSZKY 1940) in order of decreasing number of ribs. KUSTER-WENDENBURG (1971) designated neotypes for *P. maxima denseannulata* and *P. maxima laxeannulata* giving them a subspecies level and assigning them to the genus *Creseis*. JANSSEN & KING (1988) consider these two subspecies to be two species: *Creseis maxima* (formerly var. *denseannulata*) and *C. laxeannulata*. Concerning the status of other rare species of *Praehyalocylis* and *Hyalocylis* see JANSSEN (1989).

NOSZKY's specimens of *Styliola maxima* var. *raricostata* are somewhat similar to *P. laxeannulata* in respect of the rib pattern but have wider interspaces between the transverse ribs, show a ribbed posterior shell part and they lack the steps in the outline. We therefore consider the former "variety" to be a species.

In the North Sea Basin *Praehyalocylis maxima* and *P. laxeannulata* occur in the Rupelian ("Rupel 3" in SPIEGLER 1965), Pteropod Zone 15 (JANSSEN & KING 1988). *P. raricostata* from the Kiscell Clay (correlation see in the remarks of *Ireneia tenuistriata* SEMPER, 1861) represents the youngest record of the former "*P. maxima*-group".

Subfamilia: CUVIERININAE VAN DER SPOEL, 1967

Genus: *Ireneia* JANSSEN, 1995
Type species: *Vaginella tenuistriata* SEMPER, 1861

Ireneia tenuistriata **(SEMPER, 1861)**
(Pl. 2, fig. 7, textfig. 2c, d)

* 1861 *Vaginella tenuistriata* BOLL in litt. et specim. — SEMPER, p. 272.
v. 1886 *Vaginella tenuistriata* SEMPER–KITTL, p. 53, pl. 2, fig. 6, 7.
1886 *Vaginella tenuistriata* BOLL (in litt.)–KOCH, p. 133.
1941 *Vaginella tenuistriata* BOLL–GÖRGES, p. 151.
1953 *Vaginella tenuistriata* SEMP. ? — SIEBER, p. 372.
1974 *Vaginella tenuistriata* SEMPER 1861 — BÁLDI et al., fig. 5, tab. 1, pl. 3, fig. 5.
1979 *Vaginella tenuistriata* SEMPER 1861 — R. JANSSEN, p. 351.
v. 1984 *Vaginella tenuistriata* SEMPER 1861 — JANSSEN, p. 78.
. 1986 *"Vaginella" tenuistriata* — JANSSEN, fig. 7.
. *1988* *"Vaginella" tenuistriata* — JANSSEN & KING, p. 361
. 1995 *Ireneia tenuistriata* SEMPER 1861 — JANSSEN, p. 48, pl. 4, fig. 3a-c.

Material — C. eleven pyritic specimens (M59/4988) from Romhány, Oligocene, Kiscellian, Kiscell Clay.

Description — The outline of the teleoconch is somewhat vaginelliform, straight and slightly flattened dorsoventrally. In the posterior third the transverse section is almost circular. The width is constant in the anterior two thirds of the shell, in the posterior third it decreases gradually. Lateral carinae and a posterior septum are absent. The surface of the shell is provided with a very fine longitudinal striation, which is typical for the Cuviericininae. That means that the shell is also pyritic. The largest specimen measures 6.7 mm in height and 1.6 mm in width.

The protoconch (fig. 2c, d) is not clearly separated from the teleoconch. The protoconch's axis slightly deviates from that of the teleoconch. Protoconch-II is indicated only as a weak inflation. It measures 0.33 mm in height and 0.23 mm in width. Protoconch-I is separated by a weak constriction from protoconch-II. It has a small spine at the very posterior end and measures 0.16 mm in height and 0.10 mm in width.

Distribution — Oligocene: Hungary, Kiscellian, Kiscell Clay (BÁLDI et al. 1974); ? Austria, Late Oligocene (SIEBER 1953); Germany, Chattian, boulders of "Sternberger Gestein"; Denmark, Chattian, Branden Clay (JANSSEN & KING 1988).

Remarks — In the North Sea Basin *Ireneia tenuistriata* SEMPER, 1861 is an index fossil for the Early part of the Late Oligocene ("Chatt A"). Its first occurrence marks the base of Pteropod Zone 16, which corresponds with the Chattian (JANSSEN & KING 1988; JANSSEN, in litt.). In the Paratethys it was found in the Kiscell Clay in Hungary and possibly in the Late Oligocene of Austria (boreholes Zehrmühle near Bad Hall). The Kiscell Clay belongs to the uppermost part of the Kiscellian and therefore is correlated with the upper part of the Early Chattian (BÁLDI 1986). *I. tenuistriata* is expected to be a useful tool for the interregional correlation of Late Oligocene deposits in Europe.

Subfamilia: CLIOINAE VAN DER SPOEL, 1967

Genus: *Clio* LINNÉ, 1767
Type species: *Clio pyramidata* LINNÉ, 1767

Clio aff. *triplicata* AUDENINO, 1897
(Pl. 2, fig. 6)

1897 *Clio triplicata* n. sp. — AUDENINO, p. 106, pl. 5, fig. 40a–e
v. 1940 *Cleodora* cfr. *triplicata* AUD.–NOSZKY, p. 50.

Material — One specimen (M61/7244) from Budapest–Kiscell, Oligocene, Kiscellian, Kiscell Clay, internal mould.

Description — The outline of the shell is triangular. The supposed dorsal side demonstrates three radial ribs which increase in width from posterior to anterior. Possibly these ribs split off from a single rib in the very posterior part, which is poorly preserved. The central rib is somewhat wider than the lateral ones. Adjacent to each of the lateral ribs is a flat marginal area, somewhat less wide than the rib itself. In horizontal light some weak transversal ribs are visible. The ventral side is embedded in the sediment and cannot be observed. The measurable height is 0.8 cm and the width 0.75 cm. The apical angle equals 52°.

Remarks — *Clio* aff. *triplicata* AUDENINO, 1897 differs from typical *C. triplicata* in the development of the three dorsal ribs. In *C. triplicata* these ribs are of equal size.

Clio sp. A
(Pl. 2, fig. 5)

v. 1940 *Balantium multicostatum* BELL. — NOSZKY, p. 50 (non *Balantium multicostatum* BELLARDI, 1873).
? 1974 *Clio pulcherrima* MAY. — BÁLDI et al., fig. 5, tab. 1, pl. 3, fig. 2 (non *Cleodora pulcherrima* MAYER, 1868).

Material — One specimen (M61/7247) from Budapest–Kiscell, Oligocene, Kiscellian, Kiscell Clay, internal mould.

Description — The outline is triangular. The visible side of the shell very vaguely shows the remnants of five radiating ribs which are of the same width. The margins of the shell are slightly convex over the main part of the shell height, only in the very posterior part of the shell they are concave. The shell height equals 1.25 cm and the width 1.07 cm. The apical angle measures 53°.

Remarks — Although this specimen is in a very poor state of preservation, it can possibly be assigned to the species figured by BÁLDI et al. (1974: pl. 3, fig. 2) under the name *Clio pulcherrima* (MAYER, 1868). *Clio pulcherrima* differs from the Hungarian specimens by the presence of transverse ribs, developed in the lateral shell parts, and the presence of a weak additional rib on each marginal area (on both sides). The specimen illustrated by BÁLDI et al. (1974) shows no transverse ribs but only growth lines.

Balantium flabelliforme BLANCKENHORN 1889 from Turkey, originally described as having five ribs, is very similar to the Hungarian specimens. BLANCKENHORN's material was reinvestigated by AVNIMELECH (1945). He assigned it to *Clio multicostata* (BELLARDI, 1873), which has seven ribs as stated by BELLARDI. Recently JANSSEN (1995) designated a neotype for *C. multicostata*. This specimen has five ribs on both sides, possibly seven on the dorsal side. JANSSEN also stressed the problem of *B. flabelliforme*. He examined one specimen from Nisib (Turkey) which turned out to belong to the bivalve *Propeamussium* sp. Another specimen, figured by BLANCKENHORN (1889: pl. 22, fig. 1b) and AVNIMELECH (1945: fig. 8b), was synonymized with *C. pulcherrima* by ROBBA (1971, 1977). It is difficult to count the number of ribs on the figure of AVNIMELECH. Without having seen the relevant material it is impossible to distinguish the different species.

There are two other specimens of *Clio* (reg. no. M61/7247). These are in an even worse condition and can only be referred to as *Clio* sp. indet.

Clio sp. B
(Pl. 2, fig. 1)

v. 1940 *Vaginella* cfr. *depressa* DAUD.–NOSZKY, p. 50.

Material — One specimen (M61/7242) from Budapest–Kiscell, Oligocene, Kiscellian, Kiscell Clay, internal mould.

Description — The shell is slender and lanceolate. Its middle part is somewhat inflated and smooth. The lateral areas, of which only one is preserved, are flat and bear a weak and narrow longitudinal rib. The lateral margins are convex. The apertural part and the protoconch are not preserved. The maximum height measures 8.4 mm, the width is 3.1 mm.

Remarks — This specimen is very similar to *Vaginella* in outline which accounts for the identification by NOSZKY. The presence of the flat lateral area (not produced subsequently by rock pressure) with the longitudinal rib indicates that it is a representative of the genus *Clio*. This specimen probably belongs to an undescribed species.

Subfamilia: CAVOLINIINAE VAN DER SPOEL, 1967

Genus: *Vaginella* DAUDIN, 1800
Type species: *Vaginella depressa* DAUDIN, 1800

Vaginella austriaca KITTL, 1886
(Pl. 2, fig. 2–4)

The following synonymy includes the original description and Hungarian specimens only; for an extensive synonymy see JANSSEN & ZORN (1993).

v* 1886 *Vaginella austriaca* n. f. — KITTL, p. 54, pl. 2, figs. 8—12.
v. 1886 *Vaginella depressa* DAUDIN–KITTL, p. 57 (partim).
v. *1924* *Vaginella* sp. — STRAUSZ, p. 89.
v. *1924* *Vaginella acutissima* AUD.–STRAUSZ, p. 89.
v. *1924* *Vaginella depressa* DAUD.–STRAUSZ, p. 89.
v. *1924* *Vaginella gibbosa* AUD.–STRAUSZ, p. 89.
v. *1928* *Vaginella* sp. — STRAUSZ, p. 211.
v. *1928* *Vaginella acutissima* AUD.–STRAUSZ, p. 211.
v. *1928* *Vaginella depressa* DAUD.–STRAUSZ, p. 211.
v. *1928* *Vaginella gibbosa* AUD.–STRAUSZ, p. 211.
v. *1960a* *Vaginella austriaca* KITTL–BÁLDI, p. 30, tab. 1.
v. *1960a* *Vaginella rzehaki* KITTL–BÁLDI, p. 30, tab. 1.
v. 1960b *Vaginella austriaca* KITTL–BÁLDI, p. 91, pl. 3, fig. 12.
v. 1960b *Vaginella rzehaki* KITTL–BÁLDI, p. 91.
v. 1966 *Vaginella austriaca* KITTL, 1886 — STRAUSZ, p. 490, fig. 219.
v. 1966 *Vaginella acutissima* AUD.–STRAUSZ, p. 490, fig. 220.
v. *1966* *Vaginella gibbosa* AUDENINO–STRAUSZ, p. 490.
v. *1980* *Vaginella austriaca* KITTL–BÁLDI-BEKE et al., tab. 8.
v. *1992* *Vaginella austriaca* — BOHN-HAVAS, p. 474, 476, 477, 480.
v. *1993* *Vaginella austriaca* — BOHN-HAVAS & ZORN, p. 62, 63, fig. 2, 3.
v. 1994 *Vaginella austriaca* — BOHN-HAVAS & ZORN, p. 76, 78, fig. 3, 4, pl. 2, fig. 2, 6—8.

Material — Miocene, Badenian, Lagenid Zone; Szokolya: c. seven specimens (M60/306), one specimen (M60/307), one specimen (M60/308), one specimen (M60/309), c. four specimens (M60/311), two specimens (M60/312); Zebegény: three specimens (M62/2538), one specimen (M62/2539), one specimen (M62/2540), one specimen (M62/2541), c. twenty-five specimens (M62/2542), four specimens (M62/2543), c. twenty-seven specimens (M62/2544), fragments (M62/2545), many specimens (M62/2590), c. fifteen specimens (M62/2592); Nógrádszakál: 1 specimen (M61/8340); Sámsonháza: 1 specimen (M68/6730).

Diagnosis — Shell straight and lanceolate, dorsoventrally flattened. Lateral carinae present. The maximum shell width is at the aperture. A preapertural constriction is present in most of the specimens. The shell surface is smooth. Protoconchs are not preserved in the available material.

Distribution — This species has a worldwide distribution but is most abundant in the Mediterranean area, the Central Paratehys and The North Sea Basin. In these areas its stratigraphical range reaches from the latest Burdigalian to Early Serravallian. In the Central Paratethys its characteristic occurrence is in the Karpatian and the Badenian.

Vaginella tricuspidata ZORN & JANSSEN, 1993

v. *1965* *Vaginella* sp. — BÁLDI & RADÓCZ, p. 311.
v. *1971* *Vaginella* cf. *lanceolata* (BOLL 1846). — BÁLDI & RADÓCZ, p. 133, tab. 1 (non *Belemnites lanceolatus* BOLL, 1846).
v. *1973* *Vaginella* sp. — BÁLDI, p. 95.
v. 1993 *Vaginella tricuspidata* sp. nov. — ZORN & JANSSEN, p. 63, pl. 1, fig. 1–7, pl. 2, fig. 1–5, pl. 3, fig. 1–4, pl. 4, fig. 1–5.

Material — C. 25 specimens (M95/11, paratypes), borehole Mucsony-136, 430 m, Oligocene, Egerian, Eger Formation, Molluscan Clay.

Diagnosis — *Vaginella* species with an almost straight ventral apertural margin and a curved dorsal apertural margin which is provided with three small denticles. Perpendicular to the apertural margin there are two furrows extending for a short distance on the dorsal side in apical direction. A preapertural constriction is not developed.

Distribution — Oligocene: Chattian, Marnes de St. Etienne d'Orthe, St. Etienne d'Orthe, Aquitanian Basin; Egerian, Eger Formation, Molluscan Clay, Mucsony-136, Borsod Basin, Hungary (ZORN & JANSSEN 1993).

Cavoliniidae gen. et sp. indet.

v. 1940 *Vaginella Calandrellii* MICHT.–NOSZKY, p. 50 (non *Vaginella calandrellii* MICHELOTTI, 1847).

Material — One specimen (M61/7246), Budapest—Kiscell, Újlak brickyard, Oligocene, Kiscellian, Kiscell Clay, pyritic internal cast with parts of the shell.

Remarks — The shell is straight and slender, with a smooth surface. Apertural and apical shell parts are not preserved. This specimen is in a very poor state of preservation. It is difficult even to recognize the genus. Concerning its general outline it might belong to *Creseis* or to *Vaginella*.

Conclusions

This revision of the Tertiary pteropods from Hungarian localities in the collections of the Hungarian Museum of Natural History in Budapest leads to the following results:

— Among the material from the Middle Miocene (Badenian, Lagenid Zone) of Szokolya, Zebegény (Börzsöny Mountains), Nógrádszakál and Sámsonháza (Cserhát Mountains) only one species is present, viz. *Vaginella austriaca*, the most common pteropod species of the Early Badenian in the Central Paratethys.

— The Egerian pteropods from the borehole Mucsony-136 (430 m) were already revised by ZORN & JANSSEN (1993). The sample yields *Vaginella tricuspidata*.

— The Kiscell Clay (yielding the most diverse pteropod association in the Hungarian Oligocene) is represented by material from the localities Budapest–Kiscell and Romhány. Among the material from the first locality are *Creseis* ? sp. A, *Praehyalocylis raricostata*, *Clio* aff. *triplicata*, *Clio* sp. A, *Clio* sp. B, *Clio* sp. indet. and Cavoliniidae gen. et sp. indet. A lectotype is designated for *Praehyalocylis raricostata*. *Ireneia tenuistriata* is the only pteropod from the second locality.

It is probable, that *Clio* aff. *triplicata*, *Clio* sp. A (in connection with the material of BÁLDI et al. 1974) and *Clio* sp. B represent new species, but more material showing both ventral and dorsal sides is necessary.

The record of *Ireneia tenuistriata* in the Kiscell Clay of Hungary is the first certain record outside the North Sea Basin. This species is an index fossil for the late Oligocene and may turn out to be useful for interregional correlation.

Acknowledgements

We would like to thank JÁNOS SZABÓ and ALFRÉD DULAI for their help in the collections of the museum and ARIE W. JANSSEN (Leiden) for reading the manuscript critically. The first author wishes to thank the Geological Survey of Austria for supplying the research facilities.

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Plate 1

Fig. 1–2 *Creseis* ? sp. A
Budapest–Kiscell, Oligocene, Kiscellian, Kiscell Clay, M61/7242, x14

Fig. 3–4 *Praehyalocylis raricostata* (NOSZKY, 1940)
Budapest–Kiscell, Oligocene, Kiscellian, Kiscell Clay, M60/4374
3: Lectotype on the right, with paralectotypes, x10
4: Lectotype with paralectotypes, x14

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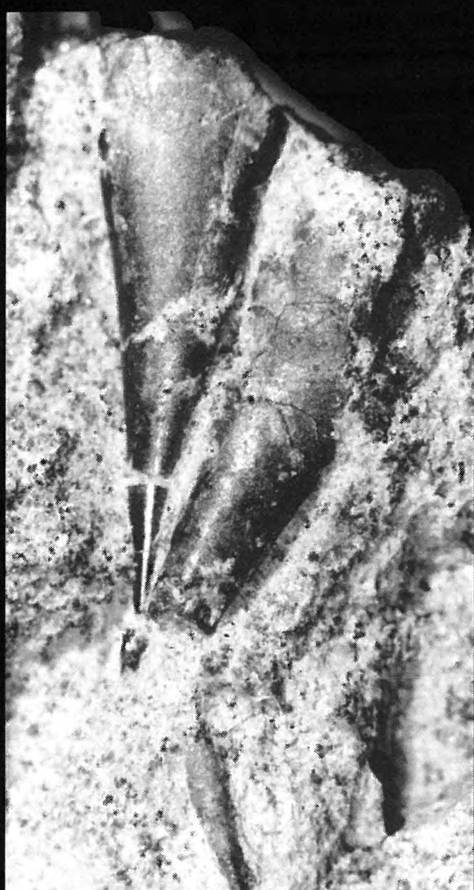

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Fig. 1 *Clio* sp. B
Budapest–Kiscell, Oligocene, Kiscellian, Kiscell Clay, M61/7245, x10

Fig. 2–4 *Vaginella austriaca* KITTL, 1886
Miocene, Badenian, Upper Lagenid Zone
Zebegény (2: M62/2590, x10; 3: M62/2542, x8; 4: M62/2544, x8)

Fig. 5 *Clio* sp. A
Budapest–Kiscell, Oligocene, Kiscellian, Kiscell Clay, M61/7247, x5

Fig. 6 *Clio* aff. *triplicata* AUDENINO, 1897
Budapest–Kiscell, Oligocene, Kiscellian, Kiscell Clay, M61/7244, x8

Fig. 7 *Ireneia tenuistriata* (SEMPER, 1861)
Romhány, Oligocene, Kiscellian, Kiscell Clay, M59/4988, x10

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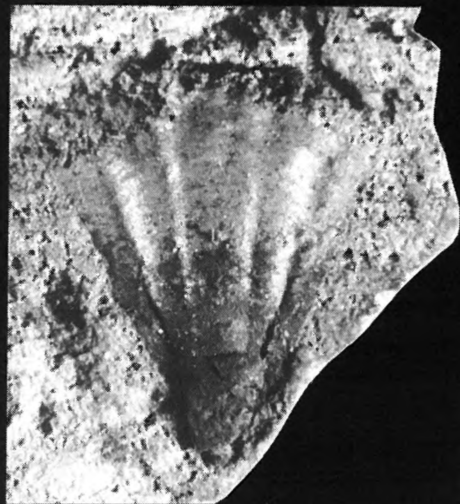

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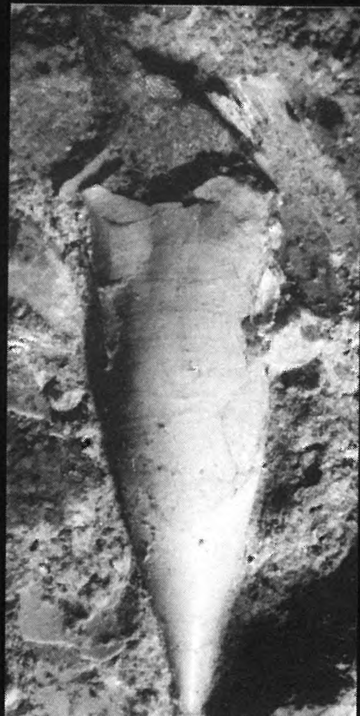

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ADVANCES
in
Austrian—Hungarian Joint Geological Research
Budapest, 1996

Integrated stratigraphic correlation of the Upper Cretaceous sequence in the borehole Bakonyjákó 528

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Keywords: stratigraphy, palaeontology, palaeomagnetic measurements, borehole Bakonyjákó 528, Upper Cretaceous, Bakony Mts, Hungary

Abstract

The chronostratigraphic subdivision of the Upper Cretaceous formations in the Bakony Mountains has not been exactly defined because ammonites are almost completely missing, planktonic foraminifers are relatively rare and the studies of nannofossils are insufficient. The grade of uncertainty was especially high in the lower, non-marine part of the sequence. The continuously cored Bakonyjákó 528 hole is situated on the eastern margin of the Devecser graben. Investigations, carried out on the cores, include palaeomagnetic measurements and studies of planktonic foraminifers, nannofossils, dinoflagellates, spore and pollen grains. Evaluation of the integrated stratigraphic studies indicates that the accumulation of the marine strata began already in the Santonian. Accordingly, the underlying non-marine strata can not be younger than Santonian.

Zusammenfassung

Die genaue chronostratigraphische Einstufung vor allem der tieferen, nicht-marinen Schichtfolge der Oberkreide des Bakony-Gebirges in Ungarn war bisher problematisch auf Grund des weitgehenden Fehlens von Ammoniten, des seltenen Auftretens von Planktonforaminiferen und der geringen Zahl von Nannofossiluntersuchungen. Für eine genaue Einstufung dieser Ablagerungen wurde eine multistratigraphische Untersuchung mit Hilfe von Paläomagnetik-Messungen, Planktonforaminiferen, Nannofossilien, Dinoflagellaten, Sporen und Pollen an Material der durchgehend gekernten Bohrung Bakonyjákó 528 vom Ostrand des Devecser Troges durchgeführt. Demnach hat die Ablagerung der marinen Schichten schon im Santon begonnen — die unterlagernden, nicht-marinen Schichten können damit nicht jünger als Santon sein.

Összefoglalás

A bakonyi felső-kréta képződmények kronosztratigráfiai besorolása nem volt egyértelmű, mert az ammoniták csaknem teljesen hiányoznak, a plankton foraminiferák viszonylag ritkák és a nannoplankton vizsgálatok nem elegendőek. A bizonytalanság különösen nagy volt a rétegsor alját képező szárazföldi rétegekben. A folyamatos magvételes Bakonyjákó 528. sz. fúrás a Devecseri-árok keleti peremén mélyült. A magokon paleomágneses méréseket, plankton foraminifera, nannoplankton, dinoflagelláta, spóra és pollen vizsgálatot végeztünk. Az integrált sztratigráfiai értékelés szerint a tengeri rétegek képződése már a szantonban elkezdődött, tehát az alattuk lévő szárazföldi rétegek nem lehetnek szantonnál fiatalabbak.

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Introduction

Marine Upper Cretaceous formations have been known in the Bakony Mountains since the middle of the last century (HAUER 1862). The non-marine part of the sequence was discovered one decade later (BÖCKH 1874). Their stratigraphic subdivisions were basically correct from the beginning but aspirations for more precise dating always lead to rekindling debate, as ammonites are almost completely missing, the presence of planktonic foraminifers is subordinate and the investigations of nannofossils are insufficient in the succession of the Bakony Mountains. The grade of uncertainty was especially high in the 100 to 300 m thick, non-marine strata that compose the lower part of the sequence, where only terrigenous palynomorphs offered a chance for dating. The aim of this paper is to collect and present the results of all stratigraphic investigations useful for an integrated stratigraphic evaluation at Bakonyjákó and by means of the interpretation to diminish stratigraphic uncertainties. Special attention is paid to the magnetostratigraphy, although the main part of the succession is of fluvial origin with intercalated red beds and the carbonate content of the marine beds is higher than the areal average.

Geological setting

Upper Cretaceous formations in the Transdanubian Range are restricted to its western part (fig. 1). Due to the Pre-Gosau tectonic phases the western part of the range is dissected into highs and troughs parallel to each other. In the traps of this unevenly karstified and eroded carbonate surface consisting of Dachstein Limestone and Hauptdolomite Formations, allitic sediments (Halimba and Nagytárkány Bauxite Formations) were deposited first (e.g. HAAS et al. 1977, HAAS & JOCHA EDELÉNYI 1979, BENCE et al. 1990). The morphology of the bauxite traps is extremely varied.

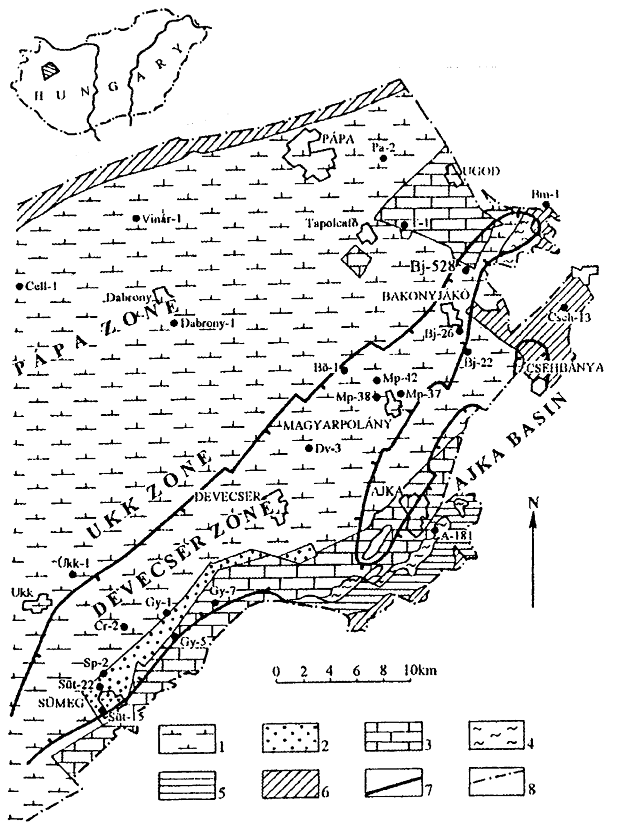


Fig. 1. Map of the Cretaceous Formations without Tertiary in the south western part of the Transdanubian Central Range

1 Polány Marl Formation; 2 Polány–Ugod Formation; 3 Ugod Limestone Formation; 4 Jákó Marl Formation; 5 Ajka Coal Formation; 6 Csehbánya Formation; 7 extension of the Ajka Formation; 8 extension of the Senonian Formations (unconformity or tectonic boundary). Sites of major boreholes are also indicated. (HAAS et al. 1992)

The continuous sedimentation starts with the deposition of the Csehbánya Formation. This is of mainly fluviatile origin with a maximum of 200 m thickness in the grabens. The grain size within the 5 to 20 m thick cycles is regularly fining upward. Coarser sediments were accumulated along drift lines of a river bed while the variegated finer grain sediments were deposited on flood plains. The cycles are often capped by coaly clays of a closed river bed (HAAS in BENCE et al. 1990). Gravel and conglomerates, characteristic for the basal beds of the cycles, are restricted to the Devecser and the Pápa zones and pinch out rapidly westward. The pebbles predominantly consist of Mesozoic, mainly Triassic limestones and dolomites. The Csehbánya Formation interfingering with the Ajka Coal Formation is getting thinner and pinching out westward. The coarse-grained sediments are missing from the southernmost (Ajka) zone and a fresh-water limestone of oncoidic and nodular character appears. Fauna is scattered within the formation; the cores of nodules are often filled by gastropods and the grey beds are rich in palynomorphs.

In the Ajka and the Devecser Troughs the Csehbánya Formation is followed by the Ajka Formation of mainly lacustrine and paludal origin seldom with brackish-water intercalations. The 30 to 130 m thick formation also shows cyclicity; lignite, coaly clay, grey clay and siltstone are alternating in the cycles. Intercalations of sandstones are subordinate (HAAS et al. 1992). In some layers gastropods or *Munieria* are present in rock-forming quantity. The formation is rapidly thinning north-eastward from Magyarpolány and pinches out at Iharkút in the Devecser zone. More to the NE it appears only in separate lenses of 10 to 20 m thickness. As a rule, the peat-bog environment is finished by the marine invasion except at Magyarpolány where it was drowned by an extensive clastic influx. In addition to the fossils mentioned above ostracods are common, foraminifers are scarce and the most common fossils are the palynomorphs. From the practical point of view only the last group is of stratigraphic importance.

As a result of marine invasion the Ajka Coal Formation was replaced by the Jákó Marl Formation which consists of a grey marl, calcareous marl and sometimes —mainly its lower, coral and bivalve-bearing member— clayey marl. The combined thickness of these, accumulated in shallow sublitoral environment, does not exceed 100 m. Towards the highs, the Jákó Marl is enriched in carbonates and interfingers with the fossiliferous Ugod Limestone Formation. In addition to the Pycnodonts and *Exogyra* occasionally found in rock-forming quantity the Jákó Marl contains lots of foraminifers including planktonic ones of stratigraphic importance, mainly globotruncanids.

As the subsidence rate exceeded the rate of sedimentation in the troughs and also on the highs the Jákó Marl was followed by the Polány Marl Formation. This is a grey marl, sometimes silty marl and calcareous marl with fragments of *Inoceramus* shells. Along the nearby margin of the troughs, the lower part of the formation is interfingering with the rudist, coral and algae-bearing Ugod Limestone Formation. Fragments of the limestone protrude far into the Polány Marl as breccia tongs. The upper part of the formation overlies the Ugod Limestone as well and contains intercalations of sandstone beds. From among its fossil content planktonic foraminifers are the most important.

Lithostratigraphic subdivision of the succession

The borehole Bakonyjákó 528 is situated on the eastern margin of the Devecser graben (fig. 1) and albeit the greater part of the formations introduced above are also represented here, nearly none of them can be considered as typical.

The karstic surface of the Dachstein Limestone is covered by brownish-red, pelitomorphic bauxitic clay of 60 cm thickness (Nagytárkány Bauxite Formation, fig. 2) with limestone debris, then by the Csehbánya Formation of 136.5 m thickness. The formation basically consists of variegated clay, silty clay and clay-marl beds of flood plain origin with scarce intercalations of sandstone. Small pebbles were recorded only from the uppermost sandstone beds. Lacustrine and in particular the peat bog facies are subordinate.

The ranging of the 5.6 m thick clay-marl between the Csehbánya and Jákó Marl Formations with dark-grey colour, occasionally rich in organic matter is uncertain. It can be either part of the Ajka Coal Formation or a lens-like intercalation within the Csehbánya Formation. Marine invasion is indicated by the 2 m thick molluscan clay-marl (Csingervölgy Member) at the base of the Jákó Marl Formation of 42 m thickness. The *Exogyra*-bearing pale grey marl is the prevailing part of the formation. The light grey or greyish-white Polány Marl with no megafossils has developed from the previous formation with gradual transition. The total thickness of its erosional remnant is 58 m.

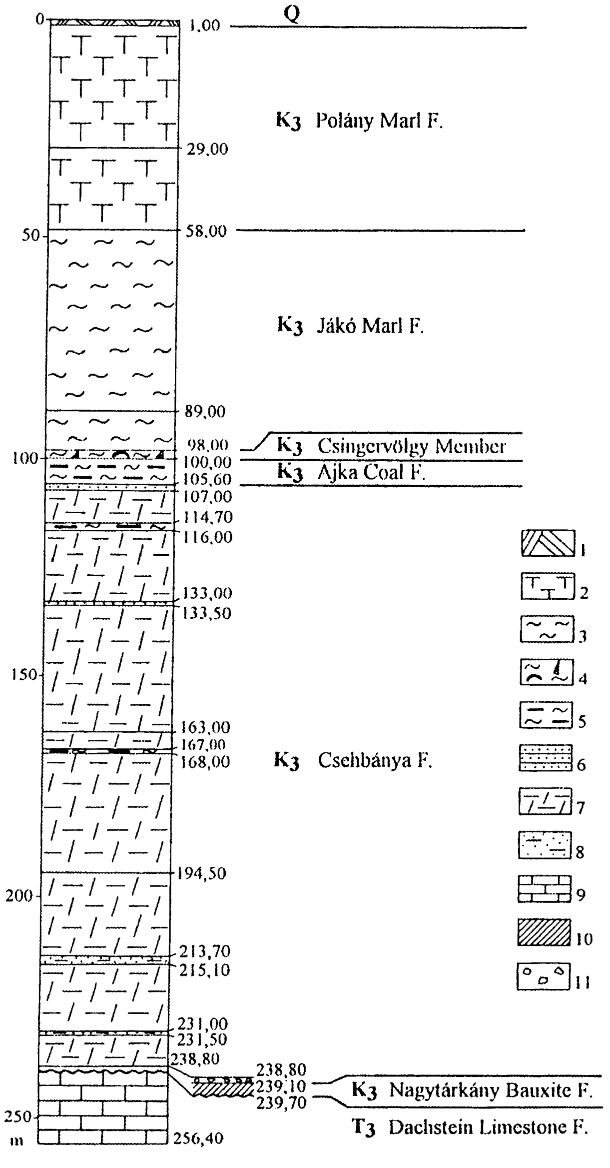


Fig. 2. Lithostratigraphy of the borehole Bakonyjákó 528

1 Soil; 2 Calcareous marl; 3 Marl; 4 Molluscan clay-marl; 5 Coaly clay-marl; 6 Sandstone; 7 Variegated clay-marl; 8 Clayey sand, siltstone; 9 Limestone; 10 Bauxitic clay; 11 Limestone breccia

Biostratigraphy

Foraminifers

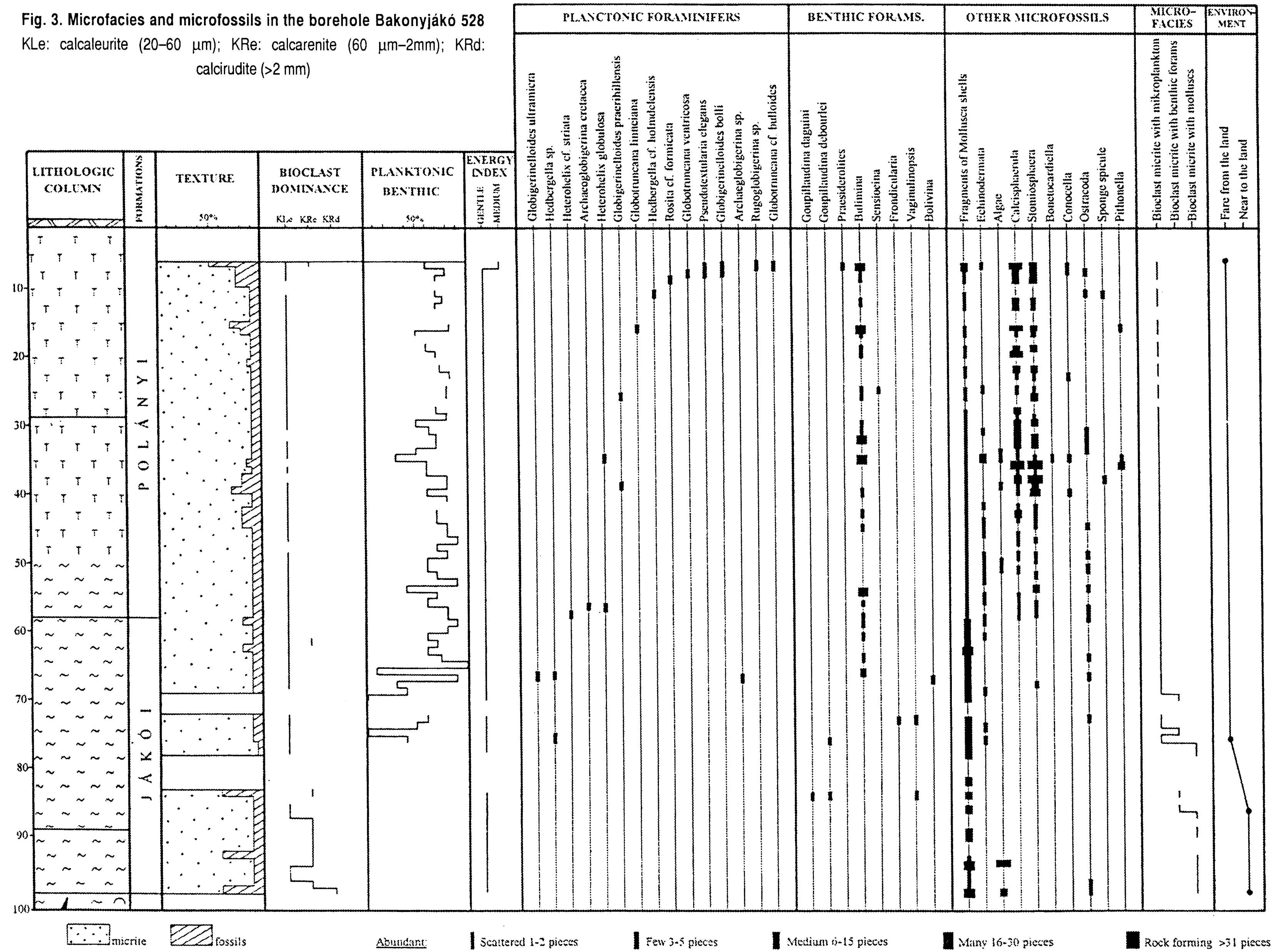
The Senonian foraminifers in Hungary were studied mainly by Majzon (1943, 1961) and Sidó (1961, 1972, 1983). Majzon assigned the strata containing *Globotruncana* to the Senonian, and Sidó dated the same strata as Santonian to Maastrichtian. The samples analysed by E. Bodnár came from washing residues and thin sections of marine rocks between 97.6–6.5 m. Preservation of the benthic and planktonic foraminifers is poor. They were studied mainly in thin sections (fig. 3).

The rock between 97.6–75.6 m is a bioclastic micrite with mudstone-wackestone texture. The grain size of the bioclastic fraction is dominantly calcaleurite (0.02–0.06 mm). The calcarenite fraction is subordinate (0–20%), and it is in form of medium worn well-sorted molluscs and echinoderm bioclastic elements. The role of benthic foraminifers is significantly high. Goupillaudinae (Plate 1) between 83.5–83.6 m are present in rock-forming quantity. The energy index is low, indicating slightly agitated marine environment. This environment, favourable for the benthic foraminifers, represents a transition to the overlying microplankton-rich neritic environment.

In the interval from 75.6 to 6.5 m the rock is biomic-

Fig. 3. Microfacies and microfossils in the borehole Bakonyjákó 528

KLe: calcaleurite (20–60 μm); KRe: calcarenite (60 μm–2mm); KRd: calcirudite (>2 mm)



rite with wackestone texture. The dominant mikro-planktonic forms are: Calcisphaerulinae, Stomiosphaerulinae, Bonetocardiellinae, Pitonellinae; planktonic foraminifers are subordinate. The quantity of the elements gradually increases upwards, indicating open sea environment. The species *Conocella ugodensis* appears at 39 m, and there are representatives of the Rendek Member of the open shelf facies (Polány Marl Formation, HAAS 1978). The occurrence of the algae species *Pieninia oblonga* BORZA-MISIK in this interval also indicates shelf facies. The dominant forms of planktonic foraminifers are very small globular and brained forms, that belong to the upper photic zone (HUBER 1992, NORRIS 1992). At 21.6 m and above, wide, double keeled planktonic forms with flat dorsal side can be found, that indicate a water depth around and below 75 m. In two intervals (15.6–15.5 m and 6.6–6.5 m), the large amount of planktonic foraminifer fragments indicates intensification of water movement.

The evaluation of the planktonic and benthic forms (Plate 1 and 2) is based on the species range of taxa selected by CARON (1985). *Heterohelix globulosa* (EHRENBERG) at 56.5 m indicates an age of Early Campanian to Early Maastrichtian, *Globigerinelloides praerihillensis* (PESSAGNO) at 25.5 m, *Globotruncana ventricosa* at 7.5 m and *Pseudotextularia elegans* (RZEHAK) at the same depth suggest an age between Middle Campanian and Middle Maastrichtian (CARON 1985).

Calcareous nannofossils

The calcareous nannofossil content of 100 core samples of the borehole Bj-528 was investigated under the light microscope. Samples for smear slide preparation were taken from the cores at a sampling interval of approximately one meter.

Samples 100 (213.5 m) to 89 (104.5 m) from the Csehbánya Formation and the Ajka Coal Formation yielded no nannofossils as a consequence of the non-marine sedimentary environment of the variegated clay and the overlying coal deposits. Nannofossil assemblages were found in samples 88 (98.5 m) to 1 (6.5 m). The nannofossil content and preservation are poor, but suitable for stratigraphic interpretation. A total number of 45 species of calcareous nannofossils has been recorded (Table 1). Nannofossil marker species are shown on Plate 3. The general composition of the nannofossil assemblages is more or less similar to those known from Santonian–Campanian deposits of the Gosau Group in the Eastern Alps of Austria (WAGREICH 1988).

Sample 88 (98.5 m), taken from the base of the Jákó Marl Formation, was the first sample that contained calcareous nannofossils. Important marker species recorded in sample 88 are *Marthasterites furcatus, Micula decussata, Lithastrinus grillii, Calculites* cf. *obscurus, Lucianorhabdus cayeuxii* and curved morphotypes of *Lucianorhabdus cayeuxii* (ssp. B of WAGREICH 1988, 1991, 1992). This assemblage indicates the standard nannofossil zone CC17 (*Calculites obscurus* Partial Zone, SISSINGH 1977) of the zonations of SISSINGH (1977) and PERCH-NIELSEN (1979, 1985). This zone can be assigned to the Late Santonian–early Early Campanian, according to correlations with the standard ammonite and planktonic foraminifer zonations of the Tethyan Late Cretaceous (e.g. BIRKELUND et al. 1984).

Table 1

Calcareous nannofossil species recorded in the core samples of borehole Bj-528

Acuturris scotus (RISATTI 1973) WIND & WISE 1977
Ahmuellerella octoradiata (GORKA 1957) REINHARDT 1964
Arkhangelskiella cymbiformis VEKSHINA 1959
Arkhangelskiella sp. (small morphotype)
Bipodorhabdus brooksi (BUKRY 1969) CRUX 1982
Biscutum constans (GORKA 1957) BLACK 1959
Braarudosphaera bigelowi (GRAN & BRAARUD 1935) DEFLANDRE 1959
Broinsonia (Aspidolithus) parca constricta HATTNER, WIND & WISE 1980
Broinsonia (Aspidolithus) parca parca (STRADNER 1963) BUKRY 1969
Calculites obscurus (DEFLANDRE 1959) PRINS & SISSINGH 1977
Calculites ovalis (STRADNER 1963) PRINS & SISSINGH 1977
Chiastozygus litterarius (GORKA 1957) MANIVIT 1971
Corollithion exiguum STRADNER 1961
Cretarhabdus crenulatus BRAMLETTE & MARTINI 1964
Cretarhabdus conicus BRAMLETTE & MARTINI 1964
Cribrosphaerella ehrenbergii (ARKHANGELSKY 1912) DEFLANDRE 1952
Cylindralithus sp.
Eiffellithus eximius (STOVER 1966) PERCH-NIELSEN 1968
Eiffellithus turriseiffelii (DEFLANDRE & FERT 1954) REINHARDT 1965
Gartnerago obliquum (STRADNER 1963) NOEL 1970
Glaukolithus diplogrammus (DEFLANDRE 1954) REINHARDT 1964
Helicolithus trabeculatus (GORKA 1957) VERBEEK 1977
Lithastrinus grillii STRADNER 1962
Lithraphidites carniolensis DEFLANDRE 1963
Lucianorhabdus cayeuxii DEFLANDRE 1959
Lucianorhabdus cayeuxii DEFLANDRE 1959 ssp. B, WAGREICH 1988
Lucianorhabdus maleformis REINHARDT 1966
Marthasterites furcatus (DEFLANDRE in DEFLANDRE & FERT 1954) DEFLANDRE 1959
Microrhabdulus belgicus HAY & TOWE 1963
Microrhabdulus decoratus DEFLANDRE 1959
Micula decussata VEKSHINA 1959
Ottavianus giannus RISATTI 1973
Prediscosphaera cretacea (ARKHANGELSKY 1912) GARTNER 1968
Prediscosphaera spinosa (BRAMLETTE & MARTINI 1964) GARTNER 1968
Quadrum gartneri PRINS & PERCH-NIELSEN in MANIVIT et al. 1977
Reinhardtites anthophorus (DEFLANDRE 1959) PERCH-NIELSEN 1968
Reinhardtites sp.
Rhagodiscus angustus (STRADNER 1963) REINHARDT 1971
Rotellapillus sp.
Russellia multiplus (PERCH-NIELSEN 1973) WIND & WISE 1977
Tranolithus orionatus (REINHARDT 1966) PERCH-NIELSEN 1968
Tranolithus sp.
Vekshinella sp.
Watznaueria barnesae (BLACK 1959) PERCH-NIELSEN 1968
Zeugrhabdotus embergeri (NOEL 1959) PERCH-NIELSEN 1984

Lucianorhabdus cayeuxii ssp. B gives evidence for the nannofossil subzone CC17b of WAGREICH (1988, 1991, 1992). Compared to the detailed integrated ammonite stratigraphy of the Gosau Group of the Eastern Alps (SUMMESBERGER 1985; WAGREICH 1988, 1992) subzone CC17b straddles just around the lower boundary of the Campanian, defined both by ammonite faunas (*Placenticeras* cf. *Placenticeras bidorsatum* (ROEMER); SUMMESBERGER 1985) and planktonic foraminifers (first occurrence of

Globotruncanita elevata as the definition of the base of the *Asymetrica-Elevata* Concurrent Range Zone, comp. WAGREICH 1992) in the sections of the Gosau Valley. Therefore, a latest Santonian to early Early Campanian age compared to the Tethyan standard macro- and microfossil zonations is probable for the base of the Jákó Marl Formation in the Bj-528 borehole (fig. 4). Nannofossil zone CC17 can also be correlated to nannofossil events in the Late Santonian to early Early Campanian of the Boreal realm (CRUX 1982; BURNETT 1990).

The next nannofossil event recognized is the last occurrence of *Marthasterites furcatus* in sample 67 (77.5 m). The position of its last occurrence is still within nannofossil subzone CC17b, below the first occurrence of species of the *Broinsonia (Aspidolithus) parca*-Group. In comparison to the normal last occurrence of *M. furcatus* at the top of nannofossil zone CC18a this species shows a somewhat restricted distribution in the core. A considerable diachronism of the last occurrence of this low-latitude nannofossil species was already noted by CRUX (1982), especially in transitional areas from the Tethyan to the Boreal realm. SVABENICKA (1993) also recorded strong differences in the abundance of *M. furcatus* during the Coniacian and Santonian of the Klement Formation in the northern Tethyan margin sections of south Moravia. *Corollithion signum,* whose last occurrence is of regional biostratigraphical value in the early Early Campanian of the Gosau sections of Austria, is missing totally in the Bj-528 core, therefore the CC17c subzone of WAGREICH (1988) could not be distinguished. The lower boundary of the Polány Marl Formation is situated still in the upper part of the nannofossil zone CC17b.

The highest nannofossil event recorded in the borehole Bj-528 is the first occurrence *of Broinsonia*

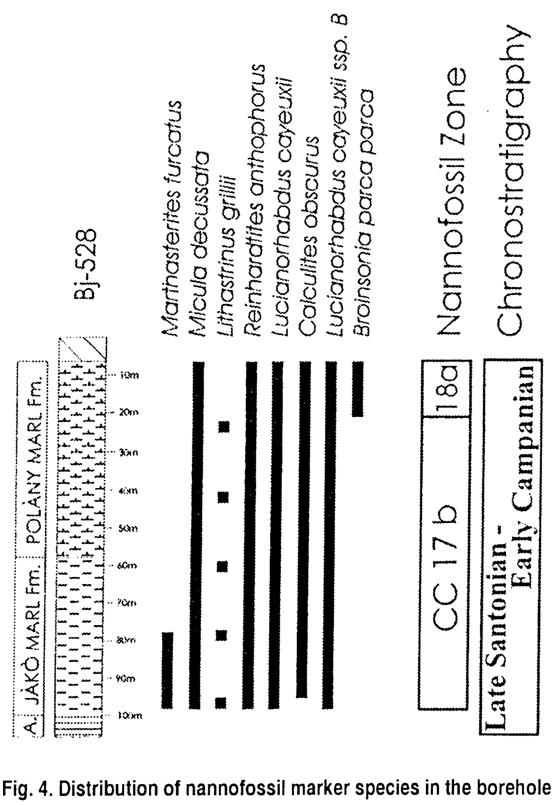


Fig. 4. Distribution of nannofossil marker species in the borehole Bakonyjákó 528

(Aspidolithus) parca parca in sample 13 (21.5 m). This defines the base of the nannofossil zone CC18a (*Broinsonia parca* Concurrent Range Zone, SISSINGH 1977), still within the Early Campanian (SISSINGH 1977; WAGREICH 1988, 1992). *Broinsonia (Aspidolithus) parca parca* is defined by a ratio of the margin to the central area of the coccolith between 1.3 and 1 (e.g. CRUX 1982; STRADNER & STEINMETZ 1984; WAGREICH 1988). The first *Broinsonia (Aspidolithus) parca constricta* (ratio below 1) appears slightly above this event in sample 3 (8.5 m). In this sample a broken specimen of *M. furcatus* has been found, which may be due to reworking from older deposits.

Younger nannofossil events, such as the first occurrence of *Bukryaster hayi* (defining the base of CC18b) and *Ceratolithoides aculeus* (defining the base of CC20), are not recorded in the Bj-528 core. This suggests, that the youngest Cretaceous deposits of the borehole belong still to the Early Campanian nannofossil zone CC18a.

Spore-pollen analyses

Palynological investigations of Upper Cretaceous formations in Hungary have a more than 30 year old record. Undivided Upper Cretaceous deposits in the continuous sequence of the Bakony Mountains have been assigned by GÓCZÁN (1961) to the Late Santonian–Early Maastrichtian. This classification was based on the comparative analysis of some Upper Coniacian–Lower Santonian samples (KÜHN 1947) of Gosau facies (Unterlaussa, Austria) together with the palynostratigraphic chart of Upper Cretaceous sediments in NW- and Central Europe elaborated by KRUTZSCH (1959).

Upon the dominance features of sporomorphs GÓCZÁN (1964) has established eight (A-H) palynozones in the Bakony Mts. classified as Late Santonian–Late Maastrichtian. The boundary between the Santonian and Maastrichtian stages was determined in different layers as a function of the palaeontological method used. Upon the study of foraminifers SIDÓ (in GÓCZÁN 1973) assigned it into the Jákó Marl and into the partly synchronous Ugod Limestone Formation, whereas palynological (GÓCZÁN 1973) and malacological (CZABALAY in GÓCZÁN 1973) investigations resulted in defining this boundary within the Ajka Coal- and the Csehbánya Formations, respectively.

Palynological correlation of the four Upper Cretaceous regions in Hungary bearing different formations was performed in the late 1980s (SIEGL-FARKAS 1993a, GÓCZÁN & SIEGL-FARKAS 1990). The introduction of palynological subzones (SIEGL-FARKAS 1983, 1986, 1993a) resulted in a more accurate interpretation of the relationship between the formations making up the Transdanubian Central Range itself as well as between the Transdanubian Central Range and the S part of the Great Hungarian Plain. The whole range of fresh-water deposits in the Transdanubian Central Range have been assigned to the Upper Santonian upon the nannoplankton (WAGREICH 1992) and the comparative palynostratigraphic analyses (SIEGL-FARKAS 1993b) of the Gosau formations (upper part of the Grabenbach Formation) in the Gams Basin.

The 94 samples taken from the Upper Cretaceous sequence yielded by the borehole Bakonyjákó 528 allowed us to define three dominance zones and one assemblage zone. Figure 5 demonstrates the variation in organic matter content and the relative amount of sporomorphs of the samples, the palynostratigraphic classification as well as the distribution of taxa. Plates 4–6 depict the most typical sporomorphs. Among the 18 samples taken from the predominantly variegated sediments of the Csehbánya Formation only the 5 deriving from the periodically inundated reductive environment yielded identifiable sporomorphs. In the depth range between 236.6–238.7 m the formation is represented by the *Oculopollis–Trilobosporites* Dominance Zone, whereas the rest (between 105.6–236.6 m) is made up of the following subzones of the *Oculopollis zaklinskaiae–Brecolpites (Tetracolporopollenites) globosus* Dominance Zone: *Oculopollis–Brecolpites* (155.5–236.6 m), *Oculopollis–Triatriopollenites* (115.5–155.5 m) and *Oculopollis–Hungaropollis* (105.6–155.,5 m). The younger section of the *Oculopollis–Hungaropollis* Subzone represents the Ajka Coal Formation (6 samples), which is only a few meters thick here.

The latter dominance zone represents the main phase of the coal formation (Ajka Coal Formation) in the SW part of the sedimentary basin (Ajka, Gyepükaján) (Siegl-Farkas 1988). The organic microfacies composition of the uppermost, *Oculopollis–Hungaropollis* Dominance Subzone (98.5–115.5 m) of this dominance zone made up of lacustrine–paludal formations is rich in organic matter and sporomorphs.

All three dominance subzones can be identified within the *Hungaropollis* Dominance Zone (61.6–98.5 m) embracing almost the whole range of the Jákó Marl Formation (42 samples) as follows: the *Hungaropollis triangularis–Oculopollis* (85.6–98.5 m), the *Hungaropollis oculus–Hungaropollis oculoglomeratus* (68.8–85.6 m), and the *Hungaropollis–Krutzschipollis* (61.8–68.8 m) Subzones. The organic matter content tends to increase upwards in this dominance zone. The variation in the amount of pteridophyte spores indicates unambiguously that the assemblages of the lower and upper subzones formed near the shore, whereas the sediments of the middle subzone were deposited inside the basin.

The 7 samples of the Polány Marl Formation between 51.5–58.6 m assigned to *the Suemegipollis triangularis–Krutzschipollis spatiosus* Assemblage Zone yielded only a small amount of organic matter but they were rich in sporomorphs. The overlying calcareous marl formations (21 samples) did not include identifiable fossil assemblages. The small size of some identified pollens indicates that they were embedded farther away from the shoreline than the afore-mentioned units.

The deposition of the fluvial–flood-plain sediments of the Csehbánya Formation made up essentially of variegated clay started in a sedimentary basin with permanent water cover. Consequently, vegetation in its immediate vicinity was dominated by pteridophytes preferring humid soil. The few redeposited ancient pine pollens identified derive from the surrounding coeval Upper Triassic land affected by erosion.

Afterwards the area had only a periodic flood-plain character. Permanent water cover was reestablished in the upper section of the formation during the deposition of paludial sediments. Angiosperms on land having several tree strata (Normapolles) and pteridophytes representing undergrowth played an equally significant role in this environment rich in organic matter and providing the source for coal formation.

The frequent change in organic matter content within the Jákó Marl Formation shows the variation in relief energy due to oscillations of the surface. Large pteridophyte spores frequently occurring in tetrads indicate near shore sedimentation in a calm environment. This calm, marine environment with high organic matter content prevailing at the starting phase of the sedimentation of the Jákó- and the Polány Marl Formations provided optimal conditions for the associations of dinoflagellates, foraminifers and burrowing worms (Annelidae) as well.

The afore-mentioned changing conditions of the palaeoenvironment can be attributed to the extension of the sea reaching the sedimentary basin of the Transdanubian Central Range during the Late Santonian. This basin belonged to the Mediterranean region of the Normapolles province.

Dinoflagellate studies

Dinoflagellates were identified in the Jákó Marl Formation as well as in the lowermost section of the Polány Marl Formation (51.5–93.,6 m). The younger environment generating the Polány Marl rich in lime was far from providing a beneficial biotope for the preservation of phytoplankton. The *Hungaropollis* Dominance Zone included only very few, or few, whereas the *Suemegipollis triangularis–Krutzschipollis spatious* Assemblage Zone medium and rich dinoflagellate associations.

Given the lack of continuous sedimentary sequence, a dinoflagellate zonation embracing the whole Upper Cretaceous sequence in the Tethys area has not yet been established. In Hungary, it is under preparation adopting the zonation of Williams 1977 (in Williams & Buják 1985) considered as global. As far as the age of the related sediments is concerned, the almost simultaneous occurrence of the most significant representatives, namely the *Dinogymnium euclaense* Cookson & Eisenak (53.6 m) and the *Odontochitina operculata* (Wetzel) Deflandre & Cookson (51.6 m) excludes Maastrichtian, but it can be assigned both to the Santonian or Campanian. Upon the lifespan of the *Spinidium* cf. *sverdrupianum* (Manum) Lentin & Williams occurring in the section between 53.6–65.6 m, it was deposited during the Santonian and Early Campanian. The part of the profile yielding simultaneously all the three afore-mentioned dinoflagellates (51.3–53.6 m) can be assigned to the early Campanian.

As a result of the correlation of the recently studied formations in the Transdanubian Central Range the section of the profile between 51.5–93.6 m can be classified as belonging to the *Odontochitina operculata* Assemblage Zone, more precisely to its *Apteodinium deflandrei* Subzone (fig. 5). (See in this volume: Siegl-Farkas Á.–M. Wagreich).

Other marine fossils

Apart from plant microfossils, fossils of animals also occurred in the Jákó and Polány Marl Formations (Plate 7). Organic tests of foraminifers, fossils assigned

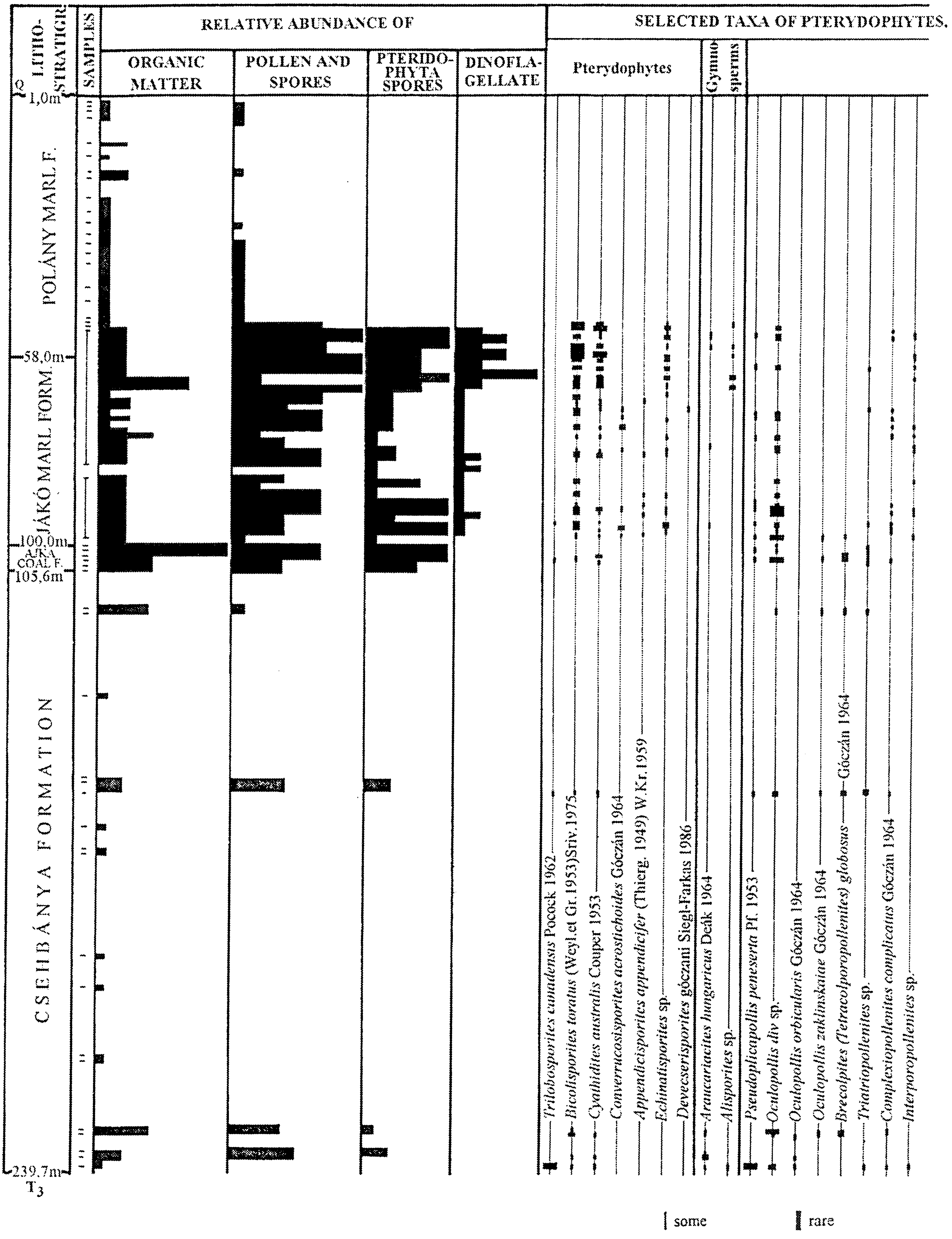
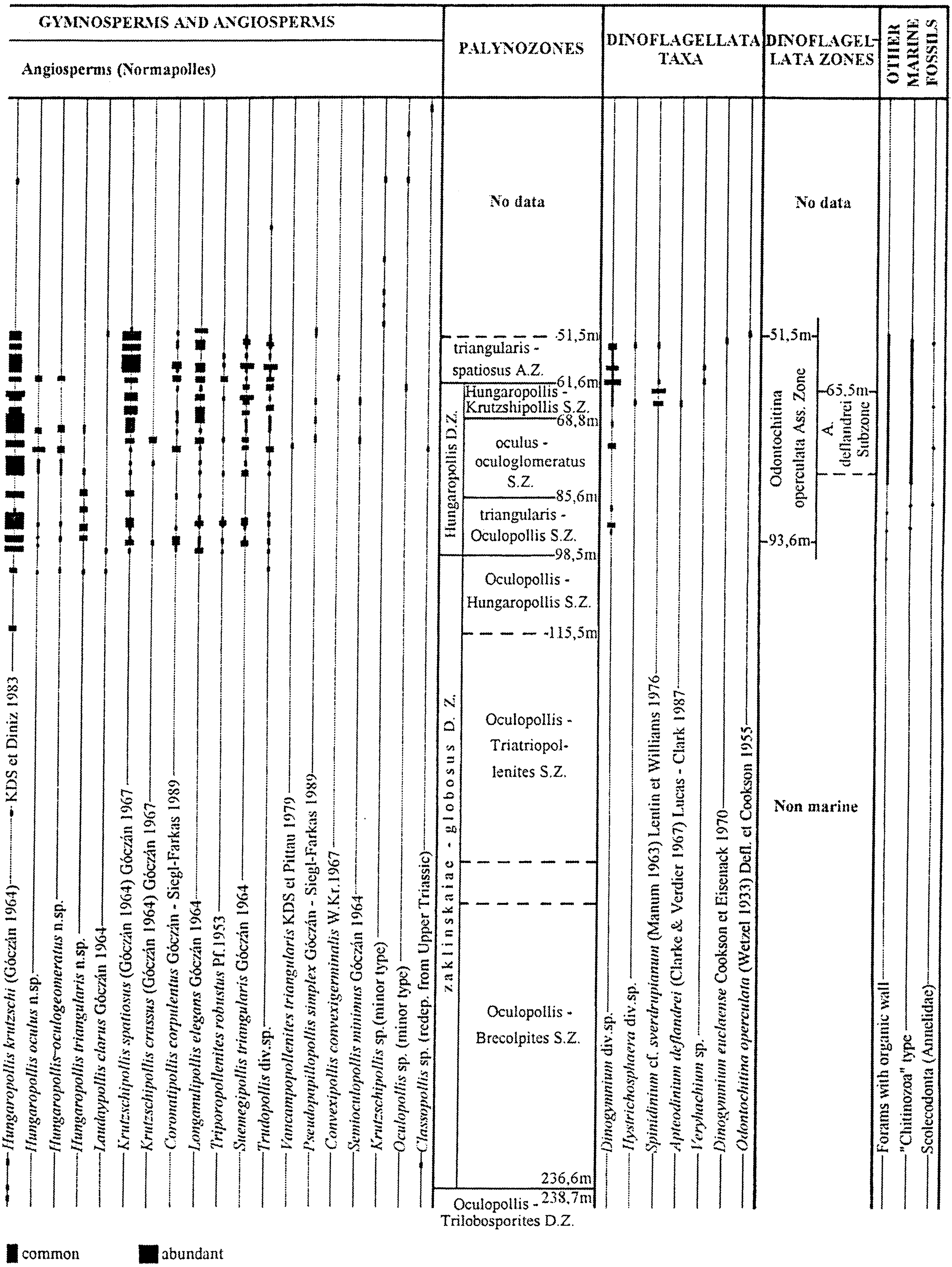


Fig. 5. Distribution of pollen, spores, dinoflagellates



and marine fossils in the borehole Bakonyjákó 528 to the "Chitinozoa" shape class and Scolecodonts (Annelidae) rather scarce in the lower section of the Jákó Marl become frequent and occur consistently in its upper part and in the layers of the Polány Marl poor in lime. Their presence is presumably due to the high organic matter content of the region skirting the shoreline.

Palaeomagnetic investigations

Palaeomagnetic samples were collected at 1 m intervals at the drill site. Samples were placed immediately in cubical plastic boxes which then were sealed. The magnetization of samples was measured in a CCL two-axis cryogenic magnetometer. Following the measurement of natural remanent magnetization, 38 pilot samples representing various lithologies, depths and magnetic polarities were selected for progressive thermal and alternating field demagnetization.

The stability of magnetization and representative behaviour during demagnetization is shown in orthogonal demagnetization diagrams (figs. 6a–d). The pilot samples exhibited two to three components of magnetization. Thermal demagnetization diagrams (Figs. 6a-b) indicated that secondary magnetizations disappeared at 200–250 °C and directions of magnetization were stable from 200–250 °C to 300–350 °C. These stable directions were considered to reflect original magnetizations acquired during deposition. Changes in directions above 350–450 °C (fig. 6b) caused by mineralogical alterations during heating. Alternating field demagnetization removed secondary magnetizations effectively from the grey and white rock samples (fig. 6c) but not from the variegated rocks (fig. 6d).

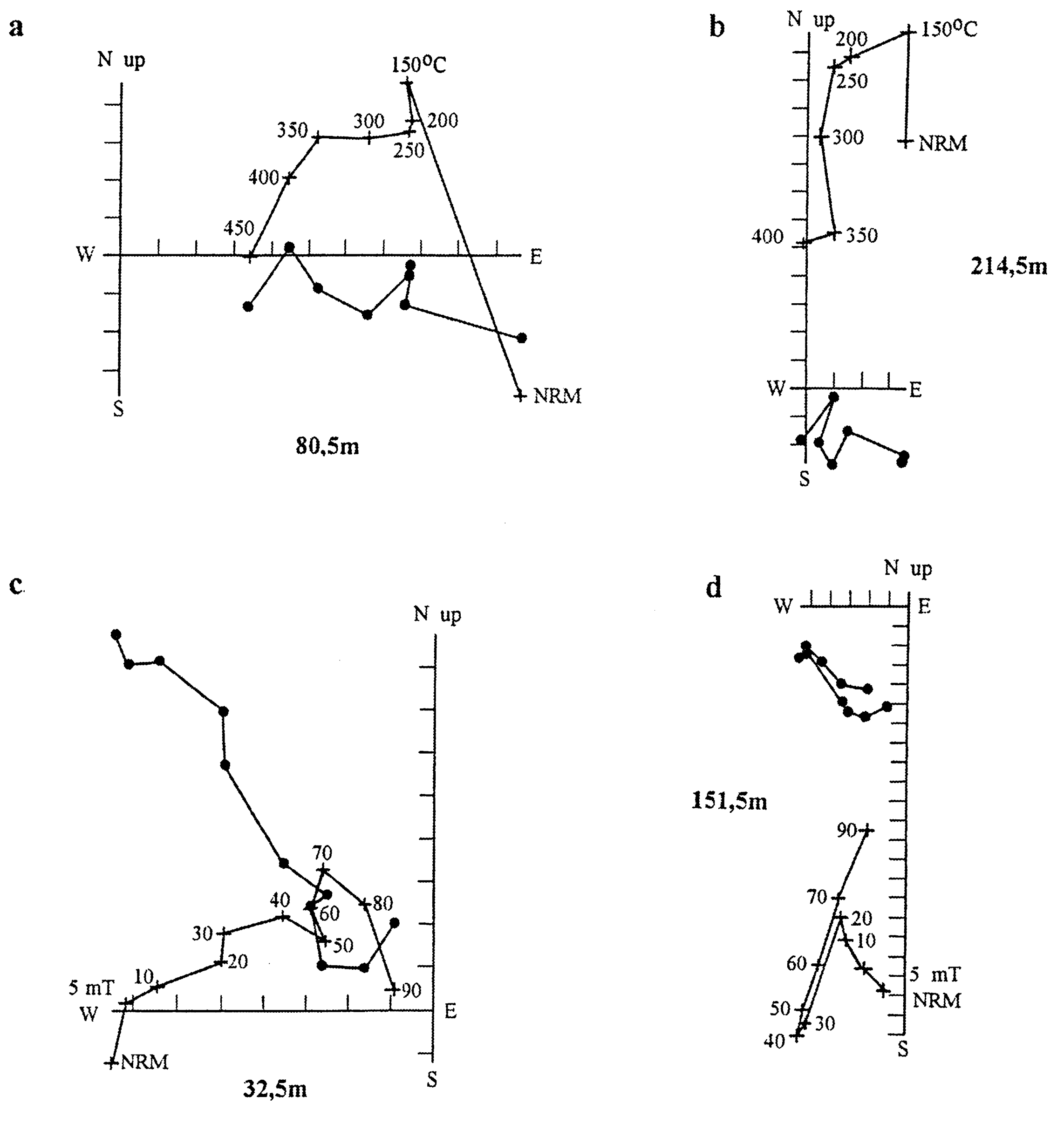


Fig. 6a–d. Orthogonal diagrams showing the demagnetization behaviour of selected pilot samples from borehole Bakonyjákó 528
Figures a–b: progressive thermal demagnetization, figures c–d: progressive alternating field demagnetization. + : inclinations • : declinations

Most remaining samples were demagnetized thermally at 250 °C. Loose or wet samples, not suitable for heating, were demagnetized in a 20 mT alternating field. Samples in which changes in inclination had appeared incomplete after demagnetization were subjected to higher levels of temperature or field. Several samples that did not contain reliable magnetization were discarded from the data set. Variegated rock samples that were demagnetized only in alternating field, also were discarded.

The plot of inclinations displays essentially two polarity zones, a long, dominantly normal interval below 87.5 m and a dominantly reverse interval above it (fig. 7). For the correlation of the polarity zones with the polarity time scale, independent data are needed. The presence of the CC17 nannozone, some of the foraminifers and dinoflagellates clearly indicate that the reverse zone above 87.5 m correlates with the C33r Chron, and the underlying interval of normal polarity in the Bakonyjákó section must correlate with the long Cretaceous Normal Polarity Chron (C34n).

Figure 7 shows several intervals of mixed polarity that are not represented in the geomagnetic polarity time scale. The origin of these mixed polarity intervals can be explained in different ways. A large part of the long normal interval came from variegated, terrestrial strata of the Csehbánya Formation. Mineralogical alterations might have occurred in these rocks after deposition, and the alterations could either destroy or overprint the original magnetization. However, the interval of mixed polarity at a depth from 72 to 63 m correlates with other sections from Germany, California and the Angola Basin (see in HAMBACH & KRUMSIEK 1991).

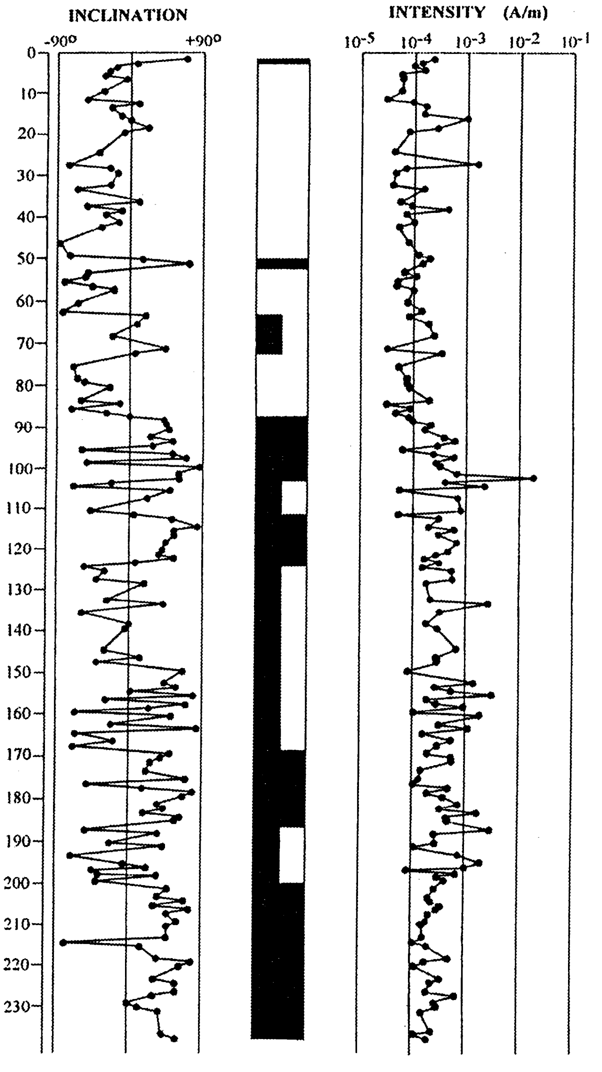


Fig. 7. Plots of inclinations, intensities of magnetization and polarity zonation in the borehole Bakonyjákó 528

Black: normal; white: reverse; black and white: mixed polarity

Discussion

The section at Bakonyjákó has been correlated with the time scale of GRADSTEIN et al. (1994) by means of magnetic polarity and nannozones (fig. 8). The boundaries of the stages, however, are not exactly defined, because the problem of exact correlation of the foraminifer and nannoplankton zonations with the ammonite orthostratigraphy has not been solved. The Santonian–Campanian boundary is defined either within the long Cretaceous normal polarity Chron 34n (e.g. HAMBACH & KRUMSIEK 1991) or at the top of the Chron C34n (e.g. STRADNER & STEINMETZ 1984, GRADSTEIN et al. 1994) or above the polarity boundary, at the first occurrence of *Broinsonia parca* (e.g. THIERSTEIN, 1976).

In the borehole Bakonyjákó 528, the top of the Chron 34n is at 87.5 m, within the Jákó Marl Formation indicating that the polarity boundary is independent of the lithology. An ammonite determined by SUMMESBERGER as *Placenticeras polyopsis* (DUJARDIN) was reported from the middle part of the Jákó Marl Formation in the borehole Csabrendek Cr. 2 (PARTÉNYI, 1986). The presence of *P. polyopsis* indicates a Santonian age. The interval of mixed polarity from 63 to 72 m correlates with a similar mixed polarity in Germany, and it was determined as Early Campanian (HAMBACH & KRUMSIEK 1991). For these reasons the Santonian–Campanian boundary can be placed somewhere within the lower part of the Jákó Marl Formation, above 100 m and below 72 m.

The nannofossil zone CC18a (PERCH-NIELSEN, 1985; WAGREICH, 1992) indicates an Early Campanian age still at a depth of 8.5 m in the Bakonyjákó 528. section. The first occurrence of *Globotruncana ventricosa* at 7.5 m, however, suggests a Middle Campanian age.

The age of the Jákó Marl Formation was previously considered as Middle Campanian (e.g. SIEGL-FARKAS 1993a) but now is determined as latest Santonian or Early Campanian at Bakonyjákó. In the western part of the basin the Jákó Marl Formation may be a little older because the transgression came from the west.

During the past decades many palynological studies were carried out on Upper Cretaceous sections in Hungary. In Bakonyjákó, the *Hungaropollis* Dominance Zone includes the top of the magnetic Chron 34n, the lower part of CC17b nannozone and the inferred Santonian–Campanian boundary. For the extrapolation of this correspondence, however, further tie-points are needed, because in many cases the dominance zones may indicate palaeoenvironments rather than ages.

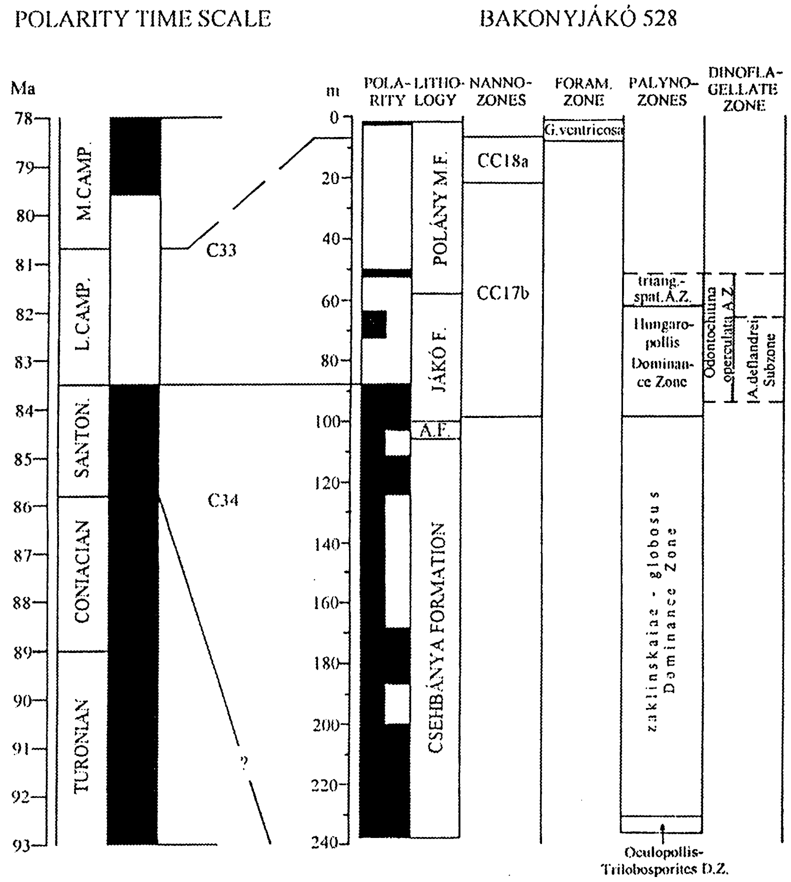


Fig. 8. Lithology, polarity zonation, nannoplankton, planktonic foraminifers, palyno- and dinoflagellate zones in the borehole Bakonyjákó 528 and their correlation with the time scale of GRADSTEIN et al. (1994)

Acknowledgements

The authors are indebted to the Bauxite Exploration Company and in particular its Farkasgyepű Group for making available the cores and the record of the borehole for sampling and investigations.

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Plate 1

1 *Goupillaudina debourlei* MARIE (83.5–83.6 m). M(magnification): 54x
2 *Goupillaudina daguini* MARIE (83.5–83.6 m). M: 54x
3 *Archaeoglobigerina* sp. (66.5–66.6 m). M: 165x
4 *Archaeoglobigerina cretacea* (D'ORBIGNY) (56.5–56.6 m). M: 130x
5 *Hedbergella* cf. *holmdelensis* OLSSON (10.5–10.6 m). M: 205x
6 *Globigerinelloides ultramicra* (SUBBOTINA) (66.5–66.6 m). M: 205x
7 *Globigerinelloides praerihillensis* PESSAGNO (38.5–38.6 m). M: 165x
8 *Heterohelix globulosa* (EHRENBERG) (34.5–34.6 m). M: 130x
9 *Heterohelix* cf. *striata* (EHRENBERG) (57.5–57.6 m). M: 165x
10 *Praesiderolites* sp. (6.5–6.6 m). M: 54x
11 *Hedbergella* sp. (75.5–75.6 m). M: 205x
12 Benthic foraminifers, bioclastic micrite, wackestone (83.5–83.6 m). M: 54x
A – *Goupillaudina* sp. B – *Vaginulinopsis*? sp. C – Echinodermata skeleton

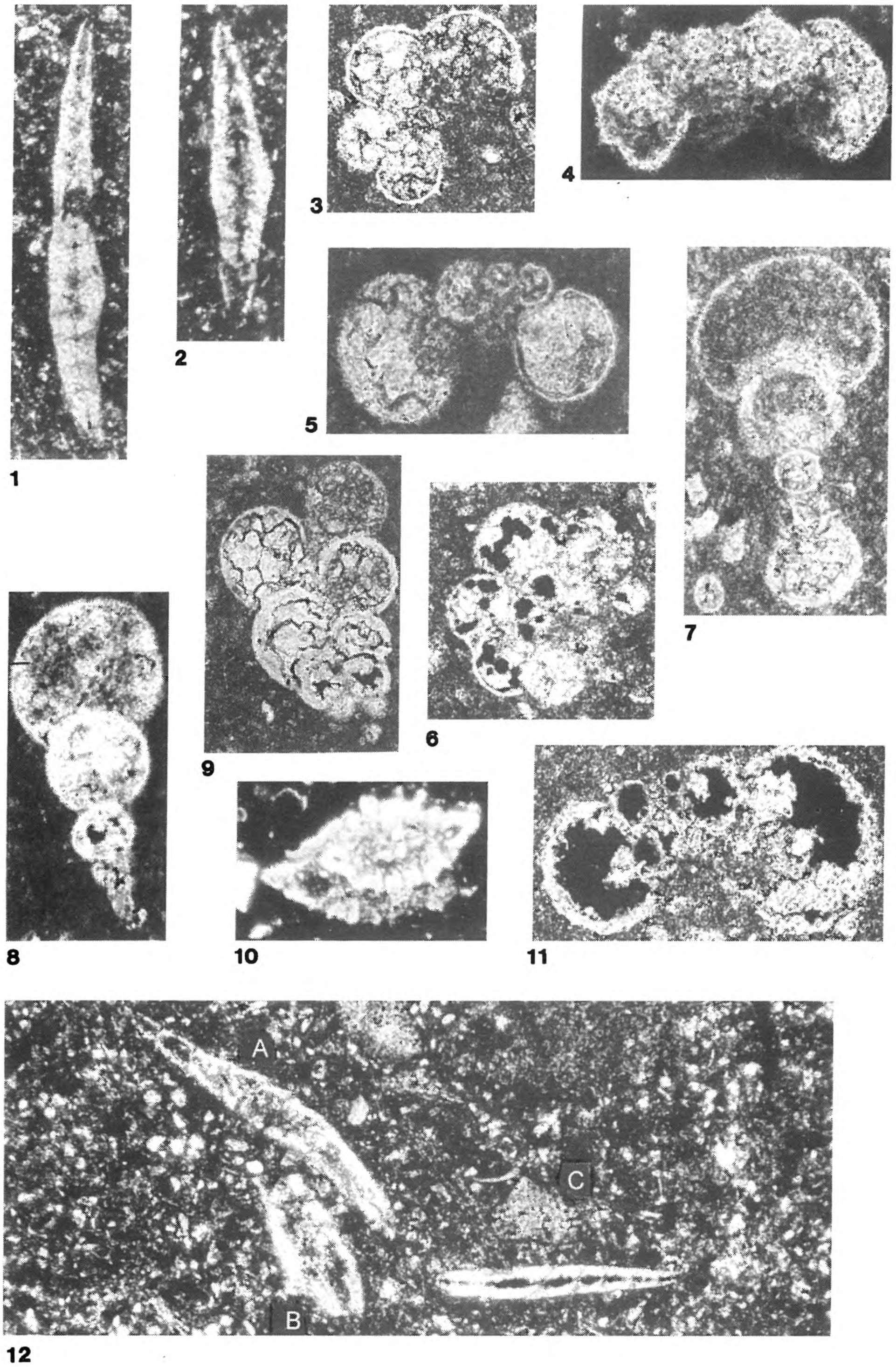
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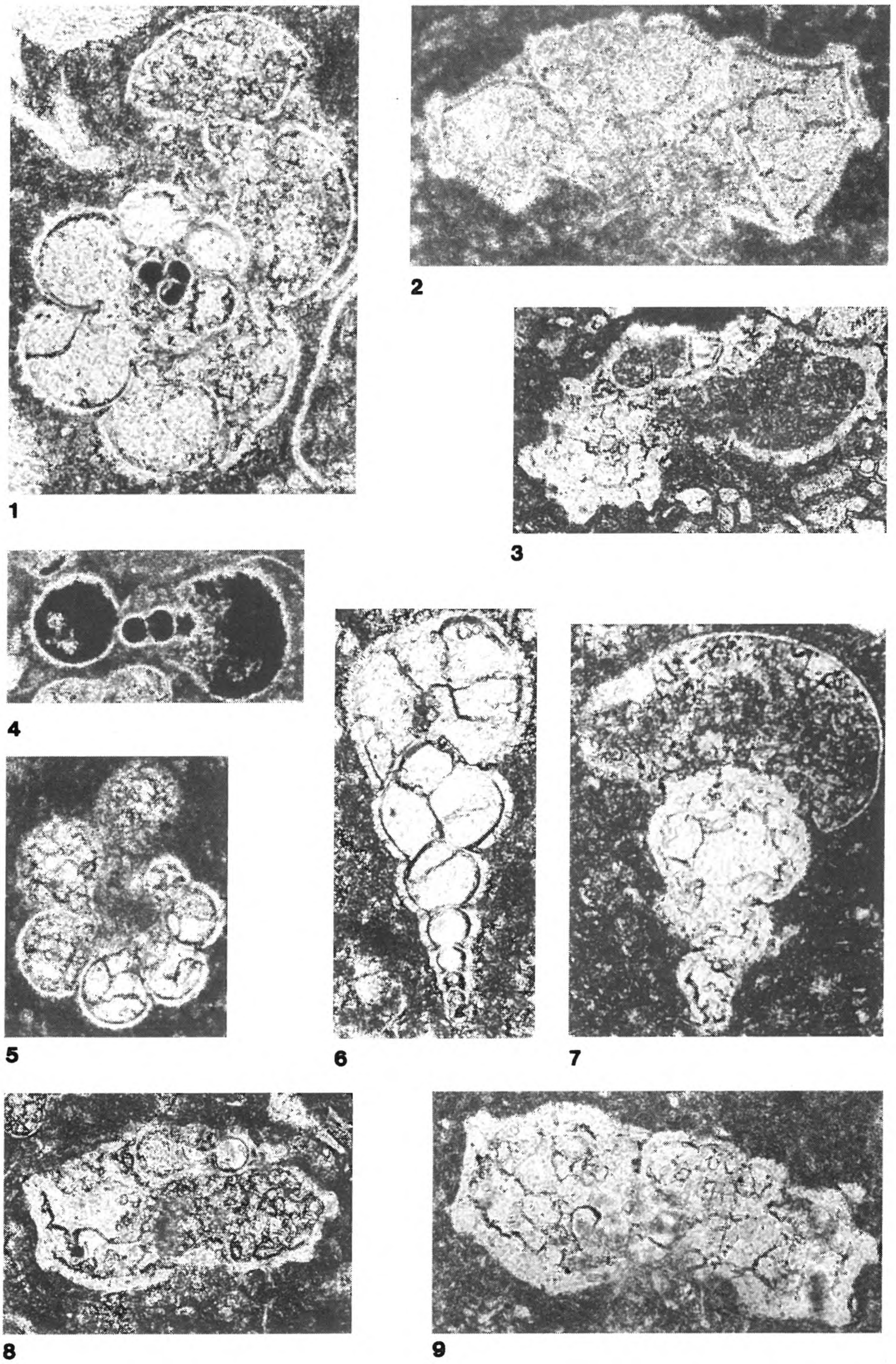
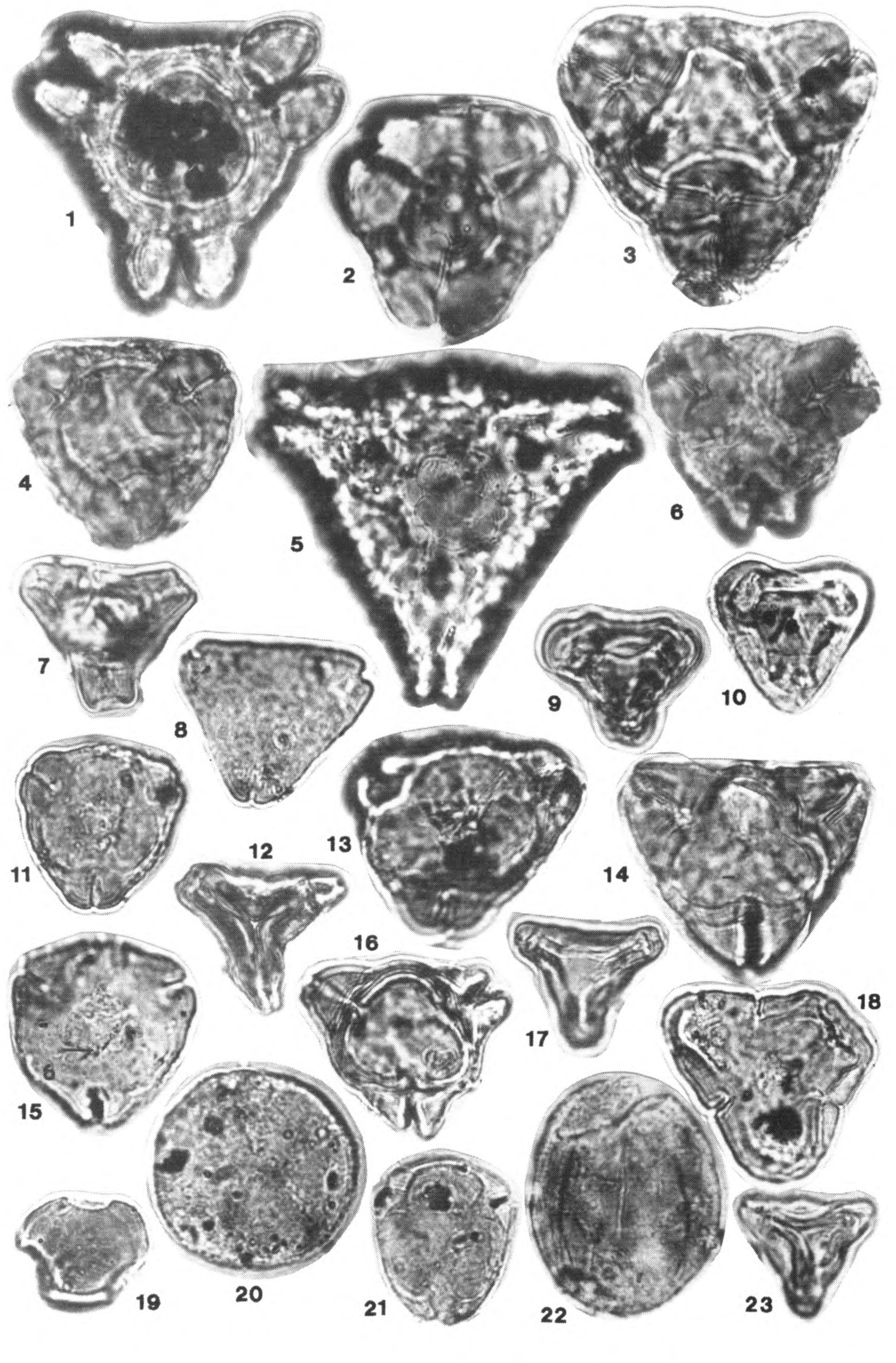
Plate 2



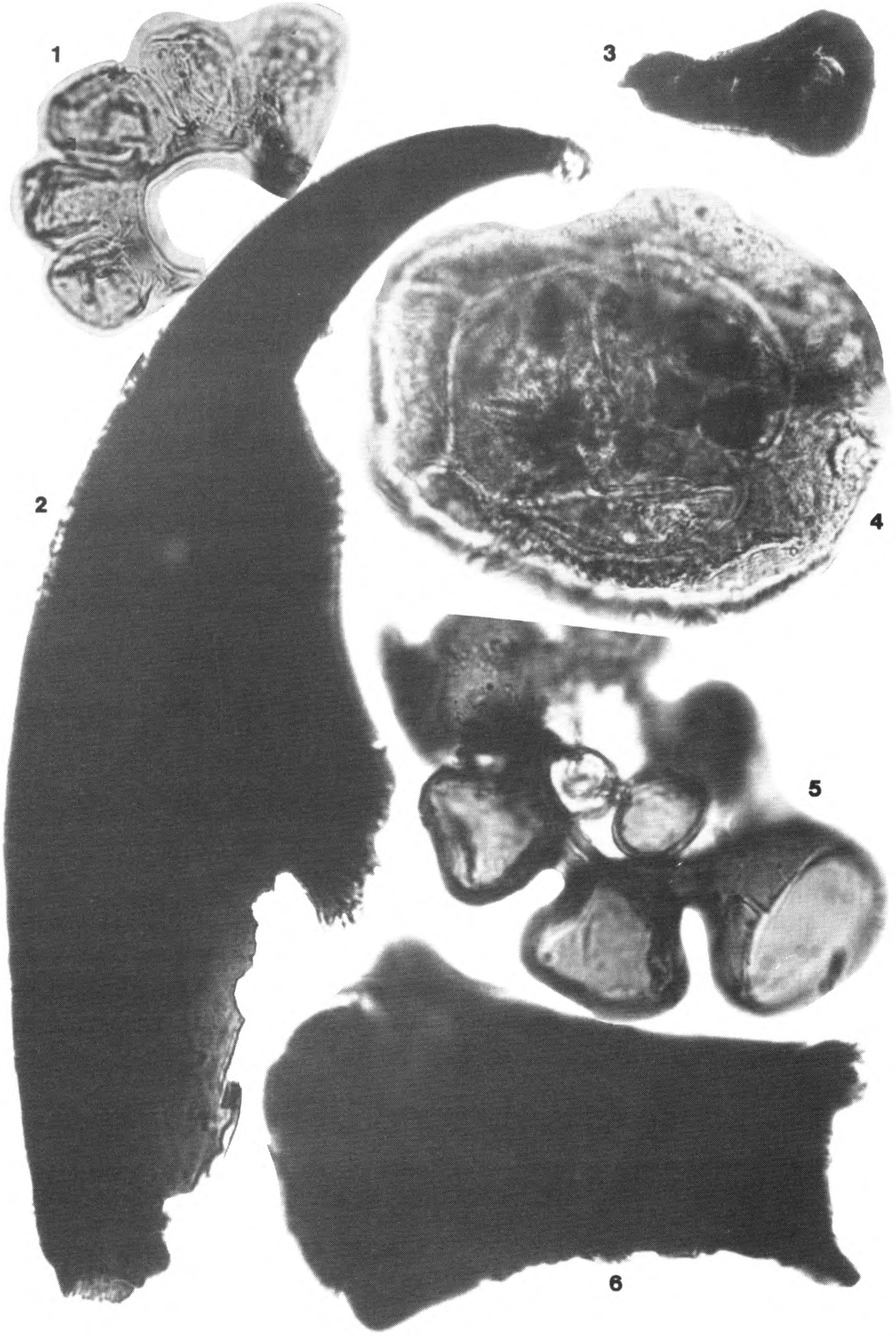
1 *Rugoglobigerina* sp. (6.5–6.6 m). M: 205x
2 *Globotruncana ventricosa* WHITE (7.5–7.6 m). M: 130x
3 *Rosita* cf. *fornicata* (PLUMMER) (8.5–8.6 m). M: 130x
4 *Globigerinelloides* cf. *bolli* PESSAGNO (7.5–7.6 m). M: 130x
5 *Globigerinelloides bolli* PESSAGNO (6.5–6.6 m). M: 130x
6 *Pseudotextularia elegans* (RZEHAK) (6.5–6.6 m). M: 205x
7 *Pseudotextularia elegans* (RZEHAK) (7.5-7.6 m). M: 205x
8 *Globotruncana linneiana* (D`ORBIGNY) (15.5–15.6 m). M: 165x
9 *Globotruncana* cf. *bulloides* VOGLER (6.5–6.6 m). M: 165x



Magnification l000x+---

1 *Hungaropollis* cf. *ajkanus* GÓCZÁN (61.5 m)
2 *Hungaropollis* sp. (234.6 m)
3 *Hungaropollis hollossyi* GÓCZÁN & SIEGL-FARKAS (92.5 m)
4 *Oculopollis* sp. (238.6 m)
5 *Krutzschipollis* cf. *spatiosus* GÓCZÁN (92.5 m)
6 *Oculopollis* sp. (92.5 m)
7 *Convexipollenites convexigerminalis* W. KR. (6l.5 m)
8 *Triatriopollenites* sp. (76.6 m)
9 *Interporopollenites proporus* WEYL. & KRIEG. (63.5 m)
10 *Interporopollenites proporus* WEYL. & KRIEG. (74.5 m)
11 *Pseudopapillopollis praesubhercynicus* GÓCZÁN (66.5 m)
12 *Complexiopollis turonis* W. KR. (238.6 m)
13 *Papillopollis* sp. (5l.5 m)
14 *Longanulipollis polanyensis* GÓCZÁN & SIEGL-FARKAS (92.5 m)
15 *Pseudopapillopollis praesubhercynicus* GÓCZÁN (70.5 m)
16 *Cuneopollis cuneolis* GÓCZÁN & SIEGL-FARKAS (92.6 m)
17 *Complexiopollis praeatumescens* W. KR. (63.5 m)
18 *Vancampopollenites triangulus* KDS & PITTAU (76.6 m)
19 *Arcanupollis* sp. (55.5 m)
20 *Subtriporopollenites* cf. *anulatus* PF. & TH. (63.5 m)
21 cf. *Pompeckjoidaepollenites* sp. (61.5 m)
22 *Hexacolporopollenites* sp. (238.6 m)
23 *Pseudoplicapollis peneserta* PF. (234.6 m)

Magnification l000x
1 *Dinogymnium euclaense* COOKS. & EIS. (53.6 m)
2 *Odontochitina operculata* (WETZ) DEFL. & COOKS. (51.5 m)
3 *Spinidinium* sp. (65.6 m)
4 *Dinogymnium euclaense* COOKS. & Eis. (53.6 m)
5 *Dinogymnium acuminatum* EVITT & CLARKE & VERDIER (58.6 m)
6 *Spinidinium* cf. *sverdrupianum* (MANUM) LENTIN & WILL. (65.6 m)
7 *Dinogymnium euclaense* COOKS. & EIS. (92.6 m)
8 *Apteodinium deflandrei* (CLARKE & VERDIER) LUCAS-CLARK (65.6 m)
9 "Foraminifera-tapeten" (60.6 m)
10 *Dinogymnium euclaense* COOKS. & EIS. (53.5 m)
11 *Veryhachium* sp. (61.5 m)
12 *Hystrichodinium* cf. *furcatum* ALBERTI (65.6 m)



1 “Foraminifera-tapeten” (60.6 m), magnification: l000x
2 Scolecodonta sp. (Annelidae) (74.5 m), magnification: 500x
3 "Chitinozoa" (55.6 m), magnification: 250x
4 “Foraminifera-tapeten” (61.5 m), magnification: l000x
5 “Foraminifera-tapeten” (78.6 m), magnification: l000x
6 "Chitinozoa" (75.5 m), magnification: 500x

ADVANCES
in
Austrian—Hungarian Joint Geological Research
Budapest, 1996

Dasycladaceae from "Zaimkalk" (=lagoonal Dachstein Limestone) of the Mandling Unit (Styria, Austria)

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Keywords: Dasycladaceae, Dachstein Limestone, Triassic (Norian), Zaimkalk, Mandling, Austria

Abstract

As already pointed out by KIESLINGER [1964] and TOLLMANN [1976a], the Zaimkalk sensu TRAUTH [1925] cannot be considered as an individual formation, but at least in part represents lagoonal Dachstein Limestone locally dominated by dasycladaceans. The dasycladacean assemblage is clearly governed by *Diplopora phanerospora* PIA. Further important taxa are *Gyroporella vesiculifera* (GÜMBEL) PIA and *Gyroporella* sp. Rather scarce taxa are *Griphoporella* sp., *Heteroporella zankli* (OTT), *Heteroporella* sp. and ?*Diplopora tubispora* OTT, while *Salpingoporella humilis* (BYSTRICKY) and *Salpingoporella sturi* (BYSTRICKY) are very rare. Also the foraminifera-assemblage is dominated by taxa characteristic for lagoonal Dachstein, respectively Upper Rhaetian Limestone, as e.g. *Aulotortus sinuosus* WEYNSCHENK, *Angulodiscus* sp. and Variostomatidae.

Zusammenfassung

Wie schon KIESLINGER [1964] und TOLLMANN [1976a] betonten, kann der Zaimkalk sensu TRAUTH [1925] nicht als eigenständiges Schichtglied aufgefaßt werden, sondern stellt — wohl zu einem erheblichen Teil — einen stellenweise Dasycladaceen-dominierten lagunären Dachsteinkalk dar. Die Dasycladaceen-Assoziation wird von *Diplopora phanerospora* PIA absolut dominiert. Weitere wichtige Taxa sind *Gyroporella vesiculifera* (GÜMBEL) PIA und *Gyroporella* sp. Untergeordnet finden sich weiters *Griphoporella* sp., *Heteroporella zankli* (OTT), *Heteroporella* sp. and ?*Diplopora tubispora* OTT sowie sehr selten *Salpingoporella humilis* (BYSTRICKY) und *Salpingoporella sturi* (BYSTRICKY). Auch die Foraminiferen-Assoziation wird von typisch lagunären Dachsteinkalk- bzw. Oberrhätkalk-Taxa dominiert, wie z.B. *Aulotortus sinuosus* WEYNSCHENK, *Angulodiscus* sp. sowie Variostomatidae.

Összefoglalás

Mint arra már KIESLINGER [1964] és TOLLMANN [1976a] is rámutatott, a TRAUTH [1925] értelmében vett "Zaimkalk" nem tekinthető önálló formációnak, hanem az — legalábbis jórészt — lagúna-kifejlődésű dachsteini mészkő, amelyre a dasycladaceák helyi dominanciája jellemző. A dasycladacea-együttes abszolút uralkodó faja a *Diplopora phanerospora* PIA. Fontos fajok még a *Gyroporella vesiculifera* (GÜMBEL) PIA és egy *Gyroporella* sp. Alárendeltek: *Griphoporella* sp., *Heteroporella zankli* (OTT), *Heteroporella* sp. és ?*Diplopora tubispora* OTT. Igen ritkák: *Salpingoporella humilis* (BYSTRICKY) és *Salpingoporella sturi* (BYSTRICKY). A foraminifera-együttes uralkodó alakjai, pl. *Aulotortus sinuosus* WEYNSCHENK, *Angulodiscus* sp. és Variostomatidae div. sp. szintén a lagúna-kifejlődésű dachsteini, illetve felső-rhaeti mészkőre jellemzőek.

Introduction

The Mandling Unit represents a tectonically isolated, elongated wedge of typical sediments of the Northern Calcareous Alps, which border the southern edge of the Tirolicum tectonic unit (fig. 1). The Unit stretches roughly from Wagrein/Radstadt in the West towards the area of Gröbming/Paß Stein in the East.

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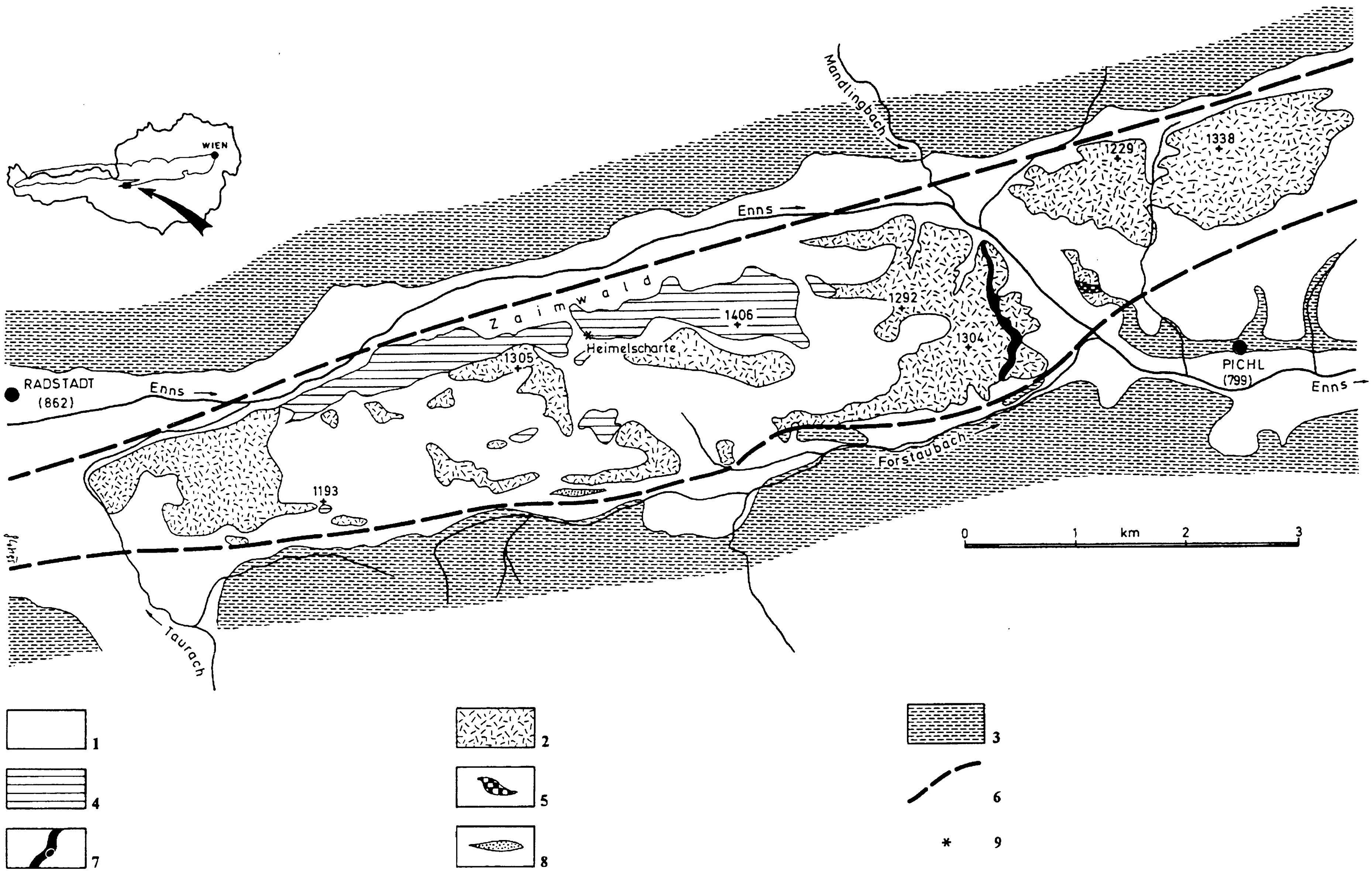

Fig. 1. Geology of the Mandling Unit, according to HIRSCHBERG (1965) and MANDL & MATURA (1995)

1 Pleistocene deposits, 2 Ramsau and Gutenstein dolomite, 3 Grauwacken zone, 4 Dachstein limestone, 5 Reifling Fm., 6 Enns valley fault system, 7 "Cardita oolite", 8 Werfen Fm., 9 Dasycladacean sample

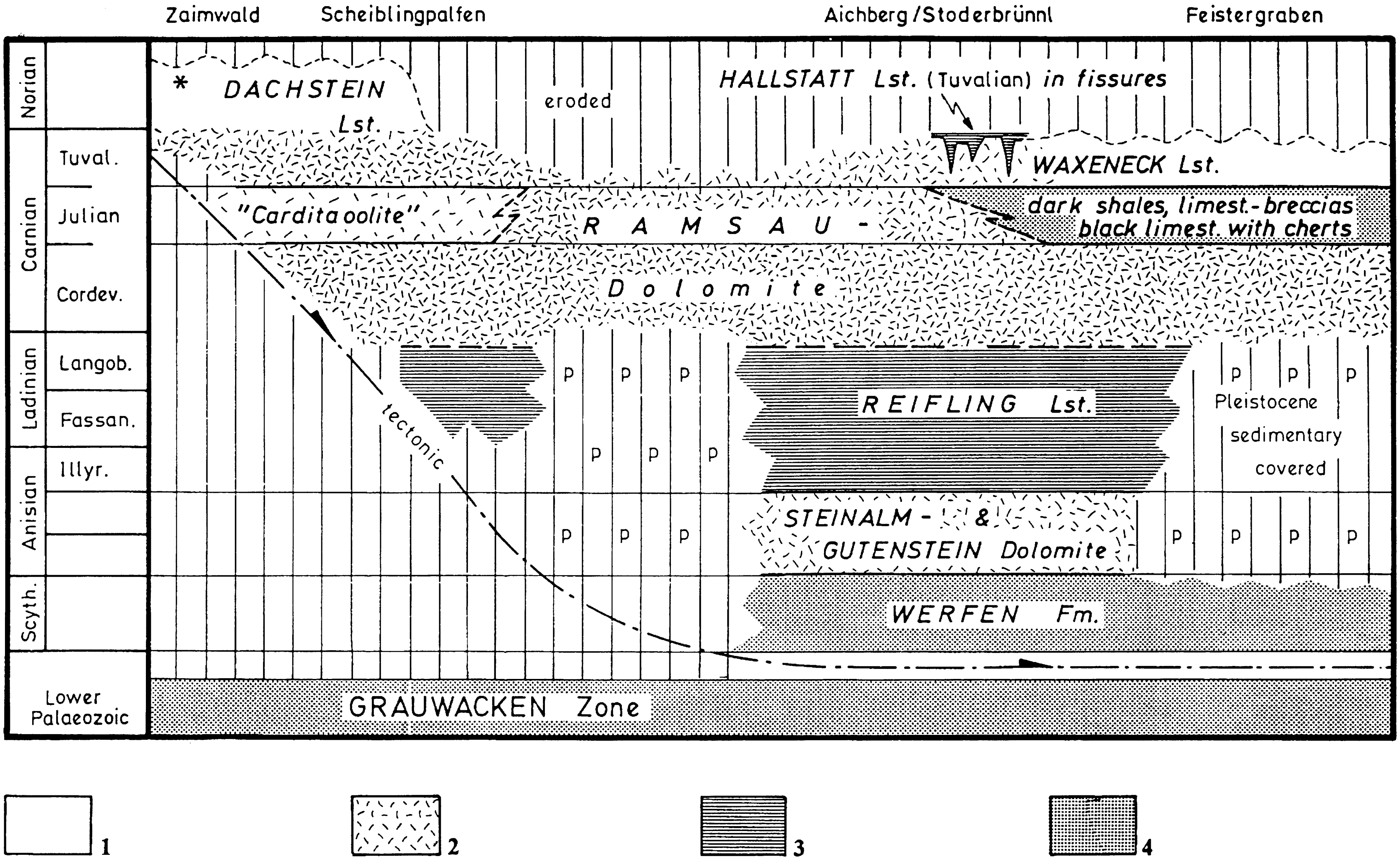

Fig. 2. Triassic sedimentary sequence of the Mandling Unit according to MANDL (in MANDL et al. 1987). Asterix indicates stratigraphic position of dasycladacean flora
1 Shallow water limestones, 2 Dolomitized platform carbonates, 3 Pelagic carbonates, 4 +/- siliciclastic marine sediments

The generally heavily tectonized Triassic sedimentary sequence (fig. 2; MANDL 1987) is dominated by Ladinian/Carnian Ramsau respectively Wetterstein Dolomite. The tectonic position is discussed e.g. by HIRSCHBERG (1965), LEIN (1976) and TOLLMANN (1976b).

Based on lithological comparison and traces of fossils GÜMBEL (1890) was the first who considered the cliff-building limestone of the Northern slope of Zaimwald as Dachstein Limestone. Already TRAUTH (1925) quotes various fossils (*Megalodus* sp., *Thecosmilia* sp., *?Montlivaltia* cf. *norica* FRECH and *Chemnitzia* sp.) which "with highest probability" point to the Norian age of the Zaimkalk of the Mandling Unit. As pointed out by TRAUTH 1925, 181 f. the Dachstein Limestone of Zaimwald in the Mandling Unit shows abundant fissures and voids stained by red pigment. Therefore TRAUTH considered, that this "special development" deserved an individual formation name, namely "Zaimkalk". Practically all later authors (e.g. KIESLINGER 1964, 138, 146 f; HIRSCHBERG 1965, 52 f.) considered this formation name as absolutely irrelevant and as a consequence the term "Zaimkalk" found acceptance not even in local literature. HIRSCHBERG (1965), 53 states that the "Zaimkalk" is typical Dachstein Limestone of reef-facies and observed already the m/dm-bedding on Heimlscharte, however, like all former authors without mentioning findings of dasycladaceans. LEIN (in TOLLMANN 1976a, 212) considers the "Zaimkalk" of the Mandling Unit as Tisovec Limestone, which shows in addition at Stoderbrünnl neptunian dykes filled by Late Tuvalian red Hallstatt Limestone.

The dasycladacean assemblage described below, however, can be clearly assigned to Norian (Rhaetian?) Dachstein Limestone. The dasycladacean-rich samples were collected in 1980 (LOBITZER et al. 1982) at a small cliff of light-grey Dachstein Limestone on the trail close to Heimlscharte in direction to Eibenberg. In the course of forestry road construction this small outcrop was blasted, however, and exposures likely can be found also along the new tourist trail No. 6 immediately east of Heimlscharte in direction to Eibenberg. The limestone shows no reddish staining as typical for the "Zaimkalk" of Zaimwald. Calcite veins are abundant and the preservation of the microfacies is fair.

Microfacies and Dasycladacean Assemblage

The irregularly dm/m-bedded or even massive Dachstein Limestone of Heimlscharte is dominated by grainstones and packstones (biopelsparites) with typical biota of lagoonal facies. Dasycladaceans, solenoporaceans and codiaceans predominate; gastropods, pelecypods, crinoids and foraminifers occur in variable quantities. Peloids, intraclasts and oncoliths are also common constituents; micritization of grains is abundant.

In addition also biointramicritic limestones (pack- and wackestones) with abundant black pebbles and similar biota, however, with more reef-derived faunal elements (e.g. corals, sponge and hydrozoan fragments) can be found locally. This type can be considered as a special development of member A of the Lofer cycle sensu FISCHER (1964).

Among the foraminifers (det. E. KRISTAN-TOLLMANN) Variostomatidae and Involutinidae (e.g. *Aulotortus sinuosus* WEYNSCHENK, *Angulodiscus* ssp.) represent the characteristic elements.

The dasycladacean assemblage is absolutely dominated by *Diplopora phanerospora* PIA, followed in abundance by *Gyroporella vesiculifera* (GÜMBEL) PIA and *Gyroporella* sp.. *Griphoporella* sp., *Heteroporella zankli* (OTT), *Heteroporella* sp., *?Diplopora tubispora* OTT, *Salpingoporella humilis* (BYSTRICKY) and *Salpingoporella sturi* (BYSTRICKY) occur in minor quantities. In addition *Thaumatoporella parvovesiculifera* (RAINERI), *Cayeuxia alpina* FLÜGEL and solenoporaceans/codiaceans indet. can be observed.

In the surroundings of Brandscharte also scarce intercalations of member B —true loferites— were traced. Here also lagoonal Dachstein Limestone, locally with megalodont shells with ± 20 cm diameter, is predominant.

Conclusions

The proof of the presence of lagoonal Upper Norian/Rhaetian Dachstein Limestone in the area between Heimlscharte and Brandscharte (Unterer Zaimwald) is important from different points of view:

- As already argued by former authors (GÜMBEL 1890, TRAUTH 1925, HIRSCHBERG 1965, KIESLINGER 1964, TOLLMANN 1976), it is now clearly proved by fossils, that the sequence of Zaimwald comprises also Norian/Rhaetian Dachstein Limestone.
- It is also important for palinspastic reconstructions that at least a major part of the Dachstein Limestone is of lagoonal facies. This implies that part of the Mandling Unit sequence represents sediments which must have been deposited on a carbonate platform in a much more "northern" position. Based on findings of megalodonts also TRAUTH (1925), p. 181 considers the "Zaimkalk" as a variation of lagoonal Dachstein Limestone of most probably Norian (l.c.p. 183) age. Due to the mainly massive character HIRSCHBERG (1965), p. 53 in contrary considers the Dachstein Limestone of Zaimberge as reef development. The tectonic situation of Mandling Unit will be discussed in a separate paper by (G. W. MANDL).
- Comparable dasycladacean assemblages have been reported as well from the Dachstein Limestone of near reef lagoon of Loserstraße outcrops and from Upper Rhaetian reefs e.g. in Adnet (PIROS in LOBITZER et al. 1994).

Acknowledgements

The authors are indebted to the directors of the Geological Surveys of Austria and Hungary for supporting this study in the frame of bilateral cooperation. Mrs. EDITH KRISTAN-TOLLMANN determined the foraminifera mentioned. She died during the preparation of this paper, which is dedicated to her memory.

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PLATE 1

Fig. 1 *Gyroporella vesiculifera* (GÜMBEL) PIA (left side),
Heteroporella zankli (OTT) (right side up), Z 1. J. x10

Fig. 2 *Griphoporella* sp. (left side in the middle),
Salpingoporella humilis (BYSTRICKY) (left side down), Z 1. J. x 10

Fig. 3 Involutinidae, (left side),
? Diplopora tubispora (OTT) (right side) Z 1. D. x10

Fig. 4 *Salpingoporella humilis* (BYSTRICKY) (right side in the middle),
Heteroporella zankli (OTT) (right side up),
Solenoporaceae, (left side), Z 1. D. x10

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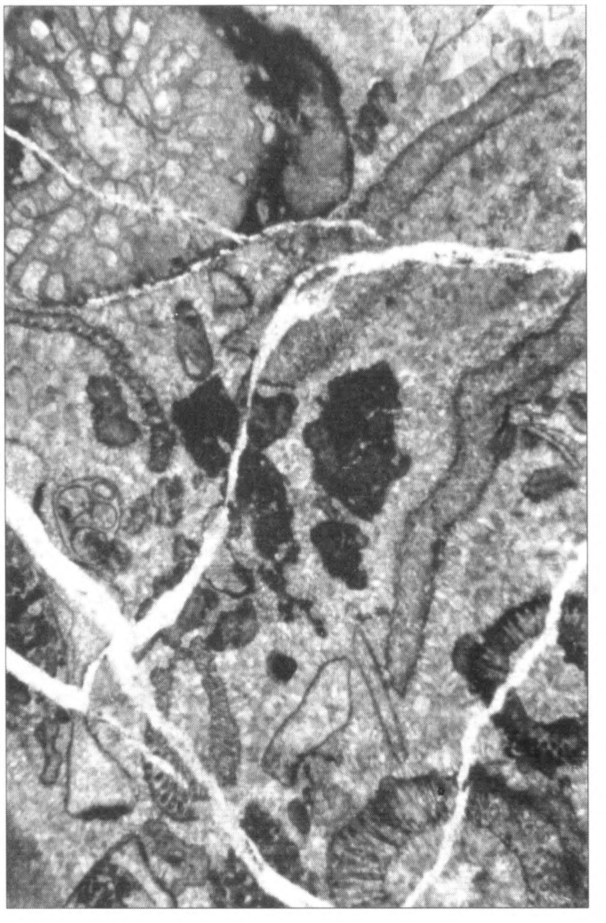

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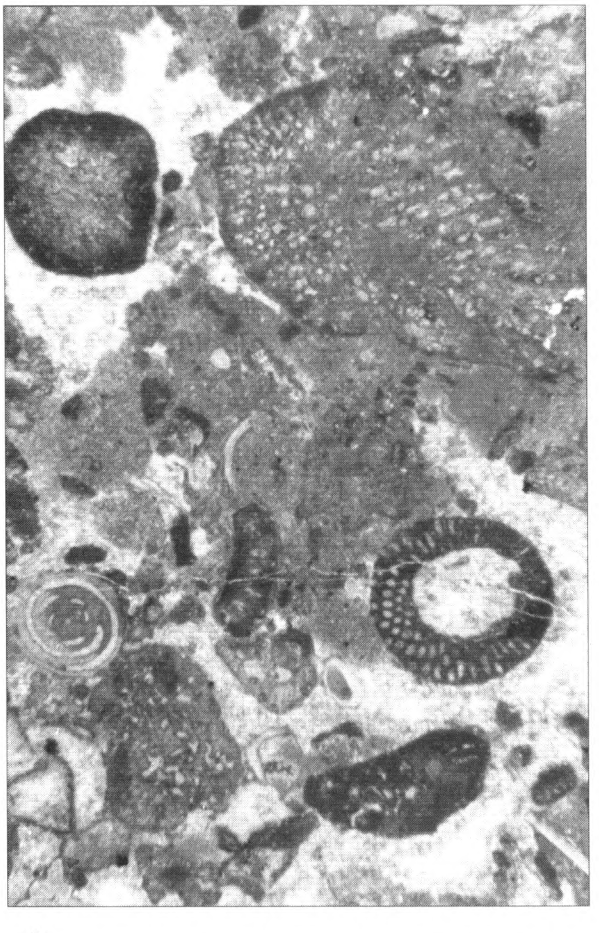

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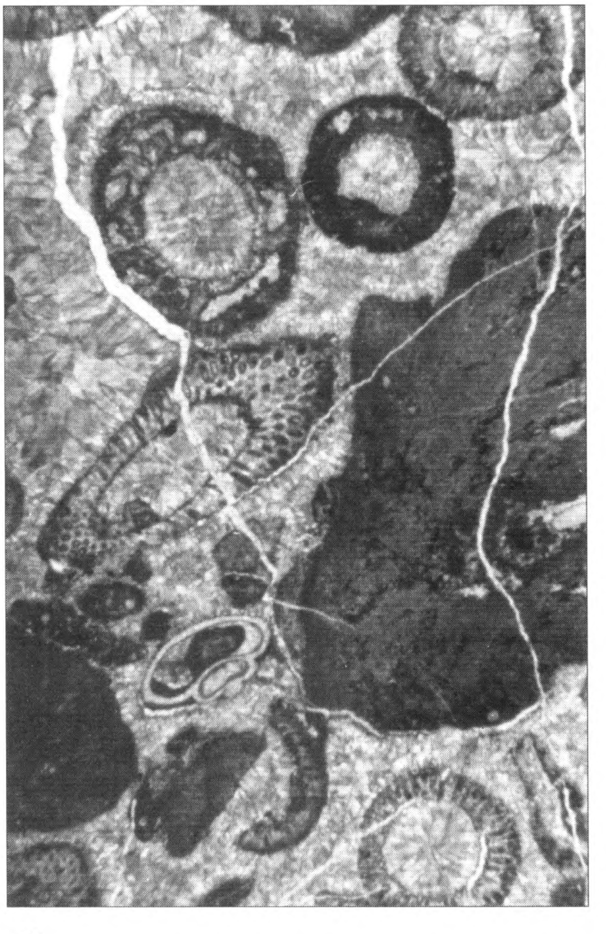

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ADVANCES
in
Austrian—Hungarian Joint Geological Research
Budapest, 1996

Correlation of palyno- (spores, pollen, dinoflagellates) and calcareous nannofossil zones in the Late Cretaceous of the Northern Calcareous Alps (Austria) and the Transdanubian Central Range (Hungary)

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Keywords: Palynostratigraphy, Transdanubian Central Range, Gosau Group of Austria, dinoflagellates, calcareous nannofossils

Abstract

The Upper Cretaceous palynostratigraphic standard zonation of the Transdanubian Central Range of Hungary has been correlated to the calcareous nannofossil zonation of the Gosau Group of Austria. In the Gams section (Northern Calcareous Alps, Austria) two new palynostratigraphic zones of the Late Turonian to Coniacian are defined: the *Subtrudopollis–Complexiopollis* Assemblage Zone, and the *Complexiopollis* Dominance Zone. For the marine formations of the Transdanubian Central Range two Dinoflagellate Assemblage Zones and two Subzones within each of these were established. The base of the transgression of the Jákó Marl Formation in the Hungarian sections is dated as late Late Santonian to early Early Campanian (nannofossil zone CC17b, *Hungaropollis* palynostratigraphic zone, *Odontochitina operculata* dinoflagellate zone). The uppermost part of the Hungarian sections is dated as Late Campanian (nannofossil zone CC22c, *Plicapollis–Subtriporopollenites* Assemblage Zone, *Pyxidinopsis bakonyensis* Assemblage Zone).

Zusammenfassung

Die palynostratigraphische Standard-Zonierung der Oberkreide des Transdanubischen Mittelgebirges Ungarns wurde mit der auf kalkigem Nannoplankton beruhenden Zonierung der Gosau Gruppe Österreichs korreliert. In dem Profil von Gams (Nördliche Kalkalpen Österreichs) konnten 2 neue palynostratigraphische Zonen definiert werden: die *Subtrudopollis–Complexiopollis* Assemblage Zone, und die *Complexiopollis* Dominance Zone. Für die marinen Ablagerungen des Transdanubischen Mittelgebirges wurden zwei Dinoflagellata Assemblage Zonen aufgestellt sowie je zwei Subzonen innerhalb dieser beiden. Die Basis der marinen Transgression der Jákó Mergel Formation der ungarischen Profile kann in das Obersanton bis Untercampan (Nannofossilzone CC17b, *Hungaropollis* palynostratigraphische Zone, *Odontochitina operculata* Dinoflagellata Zone) eingestuft werden. Der höchste Abschnitt der ungarischen Profile ist dem obersten Campan zuzuordnen (Nannofossilzone CC22c, *Plicapollis–Subtriporopollenites* Assemblage Zone, *Pyxidinopsis bakonyensis* Assemblage Zone).

Összefoglalás

A Dunántúli-középhegység felső-kréta standard palynozóna beosztását párhuzamositottuk az ausztriai Gosau Csoport mészvázú nannoplankton zónabeosztásával. A Gams-i szelvényben (Északi-Mészkőalpok, Ausztria) két új, felső turoni–coniaci pollenzónát állitottunk fel: a *Subtrudopollis–Complexiopollis* Együtteszónát és a *Complexiopollis* Dominancia Zónát. A középhegységi tengeri képződményekre két Dinoflagellata Együtteszónát és ezeken belül két-két szubzónát vezettünk be. A középhegységi szelvényekben a transzgresszió kezdetét a Jákói Márga Formációban a késő-szantoni–kora-kampani korra rögzitettük (a CC17b nannozóna, a *Hungaropollis* pollenzóna és az *Odontochitina operculata* dinoflagellata zóna). A magyarországi szelvények legfelső részét a későkampáni korba soroltuk (CC22c nannoplankton zóna, *Plicapollis–Subtriporopollenites* Együtteszóna, *Pyxidinopsis bakonyensis* Együtteszóna).

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Introduction

Within the framework of the Austrian–Hungarian cooperation joint investigations on palynomorphs and nannofossils were undertaken in several Upper Cretaceous sections of the Transdanubian Central Range (TCR) of Hungary and the Northern Calcareous Alps (NCA) of Austria. The aim of these studies was to clarify stratigraphical relationships between these two areas and to correlate the palynostratigraphic zonations established in the last 30 years in the Hungarian sections (GÓCZÁN 1964, 1973, GÓCZÁN & SIEGL-FARKAS 1990, SIEGL-FARKAS 1990) with the marine microplankton zonations of the Gosau Group (WAGREICH 1992, WAGREICH & KRENMAYR 1993). This paper gives an overview about the preliminary results worked out during the years 1991–1995. Detailed results on individual sections are reported by SIEGL-FARKAS 1993, 1995 [in press.], SIEGL-FARKAS & WAGREICH 1994, and LANTOS et al. (this volume).

So far there have been only a few papers addressing the issue of comparing palynostratigraphic and nannoplankton scales of the Late Cretaceous sample by sample within individual sections (e.g. ROBASZYNSKY et al. 1982, 1983, 1985, BLESS & STREEL 1988). Taking into account the good chronostratigraphic control of sections of the Lower Gosau Subgroup of the NCA (e.g. SUMMESBERGER 1985, IMMEL 1987, WAGREICH 1992, TRÖGER & SUMMESBERGER 1994), this correlation work bears also a significant impact on regional and global biostratigraphic and chronostratigraphic correlations in the Late Cretaceous.

Investigated sections

The Upper Cretaceous sedimentary succession of the TCR consists of a lower, terrestrial part, including bauxites and the Ajka Coal Formation, and a marine upper part, comprising mainly marls and marly limestones (e.g. HAAS 1983, HAAS et al. 1992). Several cores from boreholes in the area of the TCR (fig. 1) were investigated for their palynological and nannofossil contents in this joint study: Gat-1 near Ganna, Mp-42 near Magyarpolány and Ng-1 near Nagygörbő in the Keszthely Mountain (SIEGL-FARKAS & WAGREICH 1994 and in press). Additional data for comparison to other biostratigraphic zonations and magnetostratigraphic results are incorporated from the integrated study of borehole Bj-528 (LANTOS et al. this volume).

A recent review of the sedimentology and palaeogeographic evolution of the Gosau Group of the NCA was given by WAGREICH & FAUPL (1994). Localities sampled in the Gosau Group (Fig. 1) include a composite section from the Lower Gosau Subgroup of Gams (KOLLMANN 1964) and a few other samples from Strobl/Weissenbachtal and Weißwasser/Unterlaussa. Palynostratigraphic data on the lower part of the Gosau Group of Weißwasser/Unterlaussa, the Gosau type locality and the Kainach Basin in the Central Alps were already published by SIEGL-FARKAS (1994a,b).

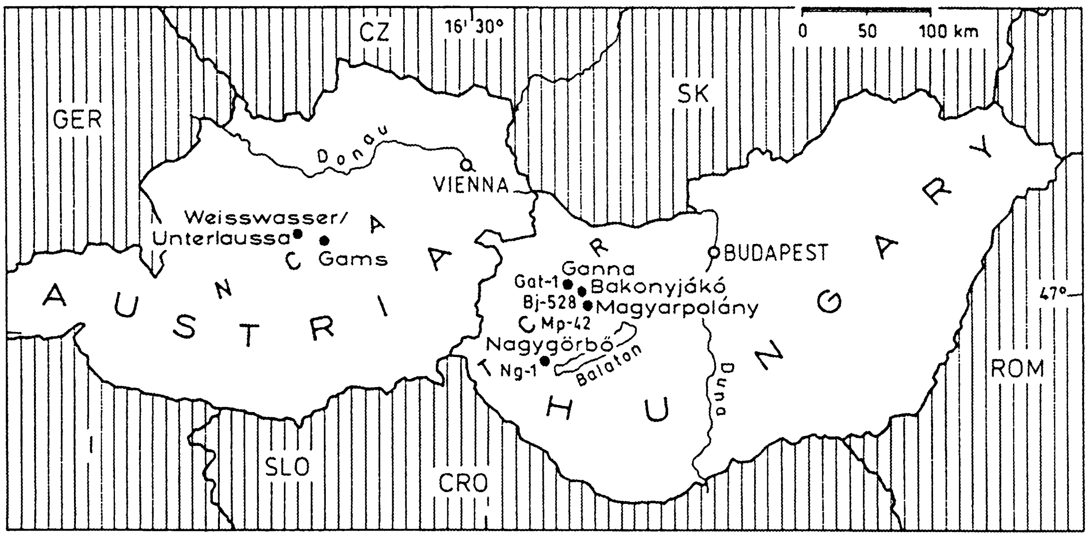

Fig. 1. Investigated localities and drillings of the Upper Cretaceous of the Transdanubian Central Range (TCR) of Hungary and the Northern Calcareous Alps (NCA) of Austria

Biostratigraphic results

The Gams section of the Northern Calcareous Alps

A composite section through the Lower Gosau Subgroup of the western Gams area (KOLLMANN 1964, WAGREICH 1994, SUMMESBERGER & KENNEDY in prep.) was sampled for nannofossil and palynostratigraphic investigations. The section includes outcrops along the Akogl forest road (basal Noth formation after WAGREICH in prep.), the western end of the Noth gorge (comp. KOLLMANN 1964), the northern Radstatt road (Grabenbach

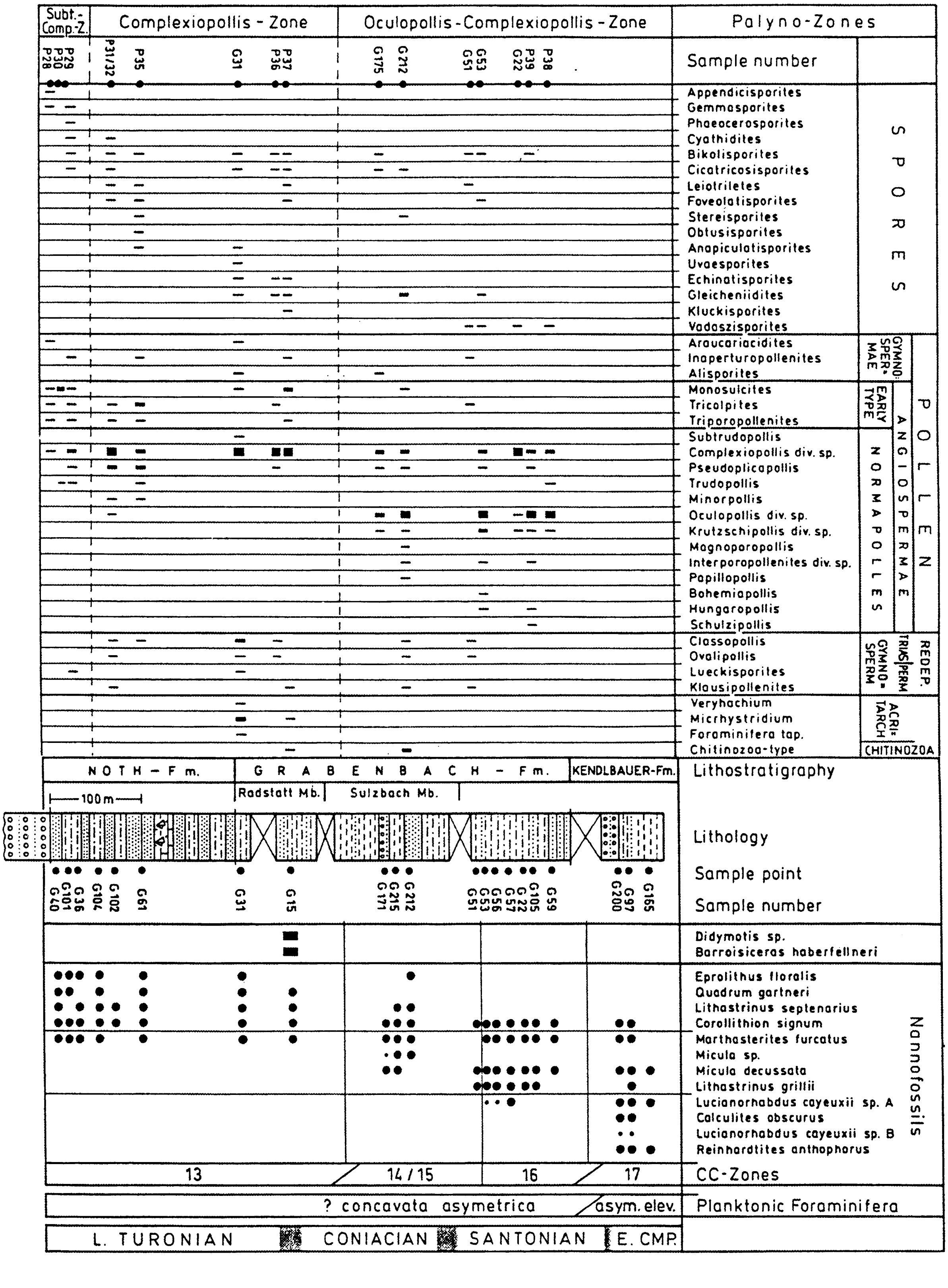

Fig. 2. Lithostratigraphy, palynostratigraphy, nannofossil zonation and chronostratigraphic correlation of the western Gams section, Lower Gosau Group of the Northern Calcareous Alps, Austria
- very rare, - rare, - common

Formation after WAGREICH in prep., KOLLMANN & SUMMESBERGER 1982, TRÖGER & SUMMESBERGER 1994), the Sulzbach valley area, outcrops in the Radstatt valley and its eastern tributary (upper part of Grabenbach Formation), and around the farming house Kendlbauer (Kendlbauer Formation, WAGREICH 1994 and in prep.).

Calcareous Nannoplankton

4 nannofossil standard zones based on the standard zonations given by SISSINGH (1977) and PERCH-NIELSEN (1985) could be distinguished in the Lower Gosau Subgroup of the western Gams area from the base to the top:

Marthasterites furcatus Zone (CC13)
Micula decussata Zone (CC14/15)
Lucianorhabdus cayeuxii Zone (CC16)
Calculites obscurus Zone (CC17).

The occurrence of *Marthasterites furcatus* without *Micula decussata* in the basal Noth Formation gives evidence for nannofossil zone CC13 at the base of the section. The first occurrence of *M. furcatus* defines a level below the uppermost standard ammonite zone of the Late Turonian (*neptuni* Zone; e.g. CECH 1989, ROBASZYNSKY et al. 1990, WAGREICH 1992). Therefore a middle to late Late Turonian age is suggested for the base of the marine transgression in the Gams area.

The *Didymotis*-bearing horizon at the Radstatt section, which defines a level very close to the Turonian-Coniacian boundary (SUMMESBERGER pers. comm., and SUMMESBERGER & KENNEDY in prep.), is within zone CC13. Up to this level (sample Gam15/P37) *M. furcatus* is still accompanied by common *Quadrum gartneri*. The next nannofossil event was found in the middle part of the Grabenbach Formation (Sulzbach valley), where *Micula* cf. *decussata* occurs for the first time together with *Micula* sp. Comparison with the Nussenbach section (WAGREICH 1992) indicates a Middle Coniacian age (*tridorsatum* Zone, SUMMESBERGER 1985, TRÖGER & SUMMESBERGER 1994). *Lucianorhabdus cayeuxii*, defining the base of the *L. cayeuxii* Zone (CC16) of the middle Santonian, has its first occurrence in sample G53 from the upper part of the Grabenbach Formation. Samples from the Kendlbauer Formation yielded a nannofossil assemblage of the *Calculites obscurus* Zone (CC17). The presence of rare curved *Lucianorhabdus* gives evidence for the upper part of zone CC17 (subzone CC17b of WAGREICH 1988, 1992), which ranges from the upper Santonian to the lowermost Campanian (WAGREICH 1988, 1992).

Palynology

The samples were generally rich in moderately and well-preserved sporomorph assemblages. Only 4 of the 20 samples taken along the section proved to be sterile, especially the samples from the Kendlbauer formation. The evolution of the Upper Cretaceous flora is remarkable within the angiosperm pollens (Early Angiospermae and Normapolles). Three distinctive assemblages have been determined so far and form the base of a preliminary tripartite palynological zonation for the Gams section:

I. *SUBTRUDOPOLLIS–COMPLEXIOPOLLIS* Assemblage Zone (nom. nov.) P-28, P-29, P-30, samples, Noth Formation (lower part of nannofossil zone CC13); Late Turonian.

Though predominant, the genera *Complexiopollis* and *Subtrudopollis* occur only in limited numbers with consistent presence of early angiosperms (*Clavatipollenites, Tricolpites, Crassipollis, Retimonocolpites*). The frequency of *Pseudoplicapollis* tends to grow upwards in the section. The consistent occurrence of gymnosperms (*Araucariacites, Inaperturopollenites, Alisporites*) withdrawing progressively while Normapolles gain ground during the Senonian, is another characteristic feature. Pteridophytes constituting undergrowth (e.g. *Appendicisporites, Bikolisporites, Cicatricosisporites* etc.) represent a moderate contribution to this assemblage.

This assemblage is very similar to the one described already from the "Liegendserie" of the Weißwasser/Unterlaussa area (SIEGL-FARKAS 1993, 1994), suggesting the same Late Turonian age for both assemblages based on nannofossil correlations.

II. *COMPLEXIOPOLLIS* Dominance Zone (nom. nov.) G-31, P-31, P-32, ?P-35 P-36, P-37 samples, Grabenbach Formation of the Gams area, (upper part of nannofossil zone CC13); Latest Turonian.

In these samples from the lower part of the Grabenbach Formation in the Radstatt area the genus *Complexiopollis* prevails. Samples from the *Didymotis* event, which marks the Turonian/Coniacian boundary (P-36, P-37), include predominantly *Complexiopollis* but also rare *Pseudoplicapollis* and early angiosperms. In the upper part of this dominance zone some individuals of the genus *Oculopollis* can be identified. According to PACLTOVA (1981) and KRUTZSCH (1957) they appear in the Lower Coniacian.

Apart from angiosperms some gymnosperm pollens and pteridophyte spores inferring rich undergrowth occur as well. Within these samples reworked pollens (*Classopollis, Ovalipollis, Klausipollenites, Lueckisporites*) give evidence for a period of most intense removal of the surrounding Permian and Triassic formations.

Marine phytoplankton (*Veryhachium, Micrhystridium*) and organic foraminifer tests have been determined only in the samples related to the *Didymotis* event.

III. *OCULOPOLLIS–COMPLEXIOPOLLIS* Dominance Zone (GÓCZÁN 1964, 1973, GÓCZÁN & SIEGL-FARKAS 1990) G-175, G-212, G-51, G-53, P-38, P-39 samples. Grabenbach Formation of the Gams area (CC14\15 and CC16 nannozones); Coniacian to Early Santonian.

The genus *Oculopollis* plays a predominant role, whereas the *Complexiopollis* tends progressively to decrease upwards. The genus *Krutzschipollis* appears in the Coniacian i.e. in the CC14\15 nannozone and from that point on it occurs consistently.

The Santonian (samples from the upper part of the Grabenbach Formation, nannofossil zone CC16) is characterized by the subsequent occurrence of the genera *Longanulipollis, Interporopollenites, Bohemiapollis*, cf. *Hungaropollis* (*Pseudohungaropollis*), *Schulzipollis* and *Pecakipollis*. Only sample G22 from the upper part of the Grabenbach Formation (locality Mooslandl) shows a dominance of *Complexiopollis*. The significance of this sample is still under debate.

The assemblage of this zone is marked, additionally, by the scarcity of pteridophytes, gymnosperms and early angiosperms. Occurrences of ancient-type pine pollens indicate the redeposition of older sediments.

Assemblages identified in the upper part of the zone show a close correspondence to the assemblages of remnants occurring in the Central Range assigned to the middle to upper Santonian (e.g. SIEGL-FARKAS 1993).

The Transdanubian Central Range

Palynology

Formations of the Transdanubian Central Range have been stratigraphically divided into 9 palynozones including 4 dominance and 5 assemblage zones (GÓCZÁN 1964, 1973, GÓCZÁN & SIEGL-FARKAS 1990, SIEGL-FARKAS 1993 c, 1995) and furthermore into eight subzones (SIEGL-FARKAS 1983, 1986). The correlation of palynozones and lithostratigraphy is given in fig. 3. The sediments were assigned by GÓCZÁN (1961) to the Late Santonian–Early Maastrichtian and, later, (GÓCZÁN 1964) to the Late Santonian–Late Maastrichtian. This standard zonation designed by GÓCZÁN in 1964 had the advantage of facilitating the stratigraphic classification of both freshwater and marine sediments.

GÓCZÁN (1964) defined the boundary between the Santonian and Campanian as stretching between the *Oculopollis–Trilobosporites* Dominance Zone and the *O. zaklinskaiae–B. globosus* zones corresponding to the lower section of the Ajka Coal- and Csehbánya Formation. The boundary between the Campanian and Maastrichtian was delineated between *the L. bajtayi–L. lenneri–Pseudopapillopollis–Semioculopollis* Assemblage Zones, in the lower part of the Polány Marl Formation.

During the 20 years following the establishment of this zonation there were not enough reliable data available that would have allowed to upgrade this chronostratigraphic correlation in more detail, although work on foraminiferas (SIDÓ in GÓCZÁN 1973) and macrofossils (e.g. CZABALAY in GÓCZÁN 1973, CZABALAY 1983) indicated modifications to that scheme. One missed opportunity for a refinement was also the identification of the ammonite *Placenticeras polyopsis* (DUJARDIN) by SUMMESBERGER (in

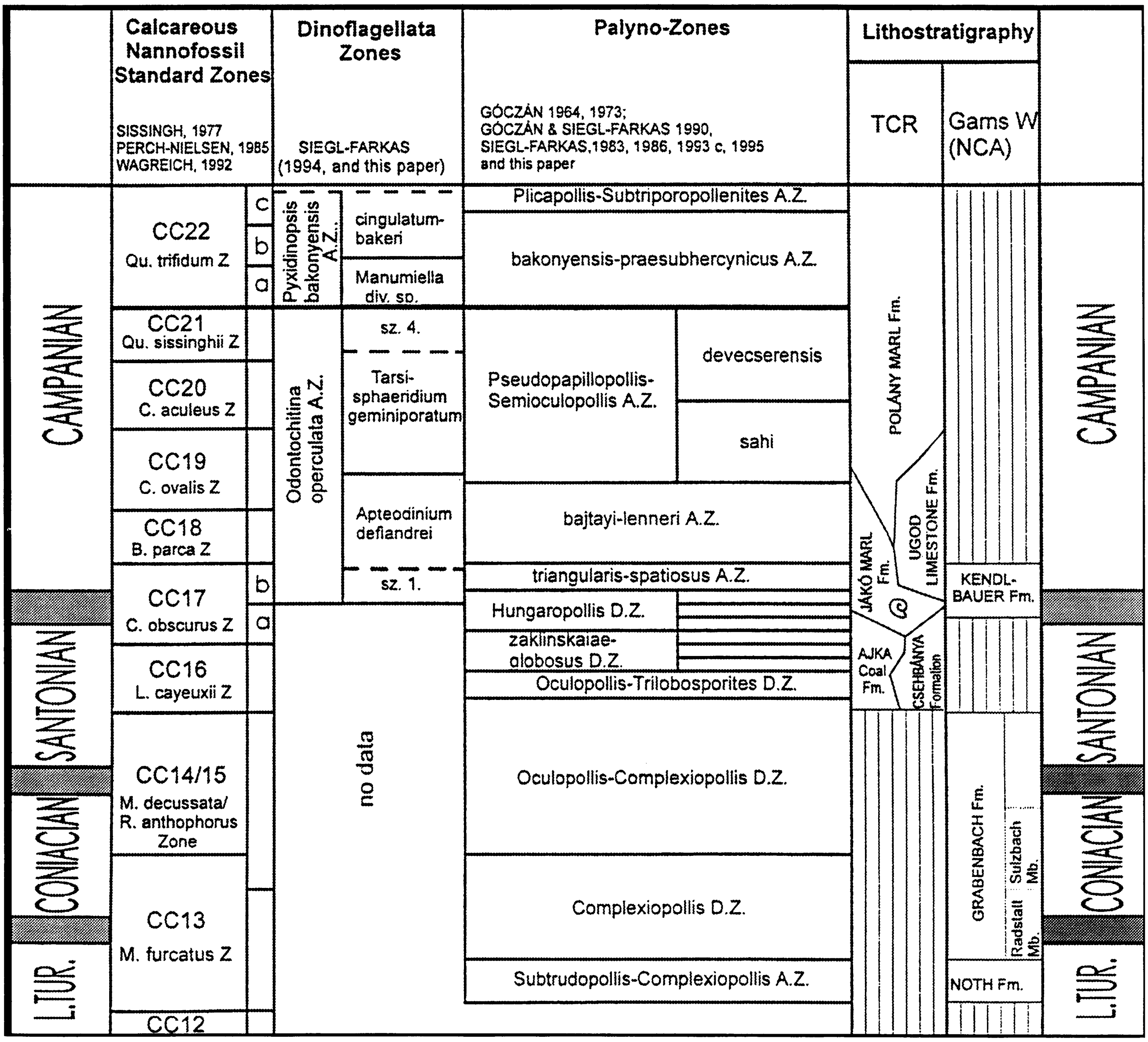

Fig. 3. Chronostratigraphic correlation of palynostratigraphic, dinoflagellate and nannofossil zones based on sections from the Gosau Group of Austria and the Senonian of the Transdanubian Central Range of Hungary. Ammonite sign in TCR column marks the Santonian marker species *Placenticeras polyopsis*

PARTÉNYI 1986) in the Jákó Marl Formation (533.3 m) of the drilling Csabrendek-2 in the TCR. This ammonite provides clear evidence of a Santonian, probably Late Santonian age. Also the results of nannoplankton studies completed in the 1980s (GÁL 1980, FÉLEGYHÁZY 1983, 1985) have not been integrated into the palynostratigraphic zonation so far.

During the Austrian–Hungarian cooperation the palynostratigraphic correlations were modified only quite recently according to new data on calcareous nannofossils and dinoflagellata (SIEGL-FARKAS 1993, SIEGL-FARKAS & WAGREICH 1994), and by applying, for the first time, integrated stratigraphic (magneto- and biostratigraphic) methods of investigation (LANTOS et al. this volume). The resulting preliminary correlation of Hungarian palynostratigraphic zones to nannofossil zones and Late Cretaceous stages is given in fig. 3.

Dinoflagellata

The first studies on Senonian dinoflagellates of the TCR were made by GÓZCÁN (1962). He assigned them to the Upper Campanian–Upper Maastrichtian. A dinoflagellate (*Palaeostomocystis bakonyensis*) is one of the eponyms of the zone representing the Upper Maastrichtian in the palynological standard established by GÓZCÁN (1964) that is based upon dominance changes of Normapolles genera.

During the last years studies on dinoflagellata were conducted in the TCR, especially in the S and N parts of the Bakony Range (boreholes Bj-528, Cr-1, Dv-4, Gat-1, Gy-9, Mp-42, Zgy-1) and in the Keszthely Range (borehole Ng-1). In general, dinoflagellates appear in the lower part of the Jákó Marl Formation. Except for the segments rich in carbonates they occur consistently throughout the sequence. A preliminary zonation was established by SIEGL-FARKAS (1994,1995 in press and LANTOS et al. in this volume) which permitted to define two dinoflagellate zones with two subzones within each of them:

Odontochitina operculata Assemblage Zone
- *Apteodinium deflandrei* Subzone
- *Tarsisphaeridium geminiporatum* Subzone

Pyxidinopsis bakonyensis Assemblage Zone
- *Manumiella* div. sp. Subzone
- *Pterodinium cingulatum–Isabelidinium bakeri* Subzone

The zonation system established shows significant correlation with the global zonation designed by WILLIAMS & BUJAK (1985) with minor modifications due specific local environmental conditions. The dinoflagellata assemblage is very similar to the assemblage reported by KIRSCH (1991) from the Helveticum in Upper Bavaria and to the assemblage from the Campanian–Maastrichtian boundary section in the Tercis quarry in France (ANTONESCU & ODIN 1995).

Calcareous nannoplankton

The first nannoplankton studies in Senonian formations of the TCR were conducted by GÁL (1980) and FÉLEGYHÁZI (1983, 1985). Within the framework of the Austrian–Hungarian cooperation analyses of the drillings Bj-528 (WAGREICH, in LANTOS et al. this volume) in the

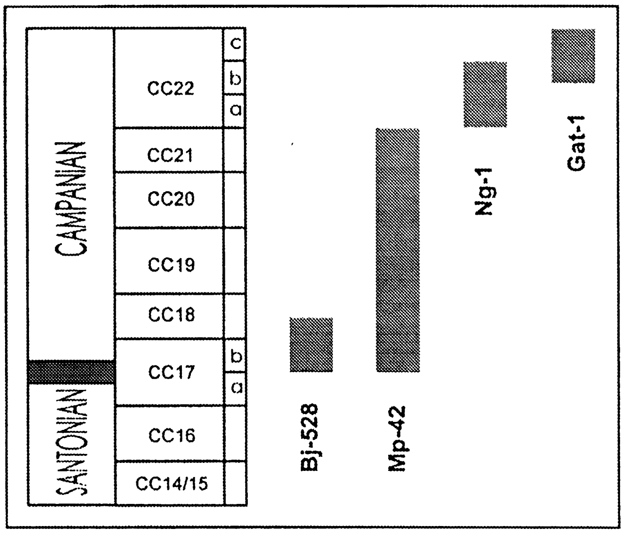

Fig. 4. Chronostratigraphic correlations based on calcareous nannofossils of the marine part of the investigated boreholes in the Transdanubian Central Range of Hungary

Bakony Range and Ng-1 in the Keszthely Range (SIEGL-FARKAS 1993, SIEGL-FARKAS & WAGREICH 1994 a, b) of the TCR have so far been completed. New results on the drillings Gat-1 and Mp-42 (partly based on FÉLEGYHÁZI 1985) are given below. These analyses allowed us to assign the Senonian marine formations of the TCR to the standard nannofossil zones CC17b, CC18a, CC19, CC20 CC21, up to CC22abc, which can be correlated to the Late Santonian/Early Campanian to late Late Campanian.

Borehole Mp-42 near Magyarpolány

The cores of borehole Mp-42 give a continuous, more than 500 m thick section through the marine part of the Late Cretaceous of the TCR. The nonmarine Ajka Coal Formation and the Csehbánya Formation are overlain by the first marine marls and marly limestones of the Jákó Marl Formation and the younger Polány Marl Formation. The nannofossil record starts in the core at 517.3 m. The presence of *Marthasterites furcatus, Lithastrinus grillii, Micula decussata, Reinhardtites anthophorus, Lucianorhabdus cayeuxii* (both straight and curved specimen as described by WAGREICH 1988, 1992) and *Calculites obscurus* gives evidence for the upper part of the nannofossil standard zone CC17 (*Calculites obscurus*-Zone) of SISSINGH (1977) and PERCH-NIELSEN (1985), which can be correlated with the latest Santonian to basal Campanian (WAGREICH 1992). The same age is reported by LANTOS et al. (this volume) from the base of the Jákó Marl Formation in the borehole Bj-528.

Broinsonia parca, defining the base of CC18a starts at 430 m, *Ceratolithoides aculeus*, defining the base of CC20, appears at 250.2 m (FÉLEGYHÁZI 1983) and *Quadrum sissinghii*, the marker species for zone CC21, starts at 123.8 m.

The top of the Mp-42 section lies in the upper part of the nannofossil standard zone *CC21 (Quadrum sissinghii* Zone). Younger ages of the top of the Polány Marl Formation are reported by SIEGL-FARKAS & WAGREICH (1994 and in press) in borehole Ng-1 where the nannofossil standard zone CC22 (*Quadrum trifidum* Zone) could be found suggesting a Late Campanian age.

Borehole Gat-1 near Ganna

The youngest samples of the Polány Marl Formation were investigated in the Gat-1 section. The presence of the nannofossil subzone CC22c of the *Quadrum trifidum* Zone (defined by the presence of *Quadrum trifidum* and *Broinsonia (Aspidolithus) parca* without *Eiffellithus eximius and Reinhardtites anthophorus*) indicates a late Late Campanian age based on correlations to Tethyan forminiferal zonations (e.g. SCHÖNFELD & BURNETT 1991, WAGREICH & KRENMAYR 1993) and the definitions on the Campanian and Maastrichtian stages drawn at the Brussels symposium on Cretaceous Stage Boundaries in 1995. Additional foraminiferal data from the Gat-1 samples, including the presence of both *Globotruncanita ventricosa* and *Globotruncanita elevata* without *Globotruncanita calcarata*, also suggest a Late Campanian age.

Correlation of palyno-, dinoflagellate- and nannozones: Age of the Senonian formations in the Transdanubian Central Range

In order to dispel the 30-year-long uncertainty shrouding the chronology of Senonian formations in the TCR this paper refines chronostratigraphic correlations with the global nannoplankton zonation. Based on our investigations, it is possible to give a preliminary correlation of Hungarian palynostratigraphic zones (GÓCZÁN 1964, GÓCZÁN & SIEGL-FARKAS 1993) with standard Tethyan nannofossil zones (SISSINGH 1977, PERCH-NIELSEN 1985, WAGREICH 1992, WAGREICH & KRENMAYR 1993). Correlations of the non-marine part of the Hungarian sections where nannofossils are absent, are possible by palynological data from well-dated marine sections of the Gosau Group of the NCA, whereas the upper, marine part of the Hungarian sections can be directly dated by calcareous nannofossils.

Upon indirect correlation with the Grabenbach Formation of the Lower Gosau Subgroup of the Gams section it can be stated that sedimentation in the TCR Senonian basin started in a freshwater environment most probably during the **Middle to Upper Santonian.** This is based on the correlation of the ***Oculopollis–Complexiopollis*** palynozone (SIEGL-FARKAS 1993) in the **CC16** nannofossil zone in the Gams section to similar assemblages characterized by *Complexiopollis complicatus* GÓCZÁN, *Complexiopollis labilis* GÓCZÁN, *Interporopollenites* sp., *Krutzschipollis crassus* GÓCZÁN, *Oculopollis orbicularis* GÓCZÁN, *Oculopollis* cf. *zaklinskaiae* GÓCZÁN, *Pseudoplicapollis peneserta* PFLUG and *Schulzipollis pannonicus* GÓCZÁN in the TCR (SIEGL-FARKAS 1993).

Integrated stratigraphic analysis of the drilling Bj-528 and the data from the Mp-42 section provides evidence that the **Santonian–Campanian boundary** can be traced in the lower section of the **Jákó Marl Formation**, within the upper part of the ***Hungaropollis*** **Dominance Zone**, on the base of the ***Odontochitina operculata*** **Zone** of the dinoflagellate-zonation, corresponding to the **CC17** nannozone (LANTOS et al. this volume). This concept is confirmed by the occurrence of *Placenticeras polyopsis* (Dujardin) determined by SUMMESBERGER (in PARTÉNYI 1986) in this area (drilling Csabrendek-2, 533.3 m depth).

The boundary between the ***Odontochitina–Pyxidinopsis*** dinoflagellate zones assigned to the upper section of the **Polány Marl Formation** coincides with the boundary between the *Palaeostomocystis bakonyensis–Pseudopapillopollis praesubhercynicus* (GÓCZÁN 1973) and the **CC21–CC22** nannozones. It provides a firm basis for making the correlation with other palaeontological methods.

The youngest Senonian formation of the TCR penetrated in the mapping borehole Gat 1 (near Ganna) can be assigned to the **CC22c** nannozone representing a level in the **Late Campanian** (SCHÖNFELD & BURNETT 1991). A Maastrichtian age (defined by the first occurrence of the ammonite *Pachydiscus neubergicus* by the Working Group on the Maastrichtian at the Brussels symposium 1995 and the correlation to nannofossil zonations, e.g. WAGREICH 1987) can be excluded based on the nannofossil record. The specific sporomorph assemblage different from the others revealed in this formation brought up the necessity to introduce a new palynozone, namely the ***Plicapollis–Subtriporopollenites*** **Assemblage Zone** (SIEGL-FARKAS 1995).

During this study the deeper part of the Gams section, including the nannofossil zones **CC13, CC14/15** of **Late Turonian to Early Santonian** age could be classified into 2 palynostratigraphic zones based on the changes in the dominance conditions and the history of evolution of angiosperms: the ***Subtrudopollis–Complexiopollis*** **Assemblage Zone**, and the ***Complexiopollis*** **Dominance Zone**. Comparable assemblages have not yet been reported in the area of the TCR. Therefore we conclude that most probably the sediments of the Late Turonian to early Santonian are missing in the TCR.

The presented new results in stratigraphy provide the conclusion that the **Senonian formations of the Central Range were deposited during the Middle to Late Santonian (CC16) to Late Campanian (CC22c).** Marine transgression attained the area of the NCA, e.g. the Gams Basin already during the Late Turonian (CC13, *Subtrudopollis–Complexiopollis* Zone) and extended to the Central Range in the Late Santonian/Early Campanian during the CC17b, the *Hungaropollis* and the *Odontochitina operculata* Zones, at the base of the Jákó Marl Formation.

Conclusions

- Upper Turonian to Lower Santonian sediments in the Gams section of the Lower Gosau Subgroup of the NCA, which correspond to the CC13 and CC14/15 nannofossil zones, can be assigned to 2 newly defined palynostratigraphic zones: the *Subtrudopollis–Complexiopollis* Assemblage Zone, and the *Complexiopollis* Dominance Zone.
- Freshwater sedimentation in the TCR started in the

Oculopollis–Complexiopollis palynozone, which corresponds to the middle to late Santonian, based on the correlation to the CC16 nannofossil zone in the Gams section of the NCA. Older assemblages as they were found in the Gams section are not present in the TCR.

— The base of the marine sedimentation of the Jákó Marl Formation in the Transdanubian Central Range lies within the upper part of the *Hungaropollis* Dominance Zone, on the base of the *Odontochitina operculata* Zone of the dinoflagellata-zonation. This is based upon the finding of the CC17 nannofossil zone at the marine base of the Transdanubian Central Range sections.

— The youngest sediments of the Senonian Polány Marl Formation in the Transdanubian Central Range were deposited during the CC22c nannozone and the *Plicapollis-Subtriporopollenites* Assemblage Zone representing a level in the Late Campanian.

Acknowledgements

This paper is a contribution to IGCP Project No. 362 "Tethyan-Boreal Cretaceous Correlation". We would like to thank H. SUMMESBERGER for his helpful comments on an earlier version of the manuscript.

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ADVANCES
in
Austrian—Hungarian Joint Geological Research
Budapest, 1996

Bivalve assemblages from the Austrian and Hungarian Hierlatzkalk (Lower Jurassic): a comparison

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Keywords: Bivalves, palaeoecology, Liassic, Hierlatz Limestone, Northern Calcareous Alps, Bakony, Austria, Hungary

Abstract

The taxonomic composition and the palaeoecology of bivalve assemblages from the Hierlatz Limestone of the type area (Northern Calcareous Alps) and of the Bakony Mts are briefly discussed and compared.

Epibyssal suspension feeders represent the dominant ecological group in the bivalve fauna of both areas. Shallow burrowing as well as cemented forms are significantly more common in the fauna of the type area than in that of the Bakony Mts. The disparity in guild composition is thought to reflect different substrate conditions characteristic of the source areas where the organisms supplying the skeletal elements of the Hierlatzkalk lived. The most characteristic bivalves are depicted, among them some of the syntypes of STOLICZKA (1861).

Zusammenfassung

Die taxonomische Zusammensetzung und die Paläoökologie der Muschelassoziationen des Hierlatzkalkes in der Typgegend (in den Nördlichen Kalkalpen) und im Bakonygebirge (Ungarn) werden kurz besprochen und verglichen. In beiden Gegenden sind die Suspensionfresser die dominante ökologische Gruppe. Seicht flachgrabende und zementierte Formen sind wesentlich zahlreicher in der Typgegend als im Bakonygebirge. Die Unterschiede in der Gildenzusammensetzung könnten auf unterschiedliche Substrate hinweisen, wovon die Elemente der Taphocönose des Hierlatzkalkes stammen. Die charakteristischen Muschelarten sind abgebildet, unter ihnen einige Syntypen von STOLICZKA (1861).

Összefoglalás

Az Északi-Mészkőalpok és a Bakony hegység hierlatzi mészkövéből származó kagyló-együttesek rendszertani és paleoökológiai összetétele kerül rövid ismertetésre és összehasonlításra. A byssussal rögzülő, szuszpenzióval táplálkozó epibenthosz formák az uralkodóak mindkét együttesben. A kis mélységbe beásódó és a cementáló életmódot folytató kagylók jóval gyakoribbak a típus-terület faunájában, mint a bakonyiban. A paleoökológiai összetételben tapasztalható különbség a Hierlatzi mészkő ősmaradvány-együttesét alkotó elemek származási területeit jellemző aljzati tényezők különbözőségével magyarazható. A két együttes leggyakoribb kagylói, köztük a STOLICZKA (1861) által leírt fajok némelyikének szüntípusai, ábrázolásra is kerültek.

Introduction

Benthic assemblages of the peri-Mediterranean Lower Jurassic differ significantly, —both in taxonomic and guild-composition—, from coeval ones which populated the NW European shelf. Articulate brachiopods are usually the dominant group in the former faunas, especially in most of the deeper-water (deep sublittoral to bathyal) facies (see e.g. AGER 1965, 1967).

The use of brachiopod-dominated assemblages in palaeoenvironmental analysis has, due to the near-exclusive presence of suspension-feeder pedunculate

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organisms, considerable limitations (see VÖRÖS 1986). In contrast, the NW European assemblages consist mainly of bivalves (see e. g. HEINZE 1991) which makes them very useful in interpreting depositional environments (see e.g. FÜRSICH 1976).

There are, however, some facies in the deeper-water peri-Mediterranean Jurassic which yielded quite diverse bivalve assemblages. The Hierlatzkalk is one of the richest among them. The aim of the present paper is to give an overall, although preliminary picture on the taxonomy and palaeoecology of the bivalve assemblage of this peculiar Jurassic facies.

The Hierlatzkalk: lithology, stratigraphic relations and depositional environments

The Hierlatzkalk or Hierlatz Limestone is a classical and richly fossiliferous facies of the Mediterranean Lower Jurassic. In a recent paper VÖRÖS (1991) gave a detailed review on the history of the Hierlatzkalk concept and summarized the characteristic features of this rock type. As he defined it (VÖRÖS 1991) the Hierlatzkalk is a skeletal limestone apparently confined to the Lower Jurassic of the Northern Calcareous Alps and the Transdanubian Central Range, characterized by a particular fossil assemblage and distinctive lithological features. The abundant bioclasts are predominantly shells of brachiopods and ammonites, less frequently those of gastropods and bivalves. They are infilled and cemented by at least two generations of sparry calcite, or subordinately by micrite.

This definition largely corresponds to the original one given by workers of the last century (see e.g. LIPOLD 1852, WÄHNER 1886). Nowadays the name "Hierlatzkalk" is mainly used to denote sparry, crinoid bearing limestones (see e.g. BÖHM 1992). In the Northern Calcareous Alps the Hierlatzkalk occurs mainly as filling of large, in most cases sub-vertical fissures ("Neptunian dykes"), penetrating into Upper Triassic Dachsteinkalk (GEYER 1886a, BÖHM 1992). In the Bakony Mts both "fissure-filling" and "bed-like" types of the Hierlatzkalk can be found. The host rocks or underlying beds are Dachsteinkalk or the lowermost Jurassic "Dachsteinkalk-type" Kardosrét Limestone.

According to the sedimentological model adopted here (GALÁCZ & VÖRÖS 1972; VÖRÖS 1986; GALÁCZ 1988) the Hierlatzkalk can be interpreted as a slope and apron sediment, related to fault scarps of submarine highs (seamounts). Differential subsidence of segments of the Late Triassic carbonate platform at the beginning of the Jurassic resulted in a very marked bottom topography. Submarine highs, their slopes and basins between them were the main depositional environments. Skeletons of organisms populating the seamounts have been preserved in submarine fissures, or were transported by currents or gravity flows to the foot of the slopes where now they form "bed-like" Hierlatzkalk. The Hierlatzkalk is therefore a skeletal concentration consisting of allochthonous fossil assemblages (VÖRÖS 1986).

Material: localities, age and previous studies

Altogether more than 600 bivalve specimens of two collections were studied. The localities mentioned in this paper are shown in fig. 1. The material has come from the Hierlatzkalk representing various levels of the Sinemurian and Pliensbachian stages. The substages and the zonal scheme used in this paper are given in fig. 2.

Northern Calcareous Alps

The collection housed in the Geologische Bundesanstalt in Vienna (thereinafter GBA) consists of 268 specimens, including the type series of STOLICZKA (1861) (35 specimens) and a larger material gathered by subsequent collectors. Some recently collected specimens were kindly supplied by Dr. A. VÖRÖS. The Austrian material came from three localities:

— Hirlatzwand (= Hierlatzberg), Dachsteingebirge;
— Kratzalm (= Gratzalpe), Hagengebirge;
— Schafberg near St. Wolfgang.

Among them the Hirlatzwand is by far the most important, where the vast majority of the specimens has been collected.

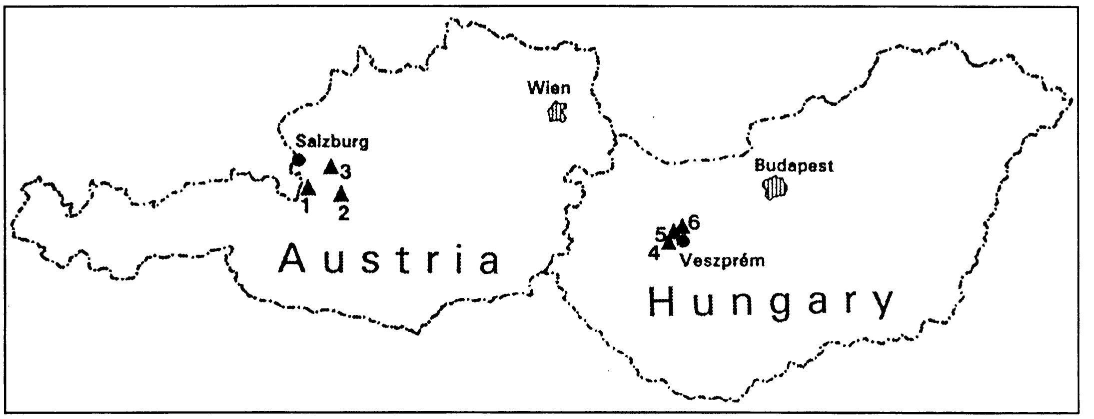

Fig. 1. Hierlatzkalk localities mentioned in this paper

PLIENSBACHIAN	Domerian	Spinatum
		Margaritatus
		Stokesi
	Carixian	Davoei
		Ibex
		Jamesoni
SINEMURIAN	Upper	Raricostatum
		Oxynotum
	Middle	Obtusum
		Turneri
	Lower	Semicostatum
		Bucklandi

Fig. 2. Substages and zonal subdivision of the Sinemurian and Pliensbachian stages as used in this paper

The age of the North Alpine Hierlatzkalk is only approximately known: as VÖRÖS (1991) and BÖHM (1992) concluded, it is mainly Sinemurian. No recent stratigraphic works are available on the localities mentioned above, so we have to rely on the classical papers by GEYER (1886b), ROSENBERG (1909) and SPENGLER (1911). The Hierlatzkalk of the first two localities most likely represents the upper part of this stage ("Lotharingien", or "Obtusus" and "Oxynotus Schichten") while on the Schafberg it is probably of Pliensbachian age.

Bivalves of the North Alpine Hierlatzkalk have already been described and figured in a classical paper by STOLICZKA (1861) and were listed subsequently by several authors (e.g. ŠTUR 1871). Except some poorly preserved specimens questionably assigned to the genus *Parainoceramus* COX 1954, no new elements as compared to the previous works have been found in the Austrian material. Seventeen bivalve species were described by STOLICZKA (1861) from the North Alpine Hierlatzkalk, among them 12 as new. The major part of the type material is now kept in the Collection of the GBA. Since STOLICZKA (l. c.) did not designate type specimens, only syntypes are available. After studying them it could be concluded that some of the figures given by STOLICZKA (l. c.) are highly restored and can be considered as composite ones based on several, usually incomplete specimens. Existing and figured specimens could be, however, identified in most cases.

In some cases differences can be observed between the features of the figured specimens and those of the existing ones, giving rise to taxonomical problems. Considering that a classical fauna is concerned which is of primary importance for the study of the Mediterranean early Jurassic bivalves, some of the syntypes seemed to be worthy of re-figuration.

Bakony Mts

The bulk of the Bakony fauna has been collected bed-by-bed from two measured sections. These are:
— Tűzköves Hill near Szentgál, and
— Kericser Hill near Lókút.

At a third locality called Fenyveskút, south of the village Lókút, some isolated outcrops were sampled. The Hierlatz limestone of Tűzköves Hill belongs to the Raricostatum Zone of the Upper Sinemurian (GÉCZY 1974) and has yielded some 120 specimens. In the Kericser Hill section the Ibex, Davoei and Stokesi Zones of the Pliensbachian are represented by Hierlatz limestone (GÉCZY 1971, 1976). The Fenyveskút locality is a group of small outcrops where Hierlatz limestone of the Upper Domerian (Margaritatus Zone) is exposed (GÉCZY B. pers. comm).

Altogether more than 250 specimens are available from the Pliensbachian. The Bakony material is now housed in the Department of Palaeontology at the L. Eötvös University, Budapest.

In his classical work BÖCKH (1874) listed the bivalve species found in the Hierlatzkalk of the Tűzköves Hill and described a new species as *"Lima rothi* BÖCKH*"*. Three syntypes of the latter have been figured by BÖCKH (1874, pl. 3, figs 5–7), one of them (fig. 7a–b) from the Hierlatzkalk of the Tűzköves Hill. The figured specimen differs markedly from the other two and can be assigned with certainty to *Praechlamys pollux* (D'ORBIGNY 1850). The specimen, however, can not be found in the type collection of the Hungarian Museum of Geology in the Geological Institute of Hungary (MÁFI), where BÖCKH's material is now housed. The other two syntypes have come from a yellowish grey micritic, bioclastic limestone different from the Hierlatzkalk and are most probably of Middle Cretaceous age.

The rich bivalve fauna of the Pliensbachian Hierlatzkalk of the Bakony Mts has not been studied in detail until now. Only the presence of thin-shelled pectinids in the Kericser fauna was mentioned by GÉCZY (1971). A preliminary account on the palaeoecology of the Pliensbachian bivalves was given by VÖRÖS (1986).

Systematics of the Hierlatzkalk bivalves: preliminary results

In the following an annotated list of the bivalve taxa identified from the Austrian and Hungarian Hierlatzkalk is given, with indications of the numbers of specimens. Full systematic descriptions will be published elsewhere. Sound generic assignment of some forms would require serial grinding of well preserved specimens. Some determinations are therefore of provisional nature. The abbreviation GBA, followed by four-figure numbers refer to the catalogue number of specimens housed in the Geologische Bundesanstalt in Vienna.

The identified forms belong to nine families:

Family Parallelodontidae DALL 1898

Some 32 specimens from the Northern Calcareous Alps and three valves from the Bakony Mts are assigned to this family.

Three arcoid species were described by STOLICZKA (1861), among them two as new. The hinge of the holotype? of *"Arca" sulcosa* (STOLICZKA 1861, pl. 5, fig. 7; GBA 2954) bears fine taxodont teeth and some posterior laterals sub-parallel to the dorsal margin, indicating that this species belongs to the Parallelodontidae, most probably to the genus *Parallelodon* MEEK & WORTHEN 1886.

The Bakony specimens are small-sized and incomplete ones and can not be identified with the North Alpine forms (pl. 1, fig. 1).

Family Inoceramidae Giebel 1852

Small, markedly inflated forms assigned to *Parainoceramus* COX 1954 (pl. 1, figs. 2–3.) are very common in the Pliensbachian Hierlatz limestone of the Bakony Mts. No representatives of this genus were hitherto recorded from the Northern Calcareous Alps. Eight poorly preserved valves in the GBA collection may be assigned, with some doubt, to *Parainoceramus*.

Family Limidae Rafinesque 1815

Limids are frequent elements both in the Austrian and Hungarian assemblages. They are represented by three genera/subgenera. Among them *Plagiostoma* SOWERBY 1814 is especially abundant in the North Alpine fauna (45 valves). These specimens, including the observed two syntypes of *Lima scrobiculata* STOLICZKA 1861 and those of *Lima deslongchampsi* STOLICZKA 1861, p. 199, pl. 7, fig. 1, GBA 2962), as well as 8 valves from the Bakony Mts, can be assigned to *Plagiostoma giganteum* J. SOWERBY 1812. The figure of *Lima scrobiculata*, as given by STOLICZKA (1861, pl. 6, fig. 10) is somewhat misleading. Although the antero-ventral region of the figured specimen (GBA 2963) is lacking, it is clearly visible that the lunule was much longer than it is suggested by the reconstruction. Three specimens identified by STOLICZKA (1861, p. 199, pl. 7, fig. 3, GBA 2859) to *Lima densicosta* QUENSTEDT 1856, as well as 42 valves from the Bakony Mts represent *Limea (Pseudolimea)* ARKELL 1943. The Austrian specimens differ from *Lima densicosta*, a possible synonim of *L. (P.) pectinoides* (J. SOWERBY 1815) by having no secondary plicae, therefore they may represent a new species. The Bakony assemblage contains three other species of *Limea (Pseudolimea)* beside the afore-mentioned form, including *L. (P.) hettangiensis* (TERQUEM 1855) (pl. 1, fig. 4), L. *(P.)* cf. *liasina* (GEMMELLARO 1874) (pl. 1, fig. 6) and a third species characterized by sharp, angular plicae.

Five specimens in the Austrian assemblage belong to the genus *Antiquilima* COX 1943. These specimens, as well as the figured type of *Lima haueri* STOLICZKA (1861, p. 200, pl. 7, fig. 2) are most probably conspecific with *A. succincta* (SCHLOTHEIM 1813).

Family Oxytomidae Ichikawa 1958

The genus *Oxytoma* MEEK 1864 is represented in both occurrences of Hierlatzkalk by the long-ranging and variable species *Oxytoma (O.) inequivalve* (J. SOWERBY 1819) (pl. 1, fig. 7). Four specimens are available from the Northern Calcareous Alps and 16 valves have been collected from the Bakony Mts, where this species seems to be confined to the Sinemurian.

Family Terquemidae Cox 1964

Three specimens of *Terquemia pectiniformis* (EUDES-DESLONGCHAMPS 1860) (pl. 1, fig. 8) and three specimens of *Placunopsis numismalis* (QUENSTEDT 1856), all of them from the Northern Calcareous Alps, represent terquemiids.

Family Pectinidae Rafinesque 1815

Pectinids are abundant both in the Austrian and Hungarian Hierlatzkalk. Some 70 and 130 specimens were found, respectively. The scallops can be assigned to the genera *Praechlamys* ALLASINAZ 1972 and *Eopecten* DOUVILLÉ 1897. The later genus is, however, confined to the Bakony fauna.

Five pectinid species were described by STOLICZKA (1861) from the Hierlatzkalk of the Northern Calcareous Alps, among them four as new. Syntypes of three species now housed in the GBA are refigured here.

Praechlamys palosus (STOLICZKA 1861) was based on an incomplete, single left valve (GBA 2958) (pl. 1, fig. 12), figured by STOLICZKA (1861, pl. 6, fig. 8). The shape of the auricles as well as the ornamentation differ from the features displayed by the figure, which latter shows a more dense ornamentation instead of the about 20 plicae mentioned in the description and observable on the holotype and on other specimens (pl. 1, figs 10, 13). Right valves of *P. palosus* are smooth or are ornamented with very fine plicae (pl. 1, fig. 11).

P. stoliczkai (GEMMELLARO 1874) (GEMMELLARO 1874, pl. 12, figs 1–2; MONARI 1994, p. 169, pl. 2, fig. 13; pl. 3, figs 1, 2) can be considered as a junior synonim of *P. palosus*.

Praechlamys was introduced by ALLASINAZ (1972) as a subgenus of *Chlamys* RÖDING 1798, for a group of Triassic pectinids ornamented with radial plicae whose number increases with intercalation, and usually bearing an exterior radial depression on the posterior part of the left valve. Later WALLER & MARINCOVICH (1992) elevated *Preachlamys* onto generic rank and listed some species, among them *P. palosus*, as evidences of the presence of the genus in the Jurassic. The marked difference between the ornamentation of left and right valves of *P. palosus* seems to be, however, a rather unusual feature in *Praechlamys*. Consequently, the generic assignment of the species is somewhat doubtful.

No syntypes of *Praechlamys rollei* (STOLICZKA 1861, p. 197, pl. 6, figs 5–6.) are housed in the STOLICZKA Collection, but several specimens are available both from the Northern Calcareous Alps and the Bakony Mts. *P. rollei* is characterized by valves bearing radial plicae and strong comarginal rugae. The number and width of plicae are variable (pl. 1, figs 14–17). This species is widespread in the peri-Mediterranean Pliensbachian, especially in the "ammonitico rosso" facies (see e. g. KULLMANOVÁ & KOCHANOVÁ (1976, pl. 24, figs 7–9; CONTI & MONARI (1991, p. 255, pl. 3, fig. 18).

No specimens identified as *Pecten amaltheus* OPPEL by STOLICZKA (1861, p. 198, pl. 6, fig. 7) were found in the material. *"P." amalthei* OPPEL 1853 is a synonim of *Propeamussium (P.) pumilum* (LAMARCK 1819) (JOHNSON 1984). The specimen figured by STOLICZKA is most probably a small-sized Praechlamys ornamented with strong primary plicae (see e. g. pl. 1, fig. 28).

Praechlamys subreticulatus (STOLICZKA 1861, p. 196. pl. 6, figs 1–2) was seemingly based on three syntypes. This series comprises a left valve (GBA 2858) from the coral-bearing grey Hierlatz limestone of the "Obtusus Schichten" of Gratzalpe (pl. 1, fig. 20, figured STOLICZKA 1861, pl. 6, fig. 1) and a right valve and a left one from the "Oxynotus Schichten" of the Hierlatzberg (GBA 2964, pl. 1, figs 21, 22; figured STOLICZKA 1861, pl. 6, fig. 2), differing somewhat in the number and strength of primary plicae.

The syntype series of *Pecten verticillus* STOLICZKA 1861 comprises three specimens: one left valve and two right ones. The specimen figured by Stoliczka (1861, pl. 6, fig. 4, GBA 2965/III) is an internal mould of a relatively large left valve, covered with remains of shell (pl. 1, fig. 19.). The specimen GBA 2965/I (figured Stoliczka 1861, pl. 6, fig. 3) is a very incomplete right valve with preserved dorsal margin. GBA 2965/II is a very incomplete left valve ornamented with numerous plicae (pl. 1, fig. 18).

P. palosus and *P. rollei* can be clearly distinguished from other congeneric species. Considering their distinct features as well as their limited stratigraphic and geographic distribution, they seem to be "good" taxa. The systematics of the Formenkreis of *P. subreticulatus* is, however, less clear. Johnson (1984), in his thoroughgoing revision of the Jurassic pectinids of Europe considered all of the four species discussed above, together with *P. lacunarius*, as variants of *Chlamys (Ch.) textoria* (Schlotheim 1820), a very variable and long-ranging species. This statement was, however, based solely on the standardized number of plicae, and as he mentioned, these forms are outside the range of *Ch. (Ch.) textoria* in all other aspects.

Preliminary study of the abundant material illustrated in pl. 1, figs 23–38. suggests that the syntypes of *P. subreticulatus* and *P. verticillus* represent extreme variants of a very variable species for which *"subreticulatus"* is the available name. *P. rusconii* (Canavari 1880) from the Lower Jurassic of peninsular Italy (see Monari 1994, p. 169, pl. 3, figs 3–6), as well as *P. lacunarius* (Rothpletz 1886, p. 169, pl. 14, figs 18, 18a, 20) from the Hierlatzkalk of the Northern Calcareous Alps are well within the supposed range of *P. subreticulatus*. All of the nominal species mentioned above are characterized by ornamentation of the same style as well as by similar metric proportions. Their height/umbonal angle values are especially distinctive. The systematics of this group and its relations to some Triassic species would require, however, further studies.

Some 20 specimens from the Lower Pliensbachian of the Kericser Hill have been provisionally identified as *Praechlamys aff. broilii* (Philipp 1904) (pl. 1, fig. 39). *P. broilii* is known from the Upper Ladinian—Lower Carnian (Triassic) of the Southern Alps (Allasinaz 1972). The Bakony specimens seem to be close to the Triassic forms, regarding both their shape and ornamentation, and further studies may reveal their conspecific nature.

Eopecten is represented in the Bakony material by four, relatively small-sized specimens (pl. 1, fig. 9), probably belonging to a new species.

Some incomplete, smooth valves in the Tűzköves Hill fauna recall *Entolium* Meek 1865 s. str. (family Entoliidae von Teppner 1922) but they are more probably right valves of *Praechlamys palosus* (see above).

Family Carditidae Fleming 1828

A single, small *Tutcheria* specimen (pl. 1, fig. 40) from the Kericser Hill represents Carditidae.

Family Astartidae d'Orbigny

1844 Astartids are abundant in the fauna of the Hierlatzberg from where 81 valves of *Opis (Trigonopis?) clathrata* Stoliczka (1861, p. 194, pl. 6, fig. 6) (pl. 1, fig. 41) and 19 valves of *Praeconia tetragona* (Terquem 1855) (= *"Cypricardia partschi"* Stoliczka 1861, p. 194, pl. 6, fig. 5) are available. The hinge margins can not be studied.

Family Pholadomyidae Gray 1847

Pholadomyids are very rare in the Hierlatzkalk. Four incomplete specimens of *Goniomya* Agassiz 1841 are available from the Bakony Mts, two of them from the Upper Sinemurian and two from the Pliensbachian (pl. 1, fig. 42).

Bivalvia, gen. et sp. indet.

The Bakony material contains some 20, relatively large-sized valves presumably belonging to shallow-burrowing benthic forms (pl. 1, fig. 43).

Palaeoecology

Although the fossil assemblage of the Hierlatzkalk is obviously of allochthonous nature, the studied material can be considered as characteristic for this deposit on the whole. The relatively large number of specimens available may allow a quantitative evaluation and some considerations on the depositional environments. The more or less equal size of the collections makes them suitable for a comparison. Four guilds are represented among the bivalves of the Hierlatzkalk. Suspension-filtration is the only mode of feeding, combined with different life habits. The palaeoecological composition of the assemblages is depicted in fig. 3. The inferred autecology is based mainly on the works by Duff (1978), Fürsich (1977), Hallam (1976) and Stanley (1970).

Although more or less the same depositional environments can be inferred for both the Austrian and Hungarian Hierlatzkalk, the bivalve assemblages differ significantly in the relative frequency of guilds. Epibyssal forms, such as pectinids and limids are the most common group among bivalves in both areas. The dominance of this guild, which is also represented by the abundant articulate brachiopods, reflects presumably hard substrate. Hanging walls of fissures, boulders of older rocks as well as rocky escarpments of the

Fig. 3. Ecological composition of the bivalve assemblages from the Hierlatzkalk of the Northern Calcareous Alps and the Bakony Mts

seamounts served as hard surfaces essential for byssal attachment (VÖRÖS 1993).

The most striking difference between the ecological compositions of the faunas is the high proportion of shallow burrowing forms at the type locality, as opposed to the subordinate role of this guild in the Bakony assemblage. *Opis (Trigonopis?) clathrata* and *Praeconia tetragona* form this ecological group. Representatives of both genera are characteristic elements in Jurassic shallow-water, peri-reefal bivalve assemblages (HALLAM 1976). Their abundance in the Hierlatzberg-fauna may indicate that shallower-water areas characterized by soft (but not "soupy") substrate existed in the sedimentological "Hinterland" from where their valves were derived. A bivalve assemblage with a similar, high proportion of infaunal forms was documented by FÓZY et al. (1994) from the "Tithonian Hierlatz Limestone" of the Gerecse Mts, Hungary. The apparent lack of cemented bivalves in the Bakony fauna can not be easily explained because both terquemiid species recorded from the Northern Calcareous Alps are also known from the Lower Jurassic of the north-eastern part of the Transdanubian Central Range (i.e. the Gerecse Mts) (VÍGH 1961).

Acknowledgments

Dr. HARALD LOBITZER (GBA Wien) kindly invited me to study the Hierlatzkalk bivalves from the Northern Calcareous Alps and encouraged me to publish the results of this work. Dr. FRANZ STOJASPAL (GBA Wien) helped me when I visited the Collection of the GBA, and kindly loaned some specimens for further studies. Prof. BARNABÁS GÉCZY (Eötvös University, Budapest) made the Hungarian material housed in the Department of Palaeontology available for study. Dr. ATTILA VÖRÖS (Hungarian Museum of Natural History) provided several specimens collected by him and shared his knowledge on various aspects of the Hierlatzkalk with me. Their help and kindness is gratefuly acknowledged herein. The work was supported by the Hungarian Science Foundation (OTKA Grant Number F 7329).

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PLATE 1

Bivalvia from the Hierlatzkalk. All specimens are coated with ammonium chloride. The abbreviations GBA and ŐT refer to the collections of the Geologische Bundesanstalt, Vienna and that of the Department of Palaeontology, Eötvös University, Budapest, respectively. The specimens are unregistered unless otherwise indicated.

Fig. 1 *Paralellodon?* sp. left valve; Kericser Hill; Lower Pliensbachian; ŐT; 1.5x
Fig. 2–3 *Parainoceramus* sp. left valve; Kericser Hill; Ibex Zone; ŐT; 1x
Fig. 4 *Limea (Pseudolimea) hettangiensis* (Terquem 1855) right valve; Kericser Hill; Davoei Zone; ŐT; 1.5x
Fig. 5 *Limea (Pseudolimea)* sp. cf. *"densicosta"* (Quenstedt 1858) sensu Stoliczka 1861 (non Quenstedt sp.)right valve; Kericser Hill; Stokesi Zone; ŐT; 1.5x
Fig. 6 *Limea (Pseudolimea)* cf. *liasina* (Gemmellaro 1874) left valve; Kericser Hill; Ibex Zone; ŐT; 1.5x
Fig. 7 *Oxytoma (O.) inequivalve* (J. Sowerby 1819) left valve; Tűzköves Hill; Raricostatum Zone; ŐT; 1x
Fig. 8 *Terquemia pectiniformis* (Eudes-Deslongchamps 1860) right valve; Hierlatzberg; "Oxynotus Scichten", GBA; 1x
Fig. 9 *Eopecten* sp. left valve; Kericser Hill, Lower Pliensbachian; ŐT; 1.5x
Fig. 10–13: *Praechlamys palosus* (Stoliczka 1861)
- 10 left valve; Fenyveskút; Margaritatus Zone; ŐT; 1x
- 11 right valve; Fenyveskút; Margaritatus Zone; ŐT; 1x
- 12 left valve; Hierlatzberg; "Oxynotus Schichten"; GBA 2958; holotype?, figured Stoliczka (1861. pl. 6, fig. 8); 1x
- 13 ?left valve; Tűzköves Hill; Raricostatum Zone; ŐT; 1x

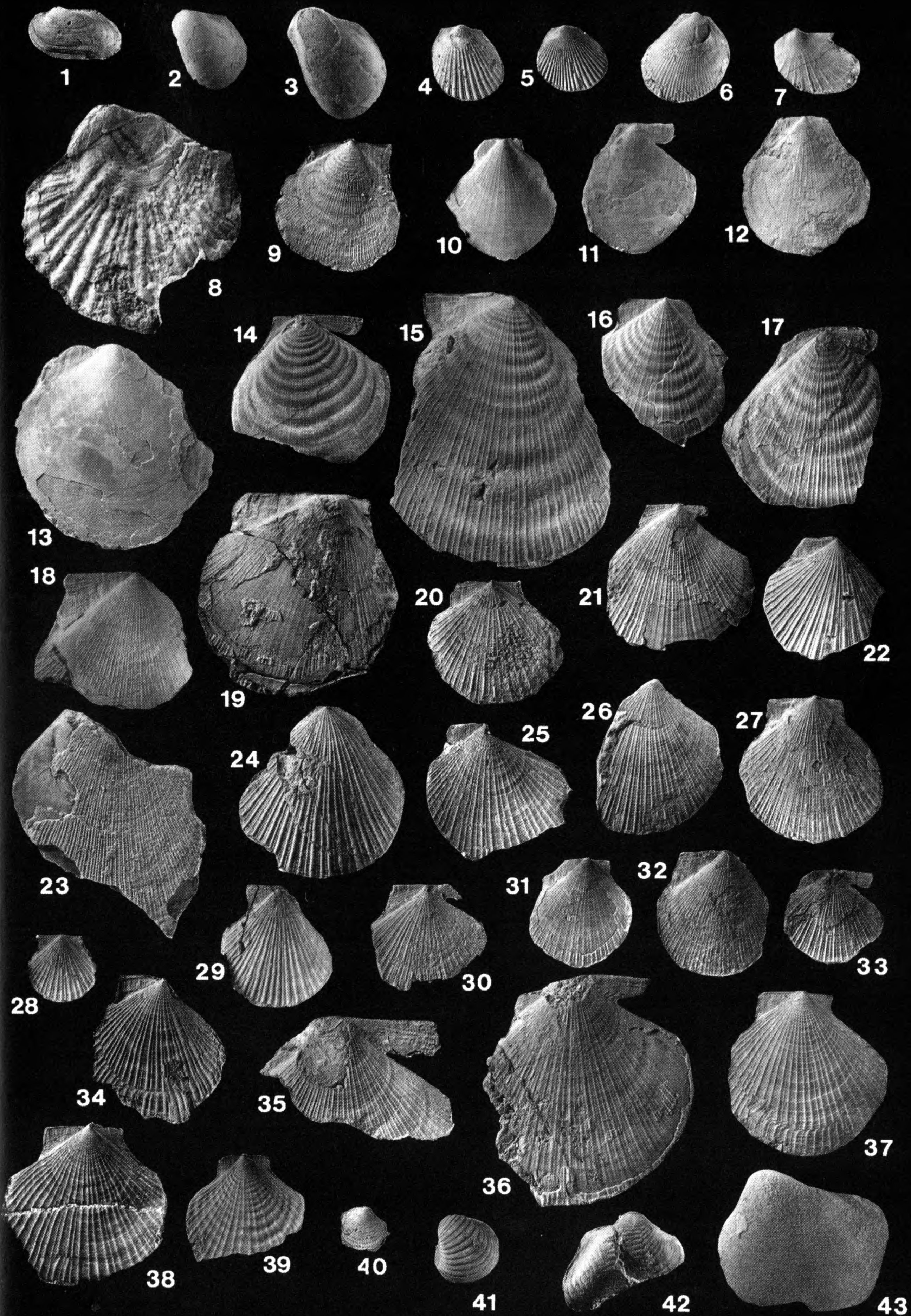
Fig. 14–17: *Praechlamys rollei* (Stoliczka 1861)
- 14 finely plicated specimen, right valve; Fenyveskút; ŐT; Margaritatus Zone; 1x
- 15 left valve; Fenyveskút; ŐT; Margaritatus Zone; 1x
- 16 left valve; Schafbergtörl; GBA; 1x
- 17 right valve; Schafbergtörl; GBA; 1.5x

Fig. 18–19: *"Pecten verticillus* Stoliczka 1861"
- 18 left valve; Hierlatzberg; "Oxynotus Schichten"; GBA 2965, syntype; 1x
- 19 left valve; Hierlatzberg; "Oxynotus Schichten"; GBA 2965, syntype, figured Stoliczka (1861, pl. 6, fig. 4; 1x

Fig. 20–22: *Praechlamys subreticulatus* (Stoliczka 1861)
- 20 left valve; Gratzalpe; "Obtusus Schichten"; GBA 2858; syntype, figured Stoliczka (1861, pl. 6, fig. 2); 1x
- 21 right valve; Hierlatzberg; "Oxynotus Schichten"; GBA 2964, syntype, figured Stoliczka (1861, pl. 6, fig. 1); 1x
- 22 left valve; Hierlatzberg; "Oxynotus Schichten"; GBA 2964, syntype; 1x

Fig. 23–38: *Praechlamys* cf. *subreticulatus* (Stoliczka 1861)
- 23 right? valve; Fenyveskút, Margaritatus Zone; ŐT; 1x
- 24 left valve; Hierlatzberg; "Oxynotus Schichten"; GBA; 1x
- 25 right valve; K ricser Hill; Ibex Zone; ŐT; 1x e
- 26 right valve; Hierlatzberg; "Oxynotus Schichten"; GBA; 1x
- 27 left valve; Hierlatzberg; "Oxynotus Schichten"; GBA; 1x
- 28 left valve; Hierlatzberg; "Oxynotus Schichten"; GBA; 1.5x
- 29 left valve; Tűzköves Hill; Raricostaum Zone; ŐT; 1x
- 30 right valve; Hierlatzberg; "Oxynotus Schichten"; GBA; 1x
- 31 left valve; Kericser Hill; Davoei Zone; ŐT; 1x
- 32 left valve; Hierlatzberg; "Oxynotus Schichten"; GBA; 1x
- 33 right valve; Kericser Hill; Ibex Zone; ŐT; 1x
- 34 right valve; Kericser Hill; Lower Pliensbachian; ŐT; 1x
- 35 right valve; Hierlatzberg; GBA; 1x
- 36 right valve; Hierlatzberg; "Oxynotus Schichten"; GBA; 1x
- 37–38 left valves; Kericser Hill; Ibex Zone; ŐT; 1x

Fig. 39 *Praechlamys* aff. *broilii* (Philipp 1904) left valve; Kericser Hill; Ibex Zone; ŐT; 1x
Fig. 40 *Tutcheria* sp. right valve; Kericser Hill; Lower Pliensbachian; ŐT; 2.5x
Fig. 41 *Opis (Trigonopis?) clathrata* Stoliczka 1861 left valve; Hierlatzberg; "Oxynotus Schichten"; GBA; 1x
Fig. 42 *Goniomya* sp. right valve; Kericser Hill; Pliensbachian; ŐT; 1x
Fig. 43 benthic bivalve, gen. et sp. indet. Kericser Hill; Ibex Zone; ŐT; 1x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GEOCHEMISTRY, PETROLOGY

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ADVANCES
in
Austrian—Hungarian Joint Geological Research
Budapest, 1996

Organic geochemistry and facies of the Carnian Göstling Beds and Opponitz Formation (Northern Calcareous Alps, Austria)

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Keywords: Organic geochemistry, Göstling Beds, Opponitz Formation, Carnian, bituminous rocks, oil source rocks, Austria

Abstract

The Lower Carnian Göstling Beds were studied in respect of organic geochemistry and microfacies at the classical locality and in the Scheiblinggraben-Profile at Großreifling. Lithologically they represent the hanging part of the Reifling Formation. They consist of siliceous and bituminous laminated biomicritic limestones, occasionally with cm-thick black shale intercalations. Radiolarians and sponge spicules are the dominant fossils. Fine-rhythmic calcarenitic allodapic stringes show shallow water elements such as dasycladaceans and *Tubiphytes*. C_{org}-content is relatively low. The kerogen is of marine and terrestrial origin as well and the reducing environment contributed towards a fair preservation of the organic matter. We consider the Göstling Beds as typical sediments of a distal turbidite on top of the otherwise basinal Reifling Formation.

In contrast the slightly bituminous "cement marl" intercalations in the Upper Carnian classical locality of Opponitz Formation in the Stiegengraben profile probably represent a much shallower depositional environment. Lithologically the "cement marls" are often developed as ostracode-micrites with filaments. Allodapic intercalations were not observed. As a consequence of an only slightly reducing environment bacteria were able to destroy a great part of the organic matter of the Opponitz cement marl intercalations.

Zusammenfassung

Die unterkarnischen Göstlinger Schichten stellen sowohl am locus classicus, als auch im Scheiblinggraben bei Großreifling anoxische, häufig bituminöse Sedimente einer distalen Turbiditentwicklung der hangenden Reiflinger Schichten dar. Kieseligen mikritischen Kalken bzw. Mergeln mit Radiolarien, Spongiennadeln, etc. sind fein-rhythmische allodapische Kalkarenite u.a. mit Dasycladaceen und *Tubiphytes* zwischengeschaltet. Auch die organische Geochemie gibt Hinweise auf marinen und terrestrischen Input des Kerogens. In Göstling und noch intensiver im Scheiblinggraben herrschten stark reduzierende Ablagerungsbedingungen, was zu einer guten Erhaltung der organischen Substanz beitrug.

Hingegen kann man bei den bituminösen "Zementmergel"-Einschaltungen in den oberkarnischen Opponitzer Schichten des Stiegengraben-Profils wohl von erheblich seichteren Ablagerungsbedingungen ausgehen. Im Schliff zeigen sich häufig Filamentmikrite sowie Anhäufungen von Ostracoden; ausgeprägte allodapische Einschaltungen wurden nicht beobachtet. Infolge der viel schwächer entwickelten reduzierenden Ablagerungsbedingungen trugen Bakterien sehr aktiv zur Zerstörung der organischen Substanzen der Opponitzer Zementmergel bei.

Összefoglalás

A dolgozat az alsó-karni Göstlingi Rétegek szervesgeokémiai és mikrofácies vizsgálatának eredményeit ismerteti a klasszikus lelőhelyen, valamint a großreiflingi szelvényben Scheiblinggrabennél. Litológiailag a Reiflingi Formáció felső részét képviselik és kovás/bitumenes laminált biomikrites mészkövekből állnak, helyenként cm vastagságú fekete agyagpala közbetelepülésekkel. Uralkodó ősmaradványai a radiolariák és a szivacstűk. A finoman ritmikus allodapikus

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kalkarenit közbetelepülések sekélyvízi környezetre utaló elemeket, mint pl. dasycladacea vázelemeket és *Tubiphytes*-t tartalmaznak. A C_{org}-tartalom viszonylag alacsony. A kerogén részben tengeri részben szárazföldi eredetű, a szervesanyag viszonylag jó megőrződését a reduktív környezet jelentősen elősegítette. A Göstlingi Rétegek tipikus disztális turbidit üledékeknek tekinthetők, amelyek a medencefáciesű Reiflingi Formációra települnek. Ezzel szemben a felső-karni Opponitz Formáció klasszikus lelőhelyén a stiegengrabeni szelvényben található enyhén bitumenes cementmárga közbetelepülések valószínűleg sokkal sekélyebb ülepedési környezetet képviselnek. Litológiailag a cement márgák gyakran filamentumos, ostracodás mikritként fejlődtek ki. Allodapikus közbetelepülésük itt nem észlelhető. A kevéssé reduktív környezetben a bakteriális működés hatására az opponitzi cementmárga betelepülések szervesanyagának nagy része lebomlott.

Introduction

This paper represents a contribution to the multilateral project "Study of Mesozoic Stratotypes of the Alpine-Carpathian-Dinaric Realm", initiated by the Central European Initiative (CEI)-Section A — Geology. Field work was carried out in the frame of bilateral cooperation between the Geological Surveys of Austria, Hungary and the Czech Republic. The sediments were studied in respect of microfacies and palaeoenvironment in Austria; the organic geochemistry was evaluated in Hungary and Rock Eval Pyrolysis was performed in Brno, Czech Republic. It is important to note that the samples studied in Budapest and Brno are not identical, but were collected during independent field campaigns.

Facies and palaeoenvironment

During the Carnian age the sedimentary system and also the biofacies of the Northern Calcareous Alps underwent remarkable changes. Especially in the Lunz nappe of Lower Austria the clastic input increased step by step parallelly with an increase of terrestrial plant growth. In the Early Carnian deeper water environment of the Göstling Beds terrestrial plant input is a consequence of allodapic sedimentation into the pelagic Reifling basin. Also most of the kerogen of the cement marl intercalations in the Late Carnian Opponitz Formation is of terrestrial plant origin, probably derived from islands with growth of Lunz flora.

Göstling Beds

The Göstling Beds represent the hanging part of the Ladinian–Carnian (Cordevolian) Reifling Formation. Our samples were collected as well in the classical area of the Reifling Formation (Scheiblinggraben forestry road) as also at the classical outcrop east of Göstling, close to the Kögerlwirt inn at entrance of Steinbachgraben. (fig. 1, fig. 2). Lithologically, the Göstling Beds consist of dark grey laminated ± siliceous limestones with cm-thick black shale intercalations. Graded bedding is common in allodapic arenitic layers consisting of shallow water debris (dasycladaceans, *Tubiphytes*, bryozoans, etc.) intercalated in an otherwise pelagic sequence. We cannot follow the idea expressed by WAGNER 1970 that these fine-rhythmic limestones were deposited under extremely shallow water conditions, in part even in supratidal environment. On the contrary, we believe that the biota and the sedimentological record clearly point to deeper water environments. Most probably the Göstling Beds are sediments of a distal turbidite sequence. The microfacies of the laminated micritic/microsparitic bituminous marly/siliceous limestones is dominated by

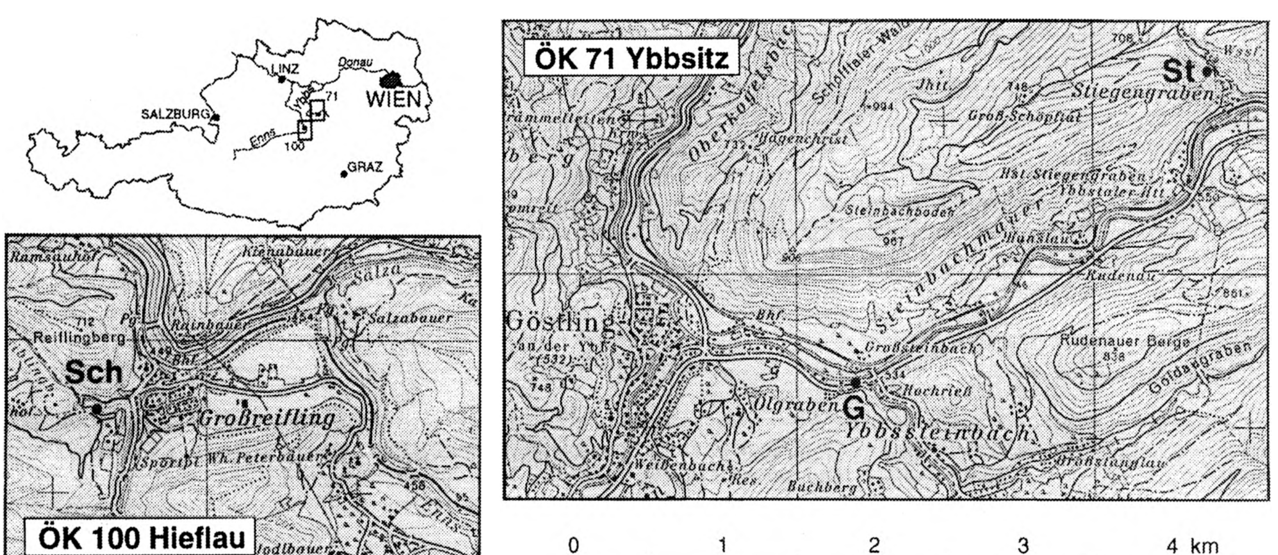

Fig. 1. Location of the sites sampled

Fig. 2. Bedding-plane of cherty bituminous Göstling Limestone. Roadcut E of Göstling, close to Kögerlwirt

delicate bivalve shell-hash ("filaments") and radiolarians, more scarcely also ammonite debris, sponge spicules, ostracods and foraminifers occur (see also MOSTLER & SCHEURING 1974 who describe also conodonts, various echinoderm elements and poorly preserved palynomorphs). Yellow, redbrown or dark brown figurated and amorphous plant debris is occasionally common in the arenitic allodapic intercalations and also in the layers rich in radiolarians. Pyrite may occur in small quantities. In stylolithic flaser zones clay minerals, organic substance, quartz and other mineral grains (e.g. pyrite) are enriched.

Also the mineral phase analyses confirm lithologies ranging from ± dolomitic siliceous limestones to siliceous marls; this is confirmed by the geochemical analysis too. The trace element spectra show some considerably elevated values (in ppm; up to e.g. B 40, Cr 60, Cu 100, Ga 25, Mo 60, Ni 60 and V 100).

Opponitz Formation

The Opponitz Formation consists of various lithologically differentiated members of Late Carnian age. The samples investigated by us come from marly intercalations in a limestone sequence cropping out along the tourist trail at the classical locality Stiegengraben southwest of Lunz. TOLLMANN 1976 calls these whitish, cream or darker greyish-brown and —when hit with a hammer— always bituminous smelling marls "Zementmergel" (cement marls). The microfauna has been described by KRISTAN-TOLLMANN & HAMEDANI 1973. In thin sections enrichments of ostracods are common, often together with peloids. Flaser-bedding is also a common feature. Another marly limestone type is dominated by delicate mollusc shells ("filaments"). Yellow structured or unstructured organic matter can be scarcely observed.

Figs. 1 and 3 show the locality sampled with greyish-brown cm-beds on the bottom which are comparatively higher bituminous and cm-dm-bedded yellow-ochre layers on the top.

In the samples studied the C_{org}-content is relatively low (0.6—0.78%) and S_{tot} amounts 0.7—0.9%. Mineralogically the samples are marly limestones with calcite 69—81%, clay minerals 27% (illite 100%, kaolinite traces) respectively 12% (illite 8%, illite-montmorillonite 4%), quartz 4—5%, pyrite 1%. The thermal analysis shows similar results: calcite 76%, illite 12%, montmorillonite 3%, pyrite 1%. The HCl-insoluble residue is about 16.3%.

The geochemical analysis shows nothing conspicuous. The trace element sprectrum indicates only slightly elevated backgrounds (in ppm; e.g. B 16, Cr 25, Ga 16, Ni 40, V 25).

List of samples

Sample St: Several cm-dm thick bituminous smelling grey/yellowish "cement marl" intercalations in Opponitz Limestone of Stiegengraben (St) on the left (western) side of the touristic trail (fig. 3). Thin-sections show a fine-grained textured peloidal marly limestone with delicate shell debris, especially "filaments", ostracodes and scarce yellow organic matter.

Sample G1: Decimeter-bedded laminated bituminous Göstling Beds east of Göstling, close to Kögerlwirt at the entrance of Steinbachgraben. Thin sections show partly flasered alternating laminae of micrite and microsparite. The micritic laminae are mostly fossiliferous with scarce grains of pyrite. The microsparitic laminae, however, are dominated by radiolarians and organic matter, the latter also figurated, more scarcely spicules of siliceous sponges, echinoderm-fragments, foraminifera and mollusc debris ("filaments" and ammonite shell hash).

Sample G2: Slightly bituminous cm-thick layers in the bioturbated upper part of the Reifling-Göstling Formation; locality as Sample G1.

Sample Sch1: Laminated bituminous Göstling Beds of the Scheiblinggraben forestry road close to

Fig. 3. Bituminous *"cement marl"* intercalation in the Opponitz Limestone Formation of the locality Stiegengraben

Großreifling. Left road branch, after crossing the bridge.

Sample Sch2: Cm-dm-bedded bituminous black micritic limestone of the Göstling Beds, locality as before.

Sample Sch3: Gutenstein Reifling Limestone transition of the Scheiblinggraben inverse profile. Outcrop uphill along a forestry road, not crossing the bridge to the left. Micritic, light brown, slightly bituminous limestone, 5–15 cm bedded.

Organic geochemistry

Experimental

Core samples were ground in a Fritsch ball mill. The extraction of rock powders was carried out with chloroform in a Soxhlet apparatus followed by careful distillation to provide soluble organic matter = bitumen. The IR spectra of the extracts were recorded using a Spekord IR 75 spectrophotometer using the KBr disc technique and evaluated by the baseline method. After precipitating asphaltenes (Asph) with large excess of petroleum ether b.p. 70 °C, the extracts were separated on a silica gel column by elution with petroleum ether for the non-aromatic hydrocarbons ($HC_{non\text{-}ar}$), benzene for the aromatic hydrocarbons (HC_{ar}) and a benzene:methanol (1:1) mixture for the resin (Res) fraction. Gas chromatographic analysis of the non-aromatic hydrocarbons was performed on a HP 5890A gas chromatograph fitted with a 25 m x 0.2 mm WCOT fused silica capillary column coated with OV-1 using hydrogen carrier gas. The oven was programmed from 110 °C to 170 °C at 25 °C/min and 170 °C to 320 °C at 5 °C/min and the samples were injected in a 20:1 split mode. After removal of inorganic carbonates with dilute HCl acid, the total organic carbon contents (TOC) of the sediments were determined using a LECO carbon analyser (see the analytical flow chart.) All Rock Eval pyrolysis and some additional TOC and C_{min} (mineral carbon of carbonates) analyses were performed in the laboratory of the Czech Geological Survey, Brno branch.

Results and discussion

The total organic carbon content (TOC) varies between 0.05 (transition Gutenstein/Reifling Fm.) and 3.58% (Göstling calcareous marl); Table 1, 2. The amount of the insoluble residue in HCl acid is 29.8% while the limestones are relatively poor in organic matter. The bitumen contents are not in close correlation with TOC contents (Table 1). The relatively high extract/organic carbon ratio (β%) reflect rather the type of original organic matter than the degree of the maturity. As far as the bright orange-red colour of the bitumens from samples of Scheiblinggraben is concerned metalporphyrins must have been solved from these samples (KODINA et al. 1988).

As a result of Rock Eval Pyrolysis data (Table 2) most of the samples contain organic matter similar to kerogen type I/II. However, the Göstling Beds of the Großreifling—Scheiblinggraben and the Opponitz Formation of Stiegengraben show pyrolysis values which point to kerogen type I.

The group compositions of bitumens are characterized by relatively smaller amount of ΣHC (26.7—52.1%) and higher NSO compound (47.9—73.3%) contents. The $HC_{non\text{-}ar}/HC_{ar}$ ratio and the $\Sigma HC/NSO$ ratio show two decreasing tendency from the Stiegengraben Opponitz Formation towards the Reifling/Göstling samples (Table 1). This variation in group composition is shown in fig. 4 as well.

Valuable information on the structure of the molecules build-up and the composition of the bitumen of

Table 1

Basic organic geochemical parameters of the Opponitz Formation in Stiegengraben section (St) and of the Göstling Formation of Göstling (G) and Scheiblinggraben (Sch)

Locality	TOC	Bitumen	Ins. res, in HCl	β	Group composition %				HC_{non-ar}/HC_{ar}	$\Sigma HC/NSO$
	%	%	%	%	HC_{non-ar}	HC_{ar}	Res	Asph		
St	0.60	0.113	16.30	18.8	33.1	19.0	39.3	7.2	1.74	1.12
G1	3.58	0.112	29.84	3.4	22.2	16.4	46.4	13.1	1.35	0.65
G2	0.36	0.034	13.03	9.4	27.4	14.8	41.7	14.3	1.85	0.75
Sch1	1.92	0.097	58.96	5.1	14.8	13.3	39.5	30.5	1.11	0.40
Sch2	0.39	0.152	14.54	38.9	13.6	13.1	44.5	27.9	1.04	0.37
Sch3	0.18	0.027	3.85	15.0						

Table 2

TOC, Cmin and Rock Eval data from the Göstling Formation resp. the Reifling Formation (first sample) of Scheiblinggraben and Göstling and of the Stiegengraben Opponitz Formation. It is important to note that the samples of this table are not identical with the other samples mentioned, on which the main part of the text is based

Locality	TOC	C_{min}	T_{max}	S1	S2	HI	PI
Göstling Beds (loc. class.)	1.70	9.45	443	0.38	5.50	324	0.06
Göstling Beds (Scheiblinggraben)	3.02	7.49	442	1.25	23.74	786	0.05
Opponitz Fm. (Stiegengraben)	0.88	8.14	432	1.14	5.40	614	0.17

the samples studied has been obtained by their infra-red (IR) spectra. Since the bitumens consist of more than thousand compounds, on the basis of their IR spectra conclusion can be drawn on the characteristic molecule parts, bond types and function groups building them up. The characteristic bands arising from the aliphatic groups ($-CH_3$, $-CH_2$) (2960–2850 cm^{-1}, ~ 1470 cm^{-1}, ~1380 cm^{-1} wavenumber) appear with high intensity in the IR spectra of every sample. This means that the hydrocarbons of different types (straight-, branched-chain, cyclic, saturated and unsaturated) play an important role in the bitumens either as independent compounds or as a part of a bigger aromatic and/or heteroaromatic (N, S, O) content compounds. The hydrocarbon compounds containing long aliphatic chain play subordinate role in the samples showed by weak absorption bands at 720 cm^{-1} in the IR spectra. The bands of aromatic and/or heteroaromatic rings (3100–3000 cm^{-1}, ~ 1600 cm^{-1}, 930—690 cm^{-1}, 1800–1500 cm^{-1}) are present in all samples with different intensities (fig. 5). This means that the aromatic, heteroaromatic compounds or compounds containing unsaturated C=C bonds conjugated with aromatic rings and other type compounds with hetero-atoms are present with different quantities in the bitumens. The bands of carbonyl groups (~ 1710 cm^{-1}) are present in the spectra of all samples with medium intensity. The acid and keton type dominate over the ester type from the compounds with oxygen atoms.

The main parameters calculated from n-alkane distribution and the characteristic biomarker compounds of the gas chromatographic analysis of the HC_{non-ar} fractions of bitumens are shown in Table 3.

The maturity indices (CPI_{22-32}, R_{29}) are slightly differing, but there is a slightly increasing trend from the Stiegengraben sample to the Scheiblinggraben samples. The pr/ph ratio decreases and the ph/n-C_{18} ratio increases in the above mentioned direction. The pr/n-C_{17} ratio does not show significant variation (Table 3). The naphtenic hump is present in every gas chromatogram. Its origin and evaluation is complex and difficult to interpret (McKirdy et al. 1980).

As far as the biological marker compounds including pristane and phytane are concerned all samples contain different amounts. The relative abundance of α-phyllocladane is higher in the Göstling samples (fig. 6), and almost equal in samples of Stiegengraben (fig. 7) and Scheiblinggraben (fig. 8). This biomarker compound is a tetracyclic diterpenoid and originates from the Coniferopsida class of Gymnosperms (Noble et al. 1985). There are several stronger and/or less intense peaks between n-C_{27} and n-C_{33} in the gas chromatograms of HC_{non-ar} fractions from samples. These compounds are very likely members of the 17β(H) 21β(H) hopane series. Ensminger et al. (1974, 1977) suggest these pentacyclic triterpenoids originated from bacteria, blue-green algae and protozoa. In the n-alkane distribution there is one maximum peak at n-C_{28} in the

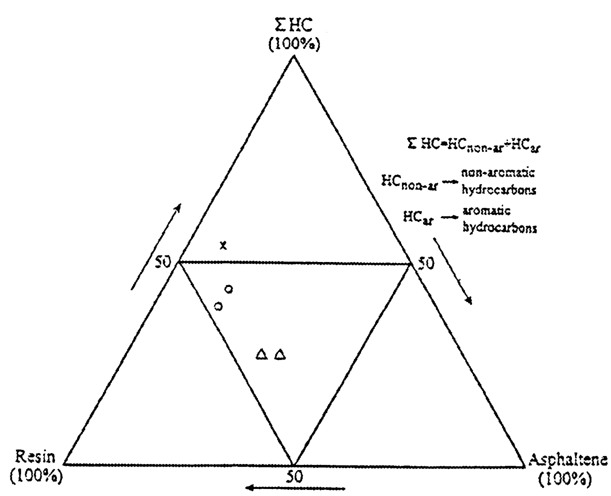

Fig. 4. Group composition of bitumens from samples of Stiegengraben (X), Göstling (O) and Scheiblinggraben (Δ)

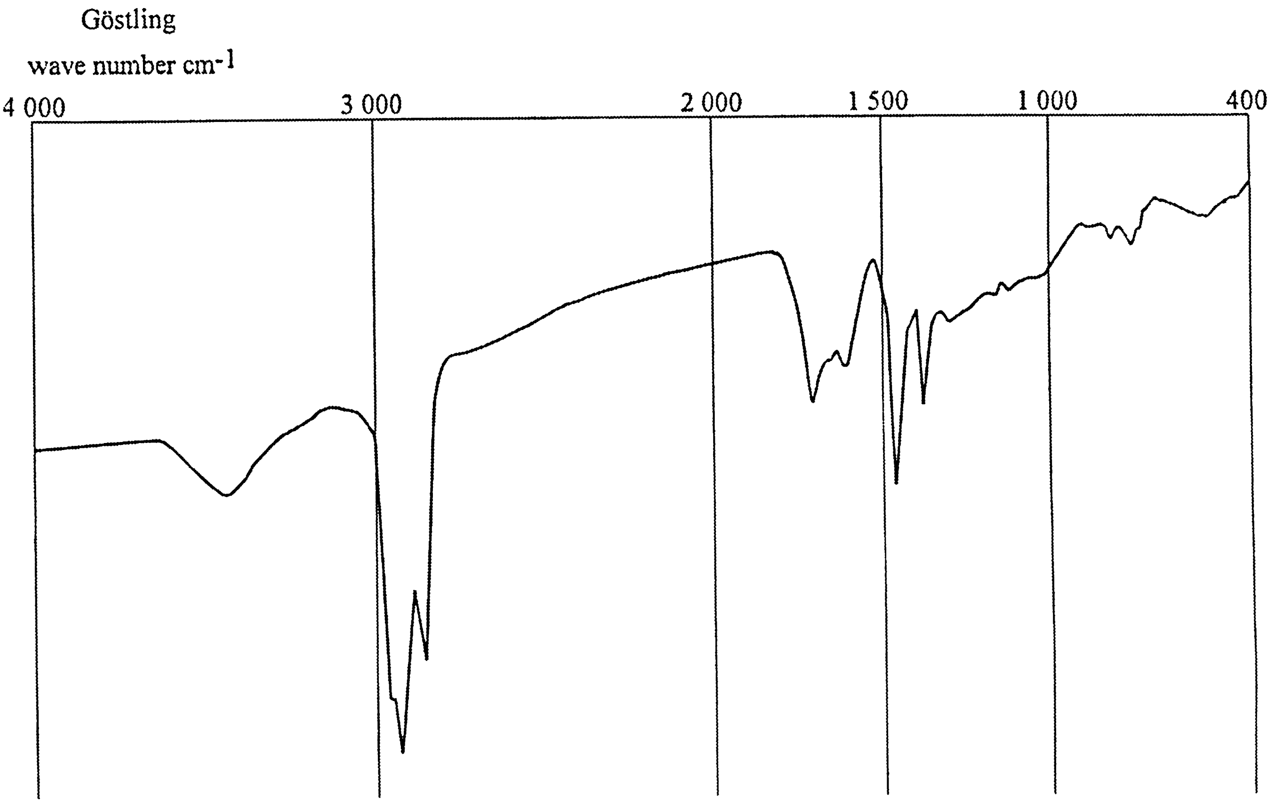

Fig. 5. IR spectra of bitumen from Göstling samples

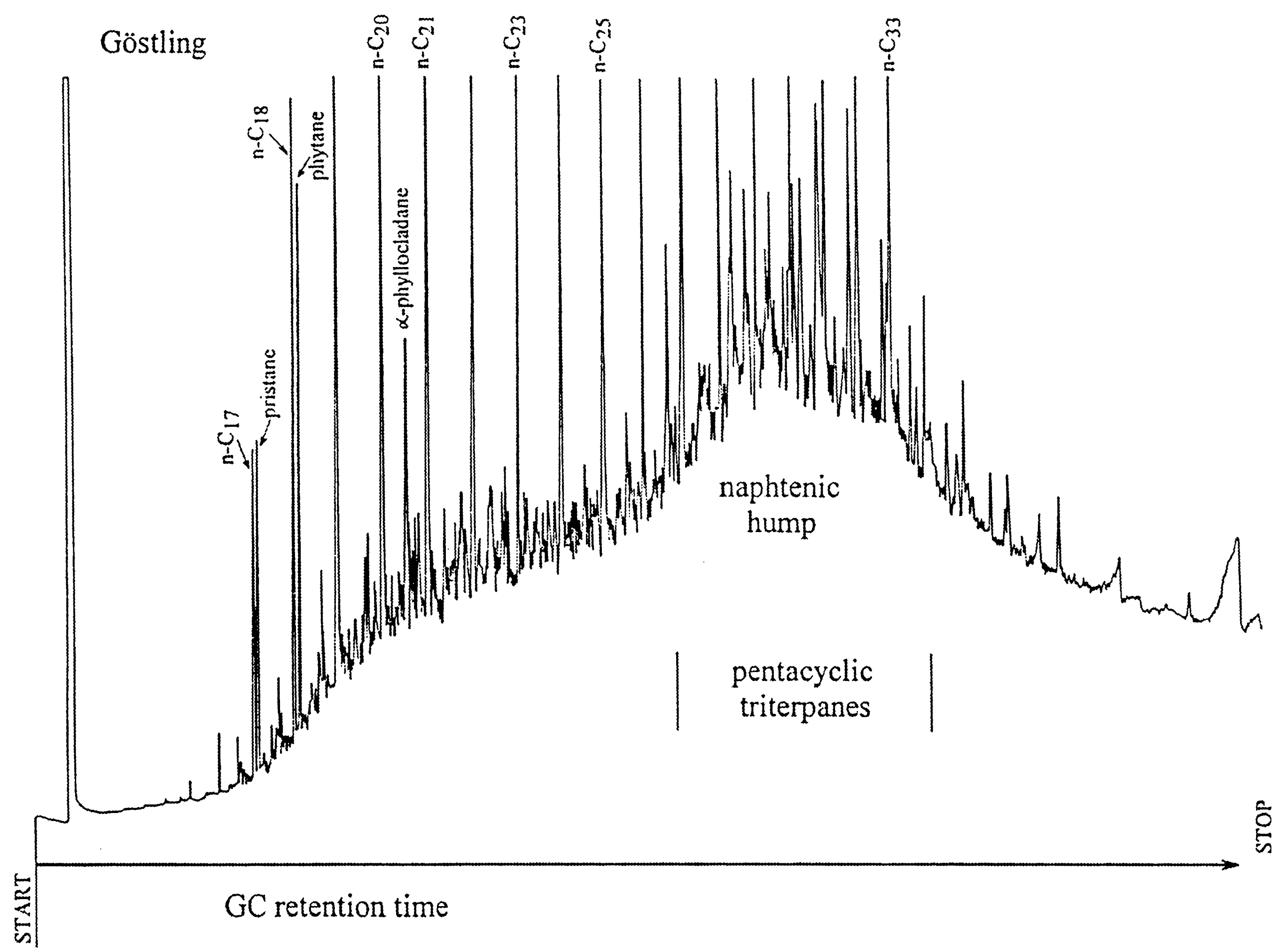

Fig. 6. Characteristic gas chromatogram of the $HC_{non\text{-}ar}$ fraction of bitumens from Göstling samples

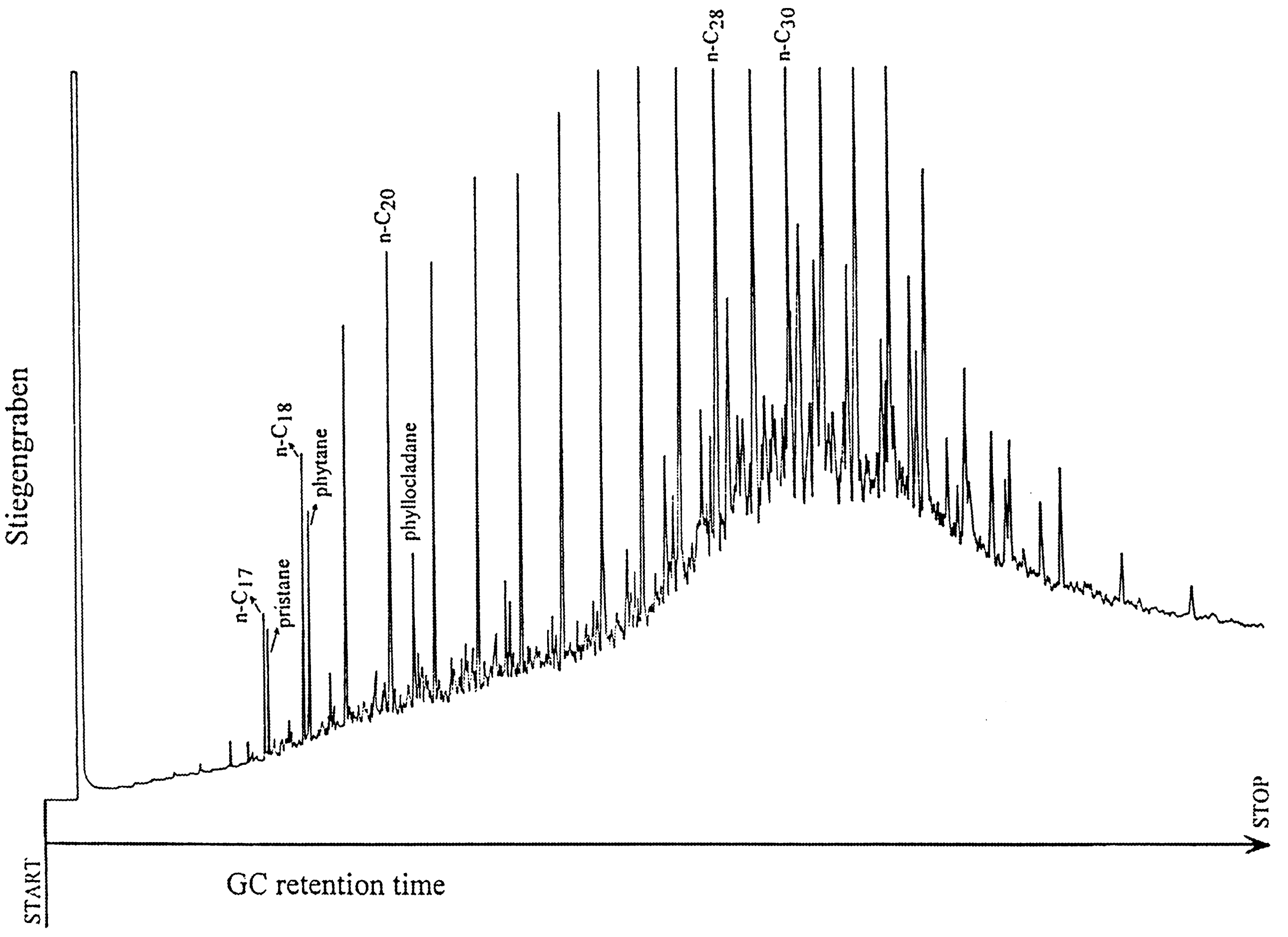

Fig. 7. Gas chromatogram of the HC_{non-ar} fraction of bitumen from the Stiegengraben sample

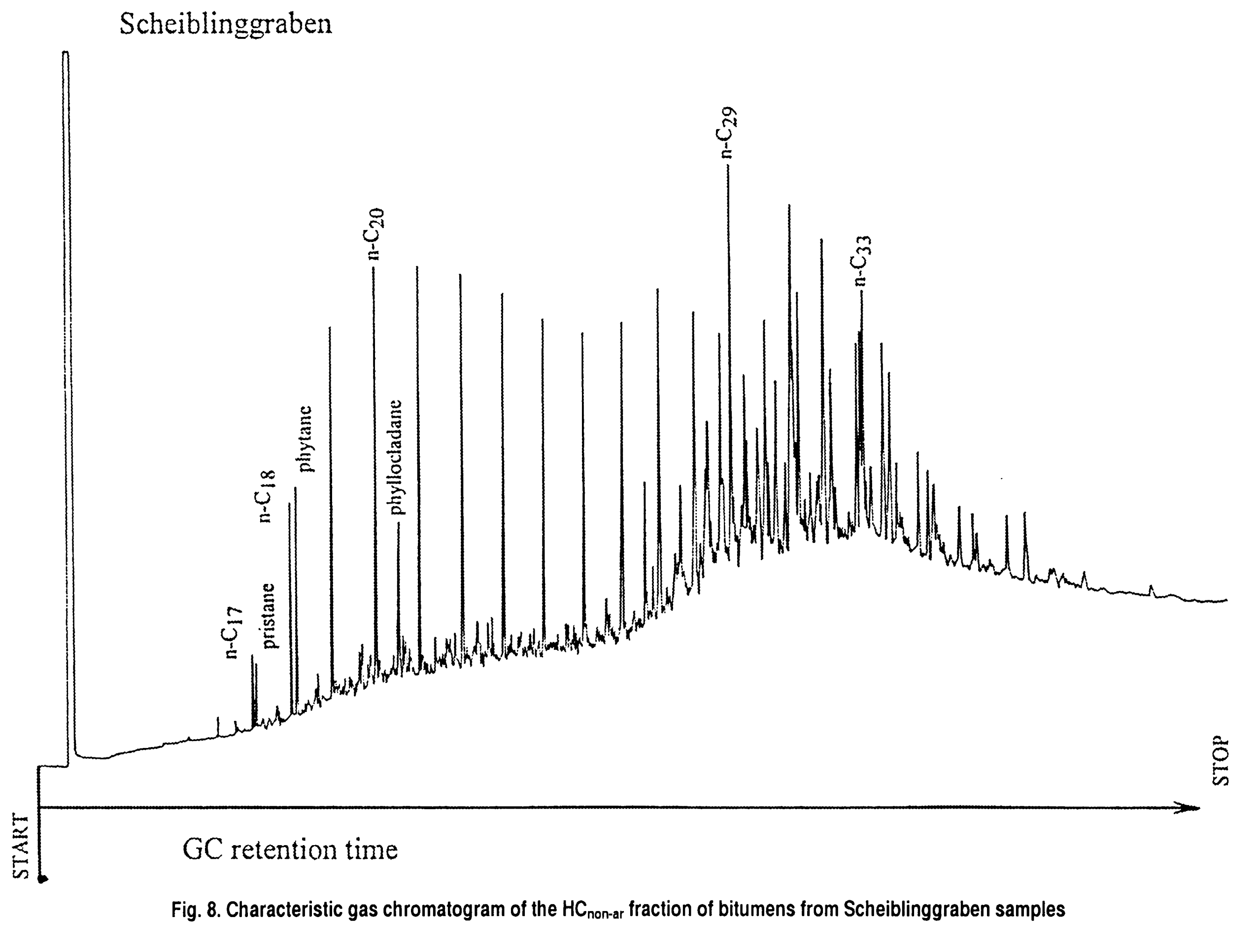

Fig. 8. Characteristic gas chromatogram of the HC_{non-ar} fraction of bitumens from Scheiblinggraben samples

Table 3

Some indices and molecular parameters used for the characterisation of $HC_{non\text{-}ar}$ fractions

Locality	R_{29}	CPI_{22-32}	$n\text{-}C_{22}\text{-}/n\text{-}C_{23}+$	pr/ph	$pr/n\text{-}C_{17}$	$ph/n\text{-}C_{18}$	n-alkanes rel. %	max. peak in n-alk. distribution	naphtenic hump	presence and rel. intensity of α-phy	peaks between n-C27 and n-C34
St	0.90	0.90	0.20	0.42	0.92	0.92	41.9	$n\text{-}C_{28}=n\text{-}C_{30}$	++	+	++ <
G1	1.28	1.11	0.55	0.43	1.21	0.98	24.6	$n\text{-}C_{23}$	++	+	++ <
G2	1.31	1.10	0.49	0.35	1.00	1.24	50.9	$n\text{-}C_{21}$	++	+	++ <
Sch1	1.38	1.12	0.41	0.27	1.01	0.21	28.7	$n\text{-}C_{29}>n\text{-}C_{23}$	+	+	++ <>
Sch2	1.27	1.03	0.23	0.22	0.98	1.67	19.4	$n\text{-}C_{35}>n\text{-}C_{22}$	+	+	+++ >

sample of Stiegengraben and at $n\text{-}C_{23}$ and $n\text{-}C_{21}$ respectively in samples from Göstling. A bimodal distribution with a dominant maximum at $n\text{-}C_{29}$ and $n\text{-}C_{35}$, respectively, and a lesser maximum at $n\text{-}C_{23}$ and $n\text{-}C_{22}$, respectively, is characteristic in the $HC_{non\text{-}ar}$ fraction gas chromatograms of the samples from Scheiblinggraben (Table 3, fig. 8).

Conclusions

In respect to the total organic carbon contents the sample Göstling 1 is excellent, Scheiblinggraben 1 is good and the Stiegengraben sample is fair as oil source rock. The other samples can not be considered as a source rock (Table 4). Although the stratigraphical units the samples coming from are similar, the small differences in the quantity and quality of the organic matter indicate small changes in the type of the original organic matter sedimented and in the depositional environment. As far as the degree of the maturity of the organic matter is concerned the samples are in the diagenetic zone, but in different stages. On the basis of the group composition and the maturity indices calculated from the n-alkane distribution (R_{29}, CPi_{22-32}, $n\text{-}C_{22}\text{-}/n\text{-}C_{23}+$) the Stiegengraben sample is at the end of the diagenetic zone. Relatively the most immature samples (those from Scheiblinggraben and Göstling) are in the late diagenetic stage.

On the basis of the detailed organic geochemical analysis (especially the GC) the samples are dominated by type II kerogen. That means, the organic matter is mixed from lower rank marine organisms and higher terrestrial plants. But the principal source of the organic matter are the marine organisms. The terrestrial input is highest in the samples of Scheiblinggraben (two maxima in the n-alkane distribution and the presence of α-phyllocladane) and somewhat less in Göstling samples. However, the α-phyllocladane biomarker compound occurs in every sample studied. But the relative abundance of the above mentioned compound is higher in the Göstling samples. This indicates a higher contribution of conifers to the initial organic matter.

As far as the depositional conditions are concerned, the organic matter was sedimented in O_2-depleted bottom water. The degree of anoxia must have been different in the two stratigraphic units. There are close relationships between the depositional conditions (redox conditions and bacterial activity), productivity and the preservation of the sedimented organic matter. Due to the relatively less reductive conditions during the sedimentation of the Opponitz cement marls, the higher bacterial activity consuming organic matter was unfavourable for the preservation of sedimented organic

Table 4

Source rock quality and type of organic matter (OM)

Locality	TOC %	Source rock quality	Type of OM	Maturity
St	0.60	fair	II.	end of diagenesis
G1	3.58	excellent	II.	late
G2	0.36		II.	diagenetic stage
Sch1	1.92	good	II.	diagenetic
Sch2	0.39		II.	stage
Sch3	0.18		II.	

matter. In case of the Göstling samples the conditions during sedimentation were somewhat more reductive and therefore the greater productivity together with the dead bacteria bodies resulted in a better preservation of organic matter. The anoxic conditions were strongest during and after the burial of the Göstling Beds in Scheiblinggraben. The palaeoclimate was favourable for higher terrestrial plant vegetation during the Carnian. In the beginning the activity of sulfate-reducing bacteria was strong and supposingly the formed sulphur may have been built into the residual organic matter (high asphaltene contents in group composition). The same phenomena can be observed in samples from Kössen Formation in Rezi, Hungary (BRUKNER-WEIN & VETŐ 1986). Due to the strong anoxic conditions the organic matter and bacteria bodies were accumulated and preserved.

Acknowledgements

This study has been carried out in the framework of bilateral cooperation between the Austrian and Hungarian Geological Surveys and is part of the Mesozoic Stratotype Project. Our sincere thanks are due to the directors of GBA Vienna, MÁFI Budapest and ČGÚ Praha for promoting scientific cooperation with the neighbouring partner institutions even in times of stressed financial situation.

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ADVANCES
in
Austrian—Hungarian Joint Geological Research
Budapest, 1996

Young alkali basalt volcanism from the Graz Basin to the Eastern Carpathians

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Keywords: Carpathian–Pannonian region, alkali basalts, isotope and trace element systematics, mantle source enrichment, Pliocene–Pleistocene

Abstract

Pliocene to Pleistocene alkali basalts with a compositional range from olivine tholeiite to nephelinite erupted in the Carpathian–Pannonian Region (CPR) following Eocene and Miocene subduction events with associated calc-alkaline volcanism, crustal extension, and basin formation. Ultramafic xenoliths from the alkali basalts provide insight into the lithology, tectonic state, and geochemistry of the lithospheric mantle beneath this region. Trace element and isotope geochemistry of alkali basalts indicate a dominant asthenospheric component. However, in some basalts there is clear evidence for an enriched lithospheric component as well, the origin of which is argued to be related to the Tertiary subduction events. These basalts apparently were generated by melting and mixing of asthenospheric and lithospheric components. The relative contributions by the lithosphere show spatial and temporal variations compatible with the idea that the convectively upwelling asthenosphere played the primary role in magma genesis rather than melting through extension of the thermally activated lithosphere.

Zusammenfassung

Pliozäne bis pleistozäne Alkalibasalte der Karpathisch–Pannonischen Region haben olivin-tholeiitischen bis nephelinitischen Chemismus. Sie eruptierten nach den kalk-alkalinen Vulkaniten, welche die Subduktions-Vorgänge im Eozän und Miozän, die Krusten-Extension und die Beckenbildung in dieser Region markieren. Ultramafische Xenolithe in den Alkalibasalten geben uns einen Einblick in die Lithologie des Erdmantels dieser Region und die dort ablaufenden tektonischen und geochemischen Prozesse. Spurenelement- und Isotopengeochemie der Alkalibasalte deuten auf eine dominante asthenosphärische Komponente. Einige Basalte zeigen allerdings auch das Vorhandensein einer an Spurenelementen angereicherten lithosphärischen Komponente, welche möglicherweise ein Produkt von Subduktion während des Tertiärs ist. Diese Basalte entstanden wahrscheinlich durch Schmelzen und Mischen von asthenosphärischen und lithosphärischen Komponenten. Der Anteil der Lithosphäre zeigt räumliche und zeitliche Veränderungen, welche eine Dominanz der Basaltproduktion in der konvektiv aufsteigenden Asthenosphäre gegenüber jener in der thermal aktivierten und gedehnten Lithosphäre erkennen lässt.

Összefoglalás

Pliocén–pleisztocén alkáli bazaltok törtek ki a kárpáti–pannóniai területen (CPR) eocén és miocén szubdukciós eseményeket követően, amelyekhez mészalkáli vulkánosság, kéreghúzódás és medenceképződés kapcsolódott. Összetételük az olivin-tholeiittől a nefelinitig terjed. Az alkáli bazaltokban talált ultramafikus kőzetzárványok bepillantást engednek a terület alatti litoszféraköpeny kőzettani és geokémiai összetételébe, valamint tektonikai állapotába. Az alkáli bazaltok nyomelem- és izotóp-geokémiája az asztenoszférából eredő összetevő túlsúlyát jelzi. Egyes bazaltokban azonban bizonyítható a litoszféra-eredetű, inkompatibilis elemekben dúsult anyag részvétele is. Ez feltehetően a harmadidőszaki szubdukciós eseményekkel függ össze. Úgy tűnik, hogy ezek a bazaltok asztenoszféra- és litoszféra-

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eredetű anyagok megolvadása és elegyedése útján jöttek létre. A litoszféra-eredetű összetevő tér--időbeli változásai összegyeztethetők azzal az elgondolással, hogy a magma keletkezésében a főszerepet az asztenoszféra konvekciós feláramlása játszotta, nem pedig a termikusan aktivált litoszféra-széthúzódás kiváltotta megolvadás.

Introduction

Alkali basalts represent a "window" through which we can gain insight into the Earth's mantle. Compared to other mantle-derived volcanic rocks, e.g., tholeiitic or picritic magmas which may interact extensively with the lithosphere and the crust, alkali basalts, due to their volatile-rich character, rise rapidly to the Earth's surface. That's why they generally escape crustal contamination. Thus, the picture they reflect of the trace element and isotope abundances of the upper mantle source rocks is much less disturbed than in other liquids derived from the upper mantle. In addition, gas-rich alkali basalts and related nephelinites, carbonatites, kimberlites, lamprophyres, and lamproites often carry mantle xenoliths (exogenous and accidental inclusions from the mantle wall rock) such as peridotites (lherzolite, harzburgite, dunite, wehrlite) as well as pyroxenites, hornblendites, and eclogites. Xenoliths supply direct information on the lithology, mineralogy, texture, and structure (i.e., tectonic state), as well as chemical and isotope characteristics of the lithospheric mantle. The information on the chemistry and isotope relations of source mantle regions provided by alkali basalts and kindred magmas is by no means a primary one. At least four factors shape the chemical and isotopic characteristics of mafic alkali magmas:

(1) Source characteristics reflecting its previous history (depletion and enrichment processes);

(2) The tectonic environment during magma generation;

(3) Physical and chemical conditions of magma generation (the degree of partial melting, depth of magma segregation, the CO_2/H_2O ratio etc.);

(4) Mixing between different mantle source regions.

In addition, subsequent magma differentiation may severely alter the chemistry of volcanic rocks and continental basalts can occasionaly become contaminated by crustal matter on their way to the surface. Therefore, alkali basalts should be carefully studied case by case in order to recognize and evaluate the effects caused by each of these factors. Without going into details, we mention for example that the ratio of two incompatible elements (elements that prefer to enter the liquid during melting) with highly different mineral/melt partition coefficients (D) such as La/Sm will likely reflect the degree of partial melting, whereas abundance ratios of incompatible elements with identical mineral/melt Ds, such as Ce/Pb, should mirror abundances in the source, regardless of the degree of partial melting. A continuous increase in $^{87}Sr/^{86}Sr$ and $^{18}O/^{16}O$ ratios with decreasing MgO content is a strong indication for contamination with crustal matter during fractional crystallization. On the contrary, the lack of correlation between these variables strongly suggests that the variation in isotope ratios of basalts was inherited from mantle sources, i.e. they reflect isotopic heterogeneity within the mantle. Whereas peridotite xenoliths invariably provide information on the evolution of the lithospheric mantle, chemical and isotope data of alkali basalts are more difficult to interpret, because they may reflect conditions in more than one mantle reservoir, e.g., asthenosphere, plume, or lithosphere, and a combination of these (e.g., CLASS et al. 1994, PERRY et al. 1987).

In the following paragraphs we try to summarize the results of almost 25 years of research work on the mineralogy, petrology, and geochemistry of the upper mantle beneath the Carpathian-Pannonian Region (CPR) and try to interpret them in the light of modern geochemical models.

Geological setting

The Carpathian–Pannonian Region (CPR) is an extensional back arc basin or, more correctly, a basin system comprising several areas of depression (e.g., Vienna Basin, Graz Basin, Little Hungarian Plain (LHP), Great Hungarian Plain, and Transylvanian Basin) separated by Mesozoic and Palaeozoic block mountains. This area is surrounded by the Eastern Alps, the Carpathian fold belt and the Dinarides (fig. 1). However, present-day geophysical characteristics like high heat flow, thin crust, high temperature within the lithosphere (e.g., DÖVÉNYI & HORVÁTH 1988), and young (Pliocene to Quaternary) alkali basaltic volcanism indicate a close similarity to young rifts (EMBEY-ISZTIN et al. 1990 and references therein). The manifestation of young alkali basaltic volcanism between about 10 to 2 Ma over large areas from the Graz Basin and Burgenland to the west, through the LHP, Balaton, and Nógrád regions, to the Persányi Mountains to the east (fig. 1) provides a good opportunity to study temporal and spatial variations in the isotope and trace element geochemistry of lavas. This knowledge may provide help in reconstructing the evolutionary history of the extensional basin system. For example, it can help us to decipher whether continental extension or upwelling convective asthenosphere was the primary cause of magma generation. In the first case, we are dealing with "passive rifting" in which the mantle is forced to rise as the continental lithosphere is pulled apart during lithospheric stretching. In the second case, rift zones are produced by deep mantle upwellings, or "plumes", which lift and split up the continent ("active rifting").

The development of the fold belt and the formation of the basin system of the CPR are believed to originate in the Mesozoic and Cenozoic collision of stable Europe with several continental fragments, including the African Italo-Dinaride microplate (ROYDEN & BÁLDI 1988, ROYDEN & BURCHFIEL 1989). During the Miocene, rapid extension, subsidence, and sedimentation took place in the basins

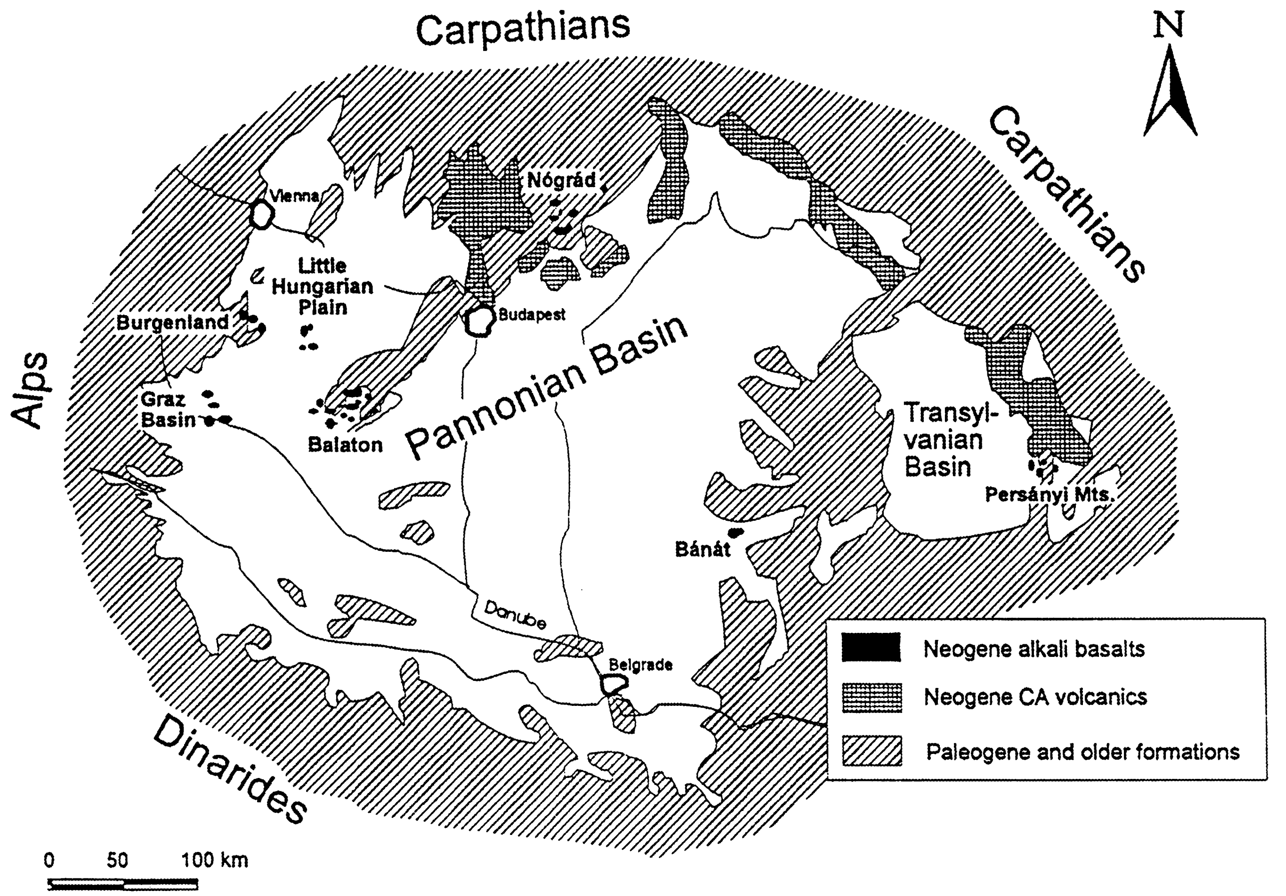

Fig. 1. Simplified map of the Carpathian–Pannonian Region showing Cenozoic alkali basalt and calc-alkaline volcanic fields

of the CPR (SCLATER et al. 1980, HORVÁTH & ROYDEN 1981). Subsidence within the Carpathian–Pannonian system and the simultaneous underthrusting in the Carpathians were accompanied by eruption of voluminous calc-alkaline volcanic rocks, mainly in the northern part of the Pannonian Basin and in the Eastern Carpathians (SALTERS et al. 1988, DOWNES et al. in press, PANTÓ et al. in press). The genesis of this volcanic chain is probably related to the subduction of the European plate southward and westward beneath the Carpathian Mountains (BURCHFIEL 1980). A remarkable feature of the calc-alkaline volcanism is that it becomes progressively younger going from the Western Carpathians (21–17 Ma, Börzsöny Mountains) to the Eastern Carpathians (12–2 Ma) following the simultaneous eastward migration of thrusting within the outer Carpathian fold belt. The extension of the continental crust ceased in late Miocene. The subsequent alkali basaltic volcanism is mainly post-extensional (10–11 Ma Burgenland, 2–3.5 Ma Graz Basin, 3.5–6.5 Ma LHP, 3–5 Ma Balaton Region, 2.5–4.5 Ma Nógrád area and <2 Ma Persányi Mountains) (BALOGH et al. 1986, 1994). Lava flows are more common than volcanic tuffs, cinder cones are rare, except for the Persányi Mountains. The volume of the lava flows and volcanic tuffs is generally small in each region, the number of eruptive centres may, however, be quite high (e.g., about 60 in the Balaton area).

Petrography of alkali basalts

Most CPR alkali basalts are remarkably fresh, moderately porphyritic and holocrystalline, but a few samples contain small amounts of glass. The mineralogy is typical of alkali basalts with an assemblage of phenocrystic olivine, occasionally accompanied by clinopyroxene. The matrix is composed of plagioclase, clinopyroxene, olivine, and titanomagnetite, occasionally coexisting with ilmenite, as well as apatite (EMBEY-ISZTIN & SCHARBERT 1981, EMBEY-ISZTIN et al. 1985, 1993a, POULTIDIS & SCHARBERT 1986). Green core clinopyroxene and Al-augite were observed only in the Nógrád area and Graz Basin (DOBOSI 1989, DOBOSI et al. 1991). Mantle-derived peridotite xenoliths and megacrysts (EMBEY-ISZTIN 1976, 1978, 1984, EMBEY-ISZTIN et al. 1989, KURAT 1971, KURAT et al. 1980, 1991, DIETRICH & POULTIDIS 1985, DOWNES et al. 1992, DOWNES & VASELLI in press) and lower crustal granulite xenoliths (EMBEY-ISZTIN et al. 1990) are abundant at some localities. Only one hornblendite vein each has been found in a lherzolite xenolith from Szigliget (Balaton area, EMBEY-ISZTIN 1976) and Kapfenstein (Styria, KURAT et al. 1980), respectively, though disseminated amphibole grains are more common in peridotite xenoliths at both localities. Veins of hornblendite are more common, however, in peridotite xenoliths from the Persányi Mountains in Transylvania (VASELLI et al. 1995, DOWNES & VASELLI in press).

Peridotite xenoliths

Large (up to 30–40 cm in diameter) peridotite xenoliths representing fragments of the shallow lithospheric mantle are known to occur in basaltic rocks at some localities (Kapfenstein, Styria; Gérce (=Sitke), LHP; Szigliget, Szentbékálla and Bondoróhegy, Balaton area; Persányi Mountains, Transylvania). Small inclusions can be found in other areas, e.g., in the basalts of the Graz Basin and from Nógrád. Detailed studies of the frequency distribution of different texture types in these xenoliths revealed an interesting picture supporting the CPR mantle diapir concept (EMBEY-ISZTIN 1984, KURAT et al. 1991). Below the western external part of CPR (Kapfenstein) the mantle seems to be essentially untectonized (predominance of coarse-grained protogranular textures), whereas in the internal part (Balaton area), where the diapiric uprise of the mantle reaches its maximum, both, protogranular and highly deformed (stressed), totally recrystallized, fine-grained equigranular peridotites frequently occur. However, in this region, a texturally composite peridotite xenolith (comprising both coarse-grained, untectonized and stressed fine-grained rocks in planar contact) indicates that the texture of the upper mantle rocks can be varied on a small scale too (DOWNES et al. 1992), similar to what has also been observed on obducted upper mantle, like Zabargad Island (e.g. KURAT et al. 1993).

Another interesting feature revealed by the systematic study of mantle xenoliths is, that a relationship could be established between deformation and the chemistry of the rocks. Undeformed peridotites are chemically rather homogeneous, whereas the chemistry of deformed upper mantle rocks is more variable (KURAT et al. 1991) and commonly metasomatically enriched in incompatible elements (e.g., Zabargad Island, KURAT et al. 1993). In addition, EMBEY-ISZTIN et al. (1989) and DOWNES et al. (1992) have shown that clinopyroxenes of protogranular peridotites frequently have a LREE-depleted (Light Rare Earth Element-depleted) pattern and MORB-like (Mid-Ocean Ridge Basalt-like) Sr and Nd isotope characteristics that may be the consequence of partial melting and extraction of basaltic liquid from the mantle several billion years ago. In contrast, xenoliths with complex deformed textures are generally enriched in LREE and other incompatible elements to varying degrees attesting to a post-depletion metasomatic enrichment event in the mantle. These xenoliths also show more variability in Sr, Nd, and Pb isotope compositions than do the protogranular peridotites (see below).

Major element chemistry of alkali basalts

Major element, trace element, and isotope analyses of alkali basalts were published elsewhere (EMBEY-ISZTIN & SCHARBERT 1981, PANTÓ 1981, POULTIDIS & SCHARBERT 1986, SALTERS et al. 1988, EMBEY-ISZTIN et al. 1993a, DOWNES et al. in press, DOBOSI et al. in press.) and most of the data have been compiled in EMBEY-ISZTIN et al. 1993b. The rocks are sodic ($K_2O/Na_2O<<1$) and range in composition from olivine tholeiite to nephelinite, however, most common are alkali basalt and basanite (fig. 2). This broad compositional spectrum corresponds to CIPW-normative nepheline contents (ne) from 0 to 30% and hypersthene (hy) contents between 0 and 10%, which is equivalent to a range of saturation index (S.I.) as defined by FITTON et al. (1991) between -60 and +5 (fig. 3). The S.I. quantifies the excess or deficiency of silica in such a way that saturated compositions with neither hypersthene nor nepheline in the norm have S.I.=0, whereas basalts with S.I.<0 are nepheline-normative and those with S.I.>0 are hypersthene-normative. Abundances of incompatible elements in alkali basalts vary with S.I. (fig. 3) and — naturally— with a variety of other parameters, like normative ne, mg# (=100 Mg/(Mg+Fe^{2+}), and others.

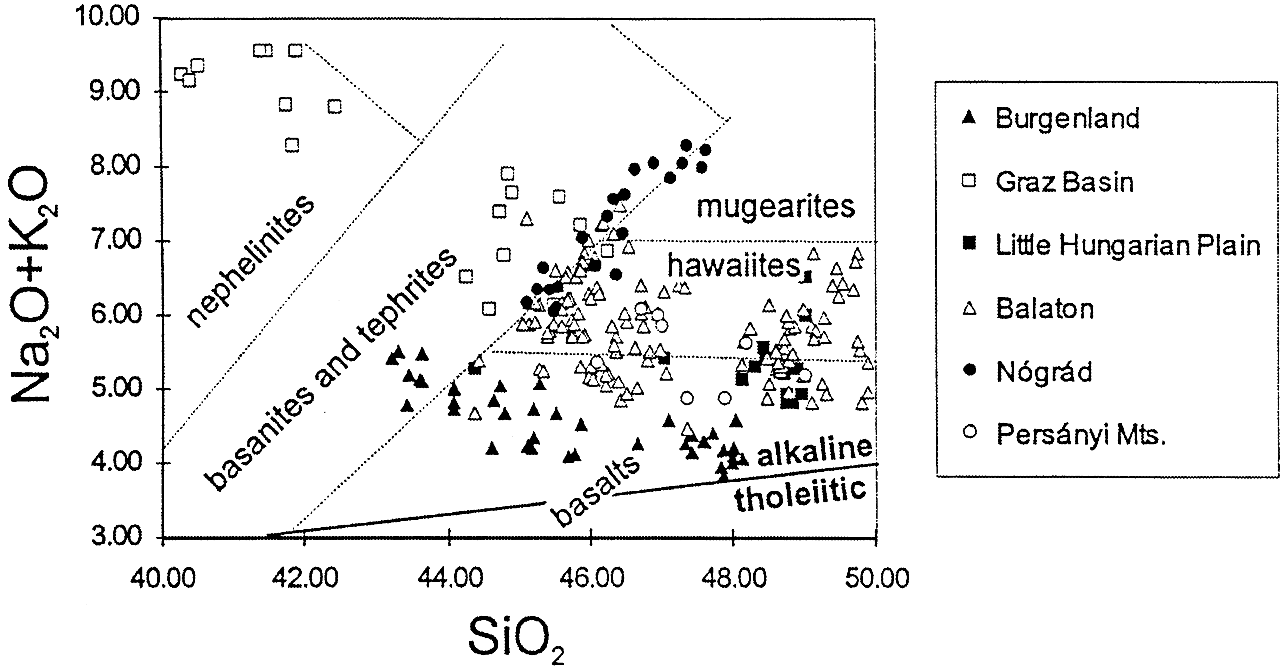

Fig. 2. Alkali vs. silica abundances (wt%) in young CPR alkali basalts; classification after COX et al. (1979)

Olivine tholeiites are among the oldest lavas, whereas highly undersaturated basanites tend to be younger and the nephelinite of Stradner Kogel (STK) from the Graz Basin is one of the youngest rocks in the CPR. However, the relationship between age and degree of undersaturation is ambiguous, because one of the oldest lavas from Pauliberg (P), Burgenland, is a fairly silica-undersaturated basanite.

Of the major oxides that behave incompatibly during partial melting, Na_2O shows good correlation between its abundance and the S.I. (fig. 3A). Much less well correlated are the abundances of K_2O and P_2O_5 with S.I. (figs. 3B, 3C) and no correlation exists for TiO_2 and S.I. (fig. 3D). These relationships indicate that the chemistry of the lavas was determined not only by the degree of partial melting and fractional crystallization, but also by the chemical and modal composition of source rocks. This is evident in the case of the Burgenland basalts, which form a distinct high-Ti group coupled with elevated High Field Strength Elements (HFSE) concentrations (see below), a feature which cannot be explained by any reasonable partial melting model. The SiO_2 content (40.3–50.8 wt%) decreases with decreasing S.I. (not shown), but the Al_2O_3 content is not correlated with S.I. (or ne), except for the Burgenland lavas. Once again, these lavas define a separate cluster very poor in Al and showing a slight decrease of Al with decreasing S.I. (fig. 3E). Total Fe contents (as Fe_2O_3: 8.9–13.6 wt%) do not change in a regular manner with S.I., whereas CaO abundances (7.7–13.6 wt%) slightly increase with increasing degree of undersaturation (not shown).

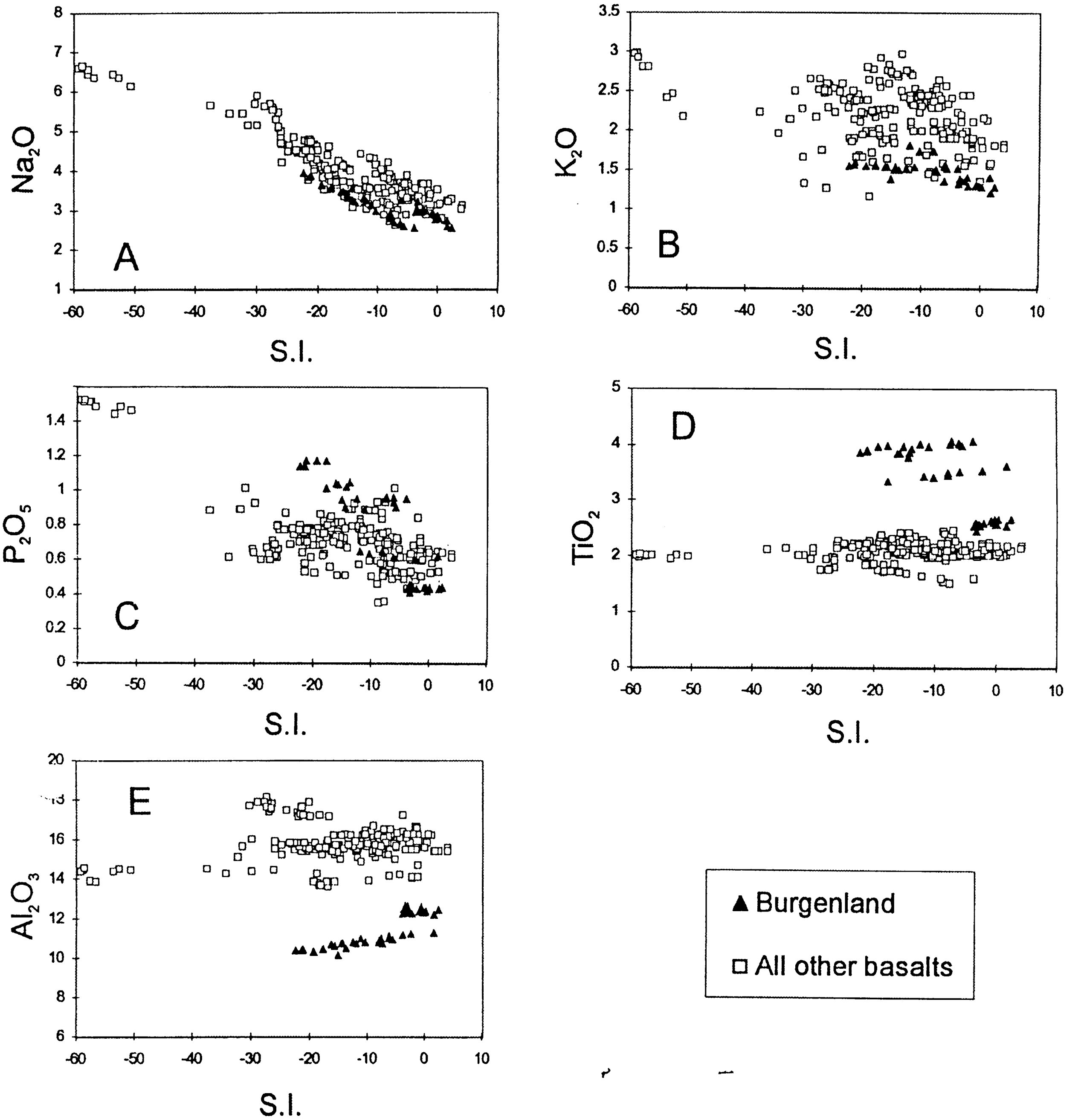

Fig. 3.

A. Weight-% Na_2O vs. Solidification Index (S.I., FITTON et al. 1991) in CPR basalts Solid triangles: Burgenland, open squares: all other basalts; B. Wt% K_2O vs. S.I. in CPR basalts; C. Wt% P_2O_5 vs. S.I. in CPR basalts; D. Wt% TiO_2 vs. S.I. in CPR basalts; E. Wt% Al_2O_3 vs. S.I. in CPR basalts

Primitive mantle-normalized trace element abundances show a general increase of incompatible trace elements with decreasing S.I. or increasing ne. Thus, the highest enrichment of incompatible elements was observed in nephelinites of the Graz Basin (figs. 4, 5). Normalized trace element patterns exhibit a more or less pronounced maximum for Nb with the exception of the lavas from Rákos and several other localities in the Persányi Mountains, Transylvania, that are the only examples to show a slight minimum at Nb. These latter rocks in addition have a strong positive anomaly in their Pb abundance, whereas most other lavas are deficient or only slightly enriched in this element. Compared to average OIB (Ocean Island Basalt), Persányi Mountains basalts are enriched in Ba, Rb, K, and particularly Pb and depleted in other trace elements, especially in Nb. These tendencies are also observable on a smaller scale in the Balaton region (western Pannonian Basin) and in Bánát basalts but are not evident in basalts from Nógrád, Burgenland, and Graz Basin (EMBEY-ISZTIN et al. 1993a, DOWNES et al., in press, DOBOSI et al. in press.).

An important feature of the chondrite-normalized REE patterns (fig. 5) is the increase of the La/Yb ratio with increasing degree of undersaturation. Chondrite-normalized La contents (La_N) range from ~30 to ~200 but YbN only from 4 to 7. Neither of these values is correlated with mg# (not shown).

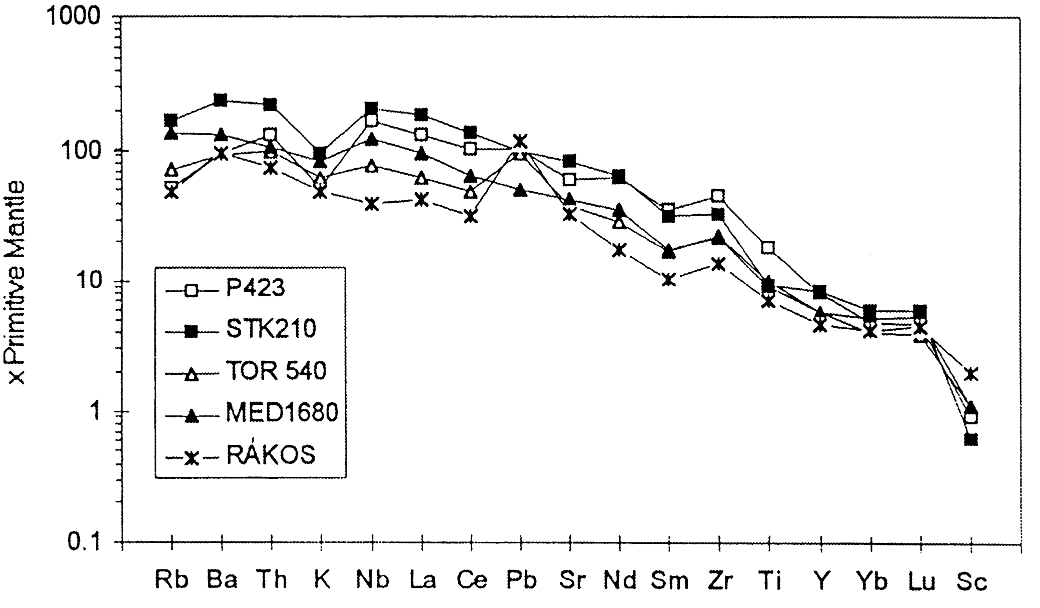

Fig. 4. Mantle-normalized (SUN and MCDONOUGH 1989) incompatible element abundances in CPR basalts
Abbreviations: P: Pauliberg, Burgenland; STK: Stradner Kogel, Graz Basin; TOR: Tormarét, Kabhegy, Balaton region; MED: Medves, Nógrád; RÁKOS: Persányi Mountains

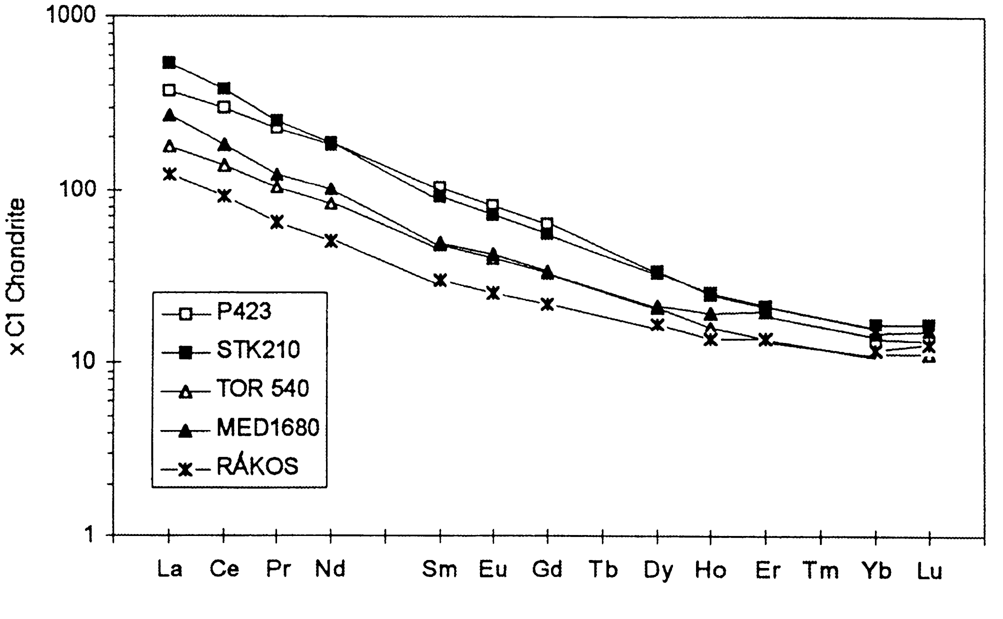

Fig. 5. Chondrite-normalized (SUN & MCDONOUGH 1989) REE abundances of CPR basalts. Symbols as in fig. 4

Isotopic composition of lavas

The young Pannonian alkali basalts occupy an intermediate position in the ranges known so far of Sr, Nd and Pb isotope ratios of basalts from around the world (DUPRÉ & ALLČGRE 1983, SALTERS et al. 1988, EMBEY-ISZTIN et al. 1993a, DOWNES et al. in press, DOBOSI et al. in press, figs. 6, 7). Radiogenic isotope abundances in alkali basaltic rocks from the CPR indicate an enriched upper mantle source and project into the range of OIB (fig. 6). However, some display a peculiarity in their Pb isotope composition by having unusually high ratios of $^{207}Pb/^{204}Pb$ for a given value of the $^{206}Pb/^{204}Pb$ ratio. Consequently, they plot above the Northern Hemisphere Reference Line (NHRL) which has been defined by Hart (1984) based on data for oceanic basalts (MORB + OIB) from the Northern Hemisphere (fig. 7).

Considering all alkali basaltic volcanic fields in the CPR, there seems to be a similar systematic change in isotope ratios with geographic position as shown by the abundances of some trace elements. Lavas from the Nógrád region (northern border of the Pannonian Basin) show the lowest degree of enrichment (are compositionally closest to MORB) and, consequently, have the least radiogenic Nd and Sr isotopes (fig. 6) and a comparatively low $^{207}Pb/^{204}Pb$ ratio with respect to the $^{206}Pb/^{204}Pb$ ratio (SALTERS et al. 1988, EMBEY-ISZTIN et al. 1993a, DOBOSI et al. in press). Several other volcanoes, also situated in the border zone of the basin system, yielded basalt lavas that share more or less similar isotopic characteristics with Nógrád basalts (e.g., Graz Basin). The basalts of the Balaton region (western Pannonian Basin) and Persányi Mountains (eastern Transylvanian Basin) define a contrasting group,

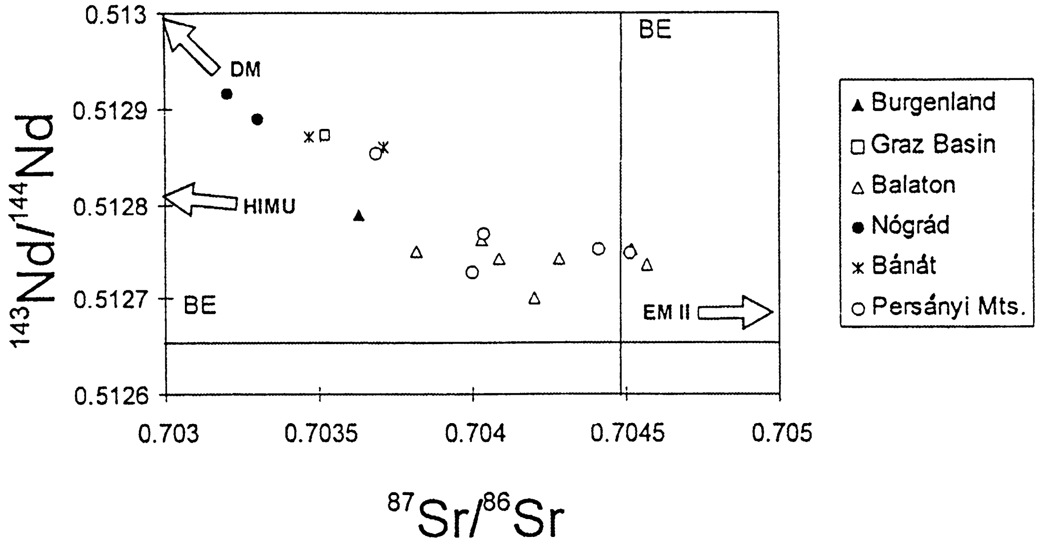

Fig. 6. Sr and Nd isotope variation for CPR young alkali basalts. Data sources: EMBEY-ISZTIN et al. (1993a), SALTERS et al. (1988), DOWNES et al. (in press)

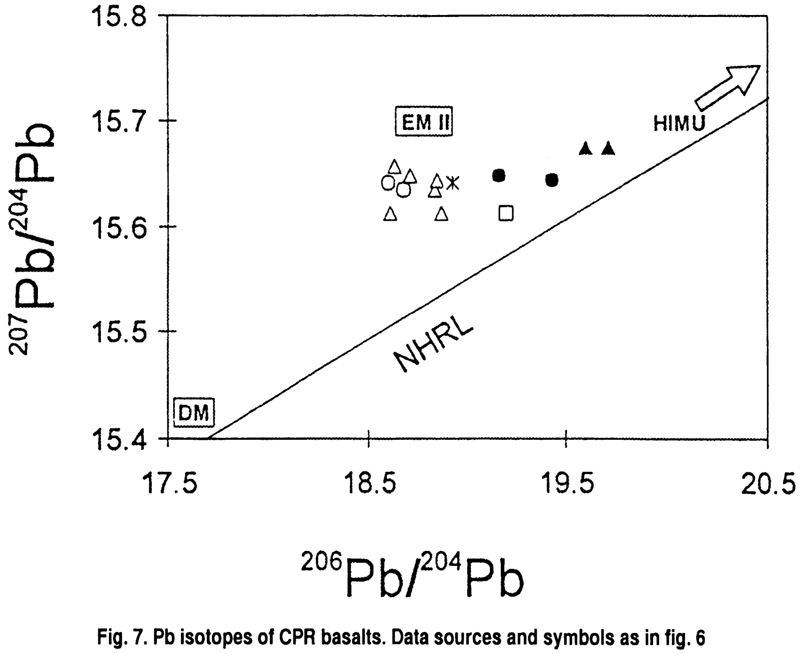

Fig. 7. Pb isotopes of CPR basalts. Data sources and symbols as in fig. 6

characterized by more radiogenic Nd and Sr isotope ratios as compared to the former. Strontium isotope ratios can occasionally be more radiogenic than the Bulk Earth (BE) value, i.e. the isotopic composition of the undifferentiated mantle (fig. 6). In addition, these rocks tend to have highly elevated $^{207}Pb/^{204}Pb$ ratios (fig. 7).

Oxygen isotope abundances of Pannonian alkali basalts are consistent with a mantle source. However, some lavas contain heavier oxygen than that of the average upper mantle, indicating an enriched mantle source (EMBEY-ISZTIN et al. 1993a).

Fractional crystallization

The mg-number of the Pannonian basaltic lavas varies between 54 and 69, but Bondoróhegy (Balaton region) and Rákos (Persányi Mountains) basalts have mg >70. In the latter two cases, however, the basalts are so rich in peridotite xenoliths and xenocrysts that it was impossible to separate a clean sample for analysis. The range of mg-values indicates that a few lavas are primitive, whereas most of them show the effects of fractional crystallization. However, even the most evolved rocks (Graz Basin and Nógrád region) remained basaltic in composition.

The Ni content of the basaltic rocks is positively correlated with the MgO content (fig. 8), suggesting that olivine was a major fractionation phase. There is also an appreciable covariation between the contents of Cr (36—539 ppm) and MgO (not shown) which implies that clinopyroxene and probably spinel fractionation were important as well. The relatively low CaO/Al_2O_3 ratios

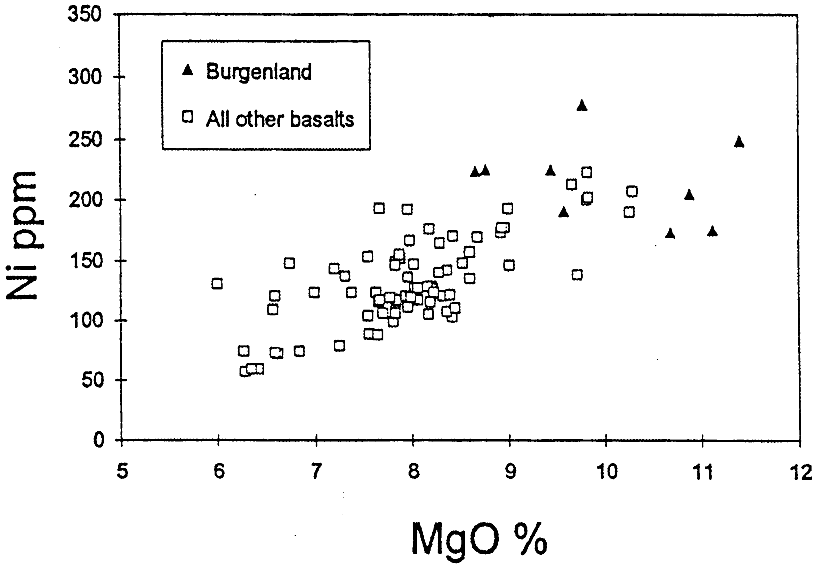

Fig. 8. Abundances of Ni (ppm) vs. MgO (wt%) in CPR alkali basalts

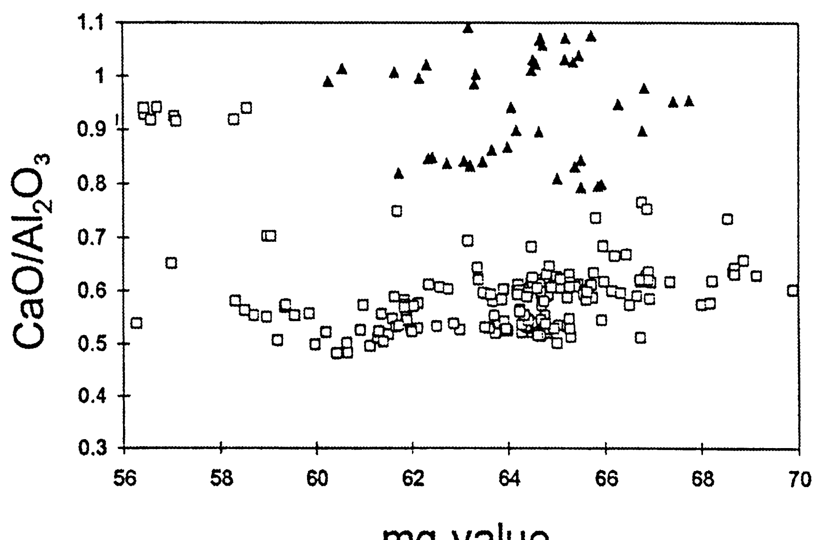

Fig. 9. CaO/Al_2O_3 ratio (wt%) vs. mg of CPR basalts

Solid triangles: Burgenland; open squares: all other basalts (mostly <0.8), which increase slightly with increasing mg (fig. 9), also indicate separation of clinopyroxene. The distinctly high CaO/Al_2O_3 ratios of the Burgenland basalts do not indicate non-differentiation but rather reflect the unusually low alumina contents of these rocks. The general absence of an Eu anomaly (fig. 5) and a negative correlation between Al_2O_3 and MgO (not shown) indicate that there was no significant crystallization and fractionation of plagioclase. This is corroborated by the ubiquitous lack of plagioclase in the phenocryst assemblages. Green-core pyroxenes reflecting polybaric differentiation are only abundant in Graz Basin and Nógrád lavas. Therefore, low-pressure fractionation seems to have been the major differentiation process (DOBOSI 1989, DOBOSI et al. 1991, DOBOSI & FODOR 1992).

Degree of partial melting and depth of magma segregation

It is obvious that the very large range in S.I. (from +5 to -60) cannot be explained by crystal fractionation alone, because there is no correlation between MgO and the S.I.. These variations should, therefore, reflect differences in the conditions of partial melting. The variety of chemical compositions of the basalts thus is likely the result of mantle partial melting at different depths. Partial melts from peridotitic source rocks become more undersaturated with increasing pressure and with increasing partial pressure of CO_2 (THOMPSON 1987, MCKENZIE & BICKLE 1988, EGGLER 1974). The effect of increasing temperature and H_2O is to enhance the silica content in the primary melt (FALOON & GREEN 1988, KUSHIRO 1972). In the CPR basalts, the S.I. is correlated with the abundance of incompatible elements (Fig. 10) and this indicates that the primary melts were produced by variable degrees of partial melting from a peridotitic source. The nephelinites from the Graz Basin have the highest contents of ne (up to 30%), the highest incompatible element concentrations, and an enrichment of LREEs over HREEs [$(La/Yb)_N$ (=chondrite-normalized La/Yb) ~29]. They may have been generated at a deep level by a small degree of melting (probably <<5%) in the upper mantle in contrast to basanites, alkali basalts, and especially olivine tholeiites in the CPR. The $(La/Yb)_N$ decreases progressively with increasing S.I., reaching a value of about 12 in the less undersaturated lavas. These latter rocks should be the products of fairly large degrees of partial melting (probably 3–10%) at shallow levels in the mantle. Whereas the chondrite-normalized La content —$(La)_N$— shows a wide range (88–380), $(Yb)_N$ varies only between 7 and 13. This could indicate variable degrees of partial melting of a garnet-bearing source (EMBEY-ISZTIN & DOBOSI in press). We can additionally constrain the depth of magma segregation from the lithospheric mantle xenoliths delivered by some of the basalts. These are usually garnet-free spinel lherzolites and harzburgites, both, in the Pannonian and Transylvanian Basins (KURAT et al. 1980, EMBEY-ISZTIN et. al. 1989, VASELLI et al. 1995, DOWNES et al. in press). The rare garnet pyroxenites also equilibrated in the spinel peridotite stability field according to available p,T estimates (EMBEY-ISZTIN et al. 1990). Geophysical evidence is consistent with a thin crust and lithosphere, at least in the central area of the Pannonian Basin, where the asthenosphere–lithosphere boundary may currently lie at a depth of <70 km (e.g., ROYDEN & HORVÁTH 1988 and references therein). Combining all these evidences, we believe that the sources of most Carpathian alkali basaltic lavas could be placed into the garnet-spinel transitional zone of the upper mantle, to a depth of about 70 km at a temperature of 1100 °C.

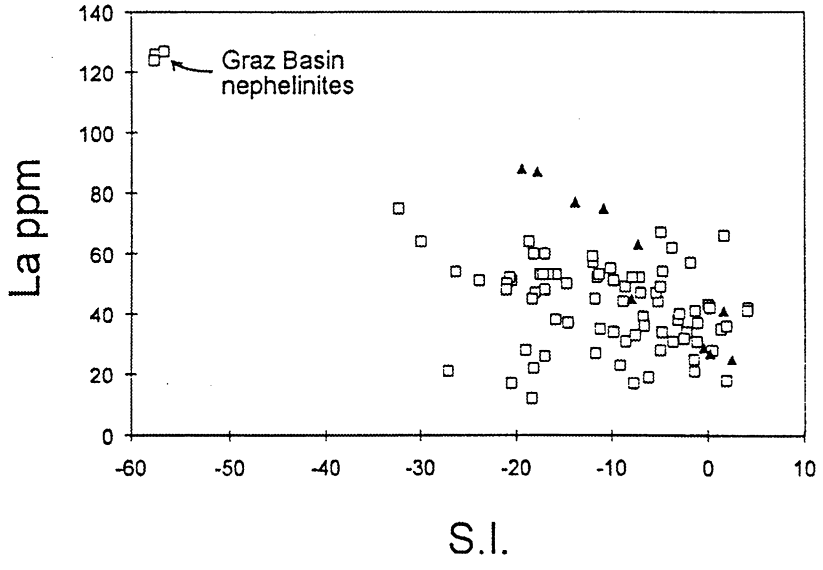

Fig. 10. Abundance of La (ppm) vs. S.I. in CPR alkali basalts. Symbols as in fig. 9

In addition to the different depths and degrees of partial melting and fractional crystallization, compositional heterogeneities of the mantle sources should also be responsible for some of the diversity of trace element compositions and radiogenic isotopic ratios in the basalts of the CPR. For example, Burgenland lavas show distinctly higher abundances of HFSE (Ti, Zr, Hf, Nb, and Ta) than does any other basalt of the Pannonian volcanic province. This feature cannot be explained by partial melting and fractional crystallization alone and, therefore, it should reflect the composition of the mantle source rocks.

Most of the basalts are sufficiently fresh with a low value of $\delta^{18}O$. Differentiation took place to a moderate degree only. Therefore, ratios of trace elements having similar solid-melt distribution coefficients should mirror mantle source composition. Crustal contamination cannot be responsible for the trace element and isotopic variations because of the lack of correlations of isotopic compositions as well as trace element abundances with MgO content. In addition, the presence of ultramafic xenoliths and high-pressure megacrysts in many basalts indicates rapid transition of the lavas through the crust (EMBEY-ISZTIN et al. 1993a).

The main questions are, how many distinct mantle reservoirs are involved, where they are located in the mantle profile, what are their relative contributions to the lavas, and what kind of geodynamical consequences can be deduced from this information. In general, CPR alkali lavas are rich in Nb (fig. 4) and have high primitive mantle-normalized Nb/La ratios (>1.1) (EMBEY-ISZTIN & DOBOSI, in press fig. 11). However, a few exceptions exist, e.g., some of the basalts in the central region (Balaton and LHP) and especially the Persányi Mountains

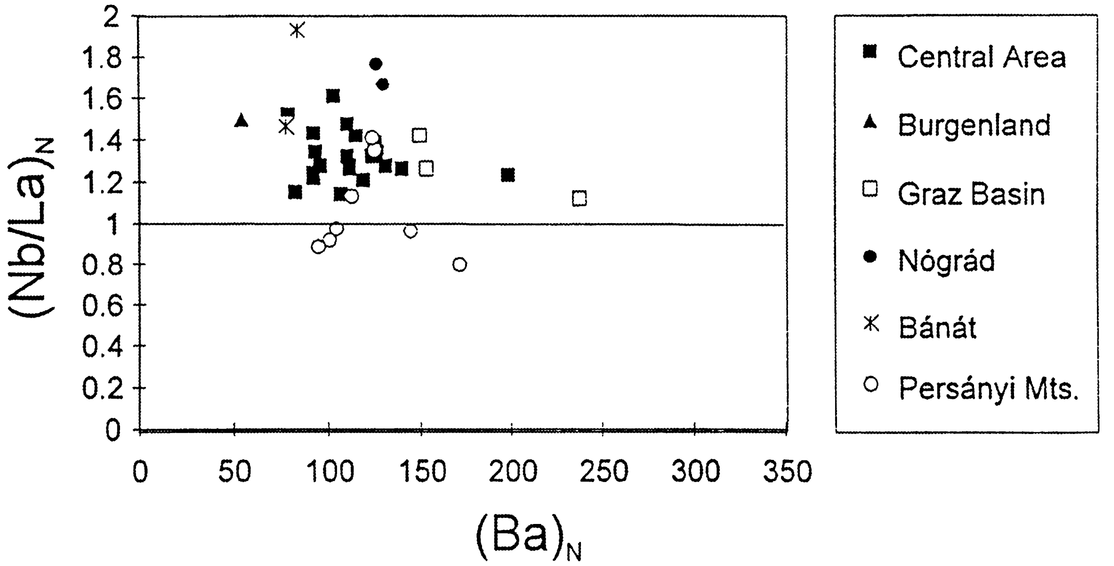

Fig. 11. Mantle-normalized $(Nb/La)_N$ vs. Ba_N of CPR basalts (normalization data from SUN & MCDONOUGH 1989)

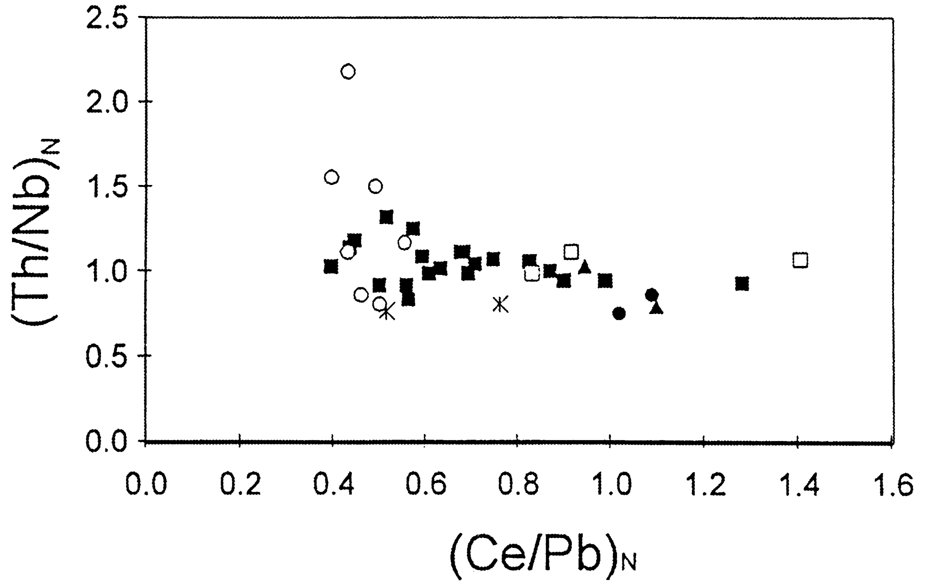

Fig. 12. Mantle-normalized $(Th/Nb)_N$ vs. $(Ce/Pb)_N$ of CPR basalts (normalization data from SUN & MCDONOUGH 1989)

rocks have slightly lower $(Nb/La)_N$, occasionally <1 (fig. 11). In contrast, Nógrád and Burgenland basalts tend to have higher-than-average $(Nb/La)_N$ (up to 1.8). Lavas from these localities, as well as those of the Graz Basin, have high primitive mantle-normalized Ce/Pb ratios (2.1–3.6), whereas the respective values in the central region and Persányi Mountains basalts are distinctly lower (0.2–1.5) (fig. 15). High $(Nb/La)_N$ ratios (>1) and high La/Ba ratios are characteristic features of OIBs derived from the convecting asthenosphere (e.g., WEAVER et al. 1987, FITTON et al. 1991, BRADSHAW et al. 1993). Thus, the fairly high Nb/La ratios of CPR basalts emphasize the OIB affinity of these rocks.

It seems useful to compare the $(Nb/La)_N$ ratios of our basalts with those of Tertiary basalts from the southern Basin and Range (SW USA, BRADSHAW et al. 1993). This province has some key geological features in common with the CPR, such as subduction with calc-alkaline volcanism which was rapidly followed by extension and alkali basalt extrusions. CPR basalts show a close similarity with the high-$(Nb/La)_N$ post-extensional (Group 1) basalts in the southern Basin and Range, whereas the much more voluminous Group 2 pre/syn/post-extensional basalts have distinctly lower $(Nb/La)_N$ ratios (0.2–0.8) than any rock in the CPR. Group 2 basalts were interpreted to have been generated by partial melting of an enriched lithospheric mantle in response to stretching of the lithosphere. Persányi Mountains basalts and several Balaton basalts show transitional features toward Group 2. Other trace element ratios, such as Ce/Pb and Th/Nb (fig. 12), or K/Nb and Rb/Nb (not shown), strongly suggest some mixing between trace element depleted OIB and an enriched component. This latter component is characterized by high Rb/Nb, Th/Nb, K/Nb, and low Ce/Pb ratios and, therefore, it most probably originates from the subcontinental lithosphere. The subcontinental lithosphere is a repository for trace elements deposited by fluids or melts derived from the asthenosphere or from dehydration of a subducted crustal slab (HAWKESWORTH et al. 1986, SAUNDERS et al. 1980, PEARCE 1982). Several features of our basalts indicate that the enriched component may be related to a subduction process rather than to a lithospheric segment modified by asthenospheric fluids or melts. In particular, the slight enrichment of Pb compared to that of Ce (PEARCE 1982) and the mild depletion of Nb compared to elements of similar incompatibility (SAUNDERS et al. 1980) support that view.

Overabundances of Rb, Ba, K, and Sr and an underabundance of Nb relative to common basalts were previously interpreted as to indicate the involvement of a subduction-related enriched lithospheric component in the basic magmas of the western USA (FITTON et al. 1988, 1991). Furthermore, the low $(Nb/La)_N$ ratio Group 2 lavas of the southern Basin and Range are also believed to have originated from the non-convective mantle lithosphere that is capable of sustaining geochemical heterogeneities (trace element enrichment) for a geologically long period of time (BRADSHAW et al. 1993). In summary, trace element ratios that are insensitive to low pressure crystal fractionation and relatively insensitive to the degree of partial melting and which, therefore, reflect mantle source chemistry, strongly suggest that young CPR alkali basic magmas should be primarily dominated by a component coming from the subcontinental asthenosphere. However, figs. 6, 7, and 13 indicate a mixing relation of this asthenospheric component with an enriched component that may be located in the subcontinental lithosphere. This component could have been formed by devolatilisation of a subducting plate.

As shown above, there seems to exist a relationship between some trace element abundances and isotope ratios. Lavas indicating the involvement of an enriched lithospheric component in their bulk chemical composition (low Nb/La, Nb/Th, Nb/K, and Ce/Pb ratios) have isotope ratios typical for enriched sources as well (high $^{87}Sr/^{86}Sr$, low $^{143}Nd/^{144}Nd$, and high $^{207}Pb/^{204}Pb$ ratios relative to a given value of the $^{206}Pb/^{204}Pb$ ratio) as compared to the other rocks. The $^{18}O/^{16}O$ ratio of enriched

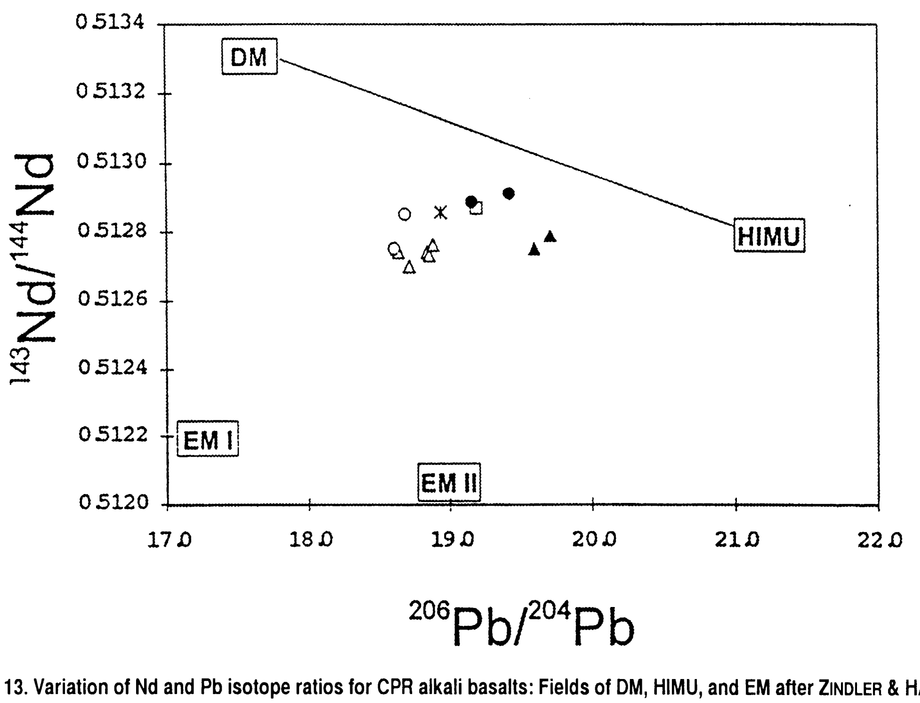

Fig. 13. Variation of Nd and Pb isotope ratios for CPR alkali basalts: Fields of DM, HIMU, and EM after ZINDLER & HART (1986). Data sources and symbols as in fig. 6

rocks is also slightly higher compared to that of basalts with high Nb/La and Ce/Pb ratios (EMBEY-ISZTIN et al. 1993a). Thus, the isotopic evidence confirms our conclusion that the origin of the lithospheric enriched component may be closely related to slab-derived fluids of preceding subduction events. Especially, the high $^{207}Pb/^{204}Pb$ ratio (fig. 7) can be interpreted in this way, because it is a characteristic feature of pelagic sediments (e.g., COUSENS et al. 1994). The Sr-Nd isotope diagram suggests a mixing trend between N-type (normal-type) MORB and enriched mantle (EM) of probably the EMII-type rather than EMI of ZINDLER & HART (1986). EMII-type isotope features seem to have been produced by hydrous agents probably derived from a source of crustal water in a subduction environment. On the other hand, the EMI signature is thought to be associated with the passage of CO_2-dominated fluids originating in the asthenosphere (e.g., COHEN & O'NIONS 1982, MENZIES 1983, CARLSON 1984). Mixing between DM (Depleted Mantle, equivalent to N-type MORB) and EMII and a third component called HIMU (for high $\mu = {}^{238}U/^{204}Pb$) is also indicated by the Pb isotope ratios (figs. 7 and 13).

In principle, excellent constraints on the isotopic and trace element characteristics of the lithospheric end-members are provided by peridotite xenoliths collected by the magmas. However, it should not be forgotten that peridotite xenoliths do not directly come from source regions of the host basalts. Nonetheless, it is highly probable that enrichment processes, that affect both the peridotite xenoliths and the lithospheric source mantle regions of the host basalts, should broadly be similar. There are LREE-enriched clinopyroxenes present in some peridotite xenoliths of the CPR (EMBEY-ISZTIN et al. 1989, DOWNES et al. 1992, VASELLI et al. 1995, DOWNES et al. in press.) and enrichments in radiogenic Sr (without any change in Nd isotope abundances) were found in peridotite xenoliths from the Balaton region. This has been interpreted by DOWNES et al. (1992) as being due to a subduction-component in the mantle, an interpretation that is in agreement with the geochemistry of Balaton lavas. New Pb isotope data showing elevated $^{207}Pb/^{204}Pb$ in Balaton peridotite xenoliths (WILSON et al. in prep.) further strengthen this view. In contrast, peridotite xenoliths from the Persányi Mountains show a depleted mantle signature (non-radiogenic Pb and Sr, and radiogenic Nd) that is clearly at variance with the trace element and isotope signature of lavas in this region (DOWNES et al., in press).

We have concluded that the dominant component in many CPR alkali basalts originated in the asthenosphere. This asthenospheric component is not well constrained, but it appears to be itself a mixture between DM (MORB) and HIMU mantle components (figs. 7, 13). The origin of the HIMU component is debated and propositions range from loss of Pb into the core to recycling of ancient altered oceanic crust or ancient continental crust into the mantle (see HART 1988, and references therein). Anyhow, the participation of this component is clearly indicated by relatively high $^{206}Pb/^{204}Pb$ ratios (up to 19.7) and by the fact, that the least enriched asthenospheric basalts plot close to the mixing line between DM and HIMU (fig. 13). Western and central European Tertiary alkali basalts of the Massif Central, west and east Eifel, as well as SW Poland show a similar compositional range between DM, HIMU, and EM end-members and were also interpreted to be mixtures of these three components by WILSON and DOWNES (1991) and BLUSZTAJN & HART (1989). Moreover, HOERNLE et al. (1995) have quite recently pointed out, that Pb, Sr and Nd isotope data for the Eastern Atlantic, Western Mediterranean, and Central European (including CPR) volcanic provinces converge on a restricted composition inferred to be that of the upwelling asthenosphere. The striking compositional similarity of the asthenospheric end-member within this huge area, with a width of about 2500 km in the NNE direction and an elongation of about 4000 km in the ESE direction, is ascribed to a common sublithospheric mantle source identified by seismic tomography as an inclined sheet of relatively hot mantle upwelling. This sheet is characterized by a low S-wave velocity anomaly (LVA) and, therefore, the component supposedly originating from it is referred to as the low velocity component (LVC). Beside the LVC, a component with low $^{206}Pb/^{204}Pb$ is also present in each geographic region mentioned above. The latter component with highly variable Sr and Nd isotope compositions and $^{207}Pb/^{204}Pb$ ratios in the different volcanic provinces is probably located in the lithosphere or shallowest asthenosphere and reflects different evolution of the lithosphere beneath each region (HOERNLE et al. 1995). Accordingly, we consider that the main difference between CPR basalts and those of the rest of Central Europe seems to lie in the nature of the lithospheric end-member and the extent of the enrichment process. In stable Europe, alkali basalts dominated by a lithospheric component are fairly strongly enriched in incompatible elements with compositional tendencies towards potassic rocks. The similar enrichments of all highly incompatible elements (Rb to Ce in fig. 4) in these rocks may reflect the complete melting of a potassic phase, such as phlogopite, in the mantle source (WILSON & DOWNES 1991). In contrast, potassic rocks are virtually absent among the Neogene alkali basalts of the CPR and enriched basalts of the CPR are depleted in K with respect to similarly incompatible elements. This seems to indicate the presence of a residual K-rich phase, such as amphibole or phlogopite, in the mantle source. The subduction-related signature (low Nb/La and Ce/Pb ratios) has not been noted in west and central European basalts and seems to be restricted to certain areas of the CPR. The recently discovered high $^{207}Pb/^{204}Pb$ ratios in a group of Balaton peridotite xenoliths are also unique; this component is not seen in the mantle beneath other European volcanic regions (WILSON et al. in prep.). This fact suggests that the relatively elevated $^{207}Pb/^{204}Pb$ ratios in Balaton alkali basalts may be inherited from the lithospheric mantle source, whereas, if it is present in basalts of other regions (e.g., Persányi Mountains or Eifel) its origin could be in a component residing outside the lithospheric mantle (probably in the asthenosphere).

A characteristic feature of the young CPR alkali basalts is that the $^{87}Sr/^{86}Sr$ and Rb/Sr ratios do not correlate, whereas such a correlation is discernible in Neogene basalts of stable Europe (fig. 14). This suggests that the incompatible element enrichment of the upper mantle may be old in the second case (according to WILSON & DOWNES 1991, possibly related to the Hercynian orogeny) and fairly young in the case of the CPR basalts. It seems that the time that has elapsed since the enrichment process was insufficient to be reflected in the Sr isotope ratios. This view is in

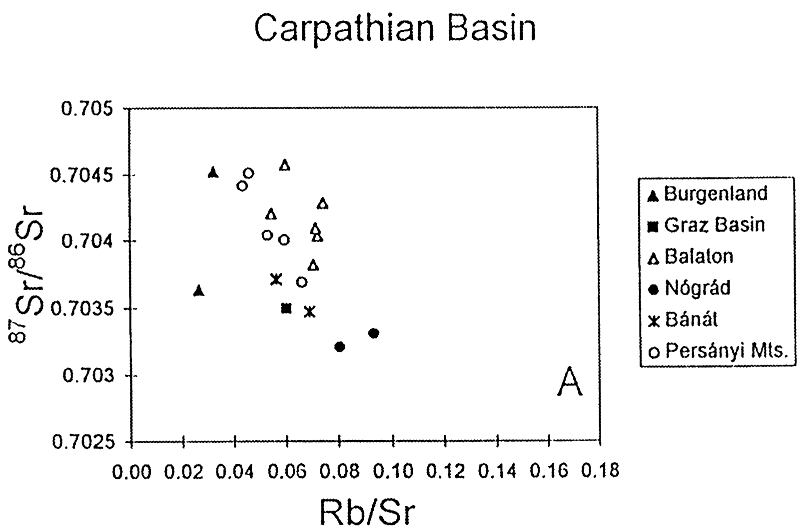

Fig. 14. Sr isotope vs. Rb/Sr ratios for CPR basalts (A) and west and central European basalts (B). Data sources: WILSON & DOWNES (1991), BLUSZTAJN & HART (1989)

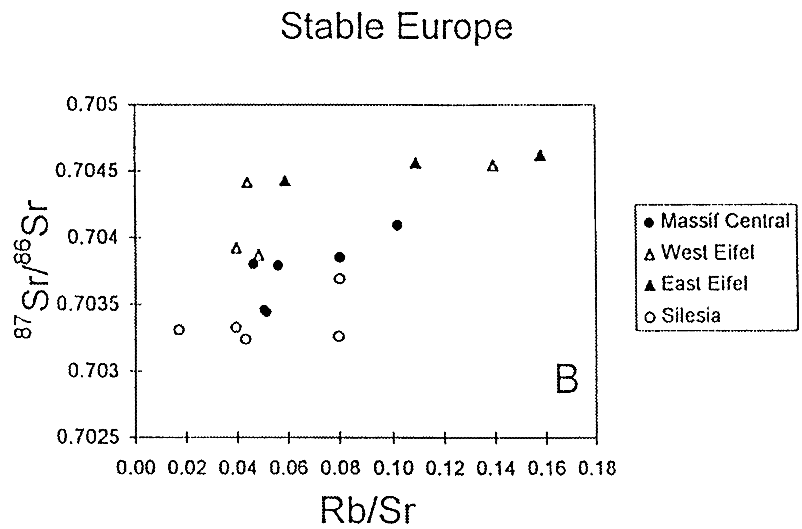

Fig. 15. $(Ce/Pb)_N$ ratio vs. absolute age of CPR basalts

accordance with the fact that in the CPR the latest subduction event is young (Eocene and Miocene). Outside the Alpine–Carpathian mountain system, while on the platform of stable Europe there was no subduction in Tertiary times and, therefore, also no young lithospheric enrichment event.

Conclusions

The young alkali basaltic magmas of the CPR seem to have been primarily generated in the upwelling asthenosphere which we can relate to the common European Astenospheric Reservoir or LVC of HOERNLE et al. (1995). However, a component pointing to a young (Tertiary) subduction-related enrichment of the local asthenosphere is evident in a group of lavas, an indication of the complexity of basalt genesis. Geochemical studies have revealed spatial differences in the relative contributions of the different mantle components. In Burgenland and Graz Basin (western border zone) and in Nógrád (north) the basalts show little evidence of a subduction-related enriched lithospheric component. They seem to be highly dominated by an asthenospheric component. Geochemically these basalts closely resemble their counterparts in western and central Europe. In contrast, Balaton and LHP basalts, and especially, basalts of the Persányi Mountains (eastern Transylvanian Basin) show evidence for an additional contribution by an enriched lithosphere component.

In addition, it is possible that the relative contributions of the two chemically and isotopically distinct components are time-dependent too. In fig. 15, the Ce/Pb ratio (a simple proxy for the enriched lithospheric component) is plotted against the absolute age of the basalts. If we disregard Persányi Mountains magmas (which represent a distinct and unique case), it is evident, that the early alkali basaltic volcanism, which started 11.5 Ma ago, was dominantly asthenospheric in nature and an increase in the relative contribution of the lithospheric component to the lavas can be observed until about 3 Ma ago (minimum Ce/Pb ratio). The youngest lavas seem to be again dominated by the asthenospheric component. This relationship is especially interesting in the case of Balaton and LHP (central area) basalts. The Bondoróhegy lava (the youngest in the Balaton region) is plotted in a different symbol by virtue of its distinct asthenospheric character. This is the only lava that carries an unusually high quantity of large (up to 3–5 kg) peridotite xenoliths, indicating a very rapid ascent through the lithosphere (EMBEY-ISZTIN 1978, EMBEY-ISZTIN et al. 1989). Apparently, this magma had no time to pick up a contamination from the mantle lithosphere during its ascent from the asthenosphere, except for some solid wall rocks.

As mentioned above, the Persányi Mountains alkali basalts represent a special case. They are very young, yet they show a pronounced signal of a subduction-related lithospheric enrichment process. However, in this region the nearby calc-alkaline volcanism is of a similarly young age and because the lithospheric mantle is isotopically depleted (DOWNES & VASELLI in press), it is possible that the enriched component was still residing in the asthenosphere at the time alkali basalt were formed.

The composition — time relationship, as well as the predominance of an asthenospheric component suggest that, in the CPR, alkali basaltic volcanism was initiated by individual partial melting events in the asthenosphere. This is in agreement with the conclusions reached from theoretical considerations by MCKENZIE & BICKLE (1988) that the site of magma generation in continental rift zones must be confined largely to the convecting asthenosphere. The lithosphere beneath the central area of the CPR is unusually thin (60–70 km, ROYDEN & HORVÁTH 1988) which is in agreement with an adiabatic partial melting in the ascending asthenosphere. Primary magmas may have been generated within the asthenosphere, or at the base of the lithosphere, as a consequence of decompression during lithospheric extension. The HIMU signature (high $^{238}U/^{204}Pb$ mantle end-member) may be indicative of a plume-type component rather than a normal asthenospheric (MORB-type) component. However, the small volumes of basaltic lavas and low eruption rates do not support the idea of an asthenospheric upper mantle having a considerably higher-than-normal temperature, which is often considered a feature of mantle plumes believed to be derived from the core–mantle boundary. This inconsistency may be explained by the model of HOERNLE et al. (1995), because the LVA is either exclusively an upper mantle feature, or it is a transient feature which has been disconnected from a deep source for a geologically long time. According to these authors, if the LVA is just an upper mantle feature fed from the boundary layer between the upper and lower mantle, this could explain why more extensive volcanism in western and central Europe is absent and why continental rifting is still incipient (e.g., Rhine Graben). In addition, we do not have sufficient information on the volumes of the non-erupted portion of the magmas generated. Various features, especially high ambient temperature in the lower crust and a 5 km thick seismic crust–mantle transitional zone beneath the Balaton region, indicate that significant volumes of magma may have intruded the uppermost mantle and the lowermost crust as dykes and sills (EMBEY-ISZTIN et al. 1990). The possible involvement of a mantle plume in the formation of CRP volcanics reinforces the hypothesis that extension of the lithosphere was probably initiated by a mantle plume ("active rift").

Trace element and isotope data indicate that magmas ascending from the asthenosphere were modified to varying degrees by interaction with a lithosphere, that had previously been enriched by a Tertiary subduction event. Interactions of this type may involve simple mixing of asthenospheric and lithospheric partial melts or diverse solid–fluid reactions, such as zone refining. The rising magma transports heat into the lithosphere and may, therefore, trigger partial melting of lithospheric domains having been enriched in incompatible elements and which led to a lower-than-normal solidus temperature. Because the lithosphere is thinnest beneath the central area of CPR (Balaton, LHP), the heating of the lithosphere by the asthenospheric diapir may have been more effective there than below the regions of Nógrád, Burgenland, and the Graz Basin, leading to an efficacious admixing of the lithospheric component. Alternatively, this picture could simply reflect differences in the amplitude of enrichment of the lithosphere beneath different areas of the CRP.

Acknowledgements

The present review is a result of a fruitful collaboration with HEINZ G. SCHARBERT, HILARY DOWNES, BRIAN G. J. UPTON, HERBERT PALME, and many others in the near past. Dodie James has helped extensively in major and trace element analysis, whereas G. A. INGRAM & R. S. HARMON have provided isotope analyses. The research of A. E-I. was supported by Hungarian Scientific Research Fund (OTKA) grants 2026 and 13976, G. K. acknowledges support by the Austrian "Fonds zur Förderung der wissenschaftlichen Forschung" (projects no. 3440 and 4773).

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ADVANCES
in
Austrian—Hungarian Joint Geological Research
Budapest, 1996

Thermal history of Austroalpine basement rocks of the borehole Fertőrákos-1004, Western Hungary

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Keywords: geochronology, fission track dating, Variscan and Alpine metamorphism, thermal history, borehole Fertőrákos-1004

Abstract

The borehole Fertőrákos-1004 offered an excellent opportunity for investigating a section of more than 1000 m of crystalline rocks near the Hungarian-Austrian boundary, where outcrops are rare and poorly preserved.

The lithological column studied shows more or less well preserved Variscan structures and metamorphic mineral assemblages in the lower part, made up of two-mica medium grained plagioclase gneisses with some amphibolite intercalations in the deepest portion. Alpine overprint is restricted to a fluid driven static alteration of plagioclase, formation of fine grained garnets and Ti loss from biotite laths.

The upper portion is characterized by fine grained phyllitic micaschists with strong Alpine penetrative overprint and some acid orthogneiss intercalations.

Rb/Sr (339±4, 287±3 Ma) and $^{39}Ar/^{40}Ar$ (>300 Ma) data from coarse grained white micas especially from the lower portion prove the Variscan metamorphism and cooling event. Biotites and partly also white micas which have been newly formed during early Alpine metamorphic overprint yielded $^{39}Ar/^{40}Ar$ ages mainly in the range 170–220 Ma. They show partly plateau type patterns with some rejuvenation. These ages are interpreted as strong arguments for the existence of surprisingly uniform ^{40}Ar overpressure during the formation of these micas. Only a few samples of biotites yielded Cretaceous $^{39}Ar/^{40}Ar$ age.

The existence of ^{40}Ar overpressure in large rock volumes at the time of deformation, mineral growth and cooling gives a strong argument that this argon overpressure was produced during nappe stacking in an active continental margin setting. In the course of this process frontal and cool parts of the Austroalpine crystalline (Wechsel unit) were dragged below the Semmering system, which has seen slightly higher thermal overprint and a distinctly more intense deformation.

The radiogenic argon released during this process was incorporated in most of the rocks of the Semmering system while cooling down from 450–300 °C, most probably in late Cretaceous times (biotite Rb/Sr 72 Ma).

A rapid cooling is indicated by somewhat older zircon fission track ages and mainly by apatite fission track ages about 43±2.3 Ma. This rapid cooling is correlated with a distinct uplift of the Wechsel dome during which several low-angle detachment faults were active.

Zusammenfassung

Die Tiefbohrung Fertőrákos-1004 bietet eine hervorragende Möglichkeit ein mehr als 1000 m mächtiges Profil im Kristallin entlang der ungarisch–österreichischen Grenze zu studieren, wo Aufschlüsse selten und schlecht erhalten sind.

Die lithologische Abfolge besteht im tieferen Teil aus mittelkörnigen Zweiglimmerplagioklasgneisen mit einigen Amphiboliteinschaltungen im tiefsten Bereich. Diese Gesteine weisen mehr oder weniger gut erhaltene variszische Strukturen und Mineral-Assoziationen auf. Die alpidische Überprägung ist durch eine fluidgesteuerte, statisch ablaufende Zersetzung der Plagioklase, Neubildung feinkörniger Granate, und Entmischung von Titanphasen in den Biotiten charakterisiert.

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Der obere Teil des Profils besteht aus feinkörnigen phyllitischen Glimmerschiefern mit intensiver penetrativer alpidischer Durchbewegung und Einschaltungen einiger saurer Orthogneise.

Rb/Sr (339±4, 287±3 Ma) und $^{39}Ar/^{40}Ar$ (>300 Ma) Altersdaten von grobkörnigen Hellglimmern aus dem tieferen Abschnitt der Bohrung belegen ein variszisches Metamorphose- und Abkühlereignis. Biotite und z.T. auch Hellglimmer, die während der alpidischen Überprägung neugebildet wurden, haben $^{39}Ar/^{40}Ar$-Alterswerte zwischen 170 und 220 Ma ergeben. Sie zeigen teilweise plateauartige Altersdiagramme mit Verjüngungen im Niedrigtemperatur–Bereich. Diese Ergebnisse werden als klarer Hinweis auf einen überraschend einheitlichen Ar-Überschuss während der Neubildung dieser Glimmer gesehen. Nur wenige Biotite haben kretazische $^{39}Ar/^{40}Ar$ Alterswerte geliefert.

Das Vorhandensein von Ar-Überschuss in grossen Bereichen während Deformation, Mineralneubildung und Abkühlung liefert ein deutliches Argument dafür, dass dieser Ar-Überschuss während Deckenstapelung im Zuge der Ausbildung eines aktiven Kontinentalrandes stattfand. Im Zuge dieses Prozesses wurden frontale und kühle Teile des ostalpinen Kristallins (Wechselkristallin) unter das Semmeringsystem geschoben, das eine etwas höhere thermische Überprägung und deutlich intensivere Deformation aufweist. Das radiogene Ar, das im Zuge dieses Prozesses aus den tiefen Teilen freigesetzt wurde, wurde hauptsächlich im Kristallin des Semmeringsystems während seiner Abkühlung von 450–300°C eingebaut und zwar offensichtlich in spätkretazischer Zeit (Rb/Sr Biotit 72 Ma).

Eine weitere rasche Abkühlung ist hauptsächlich durch Apatit-Spaltspurenalter um 43±2.3 Ma und etwas ältere Zirkon-Spaltspurenalter dokumentiert.

Összefoglalás

A Fertőrákos-1004. sz. fúrás, amely a magyar–osztrák határ közelében mélyült, ahol csak kevés és rossz minőségű kibúvás van, kitűnő lehetőséget biztosított egy több, mint ezer méter vastag kristályos kőzetösszlet vizsgálatára.

A vizsgált kőzetoszlop alsó szakaszára, mely kétcsillámú középszemű plagioklászgneiszből áll, legalul néhány amfibolit közbetelepüléssel, többé-kevésbé jól megőrződött variszkuszi szerkezet és metamorf ásványegyüttes jellemző. Az alpi hatás csak a plagioklász fluidum-okozta statikus elváltozására, finomszemű gránát képződésére és a biotitlécek titán-vesztésére szorítkozik.

A felső szakaszra finomszemű fillites csillámpala jellemző, erőteljes penetratív alpi hatással és savanyú ortogneisz közbetelepülésekkel.

A Rb/Sr (339±4, 287±3 Ma) és $^{39}Ar/^{40}Ar$ (>300 Ma) kormeghatározások, amelyek durvaszemű fehér csillámokból készültek az alsó szakaszból, variszkuszi metamorfózist és lehűlést bizonyítanak. A kora-alpi metamorf hatásra újonnan képződött biotitok és részben fehér csillámok is 170–220 Ma időközbe eső koradatokat adtak. Részben plató-jellegű kordiagramot mutatnak némi megfiatalodással. Ezek a koradatok nyomós érvnek tekinthetők arra, hogy meglepően egyöntetű ^{40}Ar túlnyomás állt fenn e csillámok képződésekor. Csupán néhány biotitminta adott kréta kort.

^{40}Ar túlnyomás léte nagy kőzettömegekben a deformáció, ásványnövekedés és lehűlés idején határozottan amellett szól, hogy ez takarófeltolódás során, aktív kontinensszegélyen jött létre. Ennek folyamán az ausztroalpi kristályos (a Wechsel-egység) homloki és hideg részei vonszolódtak be a Semmering-rendszer alá, amely kissé erősebb hőhatást és határozottan erőteljesebb alakváltozást szenvedett. Az e folyamat során felszabadult radiogén argon jórészt a Semmering-rendszer kőzeteibe záródott be a 450–300 °C-ról való lehűlés során, minden valószínűség szerint az alsó krétában (Rb/Sr kor: 72 Ma).

Gyors lehűlésre utalnak a valamivel magasabb cirkon hasadásinyom-korok, valamint az apatit hasadásinyom-kora (kb. 43±2.3 Ma).

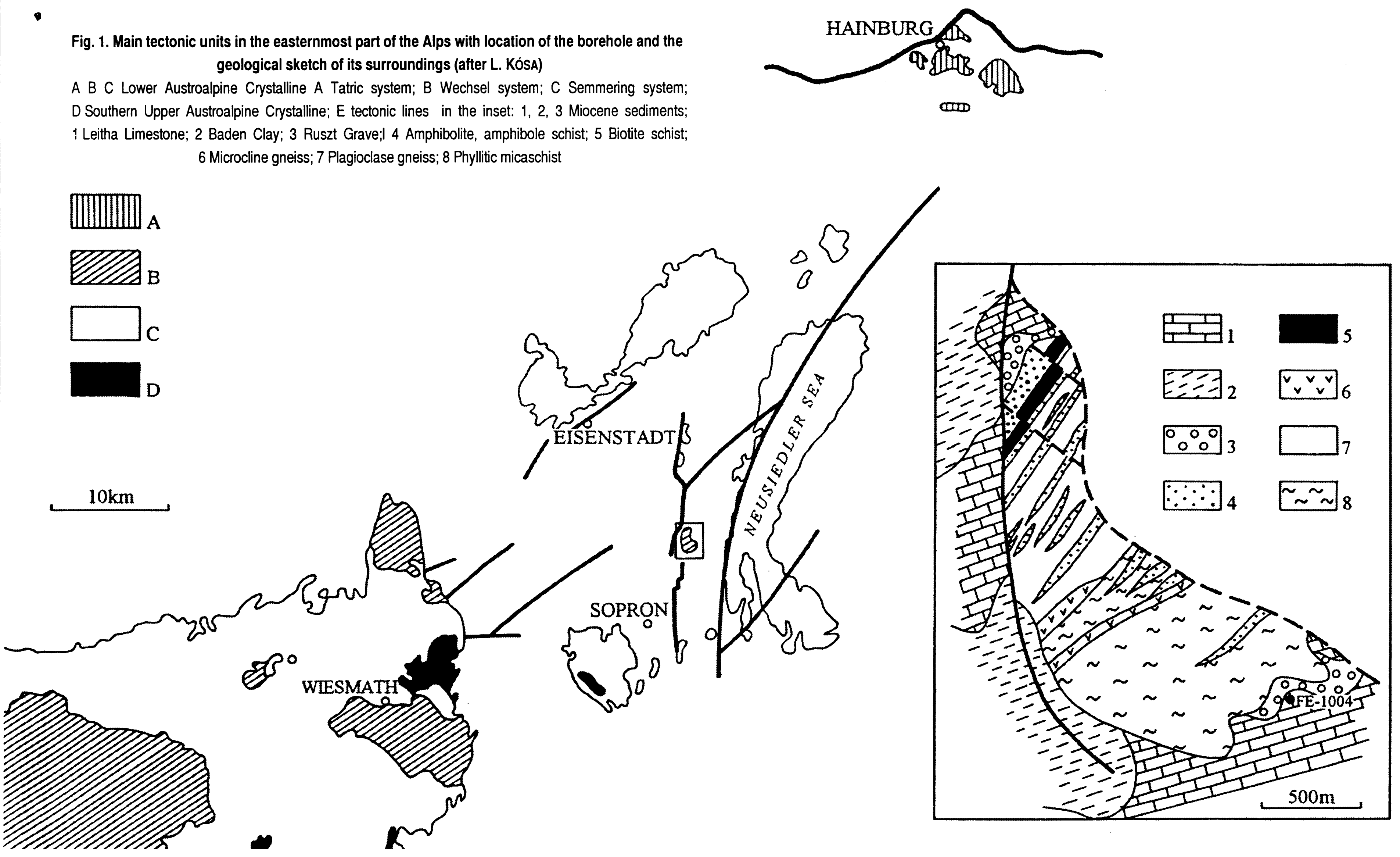
Introduction

To the SW of Lake Fertő (Neusiedler See), close to the boundary with Austria basement rocks outcrop in Hungary over an area of a few km^2. The basement rocks are highly weathered in the outcrops, however numerous drillings explored them to a depth of about 2000 m. Metamorphic rocks have a general dip to SE, the deepest portion plunges steeply to SE (70–80°) and upper horizons have a more gentle (20–25°) inclination. This basement is unconformably overlain by Miocene sediments. For the depositional age of the protoliths of these metamorphic rocks no fossil evidence is available.

The borehole Fertőrákos-1004 (FR) with a total depth of 1091 m crosscuts all the main rock units of this basement. The main tectonic units in the investigated area with the location of the borehole are shown in fig. 1. The main purpose of this study is to gain a better understanding of the metamorphic and uplift history of this basement by petrographical, geochronological and fission track methods and to correlate them with those of the surrounding areas.

Fig. 1. Main tectonic units in the easternmost part of the Alps with location of the borehole and the geological sketch of its surroundings (after L. KÓSA)

A B C Lower Austroalpine Crystalline A Tatric system; B Wechsel system; C Semmering system; D Southern Upper Austroalpine Crystalline; E tectonic lines in the inset: 1, 2, 3 Miocene sediments; 1 Leitha Limestone; 2 Baden Clay; 3 Ruszt Grave;l 4 Amphibolite, amphibole schist; 5 Biotite schist; 6 Microcline gneiss; 7 Plagioclase gneiss; 8 Phyllitic micaschist



Geological setting

Eastern Lower Austroalpine units outcrop in Hungary near Sopron and Lake Fertő, with Miocene sedimentary cover. In the Sopron area acidic gneisses, different micaschists, metaquartzites and leukophyllites occur. LELKES-FELVÁRI et al. (1984) proposed a three-stage evolutional model for this basement, which is generally considered to belong to the Raabalpen or Semmering system (called also Grobgneiss or Kern Serie).

Near Lake Fertő metamorphic rocks are known mainly from boreholes. KÓSA & FAZEKAS (1976) differentiated three main units: a lower unit, made up of amphibolites and biotite schists, a middle feldspar bearing micaschist unit, with intercalations of amphibolites. Rocks of very high apatite content (up to 70–80%) make up lenses of a few tenth of cm in several horizons. High organic content in some metapelites is also characteristic. Phyllitic micaschists with intercalations of gneisses, marbles, metaquartzites and leukophyllites make up the uppermost unit. They correlated this basement with the Wechsel series, as described by FAUPL (1972).

In the Austrian part, granite gneisses and garnet-bearing retrogressed phyllitic micaschists outcropping near Mörbisch were considered by FUCHS (1965) to belong to the Kernserie and the albite-chlorite gneisses near Silberberg and Oslip to the Wechsel series.

As concerns the age of metamorphism of these units, from the Sopron area the following geochronologic data are available obtained by Rb/Sr method (KOVÁCH & SVINGOR 1988): — model ages of coarse-grained muscovites coming from muscovite gneisses in the range 205–281 Ma. — Fine-grained muscovites yielded 90–98 Ma. — Model ages of biotites from metagranites scatter in the range 41–55 Ma.

BALOGH & DUNKL (1994) carried out K/Ar dating, — coarse-grained muscovites from gneisses yielded age values in the range 109–160 Ma, fine-grained ones in the range 84–91 Ma.; biotites from metagranites fall in the range 79–101 Ma.

From the Fertőrákos area a Rb/Sr mineral isochron age of 351±9 Ma was obtained on coarse-grained muscovites; biotite ages scatter in the range 90–121 Ma. (KOVÁCH & SVINGOR 1981).

Structures and lithology

The lithological column of the borehole is shown in fig. 2. According to meso- and microscopic observations the metamorphic rocks belong to two different units both displaying polymetamorphic character; they are separated by thrust plains. The lower unit is a succession of interlayered medium-grained two-mica plagioclase gneisses and amphibolites, with subordinate amphibole gneisses and orthogneisses. In the upper unit phyllitic micaschists prevail with intercalated quartzphyllites, amphibolites and microcline augengneisses in three banks. Organic content is high in some levels. In general the two groups have tectonic contact at 460 m.

The main difference between these two units is the different deformational history during the Early Alpine stage of their metamorphic evolution. Microphotos of thin sections (figs 3, 4, 5) illustrate the textural variations.

In the lower unit pre-Alpine fabric is generally preserved (earlier metamorphic structures, and partly that of protoliths), minerals change their composition rather than distributions. New minerals are minute and do not change the earlier textures. Complete mineralogical-textural reorganization is restricted to thin shear zones.

In the upper unit ductile deformation and syntectonic recrystallization have resulted in a new penetrative schistosity in different rock-types. In some layers completely new structures developed. In others some of the overprinted structures survive: earlier foliations, remnant hinges of crenulation defined by mica orientations, inclusion trails in different minerals, distribution of an earlier mica generation. Beside microstructures relic mineral phases also occur.

However it would be too simple to interpret the whole section as a superposition of two individual units. The tectonism is more complicated. No intercalation of Permo–Mesozoic rocks was recognized, but there are several observations of tectonic intercalations of special lithologies which had a different metamorphic structural

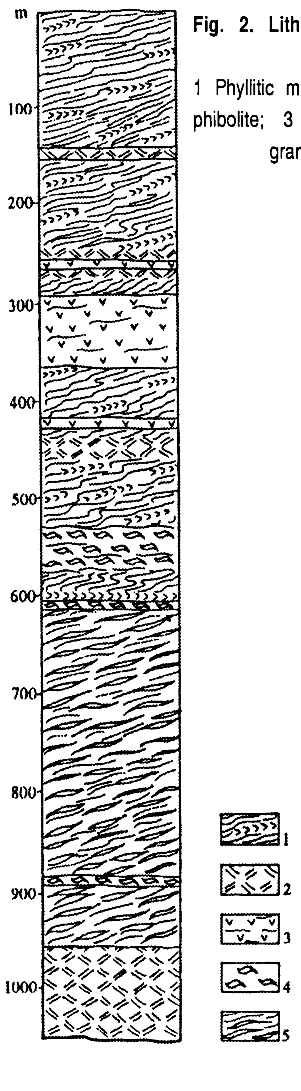
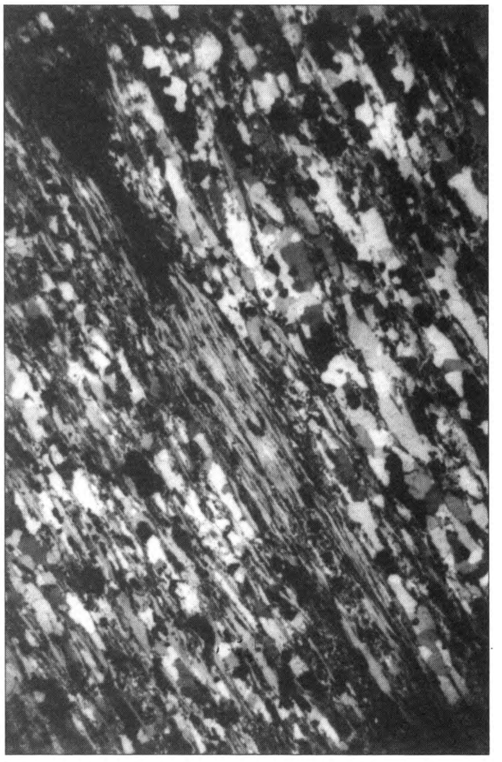


Fig. 2. Lithological column of the borehole FR-1004

1 Phyllitic micaschist; 2 Epidote-amphibolite, amphibolite; 3 Microcline augengneiss; 4 Metagranodiorite; 5 Plagioclase gneiss

A



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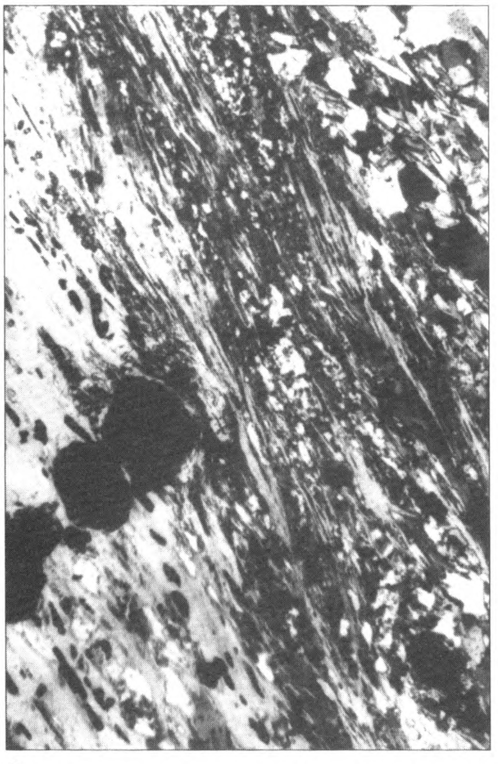

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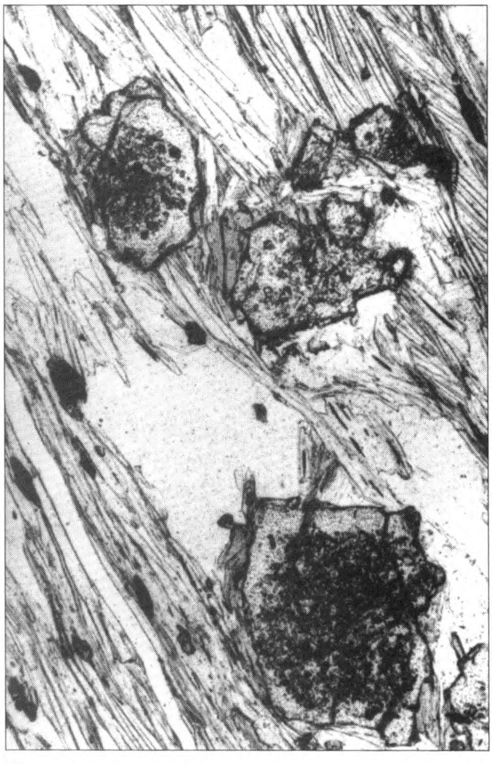


D

Fig. 3A–D

A. FR-1004 142 m, phyllitic micaschist. In hinge regions of relic crenulations mosaic of recrystallized micas replace bent bundle of crystals 32.5x B. FR-1004 186 m, garnet bearing biotite-muscovite phyllite. Subgrains with smooth grain boundaries in quartz ribbons. They are surrounded by a microcrystalline quartz+sericite+biotite+albite matrix. Coarser micas are dispersed or make up thin layers. 9.8x C. FR-1004 210 m, garnet bearing chlorite-muscovite schist. Garnet idioblasts and ilmenite needles set in a layer of coarse muscovite with a high degree of preferred orientation. Thin sheared layers are composed of quartz+albite+sericite+chlorite. 32.5x D. FR-1004 223 m, garnet and epidote bearing biotite-muscovite schist. Garnet idioblasts with incusion rich core and incusion free rims. A second phase of garnet growth on garnet crystal face outlined by opacitic dust (upper left). 65x

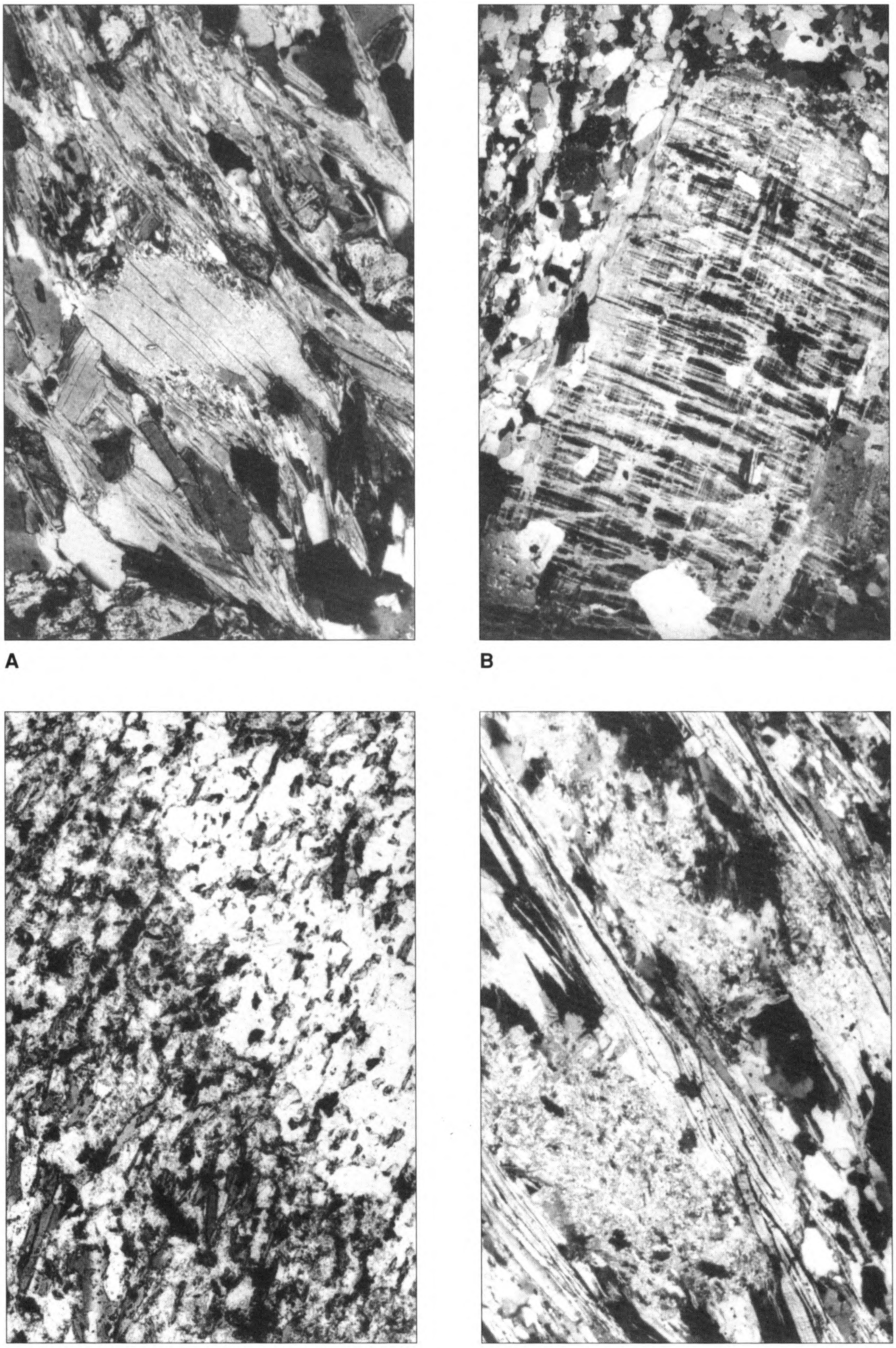


Fig. 4A–D

A. FR-1004 276 m, phyllitic micaschist. Coarse muscovite porphyroclast ("muscovite fish") with irregular grain boundaries with tails of cataclased and recrystallized fine grained mica. 65x; B. FR-1004 327 m, microcline augengneiss. Perthitic potash feldspar microaugen with albite and quartz inclusions set in a fine grained mosaic composed of quartz+albite+muscovite+biotite. 9.8x; C. FR-1004 609 m, biotite schist. Schistosity at a high angle to compositional layering. In quartz rich bands the grain size of biotite is smaller than in feldspar+biotite rich bands. Feldspar completely recrystallized in epidote+sericite. Biotite is crowded with opaque reaction products along margins of crystals. 32.5x; D. FR-1004 673 m, sericite pseudomorphs after plagioclase in muscovite gneiss. 32.5x

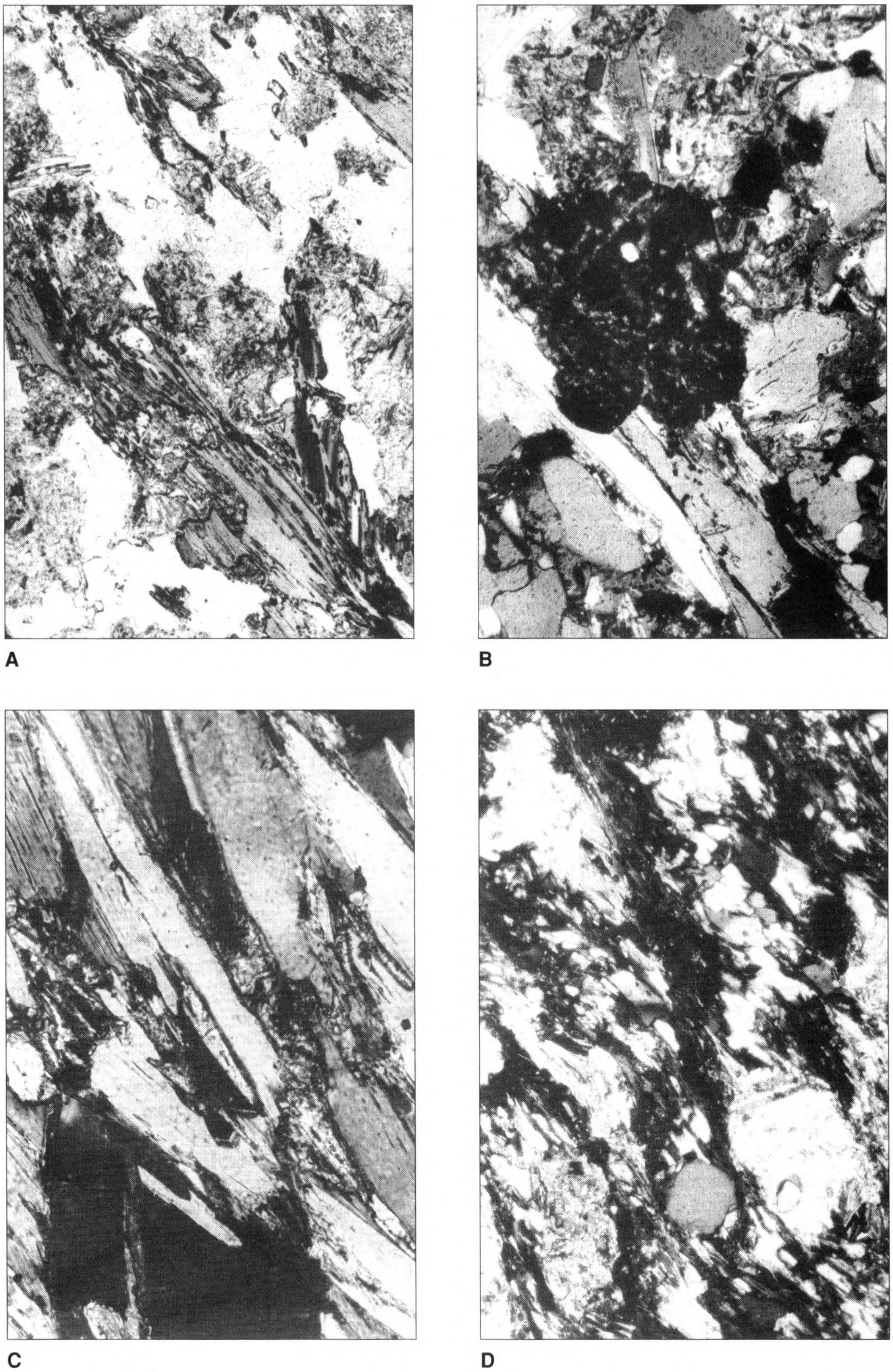


Fig. 5A-D

A. FR-1004 720 m, biotite-muscovite gneiss. Epidote+sericite+biotite+chlorite pseudomorphs after plagioclase. Biotite is partly chloritized with Fe-Ti exsolution along cleavage planes. 32.5x; B. FR-1004 745 m, biotite-muscovite gneiss. Sericite+biotite+quartz+garnet replace plagioclase. Garnet postdates muscovite-biotite crystal face. 65x; C. FFy 004 745 m, biotite-muscovite gneiss. Clinozoizite and sphene needles along biotite crystal margins. 130x; D. FR-1004 1094 m, albite-chlorite gneiss. Lens- shaped albite and polycrystalline quartz+albite lenses with assymmetrical pressure shadows in anastomosing seams of chlorite. 65x history than the surroundings. Such intercalations occur at 400–460 m and at 609 m. It was not possible to deduce the detailed orientation of the linear fabric, because the drillcores had not been oriented. We think that a considerable part of the observed textures were formed during Cretaceous nappe stacking, but from comparison with neighbouring outcrops (e.g. Sopron area), we have to assume that several low-temperature shear zones and deformational features were formed in the prominent early Tertiary extensional phase.

Petrographic description of the analysed samples

184–186 m. Fine-grained biotite-muscovite phyllite. It has an entirely newly formed Alpine fabric. Its penetrative parallel foliation is expressed by elongated quartz+feldspar rich aggregates and mica-rich layers of highly preferred orientation. Phyllosilicates are also dispersed in the quartz+feldspar rich domains. Former plagioclase crystals recrystallized in albite, biotite, sericite and tiny euhedral garnets. Muscovite and biotite occur in two generations: a very fine-grained generation is associated to feldspars or appears as very thin layers around a coarser generation of micas. Garnets occur as deformed crystals with s_i to a high angle to s_e. They often have elongated pressure shadows composed of biotite and chlorite. Euhedral garnets together with the deformed ones often have inclusion-rich cores and inclusion-free rims. Garnet atolls with a central part composed of biotite+chlorite also occur. Accessory minerals are apatite, epidote, and sphene aggregates around ilmenite.

210 m. Muscovite quartz-phyllite. This is a fine grained layered rock with strong structural reworking. Muscovite laminae with a high degree of preferred orientation alternate with granoblastic quartz rich layers in a millimetric scale. The granoblastic layers are of various mineralogy: -albite+minor mica, -quartz, -quartz+mica, -quartz+albite+garnet. Chlorite and subordinately muscovite flakes are randomly oriented. The muscovite layers contain also a few randomly oriented muscovite and chlorite flakes, dispersed albite and garnet. The albite makes up small, inclusion-free idioblasts and more robust crystals with muscovite and chlorite inclusions, sometimes polycrystalline lenses. Garnet xeno -hypidioblasts have inclusion-rich core and inclusion-free rim. Late microshear zones resulting in grain size reduction, composed of quartz+sericite, are parallel with the main foliation.

276.4 m. Phyllitic biotite-muscovite micaschist with a slight layering and two distinct schistosity planes. The structure is dominated by a younger deformation-crystallization event. Quartz+albite bearing granoblastic layers and elongated lenses containing dispersed mica flakes alternate with arcuate lepidoblastic layers composed of muscovite and biotite, containing subordinate quartz and albite. They crosscut a faint older schistosity delineated by coarse, deformed muscovites of irregular grain boundaries. Albite sometimes have inclusion rich core and a clear rim. Chessboard albite also occur. Garnet suffered postcrystalline deformation, with chlorite, epidote and biotite in their pressure shadows. Dispersed euhedral epidote occur in micaceous layers.

325, 327–328 m. Microcline augengneiss. Micro-augens up to 1 cm (mainly 3–5 mm) are set in a fine-grained mosaic which is composed of quartz+albite+microcline+muscovite+biotite. Microaugens are mainly polycrystalline twinned perthitic microclines (braid and string perthite) enclosing corroded or euhedral albite crystals with sericitic cores and xenoblastic quartz. Strongly sericitized albite makes up smaller microaugens. Thin, arcuate, anastomosing mica seams around augens are composed of decussate muscovite and subordinate biotite. More robust muscovite grains are dispersed in the groundmass or in the mica-rich seams, they are deformed, have irregular grain boundaries and contain small decussate muscovite flakes along grain boundaries. Garnet is present as small idioblasts in micas or plagioclase or make up glomeroblasts composed of small idioblasts or atoll-like crystals in quartz-rich domains. Sphene, apatite, zircon, epidote and carbonate are the accessory minerals.

609–610 m. Biotite gneiss. Compared to other lithologies, this rock exhibits a rather finegrained fabric. Biotite and feldspar rich layers are alternating in the scale of a few mm to a few cm of thickness. The grano- and lepidoblastic layers are slightly folded and an axial plane schistosity crosscuts at a high angle the compositional layering. Granoblastic layers are composed of quartz+albite+biotite. Lepidoblastic layers are made up of biotite and former plagioclase completely altered to sericite+epidote. A few muscovite flakes are intergrown with biotite. Biotite is bordered by tiny sphene idioblasts.

720, 742, 745, 747 m. Medium grained two-mica plagioclase gneiss. Structural reworking is restricted to very thin (0.1–0.2 mm) shear plains mostly parallel to the existing foliation. These Alpine deformational planes are visible only on the broken surfaces of the drillcores where coarse relictic mica flakes are visible in fine grained surfaces. This feature is practically invisible in thin section perpendicular to foliation. These rocks are slightly layered sometimes with microaugen texture, their penetrative foliation is slightly folded. Granoblastic composite quartz+feldspar spindle shaped grain aggregates or layers are surrounded by arcuate anastomosing mica rich layers. Mica occurs in dispersed flakes, too. Mica-rich layers are composed of decussate muscovite+biotite, they are slightly deformed, sometimes kinked. Biotite is bordered on intergranular faces by tiny sphene+epidote idioblasts, rutile+ilmenite appears along crystal faces and cleavage planes. Ilmenite is a stable mineral phase. Plagioclase recrystallized in sericite+epidote+biotite+chlorite. Sometimes small garnet idioblasts can be observed in them. Garnet idioblasts also occur in mica-rich layers, their crystallization postdates mica/mica or mica/plagioclase interfaces. Recrystallized quartzitic lenses are bordered by chlorite. The chloritization of biotite and garnet is subordinate.

1072.3 m. Amphibolite. It has a relic gabbroic texture, coarse hornblende nematoblasts and plagioclase make up the rock. Hornblende crystals often have actinolitic rims or actinolite+chlorite appears along cleavage planes or in intercrystalline places together with biotite. Albite+epidote+sericite replace plagioclase. Sometimes small garnet idioblasts occur in them. Sphene occurs as small, dispersed idioblasts or as aggregates around ilmenite.

Metamorphic grade

The metamorphic grade of the Alpine overprint corresponds in both units to greenschist facies. It reached a slightly higher temperature (400/450 °C max.) in the upper part, whereas it was usually distinctly less than 400 °C in the lower part, where preservation of the pre-Alpine mineralogy prevails for a considerable thickness (see "Discussion of age results"). It is obvious from the available sections that medium grade metamorphic rocks were the precursor lithologies in both units. The grade of this pre-Alpine metamorphic event can be characterized as high temperature greenschist to low amphibolite facies. It is a typical feature especially for the lower unit that except a few local occurrences, no pre-Alpine garnets have been found. Very fine garnet grains of obviously Alpine age can be observed within plagioclase or on grain boundaries of plagioclase and white mica. In the upper portion which is characterized by a distinctly more intense Alpine deformation/recrystallization, composite pre-Alpine/Alpine garnets occur in several thin sections. Single stage garnet porphyroblasts are a common feature in many lithologies there. No Al_2SiO_5 polymorphs or relics of them were observed. Only one example of randomly oriented white mica pseudomorphs after staurolite? was recognised in the upper part. From the microscopic observations low pressure type is indicated for the Variscan event.

Geochronology

The drillcores from FR-1004 offered the opportunity to study fresh material from an area where hardly any suitable material can be sampled. Earlier reconaissance investigations of some micas by the K/Ar method revealed ±Variscan white mica ages from the depth at 740 m and several white mica and biotite ages close to 180 Ma. We decided then to study the same samples with Ar/Ar method. Due to the limited number of samples and limited quantity of the mineral separates it was not possible to perform Ar/Ar and Rb/Sr-dating on the same minerals wherever it was desirable.

The term muscovite is used here for a white mica the composition of which has not been determined more precisely. We can rule out the widespread occurrence of paragonite which has not been detected by X-ray diffractometry. In the rocks which suffered a strong Alpine recrystallization the white mica can reasonably be considered a phengite.

Analytical procedure

Separation: mica concentrates processed in usual way were ground in an agate mortar mill to destroy mineral grains others than mica, to split up intergrown flakes and remove inclusions of apatite etc. For normal samples magnetic separation yields concentrates of typical purity around 99% and better. The mineral concentrates were enclosed in high purity quartz vials and irradiated at the 9MW ASTRA reactor at the Austrian Research Center Seibersdorf. Seven samples including one monitor are stored in a single level of a rotating sample holder, up to 5 levels were irradiated simultaneously. The usual duration for Variscan samples was 4 hours. After a cooling down period of at least three weeks the samples were filled in small, annealed (low blank) cylindrical tantalum capsules where the mineral grains are stored safely, but the released gas can move out through the small slit between bottom and cover measuring appr. 1 mm. The Ar extraction line presently in use is made of glass and fitted with a RF-heating furnace made from quartz glassware. The hot portion of the extraction furnace is double walled and this volume is continuously pumped to avoid diffusion from ambient air during the high temperature steps. Due to the geometry of the cylindrical tantalum capsules, which always have a horizontal position within the RF-induction spiral, a uniform temperature distribution in the sample is guaranteed. Temperatures are monitored by a calibrated pyrometer. The heating period is 10 minutes for the low temperature steps and is continuously lowered to 3 minutes at the high temperature steps.

Between the heating procedures the RF is switched off and no gas is released. The release patterns obtained with this procedure may thus not be completely reproduced by continuous heating experiments of the same samples, because thermal cycling may influence the diffusion characteristics of the mineral lattice. After measuring more than 400 samples of different ages, minerals and age-diagram patterns we can state that samples with uniform distribution of radiogenic Ar yield perfect plateau type patterns. Small disturbances in the samples are easier detected due to the reduced diffusion time for the single step. Samples with a strong thermal overprint or old cores — not incorporated in this investigation — seem to be characterised by more pronounced age variations derived from the individual domains compared to results of continuous diffusion experiments of longer duration.

Cleaning of the gas is done by a combination of cold traps and SAE-getters. To shorten the overall procedure time, no concentration of the Ar before sample inlet is made. 2/3 of the gas is introduced into the mass spectrometer, the VG-5400 model from FISONS ISOTOPES (Winsford, GB). The rest of the gas is pumped away from the extraction line. Isotopic ratios are determined from a measuring period of 10 min, representing the ratio at the time of sample inlet. Age calculation is done after corrections for mass discrimination and radioactive decay, especially of the ^{37}Ar, using the formulas given in DALRYMPLE 1984. The specific production ratios of the interfering Ar isotopes at the ASTRA reactor of Seibersdorf are: $^{36}Ar/^{37}Ar(Ca)$= 0.0003, $^{39}Ar/^{37}Ar(Ca)$=0.00065, $^{40}Ar/^{39}Ar(K)$=0.03. The K/Ca ratio is determined from the $^{39}Ar/^{37}Ar$ ratio (calculated for the end of irradiation) using a conversion factor of 0.247. This factor was determined from a plagioclase with uniform and wellknown composition.

The line blank is rather low, at 1000 °C the ^{40}Ar blank is 2–5x10–10 cm³ STP, the $^{40}Ar/^{36}Ar$ ratio of the line blank is similar to air composition. Interference of ^{36}Ar, ^{37}Ar, partly ^{39}Ar with a low background of hydrocarbon radicals in the mass spectrometer can be a limiting factor for reliable measurements of very low intensities. Carefully checked peak positions, background determination and corrections are routinely performed to overcome such difficulties. A full description of the technique used and the irradiation characteristics of the ASTRA-reactor in Seibersdorf is given in FRANK, CASTA, BICHLER and FRANK 1995 (in prep).

J values are determined with an internal laboratory standard, calibrated by international standards including muscovite Bern 4M (BURGHELE 1987; Chem. Geol.) and amphibole Mm1Hb. (SAMSON & ALEXANDER 1987). The errors given on the calculated age of an individual step include only the 1 s error of the analytical data. The error of the plateau ages or total gas ages include an additional error of ±0.4% on the J-value. Within these latter errors the age results are reproducible with the same analytical equipment. Interlaboratory reproducibility can be expected within 1–1.5%.

Results

Starting from the bottom of the borehole we obtained the following results (see fig. 6 and Table 1, 2, and 3).

1072 m. Biotite-bearing plagioclase amphibolite.

Handpicked amphibole separate yielded a typical staircase Ar/Ar pattern indicating a thermal overprint. More than 70% of the gas yielded typical Variscan step ages. There is a weak indication to a pre-Variscan age of relic domains in the amphibole.

747 m. Muscovite–plagioclase gneiss with preserved pre-Alpine structure.

Muscovite: coarse-grained flakes were separated.

Rb/Sr: 338,6±4 with a reasonable spread of 11.3

Table 1

Rb/Sr analytical results

SAMPLE		Sr ppm	Rb ppm	87Rb/86Sr	87Sr/86Sr±2sm	AGE
FR 184 m	WR	215	152	2.05	0.72559±5	
	Bi	14.7	606	121	0.84775±20	72.3±3 Ma
FR 210 m	WR	269	172	1.86	0.72703±8	due to low spread
	Mu fg	316	351	3.22	0.72735±5	no meaningful age
	Mu cg	374	337	2.62	0.72728±4	calculation possible
FR 327 m	WR	22.4	386	50.6	1.03211±7	
	Mu	5.39	1448	1161	5.66848±131	294±3 Ma
FR 745 m	WR	183	129	2.05	0.72274±4	
	Mu	63.8	207	9.45	0.75294±10	287±10 Ma
	Bi	4.67	444	288	1.16114±15	108± 3 Ma
FR 747 m	WR	187	148	2.30	0.72464±6	
	Mu	49.0	228	13.6	0.77911±4	339±12 Ma

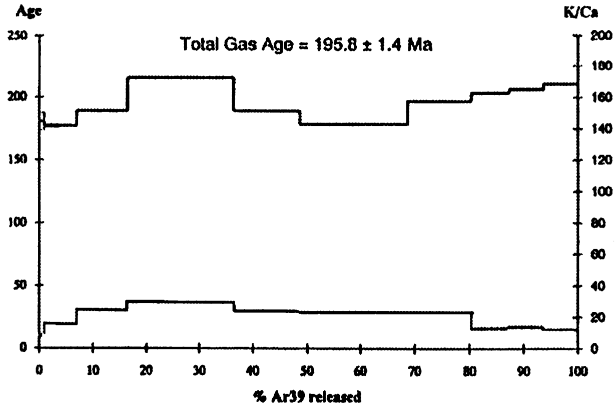
Table 2

List of $^{39}Ar/^{40}Ar$ and Rb/Sr analytical results

SAMPLE	MIN	J-VALUE	ROCK TYPE	AGE	STEPS	%RAD	IC-AGE	40836 IC	COMMENT	Rb/Sr-AGE
FR 184 m	Mu	0.001655	biotite-muscovite phyllite	**195.8 ± 1.4 Ma**	plateau 12	99.8	...	...	disturbed pattern, excess Ar	
FR 184 m	Bi	0.005771	biotite-muscovite phyllite	**293.6 ± 1.7 Ma**	5–13 13	98.0	**299 ± 9.5 Ma**	43 ± 437	uniform excess Ar	Bi 72.3 +/-3 Ma
FR 210 m	Mu	0.004099	muscovite phyllite	**141.8 ± 1.4 Ma**	11	97.5	...		disturbed pattern, excess Ar	
FR 276 m	Mu	0.001655	phyllitic micaschist	**224.6 ± 1.6 Ma**	14	99.7	...	...	disturbed pattern, excess Ar	
FR 276 m	Bi	0.001655	phyllitic micaschist	**256.3 ± 1.6 Ma**	3–6 1	98.8	**252 ± 5.2 Ma**	371 ± 237	uniform excess Ar	
FR 325 m	Mu	0.005771	augengneiss	**98.3 ± 0.7 Ma**	11	96.6	**100 ± 3 Ma**	286 ± 146		
FR 325 m	Bi	0.005771	augengneiss	**93.2 ± 0.8 Ma**	5–12 1	98.4	**93 5 ± 0.9 Ma**	318 ± 91		
FR 327 m	Mu	0.004705	microcline augengneiss	**184.5 ± 1.0 Ma**	9–14 1	99.0	**185 ± 1.4 Ma**	273 ± 43	excess Ar	Mu 294+/-3 Ma
FR 609 m	Bi	0.004852	finegrained biotite gneiss	**179.0 ± 1.4 Ma**	2–10 1	97.9	**180 ± 3.9 Ma**	256 ± 201	excess Ar	
FR 720 m	Mu	0.004949	plagioclase gneiss	**240.0 ± 3.7 Ma**	11	97.5	...	...	partially reset	
FR 720 m	Bi	0.004945	plagioclase gneiss	**171.3 ± 2.1 Ma**	2–12 1	96.4	**172 ± 1.8 Ma**	493 ± 49	partially reset?, excess Ar?	
FR 742 m	Mu	0.004949	plagioclase gneiss	**301.0 ± 2.2 Ma**	16	99.2	...	...	slightly reset	
FR 745 m	Mu	0.004949	plagioclase gneiss	**305.4 ± 2.0 Ma**	16	99.3	...	...	slightly reset	Mu 287+/-3 Ma,
FR 745 m	Bi	0.004949	plagioclase gneiss	**213.5 ± 2.0 Ma**	2–13 1	98.0	**214 ± 1.8 Ma**	354 ± 28	partially reset, excess Ar?	Bi 108+/-1 Ma
FR 747 m	Mu	0.004705	plagioclase gneiss	**305.4 ± 1.8 Ma**	12	99.2	...	...	partially reset	Mu 339+/-4 Ma
FR 1072 m	Hbl	0.004750	amphibolite	**344.0 ± 12 Ma**	9	90.0	...	...	polyphase history	

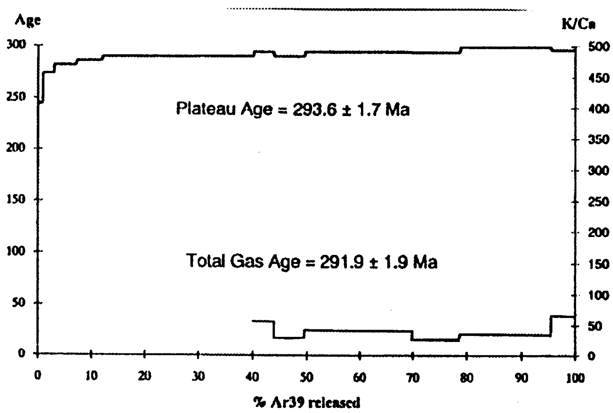
A) FR 184 m; MUSCOVITE, biotite–muscovite phyllite (J = 0.001655 ± 0.4%)

Step	T[°C]	%39	40*	%rad	39/37	%36Ca	40*/39	age
1	630	1.0%	63.36 mV	96.0%	33	0.11%	60.80 ± 4.0%	180.7 ± 6.9
2	650	2.7%	169.06 mV	97.8%	65	0.11%	59.51 ± 0.6%	177.1 ± 1.1
3	680	3.3%	207.17 mV	98.3%	62	0.15%	59.60 ± 0.4%	177.3 ± 0.6
4	700	9.5%	639.79 mV	98.4%	99	0.09%	63.77 ± 0.2%	189.1 ± 0.4
5	725	20.0%	1553.76 mV	99.4%	118	0.18%	73.14 ± 0.2%	215.4 ± 0.4
6	750	12.2%	826.70 mV	99.4%	101	0.27%	63.77 ± 0.1%	189.1 ± 0.2
7	780	10.1%	642.09 mV	98.9%	94	0.15%	59.99 ± 0.3%	178.4 ± 0.5
8	820	10.0%	636.59 mV	99.0%	97	0.16%	59.99 ± 0.1%	178.4 ± 0.2
9	840	11.6%	817.68 mV	99.3%	94	0.23%	66.53 ± 0.3%	196.9 ± 0.6
10	870	6.9%	506.24 mV	99.7%	53	0.96%	68.86 ± 0.4%	203.4 ± 0.8
11	920	6.5%	478.85 mV	99.8%	56	1.15%	69.91 ± 0.6%	206.4 ± 1.1
12	1020	6.3%	477.53 mV	98.3%	50	0.15%	71.39 ± 0.3%	210.5 ± 0.5
							total gas age:	195.8 ± 1.4



B) FR 184 m; BIOTITE, phyllitic micaschist (J = 0.005771 ± 0.4%)

Step	T[°C]	%39	40*	%rad	39/37	%36Ca	40*/39	age
1	670	0.9%	125.46 mV	62.8%	61	0.01%	23.99 ± 0.6%	244.4 ± 1.3
2	690	2.1%	331.77 mV	77.8%	123	0.01%	27.08 ± 0.2%	273.7 ± 0.6
3	710	4.2%	692.45 mV	88.5%	190	0.01%	27.93 ± 0.1%	281.7 ± 0.2
4	740	4.8%	794.33 mV	95.6%	211	0.03%	28.39 ± 0.1%	286.0 ± 0.3
5'	760	9.9%	1673.03 mV	97.0%	264	0.04%	28.79 ± 0.1%	289.7 ± 0.4
6'	820	7.5%	1269.94 mV	97.6%	331	0.04%	28.79 ± 0.1%	289.8 ± 0.3
7'	840	10.7%	1813.72 mV	97.9%	253	0.06%	28.84 ± 0.1%	290.2 ± 0.3
8'	870	3.7%	637.17 mV	98.0%	227	0.07%	29.33 ± 0.3%	294.7 ± 0.7
9'	915	5.8%	975.26 mV	98.0%	121	0.13%	28.83 ± 0.1%	290.2 ± 0.3
10'	960	20.1%	3442.75 mV	98.1%	165	0.10%	29.31 ± 0.1%	294.6 ± 0.2
11'	1000	9.1%	1553.41 mV	97.7%	107	0.13%	29.24 ± 0.1%	293.9 ± 0.3
12'	1060	16.7%	2902.07 mV	97.9%	142	0.11%	29.75 ± 0.1%	298.7 ± 0.2
13'	1120	4.5%	781.96 mV	97.6%	262	0.05%	29.47 ± 0.2%	296.1 ± 0.4
							total gas age:	291.9 ± 1.9
						88%	'plateau age:	293.6 ± 1.7



C) FR 210 m; MUSCOVITE, muscovite phyllite (J = 0.004099 ± 0.4%)

Step	T[°C]	%39	40*	%rad	39/37	%36Ca	40*/39	age
1	780	1.1%	25.79 mV	82.4%	41	0.07%	14.62 ± 1.2%	109.7 ± 1.2
2	810	5.7%	160.08 mV	83.9%	47	0.06%	16.98 ± 0.5%	126.8 ± 0.6
3	850	39.9%	1443.80 mV	97.5%	52	0.33%	21.77 ± 0.1%	161.1 ± 0.1
4	890	7.5%	183.81 mV	96.3%	34	0.49%	14.70 ± 0.4%	110.3 ± 0.4
5	940	6.3%	150.44 mV	94.1%	21	0.49%	14.44 ± 0.4%	108.4 ± 0.5
6	970	10.5%	258.39 mV	95.9%	42	0.35%	14.83 ± 0.2%	111.2 ± 0.3
7	1010	6.5%	176.96 mV	96.9%	42	0.43%	16.42 ± 0.3%	122.8 ± 0.4
8	1050	7.1%	229.78 mV	96.9%	35	0.43%	19.47 ± 0.4%	144.8 ± 0.5
9	1080	6.1%	214.13 mV	97.0%	35	0.41%	21.03 ± 0.2%	155.9 ± 0.3
10	1120	6.1%	227.65 mV	94.8%	25	0.30%	22.44 ± 0.1%	165.9 ± 0.2
11	1190	3.4%	103.10 mV	47.6%	15	0.03%	18.36 ± 1.2%	136.7 ± 1.6
							total gas age:	141.8 ± 1.4

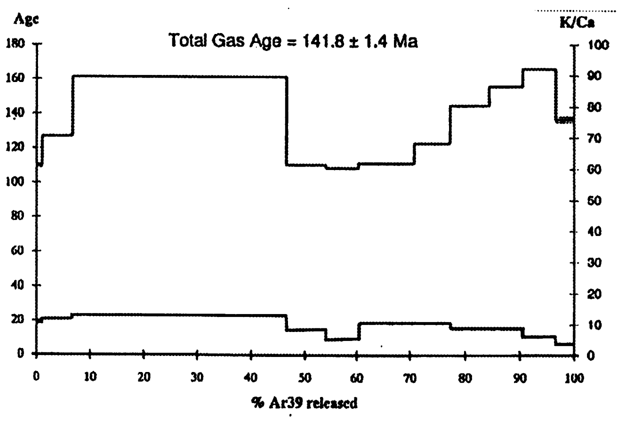
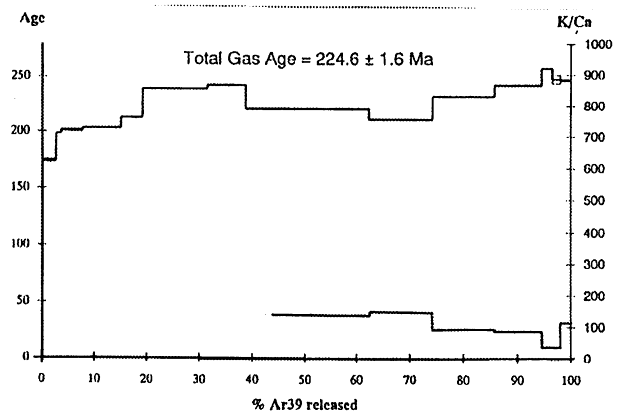


Fig. 6 (A, B, C) Ar/Ar plots

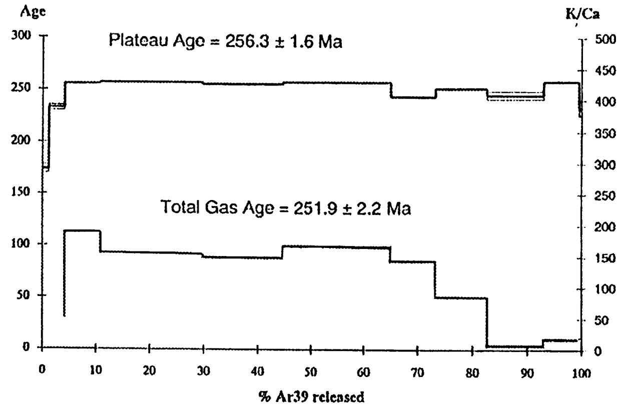
D) FR 276 m; MUSCOVITE, phyllitic micaschist (J = 0.001655 ± 0.4%)

Stop	T[°C]	%39	40*	%rad	39/37	%36Ca	40*/39	age
1	620°	2.7%	306.76 mV	84.2%	18	0.04%	58.53 ± 0.8%	174.3 ± 1.4
2	650°	1.0%	128.08 mV	97.2%	62	0.08%	67.08 ± 0.3%	198.5 ± 0.6
3	670°	4.1%	542.49 mV	97.7%	280	0.02%	67.98 ± 0.6%	201.0 ± 1.2
4	690°	7.3%	971.27 mV	97.9%	260	0.02%	68.85 ± 0.3%	203.4 ± 0.5
5	710°	4.1%	571.77 mV	97.8%	328	0.02%	72.31 ± 0.3%	213.1 ± 0.6
6	725°	12.3%	1947.15 mV	98.1%	536	0.01%	81.73 ± 0.2%	239.1 ± 0.4
7	750°	7.2%	1149.55 mV	99.0%	504	0.02%	82.96 ± 0.2%	242.5 ± 0.5
8	780°	23.6%	3435.44 mV	99.0%	554	0.02%	75.22 ± 0.1%	221.2 ± 0.3
9	820°	11.9%	1652.21 mV	98.2%	588	0.01%	71.69 ± 0.1%	211.4 ± 0.2
10	860°	11.5%	1758.94 mV	98.2%	373	0.02%	79.24 ± 0.2%	232.3 ± 0.4
11	880°	8.8%	1421.26 mV	99.1%	352	0.03%	83.06 ± 0.2%	242.8 ± 0.5
12	910°	2.0%	341.85 mV	99.5%	150	0.15%	88.62 ± 0.1%	258.0 ± 0.2
13	960°	1.5%	243.13 mV	99.1%	144	0.08%	85.05 ± 1.7%	248.2 ± 4.0
14	1040°	2.0%	324.42 mV	99.0%	460	0.02%	84.80 ± 0.5%	247.6 ± 1.2
							total gas age:	224.6 ± 1.6



E) FR 276 m; BIOTITE, phyllitic micaschist (J = 0.005771 ± 0.4%)

Step	T[°C]	%39	40*	%rad	39/37	%36Ca	40*/39	age
1	570	1.1%	57.69 mV	69.5%	36	0.01%	58.45 ± 2.4%	174.1 ± 4.1
2	580	3.0%	208.98 mV	88.0%	139	0.01%	79.34 ± 1.2%	232.6 ± 2.5
3[1]	600	6.6%	506.51 mV	95.1%	758	0.00%	87.72 ± 0.1%	255.5 ± 0.2
4[1]	620	19.1%	1473.15 mV	98.0%	626	0.01%	88.18 ± 0.2%	256.8 ± 0.5
5[1]	640	14.9%	1143.58 mV	98.6%	600	0.01%	87.48 ± 0.2%	254.9 ± 0.5
6[1]	680	20.3%	1569.58 mV	98.8%	671	0.01%	88.32 ± 0.1%	257.2 ± 0.3
7	700	8.2%	598.91 mV	97.6%	578	0.01%	83.25 ± 0.3%	243.3 ± 0.6
8	730	9.4%	707.02 mV	98.6%	340	0.02%	86.20 ± 0.4%	251.4 ± 0.9
10	850	10.4%	761.60 mV	98.7%	29	0.30%	83.82 ± 1.6%	244.9 ± 3.7
11	920	6.5%	506.20 mV	98.0%	69	0.07%	88.57 ± 0.2%	257.8 ± 0.4
12	1040	0.5%	35.61 mV	91.6%	79	0.02%	79.31 ± 3.1%	232.5 ± 6.8
							total gas age:	251.9 ± 2.2
						61%	[1]plateau age:	256.3 ± 1.6



F) FR 325 m; MUSCOVITE, augengneiss (J = 0.004099 ± 0.4%)

Step	T[°C]	%39	40*	%rad	39/37	%36Ca	40*/39	age
1	680	1.0%	68.92 mV	84.4%	80	0.08%	8.08 ± 0.4%	85.9 ± 0.3
2	710	1.6%	110.60 mV	89.7%	200	0.05%	8.60 ± 0.4%	91.3 ± 0.3
3	760	1.9%	134.06 mV	92.9%	280	0.05%	8.77 ± 0.1%	93.0 ± 0.1
4	790	5.1%	382.85 mV	93.4%	324	0.04%	9.16 ± 0.1%	97.1 ± 0.1
5	835	7.5%	583.66 mV	89.0%	669	0.01%	9.56 ± 0.1%	101.2 ± 0.1
6	860	17.9%	1383.49 mV	94.8%	1137	0.02%	9.49 ± 0.0%	100.5 ± 0.0
7	890	23.4%	1711.56 mV	95.6%	1580	0.01%	9.01 ± 0.1%	95.5 ± 0.1
8	940	20.3%	1493.92 mV	95.6%	1794	0.01%	9.03 ± 0.1%	95.8 ± 0.1
9	980	11.6%	920.06 mV	96.5%	742	0.04%	9.72 ± 0.1%	102.9 ± 0.1
10	1000	5.5%	431.96 mV	96.4%	224	0.12%	9.66 ± 0.2%	102.3 ± 0.2
11	1100	4.1%	318.34 mV	96.5%	77	0.36%	9.65 ± 0.1%	102.2 ± 0.1
							total gas age:	98.3 ± 0.7

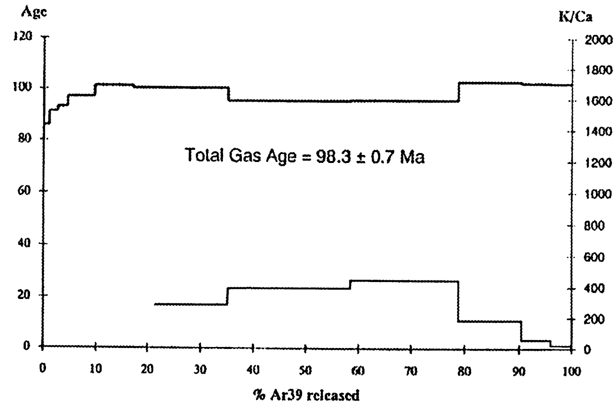
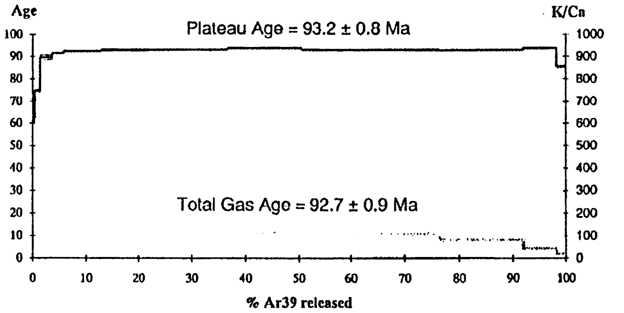


Fig. 6 (D, E, F) Ar/Ar plots

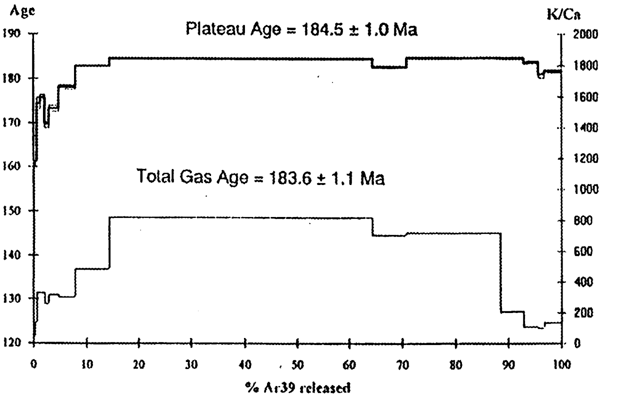
G) FR 325 m; BIOTITE, augengneiss (J = 0.005771 ± 0.4%)

Step	T[°C]	%39	40*	%rad	39/37	%36Ca	40*/39	age
1	650	0.4%	11.58 mV	65.9%	115	0.03%	5.79 ± 2.2%	61.9 ± 1.4
2	680	1.0%	35.65 mV	77.3%	110	0.04%	7.00 ± 1.1%	74.7 ± 0.8
3	700	2.3%	99.30 mV	87.1%	112	0.07%	8.44 ± 1.3%	89.6 ± 1.1
4	720	2.2%	100.54 mV	94.0%	381	0.05%	8.63 ± 0.5%	91.6 ± 0.4
5[1]	750	6.9%	315.77 mV	96.4%	446	0.07%	8.73 ± 0.4%	92.6 ± 0.4
6[1]	780	9.2%	419.88 mV	97.7%	504	0.10%	8.77 ± 0.6%	93.0 ± 0.6
7[1]	800	6.1%	280.64 mV	97.5%	528	0.09%	8.78 ± 0.5%	93.1 ± 0.5
8[1]	835	8.6%	393.52 mV	97.1%	569	0.07%	8.79 ± 0.4%	93.3 ± 0.3
9[1]	880	13.8%	634.54 mV	97.3%	457	0.09%	8.86 ± 0.4%	94.0 ± 0.4
10[1]	930	25.9%	1182.16 mV	98.1%	444	0.15%	8.77 ± 0.2%	93.1 ± 0.2
11[1]	980	15.6%	710.39 mV	98.4%	330	0.24%	8.77 ± 0.4%	93.0 ± 0.4
12[1]	1030	6.3%	288.36 mV	98.0%	174	0.35%	8.84 ± 0.4%	93.8 ± 0.4
13	1100	1.8%	75.65 mV	95.4%	82	0.31%	8.05 ± 0.7%	85.6 ± 0.6
							total gas age:	92.7 ± 0.9
						92%	[1]plateau age:	93.2 ± 0.8



H) FR 327 m; MUSCOVITE, microcline–augengneiss (J = 0.004705 ± 0.4%)

Step	T[°C]	%39	40*	%rad	39/37	%36Ca	40*/39	age
1	580	0.1%	11.26 mV	72.5%	39	0.04%	16.83 ± 6.3%	143.6 ± 8.7
2	600	0.1%	11.94 mV	81.1%	88	0.02%	18.89 ± 1.5%	160.5 ± 2.3
3	610	0.3%	29.90 mV	88.7%	294	0.01%	19.00 ± 1.0%	161.4 ± 1.6
4	620	0.7%	63.49 mV	93.4%	719	0.01%	20.63 ± 0.8%	174.6 ± 1.4
5	630	0.8%	80.52 mV	95.2%	718	0.01%	20.79 ± 0.4%	175.9 ± 0.7
6	640	0.8%	71.63 mV	96.6%	562	0.02%	20.07 ± 0.7%	170.1 ± 1.1
7	650	1.8%	172.46 mV	96.3%	692	0.02%	20.49 ± 0.4%	173.5 ± 0.7
8	680	3.2%	310.48 mV	95.2%	660	0.01%	21.09 ± 0.3%	178.3 ± 0.5
9[1]	700	6.5%	656.46 mV	96.8%	1065	0.01%	21.67 ± 0.1%	183.0 ± 0.2
10[1]	720	50.0%	5095.27 mV	98.6%	1814	0.02%	21.89 ± 0.1%	184.7 ± 0.1
11[1]	770	6.5%	650.37 mV	98.4%	1560	0.02%	21.66 ± 0.2%	182.9 ± 0.3
12[1]	830	17.7%	1803.36 mV	99.0%	1594	0.03%	21.91 ± 0.1%	184.9 ± 0.1
13[1]	860	4.4%	444.84 mV	97.7%	455	0.04%	21.90 ± 0.1%	184.8 ± 0.2
14[1]	910	2.8%	280.61 mV	94.3%	243	0.03%	21.77 ± 0.2%	183.9 ± 0.4
15	960	1.1%	111.65 mV	89.8%	223	0.02%	21.46 ± 0.5%	181.3 ± 0.9
16	1060	3.2%	321.60 mV	94.2%	301	0.02%	21.54 ± 0.2%	182.0 ± 0.4
							total gas age:	183.6 ± 1.1
						88%	[1]plateau age:	184.5 ± 1.0



I) FR 609 m; BIOTITE, fine-grained biotite gneiss (J = 0.004746 ± 0.4%)

Step	T[°C]	%39	40*	%rad	39/37	%36Ca	40*/39	age
1[1]	580°	2.5%	331.98 mV	74.8%	31	0.05%	15.69 ± 0.4%	135.3 ± 0.5
2[1]	590°	6.0%	1014.04 mV	93.7%	71	0.10%	20.00 ± 0.1%	170.9 ± 0.2
3[1]	600°	1.2%	212.04 mV	95.1%	111	0.08%	20.31 ± 0.3%	173.5 ± 0.5
4[1]	620°	5.6%	979.66 mV	97.4%	138	0.12%	20.62 ± 0.2%	176.0 ± 0.3
5[1]	640°	6.7%	1164.59 mV	97.0%	132	0.11%	20.61 ± 0.1%	175.9 ± 0.2
6[1]	720°	10.0%	1769.23 mV	97.8%	145	0.14%	21.03 ± 0.0%	179.3 ± 0.1
8[1]	730°	4.1%	719.62 mV	97.4%	134	0.12%	20.93 ± 0.2%	178.6 ± 0.3
9[1]	740°	2.4%	432.36 mV	98.2%	143	0.17%	21.26 ± 5.2%	181.2 ± 9.0
10[1]	780°	15.7%	2618.80 mV	98.1%	93	0.27%	19.79 ± 0.1%	169.2 ± 0.2
11[1]	810°	15.3%	2720.47 mV	98.1%	81	0.29%	21.15 ± 0.2%	180.3 ± 0.3
12[1]	950°	30.4%	5349.66 mV	98.5%	86	0.36%	20.90 ± 0.1%	178.3 ± 0.1
							total gas age:	175.5 ± 1.3

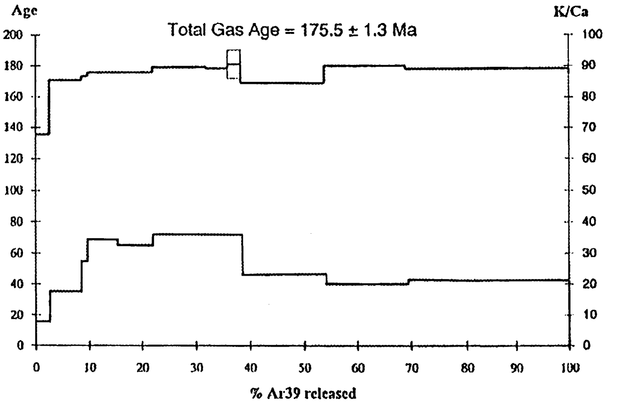
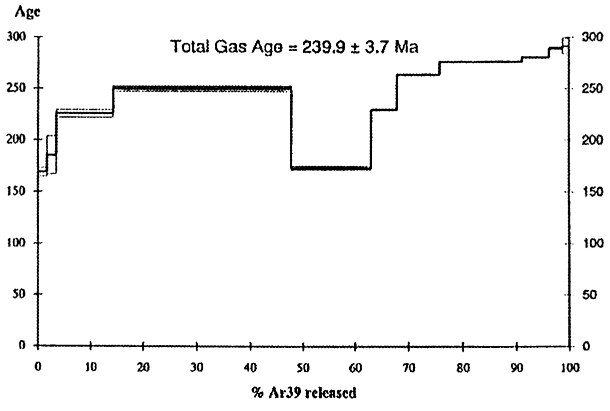


Fig. 6 (G, H, I) Ar/Ar plots

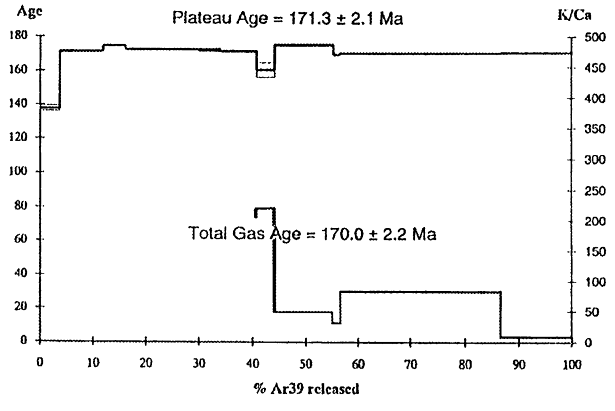
J) FR 720 m; MUSCOVITE, plagioclase gneiss (J = 0.004949 ± 0.4%)

Step	T[°C]	%39	40*	%rad	39/37	%36Ca	40*/39	age
1	670	1.7%	132.02 mV	66.7%	62	0.02%	18.94 ± 2.5%	168.9 ± 4.1
3	700	1.7%	148.84 mV	68.9%	22	0.04%	20.88 ± 10.4%	185.3 ± 18.3
4	750	10.8%	1141.06 mV	91.3%	115	0.03%	25.70 ± 1.8%	225.7 ± 3.8
5	800	33.4%	3918.80 mV	98.0%	246	0.06%	28.60 ± 1.0%	249.6 ± 2.4
6	830	15.3%	1210.71 mV	93.9%	181	0.04%	19.37 ± 1.2%	172.6 ± 2.0
7	850	4.8%	517.40 mV	97.1%	231	0.05%	26.13 ± 0.4%	229.3 ± 0.8
8	900	8.0%	989.30 mV	98.0%	281	0.05%	30.25 ± 0.1%	263.0 ± 0.3
9	930	15.3%	1996.25 mV	98.8%	274	0.09%	31.79 ± 0.1%	275.4 ± 0.4
10	980	5.1%	676.37 mV	97.5%	264	0.04%	32.36 ± 0.2%	280.0 ± 0.6
12	1000	2.6%	354.82 mV	90.1%	142	0.02%	33.47 ± 0.6%	288.9 ± 1.5
13	1100	1.2%	163.64 mV	66.5%	39	0.01%	33.74 ± 2.9%	291.1 ± 7.8
							total gas age:	239.9 ± 3.7



K) FR 720 m; BIOTITE, plagioclase gneiss (J = 0.004945 ± 0.4%)

Step	T[°C]	%39	40*	%rad	39/37	%36Ca	40*/39	age
1	640	3.7%	225.59 mV	62.8%	63	0.03%	15.32 ± 1.3%	137.7 ± 1.7
2[1]	650	8.2%	626.47 mV	87.6%	478	0.01%	19.24 ± 0.3%	171.3 ± 0.5
3[1]	680	4.2%	331.25 mV	92.5%	621	0.02%	19.63 ± 0.2%	174.6 ± 0.3
4[1]	700	7.7%	592.93 mV	94.9%	757	0.02%	19.36 ± 0.3%	172.3 ± 0.5
5[1]	720	6.1%	473.20 mV	95.9%	858	0.02%	19.37 ± 0.1%	172.4 ± 0.2
6[1]	750	4.2%	321.03 mV	95.8%	851	0.02%	19.33 ± 0.6%	172.1 ± 0.9
7[1]	800	6.6%	506.60 mV	96.4%	833	0.03%	19.25 ± 0.4%	171.4 ± 0.6
8[1]	830	3.4%	241.37 mV	93.9%	897	0.01%	17.97 ± 2.8%	160.4 ± 4.3
9[1]	870	11.2%	875.41 mV	68.4%	196	0.01%	19.68 ± 0.3%	175.0 ± 0.5
10[1]	900	1.3%	96.01 mV	95.9%	123	0.15%	19.02 ± 0.3%	169.5 ± 0.5
11[1]	960	30.0%	2289.66 mV	94.6%	335	0.04%	19.13 ± 0.1%	170.3 ± 0.1
12[1]	1000	13.5%	1027.93 mV	89.2%	33	0.19%	19.16 ± 0.2%	170.6 ± 0.3
							total gas age:	170.0 ± 2.2
						96%	[1]plateau age:	171.3 ± 2.1



L) FR 742 m; MUSCOVITE, plagioclase gneiss (J = 0.004949 ± 0.4%)

Step	T[°C]	%39	40*	%rad	39/37	%36Ca	40*/39	age
1		1.3%	74.08 mV	77.3%	42	0.03%	29.05 ± 2.1%	253.2 ± 5.0
2		0.5%	34.39 mV	92.2%	226	0.01%	33.39 ± 2.4%	288.3 ± 6.3
3	650	0.3%	20.86 mV	91.5%	331	0.01%	33.44 ± 2.9%	288.7 ± 7.7
4	660	1.5%	93.60 mV	93.6%	341	0.01%	32.17 ± 0.5%	278.5 ± 1.2
5	680	2.1%	133.02 mV	95.7%	459	0.01%	32.36 ± 0.8%	280.0 ± 2.0
6	700	2.8%	192.01 mV	96.5%	550	0.01%	33.86 ± 0.5%	292.1 ± 1.4
7	730	4.1%	277.56 mV	97.7%	710	0.02%	33.52 ± 0.2%	289.3 ± 0.6
8	750	7.0%	488.37 mV	98.1%	1174	0.01%	35.13 ± 0.2%	302.2 ± 0.6
9	780	12.0%	866.12 mV	99.0%	1829	0.01%	36.24 ± 0.3%	311.0 ± 1.0
10	800	14.8%	1052.45 mV	99.3%	1749	0.02%	35.68 ± 0.2%	306.5 ± 0.5
11	820	3.9%	268.13 mV	96.8%	1065	0.01%	34.82 ± 0.4%	299.7 ± 1.0
12	850	10.2%	672.39 mV	98.6%	634	0.03%	32.96 ± 0.1%	284.8 ± 0.4
13	900	16.5%	1146.58 mV	98.8%	420	0.06%	34.74 ± 0.1%	299.1 ± 0.3
14	950	18.2%	1319.29 mV	99.2%	660	0.05%	36.34 ± 0.2%	311.8 ± 0.5
15	1000	4.0%	293.17 mV	97.4%	135	0.07%	36.37 ± 0.3%	312.0 ± 0.7
16	1020	0.8%	58.60 mV	71.2%	50	0.01%	34.68 ± 3.0%	298.5 ± 8.3
							total gas age:	301.2 ± 2.2

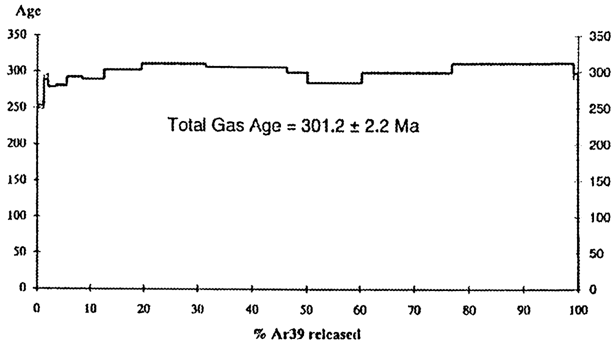
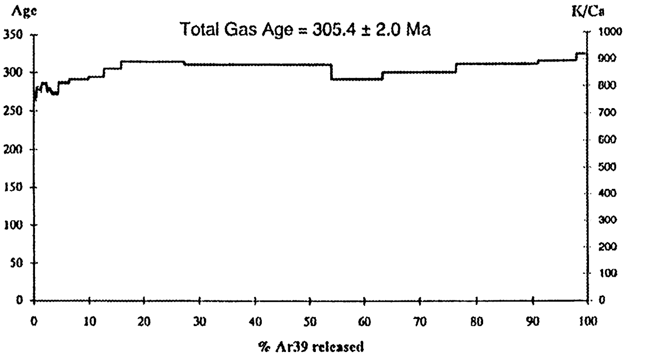


Fig. 6 (J, K, L) Ar/Ar plots

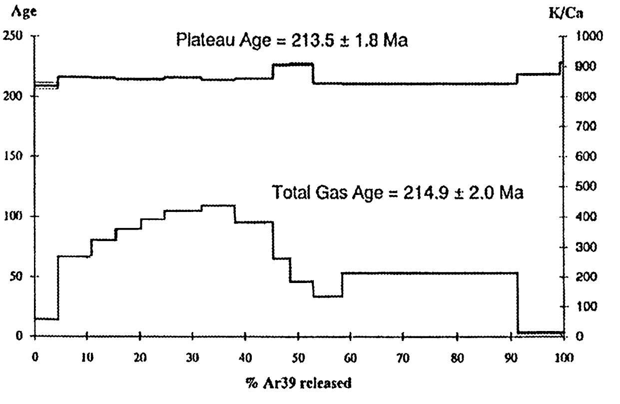
M) FR 745 m; MUSCOVITE, plagioclase gneiss (J = 0.004949 ± 0.4%)

Step	T[°C]	%39	40*	%rad	39/37	%36Ca	40*/39	age
1	650	0.5%	66.04 mV	85.9%	164	0.01%	30.72 ± 1.7%	266.8 ± 4.1
2	660	0.9%	119.74 mV	91.4%	319	0.01%	32.10 ± 1.4%	277.9 ± 3.7
3	670	1.0%	132.82 mV	93.5%	495	0.01%	32.96 ± 0.9%	284.8 ± 2.4
4	680	0.8%	109.57 mV	92.1%	485	0.01%	32.04 ± 1.2%	277.4 ± 3.0
5	700	1.3%	175.78 mV	95.0%	201	0.03%	31.50 ± 0.9%	273.1 ± 2.3
6	750	1.9%	266.89 mV	96.4%	601	0.01%	33.20 ± 0.7%	286.7 ± 1.8
7	780	3.5%	492.59 mV	97.3%	718	0.01%	33.74 ± 0.2%	291.1 ± 0.6
8	800	2.8%	402.99 mV	98.1%	789	0.02%	34.15 ± 0.3%	294.4 ± 0.7
9	820	3.2%	479.51 mV	98.1%	1233	0.01%	35.52 ± 0.1%	305.2 ± 0.3
10	850	11.5%	1769.09 mV	98.8%	2050	0.01%	36.70 ± 0.1%	314.6 ± 0.4
11	900	26.7%	4052.72 mV	99.3%	2591	0.02%	36.19 ± 0.2%	310.5 ± 0.5
12	920	9.3%	1325.46 mV	98.9%	1215	0.02%	33.81 ± 0.1%	291.7 ± 0.4
13	950	13.1%	1919.47 mV	98.9%	376	0.07%	34.90 ± 0.1%	300.3 ± 0.3
14	980	14.7%	2234.35 mV	99.3%	769	0.05%	36.33 ± 0.3%	311.7 ± 0.7
15	1000	7.0%	1078.78 mV	99.0%	681	0.04%	36.82 ± 0.2%	315.5 ± 0.6
16	1020	1.8%	289.15 mV	97.4%	1301	0.01%	37.95 ± 0.5%	324.4 ± 1.4
							total gas age:	305.4 ± 2.0



N) FR 745 m; BIOTITE, plagioclase gneiss (J = 0.004945 ± 0.4%

Step	T[°C]	%39	40*	%rad	39/37	%36Ca	40*/39	age
1	650	4.5%	783.81 mV	87.5%	113	0.02%	23.75 ± 1.4%	209.3 ± 2.8
2[1]	660	6.4%	1157.30 mV	94.9%	515	0.01%	24.62 ± 0.1%	216.6 ± 0.3
3[1]	670	4.6%	830.27 mV	96.7%	627	0.02%	24.56 ± 0.1%	216.1 ± 0.3
4[1]	680	4.7%	841.60 mV	97.3%	697	0.02%	24.39 ± 0.2%	214.7 ± 0.4
5[1]	710	4.5%	810.42 mV	97.5%	754	0.02%	24.41 ± 0.1%	214.8 ± 0.3
6[1]	730	7.1%	1283.41 mV	98.0%	808	0.02%	24.59 ± 0.3%	216.3 ± 0.6
7[1]	750	6.3%	1126.79 mV	98.0%	844	0.02%	24.34 ± 0.1%	214.2 ± 0.2
8[1]	780	7.1%	1275.52 mV	89.8%	735	0.00%	24.48 ± 0.2%	215.4 ± 0.4
9[1]	800	3.3%	619.89 mV	72.0%	508	0.00%	25.83 ± 0.5%	226.6 ± 1.0
10[1]	820	4.4%	844.15 mV	71.5%	361	0.00%	25.89 ± 0.6%	227.1 ± 1.3
11[1]	850	5.5%	970.68 mV	97.9%	263	0.07%	24.03 ± 0.2%	211.6 ± 0.4
12[1]	900	32.8%	5785.78 mV	98.1%	410	0.05%	24.01 ± 0.1%	211.5 ± 0.1
13	950	8.1%	1481.75 mV	90.4%	26	0.13%	24.90 ± 0.1%	218.9 ± 0.3
14	1000	0.6%	106.94 mV	72.3%	17	0.05%	26.02 ± 0.5%	228.2 ± 1.0
							total gas age:	214.9 ± 2.0
						87%	[1]plateau age:	213.5 ± 1.8



O) FR 747 m; MUSCOVITE, plagioclase gneiss (J = 0.004705 ± 0.4%)

Step	T[°C]	%39	40*	%rad	39/37	%36Ca	40*/39	age
1		3.9%	389.20 mV	93.0%	287	0.01%	31.16 ± 0.2%	257.8 ± 0.5
2		2.1%	230.74 mV	95.4%	425	0.01%	34.38 ± 0.6%	282.6 ± 1.7
3		1.8%	200.64 mV	96.0%	946	0.01%	35.04 ± 0.5%	287.6 ± 1.4
4		13.3%	1575.42 mV	97.0%	799	0.01%	36.73 ± 0.2%	300.5 ± 0.5
5		26.4%	3306.32 mV	98.8%	1316	0.02%	38.79 ± 0.1%	316.0 ± 0.2
6		12.8%	1505.78 mV	98.4%	1162	0.01%	36.42 ± 0.2%	298.1 ± 0.4
7		4.0%	464.91 mV	98.1%	713	0.02%	36.40 ± 0.1%	298.0 ± 0.1
8		7.9%	952.54 mV	98.2%	402	0.04%	37.17 ± 0.2%	303.8 ± 0.5
9		10.1%	1235.22 mV	98.9%	871	0.03%	38.04 ± 0.1%	310.3 ± 0.3
10		12.8%	1576.77 mV	99.2%	818	0.04%	38.18 ± 0.1%	311.4 ± 0.2
11		5.0%	638.54 mV	98.2%	407	0.03%	39.47 ± 0.1%	321.1 ± 0.4
							total gas age:	305.6 ± 1.8

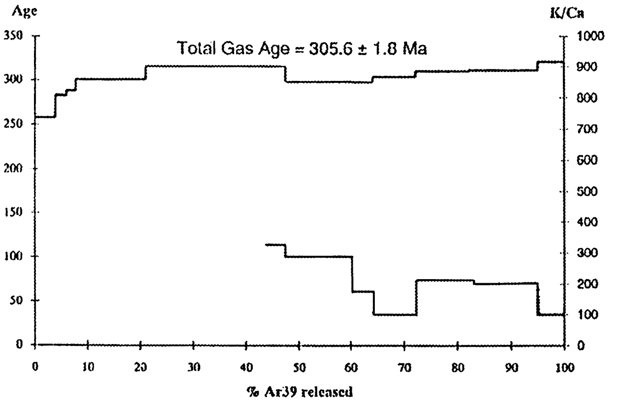


Fig. 6 (M, N, O) Ar/Ar plots

P) FR 1072 m; AMPHIBOLE, amphibolite (J = 0.004750 ± 0.4%)

Stop	T[°C]	%39	40*	%rad	39/37	%36Ca	40*/39	age
1	720	7.0%	84.24 mV	41.3%	0.07	2.67%	32.41 ± 3.0%	269.9 ± 7.5
2	730	3.9%	47.86 mV	35.5%	0.06	2.38%	32.79 ± 3.6%	272.9 ± 9.1
3	740	3.9%	51.38 mV	79.0%	0.06	14.26%	35.84 ± 15.2%	296.3 ± 41.8
4	800	29.9%	433.10 mV	90.0%	0.05	28.43%	39.29 ± 1.3%	322.6 ± 3.8
5	840	12.4%	177.71 mV	89.0%	0.06	24.87%	38.91 ± 0.4%	319.7 ± 1.3
6	860	8.8%	135.26 mV	89.4%	0.04	32.13%	41.67 ± 1.1%	340.4 ± 3.6
7	910	23.1%	392.42 mV	89.6%	0.04	31.30%	46.36 ± 0.3%	375.2 ± 0.9
8	950	9.6%	201.11 mV	78.2%	0.03	14.75%	56.93 ± 0.7%	451.2 ± 2.6
9	1000	1.4%	31.13 mV	67.3%	0.03	10.18%	61.91 ± 8.7%	485.9 ± 37.1
								343.9 ± 12.2

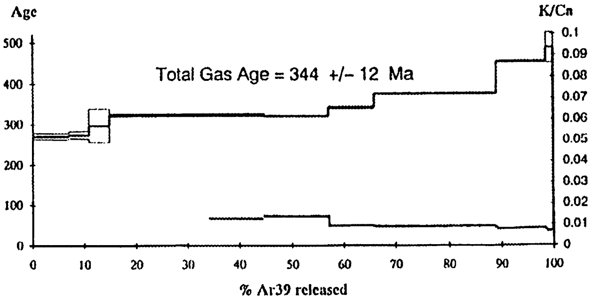


Fig. 6 (P) Ar/Ar plots

Ar/Ar: slightly disturbed plateau pattern (former age >325 Ma) with a saddle and low-temperature Ar loss (Permian?)

745 m. Muscovite–plagioclase gneiss, preserved pre-Alpine structure.

Muscovite: coarse flakes.

Rb/Sr: 286,8±3, spread only 7.4.

Ar/Ar: disturbed (saddle) plateau pattern, former age >315 Ma with Permian? low-temperature Ar loss.

Biotite: coarse pre-Alpine flakes with Ti and sphene unmixing.

Rb/Sr: 108±3 Ma, spread 286.

Ar/Ar: well developed plateau pattern, 213 Ma with a small horst at intermediate temperatures (uniform excess Ar).

742 m. Same lithology as 745 and 747 m.

Muscovite: Ar/Ar rejuvenated plateau type (>300 Ma.)

720 m. Muscovite–biotite plagioclase gneiss, well preserved pre-Alpine structure, strong fluid-driven alteration of plagioclase, sphene unmixing in biotite, new formation of a few chlorite flakes.

Muscovite: Ar/Ar: 240±3.7 Ma with a saddle shaped pattern.

Biotite: Ar/Ar: 171.3 Ma±2.1 Ma plateau type, partially reset?

609 m. Small wedge of tectonically intercalated fine-grained biotite gneiss with preserved sedimentary layering. Form relics of pre-Alpine biotite porphyroblasts with sphene unmixing.

Biotite: Ar/Ar: plateau type 178 Ma.

327 m. Microcline augengneiss.

Muscovite: coarse-grained relics.

Rb/Sr: 294±3 Ma. (extreme spread 1110).

Ar/Ar: well preserved plateau type, 184 Ma with minor low temperature argon loss.

325 m. Microcline augengneiss as described under 327 m.

Muscovite: Ar/Ar: 98±1 Ma, slightly disturbed plateau type.

Biotite: 93±1 Ma, well preserved plateau type.

276 m. Phyllitic micaschist (biotite-muscovite)

Muscovite: relic flakes were separated.

Ar/Ar: slightly discordant saddle shaped age pattern (total gas 225 Ma), lowest age step at 170 Ma.

Biotite: no relics, newly formed grains, coarse fraction.

Ar/Ar: plateau type, erratic at high temperature steps, 256 Ma.

210 m. Muscovite phyllite with distinct structural reworking.

Muscovite: Ar/Ar 142±1.4 Ma, disturbed saddle

Table 3

Apatite and zircon fission-track analytical results

Apatite ages	Depth	Cryst.	Ps	(Ns)	Pi	(Ni)	$P(\chi^2)$ [%]	FT age [Ma±2s]	Track length (n) [μm]
	184 m	33	5.83	(872)	12.2	(2074)	<1	46.2±4.8	14.0±0.8 (8)
	276 m	25	3.39	(729)	7.92	(1752)	30	42.4±4.6	13.9±0.9 (23)
	327 m	35	1.61	(362)	3.94	(894)	5	41.4±5.8	
	609 m	15	3.29	(360)	4.17	(495)	11	42.1±6.6	
	720 m	20	5.46	(910)	13.4	(2221)	18	40.5±4.1	13.8±1.0 (100)
	1047 m	14	0.08	(16)	0.30	(63)	–	25.4±14.3	
	1087 m	20	5.57	(1117)	12.1	(2440)	12	45.3±4.4	13.4±1.1 (50)
Zircon ages									
	327 m	16	100.0	(1429)	52.4	(759)	<1	54.2±6.5	
	1047 m	15	59.0	(1639)	28.7	(806)	11	57.8±6.8	
	1087 m	16	70.2	(1355)	33.9	(614)	3	61.8±7.7	

Cryst: number of dated crystals
Ps, Pi: spontaneous and induced track density [x10^5 tr./cm^2]
Ns, Ni: number of spontaneous and induced tracks counted
$P(\chi^2)$ probability obtaining Chi-square value for n degree of freedom (where n=No of crystals-1)

shaped pattern with possible excess Ar in low temperature steps. Due to the missing spread in the Rb/Sr system no meaningful age calculation for the white micas was possible.

185 m. Biotite-muscovite phyllite.

Muscovite: coarse flakes.

Ar/Ar: saddle shaped pattern, highest ages 215 Ma, no single step below 178 Ma.

Biotite: coarse flakes, intergrown with muscovite, sphene unmixing, perfectly annealed.

Rb/Sr: 72±4 Ma., spread WR/B=119.

Discussion of age results

The polymetamorphic history clearly visible meso- and microscopically is reflected also in the geochronological data. The lower unit yielded ± well preserved Variscan Rb/Sr ages of muscovites (338, 286±3 Ma) from the plagioclase gneisses. 294±3 Ma was obtained on a highly radiogenic muscovite from a microcline augengneiss from the upper unit.

We assume that 338±4 is still close to the former Variscan cooling age. The analytically distinctly younger ages up to 286 Ma most probably can be attributed to the limited spread and especially in the case of 327 m due to partial opening in the consequence of deformation induced annealing and recrystallization. KOVÁCH & SVINGOR (1981) reported well defined ages of pegmatitic muscovites of 351±9 Ma, and three more muscovites with a spread <10 also fit to the same reference line. We have no information if these samples belong to the lower unit rather than to the upper one. However the reason for these older ages preferentially may be their bigger primary grainsize. It is well known that even low grade amphibolite facies temperatures may not be sufficient to reset a cm-size white mica completely.

The microcline augengneiss at 327 m is highly radiogenic (Rb^{87}/Sr^{85} 51.6), so a whole rock age of 438 Ma can be calculated. This "single sample" Rb/Sr age may be considered with caution but it indicates that Early Palaeozoic acid magmatic rocks are associated in this crystalline unit. Dr. KOVÁCH kindly provided us with an unpublished report on the granite gneisses of the Sopron area, where he found arguments for an Early Palaeozoic protolith age.

Only one amphibole (1072 m) from the lower unit was investigated. Ages of 323–375 Ma for the 820–950 °C steps agree roughly with the Rb/Sr white mica ages. We cannot be sure, if the low-teperature ages of 270 Ma are only due to thermal resetting of the amphibole. The high K/Ca ratio of these steps make it possible that some tiny biotite inclusions could be responsible. The K/Ca ratio also indicates a chemical zonation of the amphibole. Ages of >450 Ma from the highest temperature steps were obtained. These high ages of core domains give a weak argument for a pre-Variscan age of this fine-grained gabbroic rock.

Fission track measurements (results and interpretation)

Fission track measurements were performed on apatites coming from seven samples and on zircons from three samples; analytical results are shown in Table 3. The ages are distributed in a narrow range (43.0±2.3 Ma). As there is no relationship between the depth of the samples and the obtained ages, the formation of ages was rather a rapid than a slow process, as the track length result support it. Each sample shows a significant, but not too great track shortening. The track populations do not contain strongly shortened tracks, thus the apparent apatite ages express the termination of the cooling process, which was started by the Late Cretaceous thrusting.

The thermal history was modelled by the programs of WILLETT (1992) and GALLAGHER (1993). The results of the modelling is shown in fig. 7. Only one geological control exists on the uplift-burial history of the Fertőrákos area: the beginning of the post-metamorphic sedimentation in Early/Middle Miocene during Karpatian (-17 Ma). Thus for the 17–15 Ma period we have assumed surface temperatures. The envelope of the acceptable thermal path consists of three parts:

I. The cooling during Paleocene–Early Eocene was probably monotonous until the temperature around 50 °C in Middle Eocene. This period can be characterized by a narrow t/T field.

2. The Eocene–Miocene thermal history of the studied rocks is questionable, but the temperature was less, than 55 °C. A young thermal overprint hides the details of the thermal path before the Miocene.

3. The generally mild shortening of the tracks is the consequence of a post-Karpatian burial. The final warming and rapid cooling took place during the last 14–8 Ma. Maximum temperatures were in the range of 45–65 °C between Badenian and Quaternary.

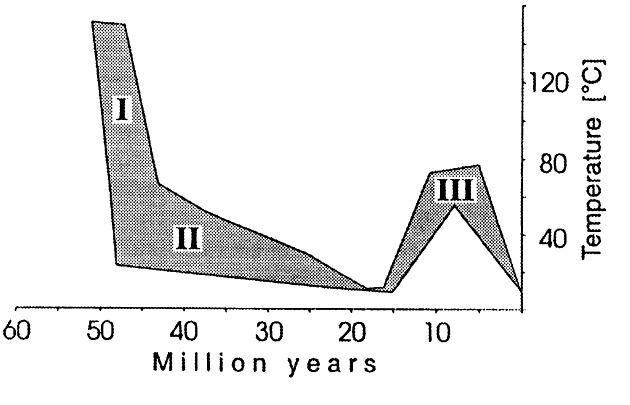


Fig. 7. Post-Cretaceous thermal history of the Fertőrákos block based on the modelling of the fission track data

I. Rapid cooling in Early–Middle Eocene, II. "Stagnation period" during Late Paleogene-Early Miocene, III. Sediment burial and erosion during Late Neogene

The Lower-Austroalpine crystalline nappes are covered by syn- and post-extensional sedimentary sequences in the nearby Rába basin. In some sub-basins Miocene sediment thickness exceeds 2000 m (FÜLÖP 1990). The subsidence of these zones could have been similar to the subsidence of the Fertőrákos block, but it was followed there by a very young uplift and erosion at the zone of Alpine foothills. This exhumation at the western margin of the Pannonian basin system is related to the Pliocene- to recent change of the stress-field of the entire regime (HORVÁTH & CLOETHING 1994). Young uplift of similar size and age was also reported from the northern margin of the Pannonian basin by DUNKL et al. (1994).

Geological significance of the thermal history in the regional framework

An important result of our investigation of this borehole was the finding that the lower portion, lithologically comparable to the Wechsel plagioclase gneisses yielded more or less preserved Variscan white mica cooling ages. This result is in good agreement with MÜLLER (1994) who was able to demonstrate an Early Variscan high pressure event in the Wechsel gneisses and a Late Variscan, Permian overprint.

Our $^{39}A/^{40}Ar$ results from the coarse-grained white micas from the Wechsel gneisses yielded usual Late Variscan cooling ages around 300–305 Ma, which are slightly affected by a later thermal overprint visible in the saddle shaped age pattern. The lower temperature steps are distinctly younger, but there was not a single step recognized below 250 Ma (samples 742, 745, 747, 1072) except the sample 720, which suffered a stronger rejuvenation. In comparison with the results of MÜLLER we interpret this as an argument for a Permian overprint of this unit. We found one biotite from sample 745, of which Rb/Sr system has been rejuvenated broadly to Cretaceous values (108±1 Ma).

MÜLLER demonstrated that the Alpine deformation in the Wechsel unit is concentrated in rather thin shear zones and dated them 86±12 Ma. Our observation of several thin sections from this lower unit corroborate this picture.

The upper unit, lithologically and structurally comparable to the Semmering unit, is characterized by a strong structural reworking within low to medium greenschist facies. The tectonic contact to the lower unit is complicated and contains several variegated intercalations.

Based on our studies of thin sections we assume that large rock volumes were recrystallized in Early Alpine times. Contrary to this straightforward interpretation of the thin sections, the $^{39}Ar/^{40}Ar$ results of the white micas of this unit are not easy to interpret. Most of the samples yielded "mixed" ages in the range 142–225 Ma. Excess argon obviously plays a major role in this whole unit. This is indicated by the sample 276 m (a well recrystallized phyllitic micaschist), from which the biotite yielded a plateau-type age pattern of 256±1.6 Ma, which is distinctly higher than the $^{39}Ar/^{40}Ar$ age of the coexisting white mica of about 225 Ma. The excess Ar of this biotite shows a uniform distribution.

Only in one sample out of six we found Cretaceous ages on both micas. Whether these ages (muscovite 98 Ma, biotite 93 Ma) represent true cooling ages or may also be affected by a small amount of excess Ar, is difficult to assess. In the light of the available regional geochronological information the latter case is more probable.

The complicated saddle-shaped age pattern of white micas of the samples 184, 210 and 276 m are difficult to interpret, but we assume a complex history. The high temperature steps may indicate domains which have not been fully reset and the low temperature portion on the age diagram is probably a combination of excess Ar and later diffusional loss. It should be mentioned that even the lowest temperature steps do not show usual Cretaceous values.

Unfortunately the Rb/Sr information is limited. One biotite from 184 m gave a late Cretaceous cooling age of 72 Ma. Due to the lacking spread it was not possible to calculate a reliable age of the white mica fraction of the sample 210 m.

The 294±3 Ma age data of the white mica from a microcline augengneiss (327 m) bears a problem in respect to our interpretation, that the fabric of this rock is dominated by Alpine recrystallization. The reason for this is that coarse-grained relictic micas were enriched during separation.

Although we were not able to get a precise geochronological information about the time of the Early Alpine overprint, the presence of excess argon in large rock volumes in the rocks of the lowermost Lower Austroalpine Units (LAA) is a useful information. It means, that during thrusting of the LAA nappes over the Wechsel unit large amounts of radiogenic argon migrated together with the released fluids from below along the tectonically active deformational zones and were incorporated in the contemporaneously cooling minerals. It is a characteristic feature that this excess argon is usually found close to the thrust plane and is not recognized in higher levels. From the LAA realm in Sopron, which represents a tectonically higher position compared to the rock unit in the investigated borehole, BALOGH & DUNKL (1994) reported a series of K/Ar data which do not indicate the incorporation of major amounts of excess argon.

HUBER (1994) dated leukophyllites from several occurrences within the LAA crystalline, including Rabenwald, and many other localities, and he found $^{39}Ar/^{40}Ar$ cooling ages of white micas in the range 72–96 Ma with a distinct clustering of data around 87 Ma.

From this geochronological information it seems reasonable that the whole LAA crystalline in the Semmering system has seen an intense Early Alpine tectonism and metamorphism. Most probably the same event has affected the Permo–Mesozoic intercalations in this area, which is checked at the moment in detail in several localities. It means that in the Semmering System the Early Alpine continental margin was overridden by the main mass of Austroalpine crystalline of Kor- and Saualm and comparable units. It should be mentioned that the metamorphic overprint of the LAA Mesozoic in the Radstädter Tauern was an Early- to Late Tertiary process (SLAPANSKY & FRANK 1987). It means that further to the west the LAA units have seen later tectonism and metamorphism than in the Semmering area.

The more or less preserved Variscan structures and ages from the Wechsel unit indicate that this unit has seen distinctly lower temperatures as the overriding LAA units. They represent therefore the frontal parts of the Austroalpine crystalline wedge, which always had a high structural position.

It may be mentioned that a similar history can be deduced for the occurrences of metamorphic rocks of the Subtatricum unit from Wolfsthal belonging to the Little Carpathians south of the Danube, where mineralogically perfectly preserved Variscan assemblages and biotite $^{39}Ar/^{40}Ar$ cooling ages up to 317 Ma are known (pers. comm. A. HAMID).

Acknowledgements

GYÖNGYI LELKES-FELVÁRI acknowledges financial support from Büro für Austauschprogramme mit Mittel und Osteuropa, Wien, Aktion Österreich–Ungarn, Wissenschafts- und Erziehungskooperation, Projekt 10ö1, 12ö15 and from Hungarian Scientific Research Fund (OTKA) No 3002 and No 7211. Fission track measurements were performed in the framework of Hungarian Scientific Research Fund (OTKA) 232/91. We are grateful to the former Mecsek Ore Mining Company, Pécs for providing samples and thin sections.

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ADVANCES
in
Austrian—Hungarian Joint Geological Research
Budapest, 1996

The DANREG programme — an international effort for unified geological database and evaluation along the river Danube

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Keywords: "DANREG" programme, Danube region, geological maps, database

Abstract

It happens for the first time that Austria, Hungary and Slovakia, three countries linked by the Danube, are going to produce, after a thorough preparatory work, a map series of unified approach, eliminating the differences due to specific national traditions and techniques which would make a uniform interpretation rather difficult, in some cases definitely impossible.

A bilateral agreement to undertake a joint study of their respective regions separated by the Danube was signed by Hungary and Slovakia in 1989. Austria joined in 1990, making it trilateral.

Joint work has been extended to the following topics and products: surface geological map, lithogenetic and thickness map of the Quaternary, lithofacies and thickness map of the Pontian and the Pliocene, lithofacies and thickness map of the Pannonian, map of the pre-Tertiary basement, tectonic map, neotectonic map, engineering-geological map, hydrogeological map, geothermal map, gravity map of the Bouguer anomalies, map of the ΔT magnetic anomalies, map of environmental hazards, geological–geophysical cross sections.

The main part of the present paper is an overview of the objectives, tasks and the present state of the pertinent cooperative work. One of the important achievements is the assessment of the obvious surface damages and harms already affecting the environment, thus rendering possible their reparation, mitigation or prevention. Furthermore, attention is drawn also to subsurface hazards e.g. those affecting the groundwater which used to be left out of consideration, and ways of practical application are indicated, thus contributing to the maintenance, eventually even to the improvement, of the standard of living of the population in the Danube Region.

Zusammenfassung

Zum ersten Mal haben sich die drei Donauländer Österreich, Ungarn und die Slowakei geeinigt, nach gründlicher Vorbereitungsarbeit eine gemeinsame geowissenschaftliche und angewandt-geologische Kartenserie herauszubringen. Unterschiedliche nationale Traditionen und geowissenschaftliche Methoden haben es bisher wesentlich erschwert und in gewissen Fällen sogar unmöglich gemacht, eine einheitliche Interpretation zu erzielen.

Im Jahr 1989 wurde ein bilaterales Abkommen von Ungarn und der Slowakei unterzeichnet, das eine gemeinsame geologische Untersuchung der durch die Donau voneinander getrennten Gebiete in beiden Ländern zum Ziel hat. Österreich schloß sich im Jahre 1990 als dritter Partner an.

Das gemeinsame Programm wurde in folgenden Themenkreisen bearbeitet: geologische Karte, genetische und Mächtigkeitskarte des Quartärs, Fazies und Mächtigkeitskarte des Pontians und des Pliozäns, Fazies und Mächtigkeitskarte des Pannons, geologische Karte des vortertiären Untergrundes, tektonische Karte, neotektonische Karte, ingenieurgeologische Karte, hydrogeologische Karte, geothermische Karte, Karte der Schwerenanomalien, Karte der geomagnetischen Anomalien, geoelektriche Widerstandskarten, Karte der Umweltrisken, Studie über die Wasserqualität, geologisch–geophysikalische Querprofile.

Der wesentliche Teil des vorliegenden Artikels gibt eine Übersicht über die Zielsetzungen, die Aufgaben und die bisherigen Ergebnisse im DANREG-Programm. Das Erkennen und die Festlegung von verschiedenen Beeinträchtigungen an der Erdoberfläche und die sich daraus ergebende Möglichkeit, diese Einflüsse auf die Umwelt zu minimieren oder überhaupt zu vermeiden, stellen ein erstes bemerkenswertes Ergebnis dar. Auch negative

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Beeinflussungen im Untergrund und die sich daraus ergebenden Gefahren, z. B. für das Grundwasser, die bisher weniger beachtet worden sind, bieten Möglichkeiten, rechtzeitig Maßnahmen zu setzen und so die Lebensqualität der im DANREG-Bereich lebenden Bevölkerung zumindest zu erhalten, wenn nicht zu verbessern.

Összefoglalás

Első alkalommal történik meg, hogy a Duna által felfűzött három ország a csatlakozó területeiről alapos előkészítő munka után egységes szemléletű térképsorozatot hoz létre, kiküszöbölve ezzel a sajátos nemzeti módszerekből és hagyományokból fakadó, az egységes értelmezést nehezítő, esetenként lehetetlenné tevő különbségeket.

A Duna által elválasztott szomszédos területek közös feldolgozására 1989-ben jött létre a magyar–szlovák egyezmény. Ausztriának 1990-ben történt csatlakozásával háromra bővült az együttes munkára vonatkozó egyezményt aláíró országok száma.

A közös munka az alábbi témakörökre, munkafajtákra terjed ki: felszíni földtani térkép, a negyedrendszer képződményeinek genetikai és vastagsági térképe, pontusi és pliocén fácies és vastagsági térkép, pannóniai fácies és vastagsági térkép, harmadrendszermentes földtani térkép, tektonikai térkép, neotektonikai térkép, mérnökgeológiai térkép, hidrogeológiai térkép, geotermikus térkép, gravitációs anomáliatérkép, mágneses anomáliatérkép, geoelektromos ellenállástérképek, környezet-veszélyeztetettségi térkép, vízminőség tanulmány és földtani-geofizikai szelvények.

A dolgozat fő részét a program céljának, feladatainak és a munka jelenlegi helyzetének áttekintése adja. A közös munka fontos eredménye a nyilvánvaló felszíni környezeti károk és veszélyek felmérése és ezáltal azok kiküszöbölési vagy megelőzési lehetőségének megteremtése. Emellett egyrészt eredetileg kevésbé értékelt felszín alatti negatív hatások és ebből pl. a felszín alatti vizek esetében jelentkező veszélyek is feltárásra kerülnek, másrészt gyakorlati hasznosítási lehetőségekre is utalás történik, hozzájárulva ezzel a DANREG térség lakossága életminőségének legalább megőrzéséhez, esetleg javításához is.

Introduction

The Danube is the second largest river in Europe and a very important historical, political and economic feature of Central and Southeast Europe. It is 2,850 km long and drains an area of about 816,000 km^2. The Danube begins in the Black Forest Mountains in Germany and passes the Jura Mountain range, the Bohemian Forest, the Eastern Alps, the Western and Southern Carpathians as well as main European lowlands. So the Danube or its tributaries cut or pass the main geological and geographical features of Central and Southeast Europe. The Danube is also a very important traffic route (it is navigable for small vessels from Ulm and for bigger ones from Regensburg) and links many Central and Eastern European peoples and countries. It passes densely populated and highly industrialized regions (e.g. the regions of Vienna, Bratislava and Budapest) as well as regions very important for the agricultural potential (e.g. the Vienna Basin with the March Lowland, the Danube Lowland east of Bratislava, or the Little and the Great Hungarian Plain) or for the recreation of local people and tourists (e.g. the Wachau, the Danube-March river forests in Austria, Dunajska Streda, Štúrovo and Kovačovske kopce Hills in Slovakia and the Szigetköz, Danube Band north of Budapest and Gemenc in Hungary). In Germany and especially in Austria it contributes to the production of electricity due to a number of dams and hydropower stations. The Danube and its attendant groundwater flow represent one of the largest freshwater resources in Europe.

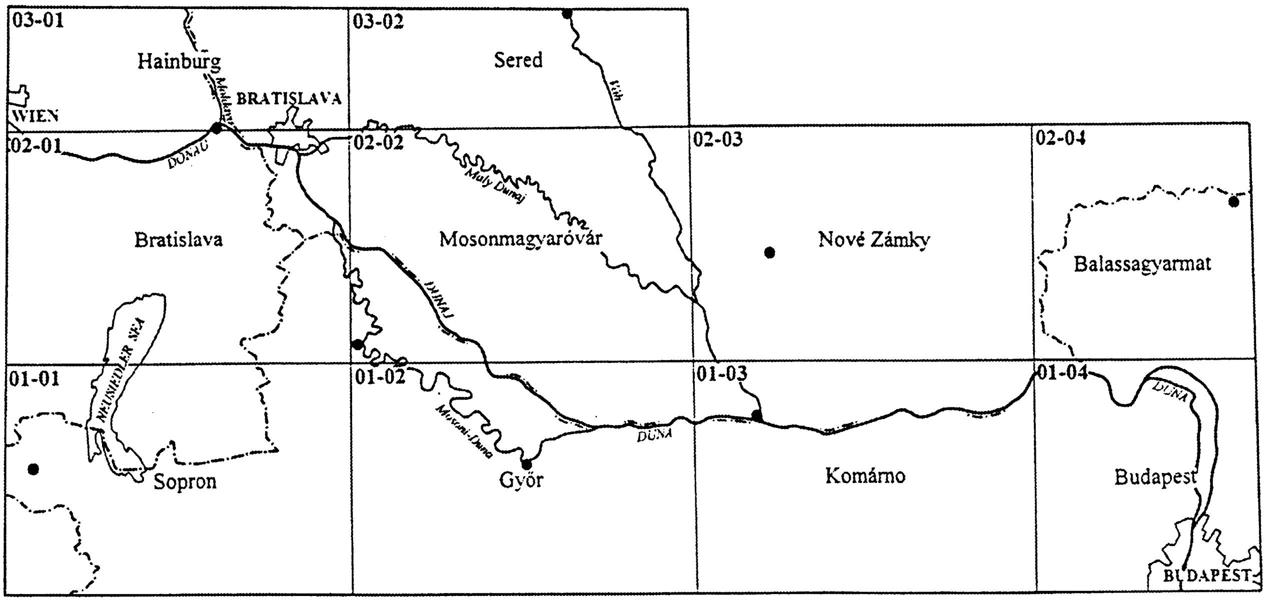
The number of natural and man-induced environmental effects of the region and the awareness of the population for environmental protection increased dramatically in the past decades.

Intensive agricultural production (the Danube Lowland is the most important agricultural area in Slovakia), large industrial cities (e. g. Vienna, Bratislava, Budapest), increased bottom erosion of the Danube provoked by the dams in Germany and Austria, or huge technical constructions (e. g. Gabčíkovo barrage) are only some examples which affect the natural conditions of the fragile environment.

The DANREG Programme

The DANREG Programme (**DAN**ube **R**egional **E**nvironmental **G**eology) was launched in 1989, originally on bilateral (Hungarian–Slovakian) basis. Later, in 1990, after the fundamental political changes in Central and Eastern Europe, the representatives of the national geological surveys of Austria (Geologische Bundesanstalt), Hungary (Magyar Állami Földtani Intézet) and Slovakia (Geologický Ústav Dionýza Štúra) signed the agreement. Since then work has been going on in 14 working groups. Results and things to be done are reviewed by a Co-ordinating Board which holds its meetings every 3–4 months. The basic objective of this co-operative effort is to integrate the existing knowledge that is inadequate along the borders and in the deep basins and should be completed with new investigations. The extension of the study area is about 20,000 km^2, including the region between Vienna, Bratislava and Budapest (figure 1). The aim was to **establish a common geological language** on national data bases different in systems, approaches and detailedness, and to compile a total of 13 map versions assisted by GIS, with explanatory notes and studies, three common geophysical and geological cross sections within the framework of the co-operation between Austria, Hungary and Slovakia.

Fig. 1. Sketch map of the DANREG area



The following products have been envisaged:

Maps

Surface geological map,	1:100,000
Lithogenetic and thickness map of the Quaternary,	1:200,000
Lithofacies and thickness map of the Pontian and the Pliocene,	1:200,000
Lithofacies and thickness map of the Pannonian,	1:200,000
Map of the pre-Tertiary basement,	1:200,000
Tectonic map,	1:200,000
Neotectonic map,	1:200,000
Engineering-geological map,	1:200,000
Hydrogeological map,	1:200,000
Geothermal map,	1:200,000
Gravity map of the Bouguer anomalies,	1:200,000
Map of the ΔT magnetic anomalies,	1:200,000
Map of environmental hazards.	1:100,000

In addition to the maps above geoelectric maps showing the lithology and thickness of the Quaternary have been supplemented for some parts of the region in a scale 1:500,000.

Cross sections

Vienna Basin–Little Hungarian Plain
Danube Lowland–Oroszlány Basin
Patince (Slovakia)–Zsámbék (Hungary)

Studies

Water quality
Geothermal energy

DANREG subjects

The ***Surface geological map*** is the base for all the other maps with special regard to the Quaternary map, to the Engineering-geological map and to the Map of environmental hazards. The national versions of the map are ready. The complicated geological setting of the area is reflected in the number of elements of the legend that exceeds 300. Special attention is paid to the Quaternary sediments, the elements of which are genetic types in contrast to the older formations where lithostratigraphic units are distinguished. The map also presents the location of the wells and boreholes of fundamental importance.

The ***Lithogenetic and thickness map of the Quaternary*** summarizes the main genetic types of sediments and their cumulative thickness. In the deepest part of the basin the thickness values are based mainly on geoelectric measurements. The isopach lines separate territories of fast subsidence from the uplifting or slowly subsiding areas. The process of fast subsidence that is going on even today was restricted to the western part of the Little Hungarian Plain in the Quaternary (where even some 600 m thick deposit was accumulated during a period of some 2 million years). The separation of subsidence and uplift is indicating the most mobile zones along which one can expect earthquakes and tectonic movements even today.

The ***Lithofacies and thickness maps of the Pannonian and the Pliocene*** show a differentiation (particularly subsidence) of the terrain that started at the beginning of the Miocene, as well as an intensive acceleration of this process during the Pannonian (the accumulation of 6000 to 7000 m deposits over a period of some 8 milllion years). The Little Hungarian Plain — the Danube Lowland area is the deepest Neogene basin within the Carpathian arc. The thickness lines are drawn with the help of various geophysical (seismic and electric) measurements, wells and borehole data. The very mighty sequence is composed of two sedimentary cycles that are illustrated on two maps: Lower Pannonian and the Upper Pannonian–Pontian ones.

The ***Map of the pre-Tertiary basement*** is used to properly document the differences in depth and age of the basement and also the origin of the individual tectonic units. The last data can be used for palaeogeographic reconstruction and for distinguishing the tectonic movements of a great number of tectonic lines indicated on the surface of the pre-Tertiary basement. In addition to the wells and boreholes indicated in the map geophysical data are also used for the setting of the isolines. Due to the irregular distribution of basement data in boreholes there are areas with great uncertainty in age, in rock type and even in depth of the basement.

The ***Tectonic map*** excluding the Quaternary formations represents units according to the successive deformation phases. The main Alpine tectonic phases are as follows: Cretaceous, Palaeogene, Early to Middle Miocene, Late Miocene to Pliocene. The present-day tectonic outline of the region was developed during the Early to Middle Miocene, that is the paroxysm of the volcanic activity and the formation of the deep basins. The majority of the lines supplied with names in the map, is connected with the events listed above. There is clear evidence for the rejuvenation of the movements along some tectonic lines. The following tectonic elements are distinguished: axes of synclines and anticlines, nappes, overthrusts, strike-slip faults and normal faults.

Separating the Pelso unit from the Veporic unit, among many important tectonic lines the Rába–Hurbanovo–Diósjenő Line is considered to be the most important one.

The folded, overthrusted structures that had developed in the Cretaceous were later pulled apart by conjugate displacement in response to a NW–SE compression. In the Neogene, the stress field changed several times and resulted in the rotation of certain tectonic units.

The ***Neotectonic map*** is based mainly on the seismic activity and on the thickness differences in the Upper Pliocene to Recent sediments. Tectonic lines and structures active this time separate faults of basinal structure (Gabčíkovo Basin) and faults of other structures. The most intensive young tectonic activity in the region has been observed on the contact of the Small Carpathian Mts. (with Hainburg Hills) to the basinal part of the Danube Lowland. Renewal of some Miocene (or older) tectonic lines is also indicated.

The ***Engineering-geological map*** belongs to the group of zoning maps. Its legend is based on the internationally accepted methodology of IAEG (International Association of Engineering Geologists).

Altogether about 30 zones (lithologic-genetic units) and more than 10 lithological types of solid rocks and soils are delineated in the map. Other data important for the engineering geology are taken from other maps (tectonics and neotectonics, selected hydrogeological data). Geodynamic phenomena — like slope deformations, erosional features, — karst phenomena, hydrocompaction in loess, underminings, places of minings and sources of possible pollution — like waste disposal sites — are also presented on the map.

In the ***Hydrogeological map*** the permeability and lithology of the aquifers have been expressed. Primary (pores), secondary (fissures) and karst permeability have been distinguished in the map, with seven categories according to their value. The lithology of the aquifers is displayed, identifying 21 types.

The ***Geothermal map*** indicates the distribution of temperature recorded at 1500 m depth. Due to their geothermal potential two main areas are delineated: the Vienna Basin and the Little Hungarian Plain–Danube Lowland. A study with several cross sections is attached to the map.

The common ***Gravity map of the Bouguer anomalies*** has been constructed using a density value of 2.67 g/cm^3, the interval of isolines is 1 mGal. A characteristic feature of the map is an elevation strip with a SW–NE oriented axis in the NW part of the project area, corresponding to the "heavier" Little Carpathian Mts. and Hainburg Hills. The large distinct depression in the Dunakiliti–Senec region represents the deepest part of the pre-Tertiary basement. The Vienna Basin shows similar gravity values, although its depth is considerably less than that of the previous depression.

Gravity maps are usually compiled for two reasons:

— to obtain information on the depth of basins;
— to obtain information on the internal structure of the crust.

However, in the DANREG area the gravity method could not deliver the above information entirely because of the distortion of the Bouguer anomalies by crustal and upper mantle effects. Therefore in addition to the Bouguer anomaly map, the map of residual anomalies, indication map of density contrasts by Blackly stripped gravity map, etc. have been compiled.

The common ***Map of the ΔT magnetic anomalies*** has been constructed in the project area in order to clarify the extent, shape, depth and distribution of the sources of magnetic anomalies, i.e. mafic and ultramafic rocks. Prior to the start of the DANREG project, the magnetic maps for Slovakia and Hungary could not be fitted together along the border (fig. 2), therefore some special problems had to be solved for the compilation of the common map. Their reason was that the previous measurements had not been agreed between the countries (measurement of ΔZ in Hungary, ΔT in Austria, ΔZ and ΔT in Slovakia, ground and airborne surveys, different altitudes in the airborne surveys, etc.). Connecting profile lines have been measured between Slovakia and Austria, and between Hungary and Slovakia, after which the Geological Survey of Austria compiled the common ΔT map (fig. 3).

Many magnetic anomalies have been detected in the project area. According to the seismic and magnetotelluric measurements, the source of major magnetic anomalies is surely within the pre-Tertiary basement.

As one version of the geoelectrical maps, the ***Maps of apparent resistivity*** have been compiled to assess the lithology of the Quaternary sediments, which represent one of the most important freshwater reservoires in Central Europe. Three resistivity maps have been constructed for different AB distances, (for AB = 200 m, 600 m and 1000 m), corresponding to approximate depth levels of 50 m, 150 m and 250 m. The maps show extensive accumulation of coarse to medium grained Quaternary sediments (gravel and sand) occurring in the central depression of the Danube Basin and the Little Hungarian Plain. Here on the basis of electrical soundings, the ***Thickness map of the Quaternary sequence*** has also been compiled, showing that the thickness reaches even 600–700 m.

Among other geophysical activities in the DANREG programme it should be mentioned that magnetotelluric and seismic measurements have been performed in the region for the investigation of deep structures. Their most important result is that the Rába–Hurbanovo structural line could be located. It is, in fact, a contact zone between two microplates of different origin. The results of the DANREG programme allow a new interpretation of the structure of the crust and the upper mantle.

The ***Map of environmental hazards*** is intended to show some phenomena of natural impact on the geological

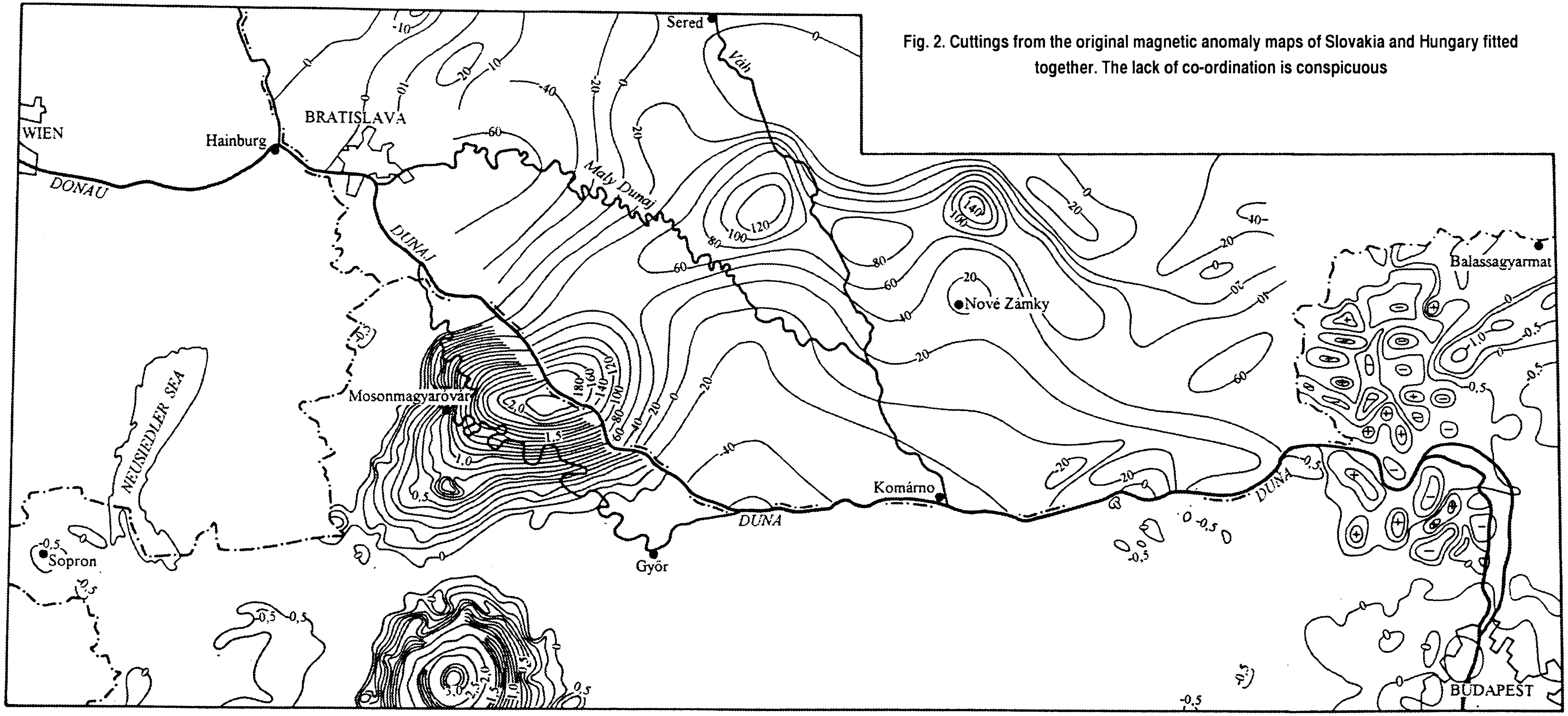
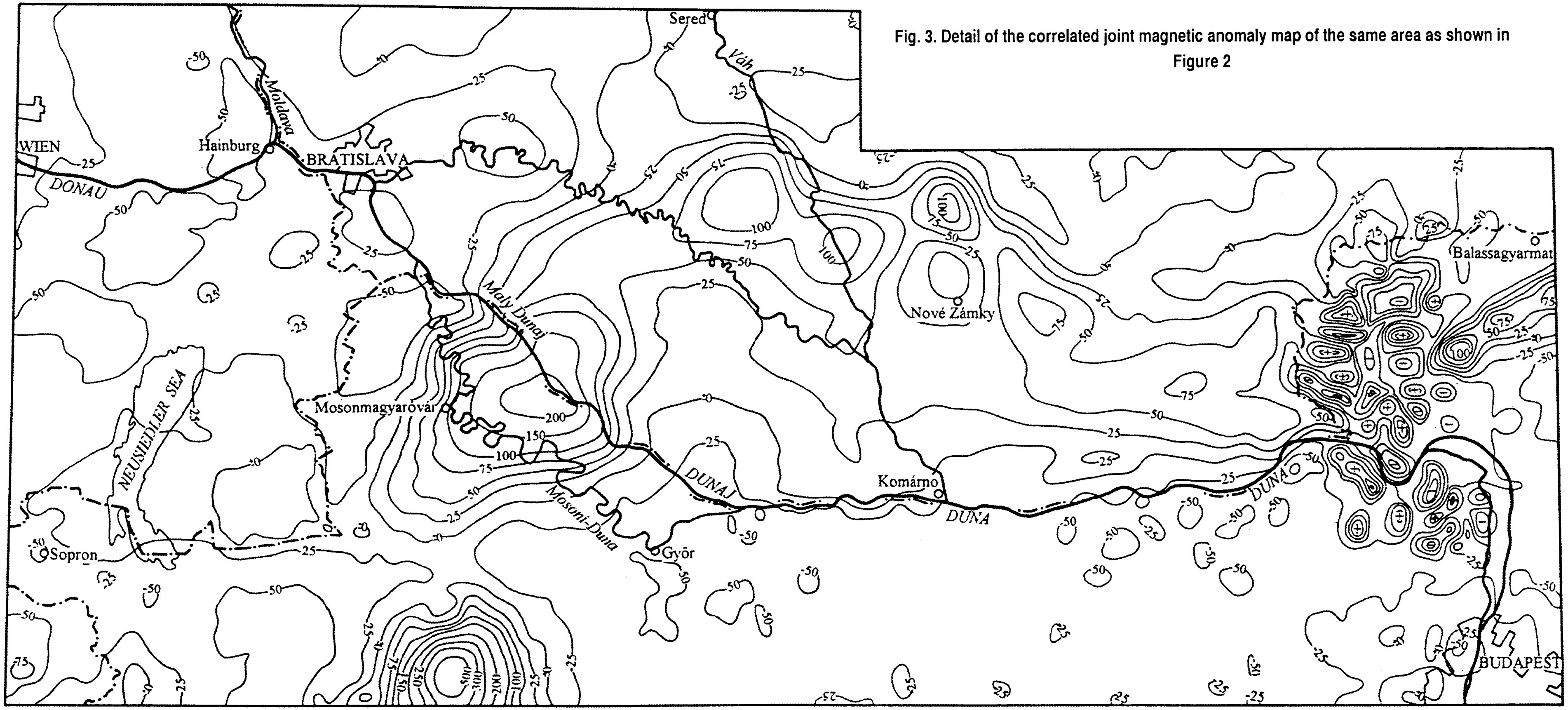


Fig. 2. Cuttings from the original magnetic anomaly maps of Slovakia and Hungary fitted together. The lack of co-ordination is conspicuous

Fig. 3. Detail of the correlated joint magnetic anomaly map of the same area as shown in Figure 2



environment and the risk factors associated with the man-made hazardous establishments. The methodology is new and has been developed specially for the DANREG programme.

The mapped area is divided into five zones according to the sensitivity of the area to pollution. Another data which represent some types of natural or man-induced environmental hazards are also presented (active tectonic faults, epicentres of recorded earthquakes, boundaries of floods, sites of waste disposals, quarries and mines, areas of high level of pollution of soils etc.).

The main philosophy of this map is to show the sensitivity of rocks to contamination (thus, the protection level of groundwater, some confined groundwaters and karst water).

All three ***cross sections*** cut the Rába–Hurbanovo tectonic line separating the Lower Austro-Alpine–Carpathian units from the Pelso unit. In addition to this the Vienna Basin–Little Hungarian Plain section shows the relation between the Austro-Alpine units and the Bohemian massif.

The ***Study of water quality*** evaluates the quality of surface water, groundwater and precipitation water. Natural and anthropogenic factors that influence the quality of water are described and evaluated. The study is based mainly on archive data. Some new sampling and laboratory testing are performed within the project. The present situation and prognosis for the future of the quality of water is presented in the study. This topic did not result in a map.

Conclusions

The region of the DANREG Programme is divided by borders into three independent states, but geoscientific questions can not be solved in isolation. Also problems of the environment cross borders and their solving needs multinational co-operation. The DANREG Programme is an attempt to create a set of unified thematic maps in the field of geoscience and applied geology. These maps and the connected data base should function as an unanimously accepted basis for decision makers for land use planning. Conflicts in land use always existed, but in highly developed industrialised regions as the DANREG area they increased dramatically in the past decades. Some of the major possible conflict topics are: residential areas, industrial precincts, recreation sites and nature parks, protected areas for groundwater use, areas preserved for mining (mass raw materials included), and agricultural areas.

All the data of the DANREG Programme should be available at the end of 1996 and they will be offered to the planning and deciding authorities in the communities, in the districts and in the states, which are covered by the DANREG Programme. All collaborators to the DANREG Programme (it have been many dozens in each participating country) hope that the information elaborated and collected could contribute to increase the quality of life of the population. If DANREG will be successful it can be an example for other regions to solve their problems.