Acta Geologica Hungarica

VOLUME 33 NUMBERS 1–4, 1990

Akadémiai Kiadó, Budapest

ACTA GEOL. HUNG. 33(1–4) 3–176 (1990) HU ISSN 0236-5278

ACTA GEOLOGICA

A QUARTERLY OF THE HUNGARIAN ACADEMY OF SCIENCES

Acta Geologica publishes original reports of studies in geology, crystallography, mineralogy, petrography, geochemistry and paleontology.

Acta Geologica is published in yearly volumes of four issues by

AKADÉMIAI KIADÓ
Publishing House of the Hungarian Academy of Sciences
H-1117 Budapest, Prielle Kornélia u. 19—35.

Manuscripts and editorial correspondence should be addressed to

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ACTA GEOLOGICA HUNGARICA

Vol. 33

Nos 1-4

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PRINTED IN HUNGARY

Akadémiai Kiadó és Nyomda Vállalat, Budapest

ACTA GEOLOGICA HUNGARICA

EDITOR

J. FÜLÖP

VOLUME 33

1828

AKADÉMIAI KIADÓ, BUDAPEST

1990

Acta Geologica Hungarica, Vol. 33/1-4, pp. 3-12 (1990)

MICROFAUNISTIC INVESTIGATIONS OF HUNGARIAN URGONIAN LIMESTONES (BARREMIAN - ALBIAN)

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Institute of Paleontology and Geology of University, Munich

The present paper deals with microfaunistic investigations (benthic foraminifera, respectively) of Urgonian limestones (Barremain - Albian) of Hungary, including the Villány Mountains to the south and the Transdanubian Central Range in the Northwest. Some species are recorded for the first time in Hungary.

Keywords: Villány Mountains, Transdanubian Central Range, Urgonian Limestones, Barremian - Albian, Benthic Foraminifera, Orbitolinids.

Introduction

A synopsis of Cretaceous Formations in Hungary was given recently by Császár - Haas (1984). Accordingly Urgonian limestones occur in different megatectonic units that are separated by NE-SW running fault lines. The paleogeographic framework of these units within the Alpine-Carpathian-Dinaric orogenic belt is presented in Haas - Császár (1987) by palinspastic sketch maps. For details about plate tectonic concepts of Hungarian tectonic units and subunits the reader is referred to the works of Kovács (1982), Brezsnyánszky - Haas (1986) and Haas (1987).

Samples of Urgonian limestones were taken from the Villány Mountains and the Transdanubian Central Range. Since the localities studied have just been treated in fundamental monographs (Fülöp, 1958, 1964, 1966; Császár, 1985, 1989), they are here described only briefly.

The best microfossils for Urgonian biostratigraphy are orbitolinid foraminifera (e.g. biozones of Schroeder, 1964, 1975). In Hungary especially the orbitolina studies of Méhes (1963-1984) should be mentioned. However,

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Received: 20/06/89

Akadémiai Kiadó, Budapest

detailed knowledge of systematic on individual genera and progress in biostratigraphy (e.g. Schroeder - Neumann, 1987) requires a revision of the former determinations.

It is worth mentioning that the sections in question have not been studied in detailed profiles and thus no stratigraphic range chart of different species can be given.

1. Villány Mountains

1.1. Nagyharsány quarry

The Lower Cretaceous rocks of the Nagyharsány Limestone Formation lie transgressively upon eroded Tithonian limestones with a distinct bauxite horizon at the base, well-exposed at the Nagyharsány quarry of the Mount Harsány (Fülöp, 1966). Based on lithology as well as faunal and floral content Fülöp distinguishes 3 members, whereas Császár (1989) recently gives a division of the section into 4 units. According to Fülöp these members are:

a) a lacustrine-brackish, basal member (about 70 m)(=1. unit of Császár), generally with ostracods and characean algae; some strata contain benthic foraminifera, miliolids, respectively. This member represents a typical tidal flat environment with stromatactis-bearing limestones, intraformational breccias, reddish paleosoil layers and reworked stromatolithic algal mats ("black pebbles") (Császár, 1989; Pl. 10, Figs 2-3 of Fülöp, 1966). In addition Császár emphasizes the strong resemblance of the Lower member to the Lofer-cycle, known from the alpine Dachstein Limestone.

The basal complex seems to comprise the Lower Barremian, whereas Upper Hauterivian cannot be excluded (see Császár, 1988: 27). Some findings of the dasycladacean alga Salpingoporella genevensis (Conrad) (uppermost Hauterivian - Lower Barremian, according to Masse, 1976) are the only biostratigraphic marker available.

b) a second member (about 70 m)(=2. and 3. unit of Császár) with numerous benthic foraminifera (Cuneolina, Sabaudia, miliolids, orbitolinids), dasycladacean algae (Salpingoporella), gastropods and pachyodonts. According to Fülöp (1966) this member represents typical Urgonian facies, ranging stratigraphically from Barremian to Lower Aptian. The micritic rudistid bearing miliolid-orbitolinid wackestones represent a typical lagoonal, inner platform environment (Facies belt 7 of Wilson, 1975).

The second member of Fülöp contains, besides abundant miliolids (e.g. Spiroloculina cretacea Reuss, "Sigmoilina" sp., Derventina filipescui

Neagu), the most remarkable:

Sabaudia minuta (Hofker)
Mayncina bulgarica Laug, Peybernes and Rey
"Siphovalvulina variabilis" Septfontaine (Pl. 14, Fig. 1, Fülöp, 1966)
Nautiloculina brönnimanni Arnaud-Vanneau and Peybernes
Glomospira urgoniana Arnaud-Vanneau
Orbitolinopsis cf. cuvillieri Moullade
Valvulineria ? n. sp. 2 Arnaud-Vanneau
"Cuneolina" camposaurii Sartoni and Crescenti
Debarina hahaunerensis Fourcade, Raoult and Vila
Nezzazatinella aff. macovei Neagu
? Falsurgonina pileola Arnaud-Vanneau and Argot
Ovalveolina cf. reicheli De Castro (="Ovalveolina" n. sp. 1, Peybernes 1979: Pl. 2, Figs 1-2).

c) a third member (30-40 m) (=4. unit of Császár) containing orbitolinids as the dominant group.

The uppermost beds of the third, terminal member represent wackestones with pelletal texture, siltic bioclasts and numerous Praeorbitolina cormyi/wienandsi Schroeder and seldom Choffatella decipiens Schlumberger (Pl. 11, Fig. 11, Fülöp, 1966). In addition Peybernes (1979) also cites the occurrence of Palorbitolina lenticularis (Blumenbach). It is noteworthy that Sabaudia minuta (Hofker) is abundant, too, but is represented only by its isolated embryonic apparata. Furthermore, the small size of the associated textulariids and miliolids is another peculiar feature of the orbitolina-beds.

These orbitolina-beds are similar to those, described from the Helvetian Schratten Limestone, that are interpreted as reflecting period of increased terrigenous input (e.g. Bollinger, 1988). In the Schratten Limestone Palorbitolina lenticularis (Blumenbach) is associated typically with the aranaceous lituolid Choffatella decipiens Schlumberger, too, as in the Nagyharsány quarry.

The Urgonian complex of the Villány Mountains was also studied microfaunistically by Peybernes (1979) confirming the Barremian - Bedoulian age for the section in question, based on findings of Orbitolinopsis gr. kiliani-cuvillieri, Palorbitolina lenticularis (Blumenbach) and Praeorbitolina cormyi/wienandsi Schroeder at the top of the section. The datations made by Peybernes (1979) can be reaffirmed by the present investigations.

Interesting is the occurrence of Ovalveolina cf. reicheli De Castro. De Castro (1988) gives the stratigraphic range of the species as Upper Gargasian to Clansayesian. Since O. reicheli had been figured together with Palorbitolina lenticularis (Blumenbach) by Velic - Sokac (1978: Pl. 4, Figs 3-4), it occurs almost in the Lower Aptian (Velic - Sokac, 1983: Fig. 2). The occurrence of O. reicheli even in the Upper Barremian in the Nagyharsány Limestone Formation cannot be excluded (Fig. 3, Peybernes, 1979). From a palaeobiogeographic point of view the findings of O. reicheli indicate Dinaric affinities, because it is only known from Italy, the Dinarids and North Africa (≠biospace a Archalveolina gr. reicheli de castroi, Pelissie et al., 1982; province a Archalveolina reicheli, Bassoullet et al., 1985).

1.2. Beremend quarry

The sequence exposed here represents the stratigraphic continuation of the Nagyharsány Limestone Formation. The microfacies of the dark to light grey limestones is characterized by miliolid-orbitolinid wackestones. In contrast to the Nagyharsány section, dasycladacean algae only occur sporadically. The Beremend section is dated as Late Aptian (Gargasian) by Peybernes (1979; Méhes, 1971: 176), doubting that it might range into the Lower Albian as assumed by Fülöp (1966). The following foraminifera species could be identified:

Sabaudia minuta (Hofker)
Sabaudia capitata Arnaud-Vanneau
Glomospira urgoniana Arnaud-Vanneau
"Cuneolina" camposaurii Sartoni and Crescenti
Valvulineria ? n. sp. 2 Arnaud-Vanneau
Orbitolina (Mesorbitolina) texana (Roemer)(=Orbitolina berremendensis Méhes, 1967)
Dictyoconus pachymarginalis Schroeder

The co-occurrence of the latter two orbitolinids indicate an Upper Aptian age (Schroeder, 1965; N'Da, 1984; Schroeder - Neumann, 1987). D. pachymarginalis Schroeder is so far only known from Iran (Schroeder, 1965), the Frioul platform/NE-Italy (Fourcade - Cousin, 1982), the French Pyrenees (N'Da, 1984) and the Northern Calcareous Alps (Schlagintweit, 1990).

2. Transdanubian Central Range

The Transdanubian Central Range with the Bakony Mountains, the Vértes Mts and the Gerecse Mts represents an elongated mass, built up mainly of Mesozoic rocks.

The sedimentary evolution from the Triassic to Cretaceous of this mountain range is summarized in Galácz, Horváth - Vörös (1985). The Cretaceous strata have been investigated by Fülöp (1974, 1966) and Császár (1985a, b).

The samples studied are from the Zirc Limestone Formation of the Bakony Mts and the Köszörükőbánya Conglomerate Formation of the Gerecse Mts.

2.1. Zirc Limestone Formation

In the Bakony Mts the Zirc Limestone Formation, representing a platform-like reef structure with pachyodonts, transgressively, overlies the paludal-lacustrine-marine Tés Clay Formation (Császár, 1985a, b). According to Császár (1985a: 180) in the Northern Bakony the Zirc Limestone is divided into the:

- Eperkéshegy Limestone Member (with pachyodonts)
- Mesterhajag Limestone Member or Orbitolina Limestone Member
- Gajavölgy Limestone Member.

In thin sections the Orbitolina Limestone Member represents an orbitolina biosparite with some fragmented and micritized mollusc remains and primitive rhodophycean algae (Marinella lugeoni Pfender). Besides, very small miliolids and textulariids important to mention are:

Sabaudia minuta (Hofker), with extremely small representative
Orbitolina (Orb.) sefini Henson
Dobrogelina ? angulata Calvez

From the Zirc Limestone Peybernes (1979) reported Orbitolina (Orb.) concava Lam. The orbitolinas figured here all belong to Orb. (Orb.) sefini Henson, which differs from the first mentioned species by the triangular shape of the chamberlets, displayed in tangential sections (Schroeder, 1987). Whereas Orb. (Orb.) concava is restricted to the Lower Cenomanian, Orb. (Orb.) sefini ranges from Upper Albian to lowermost Lower Cenomanian (Schroeder - Neumann, 1987).

Dobrogelina ? angulata was recently compiled by Calvez (1988) from the Upper Albian of the French-Spanish Pyrenees; in the Northern Calcareous Alps D. ? angulata has been discovered in Lower Cenomanian Orbitolina-sandstones, too (own observ.). Based on the mollusc fauna (nerineids, rudistids, chondrodonts) the age of the Zirc Limestone Formation is Middle to Late Albian (Czabalay, 1985). According to Czabalay the pachyodont-association can be compared with the urgonian facies; Peybernes (1979: 236) speaks of "calcaires urgoalbiens". Taking into account all available biota and because of the Vraconnian to Mid Cenomanian age of the overlying Pénzeskút marls, Császár (1985a) gives the age of the Zirc Limestone as Late Albian; the benthonic foraminifera recovered herewith indicate an Late Albian to Early Cenomanian age.

2.2. Köszörűkőbánya Conglomerate Formation

A monograph of the Lower Cretaceous Formation of the Gerecse Mountains in the northeastern part of the Transdanubian Central Range was made by Fülöp (1958). Accordingly the formation consists of three members:

- marl serie (Middle Valanginian - Lower Hauterivian)
- sandstone serie (Upper Hauterivian - Upper Barremian)
- conglomerate serie (Upper Barremian).

As a whole the lithological sequence represents an coarsening upwards cycle that has been compared by Fülöp (1958) with the Rossfeld Formation in the middle part of the Northern Calcareous Alps.

For the purpose of this article special attention was drawn to the allochthonous "exotic" Urgonian limestones that occur as clasts in the conglomerate serie. This member is best exposed at the quarry "Köszörűkőbánya" near Lábatlan, therefore also called the "Köszörűkőbánya Conglomerate Formation". In this sections of these Urgonian Limestones the following faunal and floral elements could be detected:

Foraminifera:

Orbitolina (Mesorb.) cf. texana (Roemer)
Valvulineria ? n. sp. 2 Arnaud-Vanneau
Charentia cuvillieri Neumann
Gavelinella sp.
Placosilinidae
Bdelloidina cribrosa (Reuss)

Calcareous algae:

Kymalithon belgicum (Foslie) Lemoine and Emberger
Pseudolithothamnium album Pfender
Solenopora urgoniana Pfender

The facies of the urgonian limestone boulders with corals and coralline red algae in abundance is typical for an outer platform environment. Besides angular quartz grains, the most remarkable is the presence of ultrabasic detritus (e.g. chromian spinel) in the matrix of the pebbles. As a whole these "exotic" Urgonian limestones show closest resamblances to those found in the middle part of the Northern Calcareous Alps (Schlagintweit, 1990). The occurrence of Orb. (Mesorb.) cf. texana (Roemer) is indicative for the timespan Late Aptian to Middle Albian (Schroeder - Neumann, 1987). But, as the solenoporacean alga Solenopora urgoniana Pfender only extends with question mark into the Late Albian (Poignant, 1981: Fig. 1), an Early Aptian age is most plausible. This is in good accordance with the nannoplankton assemblage recovered from intercalated siltstone layers that give a Late Aptian to Early Albian age (Sztanó, 1989).

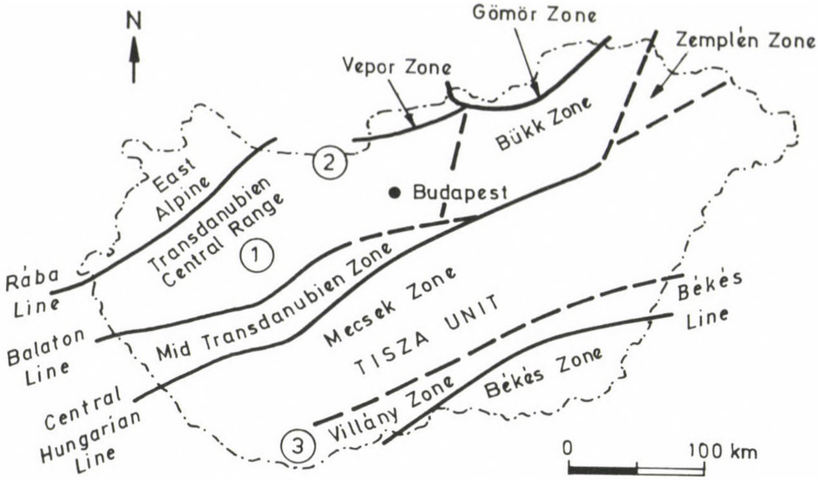


Fig. 1. Megatectonic units of Hungary (after Brezsnyánszky - Haas, 1986) and locations studied: 1. Zirc Limestone Formation; 2. Köszörűkőbánya Conglomerate Formation; 3. Nagyharsány Limestone Formation

Besides the "exotic" urgonian limestones, interesting are clasts with "unknown algal remains" that have been figured by Fülöp (1958: Pl. 11, Fig. 6) without giving an age determination. These represent fragments of the verticil of the Upper Jurassic dasycladacean alga Clypeina jurassica Favre with its typical quadrangular sporangial cavities. The paleogeographic importance is given by the fact that in the Transdanubian Central Range Upper Jurassic rocks in neritic facies are unknown (Galácz, 1984). In the Northern Calcareous Alps, facies equivalent rocks (e.g. Plassen Limestone) are known from the southern tectonic unit of the Juvavicum. In addition, pebbles of Tithonian limestones with Clypeina jurassica Favre have been described by Misik - Sykora (1980) from Upper Cretaceous conglomerates of the Silicicum, the Carpathian equivalent of the Juvavicum.

Taking into account the paleoposition of the Transdanubian Central Range as given by Kovács (1982), these neritic malm pebbles of the Köszörűkőbánya Conglomerate can be assumed to derive from the Juvavicum. The "exotic" urgonian limestones are interpreted as remnants of a former urgonian belt that bordered the western and of the former Vardar ocean and today is totally eroded away (Schlagintweit, 1990).

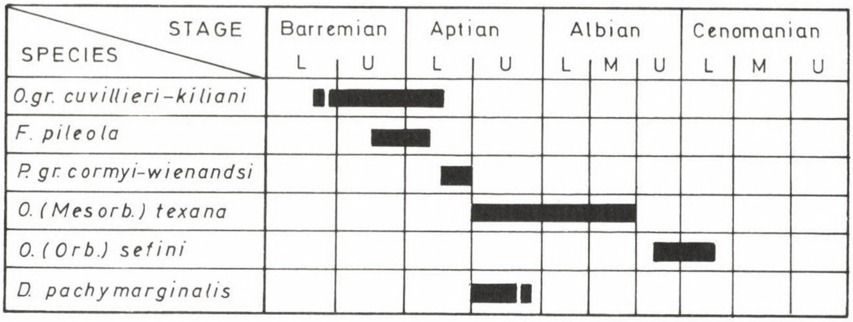


Fig. 2.

Acknowledgement

The author is indebted to G. Császár (Budapest) for presenting me the Urgonian of Hungary in joint field trips, for critically reading the manuscript and, last but not least, for his encouraging interest in this work. Mme Arnaud-Vanneau (Grenoble) was so kind to give some remarks on the fossil determinations made.

REFERENCES

Arnaud-Vanneau, A. (1980): L'Urgonien du Vercors septentrional et de la Chartreuse (Alps occidentales). Geol. Alpine, Mem., Lyon, **11**, 1-874.

Bassoullet, J.P., E. Fourcade, B. Peybernes (1985): Paleobiogeographie des grands Foraminiferes benthiques des marges neo-tethysiennes au Jurassique et au Cretace inferieur. Bull. Soc. Geol. France, Paris, 8, **5**, 699-713.

Bollinger, D. (1988): Die Entwicklung des distalen osthelvetischen Schelfs im Barremian und Früh-Aptian. Mitt. Geol. Inst. Eidg. TH and Univ. Zürich **259a**, 1-136.

Brezsnyánszky, K., J. Haas (1986): Main features of the Pretertiary basement of Hungary. - Geol. Zbornik-Geol. Carpathica. Bratislava, **37**, 297-303.

Calvez, H. (1988): Pseudonummoloculina aurigerica n. gen., n. sp. et Dobrogelina ? angulata n. sp., deux Foraminiferes nouveaux de l'Albien calcaire des Pyrenees franco-espagnoles. Rev. Paleobiol., Vol. spec., Genf, **2** (Benthos '86), 391-399.

Cousin, M., E. Fourcade (1982): Les facies Cretaces de la plateforme Frioulano-Karstique et leur environment paleogeographique (Alpes Meridionales et Dinarides). Cret. Research. London (1982), **3**, 113-123.

Császár, G. (1985a): Middle Cretaceous Formations of the Transdanubian Central Range: Stratigraphy and connection with bauxite genesis. Geol. Hung. Ser. Geol., Budapest, **23**, 1-207.

Császár, G. (1985b): Middle Cretaceous paleogeography and evolutionary history sketch of the Transdanubian Central Range in the light of key and reference sections. Schriftenr. Erdwiss. Komm., Vienna, **7**, 173-192.

Császár, G. (1989): Transgressive Urgonian sequence with black "pebbles" from the Villány Mountains, Hungary. Acta Geol. Hung., Budapest, **32**, 2-3, 3-29.

Császár, G., J. Haas (1984): The Cretaceous in Hungary: a review. Acta Geol. Hung., Budapest, **27**, 3-4, 417-428.

Czabalay, L. (1985): Die palökologische, biostratigraphische und paläogeographische Auswertung der Molluskenfauna der Zirc-Kalk-Formation. Schriftenr. Erdwiss. Komm., Vienna, **7**, 119-147.

Dercourt, J., J. Geyssant, C. Lepvrier, F. Bergerat, G. Bignot, P. Cros, P. De Wever, B. Géczy, C. Guernet, G. Lackhar (1984): Hungarian mountains in Alpine framework. - Acta Geol. Hung., Budapest, **27**, 3-4, 213-221.

Fülöp, J. (1957): Die kretazischen Bildungen des Gerecse-Gebirges. - Geol. Hung. Ser. Geol., Budapest, **11**, 1-124.

Fülöp, J. (1964): Unterkreide-Bildungen (Berrias - Apt) des Bakony-Gebirges. - Geol. Hung. Ser. Geol., Budapest, **13**, 1-194.

Fülöp, J. (1966): Les formations cretacees de la Montagne de Villány. Geol. Hung. Ser. Geol., Budapest, **15**, 1-131.

Galácz, A. (1984): Jurassic of Hungary: a review. Acta Geol. Hung., Budapest, **27**, 3-4, 359-377.

Galácz, A., Horváth, F. and Vörös, A. (19859: Sedimentary and structural evolution of the Bakony Mountains (Transdanubian Central Range, Hungary): Paleogeographic implications. Acta Geol. Hung., Budapest, **28**, 1-2, 85-100.

Haas, J. (1987): Position of the Transdanubian Central Range structural unit in the Alpine evolution phase. - Acta Geol. Hung., Budapest, **30**, 3-4, 243-256.

Haas, J., Császár, G. (1987): Cretaceous of Hungary: Paleogeographic implication.- Rend. Soc. Geol. It., Rome, **9**, (1986), 203-213.

Kovács, S. (1982): Problems of the "Pannonian Median Massif" and the plate tectonic concept. Contributions based on the distribution of Late Paleozoic-Early Mesozoic isopic zones. Geol. Rdsch., Stuttgart, **71**, 2, 617-640.

Masse, J.-P. (1976): Les calcaires urgoniens de Provence. Valangien-Aptien inferieur. Stratigraphie, Paleontologie, les paleoenvironments et leur evolution. Doctoral Thesis Univ. d'Aix-Marseille, 1-445.

Méhes, K. (1964): The foraminiferal genus Orbitolina from Hungary. Acta Geol. Hung., Budapest, **8**, 1-4, 265-281.

Méhes, K. (1965): Magyarországi Orbitolina-vizsgálatok. Földt. Int. Évi Jel., 1963-ról, 95-105.

Méhes, K. (1967): Új orbitolina faj a Villányi-hegységből. Földt. Közl., Budapest, **97**, 3, 323-325.

Méhes, K. (1968): Two species of the genus Orbitolinopsis from the Villány Mountains, Hungary. Micropaleont., New York, **14**, 2, 221-224.

Méhes, K. (1971): Orbitolinidae. Problems of Evolution and stratigraphic evaluation. Acta Geol. Acad. Sci. Hung., Budapest, **15**, 173-196.

Méhes, K. (1984): Orbitolinas képződmények korrelációja a Tethys övezetében. Földt. Közl. Hung. Geol. Soc., **114**, 563-567.

Misik, M. and Sykora, M. (1980): Jura der Silica-Einheit rekonstruiert aus Geröllen, und oberkretazische Süsswasserkalke des Gemerikums. Geol. Zbornik. Geol. Carpath., Bratislava, **31**, 3, 239-261.

N'Da, V.L. (1984): Urgonien des Pyrenees occidentales. Synthese paleoecologique, micropaleontologique et paleogeographique. - Doctoral Thesis, Pau, 1-317.

Pelissie, T., Peybernes, B. and Rey, J. (1982): Tectonique des plaques et paleobiogeographique des grands Foraminiferes benthiques et des Algues calcaires du Dogger a l'Albien sur le pourtour de la Mesogee. - Bull. Soc. Geol. France, Paris, 7, **24**, 5-6, 1069-1976.

Peybernes, B. (1979): L'Urgonien de Hongrie. - Geobios, Mem. spec., Lyon, **3**, 231-243.

Poignant, A.-F. (1981): Les algues calcaires au Cretace Moyen. - Cret. Research, London, (1981) **2**, 405-408.

Schlagintweit, F. (1990): Allochthone Urgonkalke im Mittleren Abschnitt der Nördlichen Kalkalpen: Fazies, Paläontologie und Paläogeographie. Doctoral Thesis Univ. Munich, 1-151.

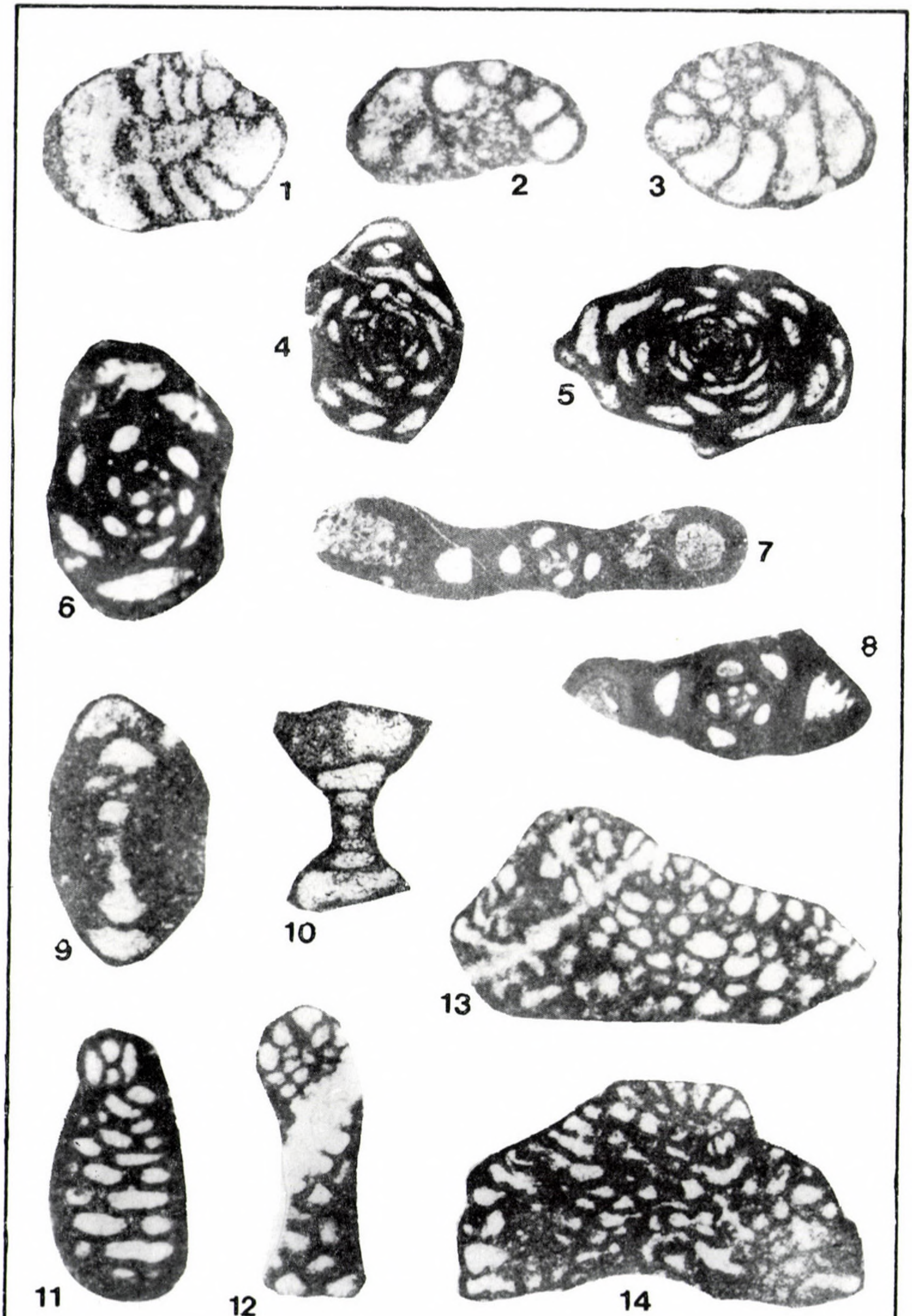
Schroeder, R. (1964): Orbitoliniden-Biostratigraphie des Urgons nordöstlich von Teruel (Spanien). N. Jb. Geol. Paläont. Mh., **8**, 462-474.

Schroeder, R. (1965): Dictyoconus pachymarginalis n. sp. aus dem Apt des Elburz-Gebirges (Nord-Iran). Ecl. Geol. Helv., Basel, **58**, 2, 975-980.

Schroeder, R. (1975): General evolutionary trends in Orbitolinas. Rev. Esp. Micropal., Madrid, num. espec., 117-128.

Schroeder, R. and Neumann, M. (eds) (1985): Les grands Foraminiferes du Cretace Moyen de la region Mediterraneene. Geobios, Mem. spec., Lyon, **7**, 1-160.

Plate I



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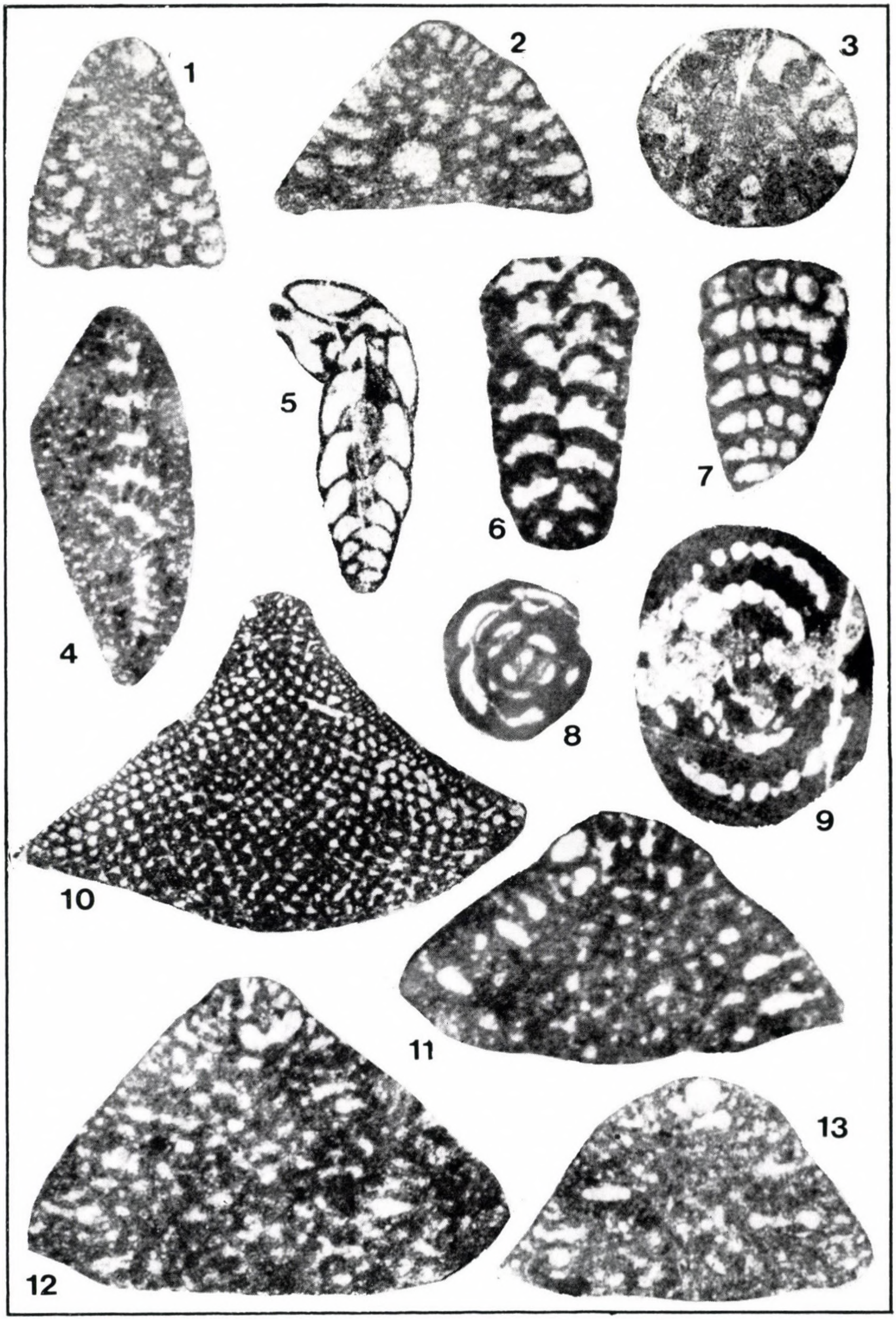
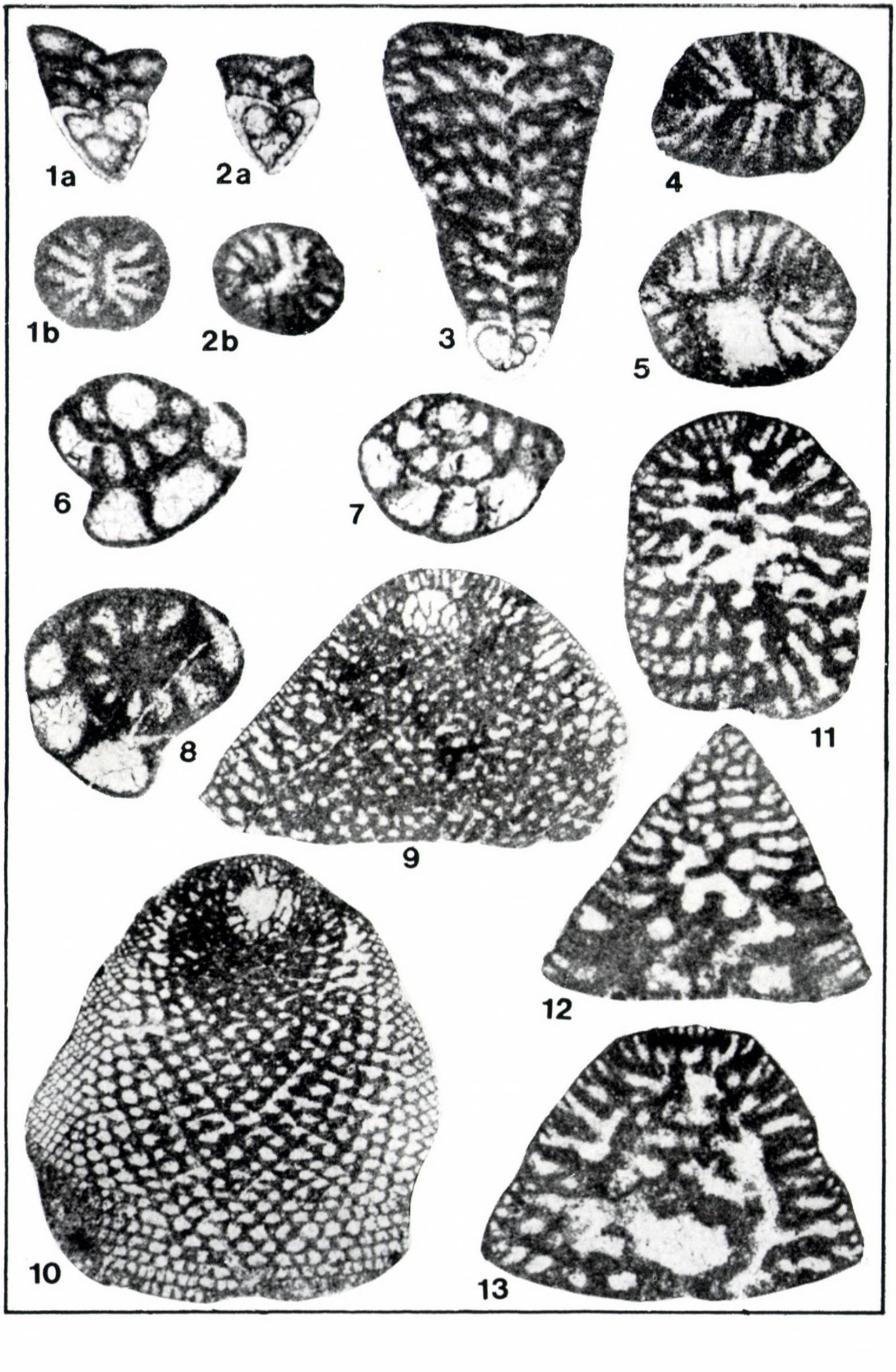


Plate III



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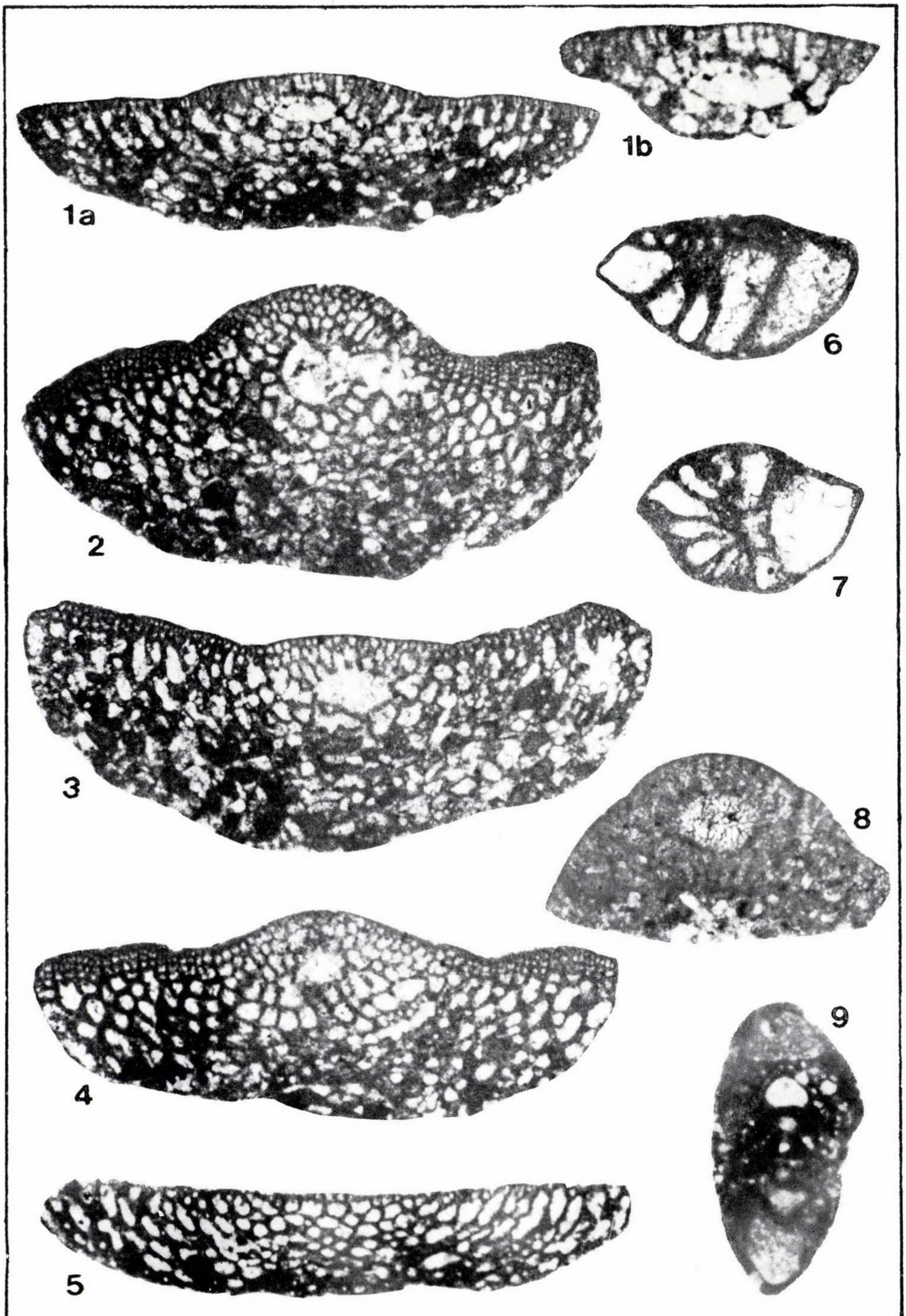

Plate I Foraminifera from the Nagyharsány quarry

Figs 1-3. Nezzazatinella aff. macovei Neagu (x 65)

Figs 4-5. Glomospira urgoniana Arnaud-Vanneau (x 90)

Fig. 6. "Sigmoilina" sp. (x 66)

Figs 7-8. Derventian filipescui Neagu (x 32)

Fig. 9. Nautiloculina brönnimanni Arnaud-Vanneau and Peybernes (x 55)

Fig. 10. Spiroloculina cretacea Reuss (x 97)

Figs 11-14 ? Falsurgonina pileola Arnaud-Vanneau (11-12: x 48 /13-14: x 40)

Plate II Foraminifera from the Nagyharsány quarry

Figs 1-3. Orbitolinopsis cf. cuvillieri Moullade

Fig. 4. Choffatella decipiens Schlumberger (x 61)

Fig. 5. Siphovalvulina variabilis Septfontaine (x 47)

Figs 6-7. "Cuneolina" camposaurii Sartoni and Crescenti (x 61)

Figs 8-9. Ovalveolina cf. reicheli De Castro (x 51)

Figs 10-13. Praeorbitolina gr. cormyi-wienandsi Schroeder (10: x 28 /11-13: x 65)

Plate III Foraminifera from the Beremend quarry

Figs 1-2. Sabaudia minuta (Hofker) (x 92)

Figs 3-5. Sabaudia capitata Arnaud-Vanneau (x 100)

Figs 6-8. Valvulineria ? n. sp. 2 Arnaud-Vanneau (x 100)

Figs 9-10. Orbitolina (Mesorbitolina) texana (Roemer) (x 40)

Figs 11-13. Dictyoconus pachymarginalis Schroeder (x 40)

Plate IV Foraminifera from the Zirc Limestone (1-7) and the Köszörűkőbánya conglomerate (8-9)

Figs. 1-5. Orbitolina (Orbitolina) sefini Henson (x 40, except 1b: x 66)

Figs 6-7. Dobrogelina ? angulata Calvez (x 80)

Fig. 8. Orbitolina (Mesorbitolina) cf. texana (Roemer) (x 80)

Fig. 9. Charentia cuvillieri Neumann (x 57)

Acta Geologica Hungarica, Vol. 33/1-4, pp. 13-30 (1990)

FISSION TRACK DATING OF TUFFACEOUS EOCENE FORMATIONS OF THE NORTH BAKONY MOUNTAINS (TRANSDANUBIA, HUNGARY)

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Fission track dating was performed in accessory minerals of strongly altered, clay mineralized tuffite strata lying in the upper part of the Eocene sequence of the North Bakony Mountains. The homogeneity of the fission track (FT) ages measured on apatite and zircon refers only to insignificant redeposition, no remarkable mingling of the detrital matter could be stated. The average of the FT-ages falls to the Bartonian, into the time interval determined by nannoplankton guide horizons for the volcanic activity (41.9 ± 4.1 Ma). As to their biostratigraphic ages the Middle Eocene samples show an FT-average of 44.2 ± 3.4 Ma, the average of the Upper Eocene group is 39.9 ± 4.1 Ma. The difference between the two groups refers to the two phases of the volcanic activity. The first maximum of volcanism generated the Upper Lutetian to Bartonian glauconitic sequence while the second maximum at the Bartonian - Priabonian boundary produced the tuff strata. The strata in the neighbouring areas relate to continuous volcanism in the Upper Eocene, in the studied area, however, the upper part of the Priabonian was eroded.

Keywords: Eocene, volcanism, geochronology, fission track dating, Bakony Mts , Hungary.

Introduction

The Eocene sequences of Hungary contain tuff intercalations of remarkable quantities but only a few geochronological determinations have been carried out in these formations so far. The main reason of this phenomenon is the fact that the volcanogenic minerals suitable to isotope geochronological studied (first of all biotite and amphibole) are strongly altered, often the tuff horizons are clay mineralized and transformed into bentonite strata. This is why the dating by FT method has been carried out on the accessory minerals that did not undergo the clay mineralogical de-

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Received: 20/03/90

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composition. By means of this method the translucent uraniferous minerals can be studied. In the calc-alkali volcanics of andesitic composition the apatite and zircon are suitable for this purpose.

Measurements were carried out on Eocene tuffaceous or tuff trace bearing rocks deriving from the North Bakony Mountains from boreholes. As a result of the archipelago-like paleogeography of the Middle Eocene of the region tuffaceous intercalations are found in several heteropic formations (Kopek, 1980). The petrographic composition of the studied samples varied from the volcanogenic crystal tuff and bentonite to the pure biogenic limestone containing only a few glauconite grains. It could be stated that in the samples containing only small quantity of glauconite and a few grains of volcanic origin, the minerals zircon, apatite and ilmenite were found in large amounts. These minerals were preserved and indicate the Eocene tuff dusting the material of which decomposed and homogenized in the high energy shallow marine environment.

Investigations aimed at gaining new geochronological data for this formations that have important role in the strata of the Bakony Mountains. When determining the FT ages of certain accessory mineral grains the measure of mingling of the tuffaceous and of the terrigeneous material can be estimated. An attempt was made to state whether this method would be suitable to distinguish between the strata of the volcanism of a relatively narrow period (Upper Lutetian - Priabonian) and whether the fission track method is suitable to refine the stratigraphic classification of a region divided extremely well by plankton stratigraphy.

Extension and petrography of the tuffaceous Eocene strata of the Bakony Mountains

In the Carpathian Basin the Bakony Mountains forms a strip of NE-SW direction (Fig. 1). The mostly shallow water marine Eocene formations lie in the syncline developed after the longitudinal axis of the strip. The pyroclastic-bearing formations can be traced in the total length of the explored strip from the Zala Basin to Recsk belonging to the Bükk unit. Volcanic centres are known from the Zala Basin, from the Velence Hills and from Recsk. The tephrae described from boreholes in the Sári environs close to the explosion centre (Csiky, 1963; Juhász, 1964a, 1964b, 1971; Balázs et al., 1969; Sztrákos, 1975) are of problematic Paleogene age.

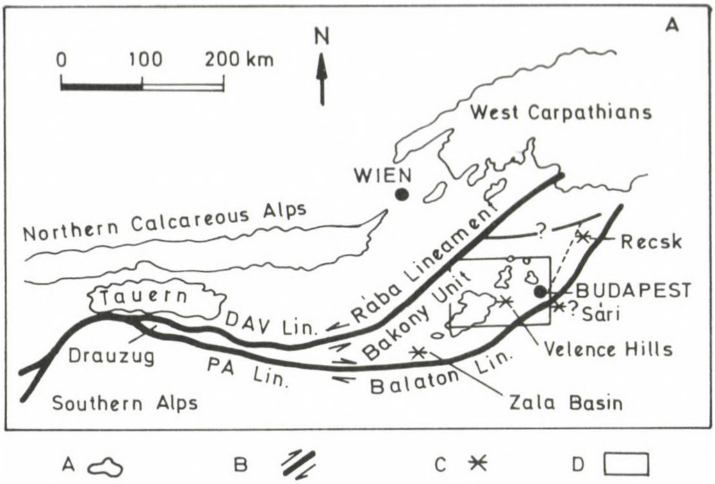

Fig. 1. Tectonic setting of the Bakony unit in the Alpine-Carpathian region (after Kázmér, 1984 and Balla, 1988). A - surface extension of the Paleo-Mesozoic of some characteristic formation groups; B - fault lines characterized by horizontal displacement; C - Paleogene volcanic centres; D - position of the studied area; PA Lin. - Periadriatic Lineament; DAV Lin. - Defereggental-Anterselva-Valles Lineament

Concerning the structural relationships of volcanism Szalai (1937) stated that the Paleogene volcanic centres lie in one strip that is parallel to the main strike direction of the Bakony Mountains. According to Wein (1969) the Balaton line constituting the southern border of the Bakony unit is the continuation of the Periadriatic line. Szepesházy (1977) found relationship between the Hungarian Paleogene volcanites explored in the north-eastern continuation of the tonalite strip and the tonalite formations of the Southern Alps. Based on facies data and tectonic considerations Balla (1981) assigned a southeastward dipping subduction plane to the subduction proceeding during the Middle to Upper Eocene. According to Csillag et al. (1983) the volcanism is of island arc character and as against Balla's opinion they believed the Periadriatic oceanic plate to be subducted from the southeast. To relate the Paleogene calc-alkali volcanites to the subduction of the Alpine ocean is in harmony with the observations in the Alps since in the flysch formations of the Western Alps and of the Helveticum the matter of andesitic volcanism is present in form of detritus from the Maastrichtian to the Oligocene (Homewood, 1983).

As to Kázmér (1984) the Bakony unit got its recent position in the Eocene-Oligocene by squeezing out from the Southern and Eastern Alps. It is in harmony with this picture that the Paleogene volcanic strip is situated close to a fault line, that it is of andesitic chemical composition and that close to its recent position other formations referring to subduction are lacking.

The volcanic centres are characterized by large sized stratovolcanic structures the thickness of which may be as high as 700 m in the Zala Basin (Dubay, 1962; Kőháti, 1965; Balázs et al., 1969, 1981; Mészáros, 1970; Ravasz, 1980; Kőrössy, 1988). In the Velence Hills intrusions and peculiar metasomatites formed from stratovolcanic sequences are known (Darida-Tichy, 1987, 1988). In the Recsk structure porphyry copper deposit and polymetasomatic ore mineralization are also known (Földessy, 1975, 1984). The rocks are mostly of andesitic composition and are strongly altered. Amphibole and biotite, subordinately pyroxene are the mafic constituents.

The provenance of the tuff and tuffite strata that deposited farther of the explosion centres is not always unambiguous. When studying the tuffs and tuff-bearing rocks only the partly decomposed mafic silicates can be used due to the strong alteration. Having studied the tuff horizons interbedded in the Eocene sequences of the Bakony Mountains Széky-Fux and Barabás (1953) recognized the areal separation of each type. Based on the extension of the rocks they believed the amphibole-bearing tuff to come from the Velence Hills, the biotite-bearing tuff to come from the Budapest environs or from norther lying areas, respectively. Nevertheless, Gidai (1971) believed that volcanic activity north of the Buda Hills is improbable. As to the micromineralogical studies of Örkényi-Bondor (1971) the tuff materials of the small basins of the Bakony Mountains lying close to each other (Mór, Balinka, Dudar, Halimba Basins) differ from each other. The glauconitic formations contain almost in all cases volcanogenic material, the glauconite formation proceeds often from biotite, volcanic glass or volcanic rock grains.

According to the formation division for the Eocene of the Bakony Mountains (Dudich, 1977) the Halimba and Csernye Formations contain the pyroclastics. The Halimba Formation has been later called Padrag Formation (Nagymarosy and Báldi-Beke, 1988). It is characterized by the predominance of magmatogenic heavy minerals over the metamoprhic ones in all strata. The proportions of biotite and amphibole varies in the profiles, amphibole is usually more frequent. Their total quantity may be as high as 100% of the heavy mineral content. Concerning the variability of pyroclastic compositions in the Eocene sediments of the Bakony Mountains, Dudich (1979), Dudich and Kopek (1980) as well as Dudich and Gidai (1980) stated: "These are dacitic in the southwest with more volcanic glass, amphibole predominates as mafic silicate. In the east these are andesitic with alternating amphibole-biotite, the proportion of biotite increases upward."

The provenance of the tuff formations of different composition can be traced with difficulties since several fault lines associated with remarkable horizontal displacement are known in the Bakony Mountains and especially the region of the Velence Hills is of complicated structure, the tectonic lines being covered by young sediments.

Chronological problems of Eocene volcanism in the Bakony Mountains

The Eocene sedimentation started in the Bakony Mountains with the Lower Lutetian transgression. The oldest sediments of the marine inundation from the southeast (Dudich and Kopek, 1980) fall into the nannoplankton zone NP-14. In the studied area the start of sedimentation can be fixed in the Upper Lutetian (NP-16 zone, Báldi-Beke, 1984). In the father, northeastern continuation of the strip (Recsk) only Priabonian sediments are known (Zelenka, 1975).

In the Bakony Mountains, in the Lower Lutetian the micromineralogical analyses determined igneous (volcanic) minerals of subordinate quantities as compared to the metamorphic ones. The uppermost part of the Lutetian sequence is characterized by high glauconite content and the volcanogenic grains are also present and become more abundant upwards in forms of heavy minerals (Sárközi-Farkas, 1964; Radócz-Komáromi, 1971). The tuff strata are found in the Uppermost Lutetian and Priabonian sediments.

The rejuvenation of volcanism presumed to follow from the southwest to the northeast (Csillag et al., 1983) seems to be less founded since in the Zala Basin there are no Lower Eocene formations and the duration of the volcanic activity in the Velence Hills and at Recsk is hardly known. It can be only stated that the maximal intensity of volcanism fell to the Upper Eocene, the pyroclastic production was more considerable than in the Late Lutetian.

Based on the nannoplankton and magnetostratigraphic data the volcanic activity recorded in the sediments of the Bakony Mountains was characteristic of the Bartonian between 43 and 40 Ma (Báldi-Beke, 1990). When taking also the whole Priabonian, the Eocene volcanic phase lasted for about 6 to

7 Ma, if accepting the 36.6 Ma value published by Berggren et al. (1985) to the Eocene/Oligocene boundary.

It is to be noted here that concerning the Bartonian there is no uniform concept in Hungary. Most of the micromineralogical and stratigraphic works cited in this work takes the s.l. Lutetian as Middle Eocene, only the researchers dealing with plankton stratigraphy started to apply the internationally accepted Bartonian to the upper part of the Middle Eocene in the Hungarian stratigraphic classification. The historic review of the so-called Bartonian problem together with the details is found in the work of Báldi-Beke et al. (1990). Since the chronostratigraphic scales published on a world scale contain the Bartonian, it will be referred to when interpreting the radiometric data.

Summing up the former geochronological studies it can be stated that 1) only a few radiometric measurements were made from the tuff strata; 2) the rocks of the volcanic centres show for the most part the age of subsequent effects.

1) Only one radiometric result was published so far from the Hungarian stratigraphically proved Eocene tuffs. Balogh (1985) determined a biotite K/Ar age of 31.7 $\pm$ 0.8 Ma in the tuff horizons lying in the Buda Marl and explored by the Alcsútdoboz-3 borehole. Author is doubtful concerning the meaning of this age, the result being much more younger than the geological age reflects probably subsequent effects.

Bagdasarjan (lecture, 1989) measured 42.3 Ma in the whole rock sample of the Upper Eocene tuff of the Urhida-1 borehole.

2) The K/Ar data measured in the Paleogene volcanic formations of the Velence Hills fall for the most part between 30 and 38 Ma (measurements of Balogh K. in: Darida-Tichy, 1988). He obtained 42.5 Ma, i.e. older than Upper Eocene only in one biotite sample. Bagdasarjan (lecture, 1989) measured 34 to 35.6 Ma in whole rock samples of lava banks of the stratovolcanic sequence. The apatite fission track ages measured in andesites fall between 30 and 36 Ma, the zircon ages vary around 36 Ma (Dunkl, 1990).

It can be stated that in the formations available from recent exposures of the volcanic centres:

- either the age of the last volcanic events
- or the rejuvenated ages due to the hydrothermal activity lasting also during the Oligocene can be measured.

Methods

The accessory minerals were enriched from rock samples of 1.5 to 2.0 kg by crushing, sieving, panning, heavy liquid separation and magnetic separation. The apatite and circon crystals were picked up by needle from the concentrate, the former was embedded in epoxi resin, the latter in FEP-teflon. The spontaneous fission tracks of the minerals were etched after slow, careful polishing. In case of apatite nitric acid of 1% was used with 2.5 to 4 min etching time (Burchart, 1972). In case of zircon crystals the eutectic melt of NaOH-KOH-LiOH was used at somewhat lower temperature (190 °C) than suggested by the prescriptions of Zaun and Wagner (1985). Etching was carried out for different durations in each preparate (41 to 85 hours), the duration was determined by the optimal etching state of fission tracks and by means of the widening of polishing cracks. Neutron irradiation was made at the Technical University of Budapest and in the reactor of Řež (close to Praha, Czechoslovakia). The neutron fluence was determined by the NBS SRM 962a uranium glass standard. The external detector method was used (Gleadow, 1981), a mica external detector was put onto the preparates and the standard and after irradiation the induced fission tracks were etched by HF during 40 to 60 min. Counting of spontaneous tracks was made in oil immersion under Zeiss NU 2 microscope, with a magnification of 1600, in case of mica detectors dry optics of 800-time magnification were used. Only the crystals embedded parallel with the c-axis, polished down to 20 microns at least and free of dislocations and near-surface inclusions were considered. Conforming to the number of suitable crystals and to the spontaneous track density, respectively, we tried to count 30 grains in each preparate or 1000 tracks, respectively. To compensate the different track registration geometry ($2\pi/4\pi$) between the external detector and the dated minerals, the geometry factor of 0.5 determined by Gleadow and Lovering (1977) was applied.

The homogeneity of ages measured in each crystal was tested by the Chi-square method (Green, 1981). Track density data measured in the crystals were plotted in the Ps/Pi coordinate system (Burchart, 1981). When the measurement results fitted well on the isochron line and extreme values occurred, this was controlled by the Grubbs and Dixon tests (Rétháti, 1985). If the crystal displaying extreme age belong to the main population with a probability of less than 5%, the doubtful result was omitted in the subsequent calculations. If in the Ps/Pi diagram the group of measurement results was diffuse (first of all due to low number of spontaneous tracks in the crystals) the elimination of the extreme data pairs was not used.

The age was calculated on the basis of the weighted average of the measured track density proportions, by the zeta-method (Hurford and Green, 1983). The limits or error are given by the classical procedure, i.e. by the double Poisson dispersion (Green, 1981).

Results

Samples derived from the North Bakony Mountains except that of Somlóvásárhely. The aim was to select boreholes investigated thoroughly by biostratigraphic and other methods. The detailed description and biostratigraphic processing of some sequences from which the samples studied by the FT method are found in the works of Bálid-Beke (1984), Kókay (1961), Horváth-Kollányi (1983), Bernhardt et al. (1988).

The areal distribution of the studied profiles is demonstrated in Fig. 2. The depth intervals of the dated samples as well as the rock material are found in Table I together with the measurement results. The last column of the Table refers to the stratigraphic position that is based on the publications above and on the oral communications of Báldi-Beke, M. and Bernhardt, B. It is to be noted that the major part of the samples derive from the proximity of the Middle/Upper Eocene boundary.

The ages measured in the crystals of each sample are uniform in each preparate and lie within the range of statistical uncertainty. The mingling of accessory populations of different ages could not be demonstrated, thus the rounded, fractured glauconite grains described Csernák and Dudich (1968) refer only to an infra-Eocene insignificant redeposition and erosion.

The FT results fall between 48 and 32 Ma which according to the scale of Berggren et al. (1985) include the time interval from the Lower Lutetian to the Lower Oligocene (Table I). This duration is longer than that of the formation of the tuffaceous sequence. When taking the samples of the profiles divided by plankton- and magneto-stratigraphy (Somlóvásárhely, Bakonyszentkirály) it is found that differences exceeding the duration of the biostratigraphic units can also be observed. Thus, the individual evaluation of the data and the refinement of the stratigraphic division have to be neglected even in this area being faunistically well dated. Nevertheless, the comprehensive evaluation of the measurement results is

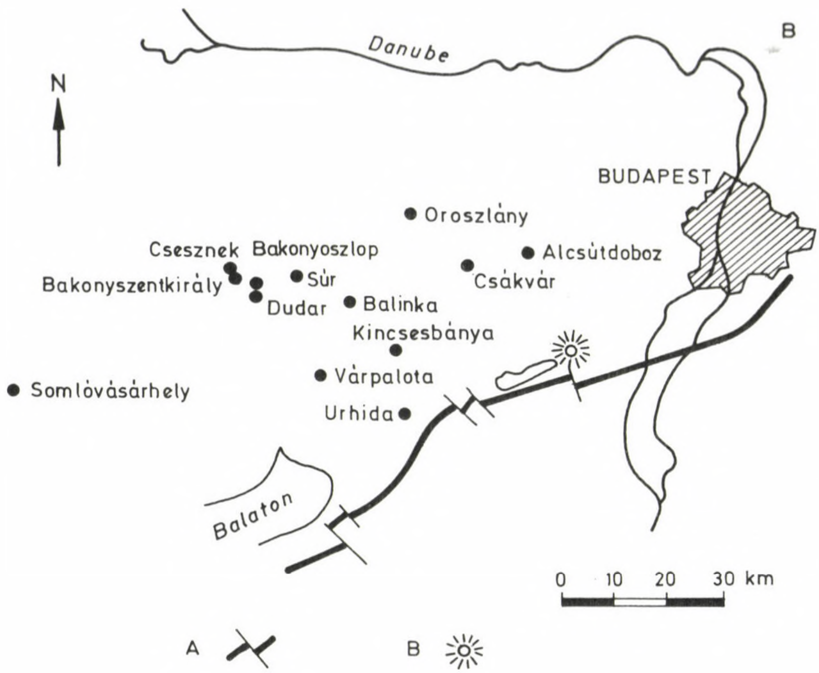

Fig. 2. Areal distribution of the studied Eocene profiles in the NE Bakony Mountains. A - The Balaton Line dissected by transversal faults after the map of Fülöp and Dank (1987); B - Paleogene volcanic centre of the Velence Hills

possible since based on the geological evidences the volcano-sedimentary sequence is uniform and was generated within a relatively short duration.

As regards some samples, the notes below can be added.

a) Based on the apatite and zircon FT ages and on the accessory mineral assemblage of the Kincsesbánya sandstone rich in amphibole, being of peculiar composition and derived earlier from the erosion of metamorphites (Gőbel, 1955) it can be unambiguously stated that the rock nearly as a whole is the erosion product of Paleogene volcanics.

b) The youngest FT age is produced by the amphibole andesite of Csákvár (32.7 Ma). The question arises whether very young age being in unconformity with the geological setting bears some geological meaning or it is an extreme value produced by the statistical uncertainty of the measurement results.

Based on the Dixon test the datum in question belong to the other measurement values on a probability level of 90%, but geological arguments

Table I

FT ages measured on Eocene tuffaceous formations

Sign of prep.	Locality	Borehole	Depth interval	Rock	Number of data	Ns	Ni	Ps	Pi	FT Age Mill. year	+-2s Poiss.	Uranium (ppm)	Geol. Age
7	Úrhida	foundations		bentonite	15/15	1144	5909	2.47	13.2	38.9	+- 4.7	23.6	(E-3)
C 14 A	-II-	-II-		-II-	13/13	2029	1582	67.6	52.7	39.9	+- 3.8	345	
18	Csákvár	Csv-18	297.4 m	amphibole andesite	30/30	453	2856	1.1	6.84	32.7	+- 4.7	12.3	(E-3)
C 14 B	-II-	-II-	-II-	-II-	37/37	2336	2108	25.2	22.8	34.8	+- 3.7	145	
35	Somlóvásár-hely	Sv-1	573.2 m	andesite tuff	20/19	1094	2530	2.39	5.57	44.2	+- 7.4	19.2	(E-3)
42	Bakony-	Bszk-3	417 m	andesite tuff	45/45	2224	5444	2.34	5.83	44.9	+- 4.2	19.8	(E-3)
C 13	szentkirály	-II-	-II-	-II-	22/22	2702	1917	49.2	34.8	43.7	+- 4.7	222	
54 B	Alcsútdoboz	Ad-3	741.5 m	tuff	12/12	181	525	0.73	2.16	35.6	+- 6.8	7.4	(E-3)
59	-II-	-II-	803.6 m	and.agglomerate	40/40	780	2114	1.27	3.43	39.2	+- 4.5	11.6	(E-3)
C 26	-II-	-II-	803.6 m	-II-	33/33	2579	1489	32.3	18.5	34.9	+- 3.3	189	
60	Súr	Sr-20	215.4 m	bentonitic tuff	33/33	2594	5965	3.0	6.92	45.6	+- 4.2	23.5	(E-3)
C 25	-II-	-II-		-II-	33/32	4585	2480	69.2	37.4	37.3	+- 3.8	400	
36	Csesznek	Cse-8	93.2 m	glaukonitic marl	30/30	1687	8240	2.41	12.0	41.3	+- 4.8	21.5	(E-2-3)
39	Várpalota	V-133	264.7 m	bentonitic tuff	36/35	348	877	0.77	2.1	41.1	+- 6.1	8.4	(E-2)
10	Kincsesbánya	pit-head		amphibole-bearing	30/29	1038	4509	3.69	16.2	46.5	+- 5.8	29.0	(E-2)
10-7	////	////		sandstone	30/29	1038	2562	3.69	8.72	46.8	+- 5.9	28.0	
C 12	-II-	-II-		-II-	16/16	1678	1145	41.9	28.6	45.3	+- 5.3	183	
29	Balinka (2)	coal mine,		glauconitic	30/30	1492	7726	2.22	11.5	39.9	+- 4.8	20.6	(E-2)
25	-II- (4)	8th blind shaft		calc-arennite	25/24	1497	8052	2.56	13.6	37.8	+- 4.4	24.2	
C 17	-II- (4)	-II-		-II-	23/23	3339	2305	59.0	40.6	45.0	+- 4.7	260	
40	Balinka	Bat-5	53.0 m	bentonitic tuff	41/40	1147	2539	1.49	3.22	47.5	+- 5.1	11.6	(E-2)
37	Oroszlány	O-2274	520.2 m	glauconitic limestone	30/30	970	4214	1.35	5.77	48.0	+- 6.0	10.4	(E-2)
41	B.szentkirály	Bszk-3	473.5 m	crystal tuff	27/26	460	1116	1.23	2.91	46.3	+- 6.3	10.7	(E-2)

Table I (cont.)

Sign of prep.	Locality	Borehole	Depth interval	Rock	Number of data	Ns	Ni	Ps	Pi	FT Age Mill. year	+-2s Poiss.	Uranium (ppm)	Geol. Age
63	Bakonyoszlop	Bob-681	312.2 m	tuffaceous marl	25/24	1383	6285	2.02	9.23	44.5	+- 5.3	16.6	(E-2)
Paleogene volcanite pebble													
22	Dudar (2)	coal mine		biotite-amphibole-andesite pebble	26/25	558	2822	1.38	7.05	40.3	+- 5.6	13.4	

If the sign of preparate begins with numbers, the measurement was made on APATITE, C refers to ZIRCON.

-II- denotes several preparates from one locality.
//// denotes multiplied measurement of one preparate.

Number of data = Crystal or field number measured and used for the results.
Ns. Ni = Spontaneous and induced track number.
Ps. Pi = Spontaneous and induced track density (10^5 track/cm^2).
Uranium (ppm) = uranium content measured in the crystals.

favour the separate discussion of it. The Csákvár sample derives from a stratovolcanic structure older than Priabonian (Báldi, 1983) that lies relatively close to the huge volcanic centre of the Velence Hills. The measured apatite FT age of 32.7 Ma fairly well correlates with the apatite FT ages for the andesites of the Velence Hills, their average being 33.6 Ma (Dunkl, 1990). Since the possibility exists that the Eocene volcanic sequence traversed by the borehole Csv-18 endured subsequent thermal effects similarly to the case of andesites of the Velence Hills, the measurement result of youngest age was omitted from averaging the data.

c) When assigning the samples to the Middle or Upper Eocene (see below) the results of Csesznek and Dudar will be omitted since

- the sample deriving from the borehole Csesznek-8 falls to the Middle/Upper Eocene boundary,

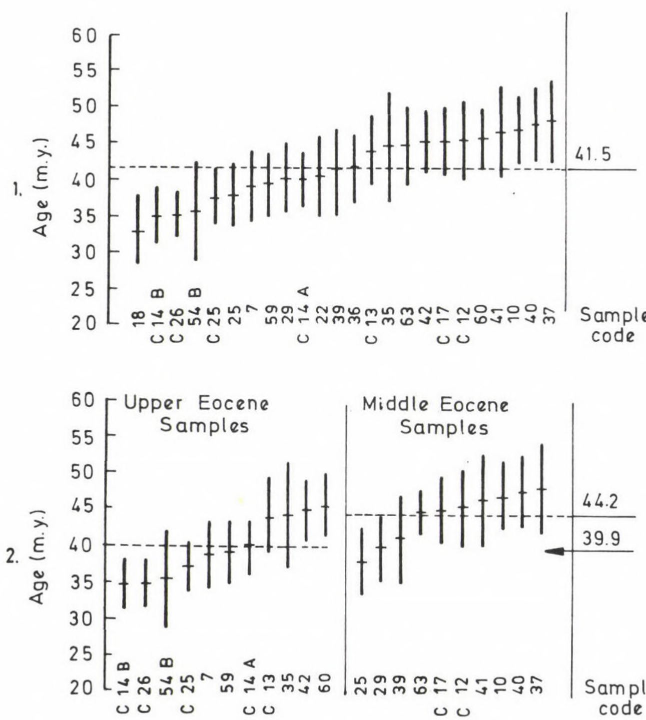

Fig. 3. Rake diagrams showing the measurement results in increasing sequence with the double Poisson dispersion range. On the right the unweighted averages are found. A - All the Eocene samples; B - Samples of known stratigraphic position, in groups

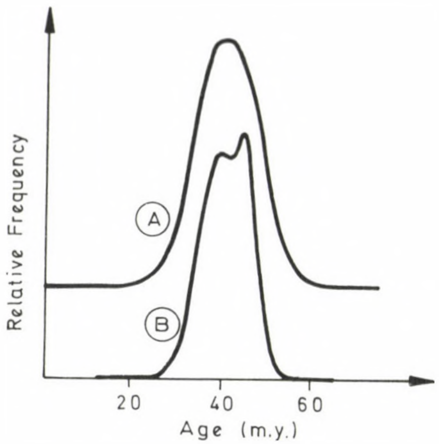

Fig. 4. Age spectra calculated by the Hurford et al. (1984) method from the measurement results. The procedure fits a Gaussian curve corresponding to the dispersion to the ages measured in each sample and the "age spectrum" is given by their summary. A - The distribution picture obtained with double Poisson dispersion is symmetric, nearly ideal; B - In the curve of higher resolution obtained with single dispersion two maxima can be distinguished

- due to the detrital origin the FT age of the andesite gravel of Dudar bears no significance from the point of view of finer stratigraphic division, the measured age proves only the Eocene formation of andesite.

The rake diagram (Fig. 3A) is most suitable to the comprehensive evaluation of the results that shows the data in increasing sequence and the reliability limits, as well. It can be stated that

- there are no extreme data, the distribution of the results shows a symmetric slightly negative skewness in first approximation,

- close to the distribution average there is a gap, no measurement results are between 41.3 and 43.7 Ma. This division is represented also by the double maximum of the age spectrum calculated with higher resolution (Fig. 4). It is remarkable that grouping the results into two fields according to the stratigraphic position this division occurs both in the Middle and in the Upper Eocene group.

The unweighted average of the FT ages measured on all Eocene samples is 41.5 Ma. Due to the subsequent possible thermal effect described under b) above, when omitting the FT age of the Csákvár apatite the average will be 41.9 $\pm$ 4.1 Ma. This value falls to the middle of the Bartonian and fits fairly well to the duration determined for the volcanism by plankton data.

When grouping the data according to the stratigraphic position of the samples it can be stated that the range of the results measured on Middle and Upper Eocene samples is practically the same. Nevertheless, there is a remarkable difference between the averages of the groups (Fig. 3B). The average of the FT ages of the stratigraphically Middle Eocene samples is 44.2 $\pm$ 3.4 Ma. This value falls to the s.s. Uppermost Lutetian and is somewhat older than the date of appearance of the tuffaceous material documented by fauna in the strata in question.

The average of the FT ages measured on Upper Eocene samples is 39.9 $\pm$ 4.1 Ma that falls to the Bartonian/Priabonian boundary of the scale published by Berggren et al. (1985), i.e. 40 Ma. The FT age falling to the Lowermost Priabonian agrees with the geological built up of the North Bakony Mountains since in the area the infra-Oligocene denudation eroded the upper part of the Priabonian formations. This is why only the lowermost part of the Upper Eocene can be locally found and this represents about 1 million years (Báldi-Beke, 1983 and personal communication, 1990).

Conclusions

The average of the fission track results falls to the range of volcanism marked also by biostratigraphy. Nevertheless between the averages of the FT ages measured on the Middle and Upper Eocene samples grouped according to their stratigraphic position, there is a difference of more than 4 million years. As to the Shapiro-Wilk test both the Middle and the Upper Eocene data group is of normal distribution at a level of p = 95%, thus the significance of the difference of the two average values can be interpreted. Based on the t-test the average values of the two groups differ from each other on a statistical probability level of 98%.

Based on the FT data, in the studied area two phases or two periods of increased intensity can be outlined in the Late Eocene volcanism. The initial volcanic activity producing less pyroclastics generated the glauconite-bearing thicker sequence in the Upper Lutetian in which less pure tuffaceous strata are found. Based on the samples' data the younger, about 40 Ma maximum of the volcanic activity produced the tuff strata close to the Bartonian/Priabonian boundary. Since based on geological grounds no division occurs in the strata, there was no break between the maxima of the volcanism, only its intensity decreased temporarily.

Acknowledgements

Samples were provided by B. Bernhardt, I. Horváth and J. Kókay (Hungarian Geological Survey), by K. Tóth, P. Vincze (Bauxite Exploration Co.) and Cs. Szabó (Eötvös Loránd University) and they gave useful suggestions concerning the sample collection. Irradiations were made by the late J. Bérczi and G. Keömley (Technical University, Budapest). The age standards were available as a favour of Ján Král (Bratislava) and C.W. Naeser (Denver, US). The refinement of the stratigraphic position of some samples was carried out after the unpublished data of M. Báldi-Beke and B. Bernhardt, thanks for their kind help.

REFERENCES

Balázs, E., I. Matyók, Á. Juhász (1969): Magyarországi harmadidőszaki képződmények összefoglaló értékelése a kőolajkutatás szempontjainak figyelembevételével (Comprehensive evaluation of the Hungarian Tertiary formations from the aspects of hydrocarbon exploration). OKGT, Adattár, 148 p.

Balázs, E. et al. (1981): A magyarországi eocén-oligocén határ képződményeinek szerkezeti-faciális vázlata (Structural-facial outline of the Eocene-Oligocene boundary formations of Hungary). Földt. Közl., **111**, pp. 145-156.

Báldi-Beke, M. (1984): A dunántúli paleogén képződmények nannoplanktonja (Nannoplankton of the Paleogene formations of Transdanubia). Geologica Hung. Ser. Paleont., **43**, 307 p.

Báldi-Beke, M., T. Báldi (1990): A bakonyi eocén medence süllyedéstörténete (Subsidence history of the Eocene basin of the Bakony Mountains). Ált. Földt. Szemle, **25**, (in press).

Báldi-Beke, M., B. Bernhardt, K. Horváth-Kollányi, M. Lantos (1990): Adatok a dunántúli eocén kronosztratigráfiájához magneto- és planktonsztratigráfiai alapon (Contributions to the chronostratigraphy of the Eocene of Transdanubia on magneto- and plankton-stratigraphic bases). Manuscript, Hungarian Geological Survey, Budapest.

Balla, Z. (1981): Plate tectonic interpretation of the South Transdanubian ultramafics. Acta Miner. Petr., Szeged, **25**, pp. 3-24.

Balla, Z. (1988): A Kárpát-Pannon régió nagyszerkezeti képe a felsőeocénben és e kép hatása a mezozóos Tethys-rekonstrukciókra (The megatectonic picture of the Carpatho-Pannonian region in the Upper Eocene and the effect of this picture to the Mesozoic Tethys reconstructions). Földt. Közl., **118**, pp. 11-26.

Balogh, K. (1985): K/Ar kormeghatározások a hazai eocén-oligocén alapszelvényekből (K/Ar age determinations from Hungarian Eocene-Oligocene key sections). Őslényt. Viták, **31**, pp. 43-51.

Berggren, W.A., D.V. Kent, J.J. Flynn, J.A. Van Couvering (1985): Cenozoic geochronology. Geol. Soc. Amer. Bull., **96**, pp. 1407-1418.

Bernhardt, B., M. Báldi-Beke, M. Lantos, K. Horváth-Kollányi, P. Márton (1988): Eocene magneto- and biostratigraphy at Somlóvásárhely, Hungary. Acta Geol. Acad. Sci. Hung., **31**, pp. 33-52.

Burchart, J. (1972): Fission-track age determinations of accessory apatite from the Tatra Mountains, Poland. Earth Planet. Sci. Lett., **15**, pp. 418-422.

Burchart, J. (1981): Evaluation of uncertainties in fission-track dating: some statistical and geochemical problems. Nuclear Tracks, **5**, pp. 87-92.

Csíky, G. (1963): A Duna-Tisza köze mélyszerkezeti és ősföldrajzi viszonyai a szénhidrogén kutatások tükrében (Deep-structural and paleogeographic conditions of the Danube-Tisza Interfluve reflected by hydrocarbon explorations). Földr. Közl., **11**, pp. 19-35.

Csillag, J., J. Földessy, T. Zelenka, E. Balázs (1983): The plate tectonic setting of the Eocene volcanic belt in the Carpathian Basin. In: Bisztricsányi, E., Gy. Szeidovitz (Eds). Proc. of the 17th Assembly of the ESC, Budapest, Akadémiai Kiadó, pp. 589-599.

Darida-Tichy, M. (1987): Paleogene andesite volcanism and associated rock alteration (Velence Mountains, Hungary). Geol. Zb. Geol. Carp., **38**, pp. 19-34.

Darida-Tichy, M. (1988): Az eocén képződmények elterjedése és jellegei a Balatonfő-Velencei hegység körzetében (Extension and characteristics of Eocene formations in the Balatonfő-Velence Hills environs). Manuscript, Hungarian Geol. Surv., Budapest, 77 p.

Dubay, L. (1962): Az Észak-Zalai medence fejlődéstörténete a kőolajkutatások tükrében (History of evolution of the North Zala Basin reflected by petroleum exploration works). Földt. Közl., **92**, pp. 15-39.

Dudich, E. (1977): Eocene sedimentary formations and sedimentation in the Bakony Mountains, Transdanubia, Hungary. Acta Geol. Acad. Sci. Hung., **21**, pp. 1-21.

Dudich, E. (1979): Agyagásvány-adatok a bakonyi eocén ősföldrajzához (Clay mineral data to the paleogeography of the Bakony Mountains). Ált. Földt. Szemle, **12**, pp. 107-120.

Dudich, E., L. Gidai (1980): A magyarországi eocén kőzetrétegtani egységei (Előzetes). (Lithostratigraphic units of the Eocene of Hungary. Preliminary report). Ált. Földt. Szemle, **14**, pp. 81-111.

Dudich, E., G. Kopek (1980): A Bakony és környéke eocén ősföldrajzának vázlata (Paleogeographic sketch of Eocene of the Bakony Mountains and its environs). Földt. Közl., **110**, pp. 417-430.

Dunkl, I. (1990): A fission track módszer és alkalmazása geokronológiai kérdések megoldásában (The fission track method and its application in solving geochronological problems). Manuscript, Laboratory for Geochemical Research, Hungarian Academy of Sciences, Budapest, 134 p.

Földessy, J. (1975): A recski rétegvulkáni andezit összlet (The stratovolcanic andesite sequence of Recsk). Földt. Közl., **105**, pp. 625-645.

Földessy, J. (1984): A recski paleogén vulkáni és intruzív képződmények kőzettani és vulkanológiai jellegei (Petrographic and volcanological features of the Paleogene volcanic and intrusive formations of Recsk). C.Sc. Theses, Recsk-Budapest.

Fülöp, J., V. Dank et al. (1987): Magyarország földtani térképe a kainozóikum elhagyásával M = 1:500 000 (Geological map of Hungary without the Cenozoic). Budapest.

Gidai, L. (1971): Az ÉK-Dunántúl eocén rétegtani kérdései (Stratigraphic problems of the Eocene of NE-Transdanubia), Földt. Közl., **101**, pp. 396-405.

Gleadow, A.J.W. (1981): Fission-track dating methods: what are the real alternatives? Nuclear Tracks, **5**, pp. 3-14.

Gleadow, A.J.W. (1977): Geometry factor for external detectors in fission track dating. Nuclear Track Detection, **1**, pp. 99-106.

Green, P.F. (1981): A new look at statistics in fission track dating. Nuclear Tracks, **5**, pp. 77-86.

Homewood, P. (1983): Paleography of Alpine flysch. Palaeogeogr. Palaeoclimat. Palaeoecol., **44**, pp. 169-184.

Horváth-Kollányi, K. (1983): Újabb korrelációs lehetőség a bakonyi és az ÉK-dunántúli terület eocénje között a Bakonyszentkirály Bszk-3 sz. fúrás plankton foraminiferái alapján. (New correlation possibility between the Eocene of the Bakony and of the NE-Transdanubia on the basis of plankton foraminifers of the Bakonyszentkirály Bszk-3 borehole). MÁFI Évi Jel., 1981, pp. 295-325.

Hurford, A.J., Green, P.F. (1983): The zeta age calibration of fission-track dating. Chem. Geol. Isot. Geosci., **41**, pp. 285-312.

Kázmér, M. (1984): A Bakony horizontális elmozdulása a paleogénben (The horizontal displacement of the Bakony Mountains in the Paleogene). Ált. Földt. Szemle, **20**, pp. 53-101.

Kőkay, J. (1961): Távlati mélykutatás Várpalotán (Long-term deep-surveying at Várpalota). MÁFI Évi Jel., 1957-58, pp. 231-241.

Kopek, G. (1980): A Bakony hegység ÉK-i részének eocénje (The Eocene of the northeastern part of the Bakony Mountains). MÁFI Évk., 63/1, 176 p.

Kőháti, A. (1965): Tortonai korú andezitvulkánosság a zalatárnoki területen (Tortonian andesite volcanism at Zalatárnok). Kőolaj és Földgáz, pp. 264-270.

Kőrössy, L. (1988): A zala-medence kőolaj- és földgázkutatás földtani eredményei (Geological results of hydrocarbon exploration of the Zala Basin). Ált. Földt. Szemle, **23**, pp. 3-162.

Mészáros, E. (1970): A zalatárnoki eocén vulkanizmus vizsgálata (The Zalatárnok Eocene volcanism). Graduation theses, Eötvös Loránd University, Department of Petrology, Budapest.

Nagymarosy, A., M. Báldi-Beke (1988): The position of the Paleogene formations of Hungary in the standard nannoplankton zonation. Ann. Univ. Budapestinensis,Sect. Geo., **28**, pp. 3-25.

Örkényi-Bondor, L. (1971): Glaukonitképződés hazai kora-harmadkori üledékekben (Glauconite formation in the Late Tertiary sediments of Hungary). Fragm. Min. Paleont. II. Budapest, pp. 57-126.

Radócz-Komáromi, E. (1971): Az É-Bakony eocén képződményeinek mikromineralógiai vizsgálata (Micromineralogical studies in the Eocene formations of the North Bakony Mountains). MÁFI Évi Jel., 1969, pp. 133-139.

Ravasz, Cs. (1980): A magyarországi medenceterületek eocén és oligocén vulkanizmusa (Eocene and Oligocene volcanism of the basin regions of Hungary). Manuscript, MÁFI.

Rétháti, L. (1985): Valószínűségelméleti megoldások a geotechnikában (Probability-theoretical solutions in geotechnics). Akad. Kiadó, Budapest, 394 p.

Sárközi-Farkas, E. (1967): A Tokod környéki eocén képződmények üledékkőzettani vizsgálata (Sediment-petrological investigation of Eocene formations in the Tokod environs). MÁFI Évi Jel., 1962, pp. 237-246.

Szalai, T. (1937): Paleogén vulkáni lánc a magyar közbülső tömeg "0" vonala mentén (Paleogene volcanic chain along the "0" line of the Hungarian median mass). Bány-Koh-Lapok, **70**, 17, pp. 306-308.

Széky-Fux, V., A. Barabás (1953): A dunántúli felsőeocén vulkánosság (The Upper Eocene volcanism of Transdanubia). Földt. Közl., **83**, pp. 217-229.

Szepesházy, K. (1977): Az Alföld mezozóos magmás képződményei (The Mesozoic igenous formations of the Great Plain). Földt. Közl., **107**, pp. 384-397.

Sztrákos, K. (1975): A Budapesttől ÉK-re elterülő terület paleogénjének ősföldrajaz, I. rész: A felső lutécitől a Kiscelli Agyag/Tardi Agyag határig (Paleogeography of the Paleogene of the region NE of Budapest, Part I: From the Upper Lutetian to the Kiscell Clay/Tard Clay boundary). Őslénytani Viták, **22**, pp. 51-80.

Wein, Gy. (1969): Tectonic review of the Neogene-covered areas of Hungary. Acta Geol. Acad. Sci. Hung., **13**, pp. 399-436.

Zaun, P.E., G.A. Wagner (1985): Fission-track stability in zircon under geological conditions. Nuclear Tracks, **10**, pp. 303-307.

Zelenka, T. (19759: A recski mélyszinti színesfém ércelőfordulás szerkezeti-magmaföldtani helyzete (Tectonic-magma geological position of the base metal occurrence of the Recsk deep horizon). Földt. Köz., **105**, pp. 582-597.

Acta Geologica Hungarica, Vol. 33/1-4, pp. 31-42 (1990)

FOLDED OLIGOCENE BEDS IN BUDAPEST

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In late 1989, on the southern slope of the Gellért Hill concentric folds of compression origin in thin-sheeted siliceous argillites were observable in new excavations. The sediments can be correlated with the Tard Clay of Early Oligocene age. Fold axes are of WSW-ENE strike, and fold axial planes dip towards the SSE. The folding cannot be related to the Pyreneean(end-Eocene) orogeny as it was frequently thought in the case of other outcrops with folds in the Buda Paleogene but are obviously of Miocene age.

Keywords: Buda Hills, concentric folds, compression, folding, Lower Oligocene, Miocene, orogeny, Paleogene.

1. Introduction

Numerous authors observed or supposed folds in the Buda Paleogene. The Buda Marl (Upper Eocene) was reported to be folded in the areas (Fig. 1) between the Sas and Márton Hills (Schafarzik and Vendl, 1929), between the Sas and Mátyás Hills (Pávai Vajna, 1934) as well as between the Sas Hill and Zugliget (Horusitzky, 1958b), unfortunately, without any information on the location, strike, size, shape,etc. of the folds. According to Wein (1977) folds are of NE-SW strike and of SE vergence. In his maps and sketches (Wein, 1974a; 1974b; Fig. 4), however, no fold is displayed.

Some concrete folds were supposed on the basis of changes in dip directions (Fig. 1, 1-3). Most of the more precisely documented folds are flexures (Fig. 1, 4-8), some of them are two-sided folds (Fig. 1, 9-11). The tectonic origin of the folds in one site of three (11) seems to be uncertain (an alternative: product of landsliding).

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Received: 02/04/90

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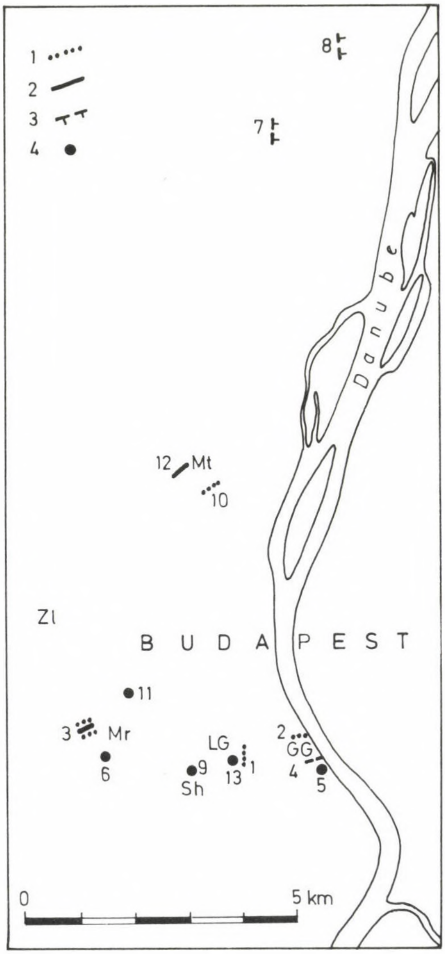

Fig. 1. Location sketch of outcrops and sites mentioned in the text. Symbols 1-3 shown out of the scale but in a true orientation. 1. syncline; 2. anticline; 3. flexure; 4. site with no data on the orientation; Mt, Mátyás Hill; Mr, Márton Hill; Sh, Sas Hill; Lg, Lesser Gellért Hill; GG, (Great) Gellért Hill; Zl, Zugliget. Numbers in the map: 1. a syncline in the Buda Marl (Schafarzik, 1921, no Fig.; Schafarzik and Vendl, 1929, Figs 14 and 20); 2. a narrow syncline in the Buda Marl (Schafarzik and Vendl, 1929, Fig. 10); 3. a series of folds in the Buda Marl (Schafarzik and Vendl, 1929, Fig. 41); 4. a large flexure in the Eocene (Schafarzik, 1926, Fig. 2; Schafarzik and Vendl, 1929, Fig. 9); 5. a flexure in the Buda Marl (Schafarzik and Vendl, 1929, no. Fig.); 6. folds in the Buda Marl (Schafarzik and Vendl, 1929, Fig. 38); 7. a flexure in Upper Eocene beds (Rozlozsnik, 1935, Fig. 8); 8. a flexure in Upper Oligocene beds (Rozlozsnik, 1935, Fig. 9); 9. small-scale drag folds in the Buda Marl below the overthrust Triassic dolomite (Földvári, 1933, Fig. 84); 10. a 150 m long and 500-100 m wide symmetric syncline of ENE-WSW strike (Jaskó, 1933, Fig. 87); 11. folded and disintegrated Buda Marl (Pávai Vajna, 1941, Fig. 20); 12. folded Triassic limestone (Lőrenthey, 1907, Fig. 1; Wein 1977, Fig. 25); 13. slate quarry (Horusitzky, 1938, Fig. 5, a photo)

With a reference to Földvári, Horusitzky (1958b: Fig. 15) published a section of the eastern slope of the Sas Hill in which the lower part of the Buda Marl thrust over Triassic dolomite is shown folded. In his reference list there are 5 Földvári's works, none of which, however, deals with the topics concerned. Horusitzky's section is in contradiction with Földvári's (1933) data in which the Buda Marl is folded below the dolomite but is in a transgressive position above it. Consequently, 'transformation' of data cannot be excluded as is obvious in the case of the southern slope of the Gellért Hill: here Horusitzky (1958b) mentioned Nummulitic Limestone folded together with Bryozoa Marl (both Upper Eocene in age) with a reference to Schafarzik's (1922) work in which, however, the same rocks are described as blocks in a transgressive breccia.

Wein (1977) considered the well-known fold in the Triassic Limestone of the Mátyáshegy quarry (Fig. 1, 12) to be the best example of the Paleogene folds in the Buda Hills; in his works, however, this is the only example of this kind. On the top of the fold Eocene limestone lies with no folding as it was clearly seen already in Lőrenthey's (1907) section and is still visible today. The fold in question is, consequently, pre-Paleogene in age.

It can be concluded that, although numerous authors mentioned or described folds in the Buda Paleogene, published materials are so much poor and in some cases so much ambiguous that both the wide distribution and compression origin of folds have remained doubtful. It is worthy of mention that most of the observations were made on marly or argillaceous sediments of the southernmost Buda Hills. Therefore, it is of certain interest that the first documentation of well-developed folds in Paleogene beds (see below) has been also produced in this area.

2. Rocks and outcrops

Prior to the building up a peculiar white thin-sheeted silicified argillaceous rock with concentric red to violet ornaments due to limonite impregnation was traceable along the whole southern slope of the Lesser and Great Gellért Hill. For a long time this rock was famous owing to the numerous plant and fish remnants (Heckel, 1856; Staub, 1886; Koch, 1904; Szörényi, 1929; Noszky, 1930; Weiler, 1935; Böhm, 1942).

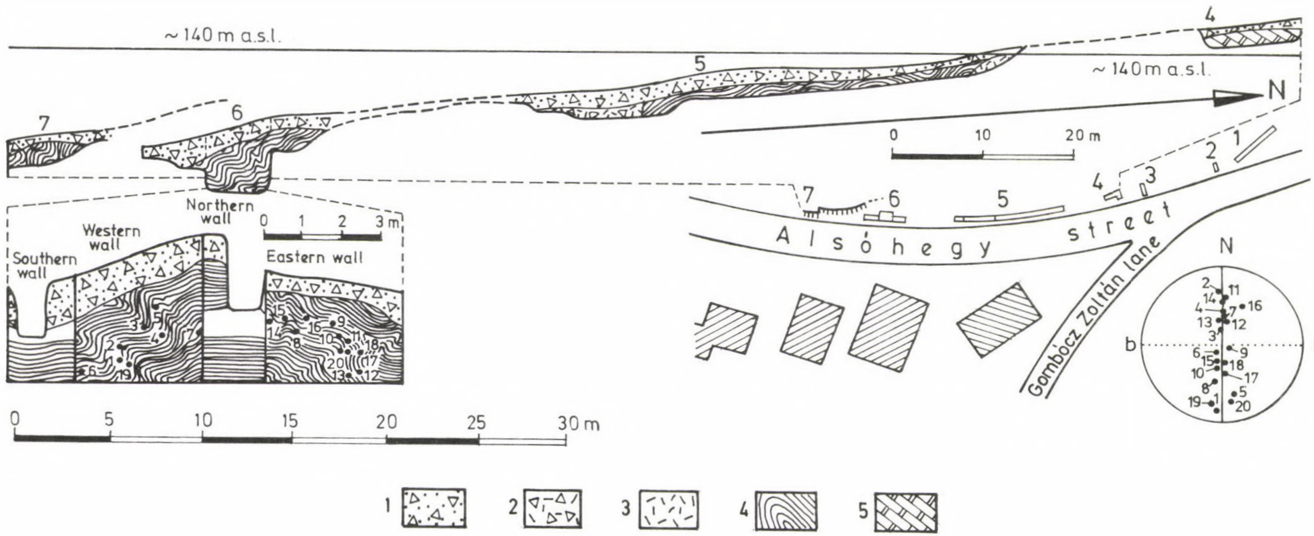

Fig. 2. Sketch and section of new trenches. A lower hemisphere stereographic projection of strata dip measurements in exposure No 6 presented in right bottom corner. Location indicated in the picture in left bottom corner. b = fold axis. 1. debris; 2. argillaceous breccia; 3. tectonic clay; 4. Paleogene sediments; 5. Triassic dolomite

The last outcrop (Fig. 1, 13) disappeared about 15-20 years ago. At the turn of November and December, 1989, in its site a series of trenches and some shafts were excavated. In the artificial exposures on the western side of the Alsóhegy street (Fig. 2) Paleogene argillaceous rocks cropped out displaying beautiful folds. These were traceable for about 56 m, up to the upper end of the trench No 5. 10 m further, in the trench No 4, tectonically disintegrated Triassic dolomite appeared. On the opposite, eastern side of the street also dolomite crops out limiting the extension of the Paleogene towards the north. All over the whole exposure No 7 and trench No 6 thin (1 cm) beds of constant thickness were traceable. The argillites were non-calcareous, and the silicification was gentle. Trench No 5 uncovered deeper horizons with thicker bedding and marly appearance.

3. Stratigraphic and tectonic position

According to Hofmann (1871) and to Schafarzik and Vendl (1929) the rocks in question, originated from marls due to their silicification connected with later hydrothermal activity, overlie the Buda Marl and underlie the Kiscell Clay. In harmony with this concept Horusitzky (1958a) and Wein (1977) correlated them with the 'Tard Beds' distinguished by Majzon (1941) on the top of the Buda Marl. Using diagnostic criteria given by Báldi (1983) for the Buda Marl (Upper Eocene), Tard Clay (Lower Oligocene) and Kiscell Clay (Middle Oligocene) one can indeed regard the thin-bedded sediments in question, rich in plant and fish remnants but poor in other fossils, as a silicified variety of the Tard Clay.

The old outcrop (Fig. 1, 13) and the new artificial exposures fall on the southern rim of the W-E striking dolomite range of the Gellért Hill. Here, near the dolomite which outcrops on both sides of the Alsóhegy street, Schafarzik (1921) measured dips in the Buda Marl towards each other. He explained the situation in terms of a syncline with a N-S oriented axis (Fig. 1, 1) and connected its origin with tilting of the dolomite blocks towards each other (Schafarzik and Vendl, 1929). The present arrangement of dolomite outcrops on both sides of the Alsóhegy street, however, leaves no place for a strip of the Buda Marl between them, therefore, the existence of the N-S oriented syncline along the Alsóhegy street is doubtful.

Lateral boundaries of the dolomite blocks dip at steep angles (Schafarzik and Vendl, 1929), and the silicified thin-sheeted rock in question cropped out close to these boundaries. Probably, the immediate neighbourhood to the Triassic dolomite was the main reason for Szőts (1958), Jámbor (1966) and Kisdi-Bulla et al. (1983) to attribute the rocks in question to the basal Buda Marl. The dolomite blocks, however, penetrated their Eocene envelope as very young (Schafarzik, 1927: Late Pliocene) diapir-like bodies. Consequently, the lateral boundaries of the dolomite blocks are of tectonic origin, and the location of the outcrops close to them is of no meaning in a stratigraphic sense.

The strongly silicified, rigid, ringing by hit rock known from the outcrop in Horusitzky's (1938) photo has not been uncovered in the excavations. It has been found in debris above the southern part of the trench No 5, i.e. approximately in the horizon uncovered by the trench No 6. The rocks in the trench No 5 are similar to the typical Buda Marl, therefore, there is no doubt about the location of the silicified rocks above the Buda Marl.

4. The folds

The general dip direction of the beds towards the south coincides with that of the slope of the hill, therefore, the problem of tectonic or landslide origin of the folds should be discussed. The sliding on the slope can be excluded since in fold hinges even the most rigid beds are bent (Plate I). Beds are sometimes broken up but only in sharp quasi-angular hinges which shows that lithification was already being in progress when the deformation took place. Consequently, the folds are of tectonic origin.

Paleogene sediments are folded in the whole length of the section studied. Fold axes are striking in a 85-265^{o} direction. Axial planes are undulatory displaying a general dip of 355/45^{o}. Fold mirrors dip at 175/10^{o} in the northern and at 175/30^{o} in the southern part of the exposure. Folds are of concentric/parallel type (thicknesses in the hinge and on limbs are equal) with occasional detachment planes.

5. Tectonic implications

The generation of folds was obviously related to longitudinal bending since some anticlines die out down in the section which excludes transversal bending. Consequently, the folding of the Paleogene sediments was connected with lateral compression. The dip of axial planes indicates a southern vergence.

Horusitzky (1943, 1958b) and Wein (1974b, 1977) regarded the Buda Marl as the youngest sediment affected by compression tectonics and attributed the last folding to the Pyreneean phase. Rozlozsnik (1935) in turn was of the opinion that the Kiscell Clay also suffered folding although less than the older Paleogene sediments. Pávai Vajna (1941 and comment to Horusitzky, 1943) also mentioned folds in the Kiscell Clay assuming that folding had been lasting up to the Pleistocene.

The Hárshegy Sandstone (Lower-Middle Oligocene) with conglomerate interlayers undoubtedly may mark an unconformity which could be attributed to the Pyreneean (end-Eocene) phase. Most of the detrital material of the conglomerate and sandstone, however, is of distal origin (Báldi, 1983), and we do not know any section in which the Hárshegy Sandstone covered Eocene sediments with angular unconformity. Moreover, stratigraphic contacts between the Hárshegy Sandstone and the Buda Marl are extremely scarse (for examples, see Wein, 1977). The Buda Marl is mostly overlain not by the Hárshegy Sandstone but by the Tard Clay which in turn is covered by the Kiscell Clay, and these successions are uninterrupted (Hofmann, 1871; Telegdi Roth, 1924; Horusitzky, 1958b; Szőts, 1958; Oravecz, 1968; Báldi, 1983).

Wein (1977) tried to fit this continuity with the 'Pyreneean orogeny' emphasizing the facial difference between the Buda Marl and Tard Clay. Besides the fact that this facial difference is insignificant (Báldi, 1983), any 'orogeny' producing folds in the Buda Marl with no folding in the Tard Clay which covers the Buda Marl with transitions seems to be doubtful. Moreover, the Paleogene beds on the Alsóhegy street, already attributed to the Tard Caly in Wein's (1974a) map, suffered strong compression folding which should produce significant unconformity. In the stratigraphic sequence of the Buda Hills the next unconformity is observable in the Lower Miocene (Wein, 1977), and this is the oldest possible age of the folding in questtion. Since Miocene or Oligocene sediments younger than the Kiscell Clay have not been established in the surroundings of the folded Paleogene, there is no possibility to determine more precisely the age of the folding in the Buda Hills.

In a regional framework folded Paleogene and Miocene is known within a narrow zone along the Balaton line (Fig. 3) where the folding took place

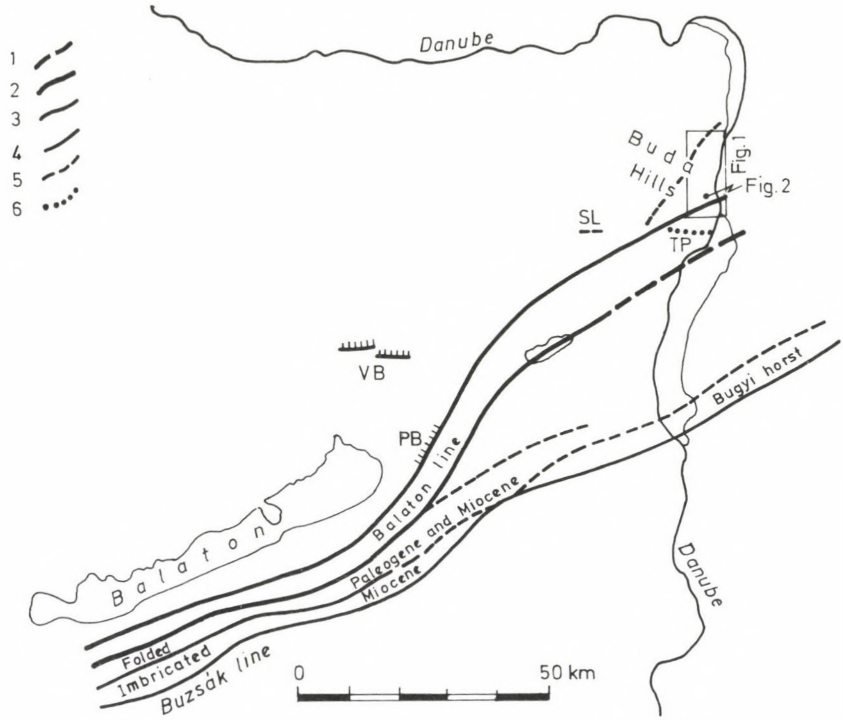

Fig. 3. Miocene compression features in Middle and Northern Transdanubia. Principal structures taken from Balla et al. (1988) and Balla and Dudko (1989). The Paleogene facies boundary divides areas of the Hárshegy Sandstone (Lower-Middle Oligocene) in the northwest and of the Buda Marl (Upper Eocene) and Tard Clay (Lower Oligocene) in the southeast. Oligocene strikeslip faults were bent in the Early Miocene. 1. Paleogene facies boundary; 2. Oligocene dextral strike-slip fault; 3. Miocene fault; 4. Miocene thrust; 5. Miocene anticline; 6. Miocene syncline; VB=Várpalota basin; PB=Polgárdi basin; Si=Szent László víz valley; TP=Tétény plateau

around the Badenian/Karpatian boundary (Balla et al., 1988). The fold and imbrication zone is probably traceable towards the Bugyi horst while the Balaton line and accompanying faults turn towards the foreland of the Buda Hills after an S-shaped bend. Due to the almost total lack in boreholes no information is available on the tectonics of the area situated between the Buda Hills and the Bugyi horst.

North of the Balaton line dispersed traces of Miocene compression are known (Fig. 3), those are the Late Badenian thrusting in the Várpalota Basin (Kókay, 1976, 1983) and the thrusting on the Sarmatian/Badenian boundary in the Polgárdi Basin (Dudko, 1988). Additionally, nearly W-E-directed gentle post-Badenian (post-Sarmatian?) folds can be revealed in the map (Szentes and Böjtös-Varrók, 1964), an anticline in the Szent László víz

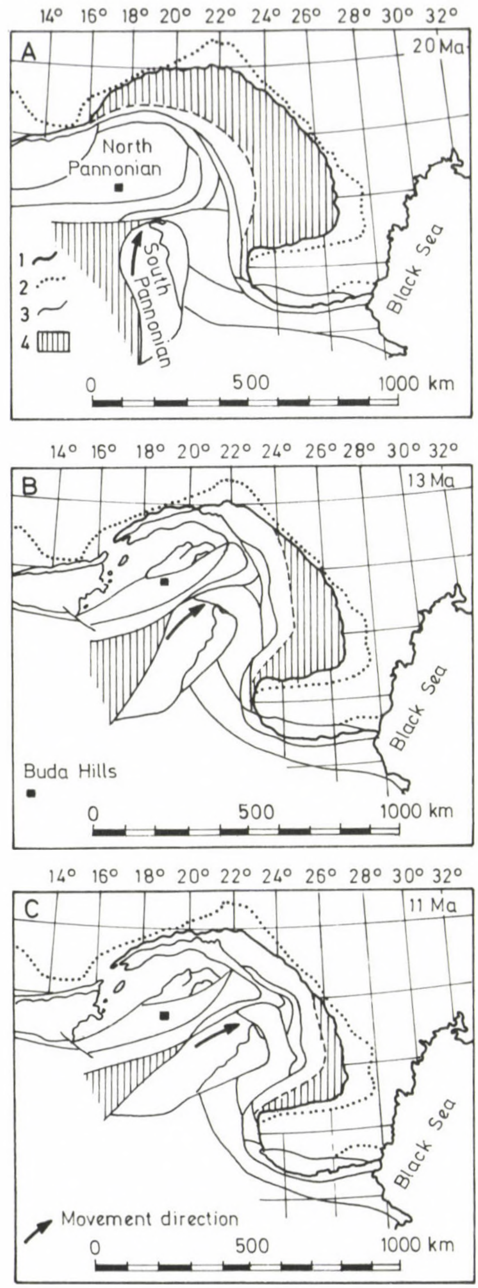

Fig. 4. Three successive situations from the Miocene rotation history of the Pannonian units, simplified after Balla (1985). A - collision, B - convergence ≫ sinistral shift, C - convergence ≪ sinistral shift. 1. Present-day geological and geographical contours; 2. outer boundary of the fore deep; 3. geological contours in the reconstruction; 4. gap in the reconstruction

valley and a syncline on the Tétény plateau. It is remarkable that folds in the Buda Hills fall in one strip with all of them. Consequently, the folds in the Buda Paleogene may be as young as post-Badenian.

In the framework of our Miocene kinematics (Balla, 1985) there are three principal features which could generate compression in the Buda Hills. In the Early Miocene it was the collision of the South Pannonian unit to the North Pannonian unit (Fig. 4A) east of Lake Balaton which resulted in the S-shaped bending of previous structures (Balla and Dudko, 1989) and probably in transversal compression east of the bend. During the Middle Miocene convergence between the two units was in progress (Fig. 4B). It was accompanied by sinistral shear of the whole southern edge of the North Pannonian unit which appeared because of the eastward-directed relative movement of the South Pannonian unit (Fig. 4C). Onwards in time the shear became stronger and the convergence weaker. W-E striking thrusts (VB) and folds (SL, TP) may have been related to the shear which would be in harmony with the comparatively young age.

Since the folds described above from the Alsóhegy street also are of nearly W-E strike, their most probable age can be fixed around the Sarmatian/Badenian boundary.

6. Conclusion

Documentation (Fig. 2) given above, as a matter of facts, is the first proof of the existence of real folds of compression origin in the Buda Paleogene, at least in certain zones. Therefore, Schafarzik and Vendl (1929), Pávai Vajna (1934), Horusitzky (1958b) and Wein (1977) probably were right insisting on the wide distribution of this phenomenon. The age of folding is not Paleogene but Miocene.

REFERENCES

Báldi, T. (1983): Magyarországi oligocén és alsómiocén formációk (Oligocene and Lower Miocene formations of Hungary). Akadémiai Kiadó, Budapest, 293 p.

Balla, Z. (1985): The Carpathian loop and the Pannonian basin: A kinematic analysis. Geophys. Trans., **30** (1984), 4, pp. 313-353.

Balla, Z., A. Dudko (1989): Large-scale Tertiary strike-slip displacements recorded in the structure of the Transdanubian Range. Geophys. Trans., **35**, 1-2, pp. 3-63.

Plate I

Plate I

Photos of the western wall of the shaft No 6

Balla, Z., A. Dudko, M. Redler-Tátrai (1988): A Közép-Dunántúl fiatal tektonikája földtani és geofizikai adatok alapján (English summary: Young tectonics of Middle Transdanubia on the basis of geological and geophysical data). Ann. Rep. Eötvös L. Geophys. Inst. for **1986**, pp. 74-94.

Böhm, B. (1942): Beiträge zur tertiären Fischfauna Ungarns. Geol. Hung., ser. Pal., **19**, pp. 7-42.

Dudko, A. (1988): A Balatonfő-Velence körzet szerkezetalakulása (English summary: The structural history of the Balatonfő-Velence area). Földtani Közlöny, **118**, 3, pp. 207-218.

Földvári, A. (1933): Új feltárások a Sashegy északkeleti oldalán (New outcrops on the northeastern slope of the Sas Hill). Földtani Közlöny, **63**, 7-12, pp. 221-233.

Heckel, J. (1856): Beiträge zur Kenntnis der fossilen Fische Österreichs. Denkschr. k. k. Akad. Wiss., Math. Naturwiss. Classe, **11**.

Hofmann, K. (1871): A Buda-Kovácsi hegység földtani viszonyai (Geology of the Buda-Kovácsi Hills). Ann. Hung. Geol. Inst., **1**, pp. 199-273.

Horusitzky, F. (1943): A Budai-hegység hegyszerkezetének nagy egységei (Large units in the tectonics of the Buda Hills). Beszámoló a Földtani Intézet Vitaüléseinek Munkálatairól, **5**, 5, pp. 238-251.

Horusitzky, F. (1958a): Az alsó oligocén agyagos kifejlődése (Argillaceous facies of the Lower Oligocene). In: M. Pécsi (Ed.-in-chief), Budapest természeti képe (Natural sketch of Budapest). Akadémiai Kiadó, Budapest, pp. 68-70.

Horusitzky, F. (1958b): Budapest és környékének hegységszerkezeti alapvonásai (Tectonic outline of Budapest and its surroundings). In: M. Pécsi (Ed.-in-chief), Budapest természeti képe (Natural sketch of Budapest). Akadémiai Kiadó, Budapest, pp. 135-142.

Horusitzky, H. (1938): Budapest dunajobbparti részének (Budának) hidrogeológiája (Hydrogeology of Buda, the right-Danube-riverside of Budapest). Hidrológiai Közlöny, **18**, pp. 1-341.

Jámbor, Á. (1966): Briozoás és budai márga (The Bryozoan and the Buda Marl). In: Á. Jámbor, L. Moldvay and A. Rónai, Magyarázó Magyarország 200 000-es földtani térképsorozatához. L-34-II, Budapest (Explanatory notes to the Geological map of Hungary, scale 1:200 000, sheet L-34-II, Budapest). Földtani Intézet, Budapest, pp. 37-41.

Jaskó, S. (1933): Adatok a Pálvölgy környékének tektonikájához (Data on the tectonics of the surroundings of the Pál Valley). Földtani Közlöny, **63**, 7-12, pp. 224-225.

Kisdi-Bulla, J., Zs. Raincsák-Kosáry, M. Szabó-Drubina (1983): Budapest területének földtani térképe, 1:40 000 (Geological map of Budapest, scale 1:40 000). In: Budapest területének földtani, vízföldtani, építésalkalmassági térképei (Geological, hydrogeological and engineering-geological maps of Budapest). Földtani Intézet kiadványa, Budapest, 1984.

Koch, A. (1904): Apró paleontológiai közlemények (Short paleontological notices). Földtani Közlöny, **34**, 8-10, pp. 332-335.

Kókay, J. (1976): Geomechanical investigation of the southern margin of the Bakony Mountains and the age of the Litér fault line. Acta Geol. Acad. Sci. Hung., **20**, 3-4, pp. 245-257.

Kókay, J. (1985): Tektonikai-geomechanikai vizsgálatok a Bántapusztai-medence területén (English summary: Tectonic and geomechanical studies in the Bántapuszta basin (Várpalota, Bakony Mountains). Ann. Rep. Hung. Geol. Inst. for **1983**, pp. 43-50.

Lőrenthey, I. (1907): Vannak-e juraidőszaki rétegek Budapesten? (Are there Jurassic beds in Budapest?) Földtani Közlöny, **37**, 9-11, pp. 359-368.

Majzon, L. (1941): Oligocén és miocén foraminifera faunák kiértékelése (Evaluation of Oligocene and Miocene foraminifers). Beszámoló a Földtani Intézet Vitaüléseinek Munkálatairól, **1939**, pp. 24-43.

Noszky, J. (1930): A Magyar Nemzeti Múzeum érdekesebb, új geológiai és paleontológiai szerzeményei (Recent remarkable geological and paleontological acquisitions of the Hungarian National Museum). Földtani Közlöny, **59**, pp. 42-49.

Oravecz, J. (1968): A Budai-hegység földtani felépítése (Geology of the Buda Hills). In: L. Alföldi et al. (eds), Budapest hévízei (Thermal waters in Budapest). Vízgazd. Tud. Kutatóint., Budapest, pp. 11-25.

Pávai Vajna, F. (1934): Új kőzetelőfordulások a Gellérthegyen és új szerkezeti formák a Budai hegyekben (New rock occurrences on the Gellért Hill and new structures in the Buda Hills). Földtani Közlöny, **64**, 1-3, pp. 1-11.

Pávai Vajna, F. (1941): Az 1938. évi Budapest környéki kiegészítő geológiai felvételi jelentésem (Report on the supplementary geological mapping in the surroundings of Budapest in 1938). Ann. Rep. Hung. Geol. Inst. for **1936-1938**, I, pp. 399-438.

Rozlozsnik, P. (1935): Adatok a Buda-Kovácsi hegység óharmadkori rétegeinek ismeretéhez (Data on the Paleogene beds of the Buda-Kovácsi Hills). Ann. Rep. Hung. Geol. Inst. for **1925-1928**, pp. 65-85.

Schafarzik, F. (1921): A Szt. Gellérthegy geológiai viszonyairól (On the geology of the St. Gellért Hill). Földtani Közlöny, **50**, (1920). pp. 41-42.

Schafarzik, F. (1922): Budapest székesfőváros legújabb geológiai térképeiről (On the recent geological maps of the capital Budapest). Mathematikai és Természettud. Értesítő, **22**, pp. 181-198.

Schafarzik, F. (1926): A Szent Gellérthegy geológiai múltja és jelene (The geological past and present of the Saint Gellért Hill). Természettudományi Közlöny, **58**, 836, pp. 460-472.

Schafarzik, F. (1927): Völgyképződés a Budai hegység déli részében (Formation of valleys in the southern Buda Hills). Földtani Közlöny, **56**, pp. 7-10.

Schafarzik, F. and A. Vendl (1929): Geológiai kirándulások Budapest környékén (Geological excursions in the surroundings of Budapest). Stádium Sajtóvállalat Rt., Budapest, 343 p.

Staub, M. (1886): A magyar királyi földtani intézet fitopaleontológiai gyűjteményének állapota az 1885. év végén (The state of the phytopaleontological collection of the Hungarian Royal Geological Institute at the end of 1885). Ann. Rep. Hung. Geol. Inst. for **1885**, pp. 179-208.

Szörényi, E. (1929): A budai márga és faunája (The Buda Marl and its fauna). Földtani Szemle melléklete, pp. 1-45.

Szentes, F. and Böjtös-Varrók, K. (1964): Magyarország földtani térképe, 200 000-es sorozat. L-34-I, Tatabánya (Geological map of Hungary, scale 1:200 000 sheet L-34-I, Tatabánya). Földt. Int., Budapest, pp. 37-41.

Szőts, E. (1958): Budai márga (The Buda Marl). In: M. Pécsi (Ed.-in-chief), Budapest természeti képe (Natural sketch of Budapest). Akadémiai Kiadó, Budapest, pp. 62-63.

Telegdi Roth, K. (1924): Paleogén képződmények elterjedése a Dunántúli középhegység északi részében (The distribution of the Paleogene formations in the northern Transdanubian Range). Földtani Közlöny, **53**, (1923), pp. 5-14.

Weiler, W. (1935): Die Fischreste aus den Budaer (Ofner) Mergel des Gellérthegy (Blocksberges) bei Budapest. Ann. Mus. Nat. Hung., **29**, pars Miner., Geol., Palaeont., pp. 29-39.

Wein, Gy. (1974a): Budai-hegység, fedetlen földtani térkép, 1:25 000 (Buda Hills, uncovered geological map, scale 1:25 000). In: Gy. Wein, A. Budai-hegység tektonikája (The tectonics of the Buda Hills). Földt. Int. alkalmi kiadványa, Budapest, 1977, Encl.

Wein, Gy. (1974b): A Budai-hegység tektonikája (The tectonics of the Buda Hills). Földrajzi Közlemények, **22**, 2, pp. 97-112.

Wein, Gy. (1977): A Budai-hegység tektonikája (The tectonics of the Buda Hills). Földtani Intézet alkalmi kiadványa, Budapest, 76 p.

Acta Geologica Hungarica, Vol. 33/1-4, pp. 43-67 (1990)

VERY LOW- AND LOW-GRADE METAMORPHIC ROCKS IN THE PRE-TERTIARY BASEMENT OF THE DRAVA BASIN, SW-HUNGARY, I: MINERAL ASSEMBLAGES, ILLITE "CRYSTALLINITY", b_o DATA, AND PROBLEMS OF GEOLOGICAL CORRELATION

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Lithologic and metamorphic petrological characterization of an incipient metamorphic sequence of unknown age and origin was carried out. The lowermost part is built up by metarhyolite and its tuff. They are overlain by quartz-rich, feldspar-free metasandstone, locally containing metavolcanite intercalations of intermediate composition. Going upwards in the profile first the phyllitic (pelitic) and then the carbonatic (dolomitic) intercalations become more and more frequent, while the amount of the psammitic detritus decreases. Peculiar, inhomogeneous, cipollino-like types originated by syn- and post-sedimentary mixing, alternation of fine-detritic and carbonatic sediments can be found in the upper part of the profile. Relatively poor dolomite marble closes the sequence on the top.

Metamorphic minerals occurring in the different rock types include quartz, sericite (muscovite-phengite) $\pm$ dolomite (ankerite), albite, potash feldspar, chlorite, calcite, siderite, pyrite, hematite, tremolite and anhydrite. Based on the illite "crystallinity" (IC) values of the fine-detritic samples, high temperature anchizonal (transitional anchi-, epizonal) metamorphic conditions (cca 300-350 ^oC) are characteristic. Comparing the average IC values of the different rock types, correlation can be found between lithology and IC indicating that the metamorphism was not strong enough to eliminate the original differences (inheritage of mica) and the differences in the regimes of post-sedimentary alterations. Evaluating the sericite-b_o values, medium pressure range may be presumed (b_o = 9.018-9.025 Å).

No biostratigraphic data exist on the age of sedimentation. Using lithostratigraphic analogies and the characteristics of regional dynamothermal metamorphism, different hypotheses were set up for geologic correlation. The lithology of the sequence seems to be very similar to that of the East Alpine type Paleozoic, and also to the Mesozoic of the Internal Dinarides, the tectonically dismembered parts of which can be found in the Yugoslavian (southern) part of the Tisza Unit as well as in the Central Hungarian (Igal) tectonic zone. To solve the age problems, K-Ar and Rb-Sr isotope geochronological studies were carried out (see paper II in the same volume).

Keywords: Very low-grade metamorphism, illite "crystallinity", b_o-geobarometry, anchizone, epizone, Drava Basin, Hungary.

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Introduction

The Neogene depression along the river Drava belongs to the Pannonian Basin system. It is filled with a maximally 5000 m thick sedimentary pile. Metamorphic basement rocks of this basin linking the crystalline complexes of the Eastern Alps, Dinarides and the Great Hungarian Plain form two main groups: medium-grade, polymetamorphic formations, and - sporadically, in small extension - very low- to low-grade (with other words, anchi- and epizonal) rocks.

The present paper aims at the lithologic and metamorphic petrological characterization and possible geologic correlation of these anchi-, epizonal rocks. The investigation of the core samples deriving from hydrocarbon exploratory wells was initiated and supported by the Oil and Gas Mining Enterprise (Nagykanizsa).

Geology, previous data

The tectonic situation of the Barcs-West area, where the incipient metamorphic sequence was penetrated by hydrocarbon exploratory bores, is shown in Fig. 1. The Barcs-West area is located in the Tisza Unit (or Tisia "microplate") which was one of the most consolidated crustal fragments of the Carpatho-Pannonian region in the Alpine tectonocycle. Its metamorphic basement is built up mainly by medium-grade rocks. Most of them (gneisses, mica schists, and their retrograded or tectonite derivates: mylonites, blastomylonites) were formed from carbonate-poor or -free pelitic-psammitic sediments. Orthoamphibolite intercalations are subordinate. The oldest detectable, medium-grade, medium pressure metamorphic event (510-600 ^{o}C/ 5.9-8.9 kbar, with geothermal gradient of 17-27 ^{o}C/km) was locally overprinted by an andalusite type (low pressure) amphibolite facies event and a low temperature ($<$450 ^{o}C), low-pressure retrograde, partly cataclastic event. The third (retrograde) event might be synchronous with or younger than the andalusite type overprint. In the latter case considerable spatial variations of the temperature have to be assumed. The chronology of these events is not known exactly. Caledono-Hercynian or pre-Hercynian - Hercynian polymetamorphic or Hercynian polyphase (plurifacial) models seem to be the most probable at present (for further details see Árkai (1984) and Árkai et al. (1985).

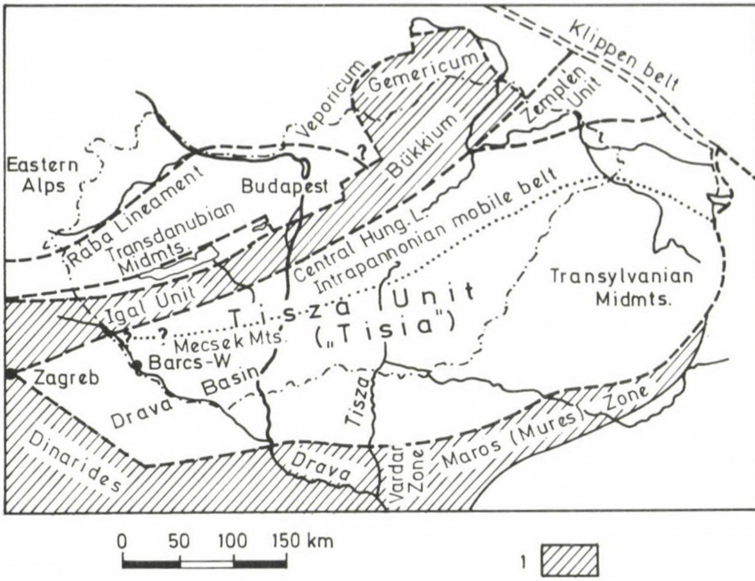

Fig. 1. Tectonic sketch map of Hungary after Kovács (1984), with the location of the Barcs-West area. 1. Alpine mobile zones

Due to the discontinuous core boring, the character of the contact between the polymetamorphic complex and the overlaying anchi-, epizonal sequence is unknown (Fig. 2). Based on the different styles of deformation the syngenetic folding seems to be very unlikely. The anchi-, epizonal sequence was intensely deformed (chaotic folding, schistosity, crenulation cleavage, cataclastic alteration), while the signs of the adequate tectonic effect could not be observed in the underlaying medium-grade rocks. The significant gap in grades indicates either time difference in metamorphic processes or - in case of contemporaneous metamorphism - considerable distance between the two units.

In other parts of the Drava Basin non-metamorphic, terrigeneous, detrital Upper Carboniferous, mostly carbonatic Permian and Mesozoic formations are found in the pre-Tertiary basement separated by erosional unconformity surfaces from the polymetamorphic basement and from the overlaying Tertiary sediments (Bardócz, 1973-1986).

At the time being neither geologic nor petrographic data have been published on the anchi-, epizonal rocks in question. The results of the first, microscopic investigations were summarized in an industrial report

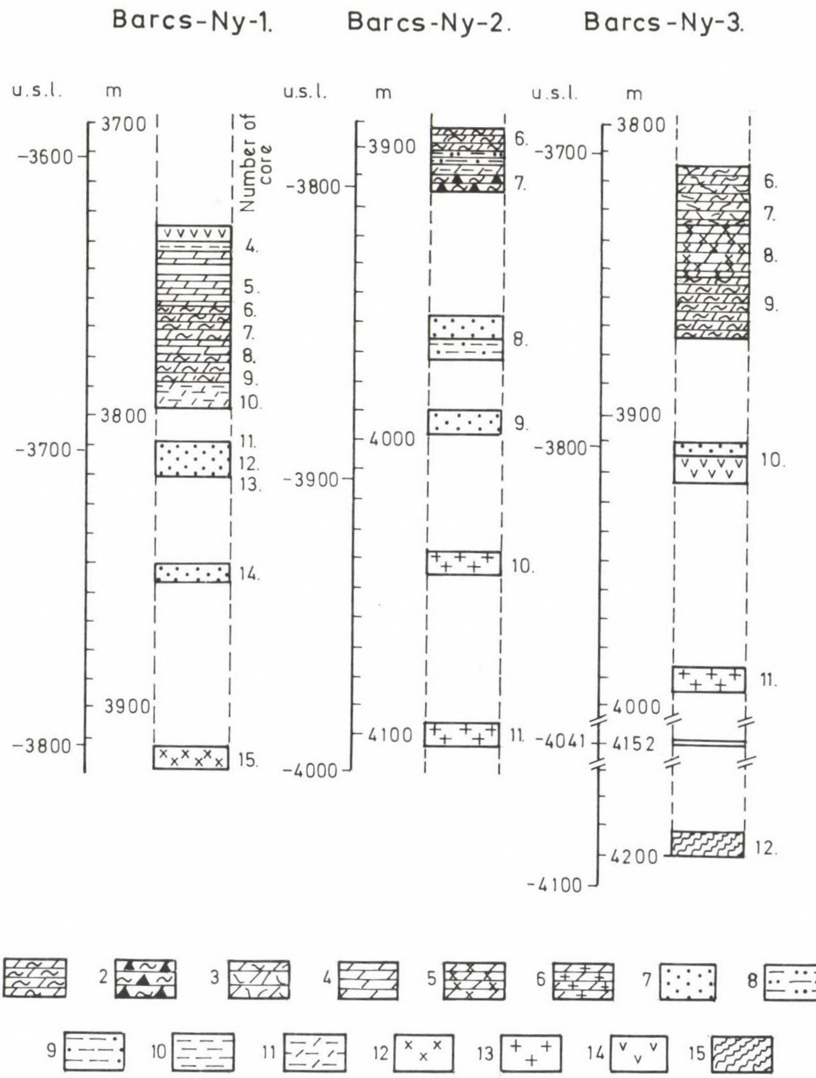

Fig. 2. Geologic profiles of some representative bores exploring the basement of the Barcs-West area. 1. cipollino-like dolomite marble with phyllite bands and lenses; 2. anhydrite bearing dolomite marble with phyllite bands; 3. brecciated dolomite marble; 4. dolomite marble; 5. albitized dolomite marble (metasomatic?); 6. dolomite marble with metarhyolite detritus; 7. metasandstone; 8. metasandstone with phyllite bands; 9. phyllite with metapsammite and/or metasilt intercalations; 10. phyllite; 11. carbonatic (dolomitic) phyllite; 12. metarhyolite tuff; 13. metarhyolite; 14. intermediate(?) metavolcanite; 15. medium-grade mica schist

(Balázs, 1980). According to Balázs the sequence of the bore Barcs-Ny-1 consists of dolomite schist, cipollino-like, serpentine-containing, sericitic, chloritic, banded dolomite marble (originated from the mixing of carbonatic sediment and basic volcanic tuff), dolomite-phyllite, phyllite, quartz porphyry, metasandstone and quartzite (in order from the top to the bottom). For lack of paleontologic and radiometric data the age of the sequence was proposed to be Devonian or Traissic, based on presumed lithologic analogies.

Methods

Out of 5 boreholes 41 samples were investigated by microscopic, X-ray diffractometric, main element chemical analytical and electron microprobe methods.

Having identified the rock types, microstructural and textural features, special attention was paid to the distinction between inherited (detrital) and newly formed (metamorphic) constitutents using normal light microscope.

Qualitative and semiquantitative mineral composition, illite "crystallinity", d(002) and b_0 parameters of sericite were determined by X-ray diffractometric method using a Philips PW-1730 type equipment. (Recording conditions were: CuK_α radiation, 45 kV, 35 mA, proportional counter, graphite monochromator, divergency and detector slits: 1^o, goniometer speed: 2^o/min and $1/2^o$/min, time constant: 2 sec, chart speed: 2 cm/min). Calculating the semiquantitative composition the direct method of Náray-Szabó and Péter (1967) was used with some modifications according to Bárdossy (1966), Rischák and Viczián (1974), taking also into account the solution residue data obtained by treatment with 3% HCl, and the mineralogic recalculation of whole rock chemical analyses.

Illite "crystallinity" (IC = Kübler-index = LS = largeur de Scherrer) was measured on unoriented powder preparations of whole rock and acid insoluble residue samples and on their $<2\ \mu m$ fractions (the latter are highly oriented thin layer preparations sedimented on glass slides from suspensions) according to the method of Kübler (1968, 1975). In order to compensate the instrumental effects, illite "crystallinity" standards Nos 32, 34 and 35 kindly provided by Kübler were used for the linear calibration by means of the least squares method. In Table IV and Fig. 4 we gave the IC boundaries corresponding to Kübler's original anchizone boundary values of 0.25 and 0.42°2θ, respectively. As the effects of the detrital white mica can be detected even in the <2 μm fractions, the actual IC boundaries may vary depending on the ratio of the inherited and newly formed muscovite and illite, on the grain size and degradation state of detrital muscovite, etc. Consequently, according to the opinion of the present author, IC-boundaries of Kübler's anchizone calibrated with the help of standards can not be applied mechanistically to different sequences. For example, in case of the "less matured" NE-Hungarian Paleo-Mesozoic (Bükkium) somewhat lower IC boundaries correspond to the "anchizone" correlated roughly with the pumpellyite-prehnite-quartz and pumpellyite-actinolite facies and with the vitrinite reflectance ranges R_{max} = 3.5-6.0%, R_{random} = 3.0-5.0% (Árkai, 1983). These values are averages of the appropriate boundaries given by Weber (1972), Wolf (1972), Kisch (1974), Teichmüller et al. (1979), Frey et al. (1980), and are somewhat higher than those proposed by Kübler (1975) and Kübler et al. (1979) (R_{random} = 2.7-4.1%).

The $b_0 \approx 6 \times d(060, \bar{3}31)$ parameter of sericite was determined using unoriented powder preparations with corrections based on the (211) reflection of quartz being always present in the rocks as "internal standard". The b_0 parameter was applied for the characterization of pressure conditions of metamorphism after the works of Sassi (1972), Guidotti and Sassi (1976, 1986) as well as Padan et al. (1982).

In silicate analyses made by J. Lefler (Lab. for Geochem. Research) a Carl Zeiss AASIM type atomic absorption spectrophotometer was used, in addition to the traditional gravimetric, photometric and chromatometric methods.

The chemical composition of rock forming minerals was determined by dr. G. Nagy (Lab. for Geochem. Research), by means of a JEOL Superprobe-733.

Rock types, lithology, mineral composition

In the anchi-, epizonal sequence of the Barcs-West area ortho-rocks are represented by metarhyolite (quartz porphyroid) and its tuff (Plate I/1-3) as well as by metavolcanite of possible intermediate composition (Plate I/4). In addition, the following metasedimentary rock types were distinguished:

- metasandstone (in some cases with phyllitic or dolomite and anhydrite containing bands): Plates II/1-4 and III/1;

- phyllite, in certain cases with metapsammitic, metasilty intercalations: Plate III/2-3;

- cipollino-like carbonate phyllite with dolomite bands: Plate III/4;

- dolomite marble (Plate IV/3-4) and its modifications: brecciated dolomite marble, cipollino-like dolomite marble with network forming phyllite bands and lenses (Plate IV/1-2, albite-rich (metasomatic?) dolomite marble, and dolomite marble with metarhyolite tuff mixing.

The vertical distributions of the different rock types are illustrated in Fig. 2. In the lowermost parts of the anchi-, epizonal sequence metarhyolites and their tuffs are found overlain by feldspar-free, quartz-rich metasandstone. In bore Barcs-NY-3 the metasandstone beds contain intermediate, partly brecciated metavolcanite intercalation. First the phyllitic (pelitic-silty), later on the carbonatic (dolomitic) intercalations appear and become more and more frequent, the amount of the psammitic detritus decreases upwards in the profiles. Finally, the psammitic constituents practically disappear, and peculiar, inhomogeneous, composite, cipollino-like rock types originated by possible syn- and postsedimentation mixing, alternation of fine-detritic and carbonatic sediments form the upper parts. In bores Barcs-NY-1 and -3 dolomite marble closes the top of the profiles.

Assuming normal (not inverse) bedding, the arrow in Fig. 3 indicates the general trend of the changes in mineral composition in a triangle diagram representing the three main types of sediments (carbonatic, pelitic and psammitic). In the lower part of the profile the (quartz + feldspar)/phyllosilicate ratio, in the upper part the silicate minerals/carbonate minerals ratio changes rapidly. It is conspicuous that the mineral compositions of the different metavolcanites are very similar to some metasediment types in this projection.

This anchi-, epizonal sequence is separated by a presumably tectonic unconformity surface from the underlaying medium-grade rocks, namely: staurolite- and garnet-bearing biotite-muscovite schist and its highly chloritized variant (cores Barcs-Ny-3.12 and -5.3).

Table I contains the average mineral compositions of the main rock types.

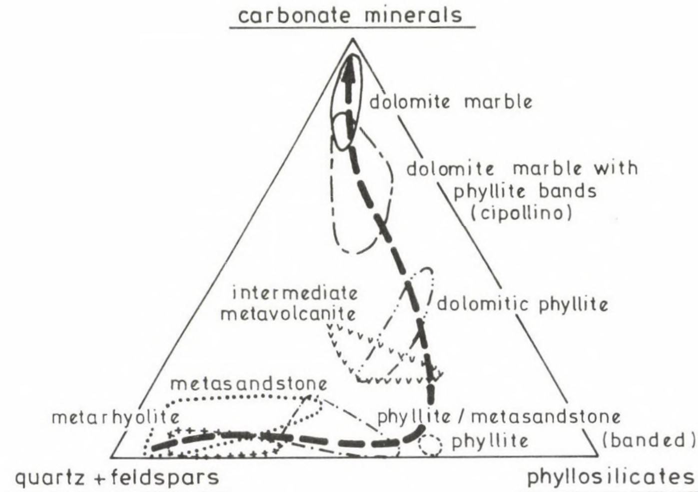

Fig. 3. Mineral composition of the main lithotypes. Arrow indicates the trend of changes upwards in the geologic profile

The metarhyolite and its tuff are characterized by their high quartz, significant albite, potash feldspar, sericite and low dolomite contents.

Based on the high quartz content as well as the practical lack of feldspars, rock fragments and chlorite, the well-sorted metasandstone might form from strongly weathered ("matured") detritus.

Sericite, quartz, dolomite, albite and potash feldspar are the dominant constituents of the intermediate metavolcanite.

Going upwards in the profile, decreasing quartz and increasing sericite contents are characteristic of the mixed rock types of pelitic - silty - psammitic origin, comparing with the metasandstone.

In the upper part carbonatic (mostly dolomitic) material predominates. The carbonate-free parts of the cipollino-like rock types contain mainly phyllosilicates (sericite $\gg$ chlorite), the amounts of quartz are also significant, while the feldspars (first of all albite) are less frequent, strongly differing from the metasomatic (albite-rich, sericite-poor) dolomite marble.

Except few cases neither compositional nor textural proofs of widespread, intense mixing of volcanogenic and sedimentary materials mentioned by Balázs (1980) as a general phenomenon, were found. The existence of serpentine minerals described by Balázs could not be verified by X-ray diffractometric investigations. Except some dolomite samples (containing quartz and feldspar porphyroclasts of presumably rhyolitic origin) no magmatic minerals, pseudomorphs or relic textures were found. Contradicting the oxidative (hematite-bearing) character of the cipollino-like mixed, volcanogenic-sedimentary rocks of the Szendrő and Uppony Mts. (NE-Hungary, see Árkai, 1977 and Árkai et al., 1981), the cipollino-like variants of the Barcs-West area contain always pyrite. On the other hand, the contribution of very fine-grained, weathered (halmirolitic?) products of volcanoclastic rocks to the sedimentary (carbonatic, pelitic) material can not be excluded either, nevertheless the evidence is lacking at present.

Chemical features

Main element composition of some para- and ortho-rocks (Table II) were used to evaluate the chemical characteristics of the regional metamorphism. Comparing with the distributions of pelitic sediments and acid volcanites in the ACF-A'KF diagrams (see Winkler, 1979), the projection points of the metapelitic-psammitic sediments as well as that of the metarhyolite are shifted towards the A and A' corners. This may relate to the high sericite content, and presumably to the allochemical character of the diagenesis and/or metamorphism.

Regional metamorphism

Microstructural characteristics

The informative microstructural features are as follows:

- metamorphic quartzite and "spiny-like" quartz-sericite overgrowth textures in metasandstone (Plate II/1-4);
- foliation, crenulation cleavage in phyllite (Plate III/2-3);
- folded, imbricated phyllitic bands, lenses in the mixed (cipollino-type) variants (Plate IV/1-2);
- elongated grains with preferred orientation (foliation) in the wholly recrystallized matrix of the marbles.

All of these characteristics indicate metamorphic conditions corresponding to the high-temperature part of the anchizone or to the beginning of the epizone. Based on the intense, syn-metamorphic deformation, the metamorphism proved to be of regional (dynamothermal) character.

Mineral assemblages

Metamorphic mineral assemblages of the different rock types in the Barcs-West area consist of quartz, sericite ± dolomite (ankerite), albite, potash feldspar, chlorite, calcite, siderite, pyrite, hematite, tremolite and anhydrite. These assemblages being stable both in anchi- and epizonal circumstances, are unsuitable for the precise determination of metamorphic grade.

The lack of biotite suggests a temperature range lower than 400 - 450 °C (Winkler, 1979 and Ferry, 1984).

Only one (dolomitic phyllite) sample contains traces of tremolite contacting quartz, sericite and chlorite (Plate III/4). According to Suk (1983) tremolite (with some Fe content) may form at temperatures as low as about 300 °C in presence of iron ions in siliceous dolomitic rocks by the reaction dolomite (ankerite) + quartz + $H_2O \longrightarrow$ tremolite (actinolite) + calcite + CO_2.

Taking into account the displacement of the d(104) reflection of the dolomite towards the lower 2θ values, and the decrease of the temperature of the endothermic reactions observed by DTA and DTG measurements, the isomorphous substitution of $Fe^{2+} \longrightarrow Mg$ is stronger in the phyllitic rock types (often containing also siderite) than in the carbonatic and mixed varieties. Based on the Fe^{2+}/Mg ratios the composition corresponds to that of the ankerite in certain cases. The Fe^{2+}/Mg ratio of carbonate mineral may vary within one sample, even in one grain, while the Mn-uptake is insignificant (Table III/a).

In all types of rocks the plagioclase is represented by ordered (low-temperature) albite ($2\theta_{(131)} - 2\theta_{(1\bar{3}1)} = 1.14$ in average).

Anhydrite usually fills the cracks of the brecciated rocks, however, it can be found in the matrix, too. The boundaries of the anhydrite-rich bands and veins are diffuse. The origin of the anhydrite is not known: concluding from the textural features, the rocks might contain it already before or during the metamorphism.

Illite crystallinity

The histograms of the IC values are shown in Fig. 3. The average of the IC determined on whole rock and acid insoluble residue samples corresponds to the boundary between the anchi- and epizones, while that of the $< 2\ \mu m$ fractions falls within Kübler's anchizone. (In case of the

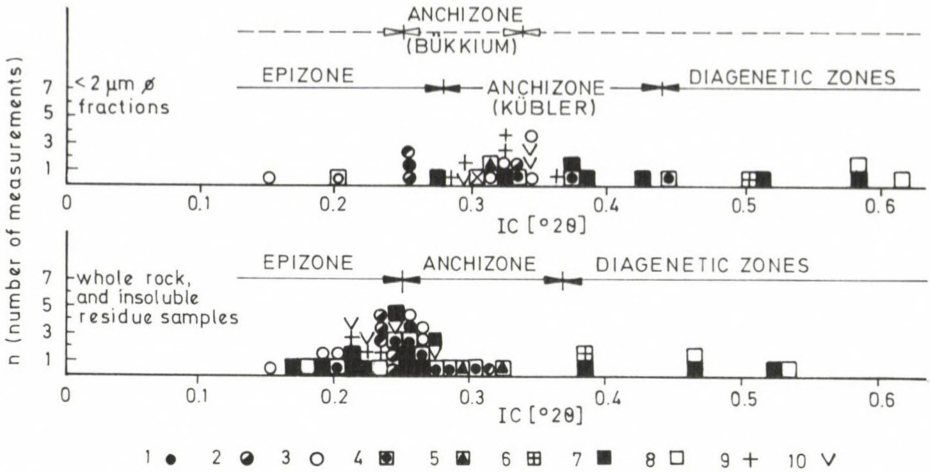

Fig. 4. Histograms of illite "crystallinity" (IC) values in different lithotypes and their <2 µm fractions (see the text for the interpretation of metamorphic zone boundaries). 1. phyllite; 2. phyllite and metasandstone intercalations in different ratios; 3. metasandstone; 4. carbonatic (dolomitic) phyllite; 5. anhydrite bearing dolomite marble with phyllite bands; 6. dolomite marble with metarhyolite detritus; 7. cipollino-like dolomite marble with phyllite bands and lenses; 8. dolomite marble; 9. metarhyolite and its tuff; 10. intermediate(?) metavolcanite

strongly weathered, "matured" fine detritic and dolomitic sediments the use of Kübler's boundaries determined originally for pelitic-marly rocks seemed to be more satisfactory than the IC-boundaries evaluated for the less matured detritic sequences of the Bükkium.)

Comparing the average IC values of the different rock types (Table IV and Fig. 4), correlation can be found between lithology and IC indicating that the regional metamorphism was not strong enough to eliminate the original differences (inheritage of mica, different weathering state, etc.) and/or the differences which existed during the diagenesis and metamorphism (isolating effect of carbonate matrix delaying phyllosilicate aggradation). With increasing carbonate (first of all, dolomite) content the IC values increase both in the whole rock, insoluble residue and in the <2 µm fraction samples (Fig. 5). As IC values found in the pelitic - silty - marly rocks can be used for the estimation of metamorphic grade (Kübler, 1975), high-temperature anchizonal (transitional anchi-, epizonal) conditions with an approximate temperature interval of 300-350 °C can be concluded.

The metasediments and metavolcanites in question having similar IC values might have been subjected to the same regional metamorphic effect.

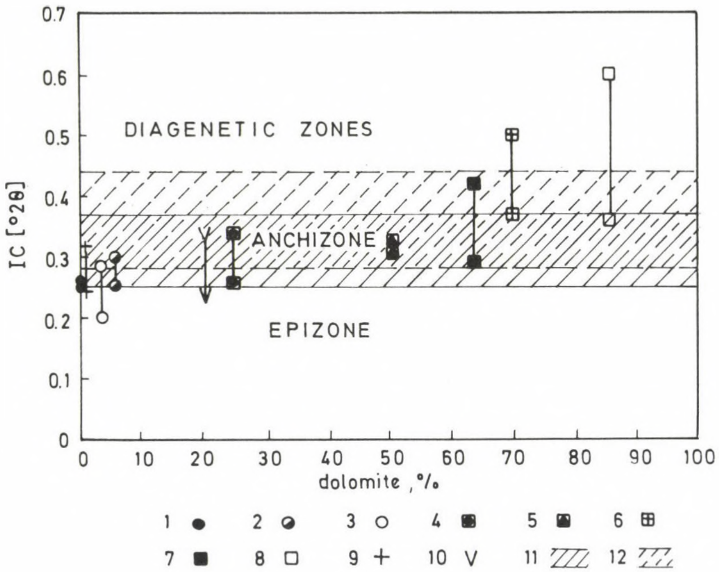

Fig. 5. Correlation between illite "crystallinity" (IC) and dolomite content in different lithotypes. The pairs of symbols tied with straight lines represent whole rock or acid insoluble residue samples (lower values) and <2 μm fraction samples (higher values). For legend 1 to 10 see Fig. 4. 11. interval of the anchizone measured on whole rock and acid insoluble residue samples; 12. Kübler's anchizone calibrated by standards, measured on <2 μm fraction samples

Taking into account the lack of contact, thermic phenomena, the presence of pyroclastic rocks as well as the similar metamorphic grade, post-metamorphic origin of the volcanites can be precluded.

White mica b_0-geobarometry

The white mica (sericite) b_0 values of the Barcs-West area (Fig. 6) are strongly scattering between 8.990 and 9.050 Å, without any well definable maximum. The standard deviation of the average is rather lage (b_0 = = 9.026 ± 0.014 Å. n = 47).

There are certain differences in b_0 among the investigated lithotypes (Table IV). The highest b_0 average (and consequently the highest (Fe^{2+} + Mg) ⟶ Al substitution) was found in the intermediate metavolcanite (9.046 Å). The average b_0 values of the metapelitic, -psammitic rocks are somewhat higher than those of the dolomite marble and cipollino, in accordance with the statement of Geyssant et al. (1973) and contradicting the observations made on the Mesozoic and Paleozoic of the Bükkium (Árkai, 1983).

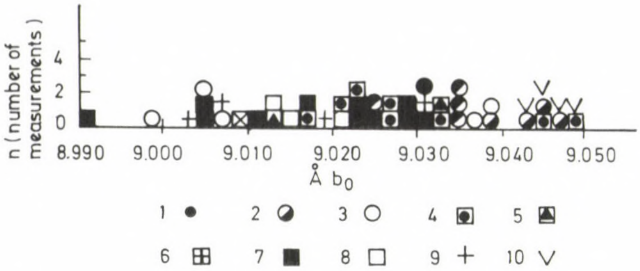

Fig. 6. Distribution of white mica (sericite) b_0 values in different lithotypes. For legend see Fig. 4

Chemical composition and atomic formula of the sericite from a phyllite are listed in Table III/a. Considering the high Fe, Mg, Si and low Al^{IV} contents, the sericite proved to be of phengitic composition.

Chemical compositions of the investigated rocks do not satisfy generally the petrochemical criteria given by Guidotti and Sassi, (1976) for geobarometric purposes. Except one metarhyolite sample all of the other types fall in the muscovite - potash feldspar - albite field of the AKNa diagram. In this field the b_0 values are usually higher than in rocks, the projections of which fall within the tie-lines connecting the muscovite and albite (Guidotti and Sassi, 1976).

The b_0 value of the metarhyolite sample with adequate chemical and mineral composition is 9.018 Å. Similar values were found in phyllite containing quartz, albite, sericite, $<20\%$ dolomite, pyrite and traces of chlorite (9.025 Å), and in mixed rock types containing also albite, more dolomite, but lacking potash feldspar (9.023 $\pm$ 0.008 Å, n = 12). In the albite-free samples, however, the b_0 values are significantly higher.

As the majority of the investigated samples regarding their chemical and mineral compositions are inadequate for b_0-geobarometry, only hypothetic conclusion can be drawn on the pressure character of metamorphism, taking also into account the results of Padan et al. (1982) who extended the b_0-method also to the high-temperature part of the anchizone. Based on the relatively few data of the different (metapelite containing mixed) rock types with mineral assemblage of quartz, albite, sericite, pyrite, moderate amounts of carbonate minerals, medium-pressure regional metamorphism may be presumed (b_0 = 9.018 - 9.025 Å). This assumption, however, needs further evidence, and does not present a basis for compilation about the age of metamorphism.

Problems of the geologic correlation

The anchi-, epizonal sequence explored in the basement of the Barcs-West area is situated in the Tisza Unit (Tisia "microplate") of the Pannonian Basin (Fig. 1). As to the recent plate-tectonic interpretations (Kovács, 1982; Kázmér and Kovács, 1985; Haas, 1987; Balla, 1988) the Tisza Unit originated from the northern (stable European) border of the Tethyan realm, and got into its present position by Meso-Alpine, mostly horizontal block (or "microplate") displacements.

The basement of the Tisza Unit is characterized by Hercynian - pre-Hercynian(?) amphibolite facies polymetamorphic recrystallizations as well as widespread syn- and sporadically late-kinematic Hercynian granitoid magmatism (for a more detailed characterization of the metamorphic evolution see Lelkes-Felvári and Sassi, 1981; Szederkényi, 1984; Árkai, 1984a; Árkai et al., 1985; and for that of the granitoid magmatism see Buda, 1985). This unit may be considered as one of the most consolidated fragments of the Pannonian Basin. In this unit the Late Paleozoic and Mesozoic formations are non-metamorphic. The (mostly presumed) metamorphic effects of the Alpine cycle were restricted to the Hercynian - pre-Hercynian(?) basement, but the effects of the Hercynian and eventual Alpine retrograde (subgreenschist and greenschist facies) alterations have not been separated systematically so far: a detailed mineral paragenetic and isotope geochronologic study of this question is needed.

The anchi-, epizonal sequence of the Barcs-West area represents an exotic body in the Tisza Unit: no similar rocks have been explored in the Hungarian part of the given realm so far. For lack of biostratigraphic data, the first estimation of the primary (sedimentary, magmatic) ages was based solely on supposed lithologic analogies with the NE-Hungarian Paleozoic and/or Mesozoic showing Dinaric affinities. Taking into account the cipollino-like marble and limestone formations in the Szendrő and Uppony Mountains or the Triassic sequence of the Bükk Mountains, Devonian or Triassic primary ages were suggested by Balázs (1980).

The comparison of mineral compositions of the cipollino-like carbonate rocks from the given area and from the NE-Hungarian Paleozoic (the characterization of the latters see in Árkai, 1977 and Árkai et al., 1981) does not support the correlation mentioned by Balázs. The main differences are as follows: dolomitic (ankeritic) character, reductive sedimentary and alteration conditions (pyrite), small amounts of chlorite in the Barcs-West area; calcite, oxidative conditions (hematite), signs of volcanogenic-sedimentary mixed materials, sporadic occurrence of epidote and biotite in the NE-Hungarian Paleozoic.

Surprising similarity has been found between the lithostratigraphic profile of the Barcs-West area and that of the Paleozoic of the Eastern Alps (Árkai, 1984b). According to the summary of Schönlaub (1979) the Upper Ordovician acidic volcanism (quartz porphyry = porphyroid = Blasseneck-porphyroid) was followed by quartz sandstone, quartzite, arkose, phyllite, and already in the Silurain but mostly in the Devonian by carbonatic sequences with intercalations of basic - intermediate volcanism, and locally, with traces of Fe-metasomatism.

In the Yugoslavian part of the Drava Basin (Tisza Unit), in the Molve area 10 oil wells penetrated schistose metasandstone, slates and phyllites. Their basement consists of mica schists and paragneisses (frequently retrograded) as well as granitoids. Neither the age(s) of the metamorphism nor the outcropping equivalents of these rocks are known (Pamić, 1986). They may belong - at least partly - to the Alpine granite - metamorphic complexes. This hypothesis is supported by the newest data (Pamić, 1989, personal communication): farther south of the Molve area, in oil well of the Moslavacka Gora region, very low-grade(?) metasandstones and slates are intercalated with Upper Cretaceous, globotruncana-bearing crystalline limestones. Najdenovski et al. (1983) also reported anchi-, epimetamorphic dolomite, slate and marble from the surroundings of Vinkovci (Yugoslavian part of the Pannonian Basin).

The Central Hungarian (or Igal) Subunit bordering the Tisza Unit to the north is built up by Triassic formations (Bérczi-Makk, 1988), certain parts of which are metamorphic (anchi- and epizonal; Árkai, 1988). Some occurrences of these rocks (e.g. Semjénháza, bore Sem-3, Inke-I, Iharosberény, bore Ib-2, etc.) are very similar to those explored in the Barcs-West area.

Thus, judging from lithologic analogies and tectonic considerations, two hypotheses may be set up for interpreting the geologic evolution:

1. The anchi-, epizonal rocks of the Barcs-West area represent an East Alpine type Paleozoic sequence ranging from the Upper Ordovician up to the Devonian. In this case the most probable age of regional metamorphism might be Hercynian. Of course, an Alpine metamorphic overprint, or - in case of lack of Hercynian metamorphism - an Alpine metamorphic event should not be excluded either.

Table I

Mineral composition of the anchi-, epizonal rocks from the Barcs-West area, Drava Basin (weight per cent)

	number of samples	quartz	plagioclase (albite)	potash feldspar	illite-muscovite	chlorite	kaolinite	smectite	calcite	dolomite (ankerite)	siderite	pyrite	hematite	goethite	anhydrite	baryte	rutile
Barcs-West area																	
dolomite marble (partly brecciated)	4	3 / 1-9	3 / 0-11		5 / 2-11				1 / 0-3	86 / 73-93		tr / 0-2					tr / 0-tr
cipollino-like dolomite marble with phyllite bands	7	12 / 4-19	3 / 0-11	tr / 0-3	15 / 5-21	5 / 0-10		tr / 0-1	tr / 0-tr	64 / 48-82		tr / 0-2					tr / 0-2
albite-rich (metasomatic?) dolomite marble	1	2	31		1					66		tr					
cipollino-like dolomite marble with anhydrite	3	9 / 9-13	3 / 0-7		9 / 4-17	tr / 0-1				51 / 34-75		tr / tr-1			27 / 11-46		tr / tr-1
dolomite marble with metarhyolite tuff	1	7	12		10					70		1					
carbonate phyllite (banded, cipollino-like)	4	23 / 13-39	3 / 0-12		35 / 26-44	8 / 0-19			4 / 0-15	25 / 4-44		1 / tr-3		tr / 0-tr	tr / 0-tr	tr / 0-tr	tr / 0-1
phyllite	1	30			59				3			6					2
phyllite with psammitic bands	3	48 / 42-52			47 / 36-57		tr / 0-tr			3 / 0-5	1 / 0-4		tr / 0-1				tr / 0-tr
metasandstone with phyllitic bands	2	55 / 51-59			32 / 31-33					9 / 3-14		tr / 0-1			3 / 0-7		tr / 0-tr
metasandstone	4	77 / 50-91		1 / 0-3	14 / 7-35				3 / 0-11	4 / 1-12		tr / 0-1	1 / 0-1				tr / 0-1

Table I (cont.)

	number of samples	quartz	plagioclase (albite)	potash feldspar	illite-muscovite	chlorite	kaolinite	smectite	calcite	dolomite (ankerite)	siderite	pyrite	hematite	goethite	anhydrite	baryte	rutile
metarhyolite (quartz porphyroid)	4	61 / 50-86	10 / 1-14	9 / 0-19	18 / 10-33		tr / 0-tr		2 / 0-6	tr / 0-2	tr / 0-1		tr / 0-tr				
metarhyolite tuff	1	42	16	18	20					3			1				
intermediate metavolcanite	3	15 / 10-18	7 / 4-11	10 / 6-16	41 / 28-55		tr / 0-tr			21 / 14-29	1 / 0-4		4 / 3-5				1 / 1-1

average / minimal-maximal values; tr - traces

2. The rocks in question may be correlated to the Alpine anchi-, epizonal metamorphic part of the Mesozoic (Triassic) formations of the Internal Dinarides which can be found also in the Central Hungarian (Igal) Zone, along which the Dinaric type Bükk Subunit was horizontally shifted to NE to its present position, now forming the innermost tectonic unit of the Western Carpathians.

Judging from the wide occurrence of similar rock types (of mostly unknown ages) in the Yugoslavian part of the Tisza Unit, the latter hypothesis seems to be more probable. In order to explain the present, allochtonous position of the Alpine metamorphic sequence within the Tisza Unit (Tisia "microplate") which was relatively stable during the Alpine tectogenesis, we have to count with large-scale tectonic movements in the Meso-Alpine phases. The style of these movements, however, is unknown. Overthrusts and large-scale (100 km and even more) nappe movements, or fragmentation of the Tisia "microplate" by faults with horizontal displacements, or the combination of the two effects mentioned above seem to be reliable explanations.

Aiming to determine the ages of sedimentation, volcanism and regional metamorphism, detailed K-Ar and Rb-Sr isotope geochronologic studies were carried out. The second part of the paper summarizes these results and their interpretation.

Acknowledgements

The author is indebted to B. Bardócz, director and Chef Geologist, to I. Tormássy, Head of Department and L. Mészáros, Head of Section (Oil and Gas Mining Enterprise, Nagykanizsa) for initiating and supporting the metamorphic petrological research, for making available the geological documentation, the core materials, as well as for the permission of publication. The present work also forms a part of the author's metamorphic petrological research program sponsored by the Hungarian National Research Fund (OTKA), Project No. 284/1987-1991.

Table II

Chemical composition of the anchi-, epizonal rocks (Barcs-West area, Drava Basin) in weight per cent (analysed by Lefler, J.)

	1	2	3	4	5	6	7
SiO_2	49.15	66.66	64.11	48.50	74.45	72.94	76.46
TiO_2	1.26	0.37	0.39	1.19	0.00	0.00	0.00
Al_2O_3	16.91	12.29	15.10	17.81	13.85	14.52	10.21
Fe_2O_3	4.91	2.85	3.31	10.93	0.95	1.08	0.50
FeO	3.55	0.63	1.02	0.46	0.27	0.28	0.45
MgO	2.01	3.07	1.10	1.58	1.19	0.59	0.49
MnO	0.01	0.02	0.01	0.02	0.01	0.01	0.02
CaO	3.76	3.57	0.95	2.95	0.84	0.44	0.51
Na_2O	0.71	0.10	0.01	1.77	1.53	1.32	1.63
K_2O	7.28	3.91	6.68	6.94	3.31	6.74	6.76
$+H_2O$	2.25	0.91	0.93	1.22	1.69	1.07	0.73
$-H_2O$	0.06	0.04	0.08	0.06	0.08	0.12	0.10
CO_2	6.94	4.44	3.61	5.42	0.66	0.09	1.16
P_2O_5	0.42	0.12	0.17	0.36	0.16	0.11	0.09
Total	99.22	98.98	99.0*	99.21	98.99	99.31	99.11

1) cipollino-like carbonate phyllite with dolomite bands (Barcs-Ny-3. 10. 3/7.); 2) phyllite with metasilty bands (Barcs-Ny-2. 8. 9.); 3.) phyllite with metasandstone bands (Barcs-Ny-2. 6. 8.); 4) intermediate metavolcanite (Barcs-Ny-3. 10. 4/15); 5) metarhyolite (Barcs-Ny-2. 11.1.); 6) metarhyolite (Barcs-Ny-3. 11. 1/11.); 7) metarhyolite tuff (Barcs-Ny-1. 15. 2/4)

*+ 1.04% S^{2-}, 0.45% SO_3

Table III/a

Electron microprobe analyses of dolomite-ankerite from phyllite with metasilty bands

(Barcs-Ny-2.8.) Analysed by Nagy, G. and Dobosi, G.

	Fe-poor parts			Fe-rich parts	
	a)	b)	c)	a)	b)
Al_2O_3	0.02	0.04	0.05	0.04	0.06
FeO^*	7.51	7.25	7.07	8.70	8.96
MgO	16.13	16.52	16.62	15.48	15.24
MnO	0.31	0.37	0.20	0.48	0.56
CaO	27.48	27.43	27.53	27.52	27.11
Total:	51.45	51.61	51.47	52.22	51.93
	numbers of cations on the basis of 6 (O)				
Al	0.001	0.002	0.002	0.002	0.003
Fe^{2+}	0.209	0.200	0.196	0.241	0.250
Mg	0.799	0.812	0.819	0.764	0.758
Mn	0.009	0.010	0.020	0.013	0.016
Ca	0.978	0.970	0.975	0.976	0.969
Total:	1.996	1.994	2.012	1.996	1.996

*Total Fe calculated as FeO and Fe^{2+}, respectively

Table III/b

Electron microprobe analyses of sericite from phyllite with metasilty bands (Barcs-Ny-2.8.)

	1	2	3	4	5	12	average	standard deviation
SiO_2	48.44	48.48	48.64	48.65	48.19	48.08	48.41	0.23
TiO_2	0.56	0.54	0.72	0.60	0.76	0.63	0.64	0.09
Al_2O_3	25.98	26.52	25.72	27.02	25.85	25.65	26.12	0.54
*FeO	5.06	5.40	5.39	5.18	5.66	5.26	5.33	0.21
MnO	0.02	0.02	0.02	0.01	0.02	0.04	0.02	0.01
MgO	2.51	2.58	2.70	2.35	2.56	2.56	2.54	0.11
CaO	-	0.02	0.01	0.01	0.01	0.19	0.04	0.05
Na_2O	0.07	0.08	0.08	0.06	0.06	0.06	0.07	0.01
K_2O	11.06	11.09	11.14	11.08	11.07	11.17	11.10	0.04
total:	93.70	94.71	94.42	94.97	94.19	93.58	94.26	0.55
				numbers of cations on the basis of 22 (O)				
Si^{IV}	6.712	6.658	6.706	6.650	6.672	6.694	6.682	0.026
Al^{VI}	1.288	1.342	1.297	1.350	1.328	1.306	1.318	0.026
Al	2.955	2.950	2.885	3.002	2.889	2.903	2.931	0.046
Ti	0.058	0.056	0.075	0.062	0.079	0.066	0.066	0.009
*Fe^{2+}	0.586	0.620	0.622	0.592	0.656	0.612	0.615	0.025
Mn	0.002	0.002	0.002	0.001	0.002	0.004	0.002	0.001
Mg	0.518	0.528	0.554	0.479	0.528	0.530	0.523	0.025
Ca	0.001	0.002	0.001	0.002	0.002	0.020	0.005	0.008
Na	0.020	0.020	0.021	0.022	0.015	0.017	0.019	0.003
K	1.955	1.943	1.959	1.932	1.955	1.984	1.955	0.017
total:	14.095	14.121	14.119	14.092	14.126	14.136	14.115	0.018

*total Fe calculated as FeO and Fe^{2+}, respectively

Table IV

Metamorphic grade indicating parameters of the illite-muscovite group

Rock type	whole rock, and insoluble residue samples*			<2 µm Ø fractions**	
	IC (°2 θ)		b_o (Å)	IC (°2 θ)	
	2°/min	1/2°/min		2°/min	1/2°/min
dolomite marble (partly brecciated)	0.354 (4)	0.213 (3)	9.015 (3)	0.599 (2)	0.560 (2)
cipollino-like dolomite marble with phyllite bands	0.289 (0.111 12)	0.180 (0.097 10)	9.019 (0.012 11)	0.418 (0.118 6)	0.348 (0.134 6)
cipollino-like dolomite marble with anhydrite	0.309 (2)	0.237 (2)	9.024 (2)	0.317 (1)	0.207 (1)
dolomite marble with metarhyolite tuff	0.368 (1)	0.323 (1)	9.008 (1)	0.501 (1)	0.392 (1)
carbonate phyllite (banded, cipollino-like)	0.257 (0.030 8)	0.190 (0.050 8)	9.030 (0.011 8)	0.341 (4)	0.286 (4)
phyllite	0.259 (1)	0.196 (1)	9.031 (1)	0.257 (1)	-
psammitic phyllite and phyllitic metasandstone (banded)	0.255 (0.027 8)	0.172 (0.023 8)	9.038 (0.007 8)	0.298 (4)	0.238 (4)
metasandstone	0.203 (4)	0.098 (4)	9.021 (0.017 5)	0.285 (4)	0.186 (4)
metarhyolite and tuff	0.247 (0.030 5)	0.200 (3)	9.017 (4)	0.319 (0.033 5)	0.286 (0.045 5)
intermediate meta-volcanite	0.242 (4)	0.177 (4)	9.046 (4)	0.330 (3)	0.280 (3)

diagenetic zones	whole rock, insolubl. res.*		2 µm Ø fractions**			
	2°/min	1/2°/min	2°/min		1/2°/min	
diagenetic zones	0.37	0.28	0.34	0.44^K	0.30	0.25^K
anchizone	0.25-0.37	0.19-0.28	0.25-0.34	0.28^K-0.44^K	0.20-0.30	0.25^K-0.42^K
epizone	0.25	0.19	0.25	0.28^K	0.20	0.25^K

IC-boundaries of the of the NE-Hungarian Paleo-Mesozoic based on mineral parageneses of intercalated metavolcanites, vitrinite reflectance and texture

K = Kübler's anchizone boundaries calibrated by standards

* unoriented powder preparations

** sedimentated, thin layer, highly oriented preparations

average / (standard deviation number of measurements)   average / (number of measurements)

Plate I

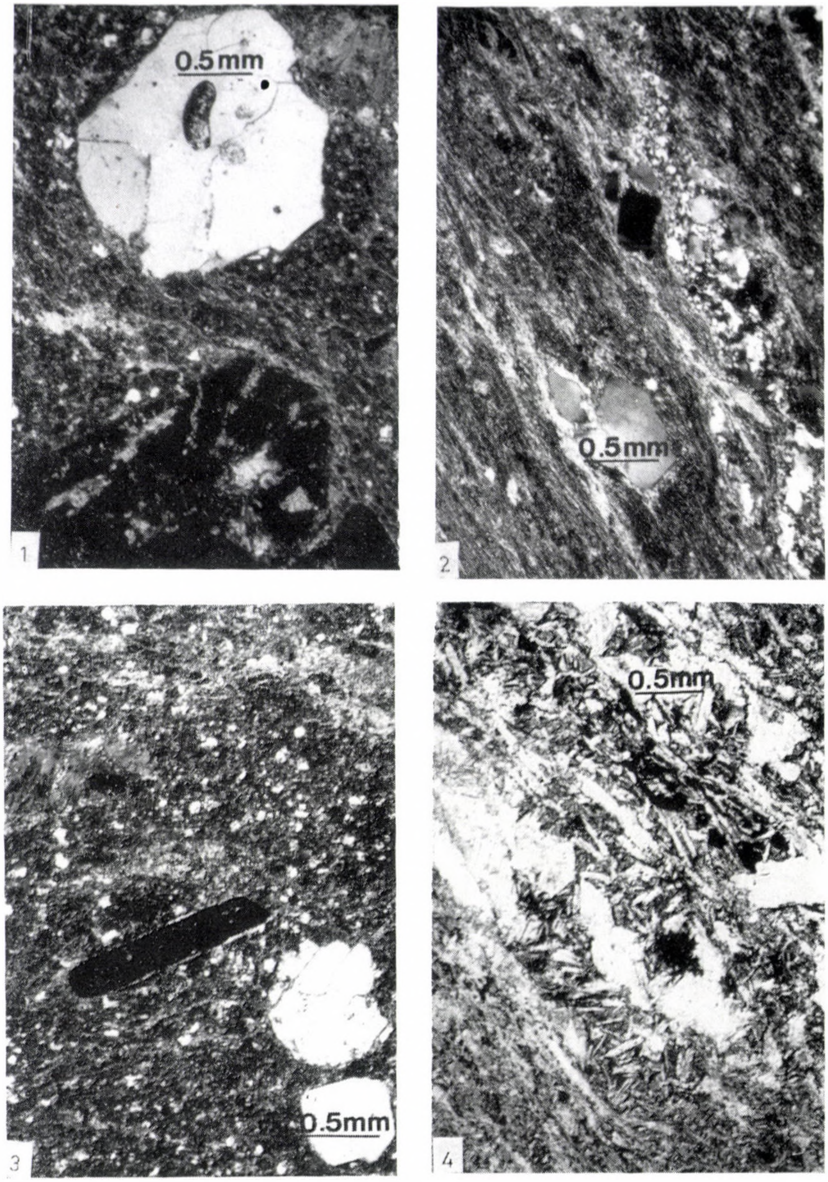

Plate II

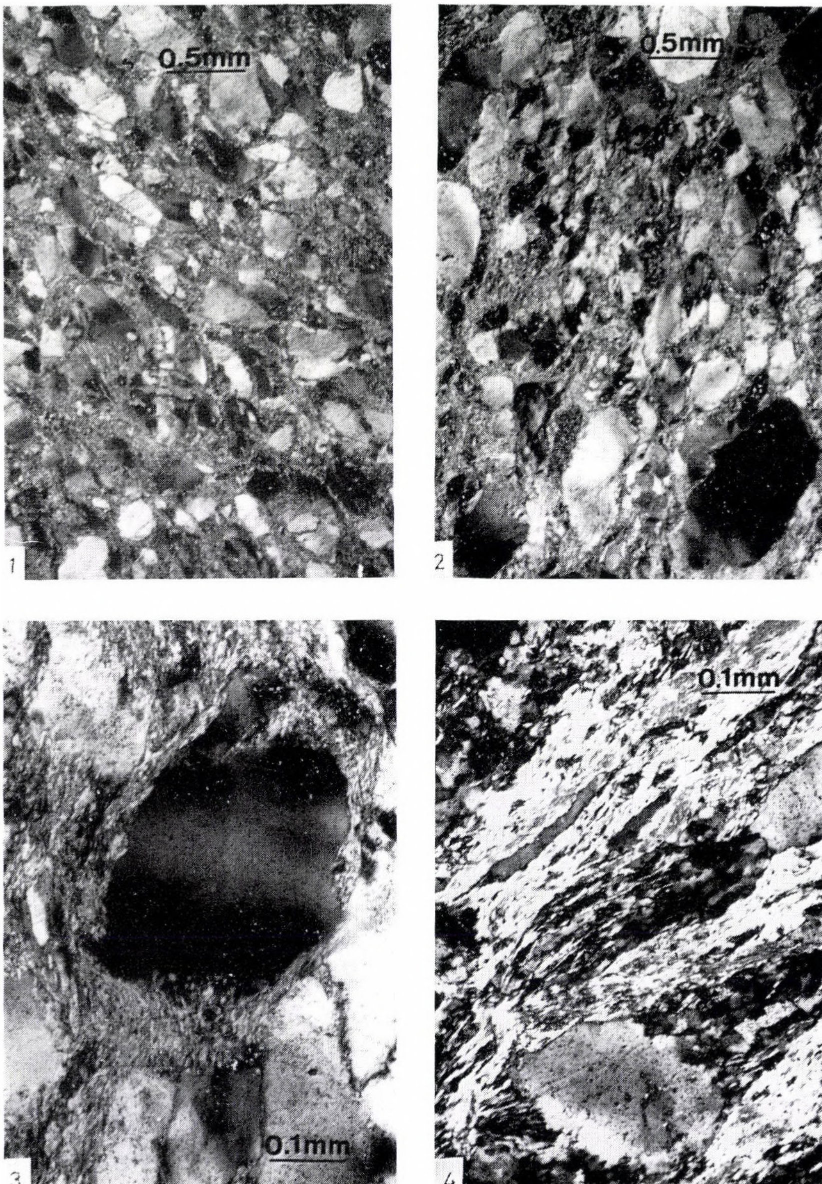

Plate III

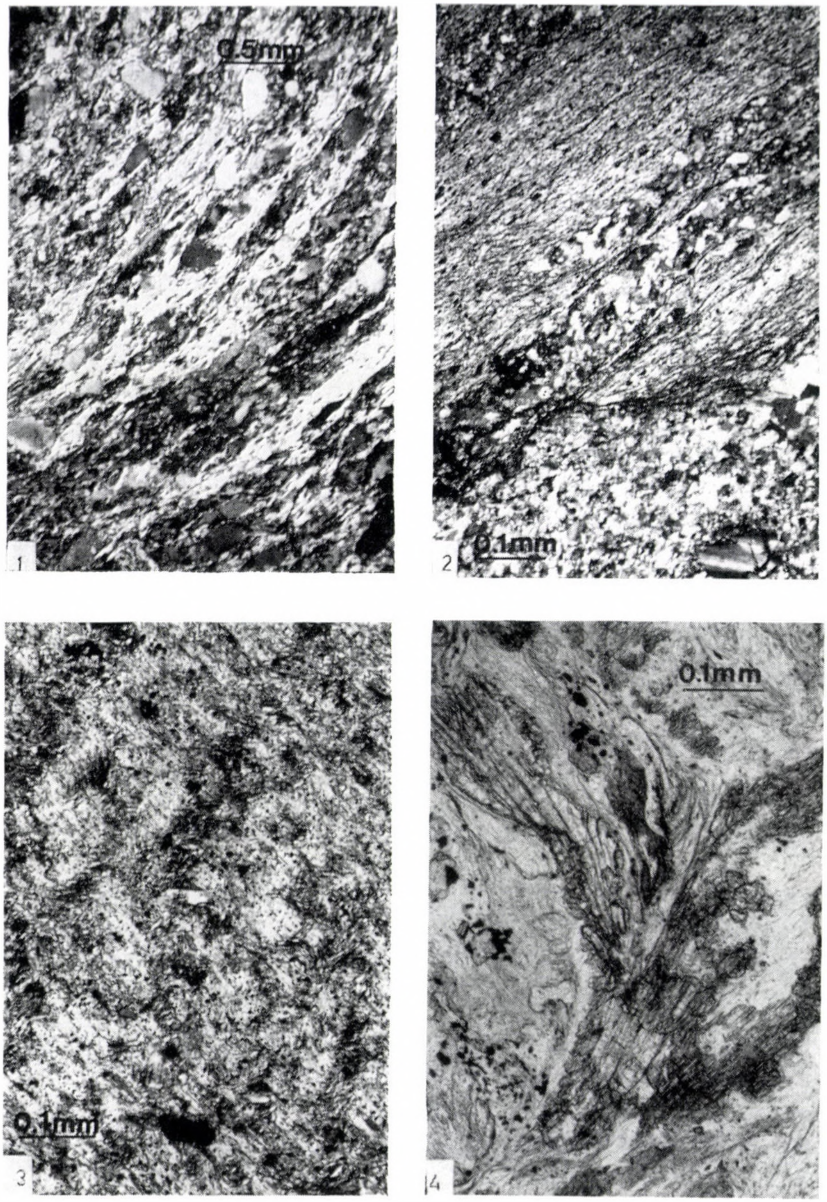

Plate IV

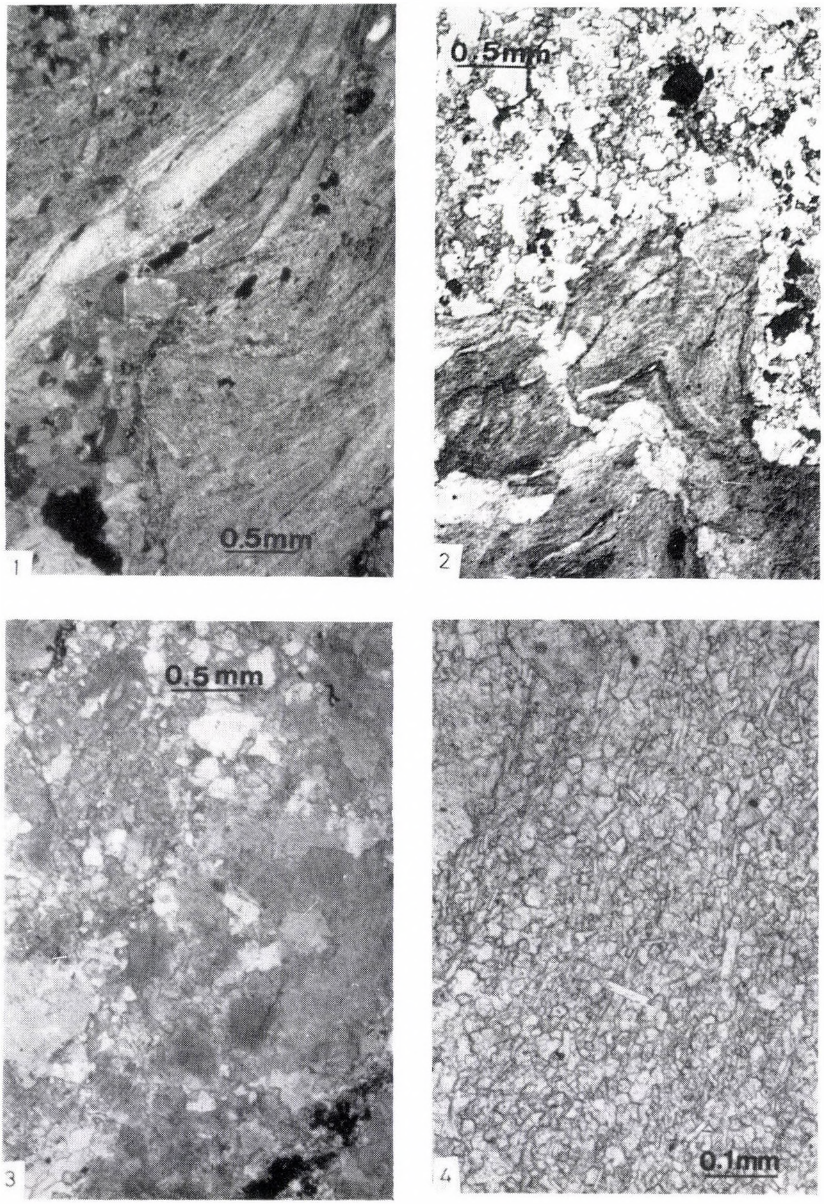

Plate I

1. Resorbed quartz and albitized potash feldspar (black) blastoporphyrs in metarhyolite. Sample Barcs-Ny-3.11. (1/3). + nicols
2. Metarhyolite tuff with fractured quartz blastoporphyr and foliated, recrystallized, sericitic groundmass. Sample Barcs-Ny-1. 15. (2/4). + nicols
3. Opaque (hematitic) pseudomorph after biotite (centre), albitized potash feldspar (top, left) and quartz (bottom, right) blastoporphyrs in metarhyolite. Sample Barcs-Ny-3. 11. (1/3). + nicols
4. Intermediate(?) metavolcanite with alibitzed feldspar laths and carbonatic lenses in the groundmass. Sample Barcs-Ny-3. 10. (6/3). 1 nicol

Plate II

1. Metasandstone with quartz grains in the sericitic groundmass. Sample Barcs-Ny-1. 13. + nicols
2. Metasandstone with quartzitic texture. Sample Barcs-Ny-1. 11. (1/12). + nicols
3. Quartz-sericitic overgrowth parallel with the foliation plain around detritic quartz grain in metasandstone. Sample Barcs-Ny-1. 11. (1/12). + nicols
4. Recrystallized, foliated matrix with sericite and quartz bands in metasandstone. Sample Barcs-Ny-2. 8. (2). + nicols

Plate III

1. Dolomitic metasandstone with sericite-rich, foliated matrix. Sample Barcs-Ny-2. 8. (2). + nicols
2. Phyllite with dolomitic bands: authigenic quartz, albite, and pyrite aggregates in the phyllitic part. Sample Barcs-Ny-2. 6. (5). + nicols
3. Phyllite with crenulation. Sample Barcs-Ny-2. 8. (4) + nicols
4. Tremolite aggregate in dolomitic phyllite. Sample Barcs-Ny-2. 7. (8). 1 nicol

Plate IV

1. Dolomite marble with phyllitic (sericitic) bands. Sample Barcs-Ny-1. 6. + nicols
2. Microfolded phyllitic band (lower part) in dolomite marble. Sample Barcs-Ny-2. 6. (5). 1 nicol
3. Dolomite marble. Sample Barcs-Ny-1. 4. 1 nicol
4. Texture of the dolomite marble sample with sericite and dolomite grains. Barcs-Ny-2. 7. (10). 1 nicol

REFERENCES

Árkai, P. (1977): Low-grade metamorphism of Paleozoic formations of the Szendrő Mountains, Northeast Hungary. Acta Geol. Acad. Sci. Hung., **17**, 67-83.

Árkai, P. (1983): Very low- and low-grade Alpine regional metamorphism of the Paleozoic and Mesozoic formations of the Bükkium, NE-Hungary. Acta Geol. Hung., **26**, 83-101.

Árkai, P. (1984a): Polymetamorphism of the crystalline basement of the Somogy-Dráva Basin (Southwestern Transdanubia, Hungary). Acta Miner. Petr., Szeged, **26**, 129-153.

Árkai, P. (1984b): Research report on the mineralogic-petrographic and geochemical investigations of the metamorphic basement in the Barcs-West area. Oil and Gas Mining Enterprise, Nagykanizsa (in Hungarian).

Árkai, P. (1987): New data on the petrogenesis of metamorphic rocks along the Balaton Lineament, Transdanubia, W-Hungary. Acta Geol. Hung., **30**, 319-338.

Árkai, P. (1988): Research report on the mineralogic-petrographic and geochemical investigations of the basement rocks in the Central Hungarian (Igal) Unit. Oil and Gas Mining Enterprise, Nagykanizsa (in Hungarian).

Árkai, P., Z.A. Horváth, M. Tóth (1981): Transitional very low- and low-grade regional metamorphism of the Paleozoic formations, Uppony Mountains, NE-Hungary: mineral assemblages, illite crystallinity, $-b_o$ and vitrinite reflectance data. Acta Geol. Acad. Sci. Hung., **24**, 265-294.

Árkai, P., G. Nagy, G. Dobosi (1985): Polymetamorphic evolution of the South-Hungarian crystalline basement, Pannonian Basin: geothermometric and geobarometric data. Acta Geol. Hung., **28**, 165-190.

Balázs, E. (1980): Report on the investigations of core samples from bore Barcs-Ny-1. Oil and Gas Industrial Trust, Budapest (in Hungarian).

Balla, Z. (1988): On the origin of the structural pattern of Hungary. Acta Geol. Hung., **31**, 53-63.

Bardócz, B. (1973-1986): Tectonic and geological map of the basement of the Transdanubian Neogene basins. Manuscript, Nagykanizsa.

Bárdossy, Gy. (1966): X-ray diffractometric investigation of the mineral composition of bauxite. Koh. Lapok, **8**, 355-363 (in Hungarian).

Bérczi-Makk, A. (1988): Re-investigation of Mesozoic formations of Transdanubia located south of the Balaton Line. Report of the Hydrocarbon Research Institute, Százhalombatta (in Hungarian).

Buda, Gy. (1985): The genesis of the Variscan collision type granitoids on the examples of Hungary, the Western Carpathians and the Central Bohemian Massif. C. Sc. Thesis, Budapest (in Hungarian).

Ferry, J. (1984): A biotite isograd in South-Central Maine, U.S.A.: mineral reactions, fluid transfer, and heat transfer. J. Petrol., **25**, 871-893.

Frey, M., M. Teichmüller et al. (1980): Very low-grade metamorphism in the external parts of the Central Alps: illite crystallinity, vitrinite reflectance and fluid inclusion data. Eclogae geol. Helv., **73**, 173-203.

Guidotti, C.V., F.P. Sassi (1976): Muscovite as a petrogenetic indicator mineral in pelitic schists. N. Jb. Mineral., Abh., **127**, 97-142.

Guidotti, C.V., F.P. Sassi (1986): Classification and correlation of metamorphic facies series by means of muscovite b_o data from low-grade metapelites. N. Jb. Mineral., Abh., **153**, 363-380.

Haas, J. (1987): Position of the Transdanubian Central Range structural unit in the Alpine evolution phase. Acta Geol. Hung., **30**, 243-256.

Kázmér, M., Kovács, S. (1985): Permian-Paleogene paleogeography along the eastern part of the Insubric - Periadriatic Lineament system: evidence for continental escape of the Bakony - Drauzug Unit. Acta Geol. Hung., **28**, 71-84.

Kisch, H.J. (1974): Anthracite and meta-anthracite coal ranks associated with "anchimetamorphism" and "very low-stage metamorphism", I-III. Proc. k. nederl. Akad. Wetensch. (B), **77**, 81-118.

Kovács, S. (1982): Problems of the "Pannonian Massif" and the plate tectonic concept. Geol. Rundschau, **71**, 617-639.

Kovács, S. (1984): The Tisia problem and the plate tectonics - critical analysis based on the distribution of the Early Mesozoic facies zones. Földt. Kut., **27**, 1, 55-72 (in Hungarian).

Kübler, B. (1968): Evaluation quantitative du metamorphisme par la cristallinite de l'illite. Bull. Centre Rech. Pau - S.N.P.A., **2**, 385-397.

Kübler, B. (1975): Diagenese - anchimetamorphisme et metamorphisme. Inst. national de la recherche sci. Petrole, Quebec.

Kübler, B., J.-L. Pittion et al. (1979): Sur le pouvoir reflecteur de la vitrinite dans quelques roches du Jura, de la Molasse et des Nappes prealpines, helvetiques et penniques (Suisse occidentale et Haute-Savoie). Eclogae geol. Helv., **72**, 347-373.

Lelkes-Felvári, Gy., F.P. Sassi et al. (1981): Outlines of the pre-Alpine metamorphism in Hungary. IGCP Project No. 5 Newsletter, **3**, 89-99.

Najdenovski, J. et al. (1983). A review on the geological relations of Variscides in the Southeastern part of the pannonian Basin. IGCP No. 5 Newsletter, **5**, 108-117.

Náray-Szabó, I., E. Péter (1967): Die quantitative Phasenanalyse in der Tonmineralforschung. Acta Geol. Acad. Sci. Hung., **11**, 347-356.

Padan, A., H.J. Kisch, R. Shagam (1982): Use of the lattice parameter b_o of the dioctahedral illite/muscovite for the characterization of P/T gradients of incipient metamorphism. Contrib. Mineral. Petrol., **79**, 85-95.

Pamić, J. (1986): Metamorfiti temeljnog gorja Panonskog bazena u Savsko-Dravskom medurjecju na osnovi podataka naftnih busotina. XI. kongres geologa Jugosl., **2**, 259-272, Tara.

Rischák, G., I. Viczián (1974): Mineralogical factors determining the reflexion intensities of clay minerals. Földt. Int. Évi Jel. in 1972, 229-256.

Sassi, F.P. (1972): The geologic and petrologic significance of the b_o value of potassic white micas in low-grade metamorphic rocks. Tschermaks' Miner. Petr. Mitt., **18**, 105-113.

Schönlaub, H.P. (1979): Das Paläozoikum in Österreich. Abh. der Geologischen Bundesanstalt, **33**, 1-125.

Suk, M. (1983): Petrology of metamorphic rocks. Academia, Praha.

Szederkényi, T. (1984): The crystalline basement of the Great Plain and its geologic connections. D. Sc. Thesis, Szeged (in Hungarian).

Teichmüller, M., R. Teichmüller, K. Weber (1979): Inkohlung und Illit-Kristallinität vergleichende Untersuchungen im Mesozoikum und Paläozoikum von Westfalen, Fortschr. Geol. Rheinl. u. Westf., **27**, 201-276.

Winkler, H.G.F. (1979): Petrogenesis of metamorphic rocks. 5th edition. Springer, New York, Heidelberg, Berlin.

Weber, K. (1972): Kristallinität des Illits in Tonschiefern und andere Kriterien schwacher Metamorphose im nordöstlichen Rheinischen Schiefergebirge. N. Jb. Geol. Paläont., Abh., **141**, 333-363.

Wolf, M. (1972): Beziehungen zwischen Inkohlung und Geotektonik im nördlichen Rheinischen Schiefergebirge. N. Jb. Geol. Paläont., Abh., **141**, 222-257.

Acta Geologica Hungarica, Vol. 33/1-4, pp. 69-78 (1990)

VERY LOW- AND LOW-GRADE METAMORPHIC ROCKS IN THE PRE-TERTIARY BASEMENT OF THE DRAVA BASIN, SW-HUNGARY, II: K-Ar AND Rb-Sr ISOTOPE GEOCHRONOLOGIC DATA

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K-Ar and Rb-Sr isotope geochronologic studies of a very low-grade (anchi-, epizonal) sequence and the underlaying medium-grade basement explored by boreholes were carried out. The detailed lithologic and metamorphic petrological characterization as well as the problems of the geologic correlation of the sequence is given by Árkai (1990), in this volume.

The Rb-Sr whole rock model age of mica schist indicates Early Hercynian or Late Caledonian medium-grade, medium thermal gradient event, in accordance with the earlier petrologic deductions (Árkai et al., 1985). In the medium-grade basement rocks only minor thermal effects and/or partial restructuration of younger (Alpine) age could be demonstrated by Rb-Sr and K-Ar data of different mineral fractions.

In the overlaying anchi-, epizonal sequence the primary (magmatic, sedimentary) ages proved to be Mesozoic (most probably Triassic), based on a poorly defined whole rock Rb-Sr isochron of metarhyolite and other Rb-Sr model age values. Thus, out of the different possibilities of geologic correlation (see Árkai, 1990), Inner Dinaric type Mesozoic (Triassic) origin of the anchi-, epizonal volcanogenic and sedimentary sequence seems to be the most probable. The majority of the Rb-Sr model ages of the 2 μm grain size sericite-rich fractions indicate Eo-Alpine (Cretaceous) very low-grade regional metamorphism, while K-Ar data of the same fractions give the age of the last (Meso-Alpine, cca 30 Ma) tectonic-thermal event corresponding to the end of the large-scale horizontal displacements of blocks ("microplates"). The youngest thermal effect caused by the sinking of the basement in the Pliocene might reduce the =2 μm sericite K-Ar ages not more than by 20 per cent.

Keywords: Isotope geochronology, K-Ar dating, Rb-Sr dating, illite-muscovite, anchizone, epizone, low-temperature metamorphism, Alpine metamorphism, Hungary.

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Received: 09/04/90

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Introduction

A low-temperature (anchi-, epizonal) regional metamorphic sequence was penetrated by hydrocarbon exploratory bores in a relatively small part of the pre-Tertiary basement of the Neogene Drava Basin (SW-Transdanubia, Hungary). The geologic, tectonic, lithologic and metamorphic petrological characterization of this sequence has been given in the first part of this paper, in this volume (Árkai, 1990).

No direct geochronologic (biostratigraphic or radiometric) data exist on the ages of sedimentation, volcanism and regional metamorphism. According to the opinion of the present authors, presumed or evidenced lithologic analogies should not be used or accepted as proofs for geologic age determination. This is why K-Ar and Rb-Sr isotope geochronologic investigations were carried out on whole rock and different mineral and grain size fraction samples formerly characterized by metamorphic petrological methods in order to get information about the age relationships of the different geologic events affected the anchi-, epizonal sequence.

Methods

Both the K-Ar and Rb-Sr isotopic measurements were carried out in the Institute of Nuclear Research of the Hungarian Academy of Sciences, Debrecen.

For K-Ar dating the samples were degassed by high frequency induction heating. Argon was cleaned with the usual method applying zeolite, cold traps and furnaces with Ti sponge and CuO. ^{38}Ar was introduced with a gas pipette. A magnetic mass spectrometer of 150 mm radius and 90^{0} deflection was used in static regime for Ar isotopic ratio measurement. Prior to K determination the samples were digested by HF + H_2SO_4 + $HClO_4$ acids and dissolved thereafter in HCl. Na buffer and Li internal standards were added and K content was measured with a flame emission photometer of OE-85 type produced by OMSZÖV, Hungary. Interlaboratory standards of Asia 1/63 (Soviet) and GL-0 were used for control and calibration of Ar and K determinations. Construction and parameters of instruments as well as the applied methods have been described in detail by Balogh (1985). Results of investigation on interlaboratory standards have been published by Odin et al. (1982), too.

The concentrations of ^{87}Rb and ^{86}Sr as well as the $^{87}Sr/^{86}Sr$ isotopic ratios were measured with the help of a computerized MI 1309 type mass spectrometer. For the determination of ^{87}Rb and ^{86}Sr concentrations the stable isotope dilution method was used. The samples were digested by a mixture of cc. HNO_3 and HF, and afterwards dissolved by HCl. Strontium was separated from the acidic solution in cation exchange columns filled with Dowex-50 synthetic resin. Corresponding to the international practice, results were corrected by normalizing the measurements to the isotopic ratio $^{86}Sr/^{88}Sr = 0.1194$. The analytical error of the measurements in case of isotopic concentrations proved to be about 1.5 - 2.0%, and in the case of $^{87}Sr/^{86}Sr$ isotopic ratios about 0.5% ^{87}Rb decay constant of 1.42×10^{-11} $year^{-1}$ was used for calculating the age values.

The methods and preparative techniques applied for the metamorphic petrological characterization and for separation of different fractions can be found in the work of Árkai (1990).

The problems of interpretation of K-Ar and Rb-Sr age data determined on low-temperature terrains were reviewed by Hunziker (1987), Hunziker et al. (1986). The first results on Hungarian very low-grade basement rocks were summarized by Árkai and Balogh (1989).

Results

The investigated samples, their depth intervals, rock types, types of the samples (whole rock, mineral or grain size fractions), the analytical results as well as the calculated age values are listed in Table I.

Measurements were carried out on the medium-grade basement rocks of presumed Hercynian - pre-Hercynian age and from the anchi-, epizonal sequence of unknown age in order to compare the geologic history of the two units. In case of the anchi-, epizonal sequence, different (volcanic, sedimentary) rock types and their $<2\ \mu m$ grain size, sericite-rich fractions were investigated aiming to get data on the ages of sedimentation, volcanism and regional metamorphism as well.

Discussion

Evaluating the Rb-Sr and K-Ar data obtained on whole rock and different fraction samples it can be concluded that

(i) there is large scattering in age values both in case of the medium-grade basement rocks and in the anchi-, epizonal sequence suggesting that isotopic equilibria had not been reached and/or have been disturbed during and/or after the regional metamorphism, and

(ii) there are significant differences in age values between the above-mentioned two groups indicating that the two units had different metamorphic and cooling history.

Considering also the error limits, the Rb-Sr whole rock model age of the mica schist (sample Barcs-Ny-3. 12 (1/5-1/7) may correspond to the Early Hercynian (Bretonian) or Late Caledonian (Taconian) tectonophases. This age value is in agreement with the geologic interpretation of the given basement complex, presuming polyphase Hercynian or polymetamorphic Caledono-Hercynian metamorphic evolution. Applying the plagioclase - biotite - garnet - muscovite thermobarometer of Ghent and Stout (1981) 543 ^{o}C and 9.0 kbar were obtained for the garnetiferous biotite-muscovite schist (sample Barcs-Ny-5.3). These P-T values indicate that in this part of the basement the equilibrium of the older ("Barrovian" type) mineral assemblage of medium thermal gradient was not destroyed by the younger, Hercynian, low-pressure type event. The given age agrees with the ages clustering around 335 Ma and obtained by Kovách et al. (1985a) for other parts of the South-Hungarian crystalline basement.

The ages determined by K-Ar and Rb-Sr methods on phyllosilicate (muscovite + chlorite and $<2\,\mu m$ sericite) as well as on partly albitized and sericitized plagioclase fractions vary between 207 and 276 Ma. Thus, in addition to the Hercynian regional metamorphism, younger (Alpine) minor thermal effects and/or partial restructuration should be taken into account, because even the 276+11 Ma (Lower Permian) is too young for indicating the possible time of cooling. (In the southern part of Transdanubia, around the Mecsek Mountains, a new, post-orogenic sedimentary cycle begun presumably in the Upper Carboniferous, surely in the Lower Permian.) The intensity (temperature, duration) of the younger effect might be low, as it did not cause the complete redistribution of the isotopic systems. Partial resetting of the K-Ar system in the muscovite fraction can be proved when comparing its age (276±11 Ma) to those given by Balogh et al. (1983), Árva-Sós and Balogh (1979) as well as Árva-Sós et al.(1987) on the granitoids and medium-grade basement rocks of the surrounding areas (350-318 Ma in the Mecsek Mts., 310-288 Ma in the Görcsöny Horst). In the Görcsöny Horst area a metamorphic evolution and cooling

Table I

Isotope geochronological (K-Ar and preliminary Rb-Sr) data of the metamorphic rocks

Sample	Depth, m	Rock type	Fraction	K, weight %	^{40}Ar/rad/, ccSTP/g	^{40}Ar/rad/, rel %	Age, Ma*	Fraction	$^{87}Sr/^{86}Sr$	^{86}Sr, ppm	^{87}Rb, ppm	$^{87}Rb/^{86}Sr$/at	Model age $^{1.42}_{0.708}$ T, Ma
Barcs-Ny-3.12.(1/5-1/7)	4198 - 4200	plagioclase-bearing (biotite)-muscovite schist						whole rock	0.7333±0.0034	8.92	41.43	4.59±0.05	387±52
Barcs-Ny-3.12.(1/5-1/7)	4198 - 4200	(with partial albitization of plagioclase and perfect chloritization of biotite)						2 μm: sericite	0.7236±0.0029	12.25	59.89	4.95±0.05	222±41
Barcs-Ny-3.12.(1/5-1/7)	4198 - 4200		muscovite+chlorite	4.466	5.173×10^{-5}	91	276±11						
Barcs-Ny-3.12.(1/5-1/7)	4198 - 4200		plagioclase (partly albitized)	1.085	9.2703×10^{-6}	88	207.6±8						
Barcs-Ny-2.11.(1)	4099 - 4100	metarhyolite						whole rock	0.7294±0.0040	9.30	97.65	10.38±0.10	145±27
Barcs-Ny-2.11.(1)	4099 - 4100	metarhyolite	muscovite (sericite)	5.580	8.989×10^{-5}	87	41.0±1.6						
Barcs-Ny-2.11.(1)	4099 - 4100	metarhyolite	albitized kalifeldspar	1.569	5.2109×10^{-6}	85	83.5±3.2						
Barcs-Ny-2.11.(1)	4099 - 4100	metarhyolite	<2 μm: sericite	6.395	7.1945×10^{-6}	56	28.8±1.2	<2 μm: sericite	0.7596±0.0004	4.3	119.80		122±15
Barcs-Ny-3.11.(1/3)	3989 - 3990	metarhyolite						whole rock	0.7383±0.0030	7.27	82.70	11.25±0.10	189±23
Barcs-Ny-3.11.(1/3)	3989 - 3990	metarhyolite	<2 μm: sericite	7.535	5.187×10^{-6}	70	17.64±0.7						
Barcs-Ny-3.11.(1/11)	3989 - 3990	metarhyolite	whole rock	6.080	6.242×10^{-6}	81	26.3±1.0	whole rock	0.7828±0.0040	3.32	91.28	27.19±0.30	193±11
Barcs-Ny-6.2.(1)	3925 - 3933.5	metarhyolite	<2 μm: sericite	6.993	5.106×10^{-6}	49	18.7±0.8						
Barcs-Ny-3.10.(3/7)	3912 - 3919	intermediate metavolcanite						whole rock	0.7201±0.0035	7.23	64.63	8.83±0.09	96±28
Barcs-Ny-3.10.(4/15)	3912 - 3919	intermediate metavolcanite	<2 μm: sericite	7.558	8.676×10^{-6}	67	29.3±1.1	<2 μm: sericite	0.7182±0.0030	6.04	59.27	9.70±0.10	74±22
Barcs-Ny-3-10.(4/15)	3912 - 3919	intermediate metavolcanite	<2 μm: sericite	6.739	6.9734×10^{-6}	59	26.4±1.1	<2 μm: sericite	0.7193±0.0035	9.24	79.55	8.51±0.09	93±27
Barcs-Ny-3.10.(1/5)	3912 - 3919	dolomitic metasandstone						<2 μm: sericite	0.7234±0.0034	19.24	105.15	5.40±0.05	200±44
Barcs-Ny-2.6.(3)	3898 - 3905	phyllite (psammitic)						<2 μm: sericite	0.7155±0.0040	18.17	72.72	3.97±0.04	132±70
Barcs-Ny-2.6.(5)	3898 - 3905	phyllite (psammitic)	<2 μm: sericite	6.960	7.1716×10^{-6}	54	26.3±1.1						
Barcs-Ny-2.6.(8)	3898 - 3905	phyllite (psammitic)						<2 μm: sericite	0.7163±0.0030	5.98	74.86	12.37±0.10	47±17
Barcs-Ny-2.8.(4)	3961 - 3969	phyllite	<2 μm: sericite	7.225	8.4710×10^{-6}	55	29.9±1.2						
Barcs-Ny-1.10	3788.5 - 3797	phyllite (carbonatic)	<2 μm: sericite	7.532	1.0313×10^{-5}	65	34.9±1.4						
Barcs-Ny-3.9.(17/7)	3852 - 3869	cipollino						<2 μm: sericite	0.7168±0.0040	4.48	77.55	17.09±0.20	36±16

*ages with standard deviations. Calculated with atomic constants suggested by Steiger and Jäger (1977)

history well extended in time is indicated also by Rb-Sr whole rock isochron (331±13 Ma) and average biotite (315±4 Ma) age data (Kovách et al., 1985b). The K-Ar age data have been interpreted as cooling ages representing the time passed since the uplift (cooling) of the area below the closure temperature of the muscovite (ca. 350 ^{o}C, see Purdy and Jäger, 1976). However, the detected younger (Alpine) minor thermal effects on the mica schist (sample Barcs-Ny 3. 12 (1/5-1/7)) favour an assumption of partial resetting of the K-Ar system of this rock.

The younger K-Ar age value of the partially albitized, sericitic plagioclase fraction (207.6±8 Ma) agrees with the Rb-Sr model age obtained for the $<2\ \mu m$ sericite fraction (222±41 Ma). Thus, these data may be interpreted either as the age of sericite formation or as mixed ages without any real geologic meaning between the ages of metamorphism and of the younger effect producing the sericite.

Despite of the partial resetting of the isotopic systems of the medium-grade basement of the Barcs-West area, their age values are significantly older than those given for the anchi-, epizonal sequence.

In order to determine the age of acidic volcanism, the application of whole rock Rb-Sr isochorn method was attempted. Using three metarhyolite whole rock data (samples Barcs-Ny-2.11 (1), Barcs-Ny-3.11 (1/3) and (1/11) a preliminary, poorly determined isochron with initial ratio of $^{87}Sr/^{86}Sr$ = 0.702 was calculated giving an isochron age of 211±52 Ma. This value (representing approximately the Triassic/Jurassic boundary) may be considered as minimal age of the acidic volcanism, as the isochemical character of the very low-grade metamorphism was not proved by the interpretation of main element chemistry of the metarhyolites (see Árkai, 1990, in the first part of the present paper). Supposing moderate changes in the Rb-Sr isotopic system of the metarhyolite, Upper Triassic volcanism seems to be very probable, as similar ages were determined by Kovách et al. (1985c) for the acidic members of the Upper Triassic bimodal volcanism of the Eastern Bükk Mountains. Products of the "geosynlcine" type bimodal Triassic volcanism occur frequently in the Dinarides and in their transported parts. The $^{87}Sr/^{86}Sr$ initial ratio of 0.702 estimated by the whole rock isochron method is characteristic of the acidic member of the bimodal volcanism. Using an initial ratio of 0.708 (which is a generally accepted value for granitic magmatic rocks, model ages of 145±27 - 193±11 Ma were obtained for the metarhyolite whole rock samples.

As the Rb-Sr model age of the intermediate metavolcanite whole rock sample (96±28 Ma) is very close to the ages of the <2 µm sericite-rich fractions of the rock (93±27 - 74 ±22 Ma), we have to count with a complete resetting of the Rb-Sr isotopic system during the regional metamorphism. Thus, no direct data exist on the age of magmatic activity, however, its Mesozoic (Triassic) age seems to be the most probable.

In the <2 µm, sericite-rich fraction of a dolomitic metasandstone sample (containing also detritic white mica) a Rb-Sr model age of 200±44 Ma was obtained. This value is very similar to those obtained on metarhyolite whole rock samples. Thus, considering also the strong discrepancy between the ages of medium-grade basement and of the anchi-, epizonal sequence, Mesozoic (Triassic) primary (volcanic, sedimentary) ages can be accepted as most probable. This conclusion is in agreement with the straigraphic conditions of the detached parts of the Dinarides (e.g. Bükkium, see Balogh, 1964, Balogh et al., 1984; Central Hungarian (Igal) Unit, see Bérczi-Makk, 1988).

In order to determine the age(s) of regional metamorphism, <2 µm sericite-rich fractions were investigated by Rb-Sr and K-Ar methods.

Two populations of <2 µm sericite model Rb-Sr ages could be distinguished, namely between 200 and 74 Ma and between 47 and 36 Ma. Taking also into account the different lithotypes the following age spectra were obtained:

- metarhyolite: 122±15 Ma;
- intermediate metavolcanite: 93±27 - 74±22 Ma;
- metasandstone: 200±44 Ma;
- phyllite: 132±70 - 47±17 Ma;
- cipollino (dolomite marble): 36±16.

In spite of the fact that the data are strongly scattering and contain large uncertainties, an Eo-Alpine (Cretaceous) regional metamorphic event between ca. 130 and 75 Ma, and a younger, Tertiary event can be concluded. In case of metasandstone the effect of detrital white mica might be the cause of the older age, while in case of certain phyllites and especially in cipollino-like dolomite marble the Tertiary tectonic-thermal effects can be considered as dominant.

On the contrary, the K-Ar age data obtained on <2 µm sericite-rich fractions indicate only the younger, Tertiary tectonic-thermal event. The K-Ar ages range between 34.9 and 17.6 Ma, giving an average of 16.5±5.4 Ma (n=8). There are no significant differences among the <2 µm sericite K-Ar ages of different rock types (see Table I).

In case of metarhyolite the Tertiary thermal effect can be observed even in the whole rock K-Ar age. The age difference between the whole white mica (sericite) fraction (41.0±1.6 Ma) and the $<2\ \mu m$ sericite fraction (28.8±1.2 Ma) of the same metarhyolite sample can be explained either by the decrease of the closure temperature with decreasing grain size of muscovite-illite (350 ^{o}C for muscovite, see Purdy and Jäger (1976) and 260±20 ^{o}C for $<2\ \mu m$ fraction illite-sericite, see Hunziker et al. (1986), and/or by the increasing loss of radiogenic argon with decreasing grain size. Considering the overprint nature of the Tertiary event, the latter explanation seems to be more probable.

The interpretation of the anomalously high K-Ar age (83.5±3.2 Ma) of the partially albitized potassium feldspar from the same metarhyolite sample is a difficult or even unfeasible task. The low-temperature feldspars had been considered as unsuitable for K-Ar dating for a long time since their K-Ar ages were frequently lower by 20-30 % than the real ages. This has been attributed to the alterations of the crystal structure due to exsolution. The low argon retentivity of orthocalse has been explained by Sardarov (1957) and later by Livinstone et al. (1967) and Foland (1974) by perthitization. Lately, however, the opinion gains ground that K-Ar ages of feldspars are also governed essentially by geological processes (Harrison and McDougall, 1982; Harrison and Bé, 1983; Parsons et al., 1988) and not by the intrinsic structural features of these minerals. Harrison et al. (1979) determined 260 ^{o}C and 160 ^{o}C closure temperatures for unaltered plagiocalse and potassium feldspar, and 130 ^{o}C has been determined for microcline (Harrison and McDougall, 1982). However, the closure temperatures of feldspars are definitely lower than that of biotite, Evernden and Kistler (1970) observed that the undeformed plagioclase retains argon better than the biotite. (For biotite the following closure temperatures were determined: 300 ^{o}C, see Berger and York, 1979; 300±50 ^{o}C, see Purdy and Jäger, 1976; 300-345 ^{o}C, see Dallmeyer, 1978). Brandt et al. (1970) experienced that feldspars did not loose completely their radiogenic argon content during heat treatment in atmosphere at 800-1000 ^{o}C for several tens of hours. In a Quaternary pumice flow Lo Bello et al. (1987) found K-feldspar grains which reserved their original Hercynian age. All of these show that feldspars may be highly resistent to short thermal pulses, but in the Barcs-West area this possibility is not reckoned with. The uncertainty of feldspar closure temperature is caused by the different thickness of perthitic lamellae, since diffusion takes place mostly along the surfaces between them. Depending on the perthitic structure, closure temperatures of 120-300 ^{o}C have been obtained for feldspars (McDougall and Harrison, 1988).The high resistance of feldspars to thermal pulses is explained by the homogenization of perthitic lamellae before the argon loss, due to K-Na interdiffusion. Thus, the surprisingly old age of albitized potassium feldspar sample from a metarhyolite may be interpreted either by partial loss of radiogenic argon from the primary, slightly altered feldspar, if its closure temperature is higher than that of the white mica, or by incorporation of excess argon from the surrounding phases during the Tertiary tectonic-thermal event.

In order to explain the K-Ar ages in a correct way, the present geothermic conditions and their consequences should be also taken into account. In bore Barcs-Ny-1 the following (quasi-equilibrium) temperatures were measured: 178 ^{o}C at 3724 m, 189 ^{o}C at 3885 m. Consequently, ca 200 ^{o}C present-day temperature can be supposed at a depth of about 4000 m where the majority of the investigated samples originated from. According to Hunziker et al. (1986) a temperature of 260$\pm$20 ^{o}C during 10$\pm$5 Ma leads to complete resetting of the K-Ar ages in illite (sericite) fractions smaller than 2 μm. Using the average values of their temperature versus apparent age diagram, the apparent K-Ar ages should decrease with approximately 40 per cent supposing 200 ^{o}C temperature and 10$\pm$5 Ma heating time. As the rapid sinking of the Drava Basin (and thus of the Barcs-West basement) begun only in the Pliocene, thus we should count maximally with 5, optimally with ca. 2-3 Ma effective hating time. (The depths of the boundaries of Miocene/Lower Pannonian and Lower/Upper Pannonian are 3425 m and 1715 m, respectively, in bore Barcs-Ny-1.). Consequently, the K-Ar ages obtained on 2 μm sericite fractions might decrease maximally with 10-20 per cent, and thus, the calculated values should be considered as possible minimal ages of resetting. The average corrected K-Ar age may be about 30 Ma which can be related to the Meso-Alpine tectonic-thermal event connected with the large-scale horizontal displacements of blocks ("microplates") in the Pannonian area.

Acknowledgements

K-Ar dating and metamorphic petrogenetic investigations have been sponsored by the Hungarian National Scientific Research Fund (OTKA) Projects Nos 1180 and 284/1987-1991.

REFERENCES

Árkai, P. (1990): Very low- and low-grade metamorphic rocks in the pre-Tertiary basement of the Drava Basin, SW-Hungary, I: mineral assemblages, illite "crystallinity", b data, and problems of geological correlation. Acta Geol. Hung., **33**, 43-66.

Árkai, P., Kad. Balogh (1989): The age of metamorphism of the East Alpine type basement, Little Plain, W-Hungary: K-Ar dating of K-white micas from very low- and low-grade metamorphic rocks. Acta Geol. Hung., **32**, 131-147.

Árkai, P., G. Nagy, G. Dobosi (1985): Polymetamorphic evolution of the South-Hungarian crystalline basement, Pannonian Basin: geothermometric and geobarometric data. Acta Geol. Hung., **28**, 165-190.

Árva-Sós, E., Kad. Balogh et al. (1987): K/Ar dates of Mesozoic igneous rocks in some areas of Hungary. Ann. Rep. Hung. Geol. Inst. on 1985, 297-307 (in Hungarian with English abstract).

Balogh, Kad. (1985): K/Ar dating of Neogene volcanic activity in Hungary: experimental technique, experiences and methods of chronologic studies. ATOMKI Rep., D/1, 277-288, Debrecen (in Hungarian).

Balogh, Kad., E. Árva-Sós, Gy. Buda (1983): Chronology of granitoid and metamorphic rocks of Transdanubia (Hungary). Proc. 12th Congr. CBGA: Ann. Inst. Geol. Geofiz., București, **61**, 359-364.

Balogh, K. (1964): Geological formations of the Bükk Mountains. Földt. Int. Évk., **48**, 243-719 (in Hungarian, with German abstract).

Balogh, K., H. Kozur, P. Pelikán (1984): Die Deckenstruktur des Bükkgebirges. Geol. Paläont. Mitt., Innsbruck, **13**, 89-96.

Bérczi-Makk, A. (1988): Re-investigation of Mesozoic formations of Transdanubia located south of the Balaton Line. Report of the Hydrocarbon Research Institute, Százhalombatta (in Hungarian).

Berger, G.W., D. York (1979): $^{40}Ar-^{39}Ar$ dating of multicomponent magnetization in the Archean Shelley Lake granite, northwestern Ontario. Canad. J. Earth Sci., **16**, 1933-1941.

Brandt, S.B., N.V. Volkova, V.N. Smirnov (1970): Discordant absolute age values and their significance for the determination of temperature and duration of rock-forming processes. Eclogae geol. Helv., **63**, 45-51.

Dallmeyer, R.D. (1978): $^{40}Ar/^{69}Ar$ incremental-release ages of hornblende and biotite across the Georgia Inner Piedmont: their bearing on late Plaeozoic - early Mesozoic tectonothermal history. Amer. J. Sci., **278**, 124-149.

Evernden, J.F., R.W. Kistler (1970): Chronology of emplacement of Mesozoic batholitic complexes in California and western Nevada. United States Geological Survey, Professional Papers, **623**, 1-42.

Foland, K.A. (1974): Ar^{40} diffusion in homogeneous orthoclase and an interpretation of Ar diffusion in K-feldspars. Geochim. Cosmochim. Acta, **38**, 151-166.

Ghent, E.D., M.Z. Stout (1981): Geobarometry and geothermometry of plagioclase - biotite - garnet - muscovite assemblages. Contrib. Mineral. Petrol., **76**, 92-97.

Harrison, T.M., R.L. Armstrong et al. (1979): Geochronology and thermal history of the Coast Plutonic Complex, near Prince Rupert, British Columbia. Canad. J. Earth Sci., **16**, 400-410.

Harrison, T.M., K. Be (1983): $^{40}Ar/^{39}Ar$ age spectrum analysis of detrital microclines from the southern San Joaquin Basin, California: an approach to determining the thermal evolution of sedimentary basins. Earth Planet. Sci. Lett., **64**, 244-256.

Harrison, T.M., J. McDougall (1982): The thermal significance of potassium feldspar K-Ar ages inferred from $^{40}Ar/^{39}Ar$ age spectrum results. Geochim. Cosmochim. Acta, **46**, 1811-1820.

Hunziker, J.C. (1986): The evolution of illite to muscovite: an example of the behaviour of isotopes in low-grade metamorphic terrains. Chem. Geol., **57**, 31-40.

Hunziker, J.C., M. Frey et al. (1986): The evolution of illite to muscovite: mineralogical and isotopic data from the Glarus Alps, Switzerland. Contrib. Mineral. Petrol., **92**, 157-180.

Kovách, Á., É. Svingor, T. Szederkényi (1985a): Geochronology of metamorphic events in the crystalline basement of the southern part of the Great Hungarian Plain. Proc. Rep. XIIIth Congr. of CBGA, Part **I**, 387-388.

Kovách, Á., É. Svingor, T. Szederkényi (1985b): Rb-Sr dating of basement rocks from the southern foreland of the Mecsek Mountains, Southeastern Transdanubia, Hungary. Acta Miner. Petrogr. Szeged, **27**, 51-57.

Kovách, Á., É. Svingor, P. Árkai (1985c): Early Alpine resetting of Rb-Sr ages in the Upper Triassic quartz porphyries of the Bükk Mountains, Northeastern Hungary. Proc. Rep. XIIIth Congr. of CBGA, Part **I**, 385-386.

Livingstone, D.E., P.E. Damon et al. (1967): Argon 40 in cogenetic feldspar - mica mineral assemblages. J. Geophys. Res., **72**, 1361-1372.

Lo Bello, Ph., G. Feraud et al. (1987): $^{40}Ar/^{39}Ar$ step-heating and laser fusion dating of a Quaternary pumice from Neschers, Massif Central, France: The defeat of phenocrystic contamination. Chem. Geol., Isotope Geosci. Sect., **66**, 61-71.

Odin, G.S. et al. (1982): Interlaboratory standards for dating purposes. In: Odin, G.S. (ed.): Numerical dating in stratigraphy, 123-150, Wiley and Sons, Chichester, New York.

Parsons, J., D.C. Rex et al. (1988): Argon-loss by alkali feldspars. Geochim. Cosmochim. Acta, **52**, 1097-1112.

Purdy, J.W., E. Jäger (1976): K-Ar ages on rock-forming minerals from the central Alps. Mem. Ist. Geol. Miner. Univ. Padova, **30**.

Sardarov, S.S. (1957): Retention of radiogenic argon in microcline. Geochemistry, No. **3**, 233-237.

Acta Geologica Hungarica, Vol. 33/1-3, pp. 79-96 (1990)

PETROLOGY OF SOME HP-METAVOLCANICS FROM THE PIEDMONT ZONE, WESTERN ALPS OPHIOLITE

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Metavolcanic rocks from the Piedmont ophiolite nappe were petrographically and geochemically investigated. These derive from Colletto Fiorenza, Lago Lausetto and Petit Belvedere (Monviso), Roche Noire (Cristillan), Refuge d'Averole, Pre clos la Clapera, Col du Mont Cenis and Carrieres du Paradis (Arc valley) and Chenaillet (Montgenévre) ophiolites in the Western Alps.

HP-facies metavolcanics (Monviso) were re-equilibrated under the early Alpine eclogitic condition and were successively involved in a polyphase retrograde tectono-metamorphic evolution. The rocks include eclogitic metabasalts and glaucophanites and often retrograded to greenschist facies (prasinites, ovardites and greenschists). The glaucophane schist facies metavolcanics of the Arc valley, Monviso and Roche Noire are also retrogressed to greenschist facies. The prasinites and ovardites (Arc valley and Monviso) frequently show the greenschist facies metamorphism with relicts of glaucophane and garnet. The well-preserved metavolcanic sequence where the rocks show only weak effects of the Alpine deformation and metamorphism is recorded in Chenaillet.

These derive from tholeiitic melts showing many affinities with N-MORB and with metovolcanics the other metavolcanics of the Piedmont ophiolite. These were also produced by partial melting and fractionation of a depleted asthenospheric source.

Keywords: Ophiolitic metavolcanics, eclogites, glaucophanties, greenschists, metamorphic evolution, petrology, geochemistry, Western Alps.

Introduction

In the Western Alps, the high pressure metamorphism affected large coherent bodies of the pre-Alpine continental and oceanic crust. The pre-Alpine continental crust is not exposed as a pile of basement nappes. Each basement nappe is surrounded by an envelope of thrust sheets consisting of dismembered ophiolite complexes and Mesozoic metasediments (Lombardo, 1988).

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Received: 10/10/89

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During the Cretaceous, most of the oceanic crust (now represented by the Piedmont ophiolite nappe system) and some parts of both continental margins underwent blueschist to eclogitic conditions and subsequently followed by the greenschist to amphibolite facies conditions of Lepontine metamorphism.

The Piedmont Zone outcrops occur along the arc of the Western Alps and consist of metamorphic dismembered ophiolite and Mesozoic sediments. The metavolcanic rocks of the Piedmont ophiolite nappe were subjected to various studies; previous research on the volcanic and gabbroic rocks was carried out in Monviso (Lombardo et al., 1978; Wisio, 1985; Nisio and Lardeaux, 1987; Lardeaux et al., 1987; Kienast and Messiga, 1987), Arc valley area (Bocquet, 1974; Leardi et al., 1986), Roche Noire (Caby et al., 1978; Mével and Kienast, 1980; Lagabrielle et al., 1984) and Montgenévre (Mével, 1975; Lewis and Smewing, 1980; Bertrand et al., 1981, 1982, 1985, 1987).

Geological setting and field relationships

Field study and sampling of the metavolcanic rocks were carried out in the eastern, middle and western parts of the Piedmont ophiolite nappe of the Western Alps, e.g. Monviso, Roche Noire, Arc valley area, and Montgenévre (Fig. 1).

Some of these metavolcanic rocks, partly escaped the strong Alpine deformation while others have no primary minerals or features. These have different structural and stratigraphic setting which are implied by different relationships between the metavolcanics and the other parts of the ophiolite sequences (peridotite, gabbros and metasediments).

The Monviso metavolcanic sequence is a part of the eclogitic metaophiolite which forms a large slice of the Eastern Piedmont Zone interposed between Dora-Maire continental unit and the Western Piedmont Zone. It shows three successive Alpine metamorphic stages characterized by the eclogitic, blueschist and greenschist facies, respectively.

Samples were collected in Colletto Fiorenza and Lago Lausetto (Italian Monviso) and Petit Belvedere (French Monviso). These are very fine grained eclogitic metabasalts and banded metabasites (prasinites, glaucophanite and greenschist).

The eclogitic metabasaltic dykes of the Colletto Fiorenza (few cm-several dm thick) are of greenish grey colour, in some places preserving a

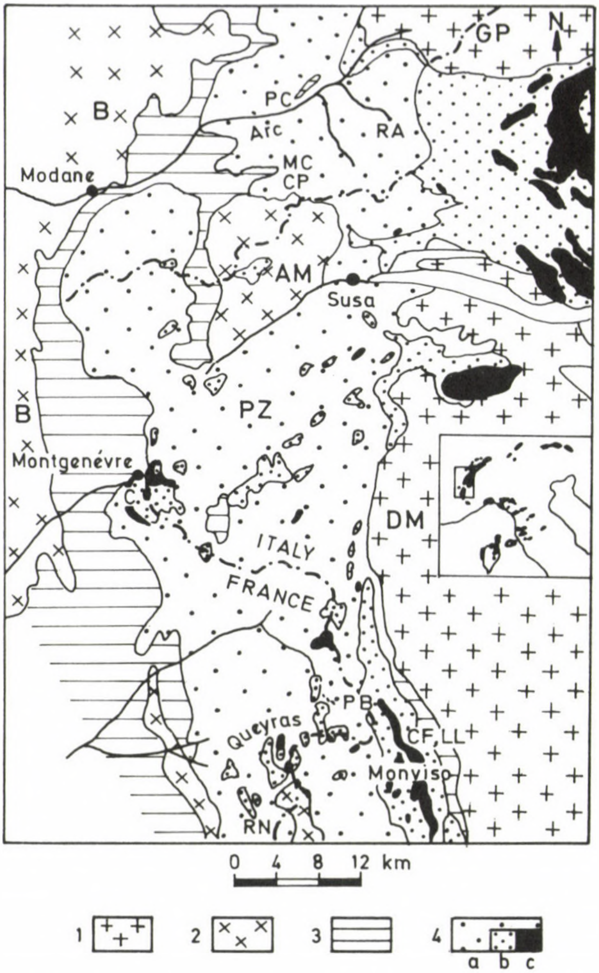


Fig. 1. Tectonic sketch map of the internal Western Alps showing the location of the main ophiolite complexes. 1. Dora-Maire (DM) and Gran Paradiso (GP) continental units (European Paleomargin); 2. Vanoise, Ambin (AM) and Brianconnais (B), continental units (European Paleomargin); 3. Mesozoic epicontinental covers; 4. Piedmont Zones (PZ): Schistes Lustrés nappe (Mesozoic, mainly oceanic material). a. undifferentiated metasediments with subordinate ophiolites; b. ophiolite complex with minor metasediments; c. metagabbro bodies. Location of samples: RA (Refuge d'Averole); PC (Pre clos la Clapera); CP-MC (Carrieres du Paradis-Mont Cenis); PB (Petit Belvedere); LL (Lago Lausetto); CF (Colletto Fiorenza); LC (Lago Chiaretto); C (Chenaillet); RN (Roche Noire)

porphyritic texture. These are crosscut by smaragditic metagabbros and were cut by late albite veins. The eclogitic assemblage appears deeply altered to greenshicst assemblage.

The prasinite (Lago Lausetto) being a greenschist facies metabasalt, is usually homogeneous, and exhibits thin layering (mm-scale), different in colour and mineral (Fig. 2). Locally white mica (phengite) and carbonate also occur.

The Arc valley metabasites of basaltic composition are the part of the Zermatt-Saas zone in the middle Piedmont unit. Samples were collected from Refuge d'Averole, Pre clos la Clapera, Col du Mont Cenis and Carrieres du Paradis between Ambin and Gran Paradiso unit (Fig. 1). These are homogenous masses up to several hundred meters of actinolite-epidote-chlorite-albite greenschist (prasinites), sometimes overlain interbedded by a thin layer of albite chlorite schists (ovardites).

The prasinites and ovardites can be derived from basaltic metamorphic rocks showing strong effects of the Alpine deformation and recrystallization, the primary minerals and structures are completely obliterated (Sandrone et al., 1986) and the rocks are characterized by conditions of glaucophane and greenschist facies assemblages, respectively.

The glaucophanites from Roche Noire, Petit Belvedere and Carrieres du Paradiso are fine grained foliated rocks of blueish-black colour and are characterized by a glaucophane, chlorite, epidote, albite actinolite, leucoxene $\pm$ garnet assemblage. These are sometimes interbedded by carbonates. The glaucophanites are usually retrogressed to greenschist facies assemblage.

The Chenaillet metavolcanic sequence in the western part of the Montgenévre ophiolite complex represents one of the best preserved ophiolite complex in the Western Alps (Bertrand et al., 1987). As the rock show only weak effects of Alpine deformation and metamorphism, the primary structure and, in part, the primary mineral assemblages are well preserved. The metabasaltic, gabbroic and ultramafic lithologies occur as separate tectonic units, as this is typically the case for dismembered Alpine ophiolites (Bertrand et al., 1981, 1982, 1987). The pillow lavas are separated from the gabbros by a shear zone of variable thickness and in some places containing serpentinite lenses. The metavolcanic sequence of Chenaillet shows a well defined stratigraphic and conformable sequence (Lewis and Smewing, 1980) starting with the lower aphyric unit (160 m) at the base, pillow breccias (up to 20 m), porphyritic unit (65 m) and upper aphyric unit (110 m) at the top. The pillow centers are grey and pass outwards into a green chloritized selvage at the margin and have varioles. The pillow breccias consist of aphyric angular pillow fragments (few cm - few m) which were coming from several pillows.

Mineralogy and petrography

The primary and secondary mineral assemblages, textures and metamorphic evolution of the ophiolitic metavolcanics in the Western Alps are summarized in Table I and II.

I. High-Pressure facies:

The HP-facies (eclogite and glaucophane schist facies mineral assemblages) of the metavolcanic rocks from the ophiolite of the Western Alps consists of eclogitic metabasalts (Monviso), and glaucophanites which include garnet-bearing glaucophanite (Monviso and Arc valley) and glaucophanite (Roche Noire), Table I.

In the eclogitic metabasalts, the rocks are very fine-grained, greenish grey, and sometimes have mm-sized spots of the preserved porphyritic texture. Microscopically, these have homogeneous grain size and essentially consist of omphacite, garnet, clinozoisite and minor galucophane, Mg-chlorite and quartz (Fig. 3). The accessories include rutile and leucoxene. Locally, these are crosscut by albite veins. The omphacite is replaced by albite with aggregates of glaucophane, clinozoisite and white mica (phengite). The glaucophane is rimmed by actinolite, the Mg-chlorite is altered to Fe-chlorite and rutile is transformed to titanite suggesting the retrogression of the eclogitic assemblage to greenschist facies assemblage.

The garnet-bearing glaucophanites consist mainly of glaucophane, leucoxene, epidote, garnet, chlorite with minor albite and stilpnomelane. The glaucophane is predominating (44-54 v. %)*, forms zoned lepidoblasts (1 mm long), is associated with chlorite and leucoxene (Fig. 4) and replaced by actinolite or stilpnomelane (in Arc valley, the glaucophane is transformed into chlorite, albite and iron oxide). The epidote/zoisite (35 v. %) are generally banded and associated by chlorite. The chlorite (6-16 v. %) forms web lepidoblasts aligned parallel to schistosity. The albite metablasts (5-12 v. %) enclose amphibole, chlorite and are sometimes replaced by calcite. Garnet is partly replaced by chlorite.

*v. % = volume per cent

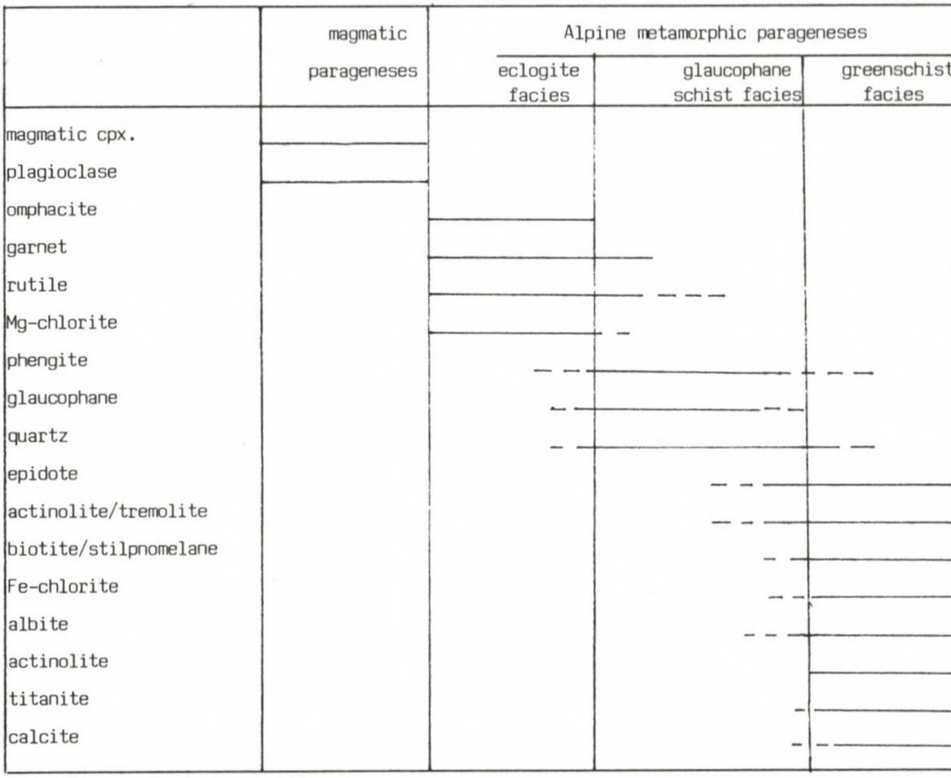
Table I

Main petrographic features of representative rocks from the metavolcanics of the Western Alps

Rock name	Texture	Main primary minerals (magmatic and late-stage primary)	Main secondary minerals (hydrothermal and metamorphic)	Metamorphic facies
	1. Monviso: Colletto Fiorenza			
Eclogitic metabas.	porph, gran	cpx	omp, gar, rut, clinoz, glau, Mg-chl, leuc, ab, phen, actin, Fe-chl, tit.	Eclogitic f.
	Petit Belvedere			
Gar.-bearing glaucophanite	granone-matobl, poikil, sch.		glau, leuc, ep, chl, ab, stilp, actin, gar.	Galucophane schist f.
Greenschist	poikil, nematobl.		actin, chl, ab, tit, clinoz, cc.	Greenschist f.
	Lago Lausetto			
Prasinite	poikil,		ab, chl, ep, glau, actin, phen, rut-tit.	Greenschist f.
	2. Roche Noire:			
Glaucophanite	nematobl, poikil, sch.		glau, chl, cc, ab, tit, qz, phen.	Glaucophane schist f.
	3. Arc valley:			
Gar.-bearing Glaucophanite	granonematobl, poikil, sch.		glau, ep, chl, ab, gar, tit, phen, cc, qz, bio.	Glaucophane schist f.
Prasinite	poikil, sch.		ab, ep, actin, rieb, glau, chl, rut-tit, cc, phen, bio.	Greenschist f.
Ovardite	poikil, porp, gne.		ab, Fe-chl, glau, actin, ep, cc, rut-tit, phen, qz±gar.	Greenschist f.
	4. Montgenévre: Chenaillet			
Metabas. pill. lava	inters, porp, aphy, que, vario, arb, ves.	cpx, pl.	ab, chl, preh, ep, cc±zeol, pump.	Preh.-pump.-greenschist f.; low grade meta.-ocean floor meta
Metabas. pill. breccia	inters, aphy, vario	cpx, pl.	ep, preh, chl, ab. hem±pump.	
Metadol. lava flow and dyke	vario, suboph, interg.	ol, cpx, pl.	ab, chl, leuc, cc±preh	
Microgabbro	hypid	cpx, pl. hb.	chl, actin-trem, leuc, ap, saus.	

Table II

Metamorphic evolution of the metavolcanics from ophiolites of Western Alps



←

Abbreviations: ol: olivine; cpx: clinopyroxene; pl: plagioclase; omp: omphacite; glau: glaucophane; actin: actinolite; trem: tremolite; rieb: riebeckite; hb: hornblende; ep: epidote; clinoz: clinozoisite; chl: chlorite; preh: prehnite; cc: calcite; ap: apatite; hem: hematite; leuc: leucoxene; rut: rutile, tit: titanite; bio: biotite; phen: phengite; stilp: stilpnomelane; gar: garnet; ab: albite; qz: quartz; pump: pumpellyite; zeo: zeolite; saus: saussurite; porp: porphyroblastic; poikil: poikiloblastic; nematobl: nematoblastic; granonematobl: granonematoblastic; gran: granular; hypid: hypidiomorphic, suboph: subophitic; inters: intersertal; interg: intergranular; sch: schistose; gne: gneissose; que: quench, vario: variolitic; arb: arborescent; ves: vesicular; metabas: metabasalt; pill: pillow, metadol: metadolerite; f: facies

The garnet-bearing glaucophanite is composed mainly of glaucophane, epidote, chlorite, albite and garnet with accessories of titanite, white mica, calcite, quartz and biotite.

The glaucophanite recorded in Roche Noire consists of fibroblastic, poikiloblastic and schistose glaucophane, calcite and albite with minor titanite, quartz and white mica.

Most of these glaucophanites are affected by glaucophane schist facies metamorphism that was followed by the development of greenschist facies mineral assemblage including Fe-chlorite, albite, epidote, titanite ± actinolite.

II. Greenschist facies

The greenschist facies metavolcanics include prasinites (Monviso and Arc valley), ovardites (Arc valley) and greenschists (Monviso), (Table I).

In the prasinites the primary minerals and structures are completely obliterated. These are basaltic metamorphic rocks, consist of fine to medium-grained greenschists with whitish poikiloblastic albite layers, and show ocellar and/or foliated structure. Under the microscope, the prasinites are composed mainly of albite, epidote, actinolite, riebeckite, glaucophane and chlorite. Titanite, calcite, phengite and biotite are the main accessories. Albite (An_{2-8}) is predominating (48.5 v %), forms 1.2-3.7 mm crystals across metablasts and usually contains amphibole, epidote, chlorite and titanite (Fig. 5). Epidote/clinozoisite (25 v %) are usually embedded in chlorite and albite. Amphibole nematoblasts (12.6 v %) are enclosed in chlorite and albite and are sometimes replaced by biotite. Chlorite (11.7 v %) occurs as web of lepidoblasts. Rutile,titanite (1.2 v %) usually replace ilmenite. Locally calcite and phengite can be observed.

The ovardites (coined by Struever, 1873, for the rocks from Torre d'Ovarda of the Piedmont, W. Alps) are fine-grained foliated and green coloured rocks. The ovardites consist of poikiloblastic albite embedded in a predominantly Fe-rich chlorite matrix, together with little amounts of amphibole, epidote and sometimes calcite and rutile/titanite. Glaucophane, white mica, quartz, +/- rutile and garnet are accessories. The albite (41.5 v %) An_{0-5}, 0.3-2.7 mm diameter poikiloblasts enclosed all other constituents of the rock (Fig. 6). Chlorite (28 v %) forms the rock matrix. Glaucophane is mantled by actinolite. Epidote is transformed into titanite. Calcite (10 v %) replaced plagioclase. Ilmenite/rutile are replaced by leucoxene/titanite. White mica (phengite) is sometimes altered to chlorite. Garnet is partly replaced by chlorite.

In the greenschists, the primary minerals and textures are completely disappeared. The rocks are fine-grain sized, massive and dark-green in colour. The greenschists consist of actinolite, chlorite, albite and titanite with minor clinozoisite and calcite.

The sequence of volcanic of the Montgenévre ophiolite (Table I) consists of low-grade metamorphic equivalents of basalt pillow lavas, pillow breccias, dolerite lava flows and dykes and microgabbros. These are usually slightly overprinted by ocean-floor and Alpine deformation (greenschist facies metamorphism).

The metabasalt pillow lavas are fine-grained with glassy-chilled margins. Microscopically, these consist of primary magmatic clinopyroxene and plagioclase and of secondary minerals such as albite, chlorite, prehnite, epidote, calcite and sometimes zeolite and pumpellyite, and display fine-grained interstitial, porphyritic and aphyric textured cores and quenched and variolitic textured margins (Fig. 7). Nearly all the pillows show arborescent and vesicular texture. The labradoritic plagioclases (6.8 v %) are magmatically resorbed phenocrysts (1.2-3.1 mm long), replaced by epidote and chlorite. The augitic clinopyroxene is transformed into chlorite and rarely into actionlite. The very fine-grained matrix (86 v %) consists of albite, small veins of epidote, chlorite and prehnite and rarely of titanite, calcite and actinolite.

The metabasalt pillow breccias consist of fine-grained fragments of variable size with a greenish matrix. The fragments have the same mineral compositions as the previous metabasaltic pillows with secondary epidote, prehnite, chlorite, albite, hematite and scarce pumpellyite as a matrix.

The metadolerite lava flows and dykes are composed of primary olivine and plagioclase phenocrysts (13 v %) embedded in a fine-grained variolitic, subophitic and intergranular matrix (86.7 v %) that consists of clinopyroxene, albite, chlorite, leuxocene and calcite. The labradoritic plagioclase is moderately clouded and replaced by epidote, chlorite, albite and scarcely by prehnite. Olivine is transformed into chlorite and epidote (Fig. 8).

The microgabbros consist of clinopyroxene, plagioclase and amphibole. Chlorite, ilmenite-elucoxene and apatite are the minor constituents. Ti-rich augitic chlinopyroxene (23.5 v %) is usually rimmed by late magmatic hornblende (Fig. 9), which in turn is overgrown by green hornblende and actinolite-tremolite. The plagioclase (53.5 v %) usually altered into saussurite.

Chemistry

Major element (wt %) analyses appear in Table III.

Trace element analyses (ppm) (Table IV) for Be, Nb, Y, La and Sc were carried out by optical spectrographic method (Model PGS-2 C. Zeiss Jena) and for Ba, Rb and Sr by atomic absorption method (Model AA-475) at the Department of Petrology and Geochemistry, ELTE, Budapest.

The investigations of the metavolcanics have been so far focussed on trace elements (i.e. Nb, Y, Zr and Sc) which are particularly useful for discriminating primary magma types and accordingly, geodynamic setting, and which are regarded as almost immobile during weathering and metamorphism (Cann, 1970; Pearce and Cann, 1973; Pearce, 1975 Floyed and Winchester, 1975; and others).

The prasinites of the Arc valley show a wide compositional range (in ppm) of Ti, Nb, Y, Zr, Sc, Ti/Y (330.7-346.5) and Zr/Y (2.7-4.9) which are largely variable. Their averages are similar to that from Combin unit (Dal Piaz et al., 1981) and are higher in Zr and Rb than that from Val d'Ala (Leardi et al., 1986). Moreover, the ovardites have lower Ti, Y and Sc than the prasinites, probably due to the strong alteration. These are also slightly higher and lower than those for ovardites from Zermatt-Saas unit (Dal Piaz et al., 1981) and from Val d'Ala (Leardi et al., 1986).

The glaucophanite of the Arc valley shows lower Nb, Y and Zr than those of the Monviso. Moreover, the Monviso glaucophanite has higher Ti and Zr than that from Zermatt-Saas unit (Dal Piaz et al., 1981) and from Arc valley (Table III-IV).

The metadolerite flow and dyke from Chanillet shows strongly lower Ti, Y and Zr and higher Nb than the average of the same rock given by Bertrand et al. (1987). The pillow lavas from Chenaillet are quite comparable to the average of Bertrand et al. (1987).

The plotting of the "incompatible" elements versus fractionation trend (FeO^+/FeO^+ + MgO ratio), (Fig. 10) shows a strong scatter that may reflect the variation in model composition, different geotectonic setting and/or metamorphic effect. The observed distribution of these elements for the analyzed samples may be also explained by supposing different degree of partial melting combined with fractional crystallization processes and/or by mantle heterogeneity and more complex partial melting events (Pearce and Flower, 1977; Langmuir et al., 1977). Moreover, the La, Ti, Y, Sc and Rb show positive correlation with the fractionation trend (Fig. 10). In term

Table III

Chemical composition of representative rock types from the ophiolitic volcanic sequence of the Western Alps

Locality	Arc valley									Monviso			Montgenévre					
	Carrieres du Paradis			Refuge d'Averole	Pre clos la Clapera			Carrieres du Paradis			Colletto Fiorenza	Lago Lausetto	Chenaillet					
Rock name	Prasinites			Ovardites			Glaucophanites				Greenschist	Eclogitic metabas.	Prasinite	Metadolerite flow and dyke		Metabasaltic pill. lavas		
Symbols and Sample No.	x 1	x 2	x 3	+ 4	+ 5	+ 6	⁎ 7(3)	o 8	9(4)●	⁎ 10	△ 11	• 12(2)	▲ 13	14 ▽	15(9) ▽	16 ▼	17 ▼	18(11) ▼
SiO_2	47.94	50.95	51.81	52.13	44.55	42.75	49.80	53.05	51.46	50.05	50.63	50.61	47.62	57.00	51.25	56.20	56.43	50.16
TiO_2	1.85	1.66	1.71	0.72	1.33	1.41	1.43	0.90	1.84	3.23	0.62	1.40	1.40	0.81	1.68	1.25	1.29	1.62
Al_2O_3	15.95	15.74	14.92	14.72	13.01	11.23	16.88	16.9	14.68	8.67	13.36	15.60	19.01	13.52	15.35	10.41	11.64	15.79
Fe_2O_3	3.80	3.89	0.95	0.92	7.54	2.01	5.78	10.49	5.48	12.52	2.97	1.40	10.46	1.57	2.59	1.94	2.92	2.43
FeO	7.89	6.56	9.04	6.34	2.70	8.84	4.57	2.92	6.58	7.84	6.42	7.07	n.d.	5.53	6.00	6.28	5.66	6.13
MnO	0.17	0.16	0.15	0.14	0.13	0.13	0.17	0.09	0.20	0.23	0.11	0.48	0.10	0.10	0.19	0.14	0.16	0.15
MgO	4.96	5.28	5.55	5.42	5.01	9.92	5.90	2.44	5.76	5.33	9.15	7.44	6.01	6.32	6.18	9.05	5.96	5.95
CaO	8.07	3.99	4.45	5.87	11.96	11.85	6.27	5.16	6.06	6.76	6.63	10.63	3.51	5.91	7.87	6.83	8.33	8.33
Na_2O	4.12	5.32	3.57	5.39	4.32	2.56	4.90	6.02	4.45	3.65	4.62	3.31	5.00	5.85	4.55	4.81	5.16	4.95
K_2O	0.70	0.23	1.73	0.10	0.15	0.82	0.48	0.93	0.80	0.10	0.11	0.27	3.46	0.10	0.11	0.10	0.10	0.04
H_2O^+	3.10	4.20	3.58	7.60	2.30	2.85	3.52	0.73	2.09	0.90	3.40	-	-	1.33	2.76	2.60	1.40	3.51
H_2O^-	0.3	0.60	0.35	0.40	0.4	0.70	0.05	0.36	0.05	0.20	1.00	1.07	2.9	1.00	-	0.60	0.20	-
CO_2	0.7	1.60	2.14	3.0	5.76	4.28	-	-	-	-	-	-	-	-	0.95	-	-	0.61
P_2O_5	0.11	0.11	0.06	0.07	0.09	0.29	-	0.04	0.29	0.03	0.09	0.34	0.12	0.06	0.23	0.23	0.11	0.20
SO_2	0.10	-	-	-	-	-	-	-	-	0.15	-	-	-	-	-	-	-	-
	99.76	100.29	100.01	99.82	99.25	99.64	99.75	100.03	99.74	99.51	99.11	99.62	99.59	99.00	99.70	100.34	99.26	99.87

n.d.: non detected
( ): number of analyses
*on the diagrams

analysis no. 7 and 9 after Bocquet (1974)
analysis no. 12 after Compagnoni et al. (1988)
analysis no. 15 and 18 after Bertrand et al. (1987)

Table IV

Trace element (ppm) analyses of some metavolcanic rocks from the Western Alps ophiolites

	Arc valley										Monviso					Montgenevre			
Locality	Carrieres du Paradis					Refuge d'Averole	Pre clos la Clapera				Carrieres du Paradis		Petit Belvedere			Chenaillet			
Rock name	Prasinites					Ovardites				Glaucophanites				Green-schist	Metadolerite flow and dyke		Basaltic pillow lavas		
Symbols, Sample No.	x 1	x 2	x 3	⁎A(13)	⁎B(8)	+ 4	+ 5	+ 6	⁑ C	⁑ D(8)	o 7	⊙ E(6)	⁎ 8	△ 9	▽ 10	▽ F(9)	▼ 12	▼ 13	▼ G(11)
Be	<1	<1	2.1	-	-	5	<1	<1	-	-	2.2	-	<1	<1	<1	0	<1	<1	0
Nb	5	3	6	4	4	5	2.5	4	4	3	6	5.8	11	5	8	<3	3	4	<3
Y	32	43	31	36	33	24	37	23	29	31	27	37	40	38	33	32	29	28	33
Zr	126	116	152	135	108	150	110	118	125	112	125	186	170	92	94	148.7	108	126	143
La	15	10	17	-	-	25	11	<10	-	-	16	-	21	18	10	<12.3	10	<10	<14
Sc	37	28	25	-	-	22	34	23	-	-	32	-	26	24	32	35.7	31	33	33
Sr	432	226	145	-	174	190	146	163	-	-	295	-	75	77	161	202	37	181	212
Ba	486	319	511	-	-	560	776	776	-	97	554	-	446	360	302	14.9	363	448	11.3
Rb	28.3	10.2	10	15	<2	4	3.5	5.3	22	2	28.2	14	3.2	4.1	3.2	<4	2.9	2.9	<4

A: Combin unit (Dal Piaz et al., 1981)
B,D: Val d'Ala (Leardi et al., 1986)
C,E: Zermatt-Saas (Dal Piaz et al., 1981)
F,G: Montgenèvre (Bertrand et al., 1987)
( ): number of analyses
- : non analyzed

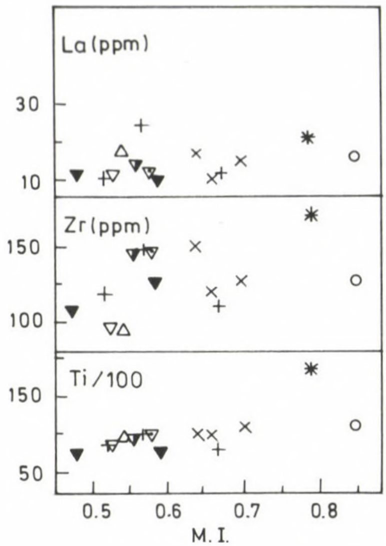


Fig. 10. Trace elements (ppm) vs M.I.(FeO^{+}/FeO^{+}+ MgO) diagrams for the Western Alps metavolcanics. Symbols see Table 3

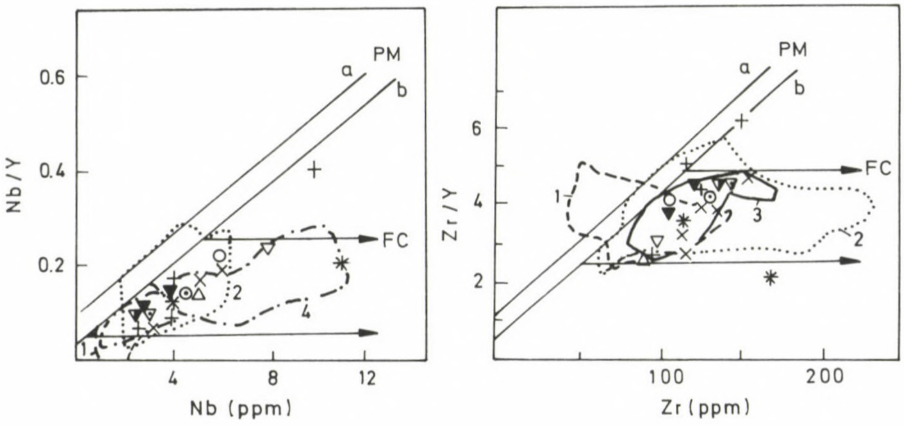


Fig. 11. Nb/Y ratio vs. Nb(ppm) and Zr/Y ratio vs. Zr(ppm) diagrams (Treuil and Joron, 1975). The oblique lines show the partial melting (PM) pattern for original melts. The horizontal lines show the melt fractionation trends (FC). PM_a and PM_b are extrapolated for the Voltri Group prasinites (Piccardo et al., 1979) and the N. Appennine ophiolite volcanites (Beccaluva and Piccardo, 1978) for the Western Alps metavolcanics. 1. Field of Monviso metabasalts (Monviso, 1980; 2. Field of Voltri Group prasinites (Piccardo et al., 1979); 3. Field of Val d'Ala prasinites (Leardi et al., 1986); 4. Field of Tauern metabasalts (Bickle and Pearce, 1975). Symbols see Table 3

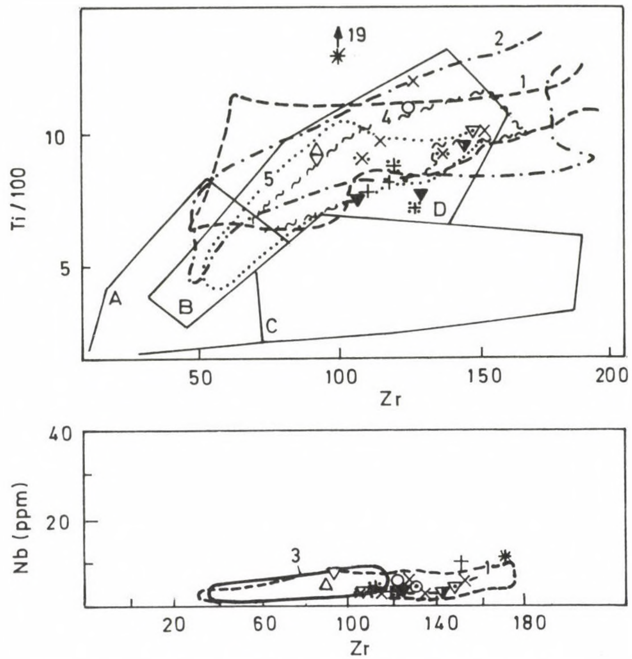


Fig. 12. Ti/1000 vs Zr (Pearce and Cann, 1973) and Nb vs. Zr diagrams for the Western Alps metavolcanics. A) and B) arc tholeiites, B) ocean-floor tholeiitic basalts, C) and B) calc alkaline basalts, D) within plate basalts. 1. Field of Piedmont ophiolite basalts (Lombardo et al., 1978; Lewis and Smewing, 1980; Dal Piaz et al., 1981); 2. Field of oceanic floor basalts (Pearce and Cann, 1973; Sun et al., 1979; Wood et al., 1979a; Le Roex et al., 1982); 3. Field of N-MORB (Sun et al., 1979); 4. Field of Val d'Ala prasinites (Leardi et al., 1986); 5. Field of Monviso metabasalts (Monviso, 1980). Symbols see Table 3

of petrogenesis, the Western Alps metavolcanics plot well on a line passing through the origin on the diagram considering Nb and Zr variations with increasing Nb/Y and Zr/Y ratios (Fig. 11), respectively (as discussed by Treuil and Joron, 1975 for the ocean ridge basalts). It can be concluded that the basaltic protoliths were probably generated under slightly different degrees of partial melting of a supposed homogeneous mantle source and suffered shallow depth fractionation. Particularly for the Nb/Y ratio - Nb (ppm) diagram, a clear separation exists (as outlined by Beccaluva and Piccardo, 1978) between some Tauern Window metavolcanics, regarded as within-plate (oceanic island) basalts (Bickle and Pearce, 1975) and the whole basaltic and metabasaltic rocks from the Alpine and North Apennine Terranes.

Moreover, considering the diagrams relating to hydromagmatophile (HYG) elements (Wood et al., 1979a) indicate that the investigated metavolcanics are related to crystal fractionation processes. This is apparent from Ti-Zr and Nb-Zr diagrams (Fig. 12) which also indicate close similarities with other basalts of the Piedmont ophiolite and of ocean floor basalts in particular N-MORB. The similar ratios of the HYG elements (e.g. Ti/Zr, Nb/Zr) observed in Western Alps metavolcanics and in many basalts of Piedmont ophiolite suggest an origin from not very different mantle (Pognante et al., 1985).

Concluding remarks

The Piedmont Zone (Western Alps) consists of metamorphic dismembered ophiolite and its Mesozoic (post Liassic to Cretaceous) metasedimentary cover. It is supposed to have been originated as "Piedmont-Ligurian oceanic basin" (Dal Piaz, 1974).

From the eastern internal Piedmont Zone, one of the most significant HP-facies metavolcanics were studied in the Monviso ophiolite.

Generally, the Monviso metavolcanics were subjected to HP-eclogitic metamorphic assemblage which later retrogressed to glaucophane schist facies and greenschist facies mineral assemblages. Glaucophane schist facies metavolcanics including garnet-bearing glaucophanite in Monviso and Arc valley and glaucophanite in Roche Noire were usually retrogressed to greenschist facies.

In the middle Piedmont Zone, the prasinites and the ovardites are characterized by greenschist facies with relics of glaucophane schist facies. These are considered to be greenschistic basaltic pyroclasts. The occurrence of phengite and calcite in the Monviso prasinite suggested its derivation from original tuffite (Compagnoni et al., 1988). The ovardites marking the transition between metabasalt and its calcschist cover are most probably originated from basalt flows, possible with addition of primary carbonate debris, alternatively from tuffites formed at their expense (Leardi et al., 1986) or by the ovarditization of the prasinites (Den Tex, 1987) as a product of metasomatic processes (Nicolas, 1966; Bearth, 1987; Chatterjee, 1971).

In the western Piedmont Zone, the well-preserved ophiolitic volcanic sequence in Montgenévre had been overprinted by prehnite-pumpellyite to greenschist facies metamorphism.

Veins filled with epidote, amphibole, albite, chlorite, prehnite, calcite and scarce by pumpellyite are attributed to ocean floor metamorphism. Primary cavities and tension cracks are filled by secondary minerals in the course of both ocean-floor and Alpine metamorphism. Similar data were recorded by Lewis and Smewing (1980).

The investigated W. Alps metavolcanics were derived by the fractionation of a tholeiitic magma similar to that producing N-MORB and metavolcanics Piedmont ophiolites. The distribution of some hydromagmatophile elements (i.e. Ti, Nb, Zr) indicates an origin from a mantle source already depleted in these elements and rather similar to the metavolcanics from other Piedmont ophiolites.

These derived from tholeiitic melts produced by partial melting during decompression of the asthenosphere already depleted in hydromagmatic elements.

REFERENCES

Bearth, P. (1967): Ophiolite der Zone von Zermatt-Saas Fee. Beitr.-Geol. Karte, Schweiz, N.F., **132**, 1-130.

Beccaluva, L., G.B. Piccardo (1978): Petrology of N. Apennine ophiolite and their significance in the Western Mediterranean area, Intern. Union Comm. Geodyn. Sci. Report, Stuttgart, **38**, p. 243-253.

Bertrand, I., B. Courtin, M. Vuagnat (1981): Le massif ophiolitique du Mongenévre (Hautes-Alpes, France et province de Turin, Italie) Données Nouvelles sur un vestige de manteau supérieur et de croute oceanique Liguro-piémontais. Bull. Suisse mineral. pétrogr., **61**, 305-322.

Bertrand, I., B. Courtin, M. Vuagnat (1982): Elaboration d'un sector de lithosphère océanique liguro-piémontaise d'après les données de l'ophiolite du Montgenévre (Hautes-Alpes, France et Province de Turin, Italie). Ofioliti, **7**, 155-196.

Bertrand, I., P. Nievergelt, M. Vuagnat (1985): Interpretation paléo-oceanique d'une série pélagique à matérial ophiolitique: La série de Chabriére, complexe de base du massif ophiolitique de Montgenévre (Alpes occidentales) C.R. Acad. Sc. Paris, **301**, II/16, 1199-1204.

Bertrand, I., V. Dietrich, P. Nievergelt, M. Vuagnat (1987): Comparative major and trace element geochemistry of gabbroic and volcanic rock sequences, Montgenévre ophiolite, W. Alps. Schweiz. Mineral Petrogr. Mitt., **67**, 147-169.

Bickle, M.J., J.A. Pearce (1975): Oceanic mafic rocks in the Eastern Alps. Contrib. Min. Petrol., **49**, 177-189.

Bocquet, I. (1974): Etudes mineralogiques et petrologiques sur les métamorphismes d'age alpin dans les Alpes françaises. These Univ. Grenoble, 489 pp.

Caby, R., J.R. Kienast, P. Saliot (1978): Structure, métamorphism et modele d'évolution tectoniques des Alpes occidentales. Rev. Geogr. Phys. Geol. Dyn., **20**, 307-311.

Cann, J.R. (1970): Rb, Sr, Y, Zr and Nb in some oceanic floor basaltic rocks. Earth Plant. Sci. Lett., **10**, 7-11.

Chatterjee, N.D. (1971): Phase equilibrium in the Alpine metamorphic rocks of the environs of the Dora Maire-massif, Western Italian Alps, Pt. I and II. N. Jahrb. Miner. Abh. **114**, 181-245.

Compagnoni, R., J.R. Kienast, B. Lombardo (1988): The Monviso eclogitic meta-ophiolite (Cottian Alps); in the IGCP Excursion to the Alps: HP eclogitic reequilibration in the W. Alps. Part **1**, 81-112.

Dal Piaz, G.V. (1974): Le métamorphisme eoalpine de haute pression et basse température dans L'evolution structurale du bassin ophiolitique alpine-apenninique. 1. Considération paleogéographiques. Boll. Soc. Geol. It., **93**, 437-468.

Dal Piaz, G.V., G. Venturelli, P. Spadea, G. Battistini (1981): Geochemical features of metabasalts and metagabbros from the Piemonte ophiolite nappe, Italian Western Alps. Neues Jahrb. Mineral. Abh., **142**, 248-269.

Den Tex, E. (1987): Two ovardite occurrences in the Piemonte Ophiolite Nappe of the Cottian Alps (NW Italy) and their significance for the process of ovarditization. Schweiz. Miner. Petrogr. Mitt., **67**, 137-146.

Floyed, P.A., J.A. Winchester (1975): Magma type and tectonic setting using immobile elements. Earth Plant. Sci. Lett., **27**, 211-218.

Kienast, J.R., B. Messiga (1987): Cr-rich chloritoid, a first record in HP metagabbros from Monviso (Cottian Alps), Italy. Min. Mag., **51**, 681-687.

Lagabrielle, Y., I. Cotten (1984): Le material detritique ophiolitiques des Liguro-Piemontaises, L'example du Hant-Queyras. Contribution A L'etude prasinites, Ofioliti, **9**, 1, 43-66.

Langmuir, C.H., J.F. Bender, A.E. Bence, G.N. Hanson (1977): Petrogenesis of basalts from the FAMOUS area, Mid-Atlantic Ridge. Earth Plant. Sc. Lett., **36**, 133-156.

Lardeaux, I.M., P. Nisio, M. Boudeulle (1987): Deformational and metamorphic history at Lago Superiore area of the Monviso ophiolitic complex (Italian W. Alps): a record of subduction-collision cycle? Ofioliti, **12**, 479-502.

Leardi, L., P. Rossetti, G.M. Crisci (1986): Greenschist altered metabasalts (ovardite) from Torre d'Ovarda (Val d'Ala, Graian Alps). Ofioliti, **11**, 3, 263-274.

Le Roex, A.P., H.J.B. Dick, A.M. Reid, A.J. Erlank (1982): Ferrobasalts from the Spiess Ridge segment of the Southwest Indian Ridge. Earth Planet. Sci. Lett., **60**, 437-451.

Lewis, A.D., I.D. Smewing (1980): The Montgenévre ophiolite (Haute Alpes, France): metamorphism and trace element geochemistry of the volcanic sequence. Chem. Geol., **28**, 291-306.

Lombardo, B. (1988): The main tectonic and paleogeographic domains, in Piccardo G.B (ed.): IGCP 235 Excursion to the Alps, Geological Framework of the W. Alps, Torino-Genova, p. 2-3.

Lombardo, B., R. Compagnoni, B. Messiga, J.R. Kienast, C. Mével, I. Fiora, G.B. Piccardo, R. Lanza (1978): Osservazioni preliminari sulle ofioliti metamorfiche del Monviso (Alpi occidentali). Rend. Soc. It. Min. Petrol., **34**, 2, 253-305.

Mével, C. (1975): Les "pillow-lavas" spilitiques des massif ophiolitiques du Chenaillet et des Gets (Alpes françaises). Thesis, Pierre et Marie Curie Univ., Paris.

Mével, C., J.R. Kienast (1980): Chromian jadeite, phengite, pumpellyite and lawsonite in a high-pressure metamorphosed gabbro from the French Alps. Min. Mag., **V**, 43, 979-984.

Monviso (1980): The Monviso ophiolite complex. Intern. Ophio. Sym. Cyprus, Geol. Surv. Dept., p. 332-340.

Nicolas, A. (1966): Le complexe ophiolites - schistes lustrés entre Dora Maire et Grand Paradis (Alpes Piemontaises). I. Etude petrographique des roches vertes et de leurs mineraux. Thése d'état, Univ. de Nantes, 178 pp.

Nisio, P. (1985): Les domaines d'antiphase des omphacités et al petrologie des eclogites: contribution à l'étude de l'evolution tectonométamorphique du Monviso (Alpes italiennes occidentales). Thése, Univ. Claude Bernard, Lyon, 137 pp.

Nisio, P., I.M. Lardeaux (1987): Petromorphic Fe-rich talc in LT-eclogites: example from Monviso (Italian W. Alps). Bull. Mineral., **110**, 427-437.

Pearce, J.A. (1975): Basalt geochemistry used to investigate past tectonic environment on Cyprus. Tectonophy., **25**, 41-68.

Pearce, J.A., J.R. Cann (1973): Tectonic setting of basic volcanic rocks determined using trace element analyses. Earth Plant. Sc. Lett., **19**, 290-300.

Pearce, J.A., M.F.J. Flower (1977): The relative importance of petrogenetic variables in magma genesis at accreting plate margins: a preliminary investigation. J. Geol. Soc. London, **134**, 103-127.

Piccardo, G.B., B. Messiga, A. Maazucotelli (1979): Chemical petrology and geodynamic evolution of the ophiolitic metavolcanites (prasinites) from the Voltri Massif, Piedmontese Ophiolite Nappe (W. Ligurian, Italy), Ofioliti, **4**, 373-402.

Pognante, U., U. Rösli, L. Toscani (1985): Petrology of ultramafic and mafic rocks from the Lanzo peridotite. Lithos., **18**, 201-214.

Sandrone, R., L. Leardi, P. Rossetti, R. Compagnoni (1986): P-T conditions for the eclogitic re-equilibration of the metaophiolites from Val A'Ala di Lanzo (internal Piemontese zone, W. Alps). J. Metamorph. Geol., **4**, 161-178.

Sun, S.S., R.W. Nesbitt, A.Y. Sharaskin (1979): Geochemical characteristics of mid-ocean ridge basalts. Earth Planet. Sci. Lett., **44**, 119-138.

Treuil, M., J.L. Joron (1975): Utilisation des éléments hydromagmatophiles pour la simplification de la modelisation quantitative des processes magmatiques. Examples de l'Afar et la dorsale medio-atlantiques. Rend. Soc. It. Min. Petr., **31**, 125-174.

Wood, D.A., J. Tarney, J. Varent, A.D. Saunders, H. Bougault, J.L. Jorron, M. Treuil, J.R. Cann (1979a): Geochemistry of basalts drilled in the N. Atlantic by IPOD Leg. 49-implications for mantle heterogeneity. Earth Planet. Sci. Lett., **42**, 77-97.

Fig. 2

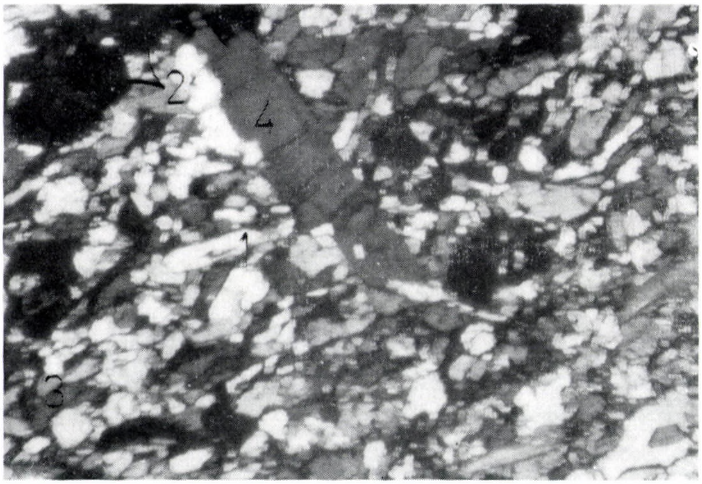
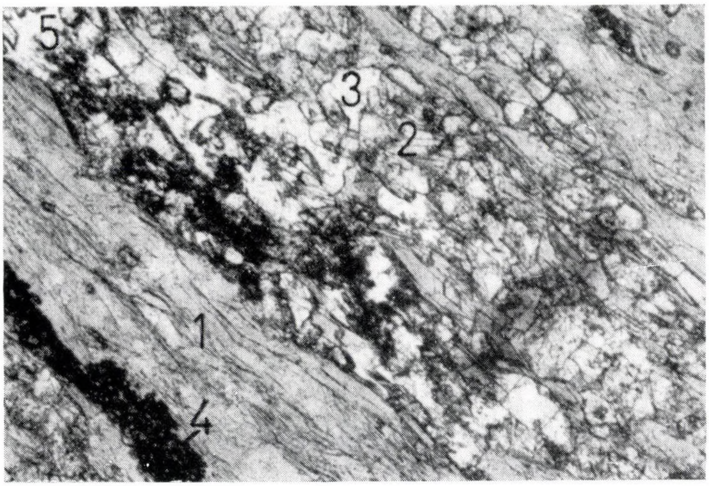


Fig. 3



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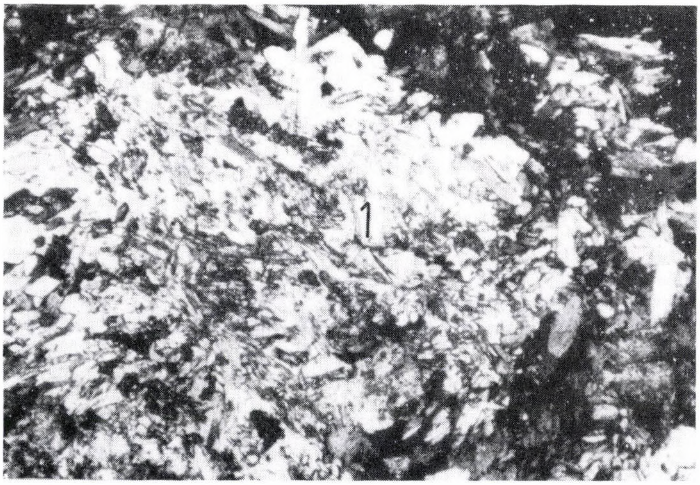

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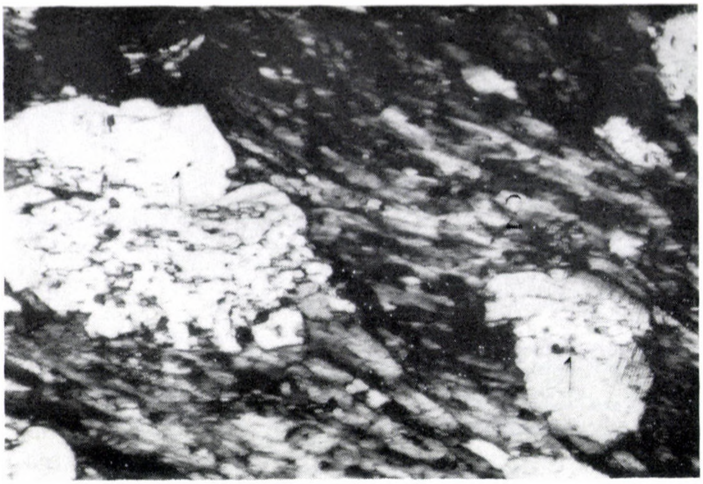

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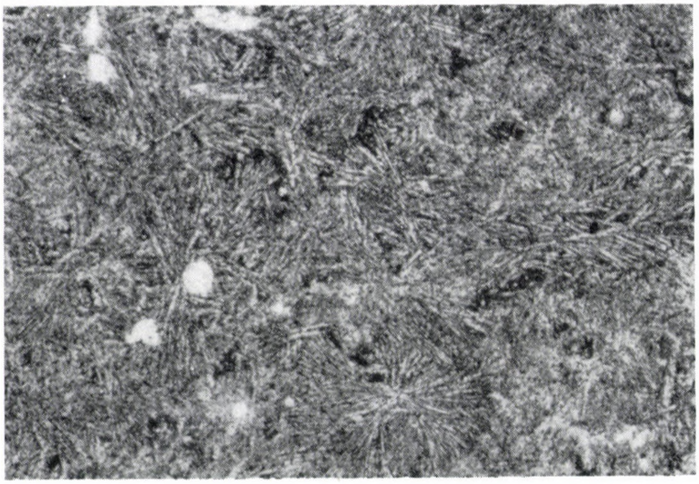

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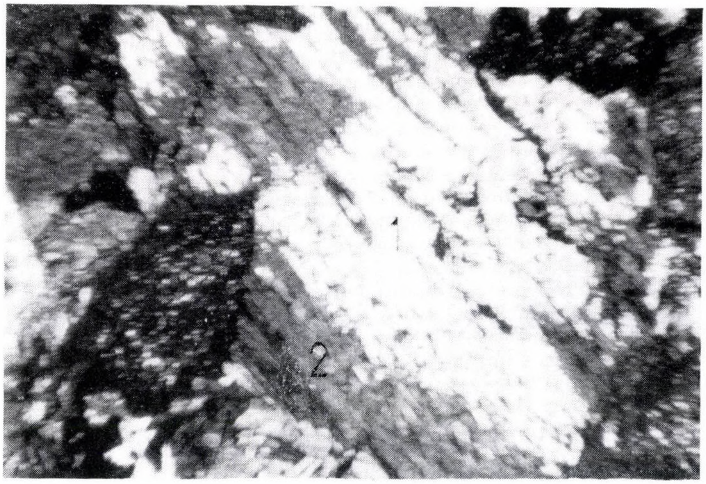

Fig. 9

Fig. 2. Field photo of the prasinites from Lago Lausettto (Monviso) showing a thin layering of different colours and minerals and quartz-filling fracture

Fig. 3. Photomicrograph of eclogitic metabasalts from Monviso (W. Alps) showing the abundance of omphacite (1) granet (2) clinozoisite (3) and glaucophane (4). C.N., M = 58

Fig. 4. Photomicrograph of the glaucophanite from Petit Belvedere (Monviso), W. Alps showing thin layering of abundant glaucophane (1), epidote (2), chlorite (3), leucoxene (4) and albite (5). P.P., M = 67

Fig. 5. Photomicrograph of the prasinite from Pre clos la Clapera (Arc), W. Alps showing a poikiloblastic albite metabasalt (1) enclosing fine inclusions of amphibole, epidote, chlorite, titanite and phengite, C.N., M = 67

Fig. 6. Photomicrograph of the ovardite from Refuge d'Averole (Arc), W. Alps showing ovoidal albite poikiloblast (1) embedded in the chlorite matrix (2). The albite contains fine trails of oriented chlorite and scarce amphibole, C.N., M = 67

Fig. 7. Photomicrograph of the metabasalt pillow lava margin from Chenaillet, W. Alps showing variolitic, arborescent and fishbone texture. Some vesicles filled by chlorite are shown. P.P., M = 67

Fig. 8. Photomicrograph of the metadoleritic lava flow and dyke from Chenaillet, W. Alps showing the pseudomorphic replacement of olivine phenocryst (1) by epidote (2) and chlorite (3) which is embedded in variolitic matrix. C.N., M = 67

Fig. 9. Photomicrograph of the microgabbro from Chenaillet, W. Alps showing the replacement of the cpx (1) by hornblendic amphibole (2) along the margin. The Ca-plagioclase is altered to saussurite. C.N., M = 58

Acta Geologica Hungarica, Vol. 33/1-4, pp. 97-104 (1990)

DIAGENETIC TRANSFORMATION OF MAGNESIUM-CALCITE IN ECHINODERM, A MONOCRYSTALLINE ROCK-FORMING CARBONATE SKELETON

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As is the case with their polycrystalline counterparts, the diagenetic stabilization of monocrystalline rock-forming carbonate skeletons which consist of the metastable calcium carbonate phase, magnesium calcite, is controlled by the process of dissolution and reprecipitation.

In this study, the meteoric diagenesis of echinoderm skeletal parts - single crystals consisting of Mg-calcite - is examined experimentally. Experiments simulating as much as possible natural meteoric vadose conditions were performed and the properties of the products were compared with those of the starting materials using standard analytical procedures. By far the most informative result was yielded by scanning electron microscopy.

It is found that in monocrystalline skeletons such as echinoderms, the monocrystals are preserved during diagenesis, despite the necessarily destructive dissolution-reprecipitation process. In addition, overgrowths on the precursor monocrystal skeletal grains are epitaxial, inheriting crystallographic information from their precursors. It is known that carbonate crystals undergoing dissolution diagenesis do so not only over geologically long periods of time, but also in most cases piecewise, slowly and on the ultrascale. In this way portions of it are always available to serve as seed for the epitaxial growth of calcite. And once single-crystal growth is seeded, provided growth rate, solution supersaturation and temperature are low enough to discourage spontaneous nucleation, the materials will continue to grow as a single crystal.

Keywords: Diagenesis, echinoderms, rock-forming carbonate

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Received: 05/05/89

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Introduction

Echinoderm skeletal parts are often preserved in carbonate rocks as fossils where they may constitute a substantial percentage of the allochem or bioclastic fraction. They are, therefore important rockforming carbonate skeletons.

Their skeletal elements (plates, spines, sclerites, etc.) being single crystals are easily identified under the polarizing microscope. However, skeletal elements are highly porous, attaining porosity values of 50% and more (Oti, 1980), and their geometry very irregular (Fig. 1a) leading to earlier doubts as to its monocrystallinity, and to the still unresolved question of its mode of diagenesis.

The monocrystalline nature of echinoderm skeletal parts is of prime importance to its mechanism of diagenesis. Fossil particles of echinoderm in ancient sedimentary rocks consist of calcite, as against metastable magnesium calcite which constitute recent forms, yet details of their ultrastructures and crystallography are replicated after they have been diagenetically transformed to calcite. Indeed, pore-filling cement of the stereom and authigenic calcite are epitaxial and in optical continuity with the original detrital particles. If the calcite in the ancient organism was originally Mg-calcite (as we must assume in compliance with the uniformitarian principle) then the magnesium must have been lost either by dissolution-precipitation or by incongruent dissolution.

Bathurst (1975) argued that the slow rate of lattice diffusion would render incongruent dissolution hard to justify, and that dissolution-precipitation (calcitization), on the other hand, would imply a total exchange of cations and CO_3^{2-} groups with the pore water during diagenesis.

The problem of diagenesis of echinodermal skeletal parts falls, however, within the broader context of the diagenesis of magnesium-calcites generally. Oti-Muller (1985) have shown that the diagenetic stabilization of Mg-calcite is controlled by the process of dissolution-precipitation. Working on specimens of Recent and fossil lithothamnium and comparing the results of their experimental products with natural ancient limestones, these authors found that the transformation appeared to be structure-preserving only at the macro- and micro-levels but not at the ultra-levels. X-ray diffraction and isotope studies also clearly indicated a dissolution-precipitation mechanism. The carbon isotope work of Manze-Richer (1979) on the sea urchin Echinocyamus pusilus from the Pliocene and Quaternary sediments of Greece confirmed Bathurst's (1971) argument that a skeleton altered by dissolution-precipitation will acquire a totally new suite of CO_3^{2-} groups with new values of $\delta^{18}O$ and $\delta^{13}C$. Manze and Richter (op. cit.) noted a correlation between progress of diagenesis and ^{13}C_ loss in the echinoderm tests.

The pertinent question, therefore, is exactly how does an echinoid skeleton dissolve and reprecipitate with crystallographic information transmitted from the old to the new crystal?

Materials and Methods

The material, recent specimens of spines of the echinoderm E. pusilus from the pacific coast of Kenya was crushed into sand-sized fragments, treated with "Chlorox" (sodium hypochlorite, pH=8) for 24 hours to oxidize the organic matter, and then examined under the SEM to ensure that no surfaces had been etched.

X-rax Diffractometry

For identifying the mineralogical phases present a Philips XRD was used. Samples were ground into powder and irradiated with Ni-filtered CuK X-rays from 26 degrees to 32 degrees 2θ. Scan speed and paper speed were 1/8 degree/min and 5mm/min, respectively.

Scanning Electron Microscopy

Sand-sized grains of the material before and after experimentation were coated with gold and scanned with secondary electrons using a Cambridge Stereoscan Model S4-10.

Petrophysical Analysis

The specific surface area, total porosity and pore radii distribution were determined. The specific surface area (S_g) was determined by the BET method in which nitrogen is adsorbed at low temperatures on internal and external surfaces. Measurements were carried out with the Area Meter using the procedure described by Haul-Dumbgen (1960) by which only one point of the adsorption isotherm is registered. Total porosity measurements were carried out using the buoyancy method, a short description of which is given by Muller (1967).

Determination of the pore radii distribution was accomplished using the principle of mercury injection. The equipment used (Porosimetro 65) is capable of measuring pore radii between 75 Å and 75000 Å. Details of limitations and sources of error in mercury porosimetry have been discussed by Oti-Muller (1979). The acid-soluble organic matter content was determined with the Mass Spectrometer.

Dissolution and Precipitation Experiments

As shown by Oti-Muller (1985) only one diagenetic reaction is responsible for the transformation of Mg-calcites under meteoric conditions:

$$xH^{+} + (Ca_{1-x}M_{g})\ CO_{3calc.} \qquad xMg^{++}_{aq} + xHCO^{-}_{3aq} + (1-x)CaCO_{3calc.}$$

This reaction describes the loss to solution of $MgCO_3$ from magnesium calcites in a dissolution-precipitation process. In an Erlenmeyer flask sealed with parafilm and containing 1 litre distilled water 2 grams of the sand-sized grains of the echinodern skeletal material were placed and the flask set up on a shaker apparatus for a period of one year. Carbon dioxide partial pressure inside the flask was in equilibrium with atmospheric CO_2 i.e. $10^{-3.5}$ atm. Temperature was maintained throughout at 25 ^{o}C. A parallel experiment was run with conditions same as above except for the addition of 10 g $CaCl_2 \cdot 2H_2O$ to provide Ca for a possible exchange with Mg if cation exchange (or incongruent dissolution) was to be verified as possible mechanism of diagenesis.

Results

Structural and Compositional Properties of the Echinoid Spine

The microarchitecture of echinoid spines generally has been well studied by Raup (1966), Towe (1967) and Weber (1969). The structure is fenestrate with porosity as high as 50% and over (Oti, 1980). The stereom opens to the outside through longitudinally arranged openings. In the species studied, the cross-section is characterized by rings which may represent growth rings. The compositional and petrophysical data obtained by the analytical methods applied are as follows:

Table I

Compositional and Petrophysical Data of the Echinoid spine studied

Mineralogic composition	Amount $MgCO_3$ in solid solution	Specific surface area	Total porosity	Amount C-org
98.0% Mg-calcite	10.3 mol %	0.01 (m^2/g)	56.68%	1.30%

Rotation and Weissenberg photographs showed typical reflections of a single crystal. From the photographs the lattice parameters were calculated with a = 4.96 Å and c = 16.99 Å. The values for pure calcite are a = 4.989 Å and c = 17.062 Å (JCPDS Card No. 5-586). The unit cell volume of the echinoderm calcite lattice, therefore, is about 1.6% lower. This is in agreement with the fact that in the lattice of echinoderm calcite calcium is partly substituted by magnesium. Oti (1980) established an amount of 10.3 mole% causing the mentioned shrinkage. Thus, the echinoderm spine represent a solid solution of type:

$$(Ca_{1-x}Mg_x)CO_3;\ \text{with } x = 0.1 \quad .$$

Dissolution-Precipitation Experiments: Results

From the dissolution and precipitation experiments no appreciable amount of calcite detectable with the XRD had formed after one year of experimentation. However, dissolution and reprecipitation textures were clearly evident (Figs 1a, b, c). Minute rhombs of calcite with the calcite space group R3c had formed and had precipitated on the hitherto smooth inner surfaces of the stereom (Fig. 1d, arrow). It should be noted that the reprecipitated calcite is firmly rooted in the magnesium-calcite template.

Discussion

The purpose of this paper is to attempt to unravel by what mechanism the monocrystalline form of biogenic Mg-calcite materials is preserved in the necessarily destructive process of its (dissolution-precipitation) diagenesis. The preservation of the monocrystals of echinoderms through the lattice destruction and reassembly that accompany their diagenetic transformation raises interesting questions. There are really two aspects to the problem. One is morphologic, the other crystallographic: (1) how does a single-crystal echinoid skeleton undergoing diagenesis by dissolution-precipitation reproduce its detailed, complex morphology; and (2) how is the single crystal form retained in that reproduction? The first part may be answered by referring to the observation of Oti-Muller (1985) relating to the same phenomenon in polycrystalline red algal skeletons. The progressive but localized process of dissolution-precipitation confines the product to the same shape as the starting skeletons, regardless of whether the beginning and end materials are single crystals or polycrystalline aggregates. This is a simple phenomenon, analogous to the gradual burning of a thread from one end: if it is lying on a flat surface and free of stress, the combustion product will inherit the gross pseudomorphosis of the original thread.

The shape-confining effect of a localized and slowly-travelling liquid feedstock in crystal growth is similar. It is used to advantage in the controlled growth of shaped single crystals in industry, notably of ceramic compounds. Techniques such as the "floating zone" method and the "edge-defined, film-fed growth" or EFG technique (La-Belle, 1971) rely on this phenomenon. The principle is that by confining the crystal regeneration from liquid to a travelling zone of such a small scale that capillary forces can sustain shape, the product crystal can be shaped as desired. Except for the effect of the chemistry of the solution, there is no difference in the theory of crystal growth between growth from melt and growth from solution (Burton, Cabrera-Frank, 1951). So it is expected that the same shape-reproducing principle can apply in our case: the sharply localised dissolution-precipitation of echinoid skeletal crystal during diagenesis. Thus would morphologic information be transmitted to the new crystal through the template effect of the parent crystal.

The second aspect of the question may be answered by recourse to the theory of crystal growth and, again, to the localized nature of the growth. Because the skeletal crystal dissolves piecewise and slowly, on a microscale, portions of it are always available to serve as seed for the epitaxial growth of calcite. And once single crystal growth is seeded, provided growth rate, solution supersaturation and temperature are low enough to discourage spontaneous nucleation, the material is energetically favoured to continue to grow as single crystal. While the seed determines the crystallography of the product, the template determines its morphology; the only "peculiarity" is that the old crystal (Mg-calcite) serves as both seed and template for the generation of the new (calcite).

There have been numerous investigations of the crystal growth behaviour of calcium-based minerals of animal skeletal materials, both from simple inorganic solutions and from simulated physiological fluids. Eanes (1980) Nancollas-Koutsouko (1980), and Legeros (1981) provide comprehensive reviews of these. The reported findings and the conclusions are in agreement with the model proposed here.

Acknowledgement

The first author (MNO) gratefully acknowledges Professor German Muller, Director of the Institut für Sedimentforschung of the University of Heidelberg, in whose Institute the bulk of the work reported here was carried out.

REFERENCES

Bathurst, R.G.C. (1975): Carbonate Sediments and their diagenesis. Developments in Sedimentology 12. Elsevier, Amsterdam 658.

Burton, W.K., N. Cabrera, F.C. Frank (1951): The growth of crystals and the equilibrium structure of their surfaces. Phil. Trans. Roy. Soc. Lond., A243, 299-358.

Eanes, E.D. (1980): Crystal growth of mineral phases in skeletal tissues. Prog. Crystal Growth - Characterization, **3**, 3-15.

Haul, R., G. Dumbgen (1960): Vereinfachte Methode zur Messung von Oberflächengrössen durch Gasabsorption. Chem. Ing. Tech., **32**, 349-359.

LaBelle, H.E. (1971): Growth of controlled-profile crystals from the melt: Part II, Edge-Defined, Film-fed Growth (EFG). Materials Research Bulletin, **6**, 581-590.

Legeros, R.Z. (1981): Apatites in biological systems. Prog. Crystal Growth and Characterization, **4**, 1-45.

Manze, U., D.K. Richter (1979): Die Veränderung des $^{12}C/^{12}C$ - Verhältnisses in Seeigelcronen bei der Umwandlung von Mg-calcit unter meteorisch-vadosen Bedingungen. N. Jb. Geol. Palaeont. Abh., **158**, 3, 334-345.

Muller, G. (1967): Methods in sedimentary petrology. E. Schweizerbartäsche Verlagsbuchhandlung, Stuttgart, 283.

Nancollas, G.H., Koutsoukos (1980): Calcium phosphate nucleation and growth in solution. Prog. Crystal Growth and Characterization. **3**, 77-102.

Oti, M.N. (1980): Experimental and Natural Diagenesis of Coralline Algal Allochems: A Contribution to the Diagenesis of Magnesium-Calcites. Doktorarbeit, Universität Heidelberg, 153.

Oti, M.N., G. Muller (1979): Recent doids from different environments: relationship between petrophysical properties and microstructure. Erdoel and Kohle, Erdgas, Petrochemie, **32**, 3, 107-115.

Oti, M.N., G. Muller (1985): Textural and mineralogical changes in coralline algae during meteoric diagenesis: an experimental approach. N. Jb. Miner. Abh., **151**, 2, 163-195.

Raup, D.M. (195): Crystallography in echinoid calcite. J. Geol. **67**, 661-674.

Towe, K.M. (1967): Echinoderm calcite: single crystal or polycrystalline aggregate. Science, **157**, 1048-1050.

Weber, J.N. (1969): The Incorporation of magnesium into the skeleton of echinoderms. Am. J. Sci., **267**, 537-566.

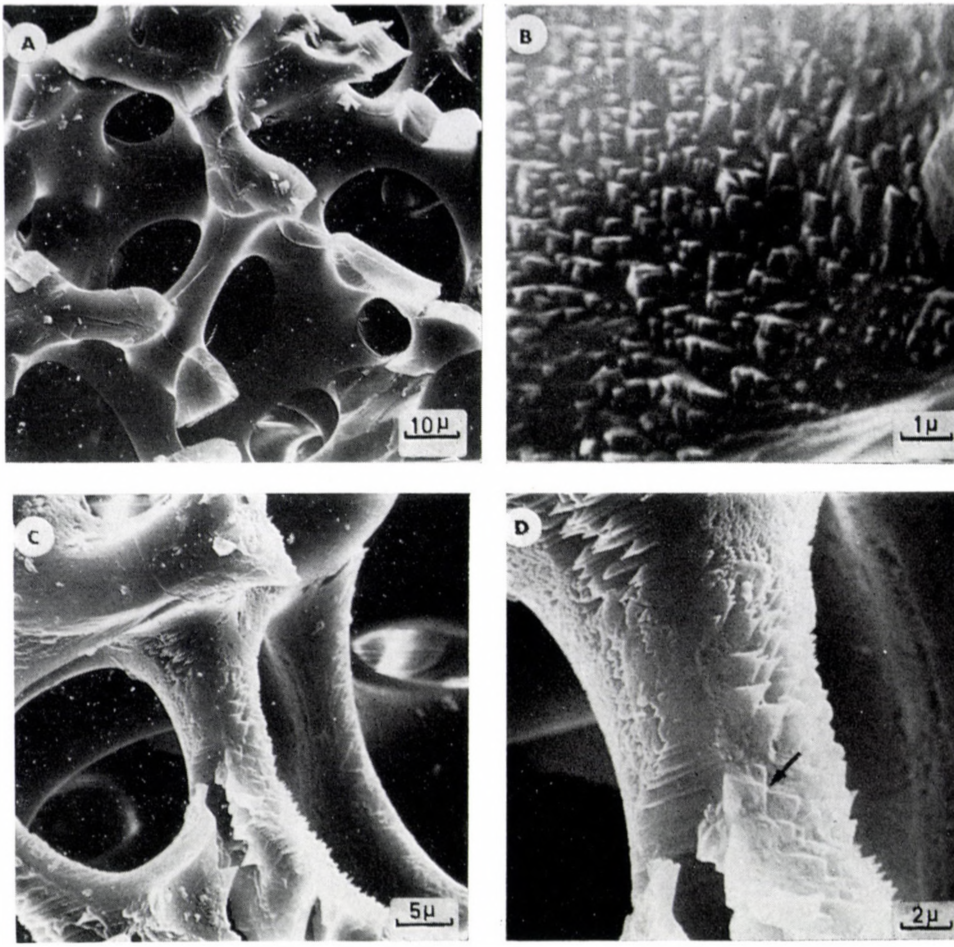

Fig. 1. Scanning Electron Micrographs of Spine of Echinoderm spp. showing diagenetic alterations under experimental meteoric conditions. (a) Stereom of spine showing fenestrate porosity, smooth fracture surfaces before onset of experimental diagenesis. (b) Fracture surface in stereom showing incipient growth of new crystallites of calcite after one year of experimentation. Note parallel orientation of crystallographic directions in dissolving template (Mg-calcite) and new crystals (calcite). (c) Framework elements of stereom showing dissolution and precipitation ultratextures after one year. (d) Same as in c, but at higher magnification. Skeletal material composed of Mg-calcite is dissolving while calcite is precipitating at lower part of structure (arrow). Because of crystallographic similarity, Mg-calcite skeleton is serving as both template and seed for the precipitation of calcite

Acta Geologica Hungarica, Vol. 33/1-4, pp. 105-119 (1990)

GEOCHEMISTRY OF Mg-Al RICH METAGABBROS AND Fe-Ti RICH METAGABBROS AND ALBITITES FROM THE WESTERN ALPS OPHIOLITES

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The geochemistry of three suites of metagabbros and albitites from Piedmont Zone (Western Alps) metaophiolite were investigated and compared with data obtained from other ophiolites of the Western Alps.

The Mg-Al rich and Fe-Ti rich metagabbros preserved their tholeiitic affinity and belong to the high-Ti-ophiolite and usually fall within the oceanic gabbros and mafic cumulate fields on the diagrams.

The Mg-Al metagabbros show higher contents of MgO, Al_2O_3, SiO_2 and CaO and low values of FeO^+/FeO^++MgO, TiO_2 and P_2O_5. They are considered as low level gabbros derived from a primitive magma. The Fe-Ti metagabbros reflect the highest contents of FeO, TiO_2 and P_2O_5 and lower values of SiO_2 and Al_2O_3, produced from high differentiated magma formed at high level depths.

There is another altered intermediate gabbro between the above mentioned two type of gabbros.

In comparison with the other two gabbros, it has higher contents of Na_2O and K_2O due to the retrograde metamorphism and lower values of MgO. That means, it may have a calc-alkaline character.

On the other hand, the albitite has higher SiO_2, Al_2O_3 and Na_2O and very low K_2O and it's rather of calc-alkaline character than the gabbros.

Keywords: Ophiolites geochemistry, Mg-Al rich metagabbros, intermediate altered gabbros, Fe-Ti rich metagabbros, albitites, Piedmont Zone, Western Alps.

Introduction

The gabbroic complex from the Piedmont Zone of the Western Alps was considered to constitute a part of a Late Cretaceous subduction of the Late Jurassic-Cretaceous oceanic lithosphere (Dal Piaz, 1974).

These generally underwent eclogitic to blueschist conditions and thrusted over the continental units, sometimes were accompanied by plastic

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deformation resulting in mainly shearing and flaser textures. Subsequently, these were affected by a partial metamorphic reequilibration under greenschist conditions.

The Mg-type and Fe-gabbros are well known from the Atlantic and Indian oceanic crust (Miyashiro et al., 1970; Bonatti et al., 1971; Thompson, 1973; Prinz et al., 1976; Caytrough, 1979) and from some ophiolite complexes from the Western Alps (Beccaluva et al., 1976, 1977; Church and Riccio, 1977; Dal Piaz et al., 1981; Lombardo et al., 1978, 1982; Pognante et al., 1982; Bertrand et al., 1987), but they are typically absent in other ophiolites.

In this paper three representative gabbro suites are presented from Refuge d'Averole (Arc valley), Chenaillet (Mongenévre), and Petit Belvedere, Colletto Fiorenza and Lago Chiaretto (Monviso), see: Kubovics-Abdel-Karim, in this volume p. 79), consist mainly of Mg-Al metagabbros, Fe-Ti metagabbros, altered intermediate gabbros and scarcely albitites (Montgenévre) from Piedmont Zone, Western Alps metaophiolite.

The petrochemistry and peterogenesis of these gabbros are discussed and compared.

Field Relationships

The greenschist facies metagabbros from Refuge d'Averole (Arc valley) are heterogeneous metamorphic rocks which are strongly affected by Alpine deformation. These occur at the western margin of the Lanzo massif, and are overlain by metaultramafics and underlain by metabasites.

The Chenaillet gabbroic rocks (Montgenévre) are the best preserved and complete gabbroic sequence. The primary structure is well preserved. These usually occur as separate tectonic unit, have ultramafic and basaltic lithologies and are partly differentiated into albitite.

The metagabbros of Monviso occur sometimes within the eclogitic sequence and represent the most complete metamorphic section characterized by eclogitic, glaucophane schist and greenschist facies conditions. These exhibit a well developed foliation. Some gabbros are crosscut by metabasalt dykes. Afew of gabbroic rocks are not affected by the Alpine metamorphism but are plastically deformed and banded.

Petrographic features

The petrographic features of metagabbros and albitites from Arc valley, Montgenévre and Monviso suites are summarized in Table I.

Table I

Main petrographic features of representative rocks from W. Alps metagabbros

Rock name	Texture	Main primary minerals	Main secondary minerals
1. Arc valley (Refuge d'Averole):			
I-Clinoz-chl-greensch. facies metagab.	poikil, she.	-	chl, clinoz, actin, trem, ab, gar, tit.
II.Chl-actin-greensch. facies metagab.	porph, poikil, flas.	-	actin-trem, chl, ab, clinoz, ep. leuc.
2. Monviso	1. Petit Belvedere		
I- Cor-cumm-gab.	pseudooph, Sch.	cor, cum, pl.	preh, chl, white mica.
II.She-cpx metagab.	oph, she, kink.	cpx	trem-actin, ep, leuc, cc, preh, glau.
	2. Colletto Fiorenza:		
Smaragdite metagab.	porph	cpx	Cr-omp, trem, jad, talc, ab, qz, chl, gar, tit.
	3. Lago Chiaretto:		
Eclogitic metagab.	porph, sch.	cpx, rut	omp, trem, gar, qz, blue amp, preh, phen.
3. Montgenévre (Chenaillet):			
Chloritized metagab.	hypid.	pl.	chl, ep, preh, tit.
Cpx metagab.	flas, hypid.	cpx, pl. Fe oxide	amp, ep, clinoz, chl.
Albitite	hypid, gran, catacl.	olig, qz, amp, bio, tit.	chl, ep, ab.

Abbreviations: cor: corundum, cpx: clinopyroxene, jad: jadeite, omp: omphacite, amp: amphibole, cum: cummingtonite, glau: glaucophane, trem-actin: tremolite-actinolite, ep: epidote, clinoz: clinozoisite, zo: zoisite, chl: chlorite, preh: prehnite, cc: calcite, leuc: leucoxene, rut: rutile, tit: titanite, bio: biotite, phen: phengite, olig: oligoclase, ab: albite, gar: garnet, qz: quartz, porph: porphyroblastic, poikil: poikiloblastic, flas: flaser, hypid: hypidiomorphic, oph: ophitic, pseudoph: pseudoophitic, she: sheared, kink: kinking, sch: schistose, catacl: cataclastic, gab: gabbro, metagab: metagabbro

1. The greenschist facies metagabbros from Refuge D'Averole (Arc) consist of clinozoisite-chlorite greenschist facies metagabbro (Sample 1) and chlorite-actinolite greenschist facies metagabbro (Sample 2). In the first one the primary texture nearly disappeared and the magmatic minerals were preserved only in relics of clinopyroxene. These are composed essentially of Mg-chlorite, clinozoisite-epidote, albite, actinolite, tremolite and garnet with minor titanite and Fe oxide. The other gabbro shows some large crystals of actinolitic amphibole (pseudomorph after magmatic cpx), while the granoblastic matrix consists of albite, epidote/clinozoisite, chlorite, actinolite/tremolite and minor titanite-leucoxene and calcite (Table I).

2. The one type of Monviso metagabbros are corundum-cummingtonite-metagabbros (Sample 3) representing the less metamorphosed gabbros. The primary magmatic minerals (corundum, cummingtonitic amphibole and plagioclase) are plastically deformed and banded. The accessoires are represented by prehnite, chlorite and white mica. The sheared cpx metagabbors (Sample 4, 5, 6, 7) are either massive or layered and varying in grain size, and only the cpx survived amidst the primary minerals. The primary cpx is usually phenocryst with two generations and is strongly sheared and kink-banded and rimmed by hornblendic amphibole. The plagioclase was replaced by albite and saussurite. The smaragdite metagabbro (Sample 8) exhibits a foliation and consists of bright green smaragdite phenoclasts in a whitish matrix. The magmatic cpx was replaced by single crystals of Cr-omphacite, +/- tremolite, +/- talc or by an aggregate of omphacite. Plagioclase is totally transformed into jadeite, albite, chlorite and zoisite. It sometimes regressed into greenschist facies mineral assemblages. In the eclogitic metagabbro (Sample 9) the magmatic cpx is transformed into omphacite. It consists of porphyroclastic omphacite in a matrix of tremolite, zoisite, omphacite, garnet and rutile and accessory apatite, quartz and titanite. Phenoblasts of blue amphibole and phengite are locally found.

3. We collected chloritized metagabbros (Sample 10) from the Chenaillet metagabbros (Montgenévre) which are characterized by plagioclase and Fe-chlorite and accessory epidote, titanite and prehnite. The pyroxene is completely pseudomorphic transformed into a single crystal of chlorite.

The cpx metagabbros show magmatic cpx in addition to plagioclase. The amphibole, epidote/clinozoisite, chlorite and iron oxide are subordinate.

The cpy is usually kink-banded and altered into hornblendic and actinolitic amphibole and scarce into chlorite. The albitites (samples 13

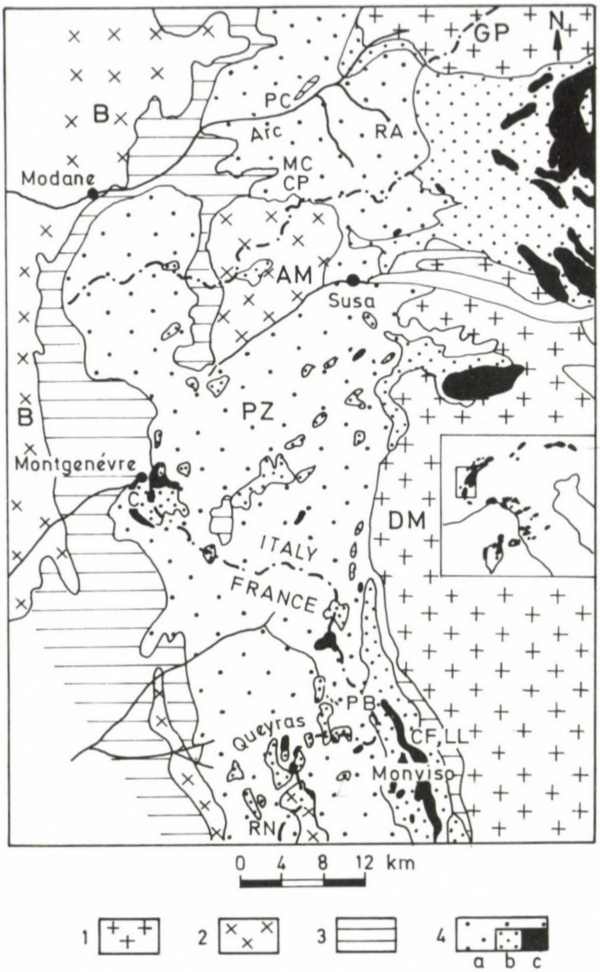

Fig. 1. Tectonic sketch map of the internal Western Alps showing the location of the main ophiolite complexes. 1. Dora-Maire (DM) and Gran Paradiso (GP) continental units (European Paleomargin); 2. Vanoise, Ambin (AM) and Brianconnais (B) continental units (European Paleomargin); 3. Mesozoic epicontinental covers; 4. Piedmont Zones (PZ), Schistes Lustrés nappe (Mesozoic, mainly oceanic material): a) undifferentiated metasediments with subordinate ophiolites; b) ophiolite complex with minor metasediments; c) metagabbro bodies. Location of samples: R) Refuge d'Averole, P) Petit Belvedere, F) Colletto Fiorenza, C) Chenaillet

and 14) represent the final product of a differentiation of the gabbroic magma and are characterized by the predominating plagioclase (oligoclase-albite) with minor amphibole, quartz, biotite, titanite, chlorite and epidote and show cataclastic deformation and recrystallization.

Analytical Methods

Nine selected samples from Refuge d'Averole (Arc valley), Petit Belvedere, Colletto Fiorenza and Lago Chiaretto (Monviso) and Chenaillet (Montgenévre), Western Alps were analyzed for major elements. With the aim of comparison we adapted five published analyses, as well. The location of the samples are plotted in Fig. 1 and the chemical data are shown in Table II.

Si was determined thermogravimetrically as potassium silicofluoride, using Sajo's method (1955). The Fe^{II} was analyzed using Hoffmann's method (301/86 OTK Patent), while the Fe^{III} was computed by the difference between FeO and total Fe. Al, total Fe, Mg, Ca, Na, K and Mn were measured by atomic absorption spectrophotometry using a Varian AA 475. Other elements were determined spectrophotometrically: P as molybdenum-blue and Ti as titan-yellow. H_2O was determined by DTA method. The analyses were carried out by L. Hoffmann in the Department of Petrology and Geochemistry, Eötvös Loránd University, Budapest.

Bulk Rock Chemistry

Major element composition (Table II) and their variations against FeO^+/FeO^++MgO (Fig. 2) are consistent with the mineral and textural evidences of most metagabbroic rocks.

According to the chemical as well as mineral compositions, the gabbroic rocks can be grouped into: Mg-Al metagabbros, intermediate altered gabbros and Fe-Ti metagabbros.

The Mg-Al metagabbros include the greenschist metagabbros (Refuge d'Averole, Arc valley), corundum-cummingtonite metagabbros and sheared cpx-metagabbros (Petit Belvedere, French Monviso), smaragdite metagabbros (Colletto Fiorenza, Italian Monviso) and chloritized metagabbros (Chenaillet,

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$^+$FeO: total FeO

Table II

Chemical composition of representative rock types from the Western Alps ophiolitic metagabbros

Locality	Arc valley Refuge d'Averole		Monviso Petit Belvedere				Monviso Colletto Fiorenza		Monviso Lago Chiaretto		Montgenèvre Chenaillet			
Rock name	Greenschist metagab.		Corun. Cumming. metagab.	Sheared cpx metagabbros			Smaragdite Eclogitic metagabbros (Campagnoni et al., 1988)			Chloritized metagabbros	Cpx. metagab.	Fe-gabbros (Bertrand et al., 1987)	Albitite	Bertrand et al., 1987
Sample No.	1	2	3	4	5	6	7	8	9(2)	10	11(9)	12(4)	13	14(7)
Symbol*	▲	▲	▲	▲	■	■	●	▲	●	▲	■	●	X	X
SiO_2	46.42	50.35	46.82	49.62	48.91	44.75	40.72	48.17	45.83	46.13	53.55	33.52	66.01	63.14
TiO_2	0.86	0.24	< 0.50	0.40	0.47	1.06	2.55	0.24	4.04	0.18	0.40	4.04	0.27	0.37
Al_2O_3	13.90	14.21	19.01	12.95	17.05	20.13	16.35	16.97	12.74	19.18	16.76	15.93	14.35	19.02
Fe_2O_3	3.60	2.66	0.92	3.14	1.22	0.10	10.67	0.15	17.53	3.89	1.29	7.77	<0.10	1.00
FeO	4.16	3.40	2.82	3.90	4.26	6.38	5.02	3.80	n.d.	1.80	3.00	12.60	3.29	1.05
MnO	0.48	0.09	0.054	0.09	0.11	0.14	0.19	0.07	0.23	0.10	0.11	0.28	0.04	0.04
MgO	11.50	13.02	11.87	11.59	6.58	6.22	6.55	10.55	8.26	11.10	6.95	9.22	1.39	2.23
CaO	12.40	9.83	11.72	12.97	11.23	11.71	10.85	10.10	8.18	9.45	9.75	10.13	1.92	2.36
Na_2O	2.38	2.48	1.38	1.84	4.78	3.78	2.46	2.73	3.44	2.87	4.76	0.66	11.43	9.60
K_2O	< 0.10	< 0.10	0.75	<0.10	0.51	0.68	<0.10	0.01	0.20	0.10	0.24	0.15	<0.10	0.10
H_2O^+	3.06	2.81	1.60	2.81	3.46	5.21	4.23	-	-		2.74	5.30	-	1.3
H_2O^-	0.27	0.26	2.4	0.24	0.11	0.33	0.78	3.17	0.31	0.7	-	n.d.	0.33	-
P_2O_5	0.05	<0.01	0.01	0.03	0.02	0.03	0.02	0.14	0.12	0.01	0.05	0.50	0.03	0.05
CO_2	-	-	-	-	-	-	-	-	-	-	0.13	0.30	-	0.13
Σ	99.09	99.35	99.83	99.58	98.71	100.43	100.40	100.09	100.88	95.51	99.74	100.40	99.06	98.03

▲: Mg-Al metagabbros; ■: altered (intermediate) metagabbros; ●: Fe-Ti metagabbros; x: albitites

The number of average samples is in brackets; n.d.: non detected.

*on the diagrams

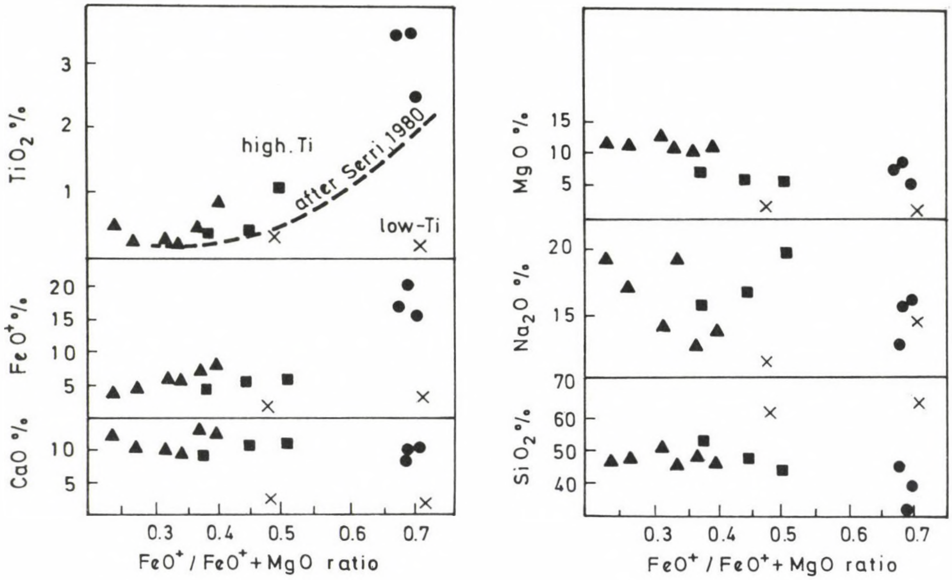

Fig. 2. Major element oxides % versus $FeO^{+}/FeO^{+}+ MgO$ ratio for the metagabbros and albitites from the Western Alps metaophiolites (symbols as in Table II)

Montgenévre) from the Piedmont Zone. These are characterized by the highest MgO ($10.55-13.02^{x}$) contents which is obviously related to the highest percentage of cummingtonite in corundum-cummingtonite metagabbros or alteration products of olivine (Mg-chlorite, actinolite-tremolite) in the other samples, by the high Al_2O_3 ($12.95-19.18^{x}$), SiO_2 ($46.13-50.35^{x}$) CaO ($9.45-12.97^{x}$) contents due to high and variable amounts of corundum, of cpx and plagioclase. These have the lowest values of $FeO^{+}/(FeO^{+}+MgO)$(0.24-0.40) ratio, TiO_2, P_2O_5 and highest MgO and Al_2O_3 in comparison with the other gabbros, respectively.

The altered intermediate gabbros include the sheared cpx-metagabbros (Petit Belvedere, French Monviso) and cpx-metagabbros from Chenaillet (Montgenévre) as shown in Table II. Their intermediate values of TiO_2 ($0.4-1.06^{x}$), MgO ($2.22-6.95^{x}$) and FeO^{+}/FeO^{+} + MgO (0.38-0.51) may be due the low amount or absence of olivine, but the highest contents of Na_2O ($3.78-4.78^{x}$) and K_2O ($0.24-0.68^{x}$) can be probably attributed to the influence of a metasomatic metamorphism (retrograde metamorphism).

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^{x} given in weight %

Table III

Average chemical composition of gabbroic rocks from some Western Alps ophiolites compared with other gabbroic rocks from the Alps

	Western		Alps (I.)		Corsica (II.)				Northern Appennines (III.)			
	Mg-Al	Gabbros	Fe-Ti	Gabbros	Mg-Gabbros		Fe-Gabbros		Mg-Gabbros		Fe-Gabbros	
	X(6)	range	X(3)	range	X(14)	range	X(3)	range	X(33)	range	X(28)	range
SiO_2	47.92	46.13-50.35	40.02	33.52-45.83	48.83	45.62-50.92	46.88	40.31-54.0	50.10	45.65-52.64	45.09	39.61-55.58
TiO_2	0.40	0.18- 0.86	3.54	2.55- 0.40	0.28	0.07- 0.82	3.74	1.44- 5.01	0.33	0.06- 1.32	4.77	1.59- 7.70
Al_2O_3	16.03	12.95-19.18	15.01	12.74-1.635	17.7	15.4 -23.35	12.77	11.27-14.15	17.33	14.33-20.9	12.49	11.01-15.29
FeO^t	5.21	3.06- 7.76	17.86	15.69-20.37	4.45	2.48- 7.48	15.03	14.2 -16.25	5.44	2.93-10.70	15.87	9.68-19.92
MnO	0.15	0.05- 0.48	0.23	0.19- 0.28	0.09	0.07- 0.15	0.20	0.15- 0.25	0.11	0.06- 0.17	0.27	0.15- 0.37
MgO	11.60	11.10-13.02	8.01	6.55- 9.22	9.8	5.53-13.4	6.18	2.76-10.27	9.79	6.48-12.70	6.21	2.68- 9.99
CaO	11.08	9.45-12.97	9.72	8.18-10.85	12.12	9.86-13.71	5.12	2.22- 8.86	10.27	6.70-13.80	7.81	5.03-11.45
Na_2O	2.30	1.38- 2.87	2.19	0.66- 3.44	2.8	1.91- 3.83	5.63	3.53- 8.02	2.87	1.75- 4.53	3.64	1.65- 6.60
K_2O	0.19	0.01- 0.75	0.15	0.10- 0.20	0.04	$<$0.01- 0.26	0.06	$<$0.01- 0.1	0.33	0.03- 1.01	0.34	0.06- 0.98
P_2O_5	0.04	$<$0.01- 0.14	0.21	0.02- 0.50	0.02	$<$0.02- 0.03	0.19	0.04- 0.4	0.02	0 - 0.07	0.29	0.01- 3.16
LOI	2.89	0.70- 4.00	3.21	0.31- 5.30	3.1	1.29- 4.59	2.52	1.3- 4.64	3.14	0.17- 0.43	2.05	1.17- 4.9
FeO^t/FeO^t+MgO	0.325	0.24- 0.40	0.696	0.72- 0.69	0.312	0.31- 0.353	0.709	0.612-0.837	0.357	0.311-0.457	0.718	0.666-0.783

I. Mg-Al Gabbros (W. Alps) include coru-cumming. metagab., greensch.-metagab., smarag-metagab. sheared cpx-metagab, and chloritized meta-gabbros.
Fe-Ti Gabbors (W. Alps) include sheared cpx-metagab., eclogitic metagab. and Fe-gabbros.

II. Mg-Gabbros (Corsica) include troctolite, oliv-gab., gab. and gabbronorite after Ohnenstetter et al., 1975 and Beccaluva et al., 1977.
Fe-Gabbroids (Corsica) include Fe-gabbroid, Fe-gab. and Fe-diorite.

III. Mg-gabbros (N. Appennines) include troctolites, oliv-gab., gab. and gabbronorite, after Serri, 1980.
Fe-gabbros (N. Appennines) include Fe-gabbros and Fe-diorites.

The Fe-Ti metagabbros comprise one sample from sheared cpx metagabbros (Petit Belvedere, French Monviso), eclogitic metagabbros (Lago Chiaretto, Italian Monviso) and ferrogabbros from (Chenaillet, Montgenévre). These can be clearly distinguished from the two former metagabbros by their highest FeO^+(15.69-20.37^x), TiO_2(2.55-4.04^x), P_2O_5 (0.02-0.13^x) and FeO^+/FeO^+ + MgO (0.68-0.70^x) values, which may reflect the high abundance of Fe-Ti oxides and apatite, and by the lower values of SiO_2 (33.52-45.83^x) and Al_2O_3 (12.74-16.35^x).

In the investigated metagabbroic rocks generally the TiO_2 and FeO^+ rapidly increase, while the MgO, Al_2O_3 and SiO_2 decrease with increasing FeO^+/FeO^+ + MgO ratio from the Mg-Al metagabbros through altered intermediate gabbros to Fe-Ti metagabbros (Fig. 2).

The comparison of the Mg-Al metagabbros with the corresponding Mg gabbros from the Alps (Table III) shows that these have slightly higher MgO, TiO_2 and P_2O_5 and slightly lower SiO_2, Al_2O_3 and Na_2O contents. The Fe-Ti metagabbros show much higher SiO_2, Al_2O_3, FeO^+, MgO and much lower Na_2O content when comparing with the corresponding rocks given by Ohnenstetter et al., 1975 and Beccaluva et al., 1966 for Corsica, Serri, 1980 for North Appennine (Table II). These show similar values of FeO^+/FeO^+ + + MgO ratio.

The albitites from Chenaillet (Montgenévre) show higher contents of SiO_2 (63.14-66.01^x). Na_2O (9.6-11.43^x) and lower FeO^+ (2.05-3.39^x), MgO (1.39-2.23^x), CaO (1.92-2.36^x). The very low content of K_2O (0.10^x) may be due to the strong effect of metamorphism (Pognante et al., 1982).

These metagabbroic rocks belong to the high-Ti ophiolite while the albitites fall in the low-Ti type (Serri, 1980, 1981) (Fig. 2).

The AFM diagram (Fig. 3) was applied by Strong and Malpas (1975) to represent the tholeiitic differentiation. The Mg-Al metagabbros and Fe-Ti metagabbros are of tholeiitic type, however these appear to overlap other gabbroids from Alps-Appennine ophiolites (Beccaluva et al., 1977; Lombardo et al., 1978, 1982; Serri, 1980; Castelli, 1985) and from modern oceanic areas (Miyashiro et al., 1970; Bonatti et al., 1971; Thompson, 1973; Prinz et al., 1976). The altered intermediate gabbros exhibit a calc-alkaline trend showing higher contents of Na_2O and K_2O probably due to the variable element mobilization during the different metamorphic events. All the investigated gabbroic rocks fall in the field of oceanic gabbros from Mid-Cayman Rise (Caytrough, 1979), Fig. 3. The albitites occur near the A-pole because of their higher content of Na_2O and K_2O reflecting the end of differentiation of the gabbroic magma.

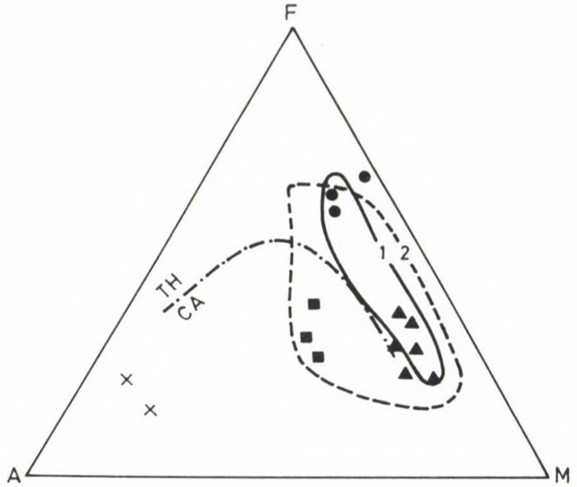

Fig. 3. AFM diagram for the metagabbros and albitites from the Western Alps metaophiolites. The compositional field of gabbros from (1) Mid-Atlantic Ridge (Bonatti et al., 1971; Thompson, 1973; Prinz et al., 1976) and (2) Mid-Cayman Rise (Cayrough, 1979) are shown

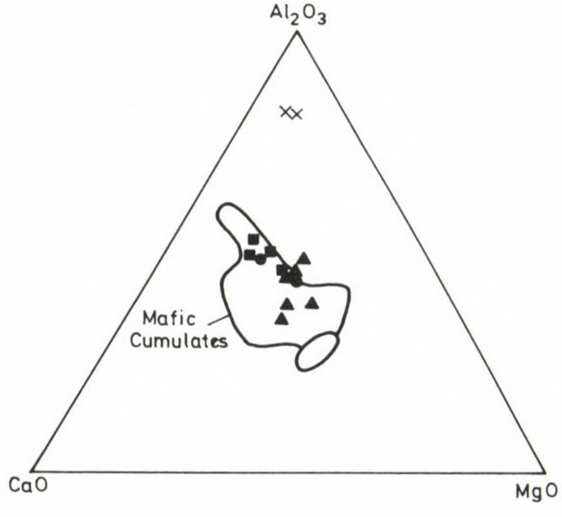

Fig. 4. CaO-Al_2O_3-MgO diagram (after Coleman, 1977) for the metagabbros and albitites from the Western Alps metaophiolites

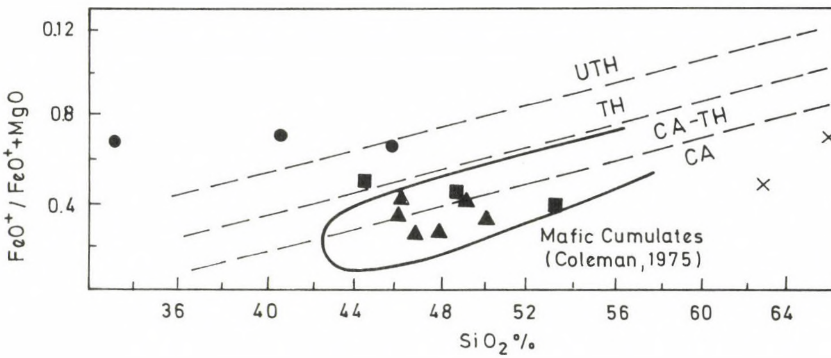

Fig. 5. The FeO^+/FeO^++MgO ratio versus SiO_2 % diagram for the metagabbros and albitites from the Western Alps metaophiolites

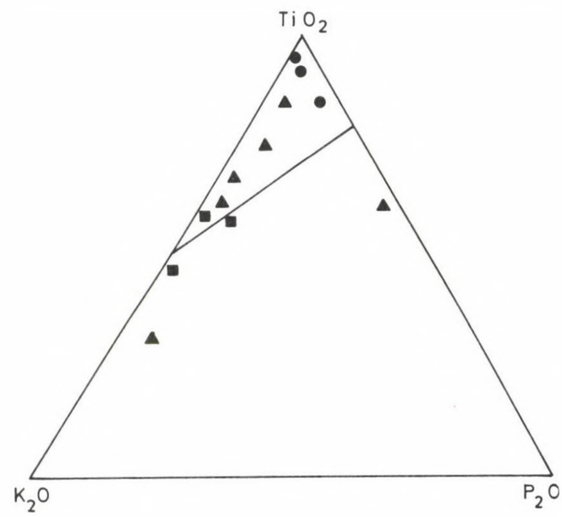

Fig. 6. K_2O-TiO_2-P_2O_5 diagram (after Pearce et al., 1975) for the metagabbros from the Western Alps metaophiolites

In the $CaO-Al_2O_3-MgO$ diagram (Fig. 4), the ophiolitic metagabbros from Arc valley, Monviso and Montgenévre are more or less plotted into the mafic cumulate field of Coleman (1977); showing equal values of CaO, Al_2O_3 and MgO, respectively. The albitites situate nearer the Al_2O_3 corner with much lower CaO and MgO content, suggesting the differentiation of the ophiolitic mafic cumulates.

To discriminate the magmatic rocks with different genetic features, Kubovics and Bilik (1984) separated the C -TH boundary (Miyashiro, 1975), (Fig. 5) in addition to CA as well as TH and UTH field based on the petrochemical characters using some equations. In this diagram ($FeO^+/FeO^+ + MgO$ vs. SiO_2), the Mg-Al metagabbros are plotted into the mafic cumulates of Coleman (1975) and distributed along the CA-TH dividing line, while the Fe-Ti metagabbros are situated near the TH and UTH field showing a high content of FeO^+.

In the $K_2O-TiO_2-P_2O_5$ diagram (Pearce et al., 1975), Fig. 6, the majority of Western Alps metagabbros is plotted in the oceanic basalt field. However, four of the samples, particularly the altered intermediate gabbros having higher K_2O values, fall into the non-oceanic basalt field which can be attributed to the influence of the greenschist facies metamorphism and oceanic floor alteration.

Concluding remarks

The Piedmont Zone of the Western Alps consists of metamorphic dismembered ophiolite and its Mesozoic metasedimentary cover.

According to the mineral and chemical composition, the gabbroic rocks can be divided into the following types.

The Mg-Al metagabbros include greenschist facies metagabbros (Refuge d'Averole), monticellite-cummingtonite and sheared cpx metagabbros (Petit Belvedere), smaragdite metagabbros (Colletto Fiorenza) and chloritized metagabbros (Chenaillet). These are characterized by high contents of MgO, Al_2O_3, SiO_2 and CaO and low values of $FeO^+/FeO^+ + MgO$, TiO_2, and P_2O_5 and can be derived from a primitive magma formed at lower level depths.

The Fe-Ti metagabbros comprise sheared cpx metagabbros (Petit Belvedere), eclogitic metagabbros (Lago Chiaretto) and ferrogabbros (Chenaillet). These clearly show the highest content of FeO^+, TiO_2 and P_2O_5 and lower values of SiO_2 and Al_2O_3, and can be derived from highly differentiated magma at low levêl depths. The Mg-Al rich and Fe-Ti rich metagabbros, preserved their original tholeiitic affinity, belong to the high-Ti ophiolite and usually fall within the oceanic gabbros and mafic cumulate fields on the diagrams.

On the other hand, the albitite has higher SiO_2, Al_2O_3 and Na_2O and lower FeO^+, MgO and K_2O contents and it's rather of calc-alkaline character than the gabbros.

There is another altered intermediate type of gabbros between the above mentioned two types. It includes sheared cpx metagabbros (Petit Belvedere) and cpx metagabbros (Chenaillet). The altered intermediate gabbros have higher Na_2O and K_2O contents due their retrograde metamorphism and lower values of MgO, that means these show a calc-alkaline character.

REFERENCES

Bonatti, E., J. Honnorez, G. Ferrara (1971): Peridotite-gabbro-basalt complex from equatorial Mid-Atlantic Ridge. Phil. Trans. Roy. Soc. Lond., A., **268**, 325-402.

Church, W.R., L. Riccio (1977): Fractionation trends in the Bay of Island ophiolite of Newfoundland: polycyclic cumulate sequences in ophiolites and their classification. Can. J. Earth. Sci., **14**, 1156-1165.

Coleman, R.g. (1977): Ophiolites. Ancient oceanic lithosphere? Springer Verlag, Berlin. pp. 1-299.

Compagnoni, R., J.R. Kienast, B. Lombardo (1988): The Monviso eclogitic metaophilite (Cottian Alps); in the IGCP 235 Excursion to the Alps: HP eclogitic reequilibration in the W. Alps, Part **1**, 81-112.

Dal Piaz, G.v. (1974): Le metamorphisme alpin d'haute pression et basse température dans l'évolution structurale du bassin ophiolitique alpino-apenninique. Boll. Soc. Geol. It., **93**, 437-468.

Dal Piaz, G.V., G. Venturelli, P. Spadea, G. Di Battistini (1981): Geochemical features of metabasalts and metagabbros from the Piemonte ophiolite nappe, Italian W. Alps. N. Jb. Miner Abh., **142**, 248-269.

Jeffery, P., D. Hutchison (1981): Chemical Methods of Rock Analysis, Pergamon Press.

Kubovics, I., I. Bilik (1984): Comparative investigations of the Hungarian Mesozoic mafic-ultramafic and some ophiolitic magmatic rocks in the Alp - Carpathian Chain. I. Petrochemical investigations. Acta. Geol. Hung., **27**, 3-4, 321-339.

Kubovics, I. (1985): Mesozoic magmatism of the Transdanubian Mid-Mountains. Acta Geol. Hung., **28**(3-4), pp. 141-165.

Beccaluva, L., G. Macciotta, G.B. Piccardo, G. Venturelli (1976): Le rocce gabbriche d'Appennino centro-settentrionale: II. Le caratteristiche chimiche. Ofioliti, **1/2**, 107-126.

Beccaluva, L., D. Ohnenstetter, M. Ohnensetetter, G. Venturelli (1977): The trace element geochemistry of Corsican ophiolites. Contrib. Mineral. Petrol., **64**, 11-31.

Bertrand, J., V. Dietrich, P. Nievergett, M. Vuagnat (1987): Comparative major and trace element geochemistry of gabbroic and volcanic rock sequences, Montgenévre ophiolite, W. Alps.Schweiz.Mineral Petrogr. Mitt, **67**, 147-169.

Bonatti, E., J. Honnorez, G. Ferrara (1971): Peridotite-gabbrobasalt complex from the equatorial Mid-Atlantic Ridge Phil. Trans. Roy. Soc. London A, **268**, 385-402.

Castelli, D. (1985): The Piemonte Nappe underlying the Southwestern margin of the Mt. Emilius Klippe. Middle Aosta Valley. Ofioliti, **10**, 1, 19-34.

Caytrough (1979): Geological and geophyiscal investigation of the Mid-Cayman Rise spreading center. In: Maurice Ewing Series 2, M. Talwani, G.E. Harrison and D.E. Hayes, eds, Am. Geophys. Union, Washington, D.C., pp. 66-95.

Lombardo, B., R. Nervo, R. Compagnoni, B. Messiga, J.R. Kienast, C. Mével, L. Fiora, G.B. Piccardo, R. Lanza (1978): Osservazioni preliminari sulle ofioliti metamorfiche del Monviso (Alpi Occidentali). Rend. Soc. It Miner. Petrol., **43**, 253-305.

Lombardo, B., U. Pognante (1982): Tectonic implications in the evolution of the W. Alps ophiolite metagabbros. Ofioliti, **2/3**, 371-394.

Miyashiro, A. (1975): Classification, characteristics and origin of ophiolites, J. Geol., **83**, 249-281.

Miyashiro, A., F. Shido, M. Ewing (1970): Crystallization and differentiation in abyssal tholeiites and gabbros from mid-oceanic ridges. Earth Planet. Sci. Lett., **39**, 127-144.

Ohnenstetter, D., M. Ohnensetter, G. Rocci (1975): Tholeiitic cumulates in a high P. metamorphic belt. Petrologie, **1/4**, 291-317.

Pearce, T.H., Be.E. Gorman, T.C. Birkett (1975): The TiO_2-K_2O-P_2O_5 diagram: a method of discrimination between oceanic and non-oceanic basalts, Earth. Planet. Sci. Lett., **24**, 419-426.

Pognante, U., B. Lombardo (1982): Petrology and geochemistry of Fe-Ti gabbros and plagiogranites from the Western Alps ophiolites. Schweiz mineral. petrogr. Mitt., **62**, 457-472.

Prinz, M., K. Keil, J.A. Green, A.M. Reid, E. Bonatti, J. Honnorez (1976): Ultramafic and mafic dredge samples from the equatorial Mid-Atlantic ridge and fracture zones. I. Geophys. Res., **81**, 23, 4087-4103.

Sajó, I. (1955): Acta. Chim. Acad. Sci. Hung., **6**, 245.

Serri, G. (1980): Chemistry and petrology of gabbroic complexes from the N. Appennine ophiolites. In: A. Panayiotou (ed.), ophiolites, Proceed. Intern. Ophiol. Symp., Cyprus 1979, p. 296-313.

Serri, G. (1980): Fractionation trends of the gabbroic complexes from high-Ti and low-Ti ophiolites and the crust of major oceanic basins: a comparison. Ofioliti, **5**, 2-3, 241-264.

Serri, G. (1981): The petrochemistry of ophiolitic gabbroic complexes: a key for the classification of ophiolites into low-Ti and high-Ti types. Earth. Planet. Sci. Lett., **52**, 203-212.

Strong, D.I., J.G. Malpas (1975): The sheeted dyke layer of the Betts Core Ophiolite Complex does not represent spreading - Further discussion. Can. J. Earth. Sci., **12**, 844-896.

Acta Geologica Hungarica, Vol. 33/1-4, pp. 121-135 (1990)

TRACE ELEMENTS IN THE AJKA-II UPPER CRETACEOUS COAL BASIN, TRANSDANUBIA, HUNGARY

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The Ajka-II coal basin is a perspectivic coal terrain with an expected reserve of about 110 Mt. It is situated above Triassic/Jurassic dolomites/limestones and/or Upper Cretaceous calcareous marly sediments. Preliminary investigations in the neighbouring coal basins revealed anomalously high trace element abundances in the coals. Altogether 263 samples were analyzed for the trace elements B, Co, Cr, Ga, Mn, Mo, Ni, Pb, Ti, U, V and Zn. As regards the vertical distributions of the elements, these accumulate in the lower part of the coal seam. Concerning the horizontal distribution of the elements it is stated that (i) two part-basins can be presumed, (ii) the major part of the material derived from the east-southeast.

Keywords: Trace elements, coal geochemistry, Ajka Coal Basin.

Introducticon

The geological exploration of the Ajka-II coal field had been carried out between 1980 and 1984. The results of this work and the concept of mine opening were summarized by Pera et al. (1987). Previously, data have been available on the trace element abundances in the so-called Ajka-I coal field (Szádeczky-Kardoss and Földvári-Vogl, 1955; Tomschey, 1988) and it seemed to be necessary to have some information on the trace element abundances and on their distribution within the coal seam to be mined in the case of Ajka-II, too. Our work aimed at the determination of the quantities of the trace elements in question, the vertical and horizontal changes of these elements and finally to make an attempt to reconstruct the provenance areas based on geological-geochemical grounds.

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Received: 01/02/90

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Geological setting

The Ajka-II coal field lies in central Transdanubia (Hungary), in the Transdanubian Mid-Mountains, in a tectonically relatively quiet environment. The formations of the basement consist of older Mesozoic strata, i.e. in the southeastern part Triassic calcareous-dolomitic formations, towards the northwestern part Jurassic formations are found. The Triassic and Jurassic sedimentary rocks are overlain by Cretaceous marls that thicken northeastwards. This marl formation represents an impermeable layer between the older Triassic-Jurassic formations and the coal-bearing sequence. The eroded surface of the marl sequence is overlain by the Senonian coal-bearing strata that is called Ajka Coal Formation. The lower part of the formation consists of clayey sediments and these are overlain by the coal sequence above which clays, marls, clayey sands alternate in a thickness of 100 to 150 m. An overall geological profile of NW-SE direction of the Ajka-II coal basin is presented in Fig. 1 after Pera et al. (1987).

The sedimentary column of the coal seam as well as the different sediment types together with the preliminary results of trace element distributions in the Ajka-I terrains were referred by Tomschey (1989).

Materials and methods

263 samples deriving from boreholes were analyzed for their ash contents and trace element concentrations. In Fig. 2 the location of the boreholes and the contours of the area to be mined are presented. All samples represent the lower seam.

Ash contents were determined by combusting at 1000 ^{o}C for two hours. The boreholes, seam thicknesses, total number of samples and the average ash contents in each borehole are shown in Table I.

The ash contents refer to the remaining material after combustion, the average ash content of the 263 samples is round 30%. The frequency distribution of the ash contents is shown in Fig. 3.

The following trace elements were determined from the ash: Co, Cr, Mo, Ni and V (by means of AAS: Perkin Elmer 5000), U (by photometry: Pye Unicam 1800 SP), B, Ga, Mn and Ti (by means of emission spectrography, Zeiss PGS-2).* Pb and Zn were also analyzed but in most cases their quanti-

*The AAS and photometric were made by A. Bittó, the spectrographic ones by O. Tomschey.

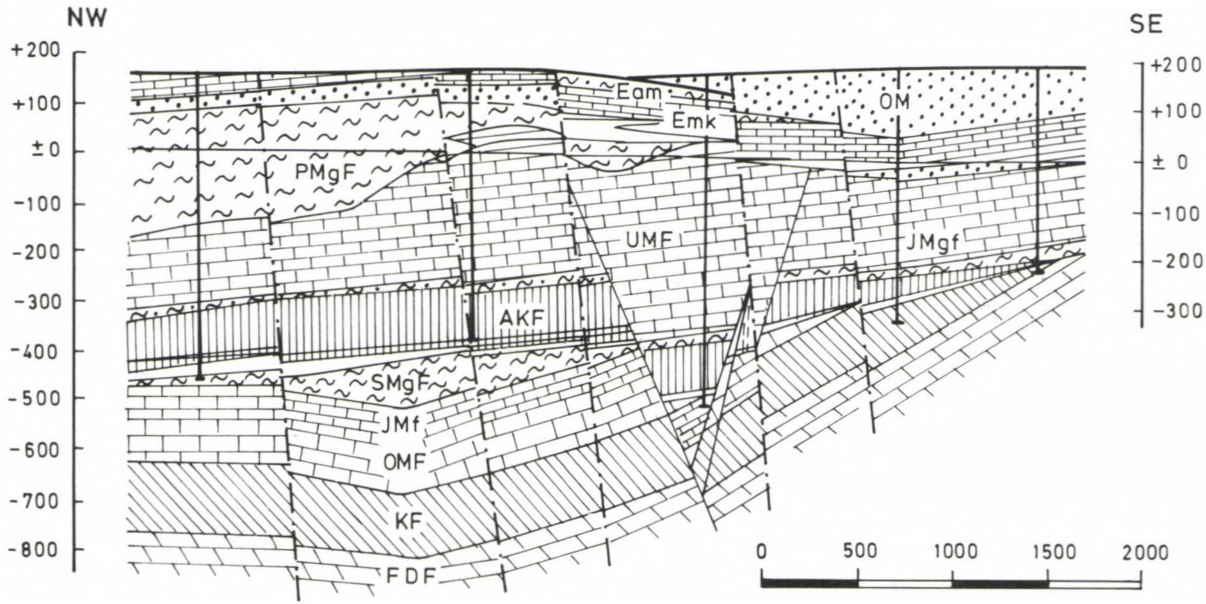

Fig. 1. Geological profile of NW-SE direction across the Ajka-II coal field (after Pera et al., 1987). OM - Oligocene-Miocene rocks; Eom - Eocene clay-marl to marl; Emk - Eocene limestones; Eko - Eocene conglomerate; PMgF - Polány Marl Formation; JMgF - Jákó Marl Formation; AKF - Ajka Coal Formation; CSF - Csehbánya Formation; SMgF - Sümeg Marl Formation; JMf - Jurassic Limestone formation; DMF - Dachstein Limestone Formation; KF - Kössen Formation; FDF - Main Dolomite Formation

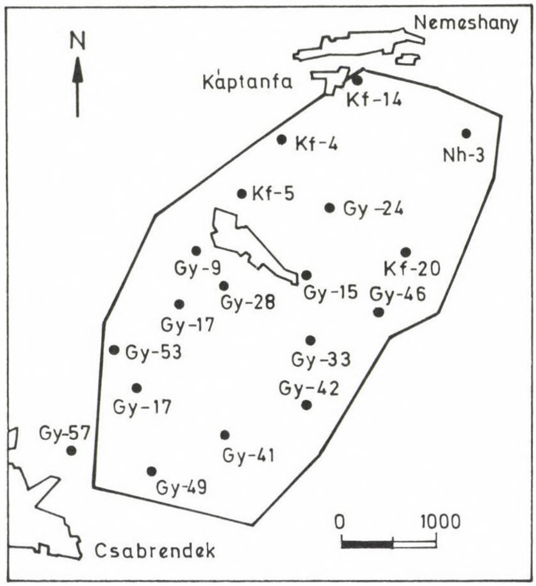

Fig. 2. Position of the boreholes and the contour lines of the area to be mined; Ajka-II coal field

Table I

Boreholes, seam thicknesses, total number of samples studied and the average ash contents

Borehole	Seam thickness (m)	Number of samples	Average ash content (%)
GY- 9	12.85	9	27.2
GY-15	14.70	14	26.7
GY-17	10.20	9	41.3
GY-24	6.80	7	18.9
GY-28	11.80	11	30.9
GY-33	14.05	33	22.0
GY-41	11.00	28	34.0
GY-42	9.05	6	33.1
GY-46	14.80	22	19.2
GY-47	17.00	32	35.5
GY-49	11.45	12	25.3
GY-53	21.60	13	34.3
GY-57	13.55	9	29.1
KF- 4	12.35	6	29.7
KF- 5	9.60	7	29.8
KF-14	15.20	15	27.6
KF-20	15.55	19	34.5
NH- 3	12.20	11	31.6

Note: Abbreviations denote village names: GY - Gyepükaján; KF - Káptalanfa; NH - Nagyharsány

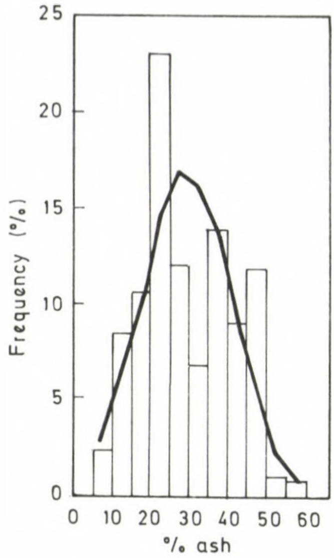

Fig. 3. Frequency distribution of the ash contents of 263 samples

ties remained below the detection limit, thus the discussion of these elements will neglected below.

Results and discussion

The average trace element contents were calculated to the 263 samples and the average values for ashes are listed in Table II.

Concerning both the vertical and horizontal distributions of the trace elements, the concentrations in the coal are more suitable for comparison. This is why the average values for ashes were recalculated for coals; these values are listed in Table III. In both tables the dispersion, the minima and maxima are also presented.

In order to try to reconstruct the probable directions of transport, the average trace element contents for each borehole were also calculated. In Table IV the average values for ashes, in Table V those for coals are presented. This type of grouping is not self-contained for the lower seam in Ajka-II since these average values may help to perform the reconstruction mentioned above, i.e. the horizontal distribution of the trace ele-

Table II

Trace element averages, dispersion, minima and maxima for ash (ppm)

Element	Average	Dispersion	Minima	Maxima
B	197.0	91.2	46	450
Co	76.6	17.9	25	127
Cr	180.7	67.8	58	530
Ga	22.3	15.9	<10	80
Mn	333.2	277.6	<50	1200
Mo	137.9	97.2	<10	473
Ni	215.6	87.2	30	465
Ti	3302.6	1663.7	180	10000
U	80.3	48.7	<10	230
V	596.6	275.6	80	1520

Table III

Trace element averages, dispersion, minima and maxima for coals recalculated from the values for ash (ppm)

Element	Average	Dispersion	Minima	Maxima
B	51.9	21.4	14	111
Co	22.6	10.9	4	56
Cr	53.6	33.5	7	248
Ga	6.4	4.5	<3	25
Mn	99.0	96.5	<20	521
Mo	37.2	24.8	<3	103
Ni	63.1	37.1	7	217
Ti	1003.7	670.5	23	3247
U	22.9	16.2	<1	73
V	167.2	90.4	19	462

ments may reflect the direction of transport as well as the geological formations of the source area.

The relative frequency distributions of the elements studied are shown in Fig. 4. In the upper part the distributions in ash, in the lower one those in coals are presented.

Boron is believed to be bound to the inorganic ash-forming constituents in coal (Bouska, 1981). Leutwein and Rösler (1956) came to the same conclusion for German coals. Otherwise, extreme values are reported from different coal seams, e.g. from several tenth ppm (Japanese coals) up to about 5000 ppm in ash (Bouska, 1981). In our case the average B content is 197 ppm in ash and 52 ppm in the coal. These values resemble to an average

Table IV

Trace element averages in ash in each borehole studied (ppm)

Borehole	B	Co	Cr	Ga	Mn	Mo	Ni	Ti	U	V
GY- 9	127	67	189	10	93	259	238	2925	102	430
GY-15	214	70	153	13	566	244	177	2617	91	524
GY-17	124	66	153	14	396	166	166	3270	82	469
GY-24	285	75	230	58	80	123	208	3545	100	1090
GY-28	250	81	199	39	129	129	249	4205	80	795
GY-33	136	81	150	33	230	100	223	2158	58	645
GY-41	183	88	118	51	353	64	205	2293	73	348
GY-42	272	81	176	27	638	36	185	5167	40	440
GY-46	318	90	192	18	717	120	225	3060	74	560
GY-47	183	83	246	43	308	105	273	3672	62	632
GY-49	192	77	106	10	614	120	158	1706	29	344
GY-53	229	70	193	15	313	197	254	4920	46	484
GY-57	255	77	225	10	423	82	276	2968	69	645
KF- 4	233	81	200	20	305	243	313	4333	163	712
KF- 5	98	101	165	13	240	193	210	2800	83	623
KF-14	198	77	162	16	226	183	238	2189	150	813
KF-20	168	48	205	19	142	28	121	5557	68	647
NH- 3	137	85	227	14	86	94	199	3560	71	661

Table V

Trace element averages in coals recalculated from the values obtained for ash (ppm)

Borehole	B	Co	Cr	Ga	Mn	Mo	Ni	Ti	U	V
GY- 9	30	19	52	3	23	64	65	699	32	114
GY-15	47	18	37	3	183	55	43	597	23	115
GY-17	50	27	64	5	156	69	69	1382	35	193
GY-24	49	14	44	10	16	26	38	710	19	212
GY-28	66	24	59	11	60	39	74	1288	24	224
GY-33	29	18	32	7	55	22	50	447	12	130
GY-41	65	29	44	17	127	22	71	937	28	127
GY-42	87	27	58	9	243	10	62	1837	12	132
GY-46	59	17	37	4	140	20	43	592	14	107
GY-47	59	30	92	14	103	36	95	1380	22	238
GY-49	46	21	32	3	155	27	45	532	10	90
GY-53	72	23	65	6	115	56	81	1665	13	159
GY-57	68	22	49	3	115	26	79	886	21	199
KF- 4	66	24	61	5	84	66	94	1236	48	223
KF- 5	26	32	50	4	62	51	64	876	26	190
KF-14	45	23	46	5	58	46	74	631	37	213
KF-20	51	16	71	7	53	10	37	1708	19	178
NH- 3	37	27	72	4	26	27	61	1104	20	196

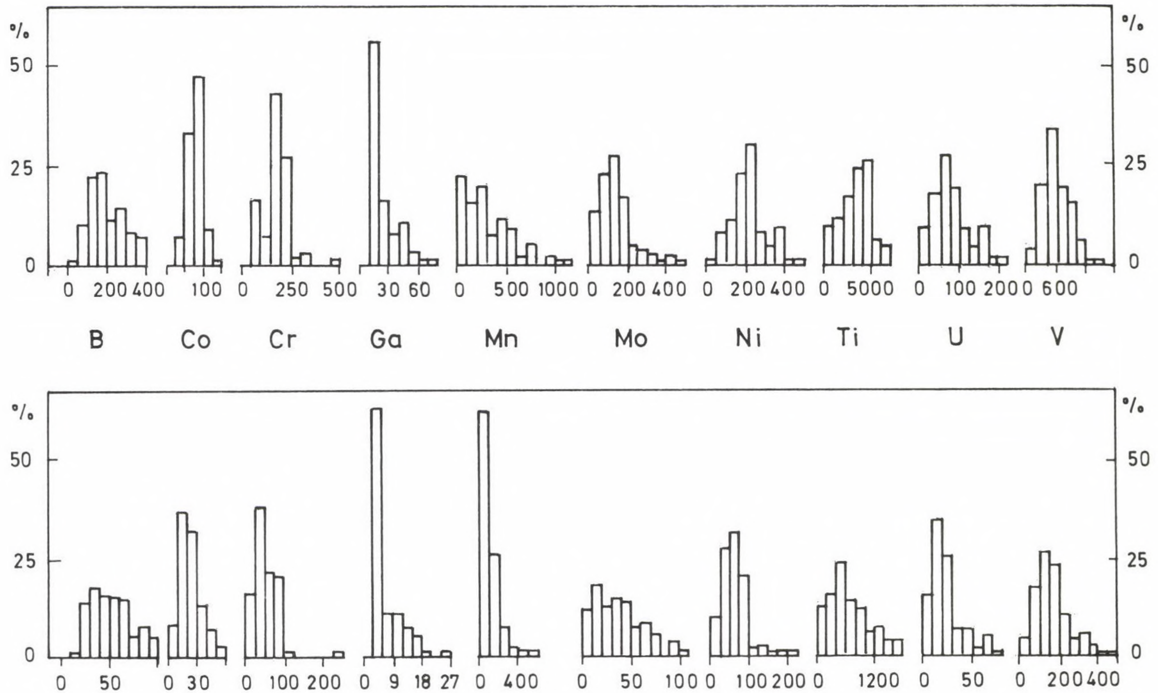

Fig. 4. Relative frequency distributions of the elements studied in the coal (upper series) and in ash (lower series)

B content in the Ajka-II coals as compared to the world average for coals and sedimentary rocks (e.g. Turekian and Wedepohl, 1961).

Cobalt is believed not to associate the organic matter but rather to be bound by sulfides, first of all pyrite which is common in coals and also in the Ajka-II coals. In the Ruhr Basin Otte (1953) determined 0.2% Co in coal ash, this seems to be highest value reported so far. In the Ajka-II coals the average Co value is round 77 ppm in ash and 23 ppm in coal. The values close to the average represent the most frequent values (Fig. 4). The values are similar to the common clayey sedimentary rocks. Co shows good correlation with Ni, first of all in the samples rich in pyrite, the correlation is roughly 0.90, on the average, but the Co values are always lower, i.e. about one-third of the Ni values.

Chromium is fairly common in coals, its amounts are several hundreds ppm on the average, but Otte (1953) reported Cr contents as high as 1.3% from the Ruhr Basin. In the Ajka-II coals the average Cr value is 180 ppm in ash and 54 ppm in coal, so it slightly exceeds the averages for clayey sedimentary rocks (Taylor, 1964). The extreme values, e.g. 530 ppm Cr are, however, higher by an order of magnitude. Cr displays slight negative correlation with the ash content, this fact may refer to the association of Cr with the organic matter.

Gallium shows extreme values in coals, i.e. between 9 and 1000 ppm (Bouska, 1981) and is believed to be bound by the ash-forming inorganic mineral matter of the coal. According to Leutwein and Rösle (1956) Ga shows sometimes positive correlation with the V content of the coals, this does not apply for the Ajka-II coals. Here the average Ga value is 22 ppm in ash and only 6 ppm in the coal, so the values are rather low as compared e.g. to the clayey sedimentary rocks. Ga is usually bound to silicates, i.e. first of all to feldspars due to the Al-Ga substitution possibility. Since the Ajka-II environs consists of carbonate rocks being very poor in silicates and first of all in feldspars, the low Ga values may be produced by the lack of this type of inorganic matrix.

Manganese is believed to be bound by the inorganic matter (e.g. Otte, 1953). Mn is present in coals in form of carbonates, silicates or oxides, in the Ajka-II region, however, the form of manganese minerals cannot be excluded (due to the close neighbourhood of Mn-bearing deposits of Jurassic age east-southeast of the coal basin). The extreme values for Mn are 1200 and less than 50 ppm, respectively. The horizontal distribution of these values shows an interesting picture (see later when discussing the direction of transport).

Molybdenum displays an average value of 1.5 ppm in the Earth's crust (Taylor, 1964). In vitrain Otte (1953) found 0.6% Mo, but usually the Mo values in coals vary between several ppm to several ten ppm. Leutwein and Rösler (1956) reported 30 to 40 ppm averages from German coals of Lower Carboniferous to Lower Permian age. Recently, Foscolos et al. (1989) described high Mo values (565 and 712 ppm) from lignites in northern Greece. In the Ajka-II coals the average Mo value is 137 ppm in ash and 37 ppm in the coal, the extreme value is 473 ppm. This means that the average values of Mo concentrations are higher by two orders of magnitude than the value reported by Taylor (1964), so in this basin remarkable Mo accumulation can be stated. As regards the chemical bond of Mo in coal seams, Golovko (1960) presumed that it may be absorbed on the clay admixture of coal or can be accumulated by sorption on the organic matter in the early phase of coal-forming processes and it will be only subsequently concentrated in sulfides. According to Tomschey (1989) in the Ajka-II coal field about 40% of the total Mo-content is bound by the organic or sulfide matter, the remaining amounts are bound to carbonates and other ash-forming constituents. So, in the Ajka region Mo seems to be bound both by the organic and by the inorganic matter. It is to be noted here that no unambiguous correlation exists between the Mo-contents and the ash contents, e.g. the greatest Mo concentration was observed in the coal of round 22.0% ash.

Nickel is also common in coal ashes, the amounts reported so far, however, are rather different. Otte (1953) found 1.6% Ni in the ash of vitrain, Fortescue referred (1954) to local enrichment of Ni. The average Ni value in the Ajka-II coal seam is 216 ppm in ash and 63 ppm in coal. Ni displays very good positive correlation with Co (more than 0.90 on the average) but the Ni values are always higher by two-to-three times.

Titanium is common in coals in minor or trace amounts though very high values were also reported (e.g. Otte, 1953). Usually, the Ti values are higher in coal ashes than in clayey rocks and this applies to the Ajka-II region, as well. The highest value is 10.000 ppm in ash, the lowest only 180 ppm. In the coal the average Ti-value is round 3200 ppm. It is to be noted that after the X-ray diffractometric records of some high-ash coals, independent Ti minerals (rutile or anatase) could be identified (analyzed by M. Tóth, Laboratory for Geochemical Research).

Uranium is known to occur commonly in coals. There are a lot of data available on the U contents of coals, here let us mention only the data from Czechoslovakia (Bouska, 1981) where 2 to 90 ppm U contents were reported from the Kladno area. In Hungary the U contents of Eocene brown coals and associated rocks were reported by Földvári (1952) and Szalay (1954, 1957). In the Ajka-II lower seam the average U content is 80 ppm in ash and round 23.0 ppm in the coal. Regarding the average of U concentrations in sedimentary rocks, i.e. round 3 ppm (Taylor, 1964), the average value is 15 times higher than this average. The adsorption capacity of organic matter to U is well known this is why it has been interesting that in the Ajka-II coals only about 10% of the total U content is bound by the organic matter, more than 80% is bound by the clay minerals in the ash-forming matrix (Tomschey, 1989).

Vanadium is also a common trace element in coals. Similarly to other trace elements, rather different V concentrations are reported from different coal regions of the world (Bouska, 1981), e.g. Rankama and Sahama (1950) mention Argentinian coal with a maximum V_2O_5 quantity of 21.4% in the ash! Of course, this is a very extreme value, but the V quantities in coal ashes show averages of about 500 to 1000 ppm, in extreme cases, usually the V content is roughly 200 to 300 ppm. According to Uzunov (1980), the major part of V in coals is bound by vitrite. In the Ajka-II coal field the average V content of the coal ash is round 600 ppm, and 167 ppm in the coal. These values are three times higher than the sedimentary averages for clayey sediments (Taylor, 1964). As regards the form of V in coals, in the Ajka-II coals only 54% of the total V content is bound by the organic matter, the remaining part is assigned to the ash-forming material. Because only about the half of the total V quantity is bound by the organic matter, only a slight correlation is displayed between V and the ash content.

Concerning the vertical distribution of the elements within the lower coal seam of the Ajka-II region it can be stated that no unambiguous trends can be determined. Usually the trace elements, first of all the siderophile ones (Co and Ni), but sometimes also the other ones show some enrichment in the lower part of the coal seam. Nevertheless, examples exist that some of the microelements show high concentrations also in the middle or upper part as compared to the values in the lower section.

When evaluating the horizontal distribution of the elements studied within the coal seam, several preconditions were made, i.e. some facts were hypothetized. Among others it has been assumed that the major part of the studied elements (Cr, Mo, V and U) is associated partly with the organic matter. It was presumed that the horizontal distribution of these elements may reflect the direction of transport so that the higher values are farther of the provenance area. In case of the siderophile elements (Co and Ni) this assumption is less valid since these elements may be bound not only by the organic matter but also by sulfides (in case of the Ajka-II coals first of all by pyrite) and also by other inorganic mineral components. Finally, it was assumed that Mn is found mainly in form of manganese minerals and these, just due to their greater specific weight, were deposited in the first phase of transportation, i.e. the higher values lie closer to the presumed provenance area.

In order to reconstruct the position of the provenance area, the iso-concentration lines of the studied elements were plotted on the basis of the concentration values for coals and taking the average value of each borehole. These iso-concentration maps are seen in Fig. 5.

Based on the figure it can be stated that the provenance area was situated east-southeast of the coal basin. This is reflected by the north-northwestwards increasing values of U, Mo, V, Cr, Co and Ni. On the contrary, the Mn values show another picture, i.e. the highest values are found in the southeastern part of the coal basin and continuous decrease can be observed west-northwestwards. This relates to the fact that the source region was situated east-southeast of the coal field and it had to be of manganese-rich material. The hypothesis is verified by the geological setting since east-southeast of the coal basin manganese indication of Jurassic age is found (e.g. Cseh-Németh, 1967).

The distribution of V, Cr, Co and Ni suggests an other phenomenon, namely it can be assumed that two part-basins existed: one in the southwestern and another in the northern-northeastern part of the coal basin. This assumption, however, is based only on geochemical ground, no other evidences exist to prove the validity of this statement, so it can be accepted only with restrictions.

Conclusions

Based on the results obtained to the geochemical picture of the Ajka-II coal field, it can be stated that in the lower seam

- some of the rare elements show remarkable accumulation. The enrichment of U and Mo is as high as two orders of magnitude as compared to the average sedimentary average values. The enrichment of V, Cr and Ni is less but the quantities of the elements, especially those of V are con-

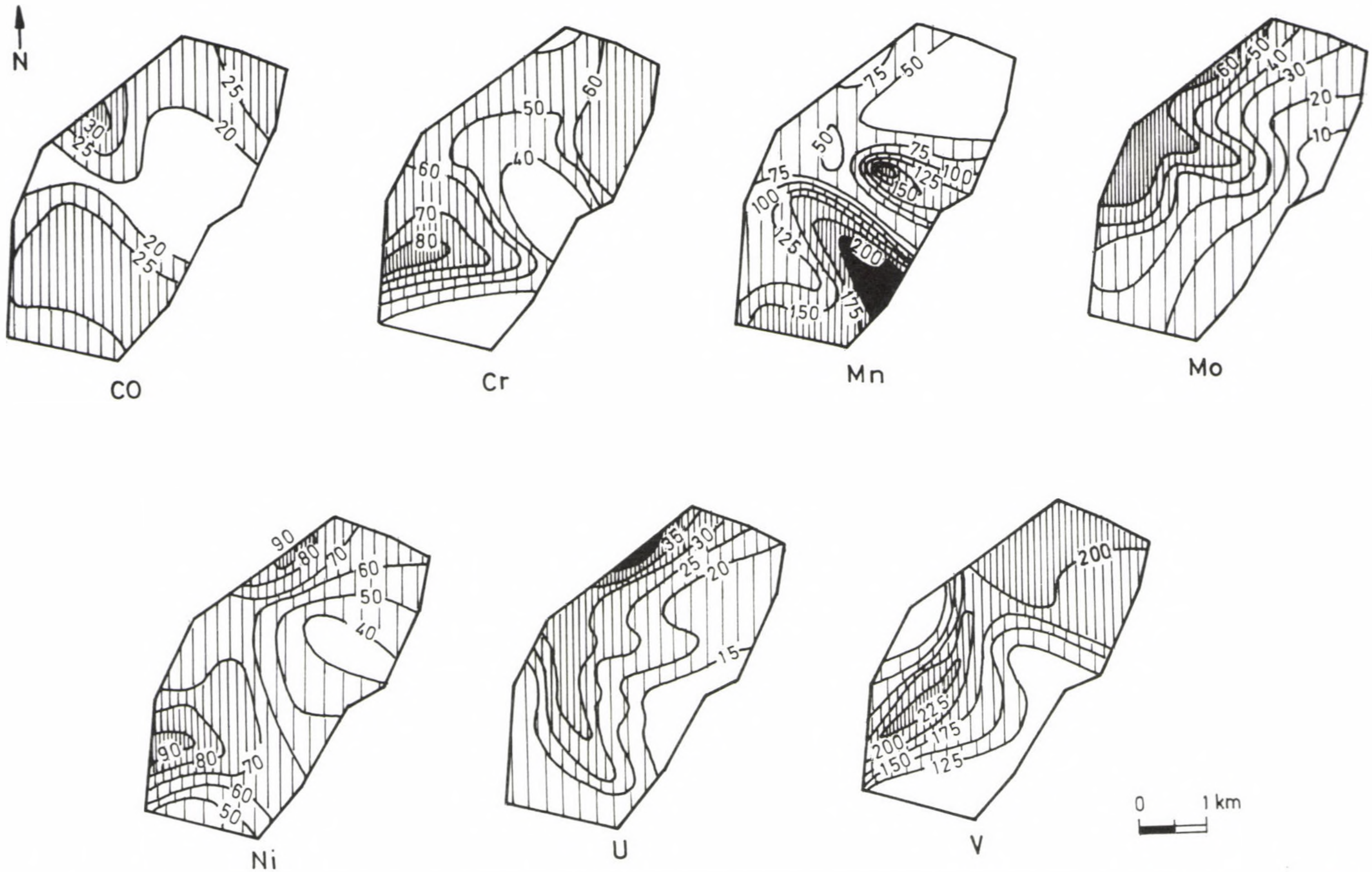

Fig. 5. Iso-concentration maps of the elements studied. For details see the text. Numbers of iso-concentration lines represent ppm values

siderable. These rare element concentration values may increase the value of the coal seam since in case of energetic utilization of the coal, the coal ash can be used for these elements as a secondary raw material.

- No regular change can be determined in the vertical distribution of the elements; in general, the lower part of the coal seam exhibits somewhat higher rare element concentrations than the middle or upper parts.

- The horizontal distribution of the elements shows a relatively uniform picture: on the one hand, based on the iso-concentration maps two part-basins can be presumed, and the material might derive from the east-southeast, on the other. The position of the provenance area was evidenced by other, e.g. paleontological and paleogeographical analyses, as well.

Acknowledgements

Author is highly indebted to the authorities of the Veszprém Coal Mines, first of all to László Makrai, geologist-in-chief, for making possible these investigations, and to the staff of the Laboratory for Geochemical Research of the Hungarian Academy of Sciences for their valuable aid in the analytical work.

REFERENCES

Bouska, V. (1981): Geochemistry of Coal. Academia, Praha, 284 p.

Cseh-Németh, J. (1967): Úrkút és Eplény mangánterületeinek összehasonlítása (Comparison of the manganiferous regions of Úrkút and Eplény). Földtani Közl., **97**, pp. 29-38.

Dudich, E., O. Tomschey (1979): Oligo and microelements in some Mesozoic and Cainozoic rock samples of Hungary. Chem. Erde, **38**, pp. 298-314.

Fortescue, J.A.C. (1954): Germanium and other trace elements in some western Canadian coals. Amer. Miner., **39**, pp. 510-519.

Foscolos, A.E., F. Goodarzi, C.N. Koukouzas, G. Hatziyannis (1989): Reconnaissance study of mineral matter and trace elements in Greek lignites. Chem. Geol., **76**, pp. 107-130.

Földvári, A. (1952): The geochemistry of radioactive substances in Mecsek Mountains. Acta Geol. Acad. Sci. Hung., **1**, pp. 37-48.

Golovko, V.A. (1960): Distribution of trace elements in the coal-bearing strata of the central region (in Russian). Dokl. AN SSSR, **132**, 4, 911-914.

Leutwein, F., H.J. Rösler (1956): Geochemische Untersuchungen an paläozoischen und mesozoischen Kohlen Mittel- und Ostdeutschlands. Freib. Forsch., C 19, pp. 1-196.

Otte, M.U. (1953): Spurenelemente in einigen deutschen Steinkohlen. Chem. Erde, **16**, pp. 239-294.

Pera, F. (1987): A tervezett Ajka-II bányaüzem bemutatása (The projected Ajka-II mine). Published by the Vezsprém Coal Mines (in Hungarian), p. 1-32.

Rankama, K., T.G. Sahama (1950): Geochemistry. Univ. of Chicago Press, 912 p. Chicago.

Szalay, S. (1954): The enrichment of uranium in some brown coals in Hungary. Acta Geol. Acad. Sci. Hung., **2**, pp. 299-310.

Szalay, S. (1957): The role of humus in the geochemical enrichment of U in coal and other bioliths. Acta Phys. Acad. Sci. Hung., **8**, pp. 25-35.

Szádeczky-Kardoss, E., M. Földvári-Vogl (1955): Magyarországi szénhamuk geokémiai vizsgálata (Geochemical investigation of Hungarian coal ashes). Földt. Közl., **85**, pp. 7-43.

Taylor, S.R. (1964): Abundance of chemical elements in the continental crust: a new table. Geochim. Cosmochim. Acta, **28**, pp. 1273-1278.

Tomschey, O. (1988): Az Ajka-II terület szénkőzeteiből várható pernye ritkafém és sugárzó-anyag tartalmának vizsgálata és összehasonlítás az Ajka-I terület adottságaival (Trace metals and radioactive elements in the coals of the Ajka-II coal field and comparison with Ajka-I). Kutatási jelentés, 25 p.

Tomschey, O. (1989): Összefoglaló értékelés az Ajka-II terület szénkőzetein végzett nyomelem geokémiai vizsgálatokról (Comprehensive evaluation of the trace element geochemical investigations on the coals of the Ajka-II region). Kutatási jelentés, 71 p.

Turekian, K.K., K.H. Wedepohl (1961): Distribution of the elements in some major units of the Earth's crust. Bull. Soc. Geol. Amer., **72**, pp. 175-191.

Uzunov, J. (1980): Geochemical nature of petrographic components of coal and ways of vanadium concentration in them. Geol. Balcanica, **10**, 1, p. 57-74.

Acta Geologica Hungarica, Vol. 33/1-4, pp. 137-146 (1990)

TRENCH FORMATION ON A COMPRESSED CONTINENTAL PLATE: A MODEL FOR BAKONY TECTONIC UNIT

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The Paleogene history of the Bakony tectonic unit features some pecularities which are difficult to understand in terms of existing geodynamic models. The application of classic mechanical analysis allowed to explain the evolution of a trench on the Bakony plate, the cyclic change of deep- and shallow water basins and the character of volcanism.

Keywords: Bakony tectonic unit, Paleogene evolution, trench formation mechanism, border effect, deformation, cyclicity, contaminated melt.

Introduction

The Bakony tectonic unit (Kázmér, 1986) is a part of the Intracarpathian basin. During the Paleogene the Takony tectonic unit underwent complex geological evolution including the formation and gradual disappearance of sedimentary basins of different depths, mountain building, intensive volcanism as well as substantial horizontal displacement. It is difficult to explain in the Paleogene evolution of the Bakony tectonic unit in terms of the existing geodynamic models. To explain it we apply the classical mechanical analysis.

We do not consider here the Paleogene sedimentation history of BTU in details for which we refer to T. Báldi, M. Báldi-Beke (1985). We only point to the characteristic features of this history as follows:

1. Paleogene sedimentation started in the Middle Eocene (Lutetian) in the SW Bakony (as to the present orientation of the tectonic unit).

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Received: 16/03/90

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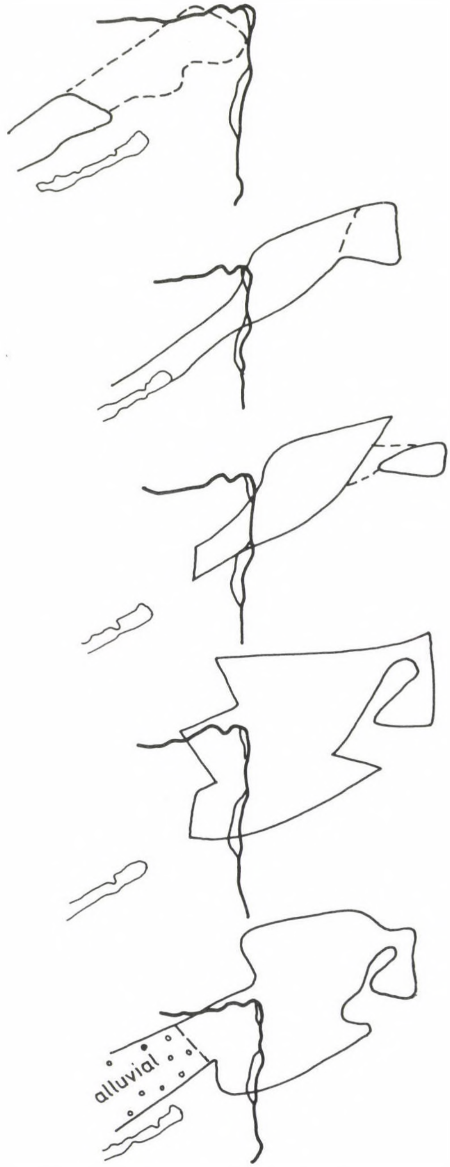

Fig. 1. Contours of Paleogene sedimentary basins of the Bakony Mts. (Báldi, Báldi-Beke, 1985). 1a. Early and Late Lutetian basins. 1b. Late Priabonian basin. 1c. Latest Priabonian and Early Kiscellian basins. 1d. Late Kiscellian basin. 1e. Egerian basin

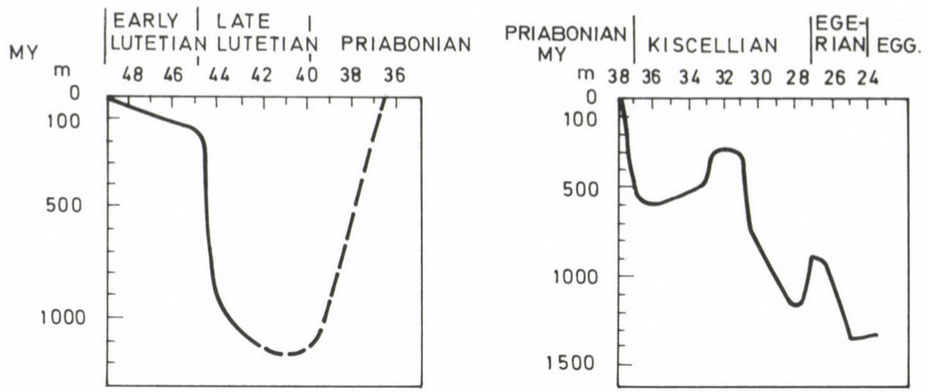

Fig. 2. Subsidence history of the Bakony tectonic unit (after T. Báldi, M. Báldi-Beke, 1985, slightly modified). 2a. Subsidence history of the Early Lutetian basin (SW part of BTU). 2b. Subsidence history of the Late Priabonian to Egerian basins (central and NE parts of BTU)

2. From the Middle Eocene till the end of Oligocene (Egerian) a number of successive basins developed on the BTU (Fig. 1). These basins were gradually moving towards NE along the longitudinal axis of the BTU while basins in the rear (i.e. in SW) were disappearing.

3. The basin depth was substantially changing in time (Fig. 2). There were two periods of intensive calc-alkaline volcanism: in Late Lutetian to Early Kiscellian and Latest Kiscellian to Early Egerian.

4. At the end of the Paleogene (Egerian) an area of alluvial sedimentation appeared in the central part of the BTU (Csatka and Mány Formations, Fig. 1e). Source area for these big volumes of clastics was situated in the west at the rear of the sedimentary basin (Korpás, 1981).

M. Kázmér and S. Kovács (1985) showed that until the Middle Eocene (Lutetian) the BTU was situated much farther to the west than it is now. It was squeezed between the Northern Calcareous and Southern Alps i.e. in a zone of interaction of Europe and Apulia. Mutual approaching of these two under some acute angle (73 degrees as estimated by Z. Balla (1988b), resulted in growing compression and continental escape of the BTU to the east. This escape began in the Middle Lutetian and lasted till the end of Egerian.

Figure 3a shows the BTU's schematic position relative to the Northern and Southern Alps in the Middle Eocene, i.e. before the continental escape. The eastward displacement of the BTU was hindered by the large tectonic units of Veporides, Gemerides and Tatrides. The BTU had to push them in front of it while escaping, these tectonic units being rotated counterclockwise and moved to NE (Fig. 3b).

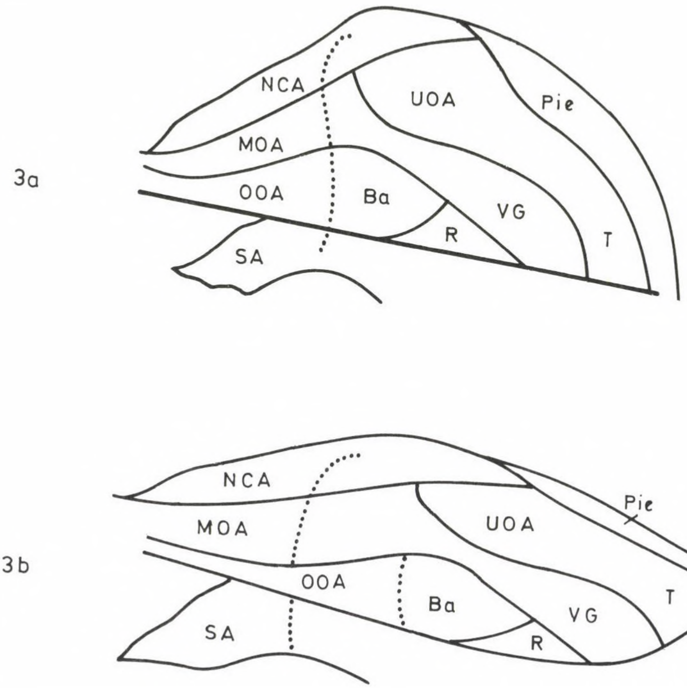

Fig. 3. BTU's position relative to the Northern Calcareous and Southern Alps in: a) Middle Eocene; b) Late Oligocene (after Z. Balla, 1988a; R. Jiřiček, 1988; modified). NCA - Northern Calcareous Alps, Pie - Pienniny Klippen zone, UOA - Unterostalpin, T - Tatrides, MOA - Mittelostalpin, VG - Veporides and Gemerides, OOA - Oberostalpin, Ba - Bakony, R - Recsk, SA - Southern Alps. Dotted line is Norian facies boundary (between Hauptdolomit and Dachstein Limestone)

Mechanical model and geological evolution

To analyze the mechanism of interaction between the BTU and other tectonic units we postulate the following:

1. BTU is a plate with non-parallel borders (Fig. 4). This plate can be deformed by other tectonic units.

2. Tectonic units I, II and III (Fig. 4) are absolutely rigid plates with masses much bigger than that of the BTU.

3. The part of the BTU which contacts plate III is its head part, the opposite part is a tail. These two parts constitute one third of the BTU's length each.

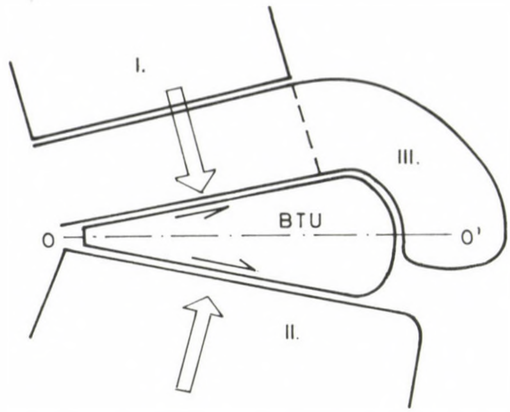

Fig. 4. Positions of the BTU and plates I-III before continental escape

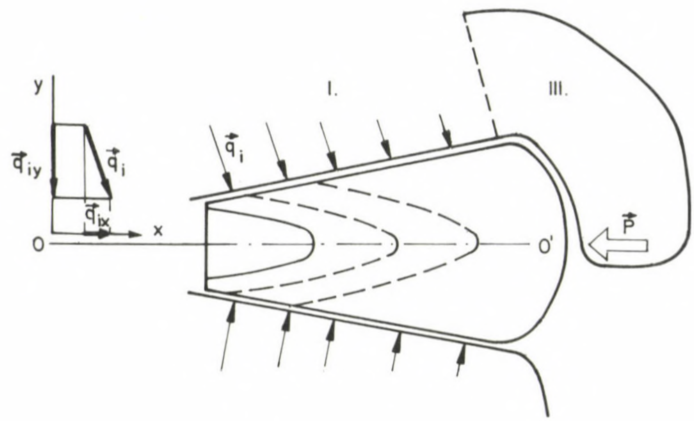

Fig. 5. System of forces on plate contacts

In the Early Lutetian plates I and III began pressing the BTU. As the plate borders contacting the BTU were not parallel, the BTU was compressed unevenly and compressional forces decreased along its longitudinal axis from tail to the head. Compression resulted in the downwarping (i.e. subsidence) of the BTU along its longitudinal axis where the forces had reached critical values. The difference of values of compressional forces along the BTU's borders led to the so-called "border effect". Under this effect loading localized in the tail and adjacent parts causing the deformation of the BTU. Beyond the border effect zone the BTU's reaction to this local load was decreasing reaching zero at large (relative to BTU's size) distances. Compressional forces on BTU's borders beyond the border effect zone were less contributing to the deformation. This explains the beginning of deep-water trench formation in the western part of the BTU. This trench had a parabolic form in a plan view (Fig. 5). The depth of the trench decreased to the east along the longitudinal axis.

Before analyzing the interaction of BTU with other tectonic units we consider the system of forces on their contacts.

In Fig. 5 the vector $\vec{q}$ is projected on the axis of the plate Decart coordinate system. Vector $\vec{q}$ is a vector of external load ($\vec{Q}$), spread along the BTU's longitudinal axis ($\vec{Q} = \sum_{i=1}^{\infty} | \vec{q}_i |$).

Resulting force of X projections $\vec{Q}_x = \sum_{i=1}^{\infty} | \vec{q}_{ix} |$ pushes BTU out of the zone of interaction between plates I and II. But plate III hinders it from escape till the following equation is right:

$$| \vec{P} | > \sum_{i=1}^{\infty} | \vec{q}_{ix} |$$

where $| \overline{P} |$ is reaction of plate III. So BTU which stays squeezed between plates I and II and is hindered from escape by plate III, continues to be compressed. The process of downwarping (i.e. subsidence) along its longitudinal axis will further develop.

In the Late Lutetian the basin evolution was going on in the SW part of BTU. It combined the process of parabola's branches expansion with simultaneous motion of parabola's top along BTU's longitudinal axis towards its head part. As the parabola's branches reached the borders of the BTU these were adjusted to them and the basin lost partly its parabolic shape in a plan view (Fig. 5).

From the Middle Late Lutetian to the Early Priabonian the rate of subsidence was growing (Fig. 2). It seems that it was caused by increasing load $\overline{Q}$ which in its turn was the result of increasing pressure of plates I and III. At that time the rate of basin expansion and subsidence were also increasing and the top of the basin's parabola was moving farther towards the head of the BTU.

In the Late Lutetian - Priabonian calc-alkaline volcanism took place in the tail part of the BTU. There are no data to testify the subduction character of this volcanism. To explain this volcanism we consider the possibility of local destruction of BTU as a result of loading.

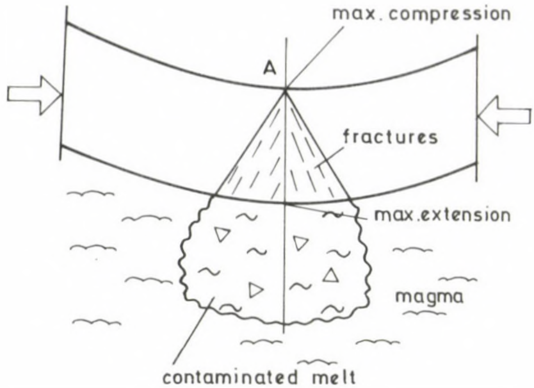

Fig. 6. Creation of contaminated melt as a result of plate destruction

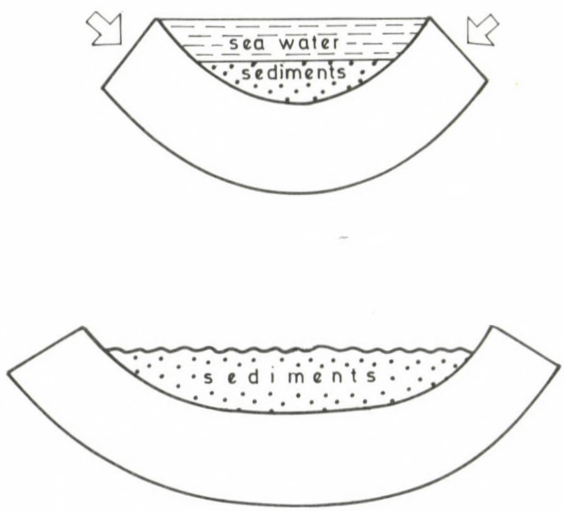

Fig. 7. Partial return of a plate into non-deformed state after compression

As it was shown above the compression of BTU resulted in downwarping of its tail part. It's obvious that in the axial part which was the most subsided one the loads were distributed so that the maximum compression was in point A (Fig. 6). This compression led to the destruction of brittle rocks and created local fractures. Downwards along the axis, compression was changed by increasing extension which caused cracking and partial collapse of rocks from the BTU's bottom. The fragments of the continental crust got into the upper layers of the magma so a contaminated melt was produced. This melt could have serve as a source of calc-alkaline volcanims.

In the Late Priabonian the rapid uplift of the basin floor nearly up to zero level took place (Fig. 2). In this period the growing compressional forces exceeded the reaction of plate III and BTU began escaping from in between plates I and III. In this case equation (1) can be written as follows:

$$|\vec{P}| \quad \sum_{i=1}^{\infty} |\vec{q}_{ix}| \qquad (2)$$

Compressional forces in the BTU were decreasing and it was trying to attain its initial non-deformed state. This means that the basin floor was uplifting, sea was regressing and the basin was becoming shallow.

Because of the difference between the basin floor and sea depth which was equal to the sediment thickness the complete regression of sea did not mean the complete return of the plate back into its initial state (Fig. 7).

The process of sea depth increase and decrease was periodically repeated (Fig. 2): there were 3 cycles of depth increase and decrease during Lutetian-Egerian. To explain this phenomenon we suppose that the force which had accumulated during long-time compression in the first cycle ($|\vec{Q}_x| = \sum_{i=1}^{\infty} |\vec{q}_{ix}|$) was not enough to push the big mass of plate III in front of the escaping BTU immediately into the final position of the former (that is into the position corresponding to the Egerian time). At the beginning of escape process the sum of compressional forces exceeded the resistance of plate III and the BTU began moving. But plate III had big mass and was very inertial and its displacement was accompanied by friction along the borders of other tectonic units. After some time the pushing force equalled again the reaction of plate III and equation (1) was right again. But continuing pressure of plates I and III led to the increase of pushing force in the BTU, i.e. value of $|\bar{Q}_x| = \sum_{i=1}^{\infty} |\bar{q}_{ix}|$ was increasing and in some time equation (2) became right again and the escape process renewed.

The border effect of compression in the tail and the middle parts of BTU resulted in the downwarping of the head part (trench formation in the NE BTU from the Latest Priabonian, Fig. 1b-e). In the tail and middle parts where thick sedimentary formations had accumulated these formations were subjected to substantial compression, folded and gradually pushed out of the trench in which they had accumulated. This means the beginning of mountain building and the increase of clastics income into the sedimentary basin (Late Kiscellian Hárshegy Sandstone, Egerian Csatka and Many Formations).

Conclusions

The application of mechanical analysis to the Paleogene geodynamics of the Bakony tectonic unit helps to explain the peculiarities of its evolution.

1. The gradual evolution of the trench from W to E is a result of uneven compression of a plate with nonparallel borders.

2. The cyclic change of deep and shallow basins is a result of periodical return of BTU into nondeformed state because of discontinuous escape process.

3. The calc-alkaline character of volcanism is a result of destruction of BTU's bottom during compression.

REFERENCES

Báldi, T., M. Báldi-Beke (1985): The evolution of the Hungarian Paleogene basins. Acta Geol. Hung., **28**, 1-2, pp. 5-28.

Balla, Z. (1988a): Late Eocene tectonic pattern of the Carpatho-Pannonian region and its bearing on the Mesozoic reconstructions of the Tethys (in Hungarian). Földt. Közl., **118**, 1, pp. 11-26.

Balla, Z. (1988b): Clockwise palaeomagnetic rotations in the Alps in the light of the structural pattern of the Transdanubian range (Hungary). Tectonophysics, **145**, 3-4, pp. 277-292.

Jiřiček, R. (1988): Navrh společneho tektonickeho členeni Alpsko-Karpatskeho orogenu. Zemny plyn a nafta. **33**, 1, pp. 69-98.

Kázmér, M. (1986): Tectonic units of Hungary: their boundaries and stratigraphy (a bibliographic guide). Ann. Univ. Sci. Budapest, Sect. Geol., **26**, pp. 45-120.

Kázmér, M., S. Kovács (1985): Permian-Paleogene palaeogeography along the Eastern part of the Insubric-Periadriatic lineament system: Evidence for continental escape of the Bakony-Drauzug Unit. Acta Geol. Hung., **28**, 1-2, pp. 71-84.

Korpás, L. (1981): Oligocene-Lower Miocene formations of the Transdanubian Central Mountains in Hungary (in Hungarian with English abstract). Magy. Állami Földt. Intézet Évkönyve, **64**, 140 pp.

Timoshenko, S.P. (1948): Plates and membranes (in Russian). Gostehteorizdat, Moskva, Leningrad, 460 pp.

Acta Geologica Hungarica, Vol. 33/1-4, pp. 147-162 (1990)

PLANNING OF EXPERIMENTAL COMPLEX AIRBORNE GEOPHYSICAL AND GEOCHEMICAL MEASUREMENTS FOR HYDROCARBON PROGNOSTIC PURPOSES

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The review of remote sensing geological exploration methods and the planning of application of experimental airborne remote sensing measurements are discussed. The realization plans of the two-step experimental airborne infrared records were prepared on the basis of geothermal gradient and temperature maps constructed after the layer temperature data gained in the course of drilling hydrocarbon exploration for the Pusztaföldvár-Battonya ridge. The concrete realization plans of the experimental airborne geophysical and geochemical measurements were prepared for the Szeghalom and Komádi environs. The realization of measurements, the computer data processing and interpretation could be realized on high level by the methodology developed by Canadian researchers.

By applying the remote sensing methods as novel ones we try to improve the efficiency of the petroleum and gas exploration in Hungary.

Keywords: Remote sensing, airborne geophysical measurements, airborne geochemical measurements, hydrocarbon exploration.

Introduction

In numerous countries of the world the airborne varieties of classical surface geophysical instruments and methods (gravitation, magnetic, electromagnetic, radiometric) are used. In the course of exploration satellite records are also used. Records are made both in the visible and in the invisible wavelength ranges. Instruments developed for geological explorations and operating in the infrared and ultraviolet ranges as well as the gamma radiation spectroscopy are also in practice.

In Hungary the possibilities of remote sensing exploration methods are known in hydrocarbon industry only by a few experts. A negligible proportion of geologists, geophysicists and geochemists working in hydrocarbon

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Received: 09/03/90

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industry possess only sporadic knowledge on the geological exploration by remote sensing. Most of the experts if heard or read about these methods believed that in Hungary these methods cannot be used in petroleum and natural gas exploration in addition to the high-grade state of exploration.

In favour to eliminate this inadequacy and to make more complex the hydrocarbon pre-exploration and taking into account the circumstances and conditions, experimental complex airborne geophysical and geochemical measurements have been planned that ought to be performed in the frame of Canadian-Hungarian cooperation. The optimal realization of our aims could be assured by the Canadian realization since Canada has leading role not only in the production of airborne geophysical and geochemical instruments but also in the field of computer processing and interpretation.

The complex airborne geophysical and geochemical systems are rapid and powerful. In Hungary no complex airborne geophysical and geochemical measurements were carried out so far in the hydrocarbon industry aiming at the petroleum and natural gas exploration.

The complex airborne geophysical and geochemical measurements may provide useful help to explore the subtile traps and hydrocarbon occurrences. Remote sensing is advantageous in the investigation of environmental pollution of petroleum and gas outbursts occurring in drilling hydrocarbon exploration activities from the aspect of safety technique (methane sensors) and of the delimitation of areas damaged by oil pollution (Luminescope LMX-3 type).

Geological bases of planning the experimental airborne infrared records

Geothermal conditions of the Great Plain basins to be investigated

In the frame of technical development research project entitled "Improvement of exploration methods serving as a basis of hydrocarbon prognostics of Hungary" the computer processing and interpretation of the topic "Analysis of the changes of composition of confined water and dissolved gases of the Great Plain from the aspect of hydrocarbon prognostic with the aid of determining the possible direct and indirect hydrocarbon exploration indices" have been carried out in the Department of Geology and Metallogeny (Faculty of Mine Engineering, Technical University for Heavy Industry, Miskolc) on behalf of the Hydrocarbon Exploration Company in 1985. In addition to the methodological researches the area of the Szeged

Basin was processed in 1986, that of the Bihar and Békés Basins in 1987 and that of the Nagykunság and Hajdúság Basins in 1988 were processed. Reports presented the geological structures, the hydrocarbon generation zones and the spatial distribution of the known prognostic hydrocarbon reserves based on the data of 1.01.1985. In the course of computer processing aiming at the determination of secondary hydrocarbon migration directions the interpretation of the layer-physical, hydrochemical, petroleum and gas analytical data was also performed. In case of these data the determination of the vertical trends, of the geothermal and pressure conditions was also carried out. In relation with the temperature conditions the reports made valuable statements and conclusions to be introduced below for each basin.

Szeged Basin

The values of the geothermal gradient vary between 7.85 °C/100 m (Ásotthalom) and 4.18 °C/100 m (Hódmezővásárhely). The localities of hydrocarbon occurrences are marked by closing maxima. The vicinity of the Zombor-4 borehole is worthy of mention. The site of "hot spots" is marked by isotherms constructed in a definite depth. This surface was chosen at 1000 m since in the southern part of the study area the basement is in uplifted position and this did not allow the construction in deeper horizons. Along this surface the temperature values vary between 98.48 and 56.38 °C. In harmony with their statement the isotherm curves indicate that the locality of hydrocarbon occurrences can be localized not on the basis of absolute values but according to the local anomalies. The so-called "hot spots" are not by all means the sites of highest temperature in the given depth horizon. In the Szeged Basin the temperature values show a regional increase southwestwards and the local temperature anomalies of the productive areas can be effectively recognized.

The shape of the isotherm curves constructed at the surface of the lower overpressure zone indicates the change of temperature does not correlate with the change of depth. The isotherm curves have to run parallel to the contour lines showing the paleogeomorphology if the value of the geothermal gradient would be the same everywhere in the area. The difference between the two curves refers to the temperature anomalies the direction and measure of which can be determined from the map. The areal changes of temperature were also presented in the geological profiles plotting the values of 60, 120 and 180 °C.

Békés Basin

In the area of the basin explored by boreholes the value of the geothermal gradient varies between 5.3 and 9.8 °C/100 m. The highest values are found in the region of Tótkomlós-East and Végegyháza-West, in the Pusztaföldvár environs and at Csanádapáca. The values of geothermal gradient are relatively low at Battonya. The extreme high values coincide with the contact zone of Paleozoic-Mesozoic sequences. The isotherms constructed to the horizon of 1000 m below sea level indicate the "hot spots" of the basin and these are usually related to hydrocarbon occurrences. Above the basement crest zone an average temperature zone characterized by values higher than 90 °C is found in the productive areas.

Bihar Basin

Here the values of geothermal gradient vary between 5 and 7.1 °C/100 m. Relatively high values are found above the Paleozoic basement and in the contact zones of the Paleozoic and Mesozoic sequences. Values are high in the uplifted parts above the carbonate basement and low in deep position probably due to the relatively favourable water flow conditions.

The "hot spots" of the basin are marked by the isotherms constructed to the contour line of 1000 m below sea level and these can be usually related to hydrocarbon occurrences. In this depth horizon the temperature values vary between 65 and 89 °C. As compared to the environs positive anomalies with closing maxima indicate the hydrocarbon fields of Sarkadkeresztur, Álmosd, Kismarja, Körösszegapáti and Komádi, and to smaller extent those of Mezősas, Mezőpeterd and Furta. In addition to these occurrences three closing maxima are to be mentioned the most characteristic of which is found between Mezőpeterd and Biharkeresztes. These areas have been suggested to be explored by A. Somfai.

Hajdúság Basin

In the area the values of the geothermal gradient vary between 5.5 and 7 °C/100 m. In the productive areas an increase can be observed everywhere to more than 6.5 °C/100 m. Author do not mention but looking at the map enclosed to the report positive closing anomalies can be observed in the region of Hajdúszoboszló, Ebes, Kaba-South, and Nádudvar-Southeast. Close to the borehole Püspökladány-W-1 a closing maximum occurs showing 7.0 °C/100 m.

The average temperature data calculated to the contour line of 1000 m below sea level are in harmony with the geothermal gradient values, here, however, several kilometre of the Penészlek occurrence one are proved to be a "hot spot".

Nagykunság Basin

Here the values of geothermal gradient vary between 5.3 and 7.8 ^{0}C/100 m. In the productive areas values higher than 6 ^{0}C/100 m are found almost without exception.

The values of average temperature constructed to the countour line of 1000 m below sea level exactly mark the hydrocarbon fields with positive anomalies.

Interpretation of the geothermal phenomena

The investigation of geothermal phenomena was carried out by the researchers of the Technical University for Heavy Industry (Miskolc) under the guidance of A. Somfai to the major part (five basin areas) of the Great Plain and the work is in progress concerning the North Great Plain basin. Based on the researches carried out so far it can be stated:

- In the maps geothermal gradient values are seen that are relatively high as compared to their environs.

- In many cases the locality of hydrocarbon occurrences is marked by the closing maxima of the values of geothermal gradient.

- Relatively high geothermal values are found above the Paleozoic basement and in the contact zones of the Paleozoic and Mesozoic sequences.

- The shape of the isotherm curves constructed to the surface of the lower overpressure zone indicate that temperature changes do not correlate with the changes of depth.

- The average temperature isotherm lines constructed to the surface of 1000 m below sea level exactly mark the hydrocarbon occurrences called by the researchers "hot spots". Sometimes above the productive zone a belt with increased temperature is found.

- The locality of hydrocarbon occurrences can be marked not by the absolute values but rather by the local anomalies that are not obviously the areas of the basin of highest temperature.

Hydrocarbon beds and fault zones disturb the telluric heat flows and produce temperature anomalies. These anomalies occur most markedly in the maps of average temperature constructed to the surface of 1000 m below sea level, on the basis of layer temperature data. The surface of the Great Plain is flat, its surface is more or less parallel with the imagined surface of 1000 m below sea level. It can be presumed that the thermal anomalies related to hydrocarbon fields and fault zones occur also on the surface. It is probable that above the hydrocarbon fields and along fault zones only small-scale changes occur in the temperature values as compared to the environment but it is our opinion that these anomalies can be determined by means of sensitive infra records. Be this hypothesis valid or not, this can be decided onyl by experimental infra records. The investigation of surface geothermal phenomena based on this hypothesis can be carried out by stallite and airborne infrared records. The temperature anomalies are probably affected by the soil composition, soil structure and moisture conditions, or their values can be decisive. Subsequently to the digitization of the records a computer filter program has to be applied that eliminated the scattered infra radiation anomalies and the effects mentioned above. We are informed that the Eötvös Loránd Geophysical Institute possesses this type of computer filter programs.

Finally, the report entitled "Temperature conditions of Neogene basins in the range critical from the aspect of hydrocarbon accumulation" and made F. Horváth and P. Dövényi (1988) on behalf of the Geophysical Exploration Company has to be mentioned. Here the conclusions below are found:

- The exact knowledge of the recent temperature field is fundamentally important from the aspect of marking the genetic and preservation zones;

- The temporal evolution of basin formation can be reconstructed by means of model calculations concerning the histories of subsidence, temperature and maturity. As to the experiences these calculations may be successful only in possession of the knowledge of the recent temperature field.

- The particular analysis of the recent temperature field allows the exploration of significant water flow systems existing nowadays, as well. To study these systems may be important from the aspect of understanding the recent and former migration paths.

Among others the report contains the isotherm map series of 100, 120, 140, 160, 180 and 200 ^{o}C. The temperature anomalies determined by

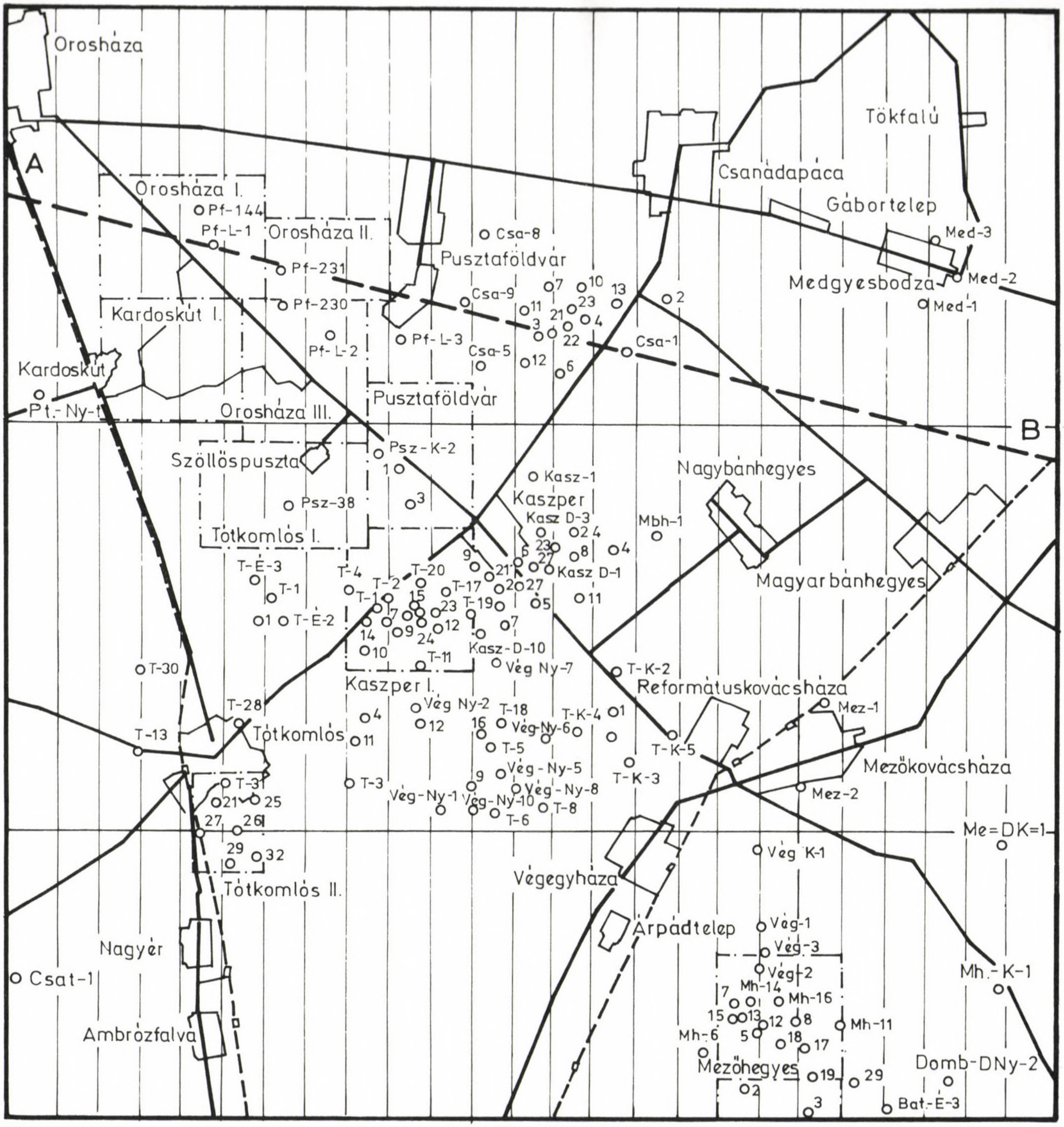

Fig. 1. The Battonya-Pusztaföldvár crest: Profile network plan of airborne infrared records. Area: 675 km^2. 26 profile of 27 km length = 702 km, one profile of 26 km length = 26 km; altogether: 728 km

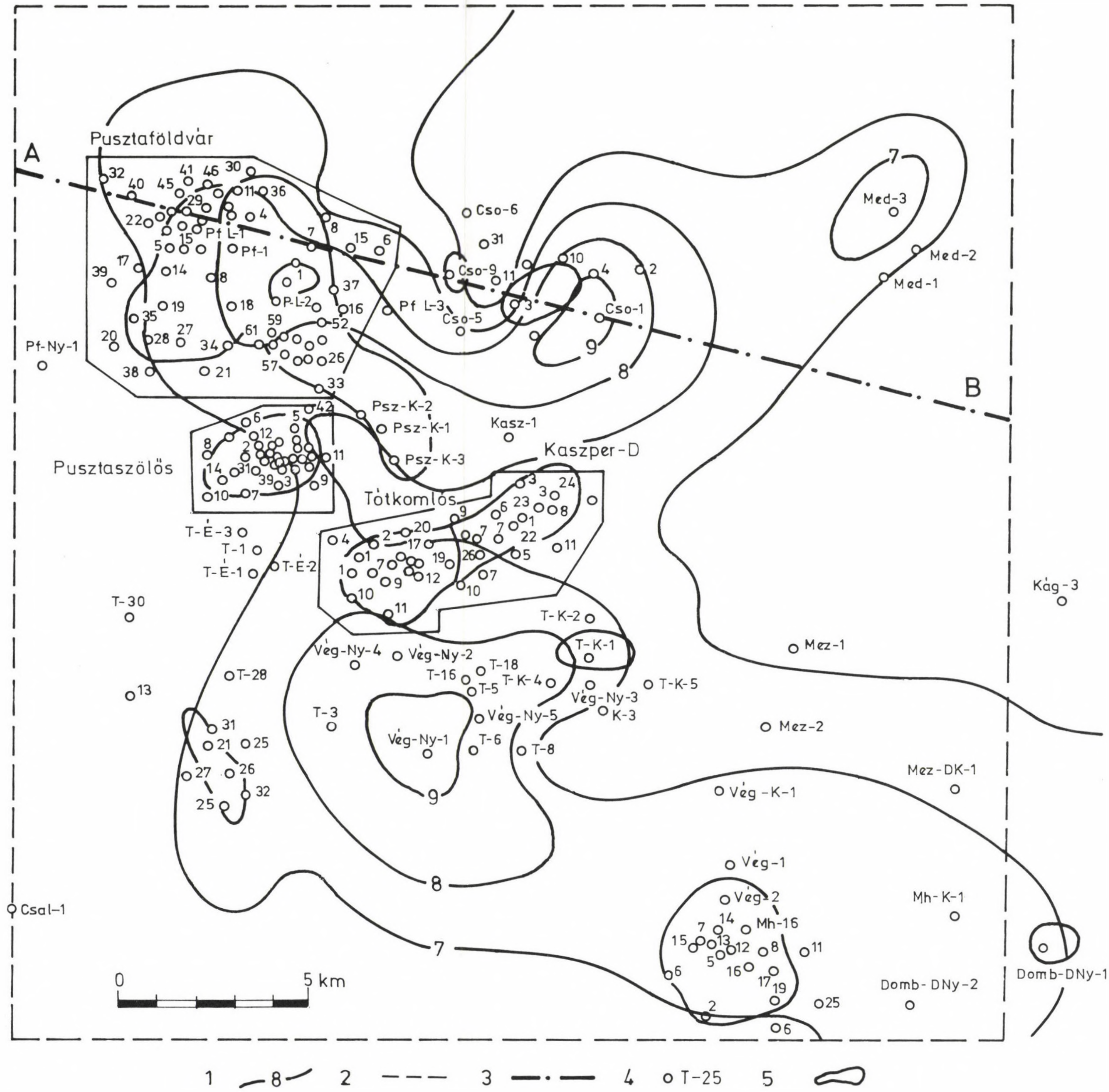

Fig. 2. Geothermal gradient map. 1. values of the geothermal gradient; 2. boundary of the infrared records; 3. transverse profile; 4. drilling points; 5. hydrocarbon beds

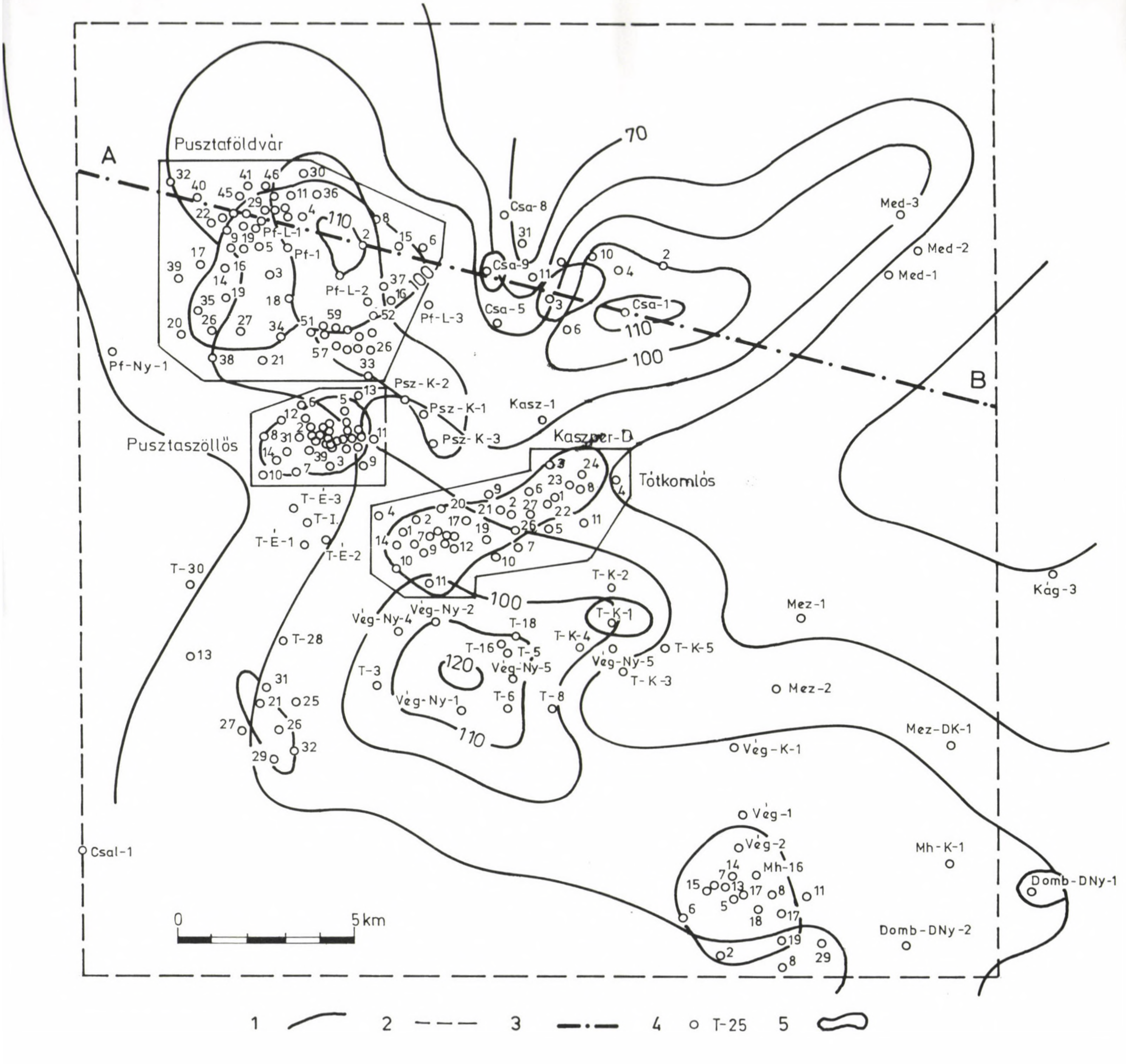

Fig. 3. The Battonya-Pusztaföldvár crest. For legend see Fig. 2

A. Somfai at the Battonya-Pusztaföldvár crest can be observed also in this map series.

Design of experimental airborne thermovision records

It was planned to perform the infra records in the areas of the experimental airborne geophysical and geochemical measurements, i.e. the Komádi and Füzesgyarmat-Dévaványa structures. Taking into account that in the areas mentioned the temperature indications are not the most marked ones, the Battonya-Pusztaföldvár structure was chosen that involves the areas of Pusztaföldvár, Csanádapáca, Pusztaszőlős, Tótkomlós, Kaszaper-South, Végegyháza-West and Mezőhegyes (Fig. 1). The area is as large as 675 km^2, the profile network has a distance of 1 km, the coordinate system is of N-S direction, the work comprises 26 profiles, each of 27 km length; this corresponds to a total path of 702 km. In Fig. 1 a transverse profile of 26 km length and of NW-SE direction can be seen between points A and B that passes through the boreholes Pusztaföldvár-2 (Pf-2) and Csanádapáca-1 (Csa-1). The geothermal characteristics of the experimental area are seen in Figs 2, 3 and 4. Here four closing positive anomalies are found in the geothermal gradient maps (Fig. 2) and three closing positive anomalies in the map constructed to the contour line of 1000 m below sea level. The maximal value of two closing isotherms is 110 ^{o}C, that of the third is 120 ^{o}C. Between the boreholes Pf-31 and Csa-1 the measure of temperature change exceeds 40 ^{o}C. Figures 3 and 4 are details of the maps constructed by A. Somfai (1987). The changes of temperature conditions of the transverse profile mentioned above are shown in Fig. 4.

The airborne thermovision records are planned to be realized in two steps. In the first step along the transverse profile between points A and B thermovision records have to be made with different optics, in different heights (50 to 4000 m) and in different dates. If these records will serve the purpose when applying the filter program during computer processing, the second step, i.e. records along the network follows based on the determination of the optimal design parameters.

It is worthy of mention that in the region of the Battonya-Pusztaföldvár crest four of the seven suggested areas fall to the area of the experimental airborne thermovision records.

We want to prepare the planned infra records by a Hungarian-made

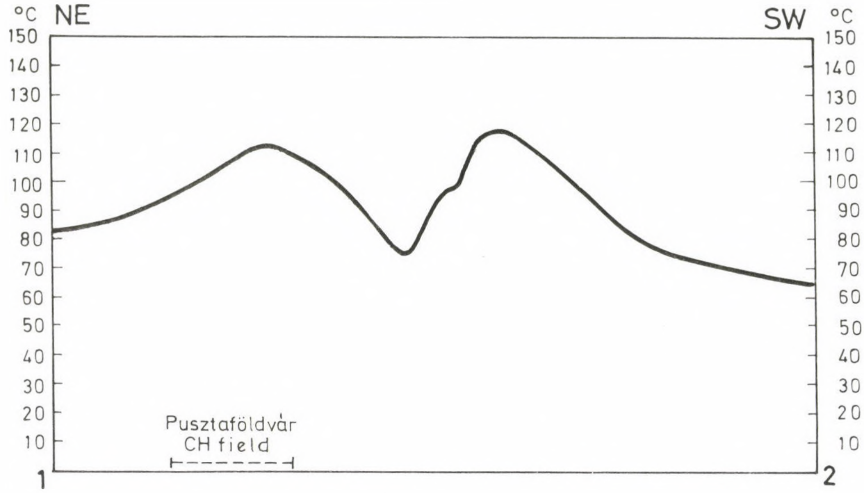

Fig. 4. The Battonya-Pusztaföldvár crest: Temperature profile between points A and B in the horizon 1000 m below sea level. A-B distance = 26 km

sensor system and this possibility was studied with the assistance of L. Schönviszky (Eötvös Loránd Geophysical Institute). The Central Research Institute for Physics and the Technical University of Budapest do not possess a sensor system that would be able to perform the airborne records planned by us, the Technical University, however, tends to prepare an experimental sensor system suitable for our purposes. The Technical Institute of the Ministry of Agriculture and Food Industry (Gödöllő) has the required infra technique (camera and thermovision system). Airborne infra records are made to study the soil and vegetation conditions, the records are made in the near-infrared range. The infra sensitive films used by them are suitable to record the ultra violet and near-infrared ranges in addition to the visible range of the electromagnetic oscillations. This is unsuitable for hydrocarbon exploration purposes using the geothermal phenomena since this records only the spectral reflection and the scattered infra radiation. By means of this film thermal pictures can be made only above 250-300 ^{o}C in case of natural thermal radiation.

The complete thermovision system of the Technical Institute of the Ministry of Agriculture and Food Industry is a Swedish-made AGA-type instrument equipped with recorder, play, image digitizing and computer units. Normal video cassettes are used for the records. The infra records can be displayed in colour by colour coded in the thermal range. The thermal range can be reduced, the number of codes can be increased. Temperature values can be displayed at any point of the screen and temperature profile can be made from screen in optional direction. The picture is recorded by digitizing to magnetic tape and according to definite programs the computer processing is carried out. The AGA infra system operates at 25 Hz. The infra records cannot be displayed by means of another system and the disk data cannot be processed by other computers.

To make the experimental airborne thermovision records for the Petroleum Exploration Co., and to filter the scattered infra radiation a computer filter program ought to be applied in cooperation with Eötvös Loránd Geophysical Institute. We need the processing and display on a map of the natural thermal emission of the Earth. We have to search for the possibilities of solving the problem since the AGA thermovision system seems to be suitable to perform the planned experiment.

Design of the experimental complex airborne geophysical and geochemical measurements

In relation with the design it is to be mentioned that this plan is the third variety. The first plan of 500 m profile distance was prepared solely to cover the hydrocarbon occurrences of Szeghalom, to cover the structure sequences of Füzesgyarmat-Dévaványa and Komádi (Furta, Mezősas and Komádi).

In case of the second variety the profile distance was planned to 250 m for the same area. Based on Canadian suggestions in the third variety a profile distance of 200 m was used and the Szeghalom oil field was omitted so that its northern and southern parts were shortened. The Furta and Mezősas hydrocarbon occurrences were also omitted. Instead of the omitted areas new ones were involved in the experimental work in favour of utilize the results as soon as possible. Theoretical considerations led to the omission of the Szeghalom oil field. In the holes drilled in this area often steel casing was used and in case of productive wells pipelines were built to the collecting stations. These factors could cause disturbing effects in the course of experimental airborne measurements.

It is expedient to perform the experimental airborne complex geophysical and geochemical measurements close to the surface, i.e. in a height of 50 to 80 m. The planned total surface to be studied is 396 km^2, the profile network is as long as 2189 km together with the transverse and closing profiles and the pure measurement time is 22 hours. The profile network consists of 138 profiles. The turne of aeroplanes consumes 4 h and

40 min , the total measurement time being 26 h and 40 min. Taking into account some reserve time altogether 30 h were planned. Under favourable weather conditions the work can be performed within one week by helicopter (two starts per day) or aeroplane (one start per day).

Measurements can be carried out after marking the profile network. During the measurements a signalling system is planned to operate. The design was performed for the three experimental areas in a basic map of 1:100 000 scale, with a profile density of 200 m. In all areas a baseline was marked and in harmony with the navigation rules the way there and back was marked red and blue lines, respectively (Fig. 5). To realize the plan board-maps prepared according to the requirements of the executors will also be made for all measurement areas.

The overwhelming majority of the experimental airborne geophysical and geochemical measurements was planned to cover hydrocarbon beds. This

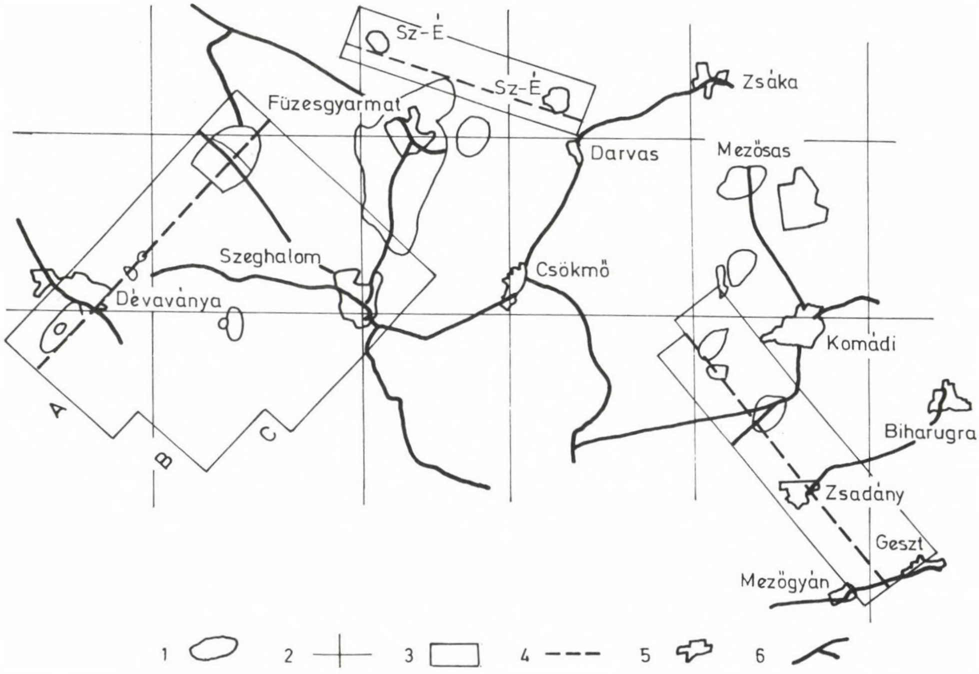

Fig. 5. Plan of the airborne geophysical and geochemical measurements. 1. contours of CH-beds; 2. coordinate system; 3. measurement area; 4. baseline; 5. settlement; 6. road

aimed at to decide whether the structural or field indications or both can be chosen from the measurement results or not. In successful case when planning the measurements the principle of analogy will be applied in hydrocarbon exploration using, of course, the hydrocarbon prognostics and the surface geophysical measurement data. The area of the planned experimental complex measurements will be used as a reference area.

It has been also considered that no exploratory well has to be marked out to prove the measurement results. In the area of the Szeghalom environs three or four localities are found where on the basis of seismic maps of 1:50 000 scale constructed to the Pannonian basement it is reasonable to mark out hydrocarbon exploratory wells. These localities would be compared and co-interpreted with the experimental airborne geophysical and geochemical measurement results.

To perform economically the experimental complex airborne measurements an air base lying close to the experimental areas is needed. Close to these areas two bituminized landing strips are found. One of these bases can be used having undersigned the contract.

The main characteristics of the measurement areas are as follows:

1) Szeghalom and evnirons

The profile network is of NE-SW direction, the baseline passes through the boreholes Füzesgyarmat-8 and Dévaványa-8. The surface of the area to be measured is 261 km^2, 84 profiles with a total length of 1433 km are marked out. The area consists of three parts, the actual experimental area is 152 km^2, the number of profiles is 41, with a total length of 779 km. By means of this profile network the hydrocarbon beds of the Füzesgyarmat-Dévaványa structure sequence and the fault zone lying in its southeastern side are covered. As a continuation two smaller areas were involved to the southeast, to the line of the river Berettyó, this allows to study the southwestern corner of the Szeghalom field. In this region hydrocarbon bed were found by means of drilling in the areas of Szeghalom-West, Körösladány and Dévaványa-South. Recently, the drilling activity is also in progress. It is believed that with the help of experimental measurements the effectiveness and rentability of the drilling activity will be improved. In the region of relatively great extension of Szeghalom and Körösladány no seismic data are available, thus the airborne geophysical and geochemical measurements are planned to perform in thisarea. When designing the profile network the siesmic maps and profiles of 1:50 000 scale constructed to the Lower Pannonian basement, the filtered gravitation anomaly map of 1:200 000 scale made by the Geophysical Exploration Company and the latest hydrocarbon prognostics were taken into account.

In harmony with the suggestions of the National Petroleum and Gas Industrial Trust and of the Petroleum Exploration Company, the researchers of the Mecsek Ore Mining Company will taken an experimental radon-profile in a length of about 7 km along the Töviskes road and above the Füzesgyarmat hydrocarbon bed. The profile starts above the bed and terminates out of the surface projection of the bed in water zone. We also suggested to record the gamma spectra. In order to compare and evaluate the data an airborne transverse profile is planned above the Töviskes road. To enlarge the circle of data to be compared and evaluated U, Th, K and Rd analyses from the gas are also planned.

2) Szeghalom-North

The profile network is WNW-ESE direction, the baseline passes through the boreholes Szeghalom-N-1 and Szeghalom-N-7. The surface of the area to be studied is 41 km^2, the total length of the 21 profiles is 239 km. The profile network will cover the two hydrocarbon beds of the Szeghalom-North region including the northern corner of the Szeghalom hydrocarbon field. To cover optimally and most efficiently the profile network was planned on the basis of geophysical data outlined in case of Szeghalom and environs.

3) Komádi and environs

The profile network is of NW-SE direction, the baseline passes through the boreholes Komádi-1 and Komádi-3. The surface of the areea is 93 km^2, the total length of the 33 profiles is 517 km. The profile network was prepared to cover the beds of the Komádi hydrocarbon field and the environs of the villages Zsadány, Geszt and Mezőgyán. In addition to the optimal and economic covering of the hydrocarbon beds and to the evaluation of hydrocarbon geological conditions the filtered gravitation map constructed by the Geophysical Exploration Company in 1988 in a scale of 1:200 000 as well as the seismic maps and profiles served as a basis to design the profile network. The extension of the area is verified by the fault zone between the gravitation maxima of Komádi and Geszt since it is well known that fault zones are favourable to hydrocarbon migration and accumulation. The anomaly values and the fault suggest the possibility of traps, as well.

The experimental airborne measurement data and their evaluation may provide advantageous turn to further drilling of the area.

Airborne instruments and their characteristics

The Canadian firm Scintrex sent the instrument catalogue as well as the price list. By the agency of the firm Capitaleng a detailed offer was sent to realize the planned measurements. The instruments and their characteristics areas follows:

- Scintrex MAC-2 "Towed-bird" vertical Cs gradient meter. The sensors of the magnetometer are optically pumped Cs-vapor sensors with a sensitivity of 0.1 nT. Sampling time is 0.5 second.

- Scintrex multichannel radiometersystem. It measures the K, U and Th content of the surficial matter and registrates the results in 256 channels. The system has a sodium-iodide content of 16.8 L and consists of the following units: Scintrex multichannel spectrometer, GSI-3 gamma radiation interface and Scintrex GSA-44L gamma radiation sensor.

- TOTEM 2A VLF electromagnetic system. The two VLF coils are equipped with amplifier units. It is able to record simultaneously 15-25 kHz signals from two VLF transmitters. Measurement parameters: changes of the total electromagnetic field and the vertical quadrature filed. The polarity pre-signal of the quadrature is also registered. VLF data are considered as addition to airborne magnetic measurements.

- DIGHEM IV helicopter-carried electromagnetic system. This is a multicoil transmitter-receiver system (four pairs) located in nacelle towed by a helicopter. Signal is received by the analyzing control desk and after preliminary signal processing it is transmitted to the digital control desk that performs synchronous data processing. The processed data are stored in the on-board analogue and digital registers.

- Scintrex data collecting system consisting of the following units: Scintrex CDI-7 digital interface, Scintrex PIC-100 peripheric interface control desk, RMS GR-33 graphic register (2 pieces), Digidata magnetic tape register of type 1140 or 1640, Scintrex VFPR-3 video flight strip register.

- Navigation positioning system: Trisponder Navigation System type 542. The position of the helicopter is continuously determined by the on-board computer and data are stored in analogue and digital form in the data collecting system.

These instruments ought to be completed by a luminescope of LMX-3 type. Scintrex wants to cooperate with the firm Dighem Surveys Processing of Missisauga in the field of computer data processing, map construction and interpretation.

Conclusions

The research companies of the National Petroleum and Gas Industrial Trust have to perform hydrocarbon prognostics fitted to the five-year plans. The prognostics according to the 1st January 1989 will be performed in 1989. To prepare the next prognostics the remote sensing hydrocarbon exploration methods, their experimental introduction as well as the application of suitable methods could provide considerable help in the re-evaluation of the prognostic hydrocarbon reserves and in the determination of the exploration trends and proportions. The methods corresponding to the geological, hydrocarbon geological and tectonic setting of Hungary and which can be chosen on the basis of complex experimental measurements to be applied may promote the more purposeful seismic measurements increasing in this manner the effectiveness and economy of drilling exploration.

In 1988 the Petroleum Exploration Company drilled 48 hydrocarbon exploration wells and by means of 247 layer analyses the investigation of 59 wells was completed. Investments costs of the exploration activity were as high as 2.2 billion forints. The value of the pure profit of the national economy is 16 billion forints based on the increase of industrial reserves and calculated with the Hungarian average price of petroleum. In 1988 each Forint devoted to hydrocarbon exploration produced 7.30 forint pure profit. Though the detailed economic analysis is out of our topic, it is worthy of mention that some years ago the pure profit was 16 Forint. The costs of the planned airborne geophysical and geochemical measurements amount only to 1% of the sum expended to exploration in the last year.

The activity costs of the Petroleum Exploration Company were 4 billion forints in 1988. Based on the increase of industrial reserves and calculating with Hungarian average prices the pure profit of the national economy was 14.284 billion forints. Each forint produced 3.60 forint pure profit.

High-level performance of the planned experimental complex airborne geophysical and geochemical measurements can be expected by the Canadian realization, though the costs will be considerably increased by the rent time and mobilization costs. The most economic realization of the measurements can be expected by the Austrians, they, however, have a magnetometer the sensitivity of which is lower by an order of magnitude than that of the Canadians and do not have luminescope.

These new remote sensing pre-exploration methods together with the surface geophysical ones may promote the more exact marking of wells, the more intense increase of industrial hydrocarbon reserves, the improvement of calculation of the prognostic hydrocarbon reserves and probably the elaboration of new reserve calculation methods. The airborne geophysical and geochemical methods together with the surface exploration ones may help the exploration for hidden traps and may promote the exploration of the Nyírség, as well.

It can be stated that the new methods may result in qualitative changes in the fields of planning, interpretation and realization works of hydrocarbon exploration in Hungary.

REFERENCES

Dank, V. (1973): A magyar geofizika feladata és perspektívái a szénhidrogénkutatások tükrében (Tasks and perspectives of geophysics in Hungary in light of hydrocarbon explorations). Magyar Geofizika, **14**, 2, pp. 43-54.

Dank, V. (1975): A geofizikai mérések és értékelési módszerek fejlődése döntő tényezője a korszerű szénhidrogénkutatásoknak (The development of geophysical measurements and evaluation methods is a decisive factor in the modern hydrocarbon exploration). Magyar Geofizika, **16**, 6, pp. 223-233.

Dank, V. (1976): A hazai szénhidrogén prognózis néhány kérdése (Some problems of hydrocarbon prognostics in Hungary). Földt. Közl., **106**, pp. 457-463.

Dank, V. (1976): A magyarországi szénhidrogén földtani kutatás értékelése és perspektívái (Evaluation and perspectives of hydrocarbon geological exploration in Hungary). Földt. Kutatás, **19**, 4, pp. 3-11.

Donald, F.S., C.K. Thompson (1987): Integrated exploration improves wildcat success. World Oil, Houston, Texas, **206**, 3, pp. 42-46.

Donovan, T.I., J.D. Hendricks, A. Roberts, P.T. Eliason (1984): Low altitude aeromagnetic reconnaissance for petroleum in the Arctic National Wildlife Refuge, Alaska. Geophysics, **49**, 8, pp. 1338-1353.

Eliason, P.T., T.J. Donovan, P.C. Chanez (1983): Integration of geologic, geochemical and geophysical data of the Cement oil field, Oklahoma, using spatial array processing. Geophysics, **48**, 10, pp. 1305-1315.

Hahn, Gy., I. Tózsa (1985): A távérzékelés hasznosítása a szénhidrogénkutatásban (Use of remote sensing in hydrocarbon exploration). Correferate, Földr. Értesítő, **37**, 1-4, pp. 25-41.

Hahn, Gy. (1988): Az MTA FKI Távérzékeléses ásványi nyersanyagkutatásainak összefoglalása (Summary on the mineral raw material exploration by remote sensing performed by the MTA FKI). Research report, IPM-KFH Távérzékelés Program Iroda.

Holczhacker, K., I. Koncz (1981): A stabil szénizotóp arány adatok felhasználási lehetőségei (Possibilities of use of stable carbon isotope ratio data). Kőolaj és Földgáz, **114**, 6.

King, E.A. (1976): Space geology: an introduction. University of Houston.

Konda, B.W., R.C. Mitchner, A.B. Hollinger (1988): Remote measurement of methane in coal mines: a review. Colliery Guardian.

Mattawelli, L., D.G. Rocchiuto, M. Schoell (1983): Geochemistry and Habitat of Natural gases in Po Basin, Northern Italy. APPG Bulletin, **67**, 12, pp. 2239-2254.

Proceedings of the NASA earth resources survey symposium. Geology, environment, information systems and services. Houston (Texas), L.B. Johnson Space Center.

Papp, Z., P. Winkler, G. Pecze (1988): Talaj- és növényállapot meghatározás légi infrafénykép segítségével (Determination of the state of soil and vegetation by means of airborne infrared records). Módszertani útmutató és segédlet légi infrafényképek készítéséhez és értékeléséhez (Methodological guide of how to make and evaluate airborne infrared records). MÉM Műszaki Intézet.

Sedelnikov, E.S., T.L. Sushkova (1988): K abosnobaniyu avtomatizirovannoy obrabotki metodom SDVR-AF. Izv. vysshikh uchebnykh zavedeniyy, Geologiya i razvedka, **8**, pp. 117-123.

Schönviszky, L. (1988): Légi geofizikai és távérzékelési módszerek különös tekintettel a szénhidrogénkutatásra (Airborne geophysical and remote sensing methods with special ragerd to hydrocarbon exploration). Research report, KV Documentation.

Tózsa, I.: Űrfelvételek a síkvidéki szénhidrogénkutatásban (Space photos in lowland hydrocarbon exploration). MTA FKI, Műhely, **10**, pp. 1-12.

Acta Geologica Hungarica, Vol. 33/1-4, pp. 163-168 (1990)

POSSIBILITIES OF MINERALOGICAL-PETROLOGICAL APPLICATION OF THE INTERFERENCE COLOUR STABILIZED POLARIZATION CONTRAST MICROSCOPE

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In the polarization microscope the polarization contrast produced by the stabilization of interference colour of optically isotropic media provides new outlooks in the quantitative evaluation of the composition of rock, ore and metal thin or polished sections, in the fine-structural observations of natural and synthetic anisotropic materials, in the microscopic investigations of great magnifications and in the microphotography. Pleochroism and anisotropy can be studied with especially high sensitivity.

Keywords: Polarization microscope, polarization filters, stabilization of interference colours, interference colour contrast, quantitative rock microscopy, automatization, scanning spectrophotometer, image analyser, pleochroism, anisotropy.

The polarization microscope has been the indispensable tool of investigating and determining minerals, rocks and ores. Its application has become widespread in studying synthetically produced crystalline material, e.g. metal alloys, ceramics, semiconductors, products of the chemical industry, and it has been an important instrument of the microchemical analysis, as well. The extension of investigations in polarized light over the infrared range increased the possibilities of application of this method.

The appearance of photometry, spectrophotometry and TV-image processing systems supplied with scanning stage and controlling-evaluating electronics allowed the automatization of quantitative phase composition determination of ore minerals under ore and metal microscope. Nevertheless, in transmission microscopy the possibility of automation of measuring the mineral composition in rock thin sections was restricted, i.e. most of the rock-forming minerals do not show discriminative difference in the light absorption capacity by means of spectrophotometer or image analyser. In

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Received: 29/11/89

case of traditional studies in polarized light either under crossed or parallel nicols the contrasts of interference colours cannot be used since due to the optical anisotropy the interference colours and their intensities of the mineral phases are direction dependent. For example in case of crossed nicols all the transitions between the maximal intensity and the complete extinction are possible. When rotating the stage not only the interference colours and their intensities are changing but the mineral phases in the visual field rotate together with the stage.

It was the task of research to try to stabilize the interference colours so that the image elements, e.g. mineral grains producing the visual field keep their position. The problem is solved by the application of new polarization contrast equipment* in the theoretical arrangement shown in Fig. 1. Based on this solution principle new types of traditional transmission and reflected light polarization microscopes supplied with polarization contrast can be designed. In the modern polarization, moreover, biological microscopes it can be applied as independent equipment, as a supplementary instrument (Plate I, Photos 1-2).

The results of mineralogical studies carried out with this experimental equipment can be summarized as follows:

1) In transmission light at crossed nicols it can be reached that the extinction of optically anisotropic minerals "disappear" and in a stable manner interference colour or colours of diagnostic value with respect to the given sections of the minerals can be seen that do not change when rotating the table. The optical traces and structures occur which derive from anisotropy, from its unevenness, from crystal intergrowths, twinning, from metasomatic replacement,etc. and that can be hardly studied by means of traditional polarization microscope. As a whole, a stable interference colour contrast is produced (with dark background) that separates the mineral phases and which gives an easily understandable image on the distribution, dimensions and quantities of the minerals even in case of very fine-grained material. This is produced by the phenomenon that the interference colours can be simultaneously seen in the visual field while in case of the traditional studies the interference colours of the minerals being in extincted position before rotating will appear while the interference colour of the other grains will be extincted.

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*Lincence of the author.

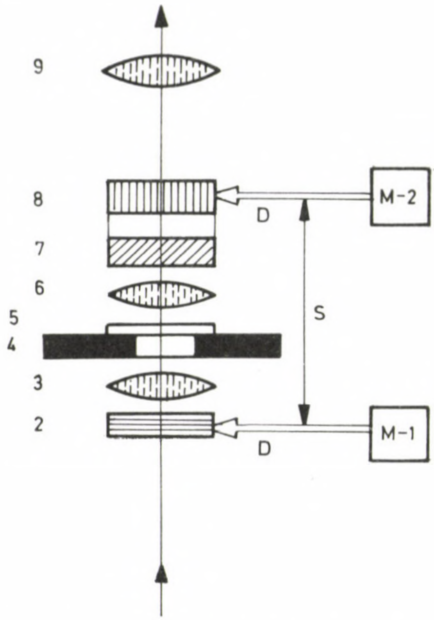


Fig. 1. Outline of the interference colour stabilized polarization contrast microscope. 1. light beam; 2. polariser; 3. condenser; 4. microscope stage; 5. thin section; 6. objective; 7. compensator; 8. analyser; 9. ocular; M-1, M2, D, S. control system

2) Similarly to the traditional polarization microscope when applying diagonal compensators related to the crossed nicols the interference colours of the polarization contrast can be shifted, thus the colour contrast of mineral phases constituting the visual field can be increased. The gypsum compensator with its "sensitive violet" colour is especially favourable.

3) In case of transmission light and parallel nicols the so-called "light field" (light background) polarization interference contrast can be realized the colours and light intensities of which are the complementary colours and intensities of the interference image characteristic of the crossed nicol position.

4) As to the analogy of the traditional studies the pleochroism in transmission polarized light and the reflexion pleochroism (bireflexion) in reflected light can be studied. Very weak pleochroism and the bireflexion that can be observed only in oil immersion can be surely observed.

5) In case of the crossed nicol polarization filters the optical

anisotropy of the crystal section or its absence can be observed even in case of very weak anisotropies. In case of reflected light this is to be understood for the so-called "anisotropy effect". When applying reflected light the observation of anisotropy is similar to the traditional procedure (addition or subtraction), but to carry out the observation the stage should not be rotated.

The advantages produced by the polarization interference colour contrast widen not only the possibilities of the material testing by mineralogical-petrographical and ore-mineralogical microscope but can be extended over the studies of synthetically produced crystalline materials (metals and their alloys, semiconductors, ceramics, products of chemical industry, chemical microanalytical products). The photographic documentation of the new image qualities represents a new quality in documentation of research results of the user fields.

The colour contrast produced by the stabilization of interference colours multiplies the number of mineral phases that can be discriminated by scanning spectrophotometer or image analyser on the basis of the intensity and colour of the light - enabling thus the automation possibility of their quantitative measurement. The perspicuity of the phase compositions determined by the diagnostic interference colours facilitates the semi-automatic measurement (by means of the "Eltinor" electromechanical integration desk) or the simple estimation of the mineral composition.

The image modifying effect of the polarization contrast is exemplified by some instances in photo plates II to VII.

The polarization contrast pictures of plates II and III (Photos 4 and 6) fairly well demonstrate the unification (Photos 3 and 5) of interference colours characteristic of the same phases (quartz crystal, different amphibole sections, feldspars) and the "disappearance" of extinctions under crossed nicols (most conspicuously the undulatory to mosaic-like (extinction of quartz - Photo 3). In Plate IV the difference between the diagonal contrast picture (Photo 7) and the interference colour modifying effect of the gypsum compensator of "sensitive violet" co-rotating with the polarization filters under crossed nicols in diagonal position (Phot 8) can be seen.

In Plate V, it is a significant difference between the traditional crossed nicol photo (No. 9) and the polarization contrast photo (No. 10) that the feldspar crystals of the groundmass can be seen without extinction, the interference colour of feldspar phenocrysts is unified but their zoning is preserved.

In Plate VI, in the polarization contrast photo of dark visual field (Photo No. 11) the carbonate cementing material becomes unified by the mixture of interference colours without extinction. This photo also examplifies when the polarization contrast does not eliminate the extinction in the section perpendicular of the optical axes and the difference between the intensities of interference colours of the same minerals remains significant if the orientation of each crystal section related to their optical axies is extremely changing (see the detrital quartz grains and their mosaic structure). In the light field polarization contrast photo (No. 12) the detrital quartz grains can be sharply distinguished from the carbonate cementing matter (Photo 12).

In the dark field polarization contrast photo of Plate VII (Photo 14) all the hydromica grains can be seen while in the traditional photo (No. 13) part of these cannot be or can be hardly observed due to their extincted or semi-extincted positions.

As a summary it can be stated that the application of the polarization contrast equipment does not replace but rather supplements the traditional mineral diagnostic and microscopic procedures and improves their efficiency.

REFERENCES

Barabás, J., J. Vadász (1966): Mikroszkópos fényképezés (Photography under microscope). Műszaki Könyvkiadó, Budapest.

Beljaj, D.P., V.E. Klejkoh, V.V. Mensenin (1985): Automatic mineralogical analisator (in Russian). In: Byulleten Patentnoy Informatsii, 1987, MKI G 01 J 3/36, Moscow.

Bernolák, K. (1981): A fény (The Light). Műszaki Könyvkiadó, Budapest.

Bernolák, K., D. Szabó, L. Szilas (1979): A mikroszkóp (The Microscope). Műszaki Könyvkiadó, Budapest.

Kubovics, I. (1968): Kőzetmikroszkópia (Rock Microscopy). Lecture notes, Tankönyvkiadó, Budapest.

Kubovics, I. (1968): Korszerű mikroszkópos vizsgálati módszerek. In: Ásványkőzettani anyagvizsgálat korszerű módszerei és eszközei. (Modern Microscopic analytical methods. In: Mineralogical-petrological modern methods and tools of material testing). Lecture notes, Mérnök Továbbképző Intézet, Budapest.

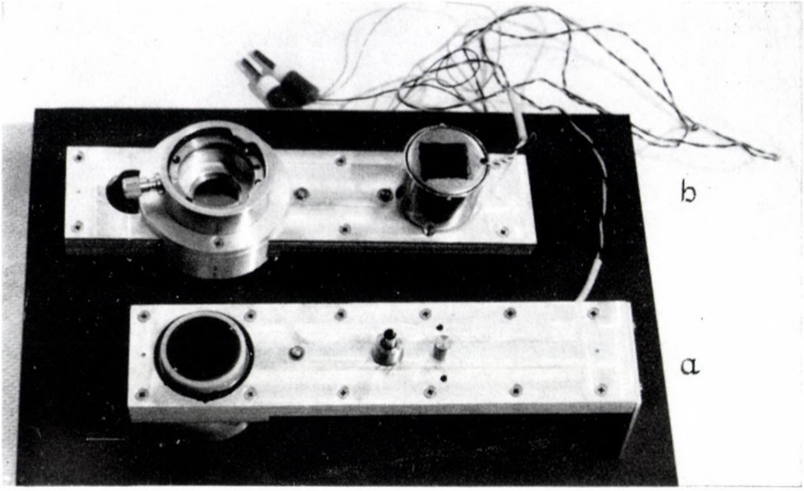
Methods of mineraological research (in Russian). Spravochnik. Ed.: A.I. Ginzburg, Nedra, 1985, Moscow.

Puskás, Z. (1979): Mikroszkópi képelemző módszerek alkalmazása a földtani anyagvizsgálatokban. In: Korszerű ásványtani-geokémiai anyagvizsgáló módszerek ankét anyaga (Veszprém, 1979. X. 26-27). (Application of microscope image analytical methods in the geological material testing.) In: Conference on "Modern mineralogical-geochemical analytical methods", Veszprém, pp. 191-204, Hungarian Geological Society, Budapest.

Sztrókay, K.I., Gy. Grasselly, E. Nemecz, J. Kiss: Ásványtani praktikum. II. (Mineralogical practices II). Tankönyvkiadó, Budapest.

Vendel, M. (1959): A kőzetmeghatározás módszertana (Methodology of rock determination). Akadémiai Kiadó, Budapest.

Vermes, M. (1967): A poláros fény (The Polarized Light). Műszaki Kiadó, Budapest.



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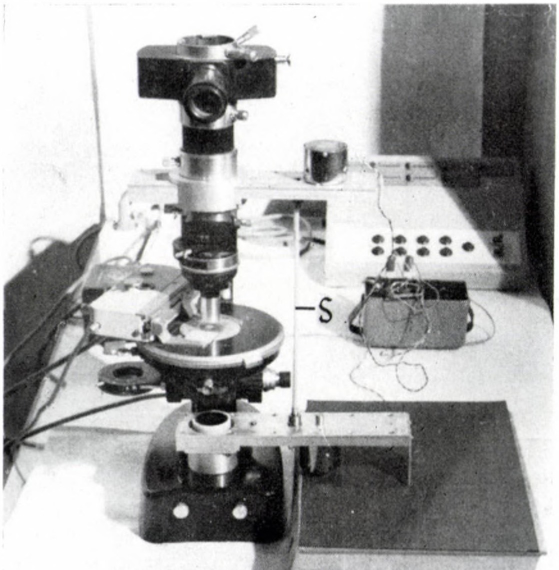

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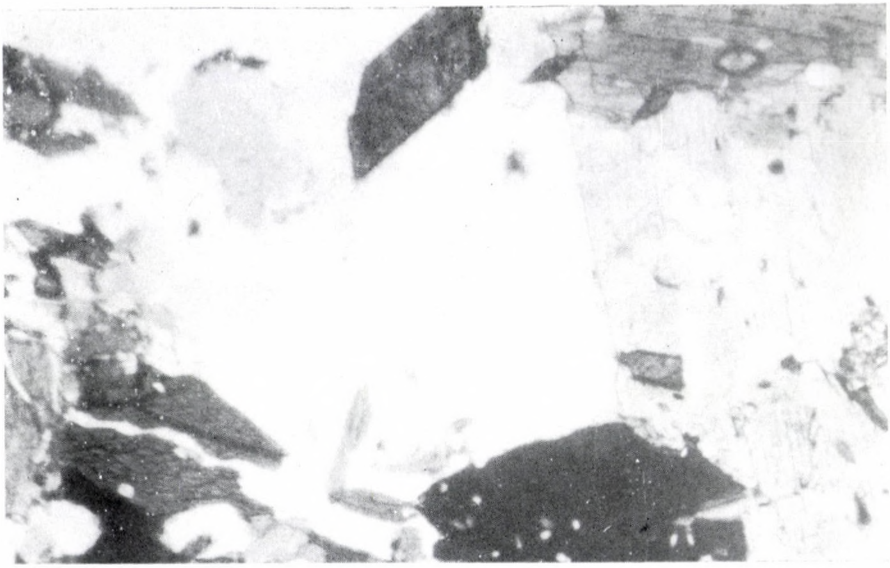
Plate II


3


4

Plate III



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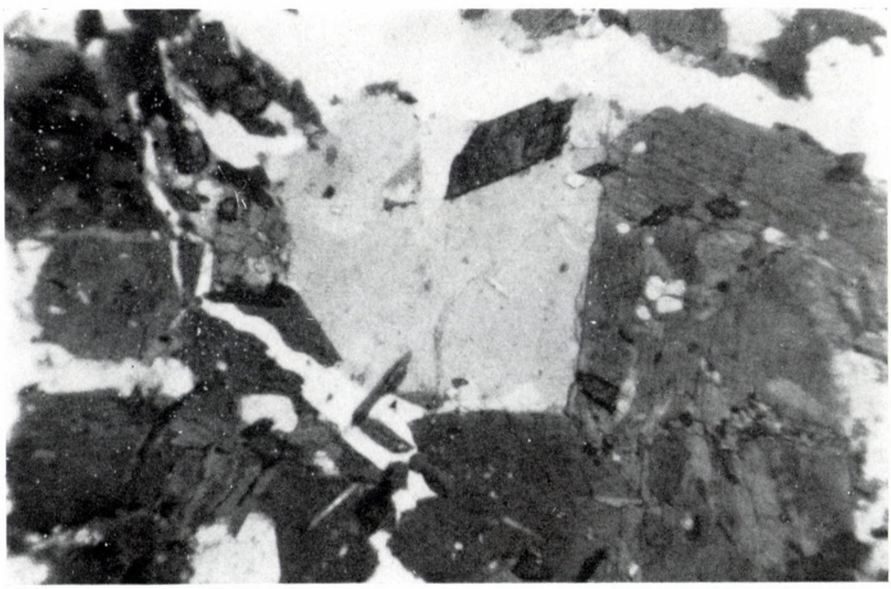

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Plate IV

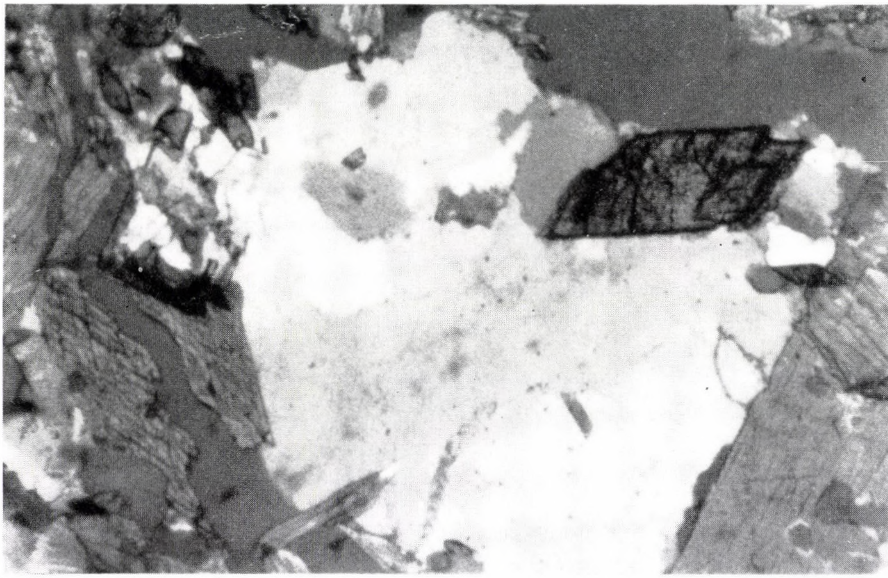

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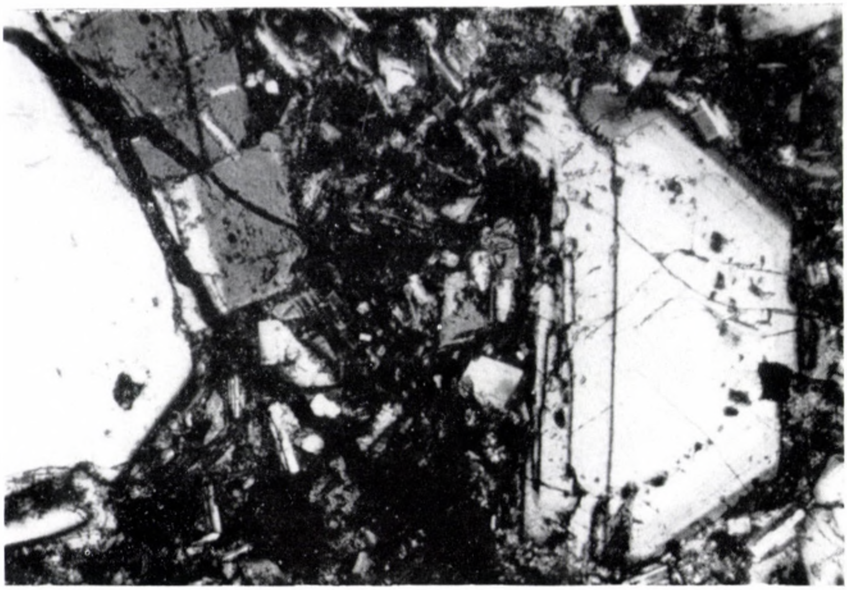
Plate V



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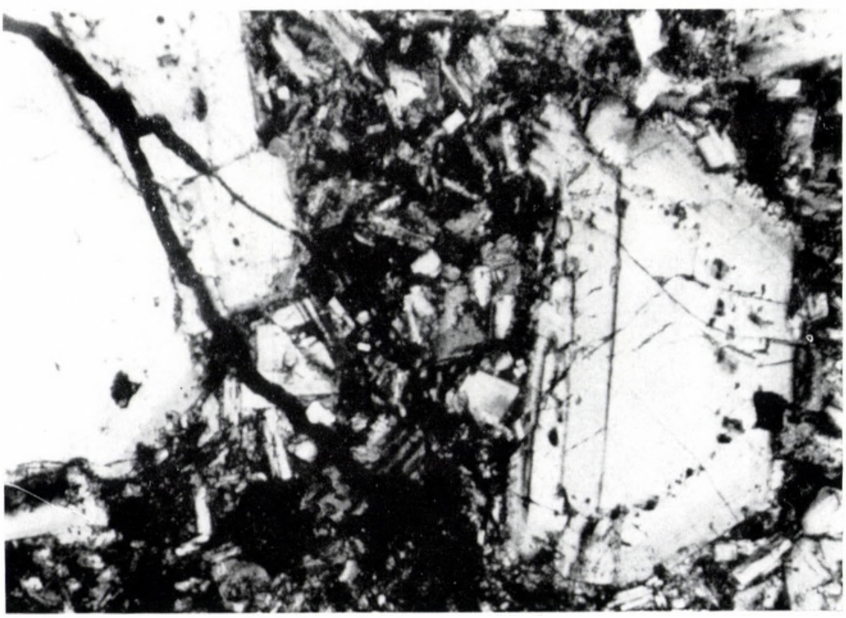

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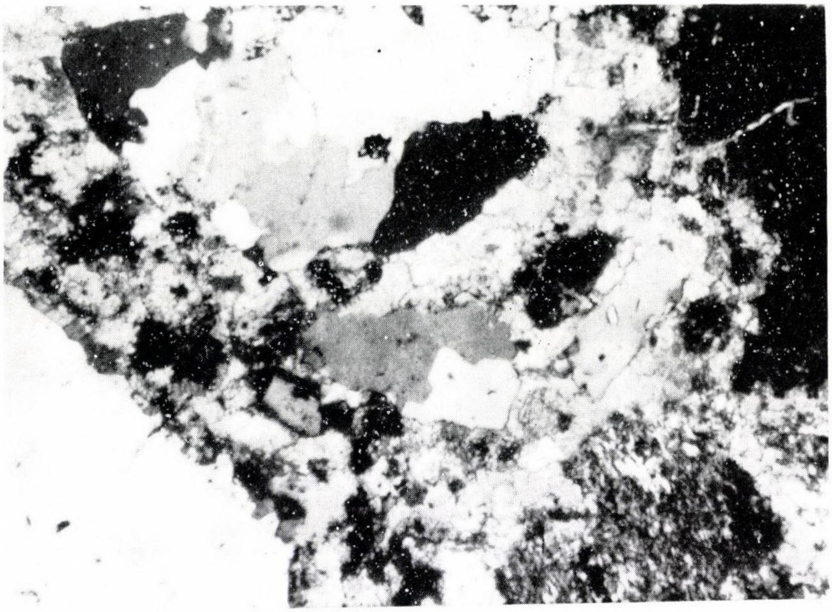
Plate VI



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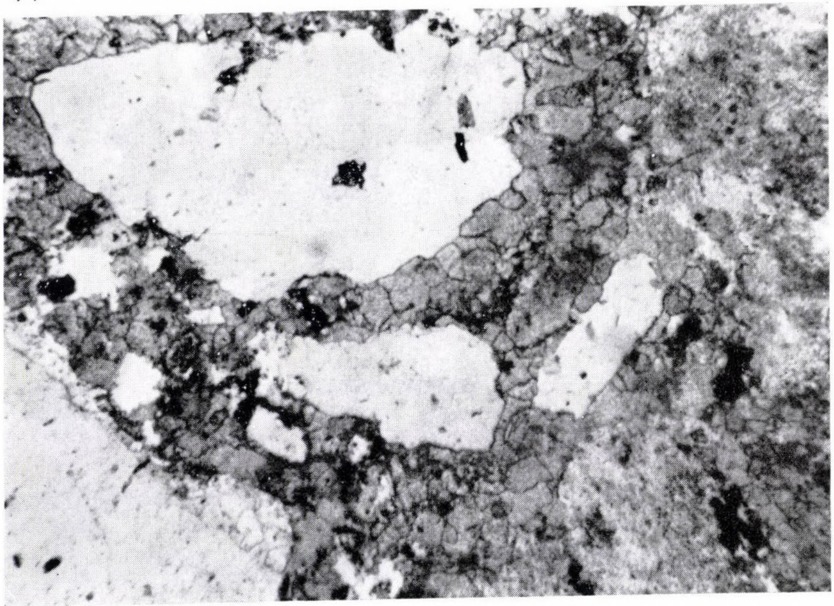

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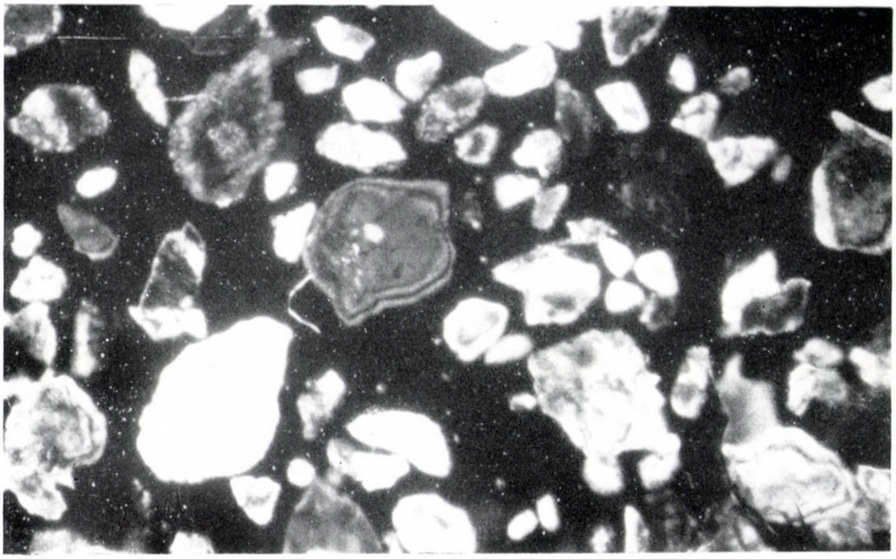
Plate VII



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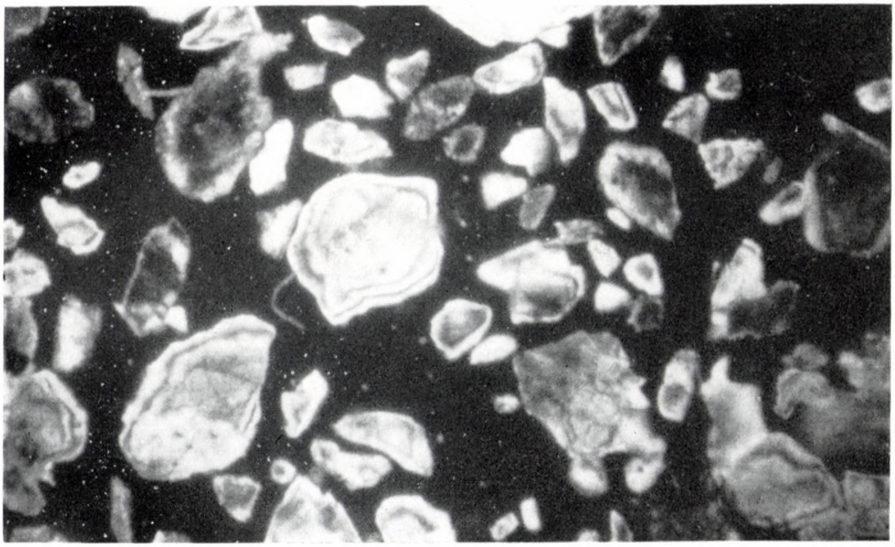

14

Plate I

Photo 1. Experimental type of the polarization contrast equipment. a - polarizer
b - analyser

Photo 2. The polarization contrast equipment fitted to "Zeiss Polmi-A" microscope

Plate II

Photo 3. Thin section of granite. In the visual field quartz, amphibole sections a sphene are seen. Traditional crossed nicol photo, M = 60 X

Photo 4. Dark field polarization contrast photo from the same area, M = 40 X. (In the margins of the greater visual field the grey minerals are feldspars).

Plate III

Photo 5. Traditional parallel nicol photo of the same area, M = 60 X.

Photo 6. Light field Polarization contrast photo of the same area, M = 40 X.

Plate IV

Photo 7. Traditional crossed nicol photo with diagonal "sensitive violet" compensator of the same area, M = 60 X.

Photo 8. Polarization contrast photo with "sensitive violet" compensator from the same area, M = 40 X.

Plate V

Photo 9. Thin section of andesite. Zoned plagioclase phenocrysts in andesitic groundmass. + N, M = 60 X

Photo 10. Dark field polarization contrast photo of the same area, M = 60 X

Plate VI

Photo 11. Thin section of sandstone. In the abundant calcite cementing matter allotigenic quartz, microquartzite, felsite. Dark field polarization contrast, M = 60 X

Photo 12. Light field polarization contrast photo of the same area, M = 60 X

Plate VII

Phot 13. Powder thin section of hydromuscovite lamellae, + N, M = 60 X

Photo 14. Dark field polarization contrast photo of the same area, M = 60 X

Acta Geologica Hungarica, Vol. 33/1-4, pp. 169-176 (1990)

BOOK REVIEWS

Helmut Hölder: Kurze Geschichte der Geologie und Paläontologie. (Ein Lesebuch). Springer Verlag, 1989 (244 p. 39 figs)

The reader holds an unusual work of history of science in his hand. Author presents the history of earth sciences not in temporal succession and not in evolutionary periods but follows the recognition and success of the most important basic principles. It can be said that the main chapters are individual studies by means of which the evolution of the historic sense of geology can be followed.

One has to be delighted when reading this book that gives a short but thorough review on the history of this branch of science of hard fate in public education.

Author is the full professor of the Department for Paleontology of the Münster University, his field of science is also paleontology this is why he has been interested mainly in the history of stratigraphy (biostratigraphy) and paleontology out of the history of earth sciences. Really, these two disciplines have been primordial in the knowledge of the Earth's history. At the same time, a review is given on the development of fundamental theories of other disciplines of geosciences.

The manuscript was finished in 1986, the year being an outstanding anniversary in the earth sciences: the 300th anniversary of the death of Nicolaus Steno (Niels Stensen, 1638-1686).

The geological basic principle occurred in scientific form first at Steno with the recently simple observation that the rock strata overlying one another reflect the process of formation, i.e. this means a temporal sequence, the fossils in the strata are remnants of life of the past, i.e. are characteristic of the period of formation. In the book the works of Steno, the significance of his theory, the exploration of roots of his ideas are dealt with, then we know how Steno's ideas became established and affected the subsequent centuries.

The next great scientific-evolutionary period falls to the second half of the 18th century when geology became an institutional science. At that time an ideological war raged between neptunism (the hydrous origin of rocks) and plutonism (the igneous origin of rocks) in increasingly extreme form. The two extreme schools are hall-marked by the names of A.G. Werner and of J. Hutton, respectively. Simultaneously though in complete form only in the first half of the 19th century the so-called catastrophe and actualist concepts had occurred which valued the events of the Earth's past in different way. Catastrophists took into account recently unimaginable great forces that formed the Earth's recent surface and the new forms of life through catastrophs. As to the actualists the life on the Earth has slowly, gradually developed in the course of the known geological forces without catastrophs. The two extreme theories are bound to the names of G. Cuvier and Ch. Lyell, respectively.

The two great opposite ways of thinking were equilibrated by evolutionarism in the second half of the 19th century that culminated in the Darwin's theory.

The development, discussions and effects of all these theories are found in individual studies in the book.

It is the author's conclusion that mainly the geological fundamentals were decisive in the fact that where and when developed the different theories (e.g. the development of the German, Franch or English geological school).

The modern megatectonics of our days, i.e. of the plate tectonics has the roots also in "old" times, since the "nappe theory" and the concept of Wegener on the continental drift founded this global tectonic theory. The great theoretical discuss between fixists and mobilists characteristic of the 20th century derived from fundamental differences of the aspects and the mobilists finally won.

These great theoretical trends have had their effects. Periodically one of them has rejuvenated in a more up-to-date guise then has disappeared and replaced by another (e.g. neocatastrophism).

In addition to presenting the main mental trends some chapters are devoted to less important problematics (e.g. the origin of terrestrial water, the formation of meteorite craters, the glacial geology, etc.).

The chapter dealing with the history of knowledge and interpretation of fossils including the appearance of the fossil man and the development of the man of today is of primordial interest.

Author does not stop at searching for the past, he studies the evolutionary tendecies of our days, too. He deals also with the recent research trends of paleontology and the possibilities of application of computers in the geosciences.

Researchers of history will find a valuable supplementary list at the end that makes easy the reading and contains a lot of useful historic relationships, supplements and references to original editions.

The book is warmly recommended to the experts of geology and to students since it teaches to evaluate our scientific results with suitable moderation and to feel that without the thoughts of our predecessors we would not be able to create our modern theories. Further the researchers of general cultural history and of history of science can also use this book since in addition to its conciseness it gives a relatively complete picture on the evolution of this science.

It is recommended to read also for the public. Goethe said: "The history of science is the science itself" and this is valid of this book, as well. In addition to be acquainted with the history, the reader may have an insight into the deepest sense of geosciences, into the history proceeding in a huge material system and during gigantic time scales.

The science-historians will have a methodological delight when may have insight into the workshop of a historian standing on bases concerning history of ideas.

T. Póka

Knut Bjørlykke: Sedimentology and Petroleum Geology. Springer-Verlag, 1989

The reader holds a text-book in his hand, but this hand-book is a gap-filling technical book not only for students but also for geologists to be trained for a new profession and for hydrocarbon exploration experts, as well. In the international market there are a lot of excellent books concerning the field of sedimentology and petroleum geology but a handbook involving both scientific fields and emphasizing the most utilizable knowledges of both disciplines, has been missing so far.

In the past two decades the hydrocarbon exploration in the North Sea has resulted in many fundamental scientific recognitions in the aforementioned branches of science, in addition to the remarkable economic benefit. These knowledges could not originate without the financial background of the industrial research. These results fairly well represent the fruitful relationship of basic and applied researches. The professor of geology of the Oslo University wrote this excellent book presumably on the effect of this research methodology and in favour to improve the industrial researches, respectively.

The structure of the book is didactic, the single topics are introduced in a pragmatic manner with abundant illustrations (186 figures). The photos have to be especially accentuated which together with the photos of the recent sedimentation environment, of the exposures of sedimentary formations and of the investigations under microscope and electron microscope, excellently support the knowledges.

The book consists of two relatively independent parts: sedimentology and petroleum geology. The chapter dealing with sedimentology begins with the description of the textural features of sediments and of the problem of sediment transport. As a logic continuation the macrostructures and the facies recognition are dealt with. Subsequently to the lithological description of sedimentary rocks and accurate and clear description and genetic characterization are given on the sedimentary facies. The mineralogical and geochemical characterizations of sediment formation, the processes of weathering and diagenesis as well as the role of water in the process of sediment formation are dealt with in individual chapters.

Author approaches the topics so that he starts from and illustrates the recent sedimentation and transformation processes discovered by modern submarine and deep-sea seismic explorations and submersibles, and without which the scientific recognition of marine and abyssal basinal sedimentation would be impossible.

An individual chapter is devoted to the relationship between the sedimentological research and different branches of stratigraphy, and to the problems of radiometric age determination of sedimentary rocks.

One of the most important methodology of petroleum exploration is the seismic stratigraphy and related basin analysis. In this relation the reader becomes acquainted with the main types of basin evolution.

The discussion of petroleum geology is based on the principle that the exploration of hydrocarbon potential is possible only by means of pragmatic and scientific analysis of the sedimentological factors.

As an introduction the modern theoretical bases of hydrocarbon generation, migration and accumulation are concisely summarized. Subsequently, the most important reservoir-related practical information (porosity, permeability) are dealt with. The presentation of hydrocarbon trap types and of the pressure conditions is useful mainly for the experts of production.

From the practical aspects, the summit of the book is related to the chapter dealing with the introduction of seismic profiles and different types of well logging, and with the didactic presentation of the application of these methods in hydrocarbon exploration and for the experts of hydrocarbon industry this chapter means the greatest profit. Similarly, the chapter dealing with the methodology of measuring the extension, porosity and permeability of the reservoirs is useful for production geologists.

Finally, the relationship of petroleum exploration and plate tectonics is discussed on the basis of analyzing the tectonic position of the main hydrocarbon occurrences of the world.

The reference list consists of 400 items. In addition to the referred papers, author tried to present items aiming at the further reading.

To qualify the value of the book it is my opinion that the book would be translated into Hungarian and would be incorporated in the education of Hungarian geologists and engineering geologists since Hungary is highly interested in hydrocarbon exploration.

T. Póka

Sawkins, F.J. (1990) Metal Deposits in Relation to Plate Tectonics. 2nd edition. Springer Verlag, Berlin, 461 pp.

Sawkins' book about the mineral deposits appeared first in 1984, and second in 1990 as the 17th volume of the excellent series "Minerals and Rocks" of Springer Verlag. This book is the first attempt for a consequent application of the plate tectonic classification of ore deposits. The plate tectonic theory was developed more then twenty years ago and it has been widely accepted by the geoscientists since then. Thought the concept of plate tectonics as a classification principle has been applied in other fields of geology, e.g. in igneous petrology in the classification of volcanic and magmatic processes, it is essentially new in the classification of ore deposits.

The text is divided into two main parts dealing with the processes of the convergent plate boundary environment (Part I) and with the divergent plate boundary environment (Part II); before the two main parts at the beginning of the book, there is an introduction giving an excellent short overview of the plate tectonics theory.

In the first part (convergent plate boundary) we can read about the metal deposits of principal arcs, the metal deposits of inner sides of principal arcs and the mineralization of arc related rifts (chapters 1 to 3, respectively) including porphyry copper deposits, copper bearing breccia pipes, skarn deposits, polymetallic vein systems, Kuroko-type massif sulphide deposits etc. The 4th chapter entitled "Additional aspects of arc-related metallogeny" is concerned with the deposits of the ones, which remained out of the previous three chapters, as Paleozoic and older porphyry copper deposits, and massive sulphide and gold deposits of greenstone belts.

The second part contains the metal deposits of divergent plate boundary and collision environments. This part begins with the metallogeny of oceanic type crust (Chapter 5) including the chromite deposits of ophiolites and the ophiolite hosted massif sulphide deposits. The next chapter gives the description of the metal deposits associated with intra-continental hotspots and anorogenic magmatism; we can read about the iron-titanium deposits associated with anorthosites, the platinum deposits of layered complexes (Stillwater Complex), the copper-nickel ores of the Sudbudy Irruptive, and the metal deposits related to carbonatites. The next two chapters, 7th and 8th deal with the metal deposits associated with the early and advanced stages of rifting, and Chapter 9 reports the metal deposits in relation to collision events. The last chapter entitled "Metal deposits and plate tectonics - an attempt at perspective" is concerned shortly with the metallogeny of lineaments and transform faults, and as an after-word this chapter gives some perspectives (geochemical, exploration and time-space perspectives) of metal deposits and plate tectonics.

The structure of the book and the individual chapters are logical, and easy to understand. The author gives not only the old, well-known examples for the illustration of the different types of the ore deposits, but there are the description of some lesser known deposits, too, with the discussion of the general geology, tectonics, mineralogy, and stable isotope and fluid inclusion geochemistry. Almost all chapters end with a brief paragraph, "suggestions for exploration".

The book, as it is indicated, is a second, revisioned and enlarged edition. This can be seen by both the text length and the reference list. In spite of the 324 page length of the first edition, the second edition has 461 pages. Almost all references are from the 1980's, and a considerable part of them are dated after 1984, the year of the appearance of the first edition; that is why, the book is very up-to-date.

However, beside the appreciation of this new concept, there are some problems with the plate tectonic classification of the metal deposits. One of the problems is, how to apply our present plate tectonic models to the Archean which was also an important period of ore formation. Another problem of this classification concept is, that similar ore deposits, as porphyry deposits or massif sulphide deposits may occur in several different plate tectonic environments, consequently they are discussed in different chapters.

This book probably cannot be used as a textbook for teaching and learning ore geology, but it can be strongly recommended for both undergraduated and graduated geologists, not only the ones, who are interested in ore deposits, but all scientists interested in plate tectonics and igneous petrology, as well.

G. Dobosi

Extinction Events in Earth History. Edited by E.G. Kauffman and O.H. Walliser. Lecture Notes in Earth Sciences, Vol. 30, 432 p. Springer-Verlag, Berlin, Heidelberg, 1990.

This book, third in a row of symposium volumes, represents the activity co-ordinated within the framework of IGCP (International Geologic Correlation Programme) Project 216 'Global Biological Events in Earth History'. The papers collected now in this volume were presented in a conference in Boulder, Colorado, on May 16-23, 1988, titled as 'Abrupt Changes in the Global Biota'. The majority of the most important papers presented at the meeting are published in the book.

The papers are mostly focused on mass extinctions at boundaries of the geological column, but the approaches are far to be conventional. The main emphasis is on the environmental crisis caused by extraterrestrial or earth-bound events, as are reflected by extinction, survival or origination of different fossil groups. Some papers demonstrated the relationship between extensive extrusive volcanism and impacting, with connected large-scale bioevents.

Most papers deal with fossil groups showing complex pictures of extinction dynamics or survival strategies. There is a general postulation of Phanerozoic biotas with narrower adaptive ranges than today. This biotic sensitivity is regarded as general background for the results of abrupt changes in climatic, oceanographic, chemical, tectonic and volcanic events triggered by impacts.

Following some accounts on general aspects (including an excellent review on Phanerozoic extinctions by A. Boucot), the papers are arranged in 'stratigraphic' order. Palaeozoic events are demonstrated by distinct fossil groups, and the suggestions on causes of extinctions may indicate paleoceanic factors as responsible for most changes. Palaeozoic/Mesozoic events, i.e. changes at or around the Permian/Triassic boundary are discussed in two review papers by C. Teichert on the whole spectrum of fossil groups and by M. Benton on land vertebrates. Both papers are rather sceptic to postulate (cyclic) catastrophic events behind the mass extinctions. Mesozoic events are treated by papers mostly on fossil biotas from North America. The high-resolution studies indicate stepwise pattern of extinction for several groups. Very interesting is the analysis given by P. Harries and E. Kauffman on Cretaceous extinctions, where the varied survival and recovery strategies of the influenced groups are demonstrated in detail. Discussion of Mesozoic/Cenozoic events is represented, obviously, by papers on the Cretaceous/Tertiary (K/T) boundary. The concept of a single catastrophic event due to a large bolide impact seems to shifting to more complex K/T interval-events, where multiple impacts, mantle degassing and other factors are involved. These and the resulted oceanic changes caused stepwise mass extinctions as documented by marine faunas, while data on some groups of land plants may suggest abrupt changes.

The volume gives an excellent overview on the state of art of studies on Phanerozoic mass extinctions, the leading topic of stratigraphy and palaeontology of the 80's. Thank to the outstanding editorship (by Earl Kauffman and Otto Walliser) the book is well-balanced, taking special emphasis on showing results of pre-K/T boundary studies. The publication of the volume in Springer's Lecture Notes in Earth Sciences was a good solution to make the results of the Boulder conference easily available. The book is highly recommended to all who are interested in global changes in general or extinctions special.

A Galácz

H. Chamley: Clay Sedimentology. Springer-Verlag, Berlin, Heidelberg, New York, London, Paris, Tokyo, 1989, 623 pp, 243 figures and 65 tables

Despite the fact that clay minerals represent a group of the most important phases of sediments and sedimentary rocks which have formed in various environments, textbooks devoted to clay geology are extremely rare because of different possible reasons, most probably, because of the extreme complexity of the subject.

Clay sedimentology - as it has been defined by Hervé Chamley - deals with the composition, properties and significance of the argillaceous fractions of recent and ancient sediments. The new textbook of H. Chamley consists of six parts, each of them containing 2-5 chapters.

Subsequently to a brief review of the main clay mineral groups including structural and crystal chemical properties, the main weathering processes as well as the basic types of zonal and azonal soils, and their more or less characteristic clay contents are highlighted. This first part is followed by a detailed, systematic description of clay sedimentation grouped according to the geographic, climatic and hydrologic conditions. Part II describes the specific features of on-land sedimentation of clays (deserts, glaciers, rivers, lacustrine, freshwater and saline environments). A separate part (Part III) deals with the transitional depositional environments between land and sea (estuaries and deltas) and with the modes of transportation into the oceans (terrigeneous supply, aeolian input, etc.). The genesis of clays in different marine facies is outlined in Part IV with special references to the alkaline evaporite environment, ferriferous clay facies, metalliferous clays, hydrothermal and organic matter-rich environments. In Part V the processes of diagenesis are interpreted. In this part especially the complexity of the approach (minealogic, petrophysical, tectonic, lithologic and hydrothermal aspects and constraints) is worthy of mention. Part VI deals with clays as important indicators of paleoclimate, paleocirculations, tectonics, and as extremely useful tools for paleoenvironmental and geodynamic reconstructions.

The thematic structure of the book is excellent. The numerous, well constructed figures and tables help a lot in understanding the subject.

sidering the large area covered by the textbook, the references are strongly selected.

Summarizing: since the fundamental, already classic work of G. Millot ("Géologie des Argiles", 1964) this is the first, really complex approach with which the author tries to summarize all information carried by the most reactive constituents of the outher shell and boundary of the lithosphere - the clays. This is why the book should be warmly suggested for all (students, postgraduates, researchers) who deals with any aspects of lcay minerals and sediments.

P. Árkai

Hervé Chamley: Sedimentology. Springer Verlag Berlin Heidelberg 1990. pp. X+286, 177 figs, 17 tables. Softcover DM 58, ISBN 3-540-52376-6

The "Sedimentology" by H. Chamley is a well-organized, concise contribution to the expanding literature dealing with the diverse processes and formations of sedimentary environments. It's principal aim is to provide introductory notions for undergraduate students through clearly-explained recent case-studies.

The book consists of two main parts. In the first part (Chapters 1 to 4) the origin, properties, deposition and diagenesis of sedimentary materials are dealt with, in the second one (Chapters 5 to 7) sedimentary environments are treated.

While dealing with the origin of sedimentary components, special attention is paid to the climatic influences governing world-wide distribution pattern of chemical weathering products (mainly clay minerals and Al-, Fe-oxihydroxides), as well as to the biogenic contribution to different forms of carbonate sedimentation. The origin of other important sedimentary components, like silica, phosphates, organic matter and evaporites are also well explained.

The properties of sedimentary particles are described in terms of grain size, shape and surface characteristics. Grain size distributions (and it's graphic presentations, together with basic statistical parameters) are used to characterize different sedimentary environments.

A very remarkable part of the book deals with the complex relationships that exist between the large-, medium- and fine-scale structure of sedimentary bodies and the mechanisms bringing them about. Among many possible mechanisms the transport phenomena, as well as syn- and post-depositional environmental influences on structural features (like settling, sliding and currents of different energy) are clearly explained. All these processes are demonstrated on recent examples, and the identification of environmental aspects on ancient sediments is also attempted.

Diagenesis of the most abundant sediment types (sands, clays, carbonates, siliceous and organic materials) are followed upon in terms of the most outstanding mineralogical and geochemical changes as well as structural modifications in the course of the process.

Sedimentary processes are considered in the framwork of continental, marine-coastal and open-marine environments.

Glacial, desert, lake, alluvial fan and river-stream sedimentation peculiarities are described on recent continental examples, and comparison is made with ancient analogues.

In the case of marine-coastal environmentas the deltas-estuaries, littoral and shelf type sedimentations are considered and interpreted also in récent and ancient examples. Balance among fluvial, wave and tidal actions serves as a basis for the classification of delta-type sediments.

In the characterization of littoral sedimentation principal influental factors are attributed to wave and tidal actions. However, arid vs humid climatic influences are also considered in the formation of littoral carbonate and evaporite deposits.

Beside tidal action, which is still important in the inner shelf, currents become dominant in the outher shelf. Sedimentary sequences of the shelf are explained in the case of detrital and carbonate environments. The characterization of carbonate shelves through recent examples is exceptionally clear and provides useful hints for the study of fossil carbonate platforms.

Open-marine environments are interpreted in the last chapter.The dnamics of sedimentation and resedimentation processes are outlined as a function of a number of governing agents, from which relief is particularly emphasized. Continental margins and open-marine basins are considered as principal scenarios, within which the formation of deep-sea sediments (carbonate, siliceous and argillaceous oozes, metallic nodules, hydrothermal and some other types of sediments) proceeds.

The book is concluded with final thoughts about relationsips between global tectonics and deep-sea sedimentation, and related global geochemical changes with ecological consequences.

In addition to the text the excellent illustrations and plenty of references make this volume a vlauable reference book for students graduating in geology and especially in sedimentology. Nevertheless, it will be useful for geologists working in the field, and for ecologists, too.

Z. Puskás

AUTHORS

PRINTED IN HUNGARY

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— an abstract of not more than 200 words
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