JAHRBUCH DER GEOLOGISCHEN BUNDESANSTALT

SONDERBAND 17

CONTRIBUTIONS FROM GEOSCIENCE POST GRADUATES

GROUP A: STRATIGRAPHY AND MICROPALAEONTOLOGY

GROUP B: PETROLOGY AND SEDIMENTOLOGY

WIEN 1971
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Foreword

Financial problems are predominant in the discussions between the developing and industrialized countries. Although there are good reasons for this we feel, that next to questions of flow and allocation of funds, the problem of transforming them into lasting, internationally convertible results — scientific or otherwise — is in our opinion of primary importance too.

During their six years experience in cooperation with Geoscience scientists from developing countries, the Austrian authorities were confronted with a whole set of closely interwoven problems; referring to the above mentioned special aspect of aiming at results of lasting value, the following volume presents some contributions, which in connection with the Vienna courses have been prepared *).

Following the organisational scheme of our courses the contributions are grouped into two sections:

group A, covers the fields of Stratigraphy and Micropalaeontology, the home country of the authors being India, U. A. R., and Iraq;

group B, covers the fields of Petrology and Sedimentology, the home country of the authors being Ghana, U. A. R., Argentine, Brasil and Tanzania.

We are thankfull to all the authors for their efforts and to the respective Austrian Authrities, for making available the funds for printing.

We trust that this selected documentation — inspired likewise by the intentions of UNESCO — will continue to serve as link between the Developing Countries and Europe, more specifically between our geological friends spread all over the world and their one-time basis in Europe, Vienna.

Vienna, January 1971

H. Küpper

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*) A similar volume was published be the Geological Survey of Austria as Sonderband 15 in 1969.

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Eigentlich ist der Mensch der Schlüssel zur Lösung unseres Problems und nicht das Geld.

Dag Hammarsköld

Vorwort

Finanzielle Probleme und finanzielle Lösungen stehen meist im Vordergrund der Diskussionen über Entwicklungsfragen; einerseits begreiflicherweise, andererseits ist es aber doch so, daß die finanziellen Mittel nur den Weg zur Lösung der Probleme ebnen, diese aber dann in ihrer Vielgliedrigkeit meist noch einer Lösung harren, von der Umsetzung der Mittel in Ergebnisse von einigem Dauerwert bis zu den sozialen und menschlich-persönlichen Beziehungen.

Im Rahmen einer mehrjährigen Befassung mit Post-Graduate-Wissenschaftern aus Entwicklungsländern haben sich für Österreich verschiedene Erfahrungen ergeben. Als Beitrag zu dem speziellen Aspekt der Erarbeitung von Ergebnissen von Dauerwert, werden im folgenden wissenschaftliche Bearbeitungen von Teilnehmern an den Wiener Kursen vorgelegt.

Es sei der Dank ausgesprochen, den Teilnehmern für ihre in die Ergebnisse investierte Arbeit, und den Österreichischen Stellen, I. K. F. E., für die Bewilligung von Mitteln zur Drucklegung.

Wir hoffen, daß diese Dokumentation, auch im Sinne der UNESCO, zu einer dauerhaften Verbindung von Entwicklungsländern und Industrieländern beitragen möge.

Wien, Jänner 1971

H. Küpper

Upper Eocene to Early Miocene Planktonic Foraminifera from the Subsurface Sediments in Cauvery Basin, South India*)

By D. S. N. RAJU

With 13 plates, 14 figures, 1 table

Palaeontology Laboratory, O. N. G. Commission, Baroda-9, India

Abstract

Fifty species and subspecies of planktonic foraminifera, belonging to the genera *Globigerina, Globigerinoides, Globigerinita, Globigerapsis, Globoquadrina, Globorotalia, Globigerinopsis, Pseudohastigerina, Hantkenina, Cribrohantkenina, Cassigerinella* and *Chiloguembelina*, are systematically described, for the first time, from the Upper Eocene, Oligocene and early Miocene subsurface sediments in Cauvery basin, South India. Two new species, *Globigerina sastrii* and *Globigerinopsis guhai*, are described.

Seven planktonic foraminiferal zones are proposed for the Upper Eocene to early Miocene sequence. The zones, in order from bottom to top, are: *Globigerapsis mexicana* zone, *Globorotalia cerroazulensis* zone, *Globigerina gortanii* zone, *Globigerina sastrii* zone, *Globigerina ampliapertura* zone, *Globigerina angulisuturalis* zone and *Globorotalia kugleri/Globigerinoides primordius* zone.

The significance of these findings in correlation of the sections in Cauvery basin with those from other tropical regions is discussed. The Eocene — Oligocene limit is placed at the top of the *Globorotalia cerroazulensis* zone. The Oligocene — Miocene limit is placed at the lower boundary of the *Globorotalia kugleri/Globigerinoides primordius* zone.

Introduction

The last two decades are marked by a stupendous increase in our knowledge on planktonic foraminifera and a rapid growth of their importance in biostratigraphic classification and intercontinental correlations. Researches of BOLLI (1957) and several others in Caribbean region have led to an elaborate planktonic foraminiferal zonal classification of the Cretaceous and Cenozoic marine sediments. These works were followed by attempts to recognize the Trinidad zones in other parts of the world. Much of additional knowledge on the mid-Tertiary planktonic foramini-

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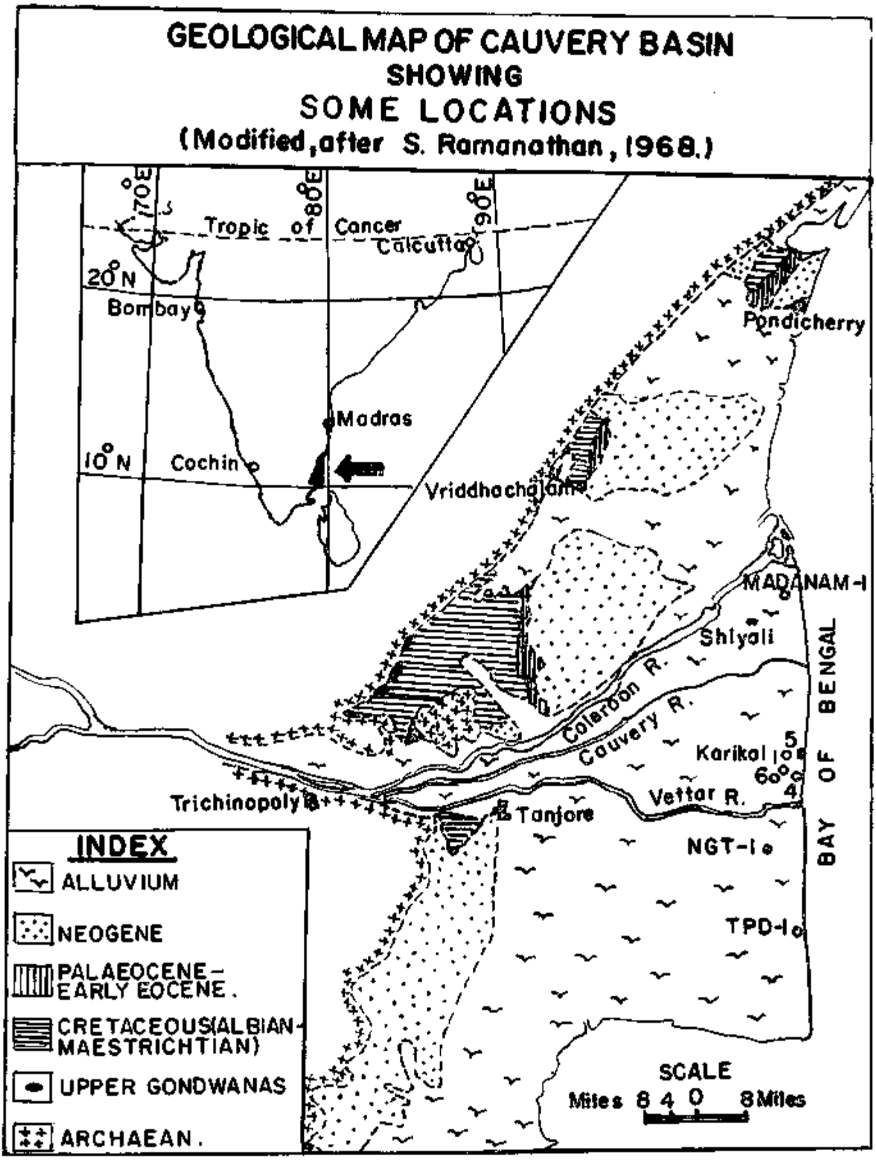
*) Published with the permission of the Director of Geology, Oil & Natural Gas Commission, Dehradun, India.

The views expressed in the paper are of the author and not necessarily those of the O. N. G. Commission.

fera was brought out by Blow & Banner (1962) and Blow (1969) from sections in East Africa and other tropical regions.

Some preliminary studies carried out during the last six years on Indian localities have indicated the presence of rich assemblages of planktonic foraminifera. However, most of the species were not systematically described and the knowledge on stratigraphic distribution of already known species is very limited.


GEOLOGICAL MAP OF CAUVERY BASIN SHOWING SOME LOCATIONS (Modified, after S. Ramanathan, 1968.)

FIGURE–1

The present study is an attempt to systematically describe the Upper Eocene, Oligocene and early Miocene planktonic foraminifera from the subsurface sections in Cauvery basin, South India; to define a sequence of biostratigraphic zones and to evaluate their value in correlation with sections outside this region.

Previous work

The Upper Eocene to Lower Miocene planktonic foraminifera are known in Cauvery basin only from the deep exploration wells drilled by Oil & Natural Gas Commission since 1964. The occurrence of some diagnostic species was reported by RAJU (1966). Later, RAJU (1967, 1968) recognized some planktonic foraminiferal zones in the Late Cretaceous to Oligocene subsurface sediments. However, the planktonic species were not systematically described so far. The knowledge on the mid-Tertiary planktonic foraminifera from other sedimentary basins in India is very limited.

Present work

The present study is essentially limited to the core samples. Data from the following intervals of the deep wells from Cauvery basin constitute the main theme of the present study.

Well No.	Depth interval	Number of cores studied
KKL-1	800—1600 m.	7
KKL-2	1000—1530 m.	6
KKL-4	800—1800 m.	15
KKL-5	1000—1800 m.	5
KKL-6	1000—1800 m.	4
NGT-1	1600—2000 m.	2
Madanam-1	800—1300 m.	3
TPD-1	450— 950 m.	5

The following abbreviations, KKL for Karaikal, NGT for Nagapattinam, TPD for Tirupundi, are used in this paper (see fig. 1).

One to six samples are studied from each core depending on the length recovered. Besides these almost all the cutting samples representing every three metres interval of the well are also studied. There are considerable gaps between the cores and as such the complete distribution of many of the species could not be satisfactorily determined during this study. Some data from well cutting samples are incorporated in preparing the range chart, only to indicate last occurrences (extinctions) of some diagnostic species.

Resume of the general stratigraphy of the Cauvery basin

The oldest sediments known, which overlie the Archaean metamorphics in Cauvery basin, are the so-called "Upper Gondwanas" exposed as small patches along the western fringes of the basin. They are essentially lacustrine to brackish water deposits of ? Jurassic to Lower Cretaceous age. Overlying the "Upper Gondwanas" are the well known Cretaceous (Albian to Maestrichtian) sediments, which are widely distributed in the Cauvery basin (see Figure 1). These marine Cretaceous sediments were the source of many palaeontological works during the last 90 years.

The Cretaceous rocks are overlain by marine Paleocene-early Eocene sediments particularly in the Pondicherry and Trichinopoly areas. The Paleocene-early Eocene sediments are overlain, on the surface, by continental deposits known as "Cuddalores" of Neogene age. Large areas in the eastern part of the basin are covered by Alluvium or laterites.

Marine sediments younger than the Lower Eocene are known only in the subsurface, deep well sections. Recent Petroleum exploration activities, geophysical surveys and deep drilling by Oil & Natural gas Commission, have added considerable knowledge on the subsurface stratigraphy and structure of this basin. For some of these details reference is made to RAMANATHAN (1968).

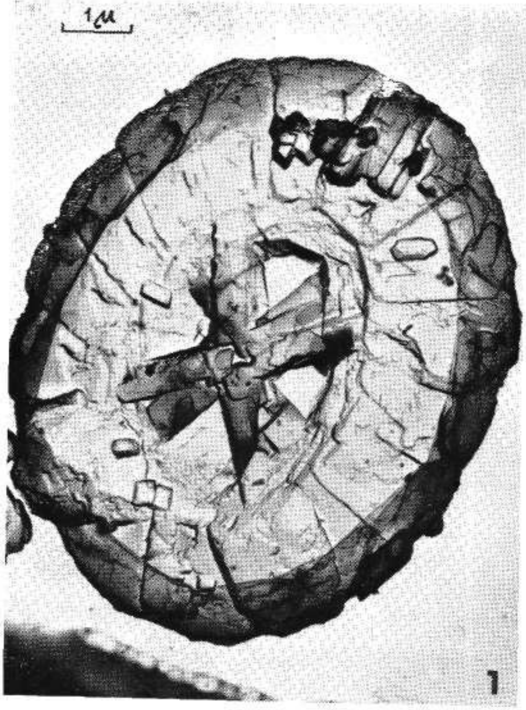
Acknowledgements

The author is thankful to Prof. Dr. H. KÜPPER, Director, Dr. M. E. SCHMID, micropaleontologist and other staff members of the Geological Survey of Austria; to Shri D. K. GUHA, Senior Geologist, Shri C. K. R. SASTRY, Chief Geologist, Shri S. N. TALUKDAR, Additional Director of Oil & Natural Gas Commission, India for providing various facilites during the study in Vienna (Austria) and Baroda (India). He is thankful to Prof. H. M. BOLLI, Zürich (Switzerland) for checking and commenting on many of the species described in this paper. He is grateful to Prof. A. PAPP, University of Vienna; Dr. P. MARKS and Prof. C. W. DROOGER of the University of Utrecht (Holland) for many suggestions. He is also thankful to Dr. C. G. ADAMS for providing facilities to examine some of the types deposited in British Museum (Natural History), London.

Zonation

Most of the Upper Eocene to early Miocene planktonic foraminiferal species, reported from other tropical regions, are now recorded from Cauvery basin. However, the recognition of the zonal boundaries within the subsurface sections in Cauvery basin is hamphered to a great extent due to the absence of continuous core samples. The boundary between the *Globorotalia cerroazulensis* zone and *Globigerina gortanii* zone falls within cored interval of a well. The microfaunal changes at the other zonal boundaries could not be precisely defined. Six of the zonal boundaries are defined here by horizons of extinction of markers, while two are defined by the first appearance level. The horizons of extinction, used here in definition

PLATE 18



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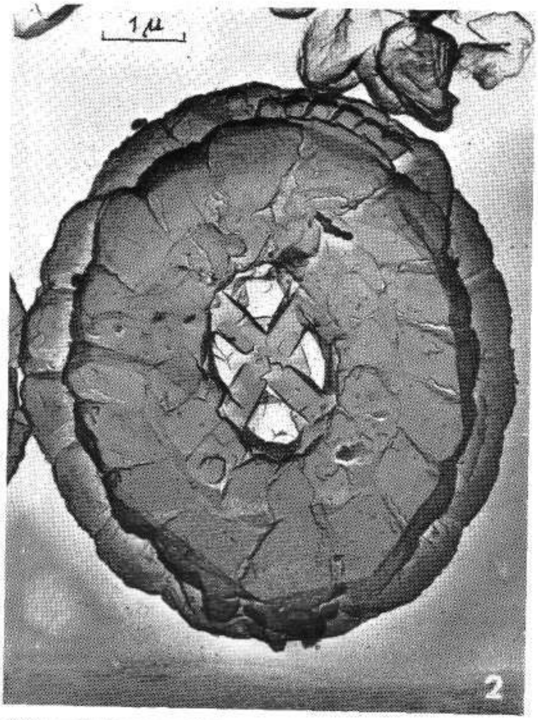

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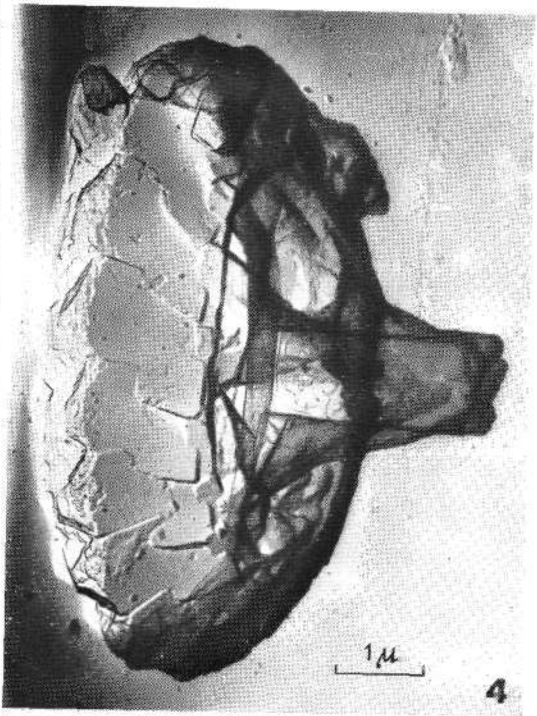


4

G. semiinvoluta-G. barri zone, *G. cerroazulensis* zone and *C. cubensis-G. ampliapertura euapertura* zone. The present study has resulted in providing additional data from the *G. mexicana* zone (= *G. semiinvoluta* zone) and *G. cerroazulensis* zone, subdivision of "*C. cubensis-G. ampliapertura euapertura* zone" into three zones and in recognition of two additional zones in the Late Oligocene-early Miocene sequence.

Globigerapsis mexicana zone

Author: BOLLI, 1957 (given as *Globigerapsis semiinvoluta* zone).
Reference section: Core between 1904. 2 and 1906. 5 m. inNGT-1.
This zone is defined as the interval from the last occurrence of *Truncorotaloides rohri* BRÖNNIMANN & BERMUDEZ to the last ocurrence of *Globigerapsis mexicana* (CUSHMAN). A very rich assemblage of planktonic foraminifera is known from this interval in NGT-1. The assemblage includes *Globigerapsis mexicana, G.* cf. *tropicalis* BLOW & BANNER, *Globigerinatheka barri* BRÖNNIMANN, *G.* cf. *lindiensis* BLOW & BANNER, *Pseudohastigerina micra* (COLE), *Hantkenina alabamensis* CUSHMAN, *H. suprasuturalis* BRÖNNIMANN, *H. trinitatensis* BRÖNNIMANN, *H.* cf. *thalmanni* BRÖNNIMANN, *Hantkenina* sp., *Globigerina corpulenta* SUBBOTINA, *G. pseudocorpulenta* CHALILOV, *G. gortanii praeturritilina* BLOW & BANNER, *G. angiporoides* HORNIBROOK, *Chiloguembelina martini* (PIJPERS), *C. cubensis* (PALMER) and *Globigerinita* spp. A poorly preserved form with doubtful cribrate aperture, referred here to as *Cribrohantkenina* cf. *inflata* (HOWE) is also found in this zone.

A rich assemblage of larger foraminifera including *Pellatispira madaraszi, Nummulites* cf. *fabianii* and *Discocyclina* spp. are recorded from core samples, at a depth of 1230 m. in Madanam-1, belonging to this zone.

The extinction level of *T. rohri* was marked in almost all the wells drilled in Cauvery basin and found to be a very useful horizon in well to well correlation. The extinction level of *G. mexicana* was marked in only a few wells so far.

Globorotalia cerroazulensis zone

Author: BOLLI, 1957 (given as *Globorotalia cocoaensis* zone).
Reference section: Cores between 1689 and 1720 m. in KKL-4.
This zone is defined as the interval between the last occurrence of *Globigerapsis mexicana* and the last occurrence of *Globorotalia cerroazulensis* (COLE). *Cribrohantkenina inflata* (HOWE), *Hantkenina alabamensis, Globorotalia cerroazulensis, G. centralis* CUSHMAN & BERMUDEZ and several other species shown in table I are common in this zone. The extinction level of *G. cerroazulensis* was marked in all the wells drilled near Karaikal, Nagapattinam and Tirupundi and this horizon is one of the most useful levels in well to well correlation of the subsurface sequence and in intercontinental correlation. In Karaikal well-6, the top of *G. cerroazulensis*

zone falls within a core and the foraminiferal assemblages above and below this horizon do not indicate any major paleoenvironmental change.

Chiloguembelina cubensis assemblage

The present author (RAJU, 1968) proposed, tentatively, the *C. cubensis-G. ampliapertura euapertura* assemblage zone from the interval from the last occurrence of *G. cerroazulensis* to the last occurrence of *Chiloguembelina cubensis* (PALMER). The present study has led to the recognition of three zones within this interval.

Globigerina gortanii zone

Authors: BLOW & BANNER, 1962, emended here.
Reference section: Core between 1800 and 1803 m. in NGT-1.
This zone is defined as the interval from the last occurrence of *G. cerroazulensis* to the first appearance of *Globigerina sastrii* n. sp. The common species in this zone are *Globigerina gortanii gortanii* (BORSETTI), *G. gortanii praeturritilina* BLOW & BANNER, *G.* cf. *pseudoampliapertura* BLOW & BANNER, *G. ampliapertura* BOLLI, *G. prasaepis* BLOW, *Globorotalia increbescens* (BANDY), *Pseudohastigerina barbadoensis* BLOW and *Cassigerinella chipolensis* CUSHMANN and PONTON. *Cassigerinella chipolensis* and *P. barbadoensis* occur together even in the very basal part of this zone. No forms referable to *Globigerina sellii* BORSETTI are found in this zone.

Globigerina sastrii zone

Author: Proposed here.
Type section: Cores between 1579 and 1586 m. in KKL-4.
This zone is defined by the range of *Globigerina sastrii* n. sp. The planktonic foraminifera recorded from the type section of this zone include *Globigerina sastrii* n. sp., *G. gortanii gortanii*, *G. sellii* BORSETTI, *G. ampliapertura*, *G. tripartita tripartita* KOCH, *G. tripartita rohri* BOLLI, *G. prasaepis*, *Globorotalia* cf. *opima opima* BOLLI, *G. opima nana* BOLLI, *G. gemma* JENKINS, *Cassigerinella chipolensis*, *Chiloguembelina cubensis* and other forms. Rare forms of *Lepidocyclina (Nephrolepidina)* cf. *isolepidinoides* are also found in this zone in KKL-4 and TPD-1. *Globigerina sastrii* n. sp. is very common in Cauvery basin and has a short range. However, it may be of local value only as this species was not described from sections outside the Cauvery basin.

Globigerina ampliapertura zone

Author: BOLLI, 1957, emended.
Reference section: Drill cutting samples from section immediately overlying the *G. sastrii* zone in KKL-4.

This zone is tentatively defined as the interval from the last occurrence of *Globigerina sastrii* n. sp. to the last occurrence of *Globigerina ampliapertura*. The study of the drill cutting samples indicate that *G. ampliapertura* extincts approximately at the same level as that of *Chiloguembelina cubensis* in Karaikal wells.

Globigerina angulisuturalis zone

Author: BLOW, 1969, emended.
Reference section: Cores between 1450 and 1500 m. in KKL-2.
This zone is defined as the interval from the last occurrence of *Globigerina ampliapertura* to the first appearance of *Globigerinoides primordius* BLOW & BANNER. The planktonic foraminifera recorded from this zone include *Globigerina angulisuturalis* BOLLI, *G. ciperoensis* BOLLI, *G. angustiumbilicata* BOLLI, *G. woodi woodi* JENKINS, *Globorotalia siakensis* (LEROY), G. *opima nana* BOLLI, *Cassigerinella chipolensis*, *Globoquadrina* cf. *larmeui* AKERS and very rare forms referable to *Globigerina gortanii gortanii* (BORSETTI). *Globoquadrina* first appears in this zone. Larger foraminifera *Lepidocyclina (Eulepidina)* sp. and *L. (Nephrolepidina)* are also recorded within this zone in KKL-2.

Globorotalia kugleri / Globigerinoides primordius zone

Author: BLOW, 1969, Zone N 4.
Reference section: Cores between 1126 and 1425 m. in KKL-2.
This zone is defined as the interval from the first appearance of *Globigerinoides primordius* BLOW & BANNER to the last occurrence of *Globorotalia kugleri* BOLLI. The planktonic species recorded from the lower part of this zone include *Globigerina angulisuturalis*, *G. ciperoensis*, *Globigerinoides primordius*, *Globorotalia siakensis*, *G. opima nana* and *Globoquadrina* cf. *larmeui*. In the middle part of this zone, though *Globigerinoides primordius*, *Globorotalia siakensis* and a few other forms are recorded, the planktonic forms are rare. Again, the planktonic foraminifera are abundant in the upper part of this zone. The assemblage includes *Globorotalia kugleri* BOLLI, *G. siakensis*, *G. obesa* BOLLI, *Globoquadrina praedehiscens* BLOW & BANNER, *G. altispira globosa* BOLLI, *Globigerinoides* cf. *altiaperturus* BOLLI, *Globigerinopsis guhai* n. sp., *Globigerinita dissimilis* (CUSHMAN), *G. stainforthi* (BOLLI, LOEBLICH & TAPPAN), *Globigerina venezuelana* HEDBERG and rare forms of *Globigerina binaiensis* KOCH.

Globigerinoides trilobus assemblage

Planktonic foraminiferal zones are not successfully recognized so far in the interval above the *G. kugleri/G. primordius* zone in the subsurface sections in Cauvery basin. In the sequence above the *G. kugleri/G. primordius* zone, the larger foraminifera Miogypsinidae and *Lepidocyclina* are common and planktonics are not adequately represented.

BIOSTRATIGRAPHIC ZONES	REFERENCE SECTIONS WELL No. / DEPTHS IN METERS	PROBABLE PALEOENVIRONMENTS
G.TRILOBUS ASSEMBLAGE	KKL – 4,	MIDDLE TO OUTER SHELF
G. KUGLERI- G. PRIMORDIUS	KKL – 2, 1128 – 1126	OUTER SHELF TO UPPER BATHYL
	KKL – 2, 1353 – 1349	
	KKL – 2, 1421.6 – 1415.6	
	KKL – 2, 1425.4 – 1421.6	
G. ANGULISUTURALIS	KKL – 2, 1460.5 – 1457.5	
	KKL – 2, 1500.5 – 1494.5	
	KKL – 4, 1509 – 1503	
G. AMPLIAPERTURA	KKL – 4, 1569 – 1549	OUTER SHELF TO UPPER BATHYL
GLOBIGERINA SASTRII	KKL – 4, 1582 – 1579	
	KKL – 4, 1586 – 1582	
G. GORTANII	NGT – 1, 1803 – 1800	
	KKL – 6, 1746 – 1749	
G. CERROAZUZENSIS	KKL – 6, 1749 – 1750	UPPER BATHYL TO OUTER SHELF
	KKL – 4, 1689 – 1665	
	KKL – 4, 1692.6 – 1689	
	KKL – 4, 1705.5 – 1702	
	KKL – 4, 1709 – 1705.5	
	KKL – 4, 1712.5 – 1709	
	KKL – 4, 1716 – 1712.5	
	KKL – 4, 1719 – 1716	
G. MEXICANA	NGT – 1, 1906.5 – 1904.2	UPPER BATHYL
T. ROHRI	KKL – 4, 1764 – 1734	MIDDLE TO OUTER SHELF
O. BECKMANNI	KKL – 4, 1770 – 1764	

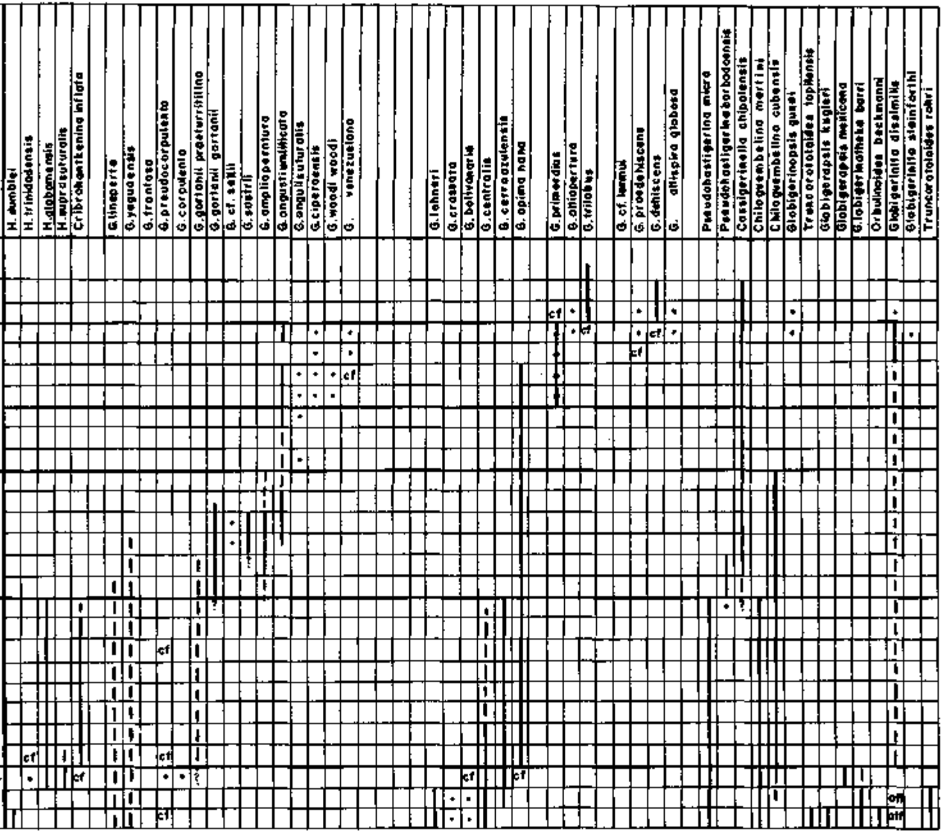


TABLE-I THE DISTRIBUTION OF SOME STRATIGRAPHICALLY IMPORTANT MIDDLE EOCENE TO LOWER MIOCENE PLANKTONIC FORAMINIFERA IN CAUVERY BASIN

The biostratigraphic unit *Globigerinoides trilobus* assemblage is proposed here, provisionally, to denote the interval in Cauvery basin from the top of *G. kugleri/G. primordius* zone to the level of the first appearance of *Globigerinoides sicanus* De Stefani (= *G. bisphericus* Todd). The planktonic foraminifera recorded from this interval include *Globigerinoides trilobus trilobus* (Reuss), *G. altiaperturus* Bolli, *G. subquadratus* Brönnimann, *Globoquadrina altispira* s. l., *G. dehiscens dehiscens* (Chapman, Parr & Collins), *Globorotalia obesa*, *G. siakensis* and rare forms of *Globorotalia peripheroronda* Blow & Banner. *Globigerina binaiensis* Koch and *Globoquadrina praedehiscens* are found in the lower part of this unit.

In KKL-4 *Miogypsina (Miogypsinoides) dehaarti-M. (Miogypsina) tani, M. (Miogypsina) globulina* and *M. (Miogypsina) antellia* are recorded from the sequence between 940 and 246 m. In Madanam well-1 *Miogypsina (Miogypsinoides) bantamensis-M.(Miogypsina) gunteri, M.(Miogypsina)* cf. *mediterranea* and *M. (Miogypsina) antellia* are recorded from the sequence between 1050 and 250 m. Further study on the planktonics and Miogypsinidae from the interval above the *G. kugleri/G. primordius* zone is under progress.

Correlations

The distribution of the Upper Eocene to early Miocene planktonic foraminifera from the tropical regions, particularly as worked out by Bolli (1957) from Trinidad, by Blow & Banner (1962) from Lindi area, East Africa and by Blow (1969) from several tropical regions, and the data from the present investigation in Cauvery basin indicates that a detailed correlation of these sections is possible. Various successful attempts were made during the last few years to correlate the sections from different continents with the zonal scheme proposed by Bolli (1957) and or by Blow & Banner (1962). The planktonic zones have found a wide spread acceptance and applicability in several regions. However, there is no agreement as to the usage of the planktonic zonal scheme. In general different zones were proposed for different parts of the world, obviously due to the reasons of geographical distribution of the planktonic foraminifera. Banner & Blow (1965) and Blow (1969) have proposed a very detailed zonal scheme for the Upper Eocene to Recent tropical regions. On the other hand, a simplified planktonic foraminiferal zonal scheme applicable also to temperate Mediterranean Neogene was proposed as a result of the coordination of some 22 specialists, Cati et al. (1968).

The correlation of the zones from Cauvery basin with those proposed by Bolli (1969) and Blow (1969) is presented in figure 3. The correlations are based on the distribution of the planktonic foraminifera within the regions concerned with the assumption that the levels of the initial appearance and extinction of the species are synchroneus events in these regions.

In general the successive levels of appearance and extinction of species are comparable.

However, a few minor discrepancies in the ranges of the presently recorded species could be noted from the published accounts. But it may be mentioned that the present observations are very close to those of Blow (1969).

1. *Cassigerinella chipolensis:* Bolli (1957) has shown that *Cassigerinella chipolensis* first appears at the base of *G. ampliapertura* zone in Trinidad. Blow & Banner (1962) traced its range from the base of *G. oligocaenica* zone in East Africa. Blow (1969) gave the range of *C. chipolensis* from the Zone P 18 (= *Globigerina tapuriensis* zone) to Zone

Zones proposed here for Cauvery Basin	Blow W. H. (1969)	Bolli H. M. (1966)
Globigerinoides trilobus assemblage	N. 6 Globigerinatella insueta / Globigerinita dissimilis	Catapsydrax stainforthi
	N. 5 Globoquadrina dehiscens praedehiscens-G. dehiscens dehiscens	Catapsydrax dissimilis
Globorotalia kugleri / Globigerinoides primordius	N. 4 Globigerinoides quadrilobatus primordius / Globorotalia kugleri	Globorotalia kugleri
Globigerina angulisuturalis	N. 3 (P. 22) Globigerina angulisuturalis	Globigerina ciperoensis ciperoensis
	N. 2 (P. 21) Globigerina angulisuturalis / Globorotalia (T) opima opima	Globorotalia opima opima
Globigerina ampliapertura	N. 1 (P. 20) Globigerina ampliapertura	Globigerina ampliapertura
Globigerina sastrii	P. 19 Globigerina sellii / Pseudohastigerina barbadoensis	Cassigerinella chipolensis / Hastigerina micra
	P. 18 Globigerina tapuriensis	
Globigerina gortanii	P. 17 Globigerina gortanii gortanii / Globorotalia (T) centralis	
Globorotalia cerroazulensisis	P. 16 Cribrohantkenina inflata	Globorotalia cerroazulensis
Globigerapsis mexicana	P. 15 Globigerapsis mexicana	Globigerapsis semiinvoluta
Truncorotaloides rohri	P. 14 Truncorotaloides rohri / Globigerinita howei	Truncorotaloides rohri
Orbulinoides beckmanni	P. 13 Orbulinoides beckmanni	Porticulasphaera mexicana

Figure 3. Relationship of the zones proposed here for Cauvery basin to those given by Bolli (1966) and Blow (1969).

N 13 and gave the range of *Cassigerinella eocaena* CORDEY from Zone P 16 to Zone P 19. In Cauvery basin *Cassigerinella chipolensis* is found at the very basal part of the *G. gortanii* zone.

2. *Globigerinoides primordius:* This species appears in Cauvery basin at the base of *G. kugleri/G. primordius* zone, at a level before the first appearance of *Globorotalia kugleri* and the extinction of *Globigerina angulisuturalis.* BLOW (1969) has already noted the concurrence of the ranges of *G. primordius* and *G. angulisuturalis* in the lower part of Zone N 4. However, there are some minor discrepancies in the published accounts regarding the first appearance of *Globigerinoides.*

3. *Globoquadrina* appears in Cauvery basin in the *G. angulisuturalis* zone.

4. Many planktonic species viz. *Globoquadrina altispira globosa, Globigerinita stainforthi* appear in Cauvery basin in the uppermost part of the *G. kugleri/G. primordius* zone. In Trinidad these species are known to appear at the base of *C. dissimilis* zone (BOLLI, 1957). BLOW (1969) has shown that *Globorotalia kugleri* overlaps the ranges of *G. stainforthi* and *G. altispira globosa.*

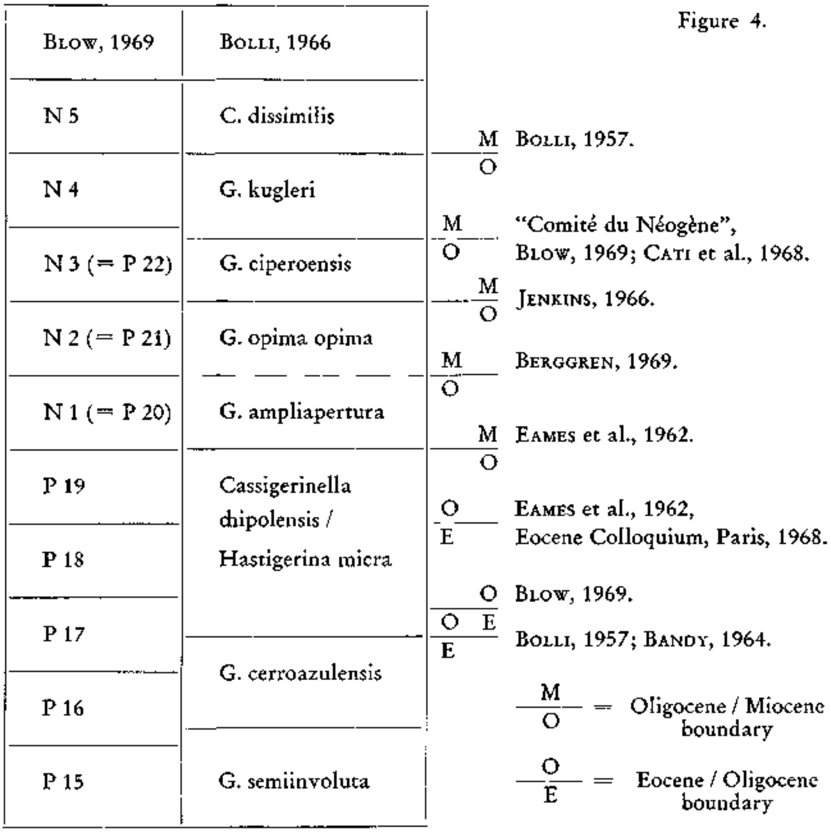


Figure 4.

Limits of Oligocene

The problem of marking the limits of Oligocene is topic of many debates and discussions during the last one and half decades. Recent attempts to relate the European Stages to the tropical planktonic zonal sequence have led to many controversial conclusions (EAMES et al, 1962; DROOGER, 1964; BLOW, 1969; BERGGREN, 1969, and others). The interpretations by various authors have led to controversies in marking the Eocene-Oligocene and Oligocene-Miocene boundaries. Some of the interpretations are summarized in figure 4.

Eocene-Oligocene boundary

The top of the *Globorotalia cerroazulensis* zone was taken to mark the Eocene-Oligocene boundary by many authors (BOLLI, 1957, 1966; BANDY, 1964, and others). The present author (RAJU, 1968) has earlier supported this view particularly taking account of the subsurface sections in Cauvery and Cambay basins, India.

The delegates to the Eocene Colloquium, Paris, 1968 (in Press, see BRABB, 1969) unanimously agreed for placing the Eocene-Oligocene limit between the *Nummulites fabianii* and *N. intermedius* zones for the *Nummulites*, between the *Globigerina gortanii* and *Hastigerina micra/ Cassigerinella chipolensis* zone (= *Globigerina sellii* zone) for the planktonic foraminifera and between the *Isthmolithus recurvus* and *Ellipsolithus subdistichus* zones for the nannoplanktons.

In Cauvery basin, in three of the wells, namely Madanam-1, TPD-1 and Tiruttaraipundi-1, where the larger foraminifera are dominant, the Eocene-Oligocene boundary is marked at the extinction level of *Pellatispira*. This level could be interpreted as marking the top of the Priabonian Stage. However, in the well sections around Karaikal and Nagapattinam the Upper Eocene larger foraminifera are not present and it is difficult to mark a horizon in the planktonic scale time equivalent to extinction level of *Pellatispira*. In these sections the extinction level of *G. cerroazulensis* and *Hantkenina* could be confidently marked on the basis of either core or cutting samples.

BLOW (1969) considered that the Eocene-Oligocene boundary will be approximately between the Zone P 17 (= *G. gortanii/G. [T.] centralis* zone) and Zone P 18 (= *G. tapuriensis* zone). BLOW (1969) and CLARKE & BLOW (1969) have shown that the characteristic Eocene foraminifera *Pellatispira, Discocyclina, Hantkenina,* and *Globorotalia cerroazulensis* all range only to the lower part of Zone P 17. It may be noted that the lower part of Zone P 17 of BLOW (1969) is equivalent to the uppermost part of *G. cerroazulensis.*

BAUMANN & ROTH (1969) observed that the *Ericsonia subdisticha (= Ellipsolithus subdistichus)* zone is restricted to the lower part of the *Globigerina gortanii gortanii* zone and further noted that the Latdorfian belongs to the *E. subdisticha* zone, and to the very base of the *Cyclococco-*

lithus margaritae zone. These evidences indicate that the Eocene-Oligocene boundary could be best placed at the top of the *G. cerroazulensis* zone.

Oligocene-Miocene boundary

This problem was discussed in detail by EAMES et al. (1962), DROOGER (1964), JENKINS (1966), RAJU (1968), BERGGREN (1969), and BLOW (1969). BERGGREN (1969) has drawn, provisionally, the Oligocene-Miocene boundary at the N 1/N 2 zonal boundary. BLOW (1969) accepted the recommendations of the "Comité du Néogène" in placing the Oligocene-Miocene boundary at the *Globigerinoides* datum, which coincides with the base of Zone N 4.

The Committee on Mediterranean Neogene stratigraphy has defined, in 1964 and 1967, the lower limit of the Miocene by the first appearance of *Globigerinoides* and *Miogypsina gunteri* (see PAPP et al., 1968). In Cauvery basin this level coincides with the lower boundary of *G. kugleri*/*G. primordius* zone. In Madanam well *M. (Miogypsina) gunteri-M. (Miogypsinoides) bantamensis* assemblage is found. Thus in Cauvery basin the Oligocene-Miocene boundary could be marked on the basis of the criteria set forth by the Committee on Mediterranean Neogene Stratigraphy.

Systematics

General remarks

Planktonic foraminifera are very rich in the Upper Eocene to early Miocene sediments in parts of Cauvery basin. The preservation of the specimens is good and the morphological details could be easily observed. Some specimens from the *G. sastrii* zone are, however, poorly preserved.

The specific determination was made first with the aid of the description and illustrations of the types. Most of the specimens were sent to Prof. H. M. BOLLI (Zürich) in 1968 for checking the identifications. Prof. BOLLI has kindly gone through the specimens and opined that the identications are also in accordance with his views. The present author has compared the specimens of Cauvery basin with the types deposited by BLOW & BANNER (1962) in the British Museum (Natural History), London. However, the determination of a few species viz. *Globigerina corpulenta* SUBBOTINA, *G. pseudocorpulenta* CHALILOV, is only on the basis of literature.

No attempts are made during the present work to trace the lineages as the available samples do not represent a complete subsurface sequence.

The following five species were illustrated earlier by the present author (RAJU, 1968) and they are not repeated here. *Globorotalia centralis* CUSHMAN & BERMUDEZ, *G. cerroazulensis* (COLE), *Chiloguembelina cubensis* (PALMER), *C. martini* (PIJPERS) and *Cassigerinella chipolensis* (CUSHMAN & PONTON).

A few of the species viz. *Globigerina officinalis* SUBBOTINA, *G. praebulloides* group, *G. ouachitaensis* group, *Gobigerinita* spp. and *Globorotalia* *gemma* Jenkins, though determined during the present study, are not described here.

All the illustrated types are deposited in the Palaeontology Laboratory, O. N. G. Commission, Baroda, India.

Superfamily *GLOBIGERINACEA* Carpenter, Parker & Jones, 1862

Family *GLOBIGERINIDAE* Carpenter, 1862

Subfamily *Globigerininae* Carpenter, Parker & Jones, 1962

Genus *Globigerina* d'Orbigny, 1826

Globigerina ampliapertura Bolli

(Plate I, figs. 1 a—c)

Globigerina ampliapertura Bolli, 1957, p. 108, pl. 22, figs. 5 a—7 b (not figs. 4 a—b).
Globigerina ampliapertura Bolli, Blow & Banner, 1962, pp. 83—84, pls. XI A—D, XVII c, fig. 12 b.
Globigerina ampliapertura ampliapertura Bolli, Raju, 1968, pl. 4, fig. 7.

Remarks: The forms from Cauvery basin are well comparable with the type description and illustrations.

Stratigraphic range: Bolli (1957) gave the range of this species from *G. cocoaensis* zone to *G. opima opima* zone in Trinidad. Blow (1969) gave its range from the base of Zone P 17 to the basal part of Zone P 21(= N 2). In Cauvery basin this species is known from *G. gortanii* zone to the *G. ampliapertura* zone.

Globigerina angulisuturalis Bolli

(Plate I, figs. 2, 3 a, b)

Globigerina ciperoensis angulisuturalis Bolli, 1957, p. 109, pl. 22, figs. 11 a—c.
Globigerina angulisuturalis Bolli, Blow & Banner, 1962, p. 84, pl. IX, figs. A a—C c.

Remarks: The forms from Cauvery basin are well comparable with the type description and illustrations. These forms are compared with the hypotypes of Blow & Banner, 1962, from the Lower Ragusa Limestone, S. E. Sicily, deposited in British Museum (Natural History), London.

Stratigraphic range: Bolli (1957) gave the range of this species from the base of the *G. opima opima* zone to the top of *G. ciperoensis ciperoensis* zone in Trinidad. It has also been reported from the Type Aquitanian of France (Jenkins, 1966), Israel (Reiss & Gvirtzmann, 1966), south-east Australia and Newzealand (Jenkins, 1960, 1965). Blow (1969) gave its range from the base of Zone P 21 (= N 2) to lower part of Zone N 4.

Globigerina angustiumbilicata Bolli

(Plate I, fig. 6)

Globigerina ciperoensis angustiumbilicata Bolli, 1957, p. 109, pl. 22, figs. 12 a—13 c, p. 164, pl. 36, figs. 6 a—b.

Globigerina angustiumbilicata Bolli, Blow & Banner, 1962, p. 85, pl. IX x—z, figs. 9 (iv), 16 (vi, vii).

Remarks: In some of the forms from Cauvery basin the last chamber is smaller in size than the penultimate chamber, otherwise well comparable with the types.

Stratigraphic range: Bolli (1957) gave its range from the *G. ampliapertura* zone to *G. dissimilis* zone in Trinidad. Blow (1969) gave its range from the upper part of Zone P 16 to Zone N 22. In Cauvery basin this species is common and known from the *G. cerroazulensis* zone to a level above the *G. kugleri/G. primordius* zone.

Globigerina binaiensis Koch

(Text-figures 5, 6, 7, 8)

Globigerina binaiensis Koch, 1935, nom. nov. for "*G. aspera* Koch, 1926" (non Ehrenberg), type figures in Koch, 1926, Ecologae Geol. Helv., vol. 19 (1925—1926), no. 3, p. 745, figs. 22 a—c, 23 a—c.

Globigerina binaiensis Koch, Blow, 1969, p. 316, pl. 13, figs. 1, 2.

Remarks: This species is characterized in having three chambers in the last whorl and a large flattened apertural face of the last chamber. The specimens from Cauvery basin are very well comparable with the illustrations given by Blow (1969).

Stratigraphic range: Blow (1969) gave the range of *G. binaiensis* from the Zone P 22 (= N 3) to Zone N 5, and noted that it appears to be restricted to the Indo-Pacific Province. In Cauvery basin this species is abundant in the lower most part of the *G. trilobus* assemblage. Rare forms are also recorded from core samples belonging to the upper part of *G. kugleri/G. primordius* zone and also from the cutting samples belonging to the *G. angulisuturalis* zone.

Globigerina ciperoensis Bolli

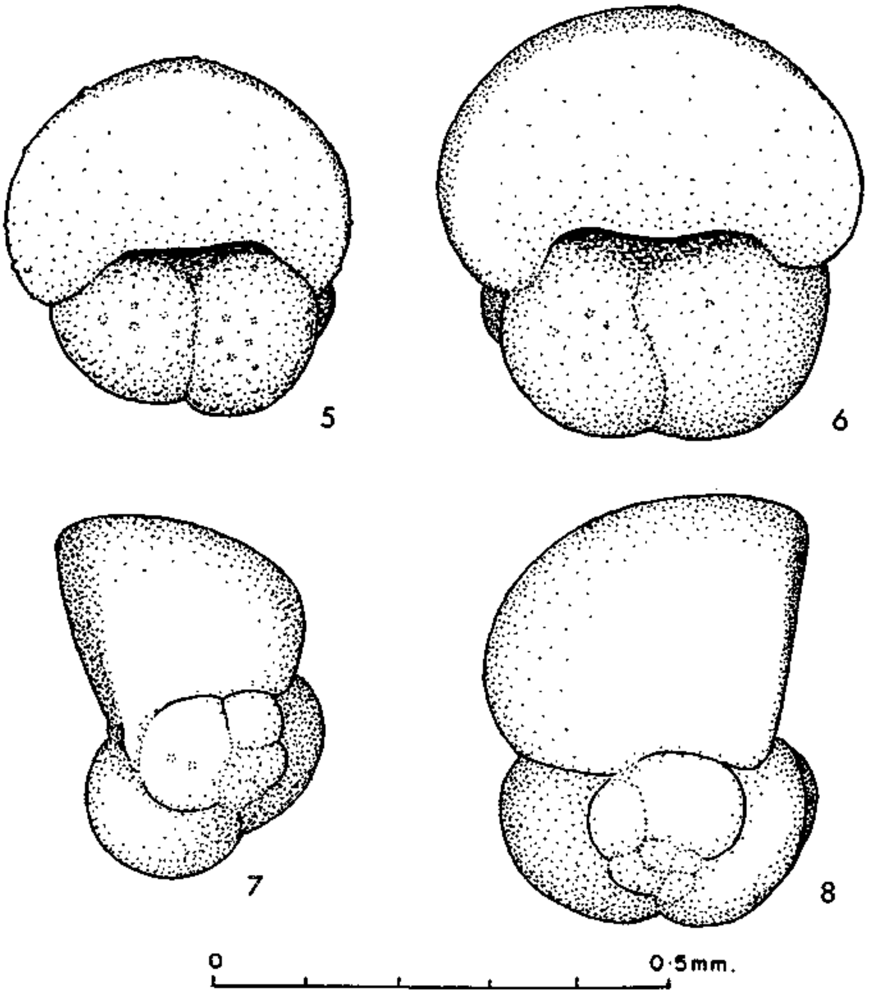
(Plate I, figs. 5 a, b)

Globigerina ciperoensis Bolli, 1954, Contr. Cushman Found. Foram. Res., vol. 5, pt. 1, p. 1, text-figs. 3—6.

Globigerina ciperoensis ciperoensis Bolli, Bolli, 1957, p. 109, pl. 22, figs. 10 a—b.

Globigerina ouachitaensis ciperoensis Bolli, Blow & Banner, 1962, pp. 90—91, pl. IX E—G, fig. 9 (i—iii).

Stratigraphic range: Bolli (1957) recorded this species from the *G. opima opima* zone to the top of *G. ciperoensis* zone in Trinidad. Blow & Banner (1962) recorded this species from the *G. oligocaenina* zone to *G. ciperoensis* zone and also mentioned its occurrence in the Aquitanian of South-west France. Blow (1969) gave the range of *G. ouachitaensis ciperoensis* forma *typica* from Zone P 19 to Zone N 4 and forma *atypica* is shown to range up to Zone N 5. In Cauvery basin this species is known from *G. angulisuturalis* zone to *G. kugleri/G. primordius* zone.



Text-figures 5, 6, 7, 8. *Globigerina binaiensis* Koch, from core sample at 874 m. in Madanam-1.

Globigerina corpulenta Subbotina

(Plate V, figs. 1 a—c)

Globigerina corpulenta Subbotina, 1953, p. 76, pl. 9, figs. 5—7, pl. 10, figs. 1—4.

Stratigraphic range: Subbotina (1953) has originally described this species from the Upper Eocene, series F 3 (middle), zone of *Globigerinoides conglobatus* and large Globigerinas, from Northern Caucasus, U. S. S. R. In Cauvery basin this species is very common in the *G. mexicana* zone and a few specimens are also recorded from the *G. cerroazulensis* zone.

Globigerina galavisi Bermudez

(Plate V, figs. 2 a—c, 3)

Globigerina galavisi Bermudez, 1961, Contribucion al Estudio de las Globigerinidea de la Region Caribe-Antillana, 3rd Congress Geol. Venezolano, Boletin de Geologia, Caracas, Venezuela, p. 1.183, pl. 4, fig. 3.

Globigerina galavisi Bermudez, Blow, 1969, p. 319, pl. 5, figs. 1—3, pl. 16, figs. 4, 5.

Remarks: The specimens from Cauvery basin are well comparable with the illustrations of holotype and metatype given by Blow (1969).

Stratigraphic range: Blow (1969) gave the range of this species from the Zone P 13 to P 21 (= N 2). This species is recorded so far from the *G. mexicana* zone to *G. sastrii* zone in Cauvery basin.

Globigerina gortanii gortanii (Borsetti)

(Plate II, figs. 1 a, b, 2)

Catapsydrax gortanii Borsetti, 1959, pp. 205—207, pl. 1, figs. 1 a—d.

Globigerina turritilina turritilina Blow & Banner, 1962, pp. 98—99, pl. XIII, figs. D—G.

Remarks: The forms from Cauvery basin, in general, are well comparable with the holotype and paratypes of *Globigerina turritilina turritilina*. In several of the specimens from Cauvery basin, the umbilicus is either filled with matrix or covered by a compressed aberrant (bulla like) final chamber. The present specimens are also well comparable with the type description and illustrations of *Catapsydrax gortanii* Borsetti.

Stratigraphic range: Borsetti (1959) has originally described this species from the Lower Oligocene of Northern Italy. Blow & Banner (1962) recorded this species from *G. turritilina turrilitina* zone to *G. oligocaenica* zone in East Africa. Blow (1969) gave its range from the base of Zone P 18 to the lower part of Zone P 22. In Cauvery basin this species is common in *G. gortanii* zone and *G. sastrii* zone.

Globigerina gortanii praeturritilina Blow & Banner

(Plate II, figs. 4 a, b, 5 a, b)

Globigerina turritilina praeturritilina Blow & Banner, 1962, p. 99, pl. XIII, figs. A—C.

Stratigraphic range: Blow & Banner (1962) gave the range of this species from *G. semiinvoluta* zone to the lower part of the *G. turritilina turritilina* zone. Blow (1969) gave its range from the Zone P 14 to the middle part of Zone P 17. In Cauvery basin this species is recorded from the *G. mexicana* zone to *G. gortanii* zone.

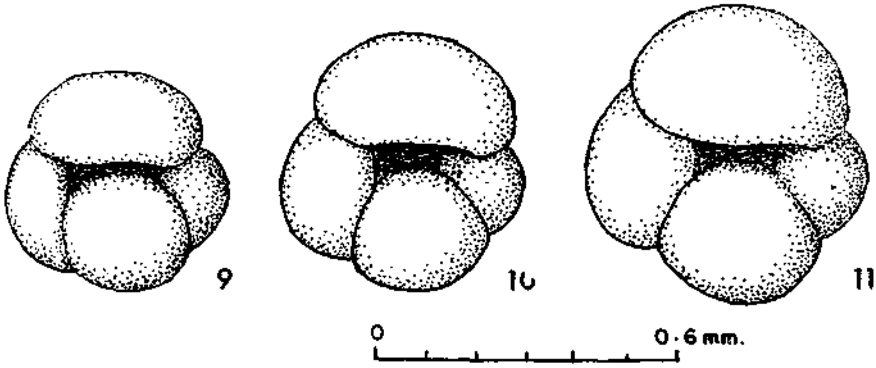
Globigerina prasaepis Blow

(Text-figures 9, 10, 11)

Globigerina ampliapertura euapertura (Jenkins), Blow & Banner, 1962, p. 84, pl. XI, figs. E—G. (= holotype of *G. prasaepis* Blow), not *Globigerina euapertura* Jenkins, 1960, p. 351, pl. 1, figs. 8 a—c.

Globigerina ampliapertura euapertura (Jenkins), Raju, 1968, pl. 4, fig. 8.

Globigerina prasaepis Blow, 1969, pp. 382—383, pl. 10, fig. 13, pl. 18, figs. 3—7.



Text-figures 9, 10, 11. *Globigerina prasaepis* Blow, from *G. gortanii* zone, core sample at 1800 m. in NGT-1.

Remarks: The present author has compared the specimens from Cauvery basin with the hypotype of *Globigerina ampliapertura euapertura* of Blow & Banner, 1962 (= holotype of *G. prasaepis* Blow, 1969) deposited in British Museum (Natural History), London. They are well comparable, except that the sutures in specimens from Cauvery basin are slightly more incised than in the type.

Stratigraphic range: Blow (1969) gave the range of this species from upper part of the Zone P 17 to Zone P 21. In Cauvery basin this species is common in *G. gortanii* zone and *G. sastrii* zone.

Globigerina pseudocorpulenta Chalilov

(Plate II, figs. 3 a, b)

Globigerina pseudocorpulenta Chalilov, 1956 (on the pelagic foraminiferal fauna of the Paleogene of Azerbaidzhan; in Russian), Akad. Nauk. Azerb. S. S. R., Inst. Geol., Baku, Trudy vol. 17, p. 245, pl. 4, figs. 3 a—c (in Ellis & Messina, 1940 et seq.).

Remarks: Specimens from Cauvery basin are well comparable with the illustrations and description of the type. However, the presently described forms seem to have less spinosity and the aperture often extends more towards extraumbilical.

Stratigraphic range: Chalilov (1956) has originally described this species from lower part of the Upper Eocene, from the northeast foothills of the Maly Caucasus, Azerbaidzhan, S. S. R. In Cauvery basin this species is comon in *G. mexicana* zone. A few forms from *O. beckmanni* zone are comparable to this species.

Globigerina cf. *rubriformis* (Subbotina)

(Plate II, figs. 6 a, b)

Globigerinoides rubriformis Subbotina, 1953, (part), p. 92, pl. 14, figs. 6—9 (not pl. 13, figs. 19 a—b).

Remarks: SUBBOTINA (1953) has placed probably the forms of both *Globigerina* and *Globigerapsis* under this species. Only one form (pl. 13, figs. 19 a—b) has been shown in her illustrations to contain definite supplementary apertures. However, the holotype (pl. 14, figs. 6 a—c) does not seem to have any supplementary apertures and she also commented that supplementary apertures are missing in some forms.

Stratigraphic range: SUBBOTINA (1953) has originally described this species from the *Globigerinoides conglobatus* zone, Upper Eocene and from the *Bolivina* zone, in Northern Caucasus, U. S. S. R. In Cauvery basin rare forms are recorded from *G. gortanii* zone.

Globigerina sastrii n. sp.

(Plate IV, figs. 1 a—c, 2 a—c)

Description: Test low trochospiral, the equatorial profile is subcircular, equatorial periphery is broadly lobate; the axial periphery is broadly rounded with dorso-peripheral shoulder. The dorsal surface is flat to very slightly convex, the ventral surface is strongly vaulted. Wall calcareous, coarsely hispid, rugosities or short thick spines are found throughout, but more prominent around the umbilicus. Chambers, earlier ones spherical, later ones subconical, arranged in 2—3 whorls; the last 2 or 3 chambers increase very rapidly in size and strongly embrace the earlier ones; in umbilical view the last two chambers are prominently visible. Sutures on spiral side curved, less distinct in early stage, radial or oblique later, slightly depressed; umbilical side radial, depressed. Umbilicus small, narrow slit like, often covered by the last chamber, elongate, depressed; not sharply delineated. Aperture is often covered, narrow slit like.

Largest diameter of the holotype is 0.64 mm.

Depository: The types are deposited in the Palaeontology Laboratory, O. N. G. Commission, Baroda, India.

Type sample: A core sample, WLC-3, at a depth of 1580 m. in Karaikal well No. 4.

Age and distribution: Presence of *Globigerina gortanii gortanii*, *G. ampliapertura*, *G. sellii*, *Globorotalia increbescens* and other forms in the type sample indicates an Oligocene age. This species is recorded from TPD-1, NGT-1, Karaikal wells and Madanam well in Cauvery basin.

Remarks: This is a distinctive, short ranged species. This species is named after V. V. Sastri, O. N. G. Commission, India in recognition of his contributions to biostratigraphy in India.

Globigerina sellii (BORSETTI)

Plate III, figs. 5 a, b, 6)

Globoquadrina sellii BORSETTI, 1959, p. 209, pl. 13, figs. 3 a—d.
Globigerina oligocaenica BLOW & BANNER, 1962, p. 88, pl. X, figs. G, L—N.

Remarks: The specimens from Cauvery basin are compared with the types of *G. oligocaenica*. In the presently described forms the overlap, on the ventral side, of the last chamber is of lesser degree than in the types. In general, the apertural face of the forms is broader and slightly more flattened than in the holotype of *G. oligocaenica*. The specimens from Cauvery basin are well comparable with the illustrations and type description of *G. sellii*.

Stratigraphic range: BORSETTI (1959) has originally described this species from the Oligocene of Northern Italy. BLOW & BANNER (1962) gave its range as restricted to *G. oligocaenica* Zone, Lindi area, East Africa. BLOW (1969) gave its range from Zone P 19 to Zone P 22 (= N 3). In Cauvery basin rare forms are recorded from *G. sastrii* zone.

Globigerina tripartita tripartita KOCH

(Plate III, figs. 3 a, b)

Globigerina bulloides D'ORBIGNY var. *tripartita* KOCH, 1926, Eclogae Geol. Helv., vol. 19 (1925—1926), no. 3, p. 746, text-figs. 21 a—b.

Globigerina tripartita tripartita KOCH, BLOW & BANNER, 1962, pp. 96—97, pl. X, figs. A—F.

Stratigraphic range: KOCH (1926) described this species from the lower beds of the "Globigerinenmergel" of East Borneo. BLOW (1969) gave the range of this species from the Zone P 14 to Zone P 22. In Cauvery basin typical forms are recorded from *G. sastrii* zone. Forms comparable to this species are also recorded from *G. mexicana* and *G. cerroazulensis* zones.

Globigerina tripartita rohri BOLLI

(Plate III, figs. 2, 4 a, b)

Globigerina rohri BOLLI, 1957, p. 109, pl. 23, figs. 1 a—4 b.

Remarks: Only forms well comparable to the types are assigned to this subspecies. Some forms from upper part of the *G. kugleri*/*G. primordius* zone and lower part of *G. trilobus* assemblage in Cauvery basin are comparable to this subspecies except in that they developed a definite umbilical teeth, on the basis of which they are referred here to *Globoquadrina praedehiscens* BLOW & BANNER.

Stratigraphic range: BOLLI (1957) gave its range from the *G. ampliapertura* zone to *C. dissimilis* zone in Trinidad. In Cauvery basin a few forms are recorded from the *G. sastrii* zone.

Globigerina venezuelana HEDBERG

(Plate V, fig. 4, plate VI, figs. 1 a—c)

Globigerina venezuelana HEDBERG, 1937, Jour. Paleont., vol. 11, no. 8, p. 681, pl. 92, figs. 7 a—b.

Globigerina venezuelana HEDBERG, BOLLI, 1957, p. 110, pl. 23, figs. 6 a—8 b.

Globigerina venezuelana HEDBERG, BLOW & BANNER, 1962, text fig. 11.

Stratigraphic range: Bolli (1957) recorded this species from the *G. ampliapertura* Zone to *G. menardii* Zone in Trinidad. Blow (1969) gave its range from Zone P 22 to Zone N 9. In Cauvery basin typical forms are recorded so far from the *G. kugleri*/*G. primordius* zone and lower part of *G. trilobus* assemblage.

Globigerina woodi woodi Jenkins

(Plate V, figs. 5 a—c)

Globigerina woodi Jenkins, 1960, p. 352, pl. 2, figs. 2 a—c.
Globigerina woodi Jenkins, Reiss & Gvitzmann, 1966, pl. 91, figs. 1 a—c.
Globigerina woodi woodi Jenkins, Jenkins, 1966, p. 6, pl. 1, figs. 18 a—c.

Stratigraphic range: Jenkins (1960) gave its range from base of the *G. woodi* zone to *G. menardii miotumida* zone in Australia. This species has also been recorded from Newzealand (Jenkins, 1965), Israel (Reiss & Gvirtzmann, 1966) and from the type Aquitanian of France (Jenkins, 1966). In Cauvery basin this species is recorded from *G. angulisuturalis* zone and *G. kugleri*/*G. primordius* zone.

Genus *Globigerinoides* Cushman, 1927

Globigerinoides primordius Blow & Banner

(Plate VII, figs. 1 a, b, 2 a, b)

Globigerinoides quadrilobatus primordius Blow & Banner, 1962, p. 115, pl. IX, figs. D d—F f, fig. 14 (iii—viii).

Remarks: The specimens from Cauvery basin are well comparable to the holotype. The primary aperture of the Cauvery basin forms is more wider than in the holotype. However, these and other minor differences fall within the variation limits of paratypes designated by Blow & Banner (1962).

Stratigraphic range: Blow & Banner (1962) gave the range of this species as confined to the *G. kugleri* zone in Trinidad. Jenkins (1966) recorded forms comparable to this species from the type Aquitanian of France. Blow (1969) gave its range from base of the Zone N 4 to lower part of the Zone N 5. In Cauvery basin it is common throughout the *G. kugleri*/*G. primordius* zone.

Globigerinoides trilobus trilobus (Reuss)

(Plate VII, figs. 4 a, b)

Globigerina triloba Reuss, 1850 Denkschr. k. k. Akad. Wiss., Wien, mathem.-naturwiss. Cl., vol. 1, p. 374, pl. 47, figs. 11 a—d (in Ellis & Messina, 1940 et seq.).
Globigerinoides triloba triloba (Reuss), Bolli, 1957, p. 112, pl. 25, figs. 2 a—c.

Stratigraphic range: Bolli (1957) gave the range of this species from the *C. dissimilis* zone to *G. menardii* zone in Trinidad. In Cauvery basin it appears in uppermost part of the *G. kugleri*/*G. primordius* zone and is common throughout the Lower-Middle Miocene.

Globigerinoides trilobus altiapertunus Bolli
(Plate VII, figs. 4 a, b)

Globigerinoides triloba altiapertura Bolli, 1957, p. 113, pl. 25, figs. 7 a—8, text fig. 21, no. 3.

Stratigraphic range: Bolli (1957) gave its range from base of the *C. dissimils* zone to *C. stanforthi* zone in Trinidad. This species has also been recorded from the type Burdigalian of France (Jenkins, 1966), Newzealand (Jenkins, 1965), Australia (Wade, 1964), Israel (Reiss & Gvittzmann, 1966). In Cauvery basin it is recorded from uppermost part of the *G. kugleri/G. primordius* zone and *G. trilobus* assemblage.

Genus *Globigerinita* Brönnimann, 1951 emended Blow & Banner, 1962

Globigerinita dissimilis (Cushman & Bermudez)
(Plate VI, figs. 2 a, b, 3 a, b)

Globigerina dissimilis Cushman & Bermudez, 1937, p. 25, pl. 3, figs. 4—6.
Catapsydrax dissimilis (Cushman & Bermudez), Bolli, 1957, p. 36, pl. 7, figs. 6 a—8 c.
Globigerinita dissimilis (Cushman & Bermudez), Blow & Banner, 1962, p. 106, pl. 14, figs. A—D.

Remarks: The illustrated specimen from *G. kugleri/G. primordius* zone in Cauvery basin has a slightly more convex spiral side than in the holotype.

Stratigraphic range: Bolli (1957) gave its range from *T. rohri* zone to *C. stainforthi* zone in Trinidad. In Cauvery basin rare forms of this species are recorded from *G. mexicana* zone to lower part of *G. trilobus* assemblage. Very rare forms comparable to *G. dissimilis* are also recorded from sequence as low as *Hantkenina aragonensis* zone in Cauvery basin.

Globigerinita stainforthi (Bolli, Loeblich & Tappan)
(Plate VI, figs. 4 a—c)

Catapsydrax stainforthi Bolli, Loeblich & Tappan, 1957, p. 36, pl. 7, figs. 11 a—c.

Remarks: The specimens from Cauvery basin are well comparable with the type description and illustrations.

Stratigraphic range: Bolli (1957) gave the range of this species from the *C. dissimilis* zone to *C. stainforthi* zone in Trinidad. Blow (1969) gave its range from the latest part of Zone N 4 to Zone N 7. In Cauvery basin this species is known from the uppermost part of *G. kugleri/G. primordius* zone and in the sequence immediately overlying this zone.

Genus *Globigerapsis* Bolli Loeblich & Tappan, 1957

Globigerapsis mexicana (Cushman)
(Plate XI, figs. 1, 2 a, b, 3 a, b, 4, 5, 6)

Globigerina mexicana Cushman, 1925, Cushman Lab. Foram. Res., Contr., vol. 1, p. 6, pl. 1, fig. 8 a, b.

Globigerinoides semiinvoluta Keijzer, 1945, Univ. Utrecht, Geogr. Geol. Med. Phys-Geol. Reeks; ser. 2, no. 6, p. 206, pl. 4, figs. 58 a—e.

Globigerapsis semiinvoluta (Keijzer), Bolli, 1957, p. 165, pl. 36, figs. 19—20.

Globigerapsis semiinvoluta (Keijzer), Blow & Banner, 1962, p. 125, pl. XV, figs. J—L.

Globigerapsis semiinvoluta (Keijzer), Raju, 1968, pl. 2, figs. 4, 5.

Globigerapsis mexicana (Cushman), Blow & Saito, 1968, Micropaleontology, vol. 14, no. 3, pp. 357—360, text-figs. 1—4.

Remarks: The specimens from Cauvery basin are in general smaller in size than the type. The sutures are not distinct and often the initial chambers are not visible. The sutures in the hypotype of *G. semiinvoluta* of Blow & Banner, 1962, are more prominently visible than in these forms.

Stratigraphic range: Bolli (1957) and Blow & Banner (1962) have given the range of this species as restricted to the limits of its zone within the lower part of the Upper Eocene.

Globigerapsis cf. *tropicalis* Blow & Banner

(Plate XI, figs. 7 a, b)

Globigerapsis tropicalis Blow & Banner, 1962, pp. 124—125, pl. XV, figs. D—F.

Remarks: The presently illustrated forms from Cauvery basin differ slightly from the holotype of *G. tropicalis* in being larger in size, in having more depressed sutures, more elongate and lower supplementary apertures. The wall structure is comparable.

Stratigraphic range: Blow (1969) gave the range of this species from Zone P 10 (= *H. aragonensis* Zone) to Zone P 16.

Genus *Globoquadrina* Finlay, 1947

Globoquadrina altispira globosa Bolli

(Plate VII, figs. 6 a, b)

Globoquadrina altispira globosa Bolli, 1957, pp. 111—112, pl. 24, figs. 9 a—10 c.

Remarks: The specimens from Cauvery basin are often badly preserved and the umbilicus is filled with pyritized matrix. The last one or two chambers in the last whorl increase rapidly in size than in the forms described by Bolli (1957).

Stratigraphic range: Bolli (1957) gave the range of this species from base of the *C. dissimilis* zone to *G. insueta* zone and again from *G. fohsi robusta* zone to *G. menardii* zone in Trinidad. The presently illustrated forms are from uppermost part of the *G. kugleri*/*G. primordius* zone. It is common in the *G. trilobus* assemblage. Blow (1969) gave its range from Zone P 22 (= N 3) to Zone N 20.

Globoquadrina dehiscens (Chapman, Parr & Collins)

(Plate IX, figs. 3, 4 a, b)

Globorotalia dehiscens Chapman, Parr & Collins, 1934, Linn. Soc. London, Jour. Zool., vol. 38, no. 262, p. 569, pl. 11, figs. 36 a—c (in Ellis & Messina, 1940 et seq.).

Globoquadrina dehiscens (CHAPMAN, PARR & COLLINS), BOLLI, 1957, p. 111, pl. 24, figs. 3 a—4 c.

Remarks: The subspecies of *G. dehiscens* are not recognized in the present study.

Stratigraphic range: BOLLI (1957) gave its range from *G. stainforthi* zone to *G. menardii* zone in Trinidad. In Cauvery basin this species is common in the *G. trilobus* assemblage.

Globoquadrina cf. *larmeui* AKERS

(Plate IX, figs. 5 a, b)

Globoquadrina larmeui AKERS, 1955, p. 661, pl. 65, figs. 4 a—c.
Globoquadrina larmeui AKERS, JENKINS, 1960, p. 355, pl. 3, figs. 1 a—2 c.

Remarks: The specimens from Cauvery basin differ slightly from the type illustrations and description in being more convex dorsally and larger in size.

Stratigraphic range: JENKINS (1960) recorded this species from the Pre-*Globoquadrina dehiscens dehiscens* zone to the *O. universa* zone in Australia. In Cauvery basin this species is recorded so far from the *G. angulisuturalis* zone and *G. kugleri*/*G. primordius* zone.

Globoquadrina praedehiscens BLOW & BANNER

(Plate VIII, figs. 4 a—c; Plate IX, fig. 12)

Globoquadrina dehiscens praedehiscens BLOW & BANNER, 1962, pp. 116—117, pl. XV, figs. Q—S.
Globoquadrina praedehiscens BLOW & BANNER, SAITO, 1963, p. 193, pl. 55, figs. 7 a—b.
Globoquadrina dehiscens praedehiscens BLOW & BANNER, REISS & GVIRTZMANN, 1966, pl. 96, figs. 3—7.

Remarks: The specimens from Cauvery basin are compared with the holotype. In most of the present specimens the last chamber is relatively smaller, the umbilical teeth is slightly the and wider than in the holotype.

Stratigraphic range: BLOW & BANNER (1962) gave its range from middle part of the *G. ciperoensis* zone to the lower part of *G. stainforthi* zone in Trinidad. They have also reported its occurrence from Venezuela, East Africa, and Newzealand. In Cauvery basin typical forms are recorded from *G. kugleri*/*G. primordius* zone and lower part of the *G. trilobus* assemblage.

Genus *Globorotalia* CUSHMAN, 1927

Globorotalia centralis CUSHMAN & BERMUDEZ

Globorotalia centralis CUSHMAN & BERMUDEZ, 1937, p. 26, pl. 2, figs. 62—65.
Globorotalia centralis CUSHMAN & BERMUDEZ, BOLLI, 1957, p. 162, pl. 39, figs. 1—4.
Globorotalia (Turborotalia) centralis CUSHMAN & BERMUDEZ, BLOW & BANNER, 1962, p. 117, pl. XII, figs. K—M, Fig. 12 c, d.
Turborotalia centralis CUSHMAN & BERMUDEZ, RAJU, 1968, pl. 4, figs. 3 a—c.

Remarks: This species was earlier illustrated by the present author (Raju, 1968) and given as *Turborotalia centralis.*

Stratigraphic range: Bolli (1957) gave its range from the *Globigerapsis kugleri* zone to *G. cocoaensis* zone in Trinidad. Blow (1969) noted that it ranges from Zone P 11 to Zone P 17. In Cauvery basin it has been recorded from the *H. aragonensis* zone to top of the *G. cerroazulensis* zone.

Globorotalia cerroazulensis (Cole)

Globigerina cerroazulensis Cole, 1928, Bull. Amer. Pal., vol. 14, no. 53, p. 217, pl. 32, figs. 11—13.
Globorotalia cocoaensis Cushman, 1928, Contr. Cushman Lab. Foram. Res., vol. 4, pt. 3, p. 75, pl. 10, figs. 3 a—c.
Globorotalia cocoaensis Cushman, Bolli, 1957, p. 169, pl. 39, figs. 5 a—7 b.
Globorotalia (Turborotalia) cerroazulensis (Cole), Blow & Banner, 1962, p. 118, pl. XII, figs. D—F, Fig. 12 d, e.
Turborotalia cerroazulensis (Cole), Raju, 1968, pl. 3, figs. 7 a—c.

Remarks: This species was earlier illustrated by the present author (Raju, 1968) and given as *Turborotalia cerroazulensis.*

Stratigraphic range: Bolli (1957) gave its range from the base of the *G. semiinvoluta* zone to top of the *G. cocoaensis* zone in Trinidad. Blow (1969) gave its range from upper part of Zone P 14 (*T. rohri/G. howeii* zone) to the lower part of Zone P 17. In Cauvery basin it is known from the *G. mexicana* zone to top of the *G. cerroazulensis* zone. Some rare forms from O. *beckmanni* zone appear to be comparable to this species.

Globorotalia increbescens (Bandy)

(Plate IX, figs. 7 a—c)

Globigerina increbescens Bandy,1949, p. 120, pl. 23, figs. 3 a—c.
Globorotalia (Turborotalia) increbescens (Bandy), Blow & Banner, 1962, pp. 118—119, pl. XIII, figs. T—V, pl. XVII, figs. D, K, Fig. 9 (13—15).

Remarks: The specimens from Cauvery basin are compared with a metatype, from Upper Jackson, Little Stave Creek, Clarks county, Alabama, deposited in British Museum (Natural History), London. The illustrated specimen from Cauvery basin is slightly bigger in size and has slightly higher aperture, otherwise well comparable with the metatype.

Stratigraphic range: This species has been originally described by Bandy (1949) from Jacksonian Stage, Alabama, U. S. A. Blow (1969) gave the range of this species from Zone P 15 to Zone P 19. In Cauvery basin typical forms are recorded from *G. gortanii* zone and *G. sastrii* zone.

Globorotalia kugleri Bolli

(Plate X, figs. 1 a, b, 2 a, b)

Globorotalia kugleri Bolli, 1957, p. 118, pl. 28, figs. 5 a—6.
Globorotalia (Turborotalia) kugleri Bolli, Blow, 1969, p. 350, pl. 38, figs. 1—4.

Remarks: The specimens from Cauvery basin are well comparable with the type description and illustrations given by Bolli (1957) and the illustrations of topotypes given by Blow (1969).

Stratigraphic range: Bolli (1957) gave the range of this species as restricted to the *G. kugleri* zone in Trinidad. Blow (1969) gave its range from Zone P 22 (= N 3) to the top of Zone N 4. In Cauvery basin it is recorded so far only from upper part of the *G. kugleri/G. primordius* zone.

Globorotalia obesa Bolli

(Plate X, figs. 6 a—c)

Globorotalia obesa Bolli, 1957, p. 119, pl. 29, figs. 2 a—c.
Globigerina obesa Bolli, Vervloet, 1966, p. 53, pl. II, figs. 9 a—c, pl. V, figs. 2 a—c.

Stratigraphic range: Bolli (1957) gave its range from *C. dissimilis* zone to *G. menardii* zone in Trinidad. In Cauvery basin this species is common in the upper part of *G. kugleri/G. primordius* zone and *G. trilobus* assemblage.

Globorotalia opima nana Bolli

(Plate X, figs. 3 a, b)

Globorotalia opima nana Bolli, 1957, p. 118, pl. 28, figs. 3 a—c.
Globorotalia (Turborotalia) opima nana Bolli, Blow & Banner, 1962, pp. 119—120, pl. XIII, figs. Q—S.

Remarks: The specimen illustrated here is slightly larger in size than the holotype. Most of the unillustrated forms are better comparable with the type.

Stratigraphic range: Blow (1969) gave the range of this species from Zone P 15 to Zone P 22 (= N 3). In Cauvery basin it is recorded from *G. mexicana* zone to the lower part of *G. kugleri/G. primordius* zone.

Globorotalia peripheroronda Blow & Banner

(Plate IX, figs. 6 a—c)

Globorotalia fohsi barisanensis Leroy, Bolli, 1957, p. 119, pl. 28, figs. 8 a—c.
Globorotalia (Turborotalia) peripheroronda Blow & Banner, 1966, Micropaleontology, vol. 12, no. 3, p. 294, pl. 1, figs. 1—3.

Stratigraphic range: Bolli (1957) gave its range from the *C. dissimilis* Zone to *G. fohsi fohsi* Zone in Trinidad. This species has been also reported from several parts of the world including Japan (Saito, 1963), Newzealand (Jenkins, 1965), Australia (Jenkins, 1960) and Israel (Reiss & Gvirtzmann, 1966). In Cauvery basin a few forms are recorded from *G. trilobus* assemblage.

Globorotalia siakensis (Leroy)

(Plate X, figs. 4, 5 a—c)

Globigerina siakensis Leroy, 1939, Natuurk. Tijdschr. Nederl.-Indie, vol. 99, no. 6, pp. 39—40, pl. 3, figs. 30—31.

Globorotalia mayeri CUSHMAN & ELLISOR, BOLLI, 1957, p. 118, pl. 28, figs. 4 a—c (not *Globorotalia mayeri* CUSHMAN & ELLISOR, 1939).

Globorotalia siakensis (LEROY), JENKINS, 1960, p. 366, pl. 5, figs. 7 a—c.

Globorotalia (Turborotalia) siakensis LEROY, BLOW (1969), p. 356, pl. 10, figs. 7—9, holotype refigured, pl. 34, figs. 4, 5.

Remarks: This species is very common throughout its range in Cauvery basin.

Stratigraphic range: BOLLI (1957) gave its range from the *G. opima opima* zone to *G. mayeri* zone in Trinidad. BLOW (1969) gave its range from Zone P 22 to N 14. In Cauvery basin this species is known from *G. angulisuturalis* zone to Middle-Upper Miocene.

Genus *Globorotaloides* BOLLI, 1957

Globorotaloides suteri BOLLI

(Plate VI, figs. 5 a, b)

Globorotaloides suteri BOLLI, 1957, p. 116, 166, pl. 27, figs. 9—13 b, pl. 37, figs. 10 a—12.

Globorotaloides suteri BOLLI, BLOW & BANNER, 1962, pp. 122—123, pl. XII, figs. N—P, Fig. 11 (V, IX).

Remarks: The specimens from Cauvery basin are well comparable with the type illustrations and description. These specimens differ slightly from the hypotypes of BLOW & BANNER (1962) in having a low lying bulla and the rate of increase in chamber size is slower.

Stratigraphic range: BLOW & BANNER (1962) recorded this species from the upper Lutetian to about the middle part of the Aquitanian in East Africa and Trinidad. BLOW (1969) gave its range from Zone P 13 to within Zone N 8. In Cauvery basin this species is recorded from *G. mexicana* zone to the *G. kugleri/G. primordius* zone.

Genus *Globigerinopsis* BOLLI, 1962

Globigerinopsis guhai n. sp.

(Plate VIII, figs. 1 a—c, 2 a—c, 3 a—c)

Description: Test low trochospiral, equatorial profile of the test subquadrate, equatorial periphery strongly lobate, axial periphery rounded. Wall calcareous, porous, finely pitted, well preserved specimens with fine small spines. Chambers inflated, spherical except the last one or two; last two in spiral view ovate, slightly elongate; the last chamber varies in size, in general equal or larger than the penultimate. Some 16 chambers arranged in 3—4 whorls; the 4—4½, rarely 5 chambers in last whorl increase rapidly in size. Sutures on spiral side radial to slightly oblique, strongly depressed; on umbilical side radial, strongly depressed. Umbilicus wide, deep, filled often with pyritized matrix. Primary aperture a high arch, interiomarginal umbilical to slightly spiroumbilical, without lip or rim. One secondary aperture, a medium arch with small rim. Largest diameter of the holotype is 0.624 mm.

Depository: The holotype and paratypes are deposited in the Palaeontology Laboratory, O. N. G. Commission, Baroda, India.

Type sample: Holotype and illustrated paratypes are from a core sample (CC I, 1126.3—1128.8 m., 15—26 cm.) from Karaikal well no. 2, Cauvery basin. Rare specimens are also recorded from cutting sample at a depth of 1000 m. in KKL-1.

Age of the type sample: Uppermost part of *Globorotalia kugleri*/ *Globigerinoides primordius* zone, Lower Miocene (Aquitanian age).

Remarks: This species has been placed under the genus *Globigerinopsis* Bolli, 1962. However, the present species has a supplementary aperture, whereas the type of *Globigerinopsis* do not have and also the primary aperture is more spiroumbilical in the types. Schmid (1967) described a n. sp., *Globigerinopsis grilli* Schmid, which has a supplementary aperture, but its wall surface is coarselly pitted and cancellate.

This species is named after Mr. D. K. Guha, O. N. G. Commission, India, in recognition of his contributions to microfauna and biostratigraphy in India.

Genus *Pseudohastigerina* Banner & Bblow, 1959

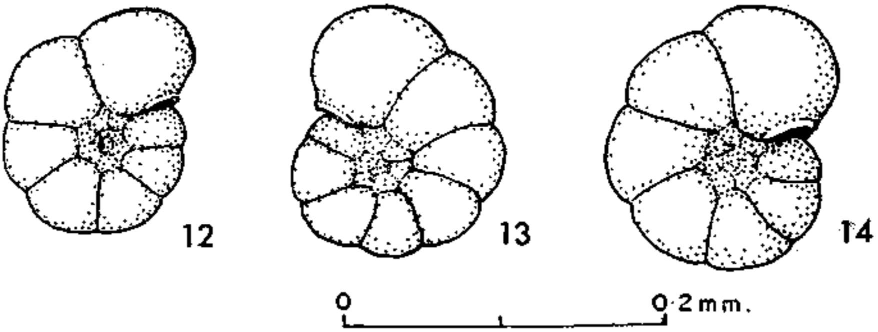
Pseudohastigerina barbadoensis Blow, 1969

(Text-figures 12, 13, 14)

Pseudohastigerina barbadoensis Blow, 1969, pp. 409—410, pl. 53, figs. 7—9, pl. 54, figs. 1—3.

Remarks: The specimens from Cauvery basin are very well comparable with the illustrations and description of the types.

Stratigraphic range: Blow (1969) gave the range of this species from Zone P 16 to the top of Zone P 19. In Cauvery basin this species is very common in *G. gortanii* zone, and very rare in the *G. cerroazulensis* zone.



Text-figures 12, 13, 14. *Pseudohastigerina barbadoensis* Blow, from *G. gortanii* zone, core sample at 1800 m. in NGT-1.

Pseudohastigerina micra (COLE)

(Plate XIII, figs. 9 a, b)

Nonion micrus COLE, 1927, Bull. Amer. Paleont., vol. 14, no. 51, p. 22, pl. 5, fig. 12.
Hastigerina micra (COLE), BOLLI, 1957, p. 161, pl. 35, figs. 1 a—2 b.
Pseudohastigerina micra (COLE), BANNER & BLOW, 1959, pp. 19—20, pl. 3, figs. 6 a—b, text-figs. 4 g—i.
Pseudohastigerina micra (COLE), BLOW, 1969, pl. 53, figs. 1, 4, 5, 6.

Stratigraphic range: BOLLI (1957) gave the range of this species from the *H. aragonensis* zone to *G. cocoaensis* zone in Trinidad. BLOW (1969) gave its range from Zone P 10 to within Zone P 19. In Cauvery basin basin typical forms are recorded from *H. aragonensis* to top of the *G. cerroazulensis* zone. Only rare forms from *G. gortanii* zone are comparable to this species.

Genus *Hantkenina* CUSHMAN, 1925

Hantkenina alabamensis CUSHMAN

(Plate XI, figs. 8, 9 a, b; Plate XII, fig. 2)

Hantkenina alabamensis CUSHMAN, 1925, Proc. U. S. Nat. Mus., vol. 66, no. 2567, art. 30, pp. 3—4, pl. 1, figs. 1—6, pl. 2, fig. 5, text-fig. 1.
Hantkenina alabamensis CUSHMAN, BANDY, 1949, p. 76, pl. 11, figs. 9 a—b.
Hantkenina (Hantkenina) alabamensis CUSHMAN, BRÖNNIMANN, 1950, p. 414, pl. 56, figs. 10, 14—16.
Hantkenina alabamensis CUSHMAN, BOLLI, LOEBLICH & TAPPAN, 1957, pp. 26—28, pl. 2, fig. 8.
Hantkenina alabamensis CUSHMAN, NAGAPPA, 1959, pl. 11, figs. 14 a—b.
Hantkenina alabamensis CUSHMAN, BLOW & BANNER, 1962, pp. 126—127, pl. XVI, figs. C—D, J, K.
Hantkenina alabamensis CUSHMAN, RAJU, 1968, pl. 1, fig. 11.

Remarks: The specimens from Cauvery basin show considerable variation in shape of the chambers and sutures. A few forms have hispid wall surface, particularly in the early chambers of the last whorl. A solitary form with twin spines (see Plate XI, figs. 9 a, b) is also found.

Stratigraphic range: BLOW (1969) gave the range of this species from within Zone P 13 (= O. *beckmanni* zone) to the top of Zone P 16. In Cauvery basin typical forms of this species are recorded so far from the *G. mexicana* zone and *G. cerroazulensis* zone.

Hantkenina suprasuturalis BRÖNNIMANN

(Plate XII, figs. 9 a, b, 10; Plate XIII, fig. 1)

Hantkenina (Hantkenina) suprasuturalis BRÖNNIMANN, 1950, p. 416, pl. 56, figs. 12, 13, text-fig. 2.

Remarks: The specimens from Cauvery basin are well comparable with the illustrations and description of the type. Several small sized specimens appear to grade morphologically to *Hantkenina alabamensis*.

Stratigraphic range: BRÖNNIMANN (1950) has originally reported this species from the Upper Eocene of Trinidad and Barbados. In Cauvery basin typical forms of this species are common in the *G. mexicana* zone and rare in *G. cerroazulensis* zone.

Hantkenina cf. *thalmanni* BRÖNNIMANN

(Plate XII, figs. 1 a—b)

Hantkenina thalmanni BRÖNNIMANN, 1950, pp. 415—416, pl. 55, figs. 19—21, pl. 56, figs. 3, 11.

Remarks: Only three specimens which are comparable with the illustrations and description of the types are found from the *G. mexicana* zone in Cauvery basin. It is not clear from the available material whether they are juvenile forms of *H. suprasuturalis.*

Hantkenina trinitatensis BRÖNNIMANN

(Plate XII, figs. 3, 4, 5)

Hantkenina (Applinella) trinitatensis BRÖNNIMANN, 1950, pp. 410—411, pl. 56, fig. 17.

Remarks: Only a few specimens which are well comparable with the illustrations and description of the types are found from the *G. mexicana* zone in Cauvery basin.

Genus *Cribrohantkenina* THALMANN, 1942

Cribrohantkenina inflata (HOWE)

(Platte XIII, figs. 2—8)

Hantkenina inflata HOWE, 1928, Jour. Paleont., vol. 2, no. 1, p. 14, fig. 2.
Hantkenina mccordi HOWE & WALLACE, 1932, Louisiana Dept. Conserv., Geol. Bull., no. 2, p. 55—56, tab. 10, figs. 1 a, b.
Hantkenina danvillensis HOWE & WALLACE, 1934, Jour. Paleont., vol. 8, pp. 35—37, pl. 5, figs. 14—17.
Hantkenina (Cribrohantkenina) bermudezi THALMANN, 1942, Amer. Jour. Sci., vol. 240, no. 11, pp. 812, 815, pl. 1, figs. 5—6.
Cribrohantkenina mccordi HOWE & WALLACE, BANDY, 1949, p. 76, pl. 11, figs. 10 a—b.
Hantkenina (Cribrohantkenina) bermudezi THALMANN, BRÖNNIMANN, 1950, p. 417, pl. 56, figs. 6—9.
Cribrohantkenina bermudezi THALMANN, BOLLI, LOEBLICH & TAPPAN, 1957, pp. 28—29, pl. 2, figs. 9 a—11 b.
Hantkenina (Cribrohantkenina) bermudezi THALMANN, NAGAPPA, 1959, pl. 11, figs. 15 a—b.
Cribrohantkenina danvillensis HOWE & WALLACE, BLOW & BANNER, 1962, p. 128, pl. XVI, figs. G—H, Fig. 19 (i—vii).
Cribrohantkenina inflata (HOWE), SPRAUL, 1963, Jour. Pleont., vol. 37, no. 2, p. 367, pl. 14, figs. 1 a—4 b.
Cribrohantkenina inflata (HOWE), RAJU, 1968, pl. 1, fig. 7.

Remarks: BLOW & BANNER (1962) discussed in detail the apertural characters of *Cribohantkenina.* SPRAUL (1963, cited above) has reillustrated the type of *Hantkenina inflata* HOWE, 1928 and shown that it is a true *Cribrohantkenina*, thus clarified the taxonomic status of several of the species.

In Cauvery basin both juvenile and adult specimens of this species are recorded from *G. cerroazulensis* zone. A study of these forms indicate that *C. inflata* has maintained the club shaped final chambers almost throughout its ontogeny. Similar data was earlier presented by DIENE & PROTO DECIMA (1964).

Stratigraphic range: This species is known to be an important world-wide index fossil of Upper Eocene. BLOW & BANNER (1962) recorded this species from about middle part of *G. semiinvoluta* zone to the top of *C. danvillensis* zone in Lindi area, East Africa. This species is common throughout the *G. cerroazulensis* zone in Cauvery basin. Very rare and poorly preserved specimens with doubtful cribrate aperture are found in *G. mexicana* zone.

Genus *CASSIGERINELLA* POKORNY, 1955

Cassigerinella chipolensis (CUSHMAN & PONTON)

Cassidulina chipolensis CUSHMAN & PONTON, 1932, Florida Geol. Survey, Bull., no. 9, p. 98, pl. 15, figs. 2 a—c.

Cassigerinella boudecensis POKORNY, 1955, Vestnik, Ustred. Geol., 30, pp. 136—140, text-figs. 1—3.

Cassigerinella globolocula IVANOVA, 1958, in BYKOVA, Mikrofauna S. S. S. R., sb. 9, vip. 115; Trudi. Vses. Neft. Naudno-Issled. Geol. Inst. (VNIGRI), p. 57, pl. 11, figs. 1—3.

Cassigerinella chipolensis (CUSHMAN & PONTON), BLOW & BANNER, 1962, pp. 81—82, pl. XV, figs. M, N.

Cassigerinella chipolensis (CUSHMAN & PONTON), RAJU, 1968, pl. 1, figs. 9 ,10.

Remarks: This species from Cauvery basin was illustrated earlier by the present author (RAJU, 1968). In general the size of the forms increase, slightly, from *G. gortanii* zone to *G. sastrii* zone.

Stratigraphic range: BOLLI (1957) gave the range of this species from the *G. ampliapertura* zone to *G. fohsi robusta* zone in Trinidad. BLOW (1969) gave its range from Zone P 18 to Zone N 13. In India this species is known from Kutch, Cambay basin, Assam, Cauvery basin, Quilon area and Andaman Islands. In Cauvery basin this species first appears in the basal part of the *G. gortanii* zone and is very common in the sequence from the *G. sastrii* zone to Middle Miocene. A few forms are found in the section above the extinction level of *Miogypsina antellia.*

Genus *Chiloguembelina* LOEBLICH & TAPPAN, 1956

Chiloguembelina cubensis (PALMER)

Guembelina cubensis PALMER, 1934, Mem. Soc. Cubana Hist. Nat., vol. 8, p. 74, text-figs. 1—6.

Chiloguembelina cubensis (PALMER), BECKMANN, 1957, p. 89, pl. 21, fig. 21, text-fig. 14, nos. 5—8.

Chiloguembelina cubensis (PALMER), RAJU, 1968, pl. 1, figs. 4 a—b.

Remarks: This species from Cauvery basin was illustrated earlier by the present author (Raju, 1968). This small and distinct species is abundant in the fine fractions of the samples, within its range, in Cauvery basin. This species is also common in shallow marine facies of Oligocene age in Cambay basin, western India and found together with *Nummulites fichteli-intermedius*.

Stratigraphic range: Beckmann (1957) gave the range of this species from *Porticulasphaera mexicana* zone to *G. opima opima* zone in Trinidad. The species has also been reported from various parts of the world in sections of Upper Eocene to Oligocene. Blow (1969) gave the range of *Chiloguembelina* ex group *cubensis* from Zone P 13 to very close to the Zone N 4/Zone N 3 (= P 22) boundary. In Cauvery basin this species is common from the *G. mexicana* zone to *G. ampliapertura* zone.

Chiloguembelina martini (Pijpers)

Textularia martini Pijpers, 1933, Univ. Utrecht Geogr. Geol. Med. Phys.-Geol. Reeks, no. 8, p. 57, figs. 6—10.

Chiloguembelina martini (Pijpers), Beckmann, 1957, p. 89, pl. 21, fig. 14, text-fig. 14, nos. 9—11, 14—18, 20—23.

Chiloguembelina martini (Pijpers), Raju, 1968, pl. 1, fig. 12.

Remarks: This species from Cauvery basin was earlier illustrated by the present author (Raju, 1968).

Stratigraphic range: Beckmann (1957) gave the range of this species from the *Globorotalia aragonensis* zone o the top of *G. cocoaensis* zone (= *G. cerroazulensis* zone) in Trinidad. In Cauvery basin this species is recorded from the *Globorotalia spinuloinflata* subzone (Lower Eocene) to the top of *G. cerroazulensis* zone.

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(All figures: a = ventral view, b = dorsal view, c = side view)

PLATE I

Figures 1 a—c. *Globigerina ampliapertura* Bolli, from *G. gortanii* zone, core sample at 1800 m. in NGT-1.

Figures 2, 3 a, b, 4. *Globigerina angulisuturalis* Bolli, from *G. kugleri/G.primordius* zone, core sample at 1421.5 m. in KKL-2.

Figures 5 a, b. *Globigerina ciperoensis* Bolli, from *G. kugleri/G. primordius* zone, core sample at 1421.5 m. in KKL-2.

Figure 6. *Globigerina angustiumbilicata* Bolli, from *G. kugleri/G. primordius* zone, core sample at 1126.5 m. in KKL-2.

Figures 7 a, b. *Globigerina* cf. *pseudoampliapertura* Blow & Banner, from *G. gortanii* zone, core sample at 1800 m. in NGT-1.

Figure 8. *Globigerina angiporoides* Hornibrook, from *G. gortanii* zone, core sample at 1800 m. in NGT-1.

PLATE I

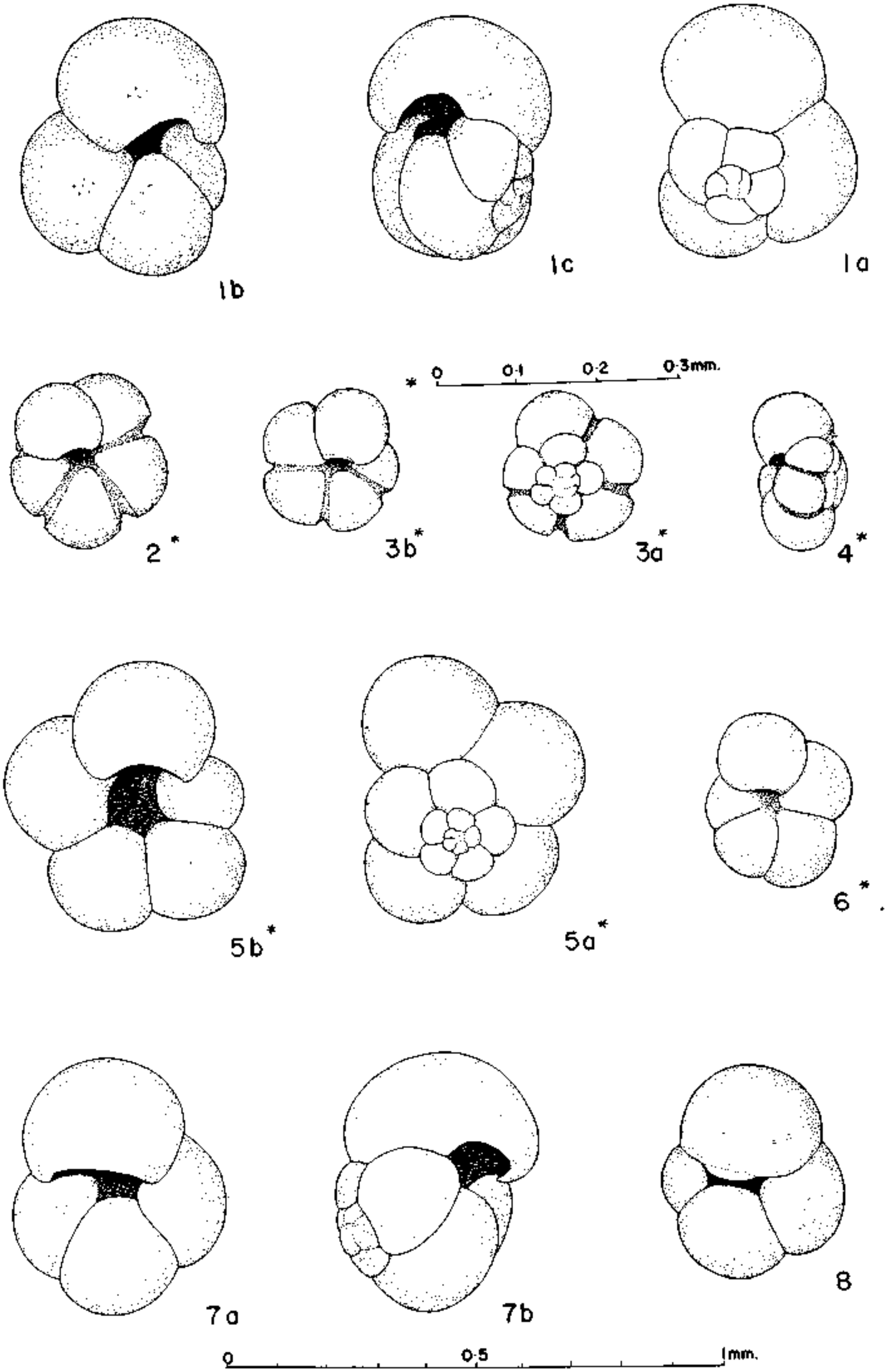


PLATE II

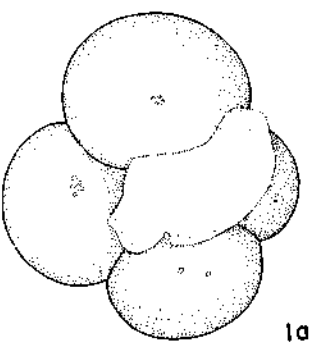
Figures 1 a, b, 2. *Globigerina gortanii gortanii* (Borsetti), from *G. sastrii* zone, core sample at 1579 m. in KKL-4.

Figures 3 a, b. *Globigerina pseudocorpulenta* Chalilov, from *G. mexicana* zone, core sample at 1904.2 m. in NGT-1.

Figures 4 a, b, 5 a, b. *Globigerina gortanii praeturritilina* Blow & Banner, from G. mexicana zone, core sample at 1904.2 m. in NGT-1.

Figures 6 a, b. *Globigerina* cf. *rubriformis* (Subbotina), from *G. gortanii* zone, core sample at 1800 m. in NGT-1.

PLATE II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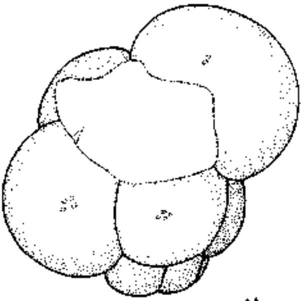
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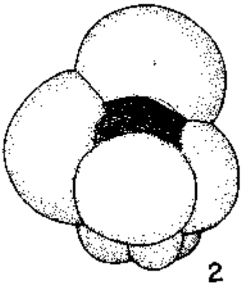
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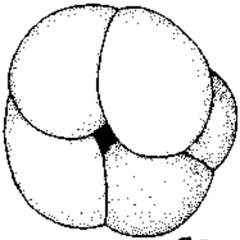
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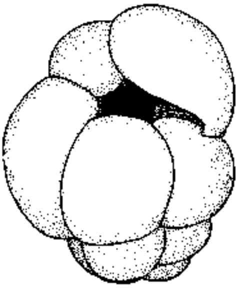
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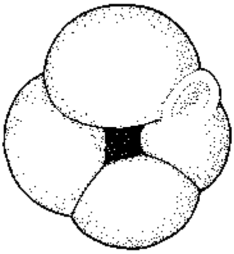
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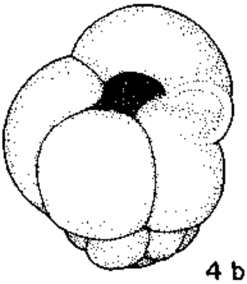
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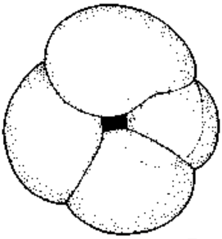
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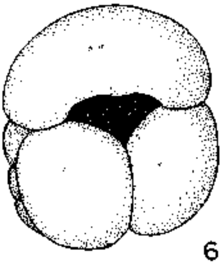
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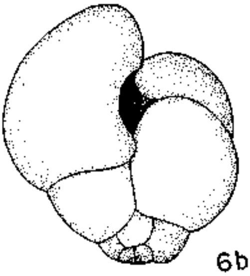
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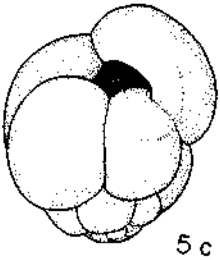
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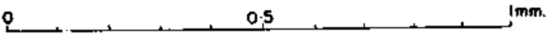


PLATE III

Figures 1 a, b. *Globigerina* sp., from G. mexicana zone, core sample at 1904.2 m. in NGT-1.

Figures 3 a, b. *Globigerina tripartita tripartita* KOCH, from *G. sastrii* zone, core sample at 1579 m. in KKL-4.

Figures 2, 4 a, b. *Globigerina tripartita rohri* BOLLI, from *G. sastrii* zone, core sample at 1582 m. in KKL-4.

Figures 5 a,b, 6. *Globigerina sellii* BORSETTI, 5 a, b from *G. sastrii* zone, core sample at 1582 m. in KKL-4; 6 from cutting sample at 1515 m. in KKL-2.

PLATE III

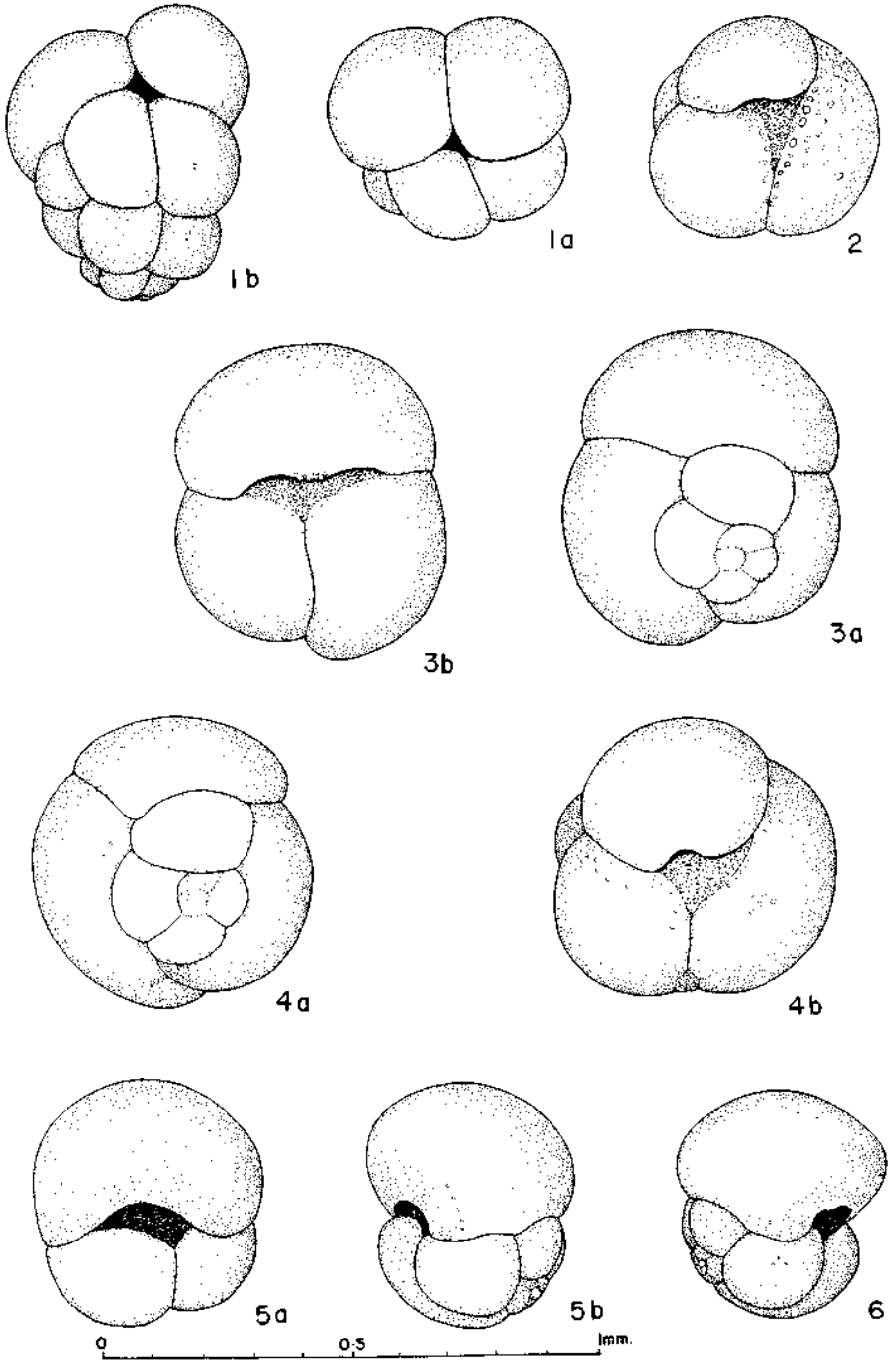
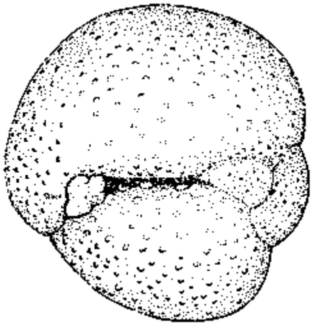


PLATE IV

Figures 1 a—c. *Globigerina sastrii* n. sp., holotype from core sample at 1579 m. in KKL-4, from *G. sastrii* zone.

Figures 2 a—c. *Globigerina sastrii* n. sp., paratype from core sample at 932 m. in TPD-1.

PLATE IV



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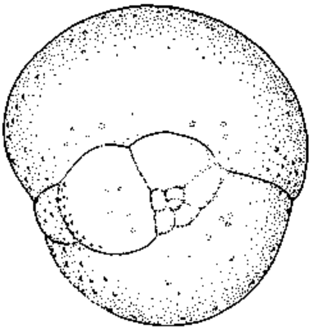

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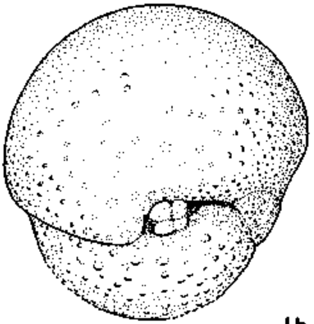

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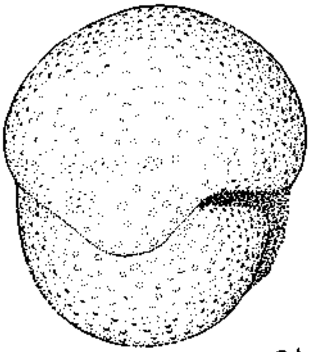

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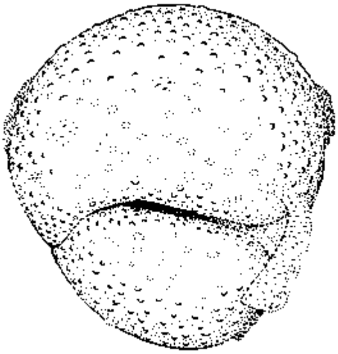

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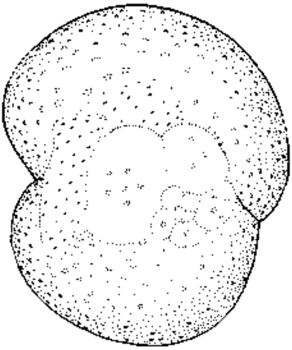

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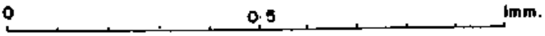


PLATE V

Figures 1 a—c. *Globigerina corpulenta* Subbotina, from *G. mexicana* zone, core sample at 1904.2 m. in NGT-1.

Figures 2 a—c, 3. *Globigerina galavisi* Bermudez, from *G. mexicana* zone, core sample at 1904.2 m. in NGT-1.

Figure 4. *Globigerina venezuelana* Hedberg, from *G. kugleri/G. primordius* zone, core sample at 1126.5 m. in KKL-2.

Figures 5 a—c. *Globigerina woodi woodi* Jenkins, from *G. kugleri/G. primordius* zone, core sample at 1421.5 m. in KKL-2.

PLATE V

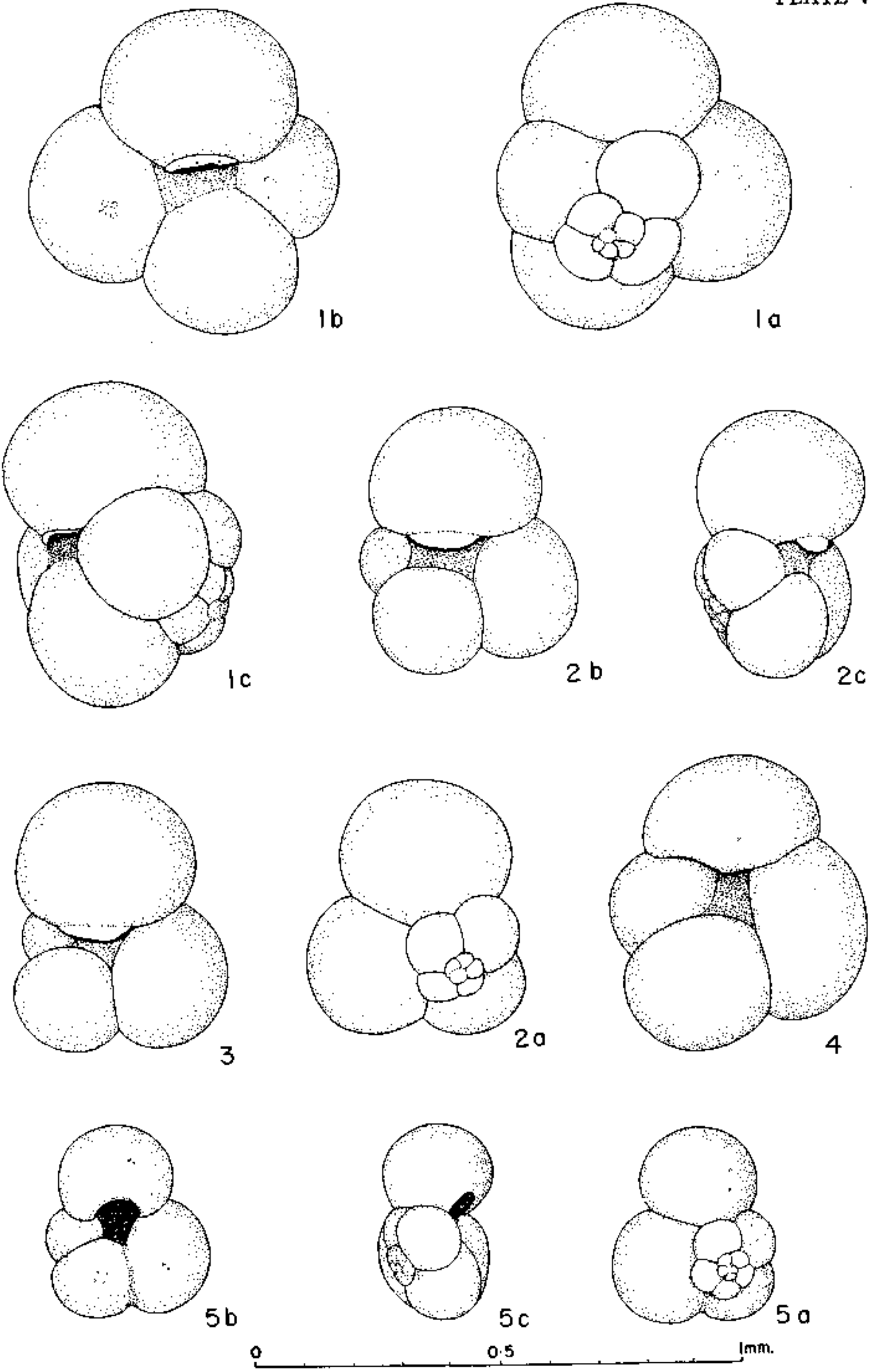


PLATE VI

Figures 1 a—c. *Globigerina venezuelana* HEDBERG, from *G. kugleri/G. primordius* zone, core sample at 1126.5 m. in KKL-2.

Figures 2 a, b, 3 a, b. *Globigerinita dissimilis* (CUSHMAN & BERMUDEZ), from *G. kugleri/G. primordius* zone, core sample at 1126.5 m. in KKL-2.

Figures 4 a—c. *Globigerinita stainforthi* (BOLLI, LOEBLICH & TAPPAN), from *G. kugleri/G. primordius* zone, core sample at 1126.5 m. in KKL-2.

Figures 5 a, b. *Globorotaloides suteri* BOLLI, from a cutting sample at 1463 m. in KKL-1.

PLATE VI

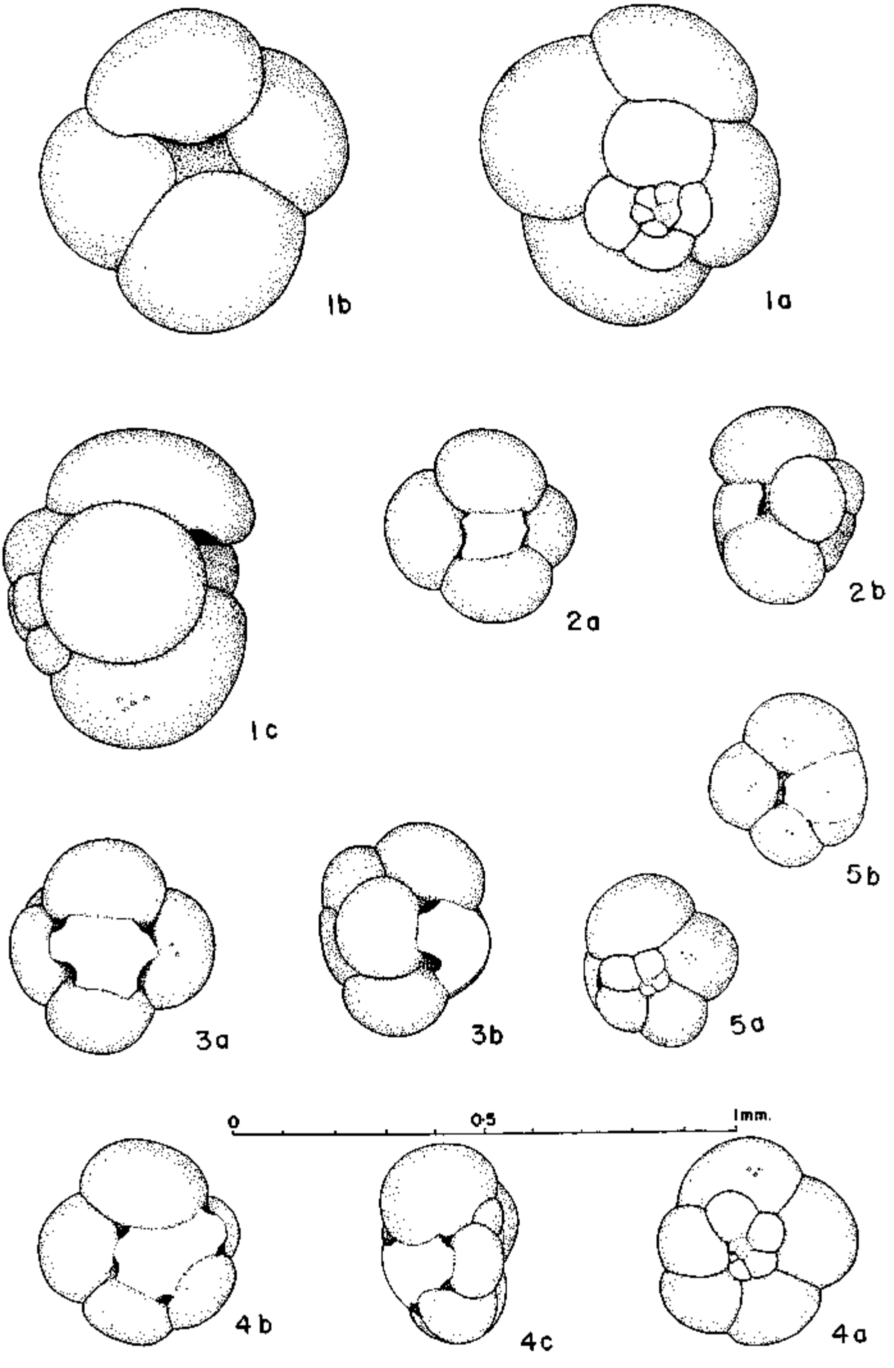


PLATE VII

Figures 1 a, b, 2 a, b. *Globigerinoides primordius* Blow & Banner, from *G. kugleri/G. primordius* zone, core sample at 1421.5 m. in KKL-2.

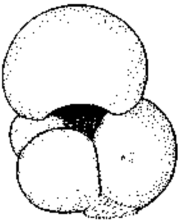
Figures 3 a, b. *Globigerinoides trilobus altiaperturus* Bolli, from core sample at 639 m. in KKL-4.

Figures 4 a, b. *Globigerinoides trilobus trilobus* (Reuss), from core sample at 495 m. in TPD-1.

Figures 5 a, b. *Globigerinoides* cf. *subquadratus* Brönnimann, from core sample at 639 m. in KKL-4.

Figures 6 a, b. *Globoquadrina altispira globosa* Bolli, from the upper part of *G. kugleri/G. primordius* zone, core sample at 1126.5 m. in KKL-2.

PLATE VII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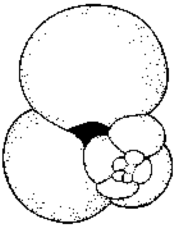
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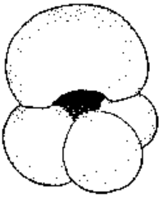
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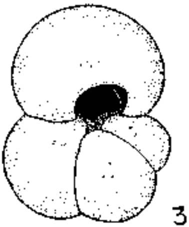
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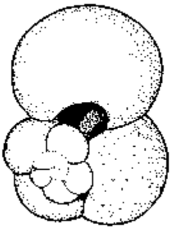
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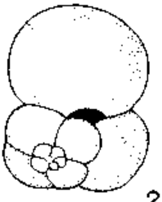
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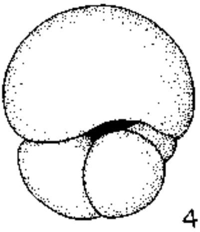
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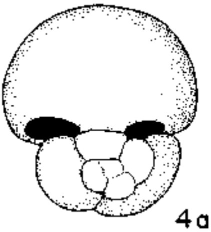
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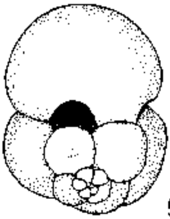
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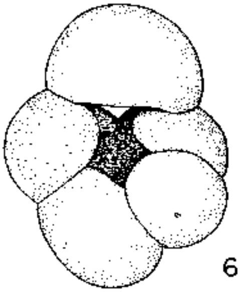
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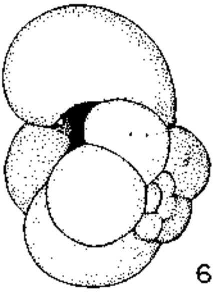
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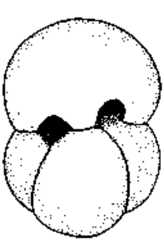
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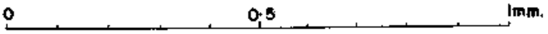


PLATE VIII

Figures 1 a—c. *Globigerinopsis guhai* n. sp., holotype from core sample at 1126.5 m. in KKL-2, upper part of the *G. kugleri/G. primordius* zone.

Figures 2 a—c, 3 a—c *Globigerinopsis guhai* n. sp., paratypes from the same level as the holotype.

Figures 4 a—c. *Globoquadrina praedehiscens* Blow & Banner, from *G. kugleri/G. primordius* zone, core sample at 1126.5 m. in KKL-2.

PLATE VIII

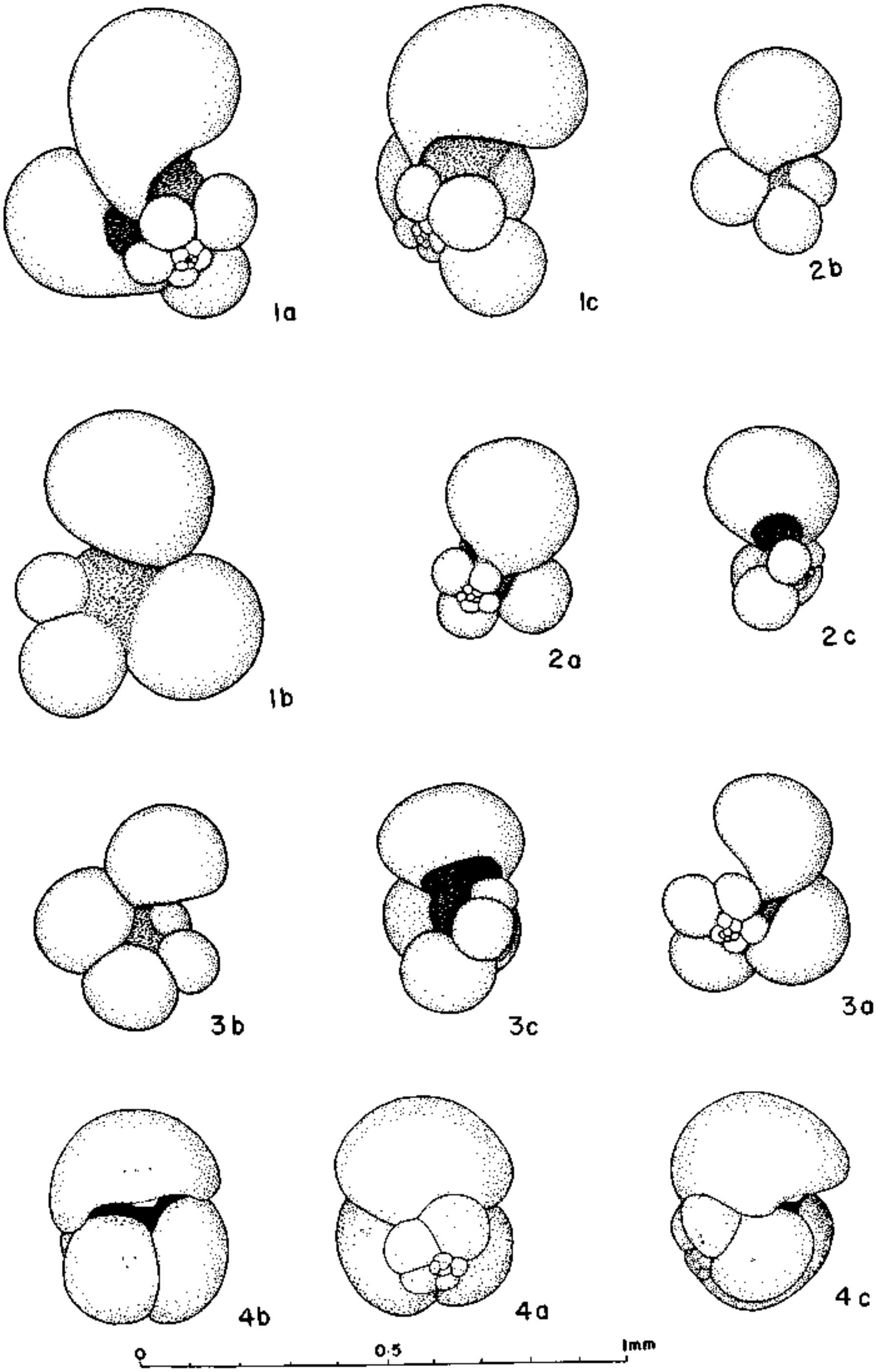


PLATE IX

Figures 1, 2. *Globoquadrina praedehiscens* Blow & Banner, from *G. kugleri/G. primordius* zone, core sample at 1126.5 m. in KKL-2.

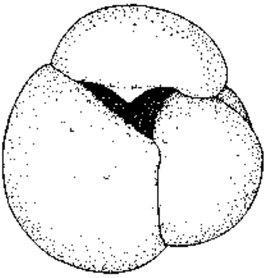
Figures 3, 4 a, b. *Globoquadrina dehiscens* (Chapman, Parr & Collins), from core sample at 495 m. in TPD-1.

Figures 5 a, b. *Globoquadrina* cf. *larmeui* Akers, from *G. angulisuturalis* zone, core sample at 1495.5 m. in KKL-2.

Figures 6 a—c. *Globorotalia peripheroronda* Blow & Banner, from core sample at 495 m. in TPD-1.

Figures 7 a—c. *Globorotalia increbescens* (Bandy), from *G. gortanii* zone, core sample at 1800 m. in NGT-1.

PLATE IX



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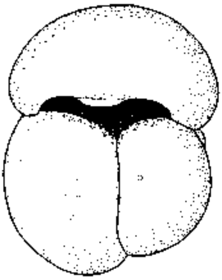

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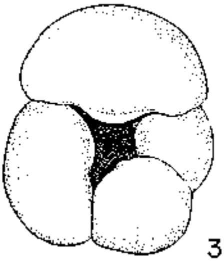

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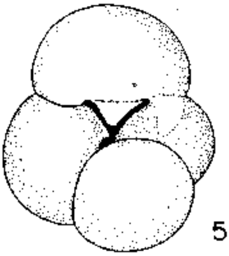

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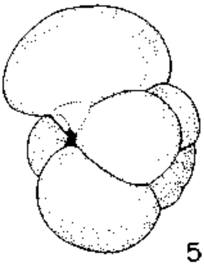

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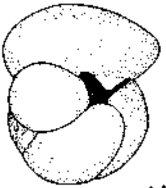

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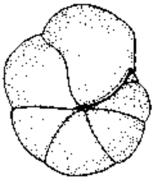

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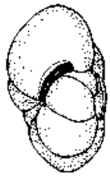

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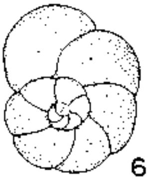

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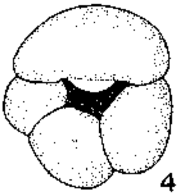

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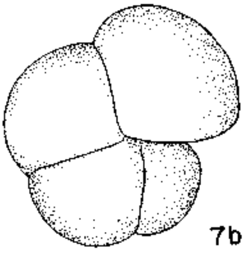

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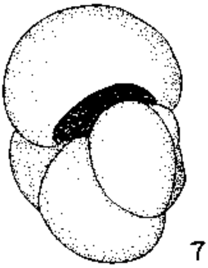

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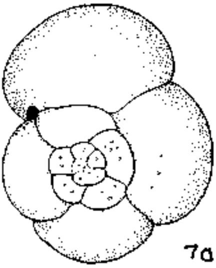

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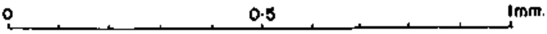


PLATE X

Figures 1 a, b, 2 a, b. *Globorotalia kugleri* BOLLI, from *G. kugleri/G. primordius* zone, core sample at 1126.5 m. in KKL-2.

Figures 3 a, b. *Globorotalia opima nana* Bolli, from *G. sastrii* zone, core sample at 1582 m. in KKL-4.

Figures 4, 5 a—c. *Globorotalia siakensis* (LEROY), from *G. kugleri/G. primordius* zone, core sample at 1126.5 m. in KKL-2.

Figures 6 a—c. *Globorotalia obesa* BOLLI, from *G. kugleri/G. primordius* zone, core sample at 1126.5 m. in KKL-2.

PLATE X

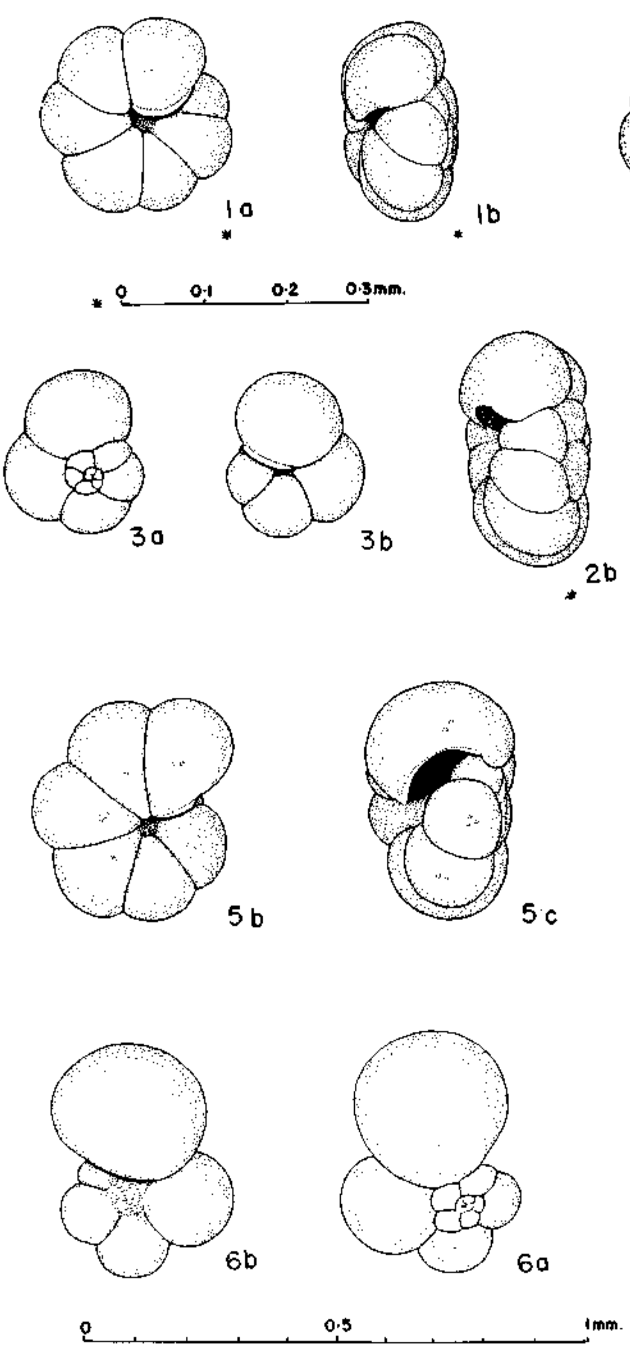


PLATE XI

Figures 1—6. *Globigerapsis mexicana* (CUSHMAN), all from *G. mexicana* zone, core sample at 1904.2 m. in NGT-1, 1—4 juvenile forms with one to two supplementary apertures.

Figures 7 a, b. *Globigerapsis* cf. *tropicalis* BLOW & BANNER, from *G. mexicana* zone, core sample at 1904.2 m. in NGT-1.

Figure 8. *Hantkenina alabamensis* CUSHMAN, from *G. mexicana* zone, core sample at 1904.2 m. in NGT-1.

Figure 9 a, b. *Hantkenina alabamensis* CUSHMAN, from a cutting sample at 1580 m. in KKL-1. A from with twin spines.

PLATE XI

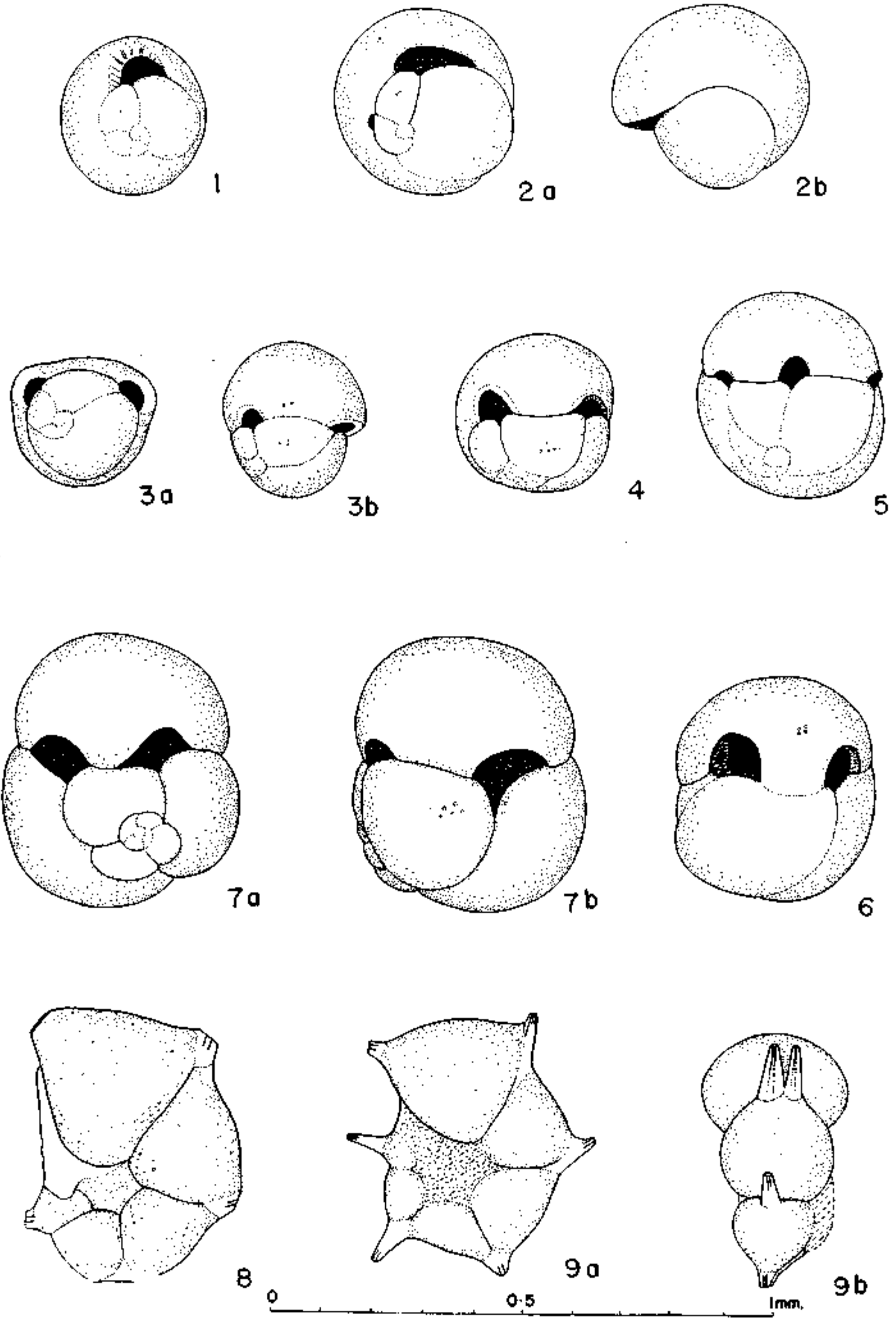


PLATE XII

Figures 1 a, b. *Hantkenina* cf. *thalmanni* Brönnimann, from *G. mexicana* zone, core sample at 1904.2 m. in NGT-1.

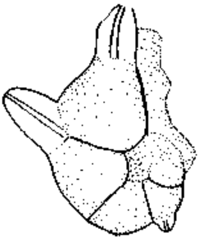
Figure 2. *Hantkenina alabamensis* Cushman, from *G. cerroazulensis* zone in KKL-4.

Figures 3, 4, 5. *Hantkenina trinitatensis* Brönnimann, from *G. mexicana* zone, core sample at 1904.2 m. in NGT-1.

Figures 6, 7, 8. *Hantkenina* sp., from *G. cerroazulensis* zone, core sample at 1716 m. in KKL-4.

Figures 9 a, b, 10. *Hantkenina suprasuturalis* Brönnimann, from *G. mexicana* zone, core sample at 1904.2 m. in NGT-1.

PLATE XII



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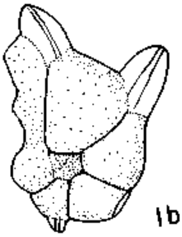

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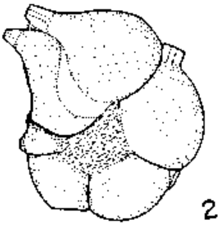

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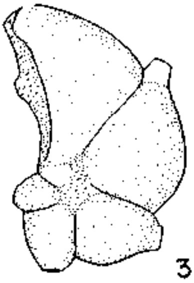

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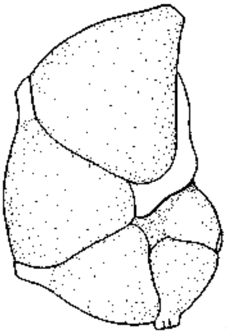

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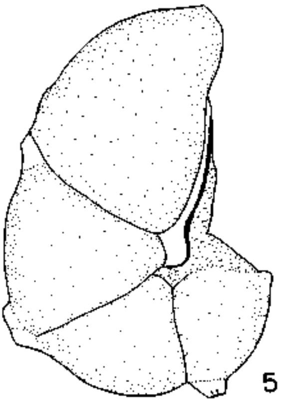

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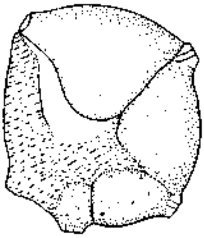

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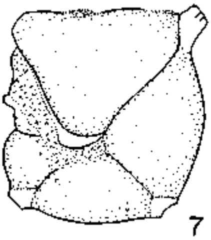

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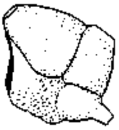

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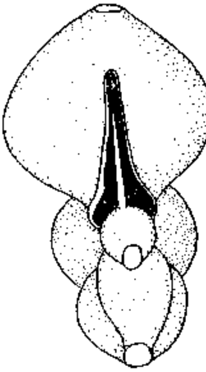

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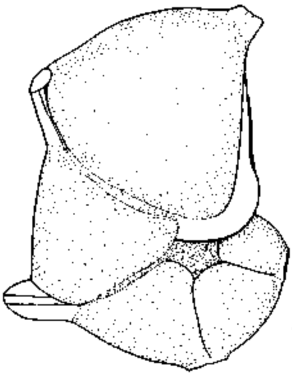

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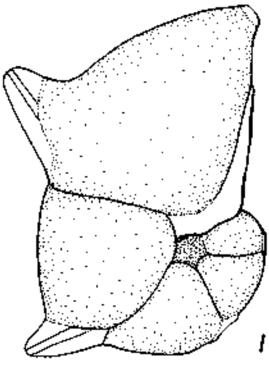

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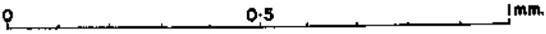


PLATE XIII

Figure 1. *Hantkenina suprasuturalis* BRÖNNIMANN, from *G. mexicana* zone, core sample at 1904.2 m. in NGT-1.

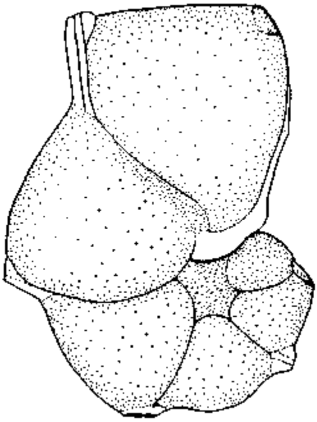
Figures 2, 7. *Cribrohantkenina inflata* (HOWE), from *G. cerroazulensis* zone, core sample at 1690 m. in KKL-4.

Figures 3, 4, 5, 6, 8 a, b. *Cribrohantkenina inflata* (HOWE), from *G. cerroazulensis* zone, all from a core sample at 1716 m. in KKL-4.

Figures 9 a, b. *Pseudohastigerina micra* (COLE), from *G. mexicana* zone, core sample at 1904.2 m. in NGT-1.

Figures 10, 11. *Hantkenina* sp., from *G. cerroazulensis* zone, core sample at 1690 m. in KKL-4, juvenile forms with the spines bending backward.

PLATE XIII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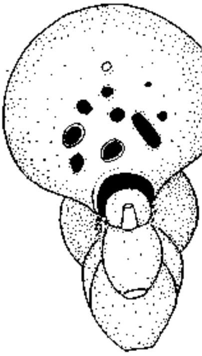
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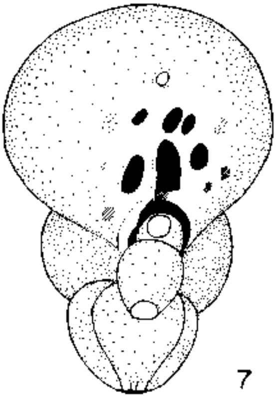
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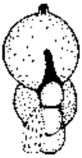
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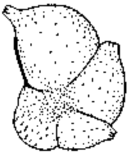
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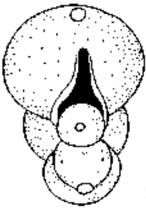
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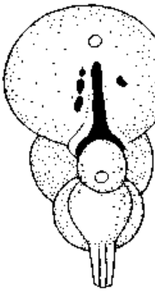
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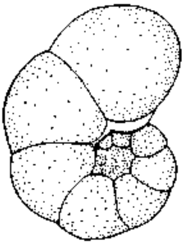
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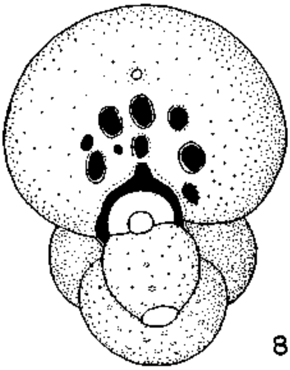
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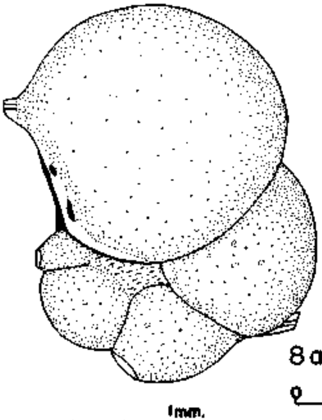
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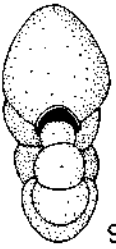
9 b*

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Nannofossils from the Eastern Desert, Egypt
with reference to Maastrichtian Nannofossils from the USSR

By Samir Shafik *) and Herbert Stradner **)

With 50 plates and 7 text-figures

1. Abstract
2. Introduction, General Discussion, Acknowledgements
3. Field Geology
4. Stratigraphy
5. Material Studied and Method of Study
6. Succession of Nannoplankton Assemblages
7. Global Correlation and Results Obtained
8. Special Taxonomic Problems
9. Systematic Paleontology
10. Conclusions
11. Selected References
12. Explanations of Plates

1. Abstract

With a view to the great importance of the Tarawan Chalk formation in the Egyptian stratigraphy its coccolith content has been investigated and is recorded here, whereby we could refer to a sample of similar age from the Dnjepr-Donetz region USSR.

A framework for a nannoplankton-zonation for the early Tertiary of Egypt is submitted. The Tarawan Chalk proves to become younger in age in southern direction. A hiatus is supposed between this formation and the overlying Esna Shale in the Gebel Tarbouli area, although no break in the sedimentation could be observed.

Stratigraphic correlations with various localities abroad are tentatively suggested. Taxonomic problems and some new coccolith-species are discussed on the basis of 50 plates.

2. Introduction, General Discussion, Acknowledgments

One of the two main aspects in connection with the problem of an improved international geological correlation, as proposed by the scientists and the experts of the UNESCO in their meeting in Budapest (September, 1969), is the need for researches, to establish clear documentation, upon which continental and intercontinental correlation can be based.

The purpose of this paper is to present and to record the coccolith contents of the Upper Cretaceous of the Gulf of Suez region, namely Gebel Tarbouli, UAR, refering also to a sample from the USSR (Dnjepr-

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*) UNESCO Postgraduate Training Center for Geology, Geological Survey of Austria, Vienna. (Home University: Univ. of Cairo, Fac. of Science, Dept. of Geology, UAR.)

**) Geological Survey of Austria, Electronmicroscopical Laboratory, Rasumofskygasse 23, A-1031 Vienna, Austria.

Donetz region). In addition a framework of the nannofossil assemblages of the early Tertiary from several sections, cropping out along the western side of both the Gulf of Suez and the Red Sea, is also given.

The coccoliths are tiny scales, secreted by unicellular marine phytoflagellates of the family Coccolithophoridae. They occur either on the surface or embedded in the layer of the mucilage, located just exterior to the cell membrane of the coccolithophorid cell. The coccolithophorids are biflagellate "protists". However, PARKE & ADAMS (1960) and recently PIENAAR (1969) have shown, that a third flagellum (the haptonema) is occasionally found situated between the two flagella of the coccolithophorid cell. Together with diatoms and dinoflagellates, the coccolithophorids form the third group of the autotrophic phytoplankton. Nevertheless COHEN (1965) considered, that species of the coccolithophorids, living in the deep water layers, are probably heterotrophic.

The two-phase life cycle of the coccolithophores produces two types of coccoliths. The holococcoliths represent the motile stage of the life cycle of the coccolithophores. Their skeletal plates are built of elements uniform in size and shape. On the other hand, the non-motile stage produces the heterococcoliths, which are constituted of elements varying in size and shape. Studies on the recent coccolithophores suggest, that the fossil coccoliths represent only the non-motile stage (the heterococcoliths) of the life cycle mainly.

The discoasters are stellate or rosette-like calcareous forms, most probably extinct. They have been found in Cenozoic strata. LECAL (1952) described a recent planktonic protist from the Mediterranean Sea as *Discoaster planctonicus*, the surface of which was covered with many five- and six-rayed stars *). Nevertheless, these organisms are not generally accepted yet as living representatives of the fossil Discoasteridae. The exact systematic position of this group of fossils is still uncertain, hence they are considered here as fossils "incertae sedis".

TAN SIN HOK (1927) was the first, to present the systematics of these forms. He introduced the term "discoaster" as a systematic unit, within his new family of Discoasteridae. SUJKOWSKI (1931) and PAREJAS (1934) described discoasters, but they were using the generic taxon *Actiniscus* EHRENBERG. DEFLANDRE (1950) arranged the Discoasteridae on account of their optical property behaving as single crystals in his new order of the Ortholithae, together with the Thoracosphaeridae and the Braarudosphaeridae. BRAMLETTE and RIEDEL (1954) drew the attention to the stratigraphic significance of these microfossils.

Collectively the term "calcareous nannofossils or calcareous nannoplankton" is applied to coccoliths, discoasters and related minute calcareous fossils. The calcareous nannofossils (nannos = dwarf) are among the typical means by which local, regional as well as transoceanic correlation

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*) BURSA (1964) described discoaster-producing flagellates, which he found in arctic waters and which he named *Discoasteromonas calciferus*.

could be established. Their rapid evolution, especially of many distinctive forms, is now evident. Their planktonic characteristics together with their minute size (generally from 1 to 20 μ in diameter), explains their wide distribution. HAY (1963) noted that "coccoliths settle much more slowly than the tests of planktonic foraminifera ...". However, results of the recent studies by McINTYRE (in press) indicate, that important quantities of the coccoliths do reach the ocean floor directly from the overlying water mass. Rapid sinking is accomplished via fecal pellets of the zooplankton.

The "assemblage" as a group of associated fossils could be used as a valuable stratigraphic indicator with great success especially in the case of the calcareous nannofossils. Moreover, when the state of preservation of a sample is not too perfect, it is easier and more appropriate to recognize an assemblage than a certain species. The one and the same species might be differently recognized and interpreted by different authors. It has been noticed by the present author, that the examination of a sample under the light microscope and the investigation of its carbon replica under the electron transmission microscope shows often apparent differences in the state of fossilization. Again, this represents another difficulty for the exact identification of a certain species, but not so much for the exact recognition of a certain assemblage.

Due to their minute size, the calcareous nannofossils are easily reworked and may appear in younger strata. The use of the assemblage, as recommended by this study, could reduce mistakes, caused by reworking of these tiny fossils. In addition, the problem of reworking could be partly solved, if the first occurence of the species is given the most consideration within the successive assemblages.

The use of the calcareous nannoplankton assemblages, provided that they show an evolutionary trend, could help solving the controversies about the subdivision of some of the stratigraphical units, e. g. Paleocene.

After recognizing well-established assemblages of the calcareous nannofossils for stratigraphical units, it will be possible, to express the probability of a correlation numerically, making use of the large numbers, in which calcareous nannoplankton occurs. This could be achieved by using the concurrent-rangezones of the different members of the successive assemblages, thus applying the probability theory to the biostratigraphic correlation.

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3. Field Geology

The Tarbouli section, the main of this paper, was sampled by the author during summer 1969, as the latest part of his project of studying and sampling most of the Upper Cretaceous-Lower Tertiary deposits cropping out in the Gulf of Suez Region and the Red Sea Coast, Egypt. As far as the writer is aware, nothing has been published up till now about Gebel Tarbouli. It represents the northern most tip of the so called Ash El-Mellaha range sediments. It stands as a topographic cone about 100 m above the surrounding plains. It is separated from the main body of the Ash El-Mellaha sediments by some small dissected wadies. Apparently it is bounded from its eastern and western sides by two main normal faults. Some minor faults, having a general NNW-SSE trend, were observed by the author within the Gebel Tarbouli itself.

4. Stratigraphy

The Upper Cretaceous-Lower Tertiary deposits of the western side of both the Gulf of Suez and the Red Sea are found by the author as isolated hills representing structurally basinlike hills. They are up to 565 meters thick in the Gebel Duwi, and consist of six easily recognizable lithostratigraphic units (from below) the Nubia Formation, the Quesseir (variegated) Shale, the Duwi (Phosphate) Formation, the Dakhla Shale, the Tarawan Chalk and the Esna Shale. They are often caped by the Thebes Formation (Lower Eocene). The formational names given here are in general accordance with those given by Said (1962). The lower three units sampled from many localities, show that they are nonfossiliferous, mainly as far as the microscopic fossils are concerned. The other three formations are abundantly fossiliferous.

Though the lithology of the Tarawan Chalk varies in different places from marl, marly limestone to pure chalk, its constant position between the two shale formations (namely the Dakhla Shale below and the Esna Shale above) and its wide geographical distribution, from the Kharga, Dakhla, and Abu Mungar oases in the Western Desert, to the Esna-Idfu region in the Nile Valley, to the Quesseir Safaga and Ash El-Mellaha at the Red Sea Coast and Gulf of Suez Region, make it one of the best stratigraphic markers in the Upper Cretaceous-Lower Tertiary of Egypt. Due to the great importance of the Tarawan Chalk in the Egyptian stratigraphy, the main part of this paper is devoted to the documentation of its coccolith assemblage.

The Tarawan Chalk at the Gebel Tarbouli constitutes nearly the lower half of the section, its base being not exposed. The exposed part of the Tarawan Chalk in the studied area is 48,60 meters thick. Its lithology is mainly marl to marly limestone. The contact between the Tarawan Chalk and the underlying Dakhla Shale, as exposed in the south at Ash El-Mellaha range, itself is sharp, while less conspicuous contact-conditions could be observed at the boundary between the Tarawan Chalk and the overlying Esna Shale in the Gebel Tarbouli. Amongst the megafossils found in this rock unit in the area under consideration, *Pecten farafrensis* ZITTEL, is abundant.

The Esna Shale at Gebel Tarbouli attains its minimum thickness, 10 m; it is a clayey shale or shale to marl with some salt and gypsum as veinlets. The Esna Shale at Tarbouli section grades downwards and upwards into the Tarawan Chalk and into the Thebes Formation respectively.

5. Material studied and Method of Study

The coccoliths presented and photographed in this paper are from Gebel Tarbouli, Gulf of Suez Region, Egypt (Lat. 27° 55′ N and Long. 33° 5′ E); and from the Maastrichtian of the USSR *).

Text-figure 1 represents a location map of the Tarbouli section and also of most of the Upper Cretaceous-Lower Tertiary sections of the Gulf of Suez Region and the Red Sea Coast. A columnar section of the Gebel Tarbouli is given by text-figure 2.

The method of preparation and study of the coccoliths is the same as given by ADAMIKER in STRADNER et al (1968), with some slight modifications when required. The negatives of the microphotographs belonging to this study are deposited in the ELMI laboratory at the Geological Survey of Austria, Vienna.

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*) The Dnjepr-Donetz region (Sinev-Shuravnin drilling, depth 278/279 m.).

Fig.1

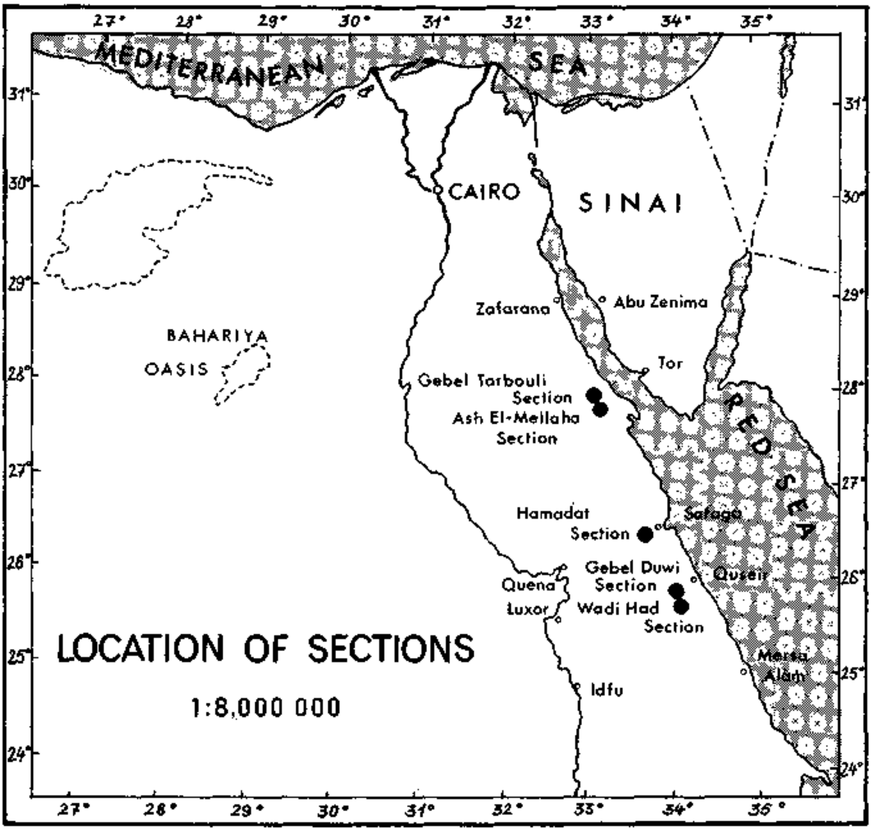

Fig. 1: Orientation map showing the geographic position of the studied sections in Egypt.

6. Succession of Nannoplankton Assemblages

The nannoplankton assemblage of the Tarawan Chalk of the Tarbouli section, Egypt, and those from the Dnjepr-Donetz region (Sinev-Shuravnin drilling, depth 278/279 m). are given below. The assemblages recorded here for the two localities are found to be typical for the Upper Maastrichtian; their correlation is possible.

The following species are found in the Maastrichtian of both the Tarbouli section, Gulf of Suez, Egypt, and of the Dnjepr-Donetz region (Sinev-Shuravnin drilling, depth 278/279 m.):

Arkhangelskiella cymbiformis VEKSHINA
Biscutum constans (GORKA) BLACK
Biscutum testudinarium BLACK
Eiffellithus trabeculatus (GORKA) REINHARDT & GORKA

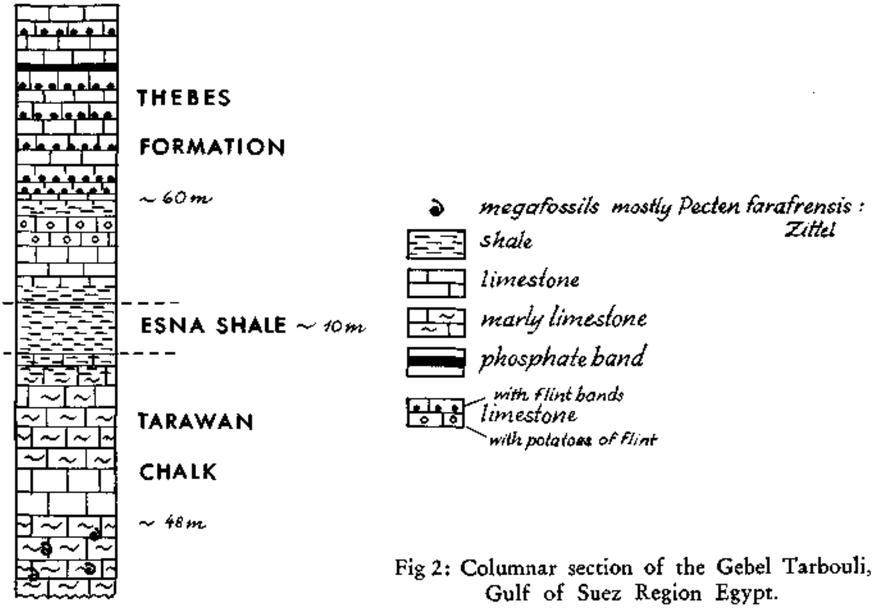

Fig 2: Columnar section of the Gebel Tarbouli, Gulf of Suez Region Egypt.

Kamptnerius magnificus Deflandre
Lithraphidites quadratus Bramlette & Martini
Micula staurophora (Gardet) Stradner
Polypodorhabdus crenulatus (Bramlette & Martini) nov. comb.
Prediscosphaera honjoi Bukry
Reinhardtites mirabilis Perch-Nielsen
Rhagodiscus plebeius Perch-Nielsen
Vekshinella crux (Deflandre & Fert) nov. comb.
Watznaueria barnesae (Black) Perch-Nielsen
Zygodiscus spiralis Bramlette & Martini
Zygolithus erectus Deflandre

The following is a list of the coccoliths encountered only in the Tarawan Chalk of the Tarbouli section and not in the Russian sample:

Corollithion exiguum Stradner
Cribrosphaerella numerosa (Gorka) Reinhardt & Gorka
Cylindralithus serratus Bramlette & Martini
Kamptnerius punctatus Stradner
Podorhabdus dietzmanni (Reinhardt) Reinhardt
Polypodorhabdus pienaari nov. spec.
Polypodorhabdus schizobrachiatus (Gartner) nov. comb.
Pontosphaera multicarinata (Gartner) nov. comb.
Rhabdolithina splendens (Deflandre) Reinhardt
Stephanolithion laffitei Noel

Vekshinella elliptica GARTNER
Zygodiscus tarboulensis nov. spec.

The following species are found only in the Russian material and not in the Egyptian samples:

Ahmuellerella octoradiata (GORKA) REINHARDT
Eiffellithus anceps (GORKA) REINHARDT & GORKA
Markalius inversus (DEFLANDRE) BRAMLETTE & MARTINI
Nephrolithus frequens GORKA
Prediscosphaera stoveri PERCH-NIELSEN
Vekshinella cruciata (NOEL) nov. comb.
Zygodiscus acanthus (REINHARDT) REINHARDT
Zygolithus cf. *diplogrammus* DEFLANDRE

A study of the planktonic foraminiferal content of the Tarawan Chalk of the Gebel Tarbouli reveals, that the fossils are to be located within the vertical limits of the *Abathomphalus mayoroensis* zone. This result ascertains the age of the Tarawan Chalk of the Gebel Tarbouli to be Upper Maastrichtian.

In an attempt to correlate the nannoplankton assemblages of both the Esna Shale and the Tarawan Chalk of Gebel Tarbouli with those of the same two formations exposed at the Gulf of Suez region and the Red Sea coast, it was possible to recognize some nannoplankton zones; however, the zonation outlined below is merely a framework; the details of such a zonation should be the subject of further studies.

The assemblages recognized are the following:

Top:

a) *DISCOASTER BINODOSUS ZONE:* the definition of this zone as given by HAY et al. (1967) is followed here. The upper half of the Esna Shale of the Gebel Tarbouli, and only the uppermost part of the same formation of the Hamraween section and the Gebel Duwi belong to this zone. Among the nannoplankton species found in this zone are the following:

Discoaster binodosus MARTINI, *Discoaster mediosus* BRAMLETTE & SULLIVAN, *Marthasterites tribrachiatus* (BRAMLETTE & RIEDEL) DEFLANDRE, *Discoaster diastypus* BRAMLETTE & SULLIVAN and *Coccolithus* spp.

This zone is characterized in the Egyptian sections by the flood of *Discoaster binodosus* MARTINI and by the absence of both the *Marthasterites contortus* (STRADNER) DEFLANDRE and *M. bramlettei* BRÖNNIMANN & STRADNER.

b) *MARTHASTERITES CONTORTUS ZONE:* the author follows the definition of this zone given by HAY (1964 b). The common species are: *Marthasterites contortus* (STRADNER) DEFLANDRE, *Marthasterites bramlettei* BRÖNNIMANN & STRADNER, *Discoaster binodosus* MARTINI, *Discoaster* *diastypus* BRAMLETTE & SULLIVAN, *Discoaster multiradiatus* BRAMLETTE & SULLIVAN and *Discoaster mediosus* BRAMLETTE & SULLIVAN.

This zone is present in the Esna Shale of Gebel Duwi, and Gebel Hamraween. The lowermost part of the Esna Shale of Hamadat section and Gebel Tarbouli also belong to this zone.

c) *MARTHASTERITES SPINEUS ZONE:* this zone is recognized for the first time here and is defined by the interval between the first occurrence of *Marthasterites spineus* nov. spec. and the first occurrence of *Marthasterites bramlettei* BRÖNNIMANN & STRADNER. Common species are: *Marthasterites spineus* nov. spec., *Discoaster diastypus* BRAMLETTE & SULLIVAN and *Discoaster multiradiatus* BRAMLETTE & RIEDEL.

This zone has been observed in the Esna Shale of the Wadi Had section (south Gebel Duwi) and in the same formation of the Ash El-Mellaha range sediments. It is worth to mention that these two localities are almost 200 km distant, as shown in text-figure 1. This zone has not been found in the Gebel Tarbouli Section.

Type section: The Ash El-Mellaha range Esna shale, Western Red Sea Coast, Egypt.

d) *DISCOASTER MULTIRADIATUS ZONE:* this zone is defined by the vertical interval between the first occurence of *Discoaster multiradiatus* BRAMLETTE & RIEDEL and first occurrence of *Marthasterites spineus* nov. spec. This zone is readily recognizeable in most of the sections of the Red Sea coast. It is well-developed in the Hamraween section and in Gebel Duwi in the Esna shale, it is absent in the Tarbouli section. Together with *Discoaster multiradiatus* BRAMLETTE & RIEDEL, the following nannofossil species are present: *Discoaster delicatus* BRAMLETTE & SULLIVAN, *D. lenticularis* BRAMLETTE & SULLIVAN, *D. limbatus* BRAMLETTE & SULLIVAN, *D. mediosus* BRAMLETTE & SULLIVAN and *Heliolithus riedeli* BRAMLETTE & SULLIVAN.

e) *HELIOLITHUS RIEDELI ZONE:* the range of this zone extends from the first occurrence of *Heliolithus riedeli* BRAMLETTE & SULLIVAN until the first occurrence of *Discoaster multiradiatus* BRAMLETTE & RIEDEL. This zone is well-developed in the Tarawan Chalk of the Gebel Duwi and it is absent in the Tarbouli section. The common nannoplankton species of this zone are: *Heliolithus riedeli* BRAMLETTE & SULLIVAN, *Discoaster delicatus* BRAMLETTE & SULLIVAN, *Discoaster limbatus* BRAMLETTE & SULLIVAN and *Discoaster helianthus* BRAMLETTE & SULLIVAN.

Though the above-mentioned nannoplankton zonation is preliminary, the author ventures to conclude, that the lithostratigraphic units assigned to the Upper Cretaceous-Lower Tertiary of the Gulf of Suez region and the Red Sea coast become younger toward the south. This conclusion is clearly proved by the nannoplankton content of the Tarawan Chalk rock unit, being of Upper Maastrichtian in the north at Gebel Tarbouli and of Lower Landenian in the south at Gebel Duwi. This result is also confirmed in other parts of Egypt by authors working on foraminifera (e. g. SAID [1961]; SHAFIK [1968], Msc. THESIS).

7. Global correlation and results obtained

Among the calcareous nannoplankton zones of New Zealand given by EDWARDS (1970), is the *Nephrolites frequens* zone, which according to him is of Maastrichtian age. Unfortunately, this zone, as shown in his table, lies vertically between unsuitable facies. The *Nephrolithus frequens* zone was found well developed in the Russian material, while no single specimen of this species could be found in the Egyptian samples. These results are found to be in harmony with the findings of MARTINI (1970), who pointed out that the two of the latest Maastrichtian nannofossil index species, *Tetralithus murus* and *Nephrolithus frequens,* are climatically restricted. *N. frequens* occurs towards the poles, its vertical range is reduced towards the equator. Contrarily *T. murus* occurs towards the equator, its stratigraphic range is diminishing towards the higher latitudes. Therefore, it seems, that the Russian locality falls geographically within the *N. frequens* domains, while the Egyptian section lies within the low latitude region of *T. murus.*

It is worthy to mention, that in most of the Maastrichtian samples of Austria the *N. frequens* is missing, however, it is found frequently reworked in the Paleocene of Reingruberhöhe (Lower Austria). It might be concluded that *Nephrolithus frequens* was probably occuring in the latitude of Austria too.

The oldest known species of the genus *Pontosphaera* was found by KAMPTNER (1963) in the Eocene (Pacific ocean). However one species of this genus ist recorded by the present authors in the Upper Maastrichtian of the Gulf of Suez Region, Egypt, by use of the electron microscope. Moreover, checking the same sample by the light microscope reveals again this genus being represented by one species (Pontosphaera multicarinata [GARTNER] nov. comb.). Therefore it could be concluded, that *Pontosphaera* may have its first occurrence at least in the Upper Maastrichtian.

BUKRY (1970) established the *Zygodiscus macleodae* zone from the Lower Campanian of Texas. He did not find this species in his overlying *Prediscosphaera germanica* zone. Therefore and owing to the apparent differences between these two zones, he concluded, that there is an unstudied interval inbetween his two zones, not represented in his samples. In the Egyptian Maastrichtian *Zygodiscus tarboulensis* nov. spec. could be discovered, which is a close relative to the abovementioned *Z. macleodae* BUKRY.

Though a gradational contact is observed by the author between the Tarawan Chalk and the overlying Esna Shale at the Gebel Tarbouli, thus suggesting a continuous sedimentation, by means of the nannofossils a hiatus along this contact is indicated. This hiatus represents the missing of the entire Danian and most of the Landenian, therefore, indicating a great interruption in sedimentation. This disconformity may explain the unusually reduced thickness of the Esna Shale rock unit (10 m.) at the Gebel Tarbouli.

The electron transmission microscope investigation of the Egyptian coccoliths dealt with in this study shows, that they had suffered some sort of dissolution or corrosion, while the Russian coccoliths seem to be somewhat recrystalised. However it is not impossible to compare both the Egyptian and the Russian coccoliths, though they show extremes as to the state of their preservation. Many coccolith species are common to the Egyptian and the Russian materials. This indicates that the two localities are easily correlated by means of their coccolith contents, regardless their wide geographic separation.

8. Special taxonomic problems

The taxonomy of the coccolithophoridae seems to be in a state of confusion. It is well known that the systematic classification of the coccolithophoridae is based mainly on the structure and the morphology of the hard parts (coccoliths). Therefore, a detailed study of the structure of the coccoliths is necessary. However, inspite of the fact that the analysis of the ultrastructures of the coccoliths is beyond the resolution power of the light microscope, many workers have utilized the light microscope in their study and description of the coccoliths. On the other hand, other workers have made use of the much higher degree of resolution of the electron microscope. It is quite clear that the results obtained by these two groups of workers are not easily to be compared. PERCH-NIELSEN (1967) introduced a method by which the same coccolith can be studied using a light microscope and subsequently by an electron microscope. Unfortunately, this method has not gained much support among most of the workers yet.

The lack of a continuous contact between the numerous workers in the different countries increases the difficulties met with in classifying the coccolithophoridae systematically.

The coccolithophoridae possess some of the characters of both plants and animals. Botanical and zoological nomenclature have been used with almost equal frequency for the coccoliths by different scientists. LOEBLICH & TAPPAN (1966) in their "Annotated index and bibliography of the calcareous nannoplankton" have solved many of the objective nomenclatural problems.

The coccolith dimorphism could be also a problem in the systematics of the coccolithophoridae. One form possesses two types of coccoliths on one cell (e. g. *Acanthoica*); when found as fossils, these would be given two different names. More work should be done by the neontologists on the coccolith morphology, the coccolith dimorphism and the life cycles of the living representatives of the coccolithophoridae.

A given coccolith has a different structural pattern in the distal and proximal view. In the electron microscope study the erection of a new genus or species is based often on the description of only one view of a coccolith. In some cases both the distal and the proximal view of the same coccolith have been described by different authors as two different species or even genera. This could be avoided firstly by studying the coccolith in a liquid medium (silicone oil) using the light microscope to recognise its two views, and then using the method given by PERCH-NIELSEN (1967) for studying the same coccolith, using the light microscope followed by the electron microscope for the two views of the coccolith.

The left-right reversed microphotographs of the nannofossils given by a few workers, could also add to the confusion as to the recognition of the nannofossils and hence their systematics.

9. Systematic Paleontology

A detailed description of all coccoliths and discoasters found in the Maastrichtian and Paleogene of Egypt would go beyond the scope of this paper, which as the result of the authors' part-time occupation with these samples during the 1969/70 UNESCO Postgraduate Training Course on Geology can only be considered as an initial study, no more.

The following short comments and the selected synonymy therefore are rather fragmentary: a small plattform only for continued future work on these sections, on a broader scale, as we hope; and maybe some help for those of our younger colleagues, who just start working on similar samples.

Ahmuellerella octoradiata (GORKA) REINHARDT

(Plate 23, fig. 1—4)

1957 GORKA, p. 259, pl. 4, fig. 10. *Discolithus octoradiatus.*
1964 REINHARDT, p. 751, pl. 2, fig. 6. *Ahmuellerella limbitenuis.*
1967 REINHARDT, p. 166, Abb. 1, Abb. 7: 1, 2, 3. *Ahmuellerella octoradiata.*
1969 BUKRY, p. 58, pl. 33, figs. 5—7. *Vagalapilla octoradiata.*

Comments: Biserial crossbars, which are diverging along the median suture from the centre to the rim.

Central cross not in all specimens exactly in axial direction.

Closely related to the species of the genera *Vekshinella* and *Reinhardtites.*

Arkhangelskiella cymbiformis VEKSHINA

(Plate 5—7)

1912 ARKHANGELSKY, pl. 6, fig. 24. *Coccolith of uncertain affinity.*
1959 VEKSHINA, p. 66, pl. 2, figs. 3 a, 3 b.
1963 STRADNER, p. 170, pl. 1, figs. 4 a, 4 b.
1965 REINHARDT, p. 31, pl. 2, fig. 6.
1966 REINHARDT, p. 31, pl. 6, figs. 1—3; pl. 22, figs. 14—19.
1969 BUKRY, p. 21, pl. 1, figs. 1—3.

Comments: Distal and proximal shield subdivided by a marginal groove into two tiers each (see pl. 6, fig. 2). Central area with axial sutures on the distal side and axial plus diagonal sutures on the proximal side. Perforations of central area sometimes transversed by a septum (pl. 5, fig. 3).

Central area more subject to recrystallisation than the shields.

Biscutum constans (GORKA) BLACK

(Plate 2)

1957 GORKA, p. 279, pl. 4, fig. 7. *Discolithus constans.*
1967 BLACK, p. 139.
1968 PERCH-NIELSEN, p. 78, pl. 27, figs. 1—11, text-fig. 39.

Comments: Those elements of the distal and the proximal shield, which lie in direction of the main axis of the elliptical shields, are wider than those lying in direction of the transverse axis.

Centre of proximal side with granulae, which could be proximal ends of wall elements lining the crater of the distal side.

Crooked sutures of the distal shield suggest the existence of an intermediary crystal-ring.

Biscutum testudinarium BLACK

(Plate 3, figs. 1, 2; plate 4, fig. 1)

1959 BLACK, in BLACK & BARNES, p. 325, pl. 10, fig. 1.
1966 REINHARDT, p. 30, pl. 19, fig. 1.
1968 STRADNER, in STRADNER, ADAMIKER & MARESCH, p. 29, pls. 11—12.
1969 BUKRY, p. 28, pl. 8, figs. 7—12.

Comments: Coccoliths circular or subcircular, with shield elements of almost identical width. An internal view of a fragmentary coccosphere (pl. 4, fig. 1) shows the overlapping of adjacent coccoliths. The number of coccoliths in a coccosphere seems to exceed 24.

Corollithion exiguum STRADNER

(Plate 46, figs. 1—4)

1961 STRADNER, p. 83, text-figs. 58—61.
1964 BRAMLETTE & MARTINI, p. 308, pl. 5, figs. 8, 9.
1966 MARESCH, p. 381, pl. 3, fig. 4.
1968 GARTNER, p. 35, pl. 10, fig. 26.
1969 BUKRY, p. 40—41, pl. 18, fig. 12; pl. 19, fig. 1.

Comments: Rim consisting of imbricating crystal plates, which are aligned along the hexagonal outline of the rim and are slightly slanted. Central sixrayed structure with or without knob.

Corollithion rhombicum (STRADNER & ADAMIKER) BUKRY

(Plate 47, fig. 3)

1966 STRADNER & ADAMIKER, p. 339, pl. 2, fig. 1, text-figs. 5—7. *Zygolithus rhombicus.*
1969 BUKRY, p. 41, pl. 19, figs. 2—4.

Comments: Only a single specimen of this species was found in the Upper Maastrichtian Chalk of Tarbouli section, Egypt. *C. rhombicum* was not met with in the Russian material studied.

Cribrosphaera laughtoni (Black) Bukry

(Plate 30, figs. 1—4; plate 31, figs. 1—4)

1964 Black, p. 313 pl. 53, figs. 1, 2. *Favocentrum laughtoni.*
1969 Bukry, p. 45, pl. 23, figs. 1—9.

Comments: This species differs from the rather similar *Cribrosphaera ehrenbergi* Arkhangelskii by "the absence of a regular set of throughgoing perforations" (Bukry). In the USSR material intermediate forms with some pores between the crystal triplets could be found (pl. 30). Secondary crystal growth might account for the closing of the pores in some materials.

Cribrosphaera numerosa (Gorka) Reinhardt & Gorka

(Plate 32, figs. 1, 2)

1957 Gorka, p. 257, pl. 4, fig. 5. *Discolithus numerosus.*
1967 Reinhardt & Gorka, p. 243, pl. 33, fig. 2, text-fig. 1.

Comments: Central area perforated by hexagonal pores between a grid of crystaltriplets. The arrangement of pores and crystal structures is in quincunx pattern.

Found in the Tarbouli Chalk, Egypt, where nannofossils are not overcalcified.

Cylindralithus serratus Bramlette & Martini

(Plate 45, figs. 1—4)

1964 Bramlette & Martini, p. 310, pl. 5, figs. 18—20.
1966 Stover, p. 141, pl. 4, figs. 31—33. *C. crassus.*
1968 Gartner, p. 47, pl. 10, fig. 9.
1969 Bukry, p. 43, pl. 20, figs. 11, 12.

Comments: In axial view two rings with different diameters can be discerned, one having the crystal elements inclined clockwise, the other counter-clockwise (pl. 45, fig. 1). One specimen (pl. 45, fig. 2), which is tentatively assigned here, has something like a reticulate membrane filling the central window. Not present in USSR material, but found in Tarbouli, Egypt.

Eiffellithus anceps (Gorka) Reinhardt & Gorka

(Plate 44, figs. 1—4)

1957 Gorka, p. 252, pl. 3, fig. 4. *Discolithus anceps.*
1965 Reinhardt, p. 38, pl. 8, fig. 2; pl. 11, fig. 3 a, b, text-fig. 19. *Eiffellithus turriseiffeli inturratus.*
1967 Reinhardt & Gorka, p. 251, pl. 31, figs. 15, 16, text-fig. 6.

Comments: Elliptical rim composed of up to 70 dextrally imbricate elements. Inner cycle consisting of heavy blocks, which are readily recrystallized (compare pl. 42, fig. 1 and fig. 3).

X-shaped crossbars composed of two elements of equal size.

Eiffellithus trabeculatus (GORKA) REINHARDT & GORKA

(Plate 43, fig. 2)

1957 GORKA, p. 255, pl. 3, fig. 9. *Discolithus trabeculatus.*
1966 REINHARDT, p. 39, pl. 19, fig. 2. *Eiffellithus testaceus.*
1966 STOVER, p. 142, pl. 2, figs. 11, 12. *Discolithus disgregatus.*
1969 BUKRY, p. 49, pl. 27, figs. 1—4. *Chiastozygus disgregatus.*

Comments: Elliptical rim composed of up to 40 dextrally imbricate elements. Two of the diagonal crossbars do not meet at the centre, but are offset. The inner cycle of rim elements is flat and lining the inner wall of the rim.

Kamptnerius magnificus DEFLANDRE

(Plate 8—10, 11, fig. 1)

1959 DEFLANDRE, p. 135, pl. 1, figs. 1—4.
1968 GARTNER, p. 39, pl. 2, figs. 1—2.
1968 PERCH-NIELSEN, p. 41, pl. 6, figs. 1—3, 5.
1969 BUKRY, p. 25, pl. 5, figs. 7—9.

Comments: Large elliptical coccoliths with flaring asymmetric outer rim, a derivate of the distal shield. The width of the flange is rather variable, as shown by pl. 8, fig. 1 and pl. 11, fig. 1. The proximal side of the central area is subdivided by a double ridge of crystals along the main axis. In some specimens the central area is open, the elongate slot lying in the direction of main axis (pl. 9).

Kamptnerius percivalii BUKRY

(Plate 11, fig. 2)

1969 BUKRY, p. 25, pl. 6, figs. 1—3.

Comments: Only poorly preserved specimen encountered. The arrangement of the pores in the central area corresponds to *K. percivalii* rather than to *K. punctatus.*

Lithraphidites quadratus BRAMLETTE & MARTINI

(Plate 49)

1964 BRAMLETTE & MARTINI, p. 310, pl. 6, figs. 16—17; pl. 7, fig. 8.
1968 GARTNER, p. 43, pl. 2, fig. 3; pl. 3, fig. 3; pl. 5, figs. 1, 2; pl. 6, fig. 9.

Comments: Similar to *L. grossopectinatus* BUKRY the four keels consist of two closely appressed lamellae. As indicated by GARTNER the four keels may differ in their dimensions (pl. 49, fig. 1).

Markalius inversus (Deflandre) Bramlette & Martini

(Plate 3, figs. 3, 4)

1954 Deflandre, in Deflandre & Fert, p. 150, pl. 9, figs. 4—5. *Cyclococcolithus leptoporus var. inversus.*
1964 Bramlette & Martini, p. 302, pl. 2, figs. 4—9.
1968 Perch-Nielsen, p. 72, pl. 24, figs. 1—8; pl. 25, fig. 1.

Comments: Circular coccoliths with 2 shields consisting of about 30 elements. The inner part of the deep crater of the distal side is lined with flat crystal plates in conical arrangement.

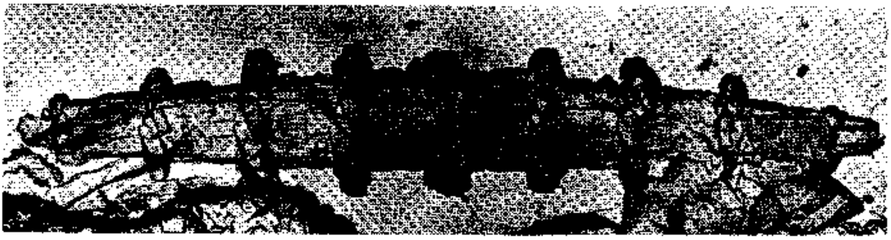

Fig. 3: *Microhabdulus belgicus* Hay. Magnification appr. × 12.500. Gebel Tarbouli, Egypt.

Microhabdulus belgicus Hay

(Text-fig. 3)

1963 Hay, p. 95, p. 95, pl. 1.
1963 Deflandre, p. 3486, figs. 12—18. *M. margaritatus.*
1963 Stradner, p. 11, pl. 4, fig. 13. *M. nodosus.*
1968 Gartner, p. 44, pl. 6, fig. 13.
1969 Bukry, p. 66, pl. 39, figs. 9—11.

Comments: Elongate rod, tapering on both ends, with evenly spaced cycles of subrhomboidal nodes.

The rare specimen from Tarbouli, Egypt, has both ends intact.

Micula staurophora (Gardet) Stradner

(Plate 50)

1955 Gardet, p. 534, pl. 10, fig. 96. *Discoaster staurophorus.*
1959 Vekshina, p. 71, pl. 1, fig. 6. *Micula decussata.*
1963 Stradner, p. 8, fig. 12 a—c. *Micula staurophora.*
1964 Bramlette & Martini, p. 318, pl. 6, figs. 7—11.
1968 Gartner, p. 47, pl. 2, figs. 5—8; pl. 4, fig. 18; pl. 9, figs. 18—20; etc. *M. decussata.*
1969 Bukry, p. 67, pl. 40, figs. 5—6. *M. decussata.*

Comments: Six-sided cubes with concave faces. When well preserved and after suitable metal-shadowing the concave craters reveal some ultrastructural details. Only one size of microcrystals is used to build up the entire fossil, thus indicating that Micula might be a "holoccolith" (?).

In older literature only one half of *Micula* was shown, due to difficulties in interpreting its real structure with the light microscope.

Nephrolithus frequens GORKA

(Plate 28, 29)

1957 GORKA, p. 263, pl. 5, fig. 7.
1968 PERCH-NIELSEN, p. 56, pl. 7, figs. 12—14; pl. 18, figs. 1—9.
1970 MARTINI, pp. 1242—1243.

Comments: Coccoliths kidney-shaped. Very small specimes are elliptical (pl. 29, fig. 1). The central area is filled with from 2 to 15 rings of granulae with a throughgoing pore.

In agreement with MARTINI's regional distribution charts *N. frequens* was found only in the high latitude USSR material and not in the low latitude Egyptian samples.

Podorhabdus dietzmanni (REINHARDT) REINHARDT

(Plate 17)

1965 REINHARDT, p. 30, pl. 1, fig. 1. *Ahmuellerella dietzmanni.*
1967 REINHARDT, p. 169, fig. 4.
1969 BUKRY, p. 37, pl. 16, figs. 1—3.

Comments: Rim composed of a proximal and an overlapping distal shield. Wide central area spanned by an elongate hexagonal structure, which leaves open four large perforations — one in each quadrant — and extends into a hollow central tube. In both speciments of pl. 17 the central tube is broken off.

Podorhabdus granulatus (REINHARDT) BUKRY

(Plate 16)

1965 REINHARDT, p. 39, pl. 3, fig. 2. *Ahmuellerella? granulata.*
1966 REINHARDT, p. 27, pl. 8, fig. 1. *Cretarhabdus? granulatus.*
1969 BUKRY, p. 37, pl. 16, figs. 4—6.

Comments: Elliptical bilamellar rim. Intermediate crystalring of distal side very narrow. Central area spanned by an diagonal cross composed of many small elongate crystal elements. Openings in direction of the longer main axis wider than those along the shorter axis. Hollow central tube.

Polypodorhabdus crenulatus (BRAMLETTE & MARTINI) PERCH-NIELSEN

(Plate 12, 13)

1964 BRAMLETTE & MARTINI, p. 306, pl. 2, figs. 21—24. *Cretarhabdus crenulatus.*
1968 PERCH-NIELSEN, p. 48, pl. 11, figs. 2—5.

Comments: Assuming a wide variety among this species also those specimen with only a faintly indicated axial cross and those with a pronounced cross were included here. Appearance in light-microscope of "*crenulatus*" type: with crenulated margin of central area.

Polypodorhabdus pienaari nov. spec.

(Plate 14, figs. 1—4, text-fig. 4)

1969 Pienaar, p. 92, pl. 8, fig. 8. *Cretarhabdus decorus.*
non
1954 Deflandre, in Deflandre & Fert, p. p. 45, pl. 13, figs. 4—6, text fig. 87.
non
1964 Bramlette & Martini, p. 300, pl. 3, figs. 9—12.

New Description: Elliptical coccoliths with bilamellar rim and a wide central area spanned by a complicated symmetric structure, which according to Pienaar, is described as follows: "Two parallel bars originate halfway down the longitudinal and transverse arms of the cross and are attached to the distal shield. From each of these bars two further bars develop opposite each other. These small bars fuse resulting in 4 pores in each quadrant.".

The central stalk was not found to be hollow, but compact and quadrangular in cross-station.

Holotype: EM no. 1395, Pl. 14, fig. 4.

Paratypes: EM no. 1119 u. 1467, Pl. 14, figs. 1 u. 3.

Type-locality: Gebel Tarbouli, Egypt, Stat. Nr. 6.

Type-level: Upper Maastrichtian.

Comments: Differential diagnosis: *Polypodorhabdus pienaari* does not have a hollow stem as indicated by microphotographs showing *C. decorus* in side view (see Deflandre, Bramlette & Martini, and Pienaar, pl. 11, fig. 8). All available electronmicrographs give evidence of a compact stalk. Therefore a distinction from *Cretarhabdus decorus* seems justified.

Derivatio nominis: This new species is dedicated to Richard N. Pienaar, University of Natal, Durban, S. A., who published the first picture of this species in 1968.

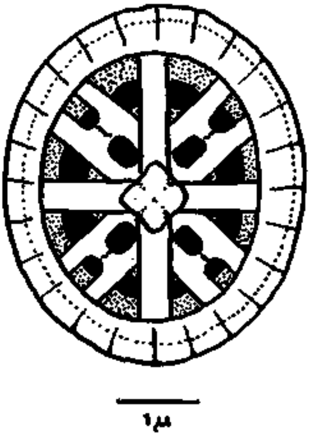

Fig. 4: *Polypodorhabdus pienaari* nov. spec. Schematized drawing of distal side; magnification appr. × 11.000. Gebel Tarbouli, Egypt.

Polypodorhabdus schizobrachiatus (GARTNER) nov. comb.

(Plate 15, figs. 1—3)

1968 GARTNER, p. 31, pl. 13, figs. 10—11; pl. 20, fig. 5. *Vekshinella schizobrachiata.*
1969 BUKRY, p. 36, pl. 15, figs. 4—6. *Cretarhabdus schizobrachiatus.*

Comments: Bilamellar coccoliths with distal and proximal shield. According to the emended generic diagnosis of the genus *Cretarhabdus* given by PERCH-NIELSEN in 1968, p. 51, that genus is reserved to coccoliths with the central area composed of many small granulae. Therefore we suggest a transfer of this species here into the genus *Polypodorhabdus* NOEL, the genus Podorhabdus NOEL being restricted to species with four pericentral openings only.

Pontosphaera multicarinata (GARTNER) nov. comb.

(Plate 48, figs. 2, 3)

1968 GARTNER, p. 41, pl. 7, figs. 10, 11. *Prolatipatella multicarinata.*

Comments: The only genuine "*Pontosphaera*" occurring in the Upper Cretaceous was registred by GARTNER in 1968 first. His description was based on lightmicroscopic pictures of this rare species. In the Gebel Tarbouli sample it is not so rare, so that also one electronmicrograph could be accomplished, showing the typical spiral microcrystal arrangement of the distal side. No indication of a multitier rim was found in the specimes from Egypt.

Prediscosphaera cretacea (ARKHANGELSKY) GARTNER

(Plate 18, 19)

1912 ARKHANGELSKY, p. 410, pl. 6, fig. 12. *Coccolithophora cretacea.*
1952 DEFLANDRE, p. 463, fig. 300 D. *Coccolithus cretaceus.*
1964 BRAMLETTE & MARTINI, p. 310, pl. 2, figs. 11—12. *Deflandrius cretaceus.*
1959 VEKSHINA, p. 73, pl. 1, figs. 8, 9. *Prediscosphaera decorata.*
1968 GARTNER, p. 19, pl. 2, figs. 10—14; pl. 3, fig. 8; pl. 4, figs. 19—24; pl. 6, figs. 14—15 etc.
1969 BUKRY, p. 38, pl. 16, fig. 12; pl. 17, figs. 1—6. *P. cretacea cretacea.*

Comments: According to BUKRY the diagnostic differences of this species in regard to the following species of *Prediscosphaera* are the interlocking sutures of the distal rim, the diagonal x-shaped crossbars and the sinistral rotation of the second internal set of crossbars.

Prediscosphaera honjo BUKRY

(Plate 22, figs. 2—4)

1969 BUKRY, p. 39, pl. 18, figs. 4—6.
1968 PERCH-NIELSEN, pl. 16, fig. 11. *Deflandrius stoveri* (pro parte).

Comments: This species differs from *P. stoveri* by the dimension of the inner cycle, which is not overlapping the distal rim, but is inserted into it and slightly depressed (pl. 22, fig. 2). Central cross in axial direction.

Also the specimen in Perch-Nielsen plate 16, fig. 11 (*Deflandrius stoveri,* Paratype) can be included here.

Prediscosphaera spinosa (Bramlette & Martini) Gartner

(Plate 20, figs. 1—4)

1964 Bramlette & Martini, p. 301, pl. 2, figs. 17—20. *Deflandrius spinosus.*
1968 Gartner, p. 20, pl. 1, figs. 15—16; pl. 3, figs. 9—10; pl. 5, figs. 7—9; pl. 6, fig. 16; pl. 11, fig. 17.
1969 Bukry, p. 40, pl. 18, figs. 7—9.

Comments: Characteristic of this species are the delicate spines at the top of the stem (often altogether missing). The basal plate consists of two elliptical rims, die distal one with sutures straight and less complicated than in *P. cretacea.* The crossbars are almost in axial direction and almost completely united with the second set of crossbars.

Prediscosphaera stoveri (Perch-Nielsen) nov. comb.

(Plate 22, fig. 1)

1968 Perch-Nielsen, p. 66, pl. 16, fig. 13 (Holotype). *Deflandrius stoveri.*
1969 Bukry, p. 39, pl. 18, figs. 1—3. *Prediscosphaera germanica.*

Comments: This species is easily recognized by the distinctive inner cycle of crystal rods, which extend onto the distal side of the distal rim. Crossbars in axial direction. The new combination is required by the priority of the description given by Perch-Nielsen.

Rhabdolithina splendens (Deflandre) Reinhardt

(Plate 32, figs. 3, 4)

1953 Deflandre, p. 1786, text-figs. 4—6. *Rhabdolithus splendens.*
1966 Reinhardt, p. 167.
1968 Stradner, Adamiker & Maresch, p. 32, pl. 21—23.

Comments: Central area filled with tightly packed crystal triplets. Central stem hollow, built of elongate crystal laths in spiral arrangment.

Rhagodiscus plebeius Perch-Nielsen

(Plate 26, figs. 2—4; plate 27, figs. 1, 2, 4)

1968 Perch-Nielsen, p. 44, pl. 7, figs. 2—6.

Comments: Rim composed of imbricated plates in "*zygodiscus*"-style. Central area filled with a granulated conical structure, which is perforated in the centre.

Reinhardtites mirabilis Perch-Nielsen

(Plate 24, 25)

1968 Perch-Nielsen, p. 40, pl. 7, fig. 1, text-fig. 15.

Comments: Simple rim of socalled "*zygodiscus*"-style, with central area spanned by an unperforated cone-shaped structure consisting of 8 imbricating double rows of crystalplates. Thus in distal view 8 ridges ascending in radial direction unite to form a central stem. The sloping of these ridges is clockwise, their overlapping counterclockwise.

Stephanolithion laffitei NOEL

(Plate 47, fig. 2)

1956 NOEL, p. 318, pl. 2, fig. 5.
1968 STRADNER, ADAMIKER & MARESCH, p. 41—42, pls. 40, 41.
1969 BUKRY, p. 43—44, pl. 21, figs. 7—11.

Comments: One typical specimen with 8 radial arms and the typical *Stephanolithion* processes was found in the Gebel Tarbouli material.

Vekshinella aachena BUKRY

(Plate 40, figs. 2, 3)

1969 BUKRY, pl. 55, pl. 31, figs. 1—6.

Comments: Ends of central cross widely flaring. Cross in axial direction, without central stem.

Vekshinella cruciata (NOEL) nov. comb.

(Plate 40, figs. 1, 4)

1958 NOEL, p. 162, pl. 1, fig. 3. *Discolithus cruriatus.*
1965 REINHARDT, p. 39, pl. 3, fig. 3. *Staurolithites cruciatus.*
1968 PERCH-NIELSEN, p. 26, pl. 2, fig. 6. *St. cruciatus.*

Comments: Central cross slightly shifted counterclockwise from the direction of the main axes, especially the shorter crossbar. The ends of the crossbars are flaring.

Vekshinella crux (DEFLANDRE & FERT) nov. comb.

(Plate 39)

1952 DEFLANDRE & FERT, p. 2101, text-fig. 8.
1954 DEFLANDRE & FERT, p. 143, pl. 14, fig. 4, text-fig. 55. *Discolithus crux.*
1961 BRAMLETTE & SULLIVAN, p. 149, pl. 6, figs. 8—10. *Zygolithus crux.*
1965 REINHARDT, p. 39, pl. 3, fig. 3. *Staurolithites bochotnicae.*
1968 STRADNER, ADAMIKER & MARESCH, p. 36 pls. 28—30. *Zygolithus crux.*

Comments: The genero-type of the genus *Zygolithus* KAMPTNER is *Zygolithus dubius*, which by BLACK 1967 was transferred into the genus *Neococcolithes* SUJKOWSKY, which only contains Tertiary species. "*Zygoliths* with an axial cross" found in Mesozoic deposits were put into the genus *Vekshinella* by LOEBLICH & TAPPAN 1963.

Vekshinella elliptica GARTNER

(Plate 38, figs. 1—4)

1969 GARTNER, p. 30, pl. 25, fig. 26; pl. 17, fig. 5.

Comments: Central structure rhombical, somewhat similar to that of *Discolithus quadriarcullus* NOEL (1965, p. 74, fig. 7), from which it differs by a round or rhombical central perforation.

Watznaueria barnese (BLACK) PERCH-NIELSEN

(Plate 1, figs. 1—5)

1959 BLACK & BARNES, p. 325, pl. 9, figs. 1, 2. *Tremalithus barnesae.*
1964 REINHARDT, p. 753, pl. 2, fig. 2, text-fig. 4.
1968 PERCH-NIELSEN, p. 68, pl. 22, figs. 1—7; pl. 23, figs. 1, 4, 5, 6,text-fig. 32.

Comments: Most common of all cretaceous coccoliths. Its ultrastructure is easily reduced by recrystallization or corrosion.

One of the most prolific rockforming fossil species of the world!

Zygodiscus acanthus (REINHARDT) REINHARDT

(Plate 36, figs. 1—4)

1965 REINHARDT, p. 37, pl. 3, fig. 1. *Zeugrhabdotus acanthus.*
1966 REINHARDT, p. 40, pl. 15, fig. 5; pl. 23, fig. 8.
1969 BUKRY, p. 58, pl. 33, figs. 8—9.

Comments: Rim consisting of an outer dextrally imbricate cycle with radial sutures and an inner cycle with strongly dextrally inclined crystals. Transversal bridge with stem.

Zygodiscus spiralis BRAMLETTE & MARTINI

(Plate 33, figs. 1—4)

1964 BRAMLETTE & MARTINI, p. 303, pl. 4, figs. 6—8.
1968 GARTNER, p. 35, pl. 5, figs. 21; pl. 7, fig. 3.
1969 BUKRY, p. 61, pl. 36, figs. 1, 2. *Zygodiscus* sp. aff. *Z. sigmoides.*

Comments: According to GARTNER a radiant arrangement of the rim elements is characteristic. Transversal bridge constructed of several rods, with transversal groove on the proximal side.

Zygodiscus sisyphus GARTNER

(Plate 34, figs. 1—4)

1968 GARTNER, p. 34, pl. 25, fig. 22; pl. 14, fig. 19.
1969 BUKRY, p. 61, pl. 36, figs. 3, 4.

Comments: Elliptical "*zygodiscs*" with dextrally imbricating rim elements and slanted sutures. Central bridge broader than in *Z. spiralis.*

Zygodiscus tarboulensis nov. spec.

(Plate 37, figs. 1—3, 4, text-fig. 5)

Holotype: EM no. 1135 (fig. 2); paratypes: EM no. 443, EM no. 1147 (figs. 1, 3).

Type locality: Gebel Tarbouli, Egypt, Stat. no. 7—1.

Stratum typicum: Upper Maastrichtian.

Original description: Elliptical "zygodisc" with smooth or slightly serrate rim consisting of 30—50 dextrally imbricated elements. The central area is bridged by three elements: one transversal low bridge, from which rises a hollow stem, and two angular structures with arms of different width. These angles support the central stem with their corners and embrace less than 90 degrees. They are not symmetrical, but identical after rotation of 180 degrees. Lines bisecting the angles bypass the central stem and run about parallel to the main axis of the elliptical rim. There are six windows with notches towards the centre, two large ones und four small ones. Also inversed specimen occur (pl. 37, fig. 4).

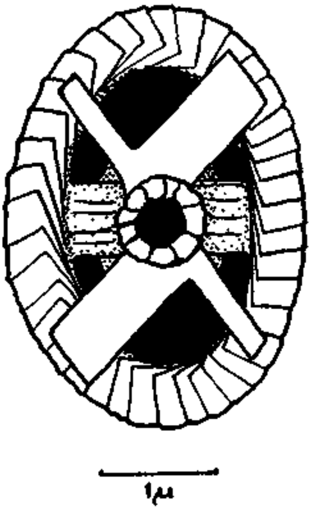

Fig. 5: *Zygodiscus tarboulensis* nov. spec. Schematized drawing of the distal side; magnification appr. × 15.000. Gebel Tarbouli, Egypt.

Comments: *Zygodiscus tarboulensis* is closely related to *Zygodiscus macleodae* BUKRY, from which it differs by the asymmetrical arrangement of the central structure and by the sharp notches of the framed perforations.

Derivatio nominis: Discovered in a sample from the Gebel *Tarbouli*, Egypt.

Zygodiscus theta (Black) Bukry

(Plate 35, figs. 1, 2)

1959 Black & Barnes, p. 327, pl. 12, fig. 1. *Discolithus theta.*
1969 Bukry, p. 62, pl. 36, figs. 7, 8.

Comments: Rim and bridge of this species are more slender than in Z. *sisyphus*. It differs from Z. *acanthus* by the lack of the inner crystal cycle (compare pl. 36).

Zygolithus cf. diplogrammus Deflandre

(Plate 35, fig. 4)

1954 Deflandre, in Deflandre & Fert, p. 148, pl. 10, fig. 7, text-fig. 57.
1968 Stradner, Adamiker & Maresch, p. 35, pl. 27, fig. 1.

Comments: The single specimen with the partly developed double bridge, which is tentatively included here also might have grown out into an other species with compact transversal bridge (?).

Zygolithus erectus Deflandre

(Plate 35, fig. 3)

1954 Deflandre, in Deflandre & Fert, p. 150, pl. 15, figs. 14—17, text-figs. 60—62.
1968 Stradner, Adamiker & Maresch, p. 34, pl. 25 and 26, figs. 1, 2.
1968 Perch-Nielsen, p. 21.

Comments: Elliptical rim composed of dextrally imbricated crystal elements. Transversal bridge of equal width, with central knob.

Possibly *Zygosdicus sisyphus* can be annexed to this species, as closest relative.

Zygolithus litterarius (Gorka) Reinhardt & Gorka

(Plate 41, fig. 1—4)

1957 Gorka, p. 251, pl. 3, fig. 3. *Discolithus litterarius.*
1967 Reinhardt & Gorka, p. 249, pl. 33, fig. 7, text-fig. 4.
1968 Stradner, Adamiker & Maresch, p. 39, pl. 34.

Comments: *Zygolithus litterarius* is distinguishable from other similar forms with x-shaped diagonal central structure by its rim, which consists of one layer of dextrally crystals plates mainly (distal view). The proximal side (pl. 41, fig. 4) may show a complicated bottom plate.

Appendix

The following newly-described Marthasterites does not come from the Maastrichtian, but from the *Paleocene* of Egypt!

Marthasterites spineus nov. spec.

(Text-figures 6 and 7 a—d)

Derivatio nominis: spineus = lat. "with spines".

Holotype: Prep. Ash/63/A (fig. 7 b, c).

Stratum typicum: Paleocene.

Locus typicus: Ash El-Mellaha range, Western Red Sea Coast, Egypt (Esna shale).

Diagnosis: An ortholithic nannofossil consisting of a pair of triradiate stars, which are united at their centre and shifted by 60 degrees to give the appearence of a regular sixradiate star with arms alternating at different focus. The arms wear spines directed towards each other at about the middle of their free length.

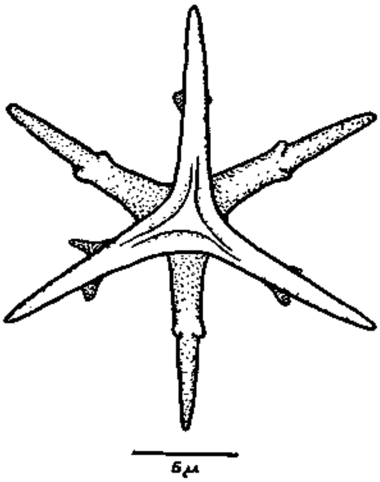

Fig. 6: *Marthasterites spineus* nov. spec. Schematized drawing; magnification app. × 3000. Ash El-Mellaha range, Western Red Sea Coast, Egypt.

Comments: A species of Marthasterites, which in its general appearance is similar to *M. reginus,* from which it differs however by the following features:

a) The spine-like bifurcation of the six free arms is not at their ends, but at about half of their free length and not very regular. Their is mostly only one spine, sometimes there are two.

b) the curving of the arms is very slight, the coiling is reversed as compared to *M. reginus.*

c) the ornamentation of the central field consists of three ridges, which are uniting at the centre enclosing angles of 120 degrees. These ridges are in the same direction as the arms and not shifted 60 degrees as in *M. reginus.*

Fig. 7: *Marthasterites spineus* nov. spec.; different specimens in axial view and in side view. Holotype from Prep. Ash 63/a at higher focus (fig. b) and at lower focus (fig. c). Sample: Ash El-Mellaha range, Esna shale, Western Red Sea Coast, Egypt.

10. Conclusions

The results reached by the authors in this study are presented in brief in the following.

1. A nannoplankton zonation is recognised for the uppermost Cretaceous and the early Tertiary of the Gulf of Suez region and the Red Sea coast, Egypt. The biozones met with are:

top a) *Discoaster binodosus* zone
b) *Marthasterites contortus* zone
c) *Marthasterites spineus* zone
d) *Discoaster multiradiatus* zone
e) *Heliolithus riedeli* zone

2. The lithostratigraphic units assigned to the Upper Cretaceous-Lower Tertiary exposed along the western side of the Gulf of Suez and the Red Sea are proved here to become younger toward the south. This is well demonstrated by the Tarawan Chalk rock unit: while it has a nannoplankton assemblage typical for the Upper Maastrichtian in the north at Gebel Tarbouli, its nannofossil content in the south at Gebel Duwi gives a Lower Landenian age.

3. A hiatus is recorded and represents the missing of the whole Danian and most of the Landenian in Gebel Tarbouli at the contact between the Tarawan Chalk and the Esna Shale, though field observations of this contact suggest that the sedimentation was unintermittent. This break in Sedimentation may explain the reduced thickness of the Esna Shale (10 m.) at the Gebel Tarbouli.

4. A list of the nannoplankton species of the Tarawan Chalk of Gebel Tarbouli is given together with a documentation of their microphotographs in addition to those of the Russian material (plates 1 to 50).

5. It is found that the Russian and the Egyptian Upper Maastrichtian could be easily correlated by means of their coccolith contents, in spite of the wide geographical separation of the two localities.

6. It has been established that the Egyptian section Gebel Tarbouli lies outside the *Nephrolithus frequens* domain, while the Russian locality falls within the high latitudes of *Nephrolithus frequens* domain (compare Martini, 1970).

7. The genus *Pontosphaera*, so far not known older than the Eocene, is recorded here for the first time in the Upper Maastrichtian of the Gebel Tarbouli, Egypt.

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PLATE 1

Watznaueria barnesae (Black) Perch-Nielsen
1 Distal view (USSR) **)
2 Proximal view (USSR)
3 Oblique distal view (USSR)
4 Distal view (UAR) *)
5 Proximal view (UAR)

*) (UAR) stands for Gebel Tarbouli, Gulf of Suez Region, Egypt.

**) (USSR) stands for Sinev-Shuravnin Deep Drilling, Dnjepr-Donetz Region, USSR (core at 278—279 meter). Sample from the collection of the Oceanographic Institute at Moscow.

PLATE 2

Biscutum constans (Gorka) Black
1 Distal view (USSR)
2 Proximal view (USSR)
3 Oblique proximal view (USSR)
4 Two distal views (UAR)

PLATE 3

Biscutum testudinarium Black
1 Distal view (USSR)
2 Proximal view (USSR)
Markalius inversus (Deflandre) Bramlette & Martini
3 Distal view (USSR)
4 Proximal view (USSR)

PLATE 4

Biscutum testudinarium Black
1 Fragmentary coccosphere, internal view (USSR)
Watznaueria barnesae (Black) Perch-Nielsen
2 Complete coccosphere (USSR)

PLATE 5

Arkhangelskiella cymbiformis Vekshina
1 Distal view (UAR)
2 Marginal rim, proximal side (UAR)
3 Pores of central area (UAR)

PLATE 6

Arkhangelskiella cymbiformis Vekshina
1 Distal view (USSR)
2 Proximal view (USSR)

PLATE 7

Arkhangelskiella cymbiformis Vekshina
1 Oblique proximal view (USSR)
2 Oblique proximal view (USSR)

PLATE 8

Kamptnerius magnificus Deflandre
1 Distal view (USSR)
2 Proximal view (USSR)

PLATE 9

Kamptnerius magnificus Deflandre
1 Distal view of coccolith with open central area (USSR)
2 Proximal view of similar specimen (USSR)

PLATE 10

Kamptnerius magnificus Deflandre
1 Oblique proximal view (USSR)
2 Oblique proximal view (USSR)

PLATE 11

Kamptnerius magnificus Deflandre
1 Oblique distal view (USSR)
Kamptnerius percivalii Bukry
2 Distal view (UAR)

PLATE 12

Polypodorhabdus crenulatus (Bramlette & Martini) nov. comb.
1 Distal view (USSR)
2 Distal view (USSR)

PLATE 13

Polypodorhabdus crenulatus (Bramlette & Martini) nov. comb.
1—3 Distal views (USSR)
4 Proximal view (UAR)

PLATE 14

Polypodorhabdus pienaari nov. spec.
1 Distal view (UAR)
2 Oblique distal view (UAR)
3 Distal view (UAR)
4 Distal view of holotype (UAR)

PLATE 15

Polypodorhabdus schizobrachiatus (Gartner) nov. comb.
1—3 Distal views (UAR)

PLATE 16

Podorhabdus granulatus (Reinhardt) Bukry
1—3 Distal views (UAR)

PLATE 17

Podorhabdus dietzmanni (Reinhardt) Reinhardt
1 Oblique distal view (UAR)
2 Proximal view (UAR)

PLATE 18

Prediscosphaera cretacea (Arkhangelsky) Gartner
1 Distal view (USSR)
2 Proximal view (USSR)
4 Oblique distal view (USSR)
Prediscosphaera sp.
3 Distal view (UAR)

PLATE 19

Transitional forms between *Prediscosphaera cretacea* (Arkhangelsky) Gartner and *P. spinosa* (Bramlette & Martini) Bukry
1 Distal view (USSR)
2 Distal view (USSR)
Prediscosphaera cretacea (Arkhangelsky) Gartner
3—4 Side views (USSR)

PLATE 20

Prediscosphaera spinosa (Bramlette & Martini) Bukry
1—2 Distal views (USSR)
3—4 Proximal views (USSR)

PLATE 21

Prediscosphaera sp.
1 Distal view (USSR)
2—4 Distal views (UAR)

PLATE 22

Prediscosphaera stoveri Perch-Nielsen
1 Distal view (USSR)
Prediscosphaera honjoi Bukry
2 Distal view (UAR)
3 Distal view (UAR)
4 Proximal view (UAR)

PLATE 23

Ahmuellerella octoradiata (Gorka) Reinhardt
1 Distal view (USSR)
2 Distal view (USSR)
3 Oblique distal view (USSR)
4 Proximal view (USSR)

PLATE 24

Reinhardtites mirabilis Perch-Nielsen
1—3 Distal views (USSR)
4 Distal view (UAR)

PLATE 25

Reinhardtites mirabilis Perch-Nielsen
1—2 Oblique proximal views (USSR)
3—4 Proximal views (USSR)

PLATE 26

Rhagodiscus plebeius Perch-Nielsen
1—2 Distal views (USSR)
3—4 Proximal views (USSR)

PLATE 27

Rhagodiscus plebeius Perch-Nielsen
1—2 Distal views (USSR)
Rhagodiscus sp.
3 Distal view (UAR)
4 Proximal view (USSR)

PLATE 28

Nephrolithus frequens Gorka
1—3 Distal views (USSR)

PLATE 29

Nephrolithus frequens Gorka
1—3 Proximal views (USSR)

PLATE 30

Cribrosphaerella laughtoni (Black) Bukry
1 Distal view (USSR)
2 Centre of same specimen in larger magnification (USSR)
3 Distal view (USSR)
4 Same specimen, close-up of central area (USSR)

PLATE 31

Cribrosphaerella laughtoni (Black) Bukry
1 Distal view (USSR)
2—3 Proximal views (USSR)
4 Oblique proximal view (USSR)

PLATE 32

Cribrosphaerella numerosa (GORKA) REINHARDT & GORKA
1 Distal view (UAR)
2 Central area of same specimen in higher magnification (UAR)
Rhabdolithina splendens (DEFLANDRE) REINHARDT
3 Proximal view (UAR)
4 Side view of shaft (UAR)

PLATE 33

Zygodiscus spiralis BRAMLETTE & MARTINI
1 Distal view (USSR)
2 Distal view (UAR)
3—4 Proximal views (USSR)

PLATE 34

Zygodiscus sisyphus GARTNER
1—3 Distal views (USSR)
4 Proximal view (USSR)

PLATE 35

Zygodiscus theta (BLACK) BUKRY
1 Distal view (USSR)
2 Oblique distal view (USSR)
Zygolithus erectus DEFLANDRE
3 Distal view (UAR)
Zygolithus cf. *diplogrammus* DEFLANDRE
4 Proximal view (USSR)

PLATE 36

Zygodiscus acanthus (REINHARDT) REINHARDT
1—3 Distal views (USSR)
4 Proximal view (USSR)

PLATE 37

Zygodiscus tarboulensis nov. spec.
1 Distal view (paratype) (UAR)
2 Distal view (holotype) (UAR)
3 Distal view (paratype) (UAR)
4 Distal view of partly inversed specimen (UAR)

PLATE 38

Vekshinella elliptica GARTNER
1 Distal view (?) (UAR)
2—4 Proximal views (UAR)

PLATE 39

Vekshinella crux (DEFLANDRE & FERT) nov. comb.
1—2 Distal views (UAR)
3—4 Proximal views (UAR)

PLATE 40

Vekshinella cruciata (NOEL) nov. comb.
1 Distal view (USSR)
4 Proximal view (USSR)
Vekshinella aachena BUKRY
2—3 Distal views (USSR)

PLATE 41

Zygolithus litterarius (Gorka) Reinhardt & Gorka

1—3 Distal views (UAR)
4 Proximal view (UAR)

PLATE 42

Eiffellithus sp. Heavily fossilized specimens

1 Distal view (UAR)
2 Distal view (USSR)
3—4 Proximal views (USSR)

PLATE 43

Eiffellithus trabeculatus (Gorka) Reinhardt & Gorka

2 Distal view (USSR)

Eiffellithus anceps (Gorka) Reinhardt & Gorka

1 and 4 Distal views (USSR)
3 Distal view with double carbon coating in rim area (USSR)

PLATE 44

Eiffellithus anceps (Gorka) Reinhardt & Gorka

1—2 Distal views (USSR)
3 Proximal view (USSR)
4 Oblique distal view (USSR)

PLATE 45

Cylindralithus serratus Bramlette & Martini

1—4 Axial views (UAR)

PLATE 46

Corollithion exiguum Stradner

1 and 4 Distal views (UAR)
2 and 3 Proximal views (UAR)

PLATE 47

Corollithion exiguum Stradner

1 Distal view (UAR)

Stephanolithion laffitei Noel

2 Proximal view (UAR)

Corollithion rhombicum (Stradner & Adamiker) Bukry

3 Distal view (UAR)

PLATE 48

1 Unidentified globular body with pore (UAR)

Pontosphaera multicarinata (Gartner) nov. comb.

2 Plan view in light microscope, crossed nicols (UAR)
3 Distal side with spiral sutures (electronmicrograph) (UAR)

PLATE 49

Lithraphidites quadratus Bramlette & Martini

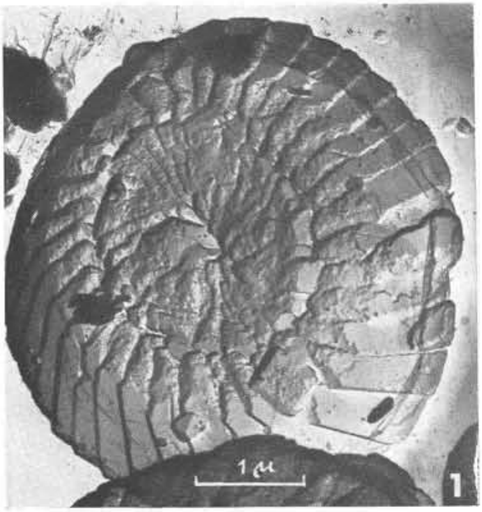
1—2 Side views (UAR)
3 Side view (USSR)

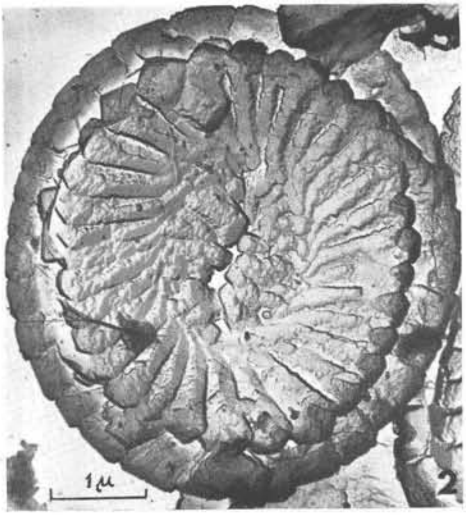
PLATE 50

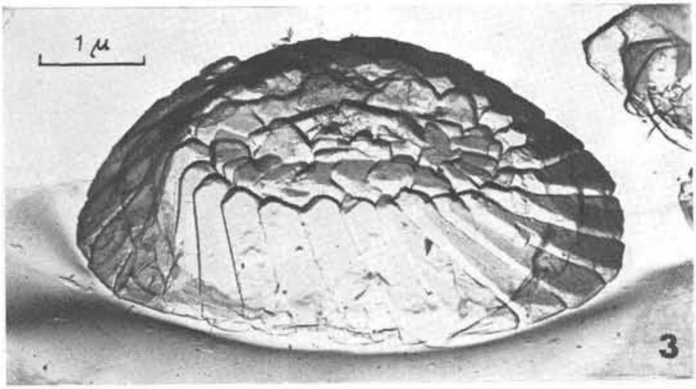
Micula staurophora (Gardet) Stradner

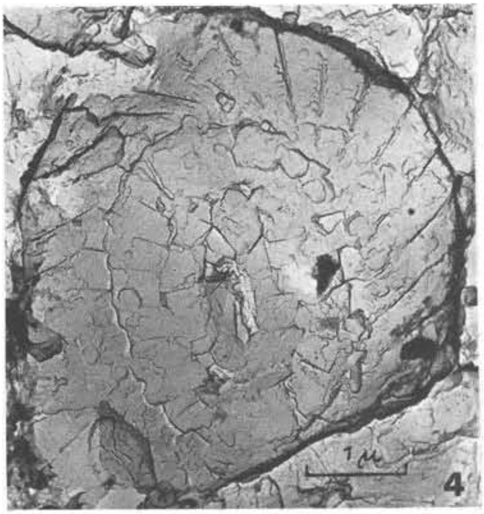
1—4 Oblique views of more or less tilted specimens (UAR)

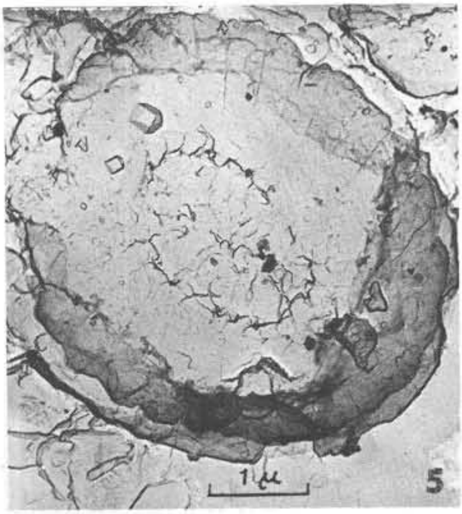
PLATE 1











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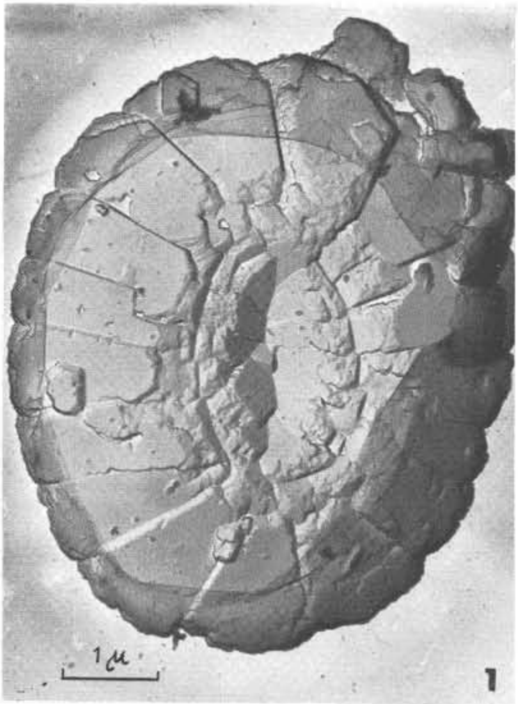

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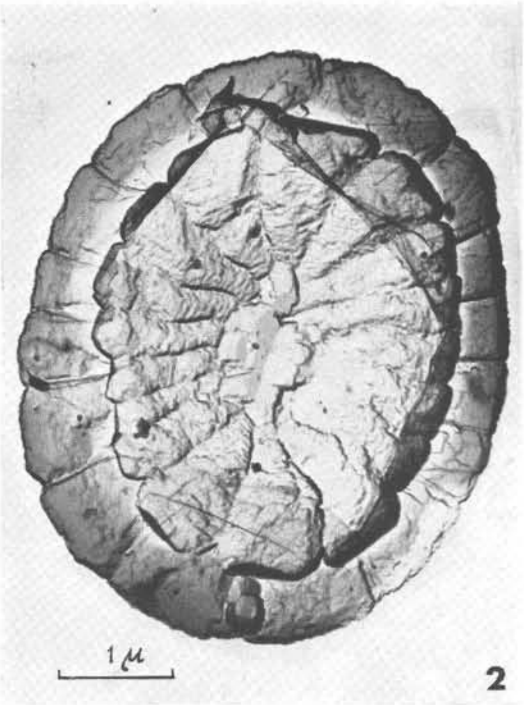

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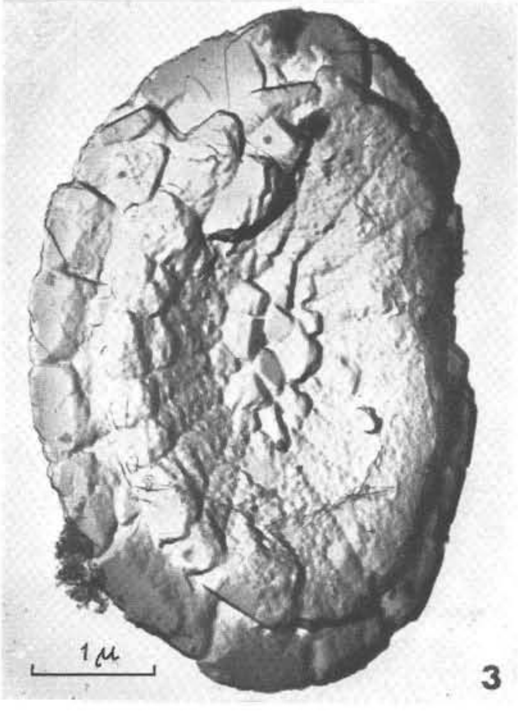

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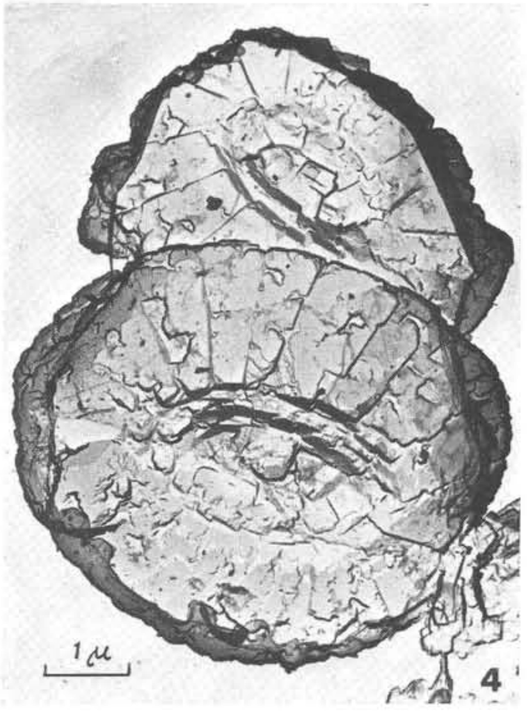

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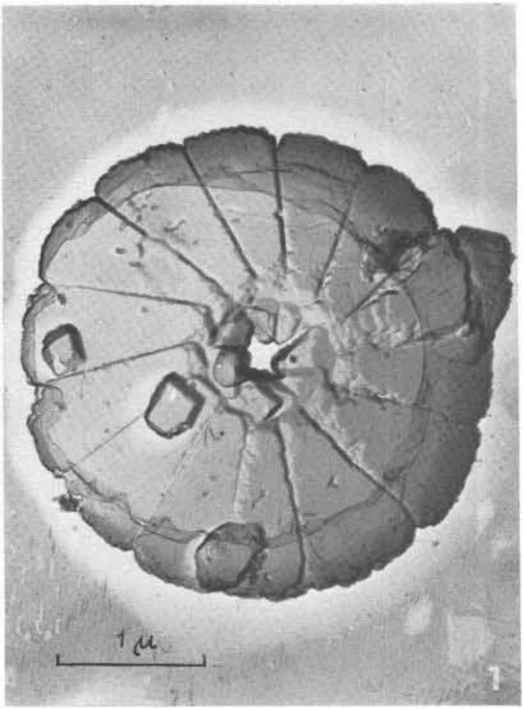

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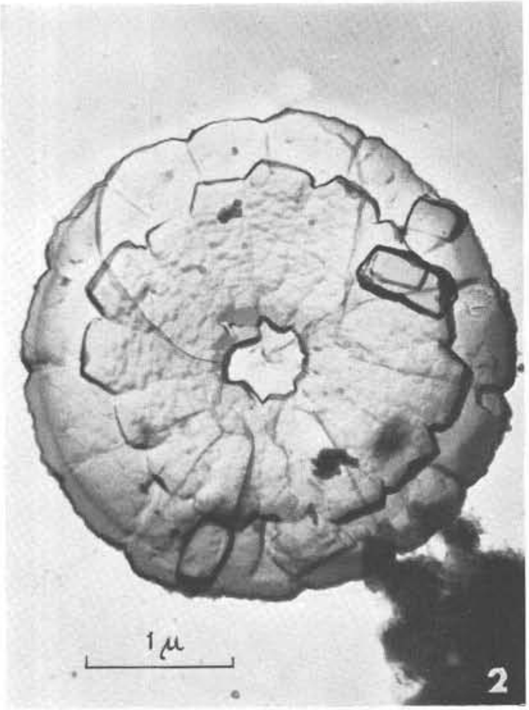

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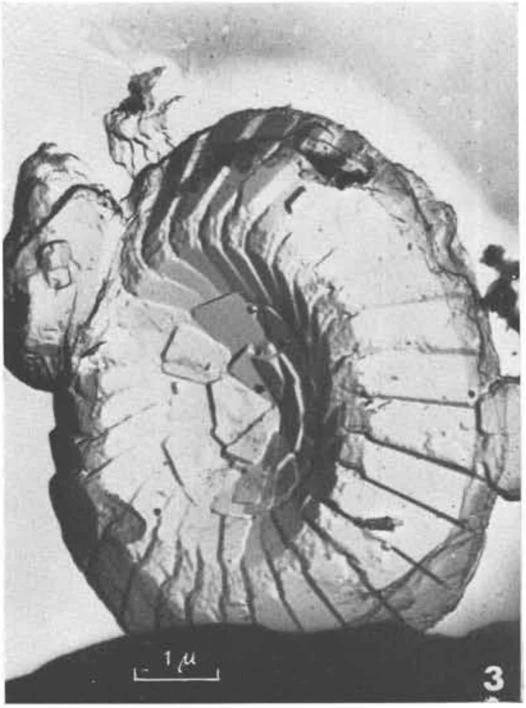

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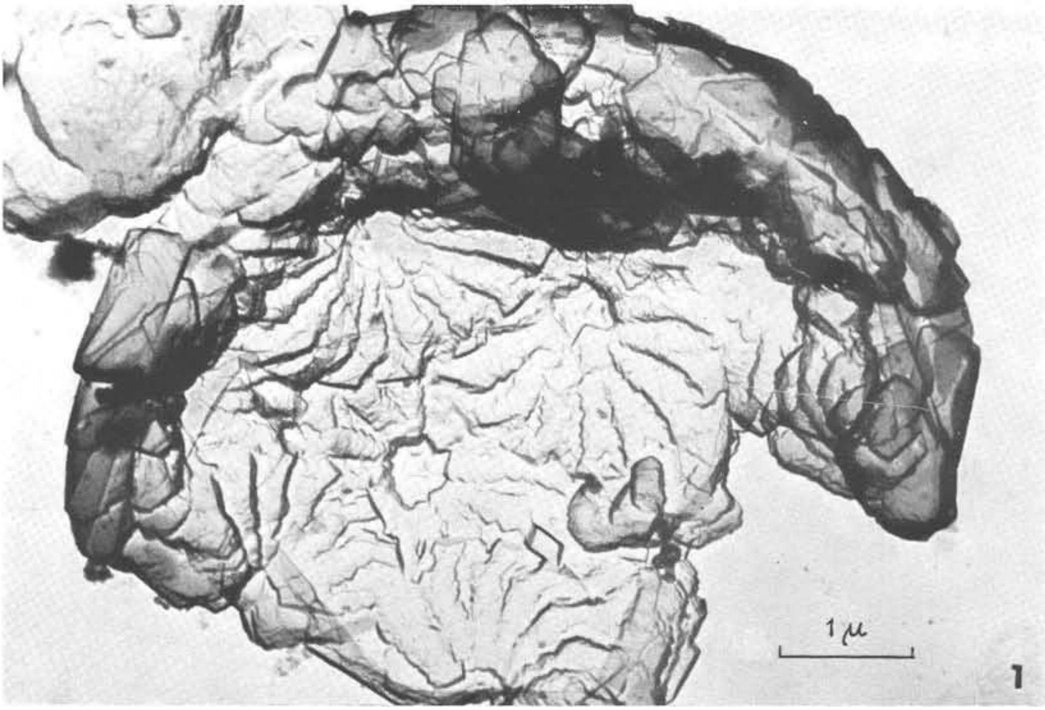
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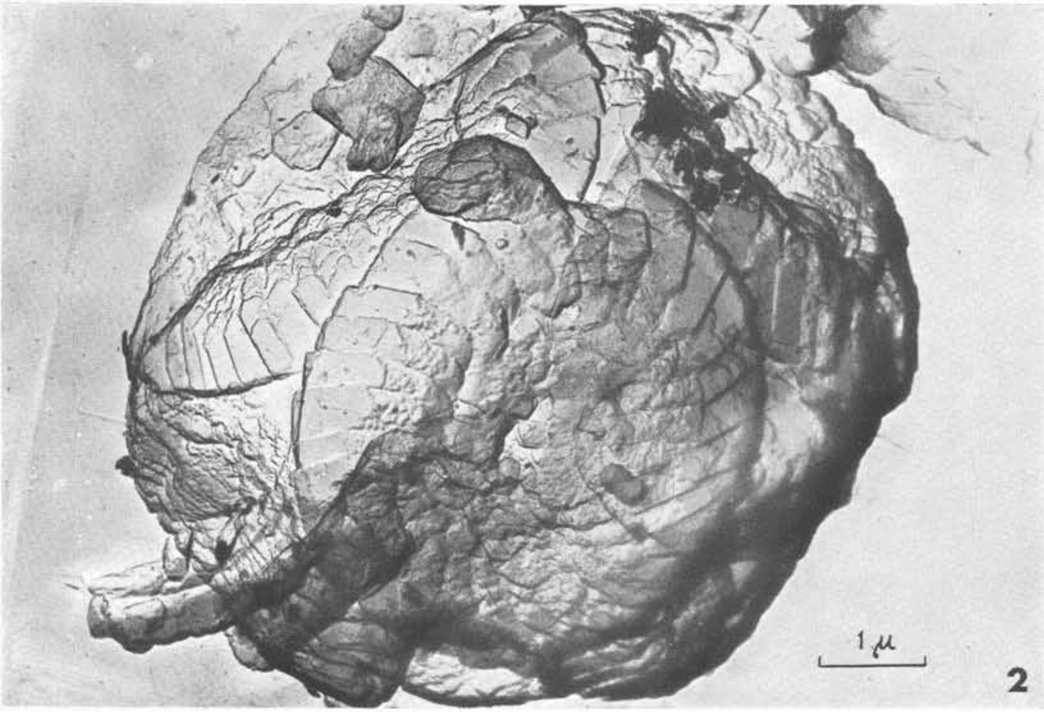
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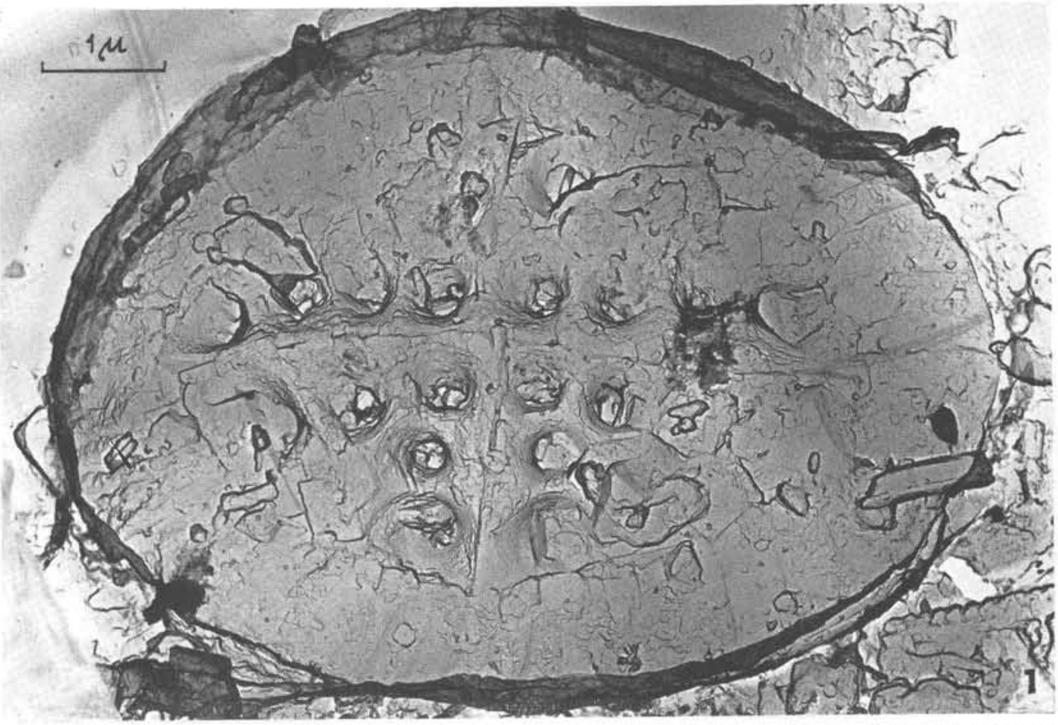
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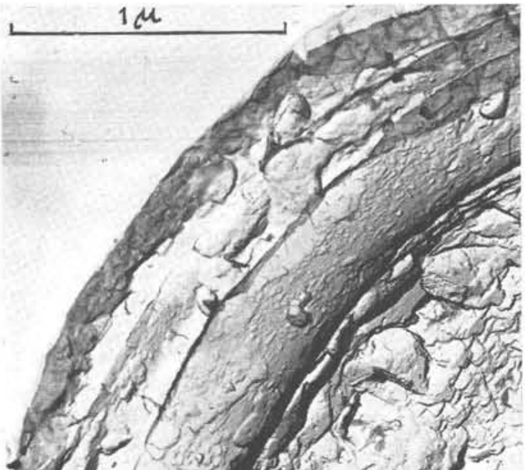
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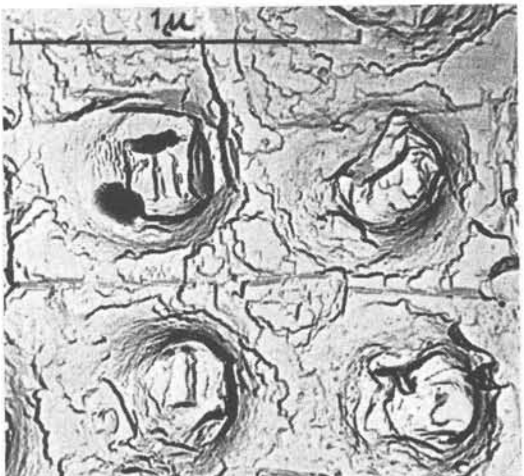
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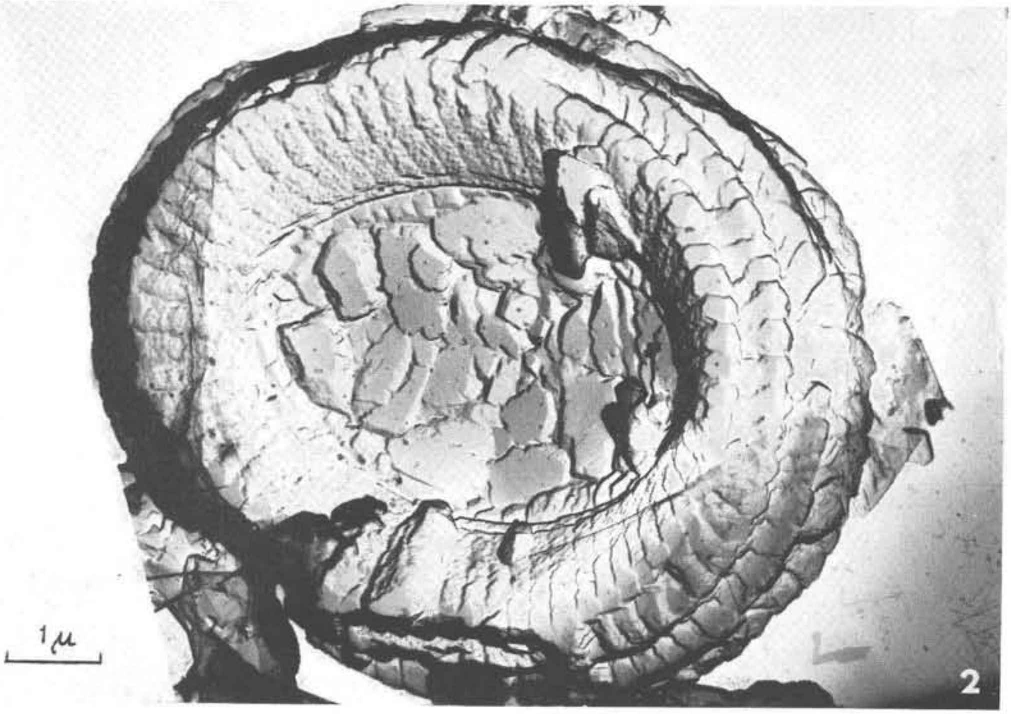
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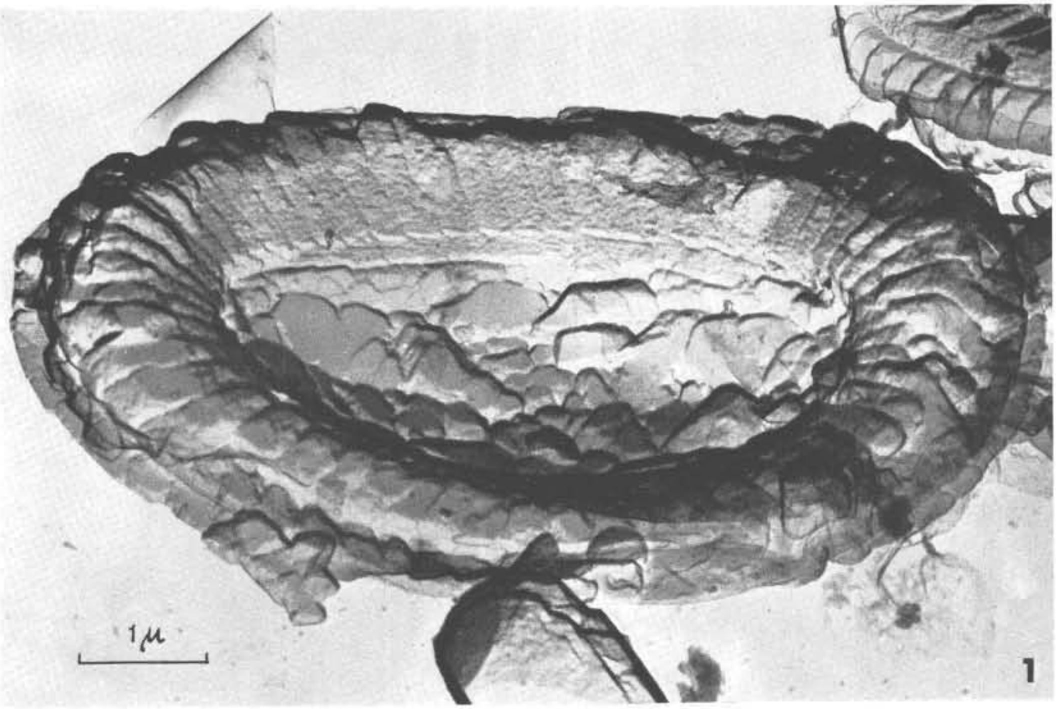
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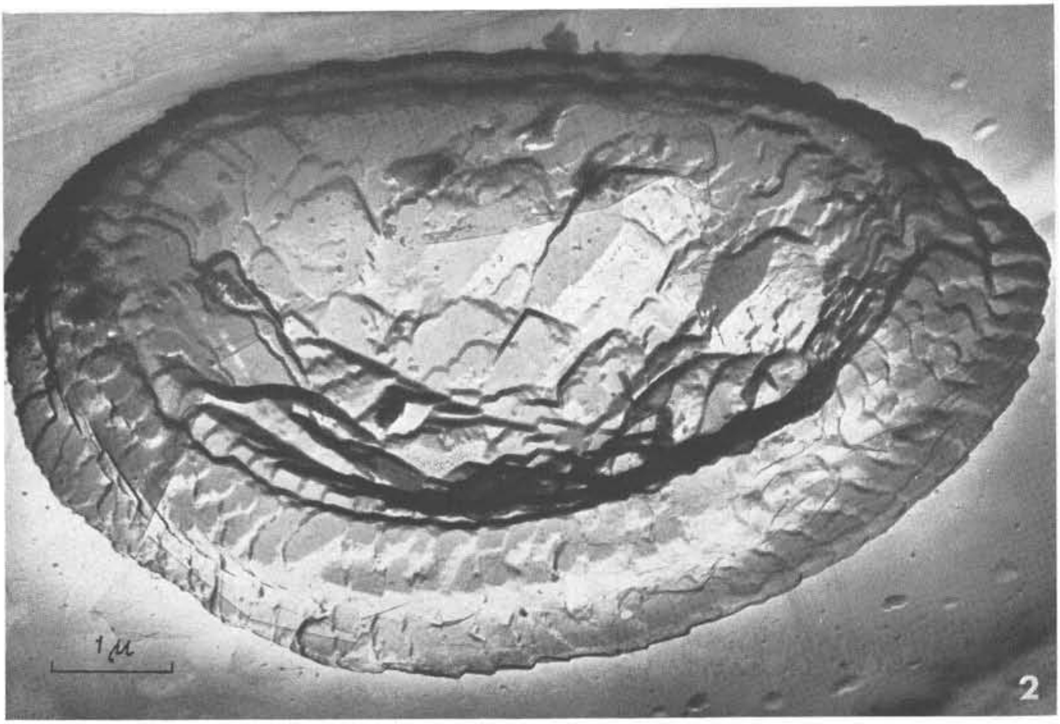
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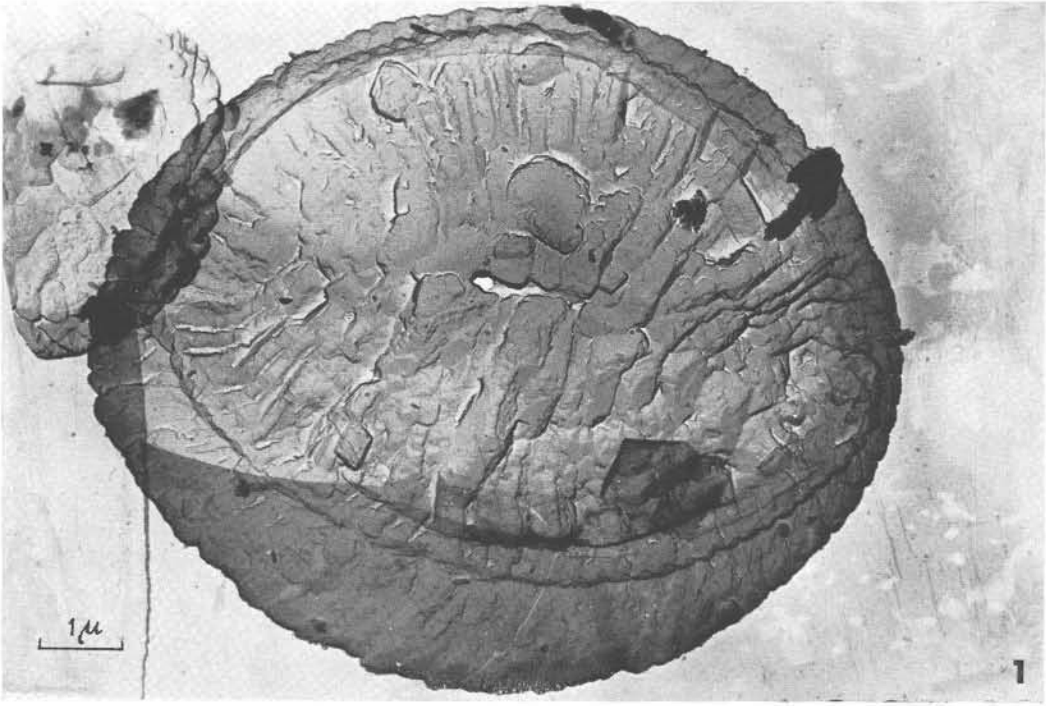

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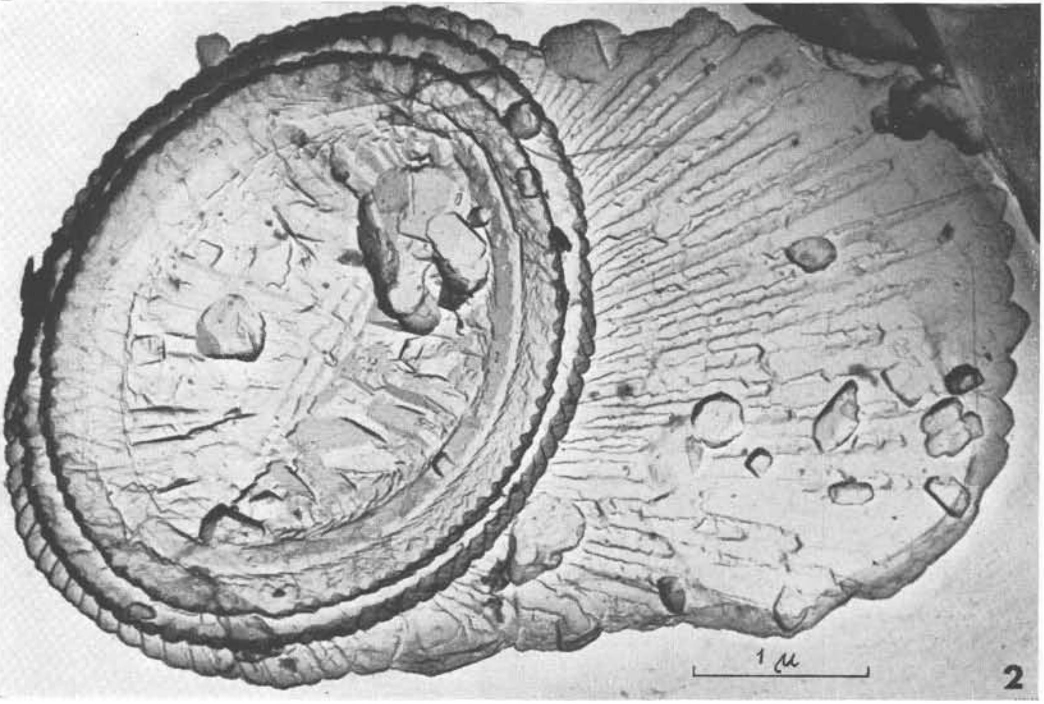

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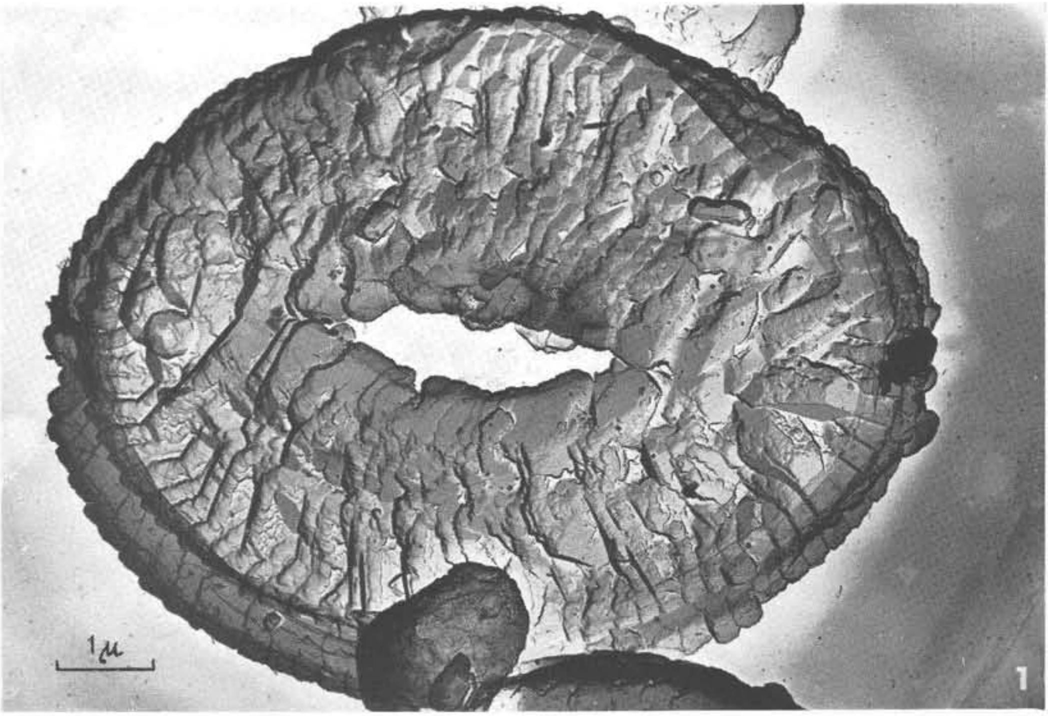

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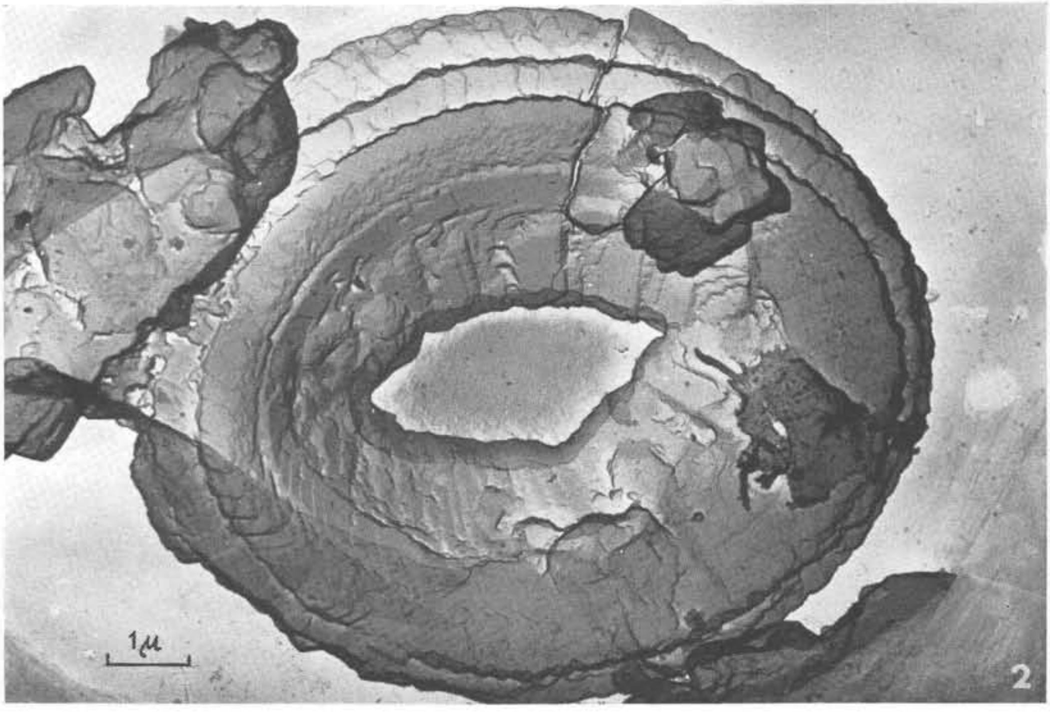

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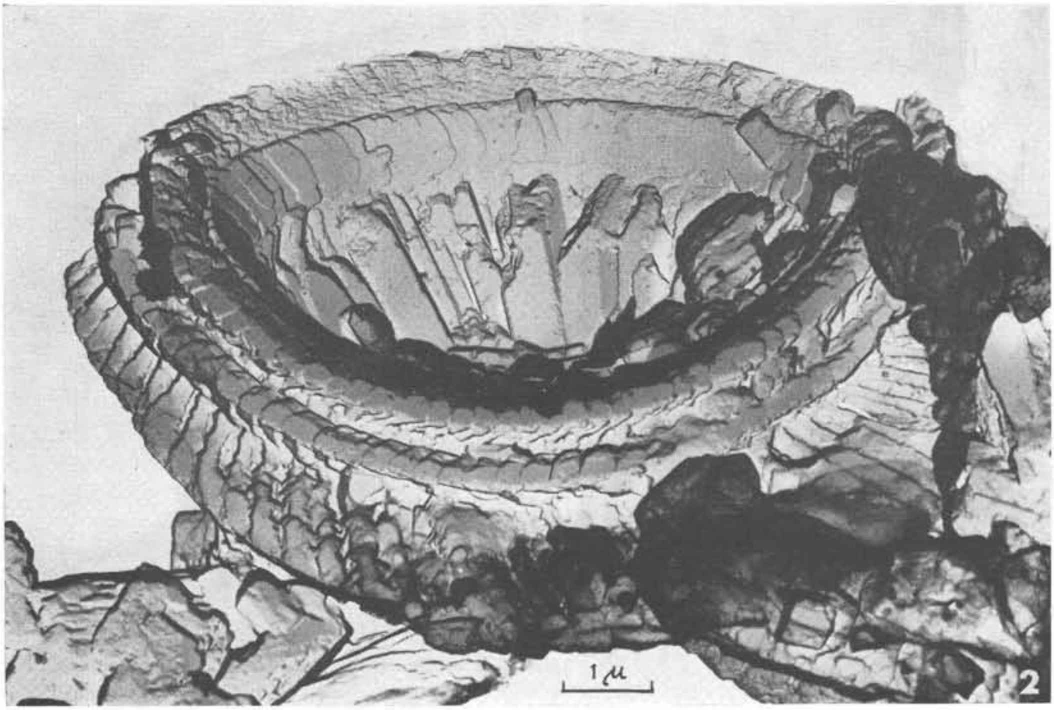
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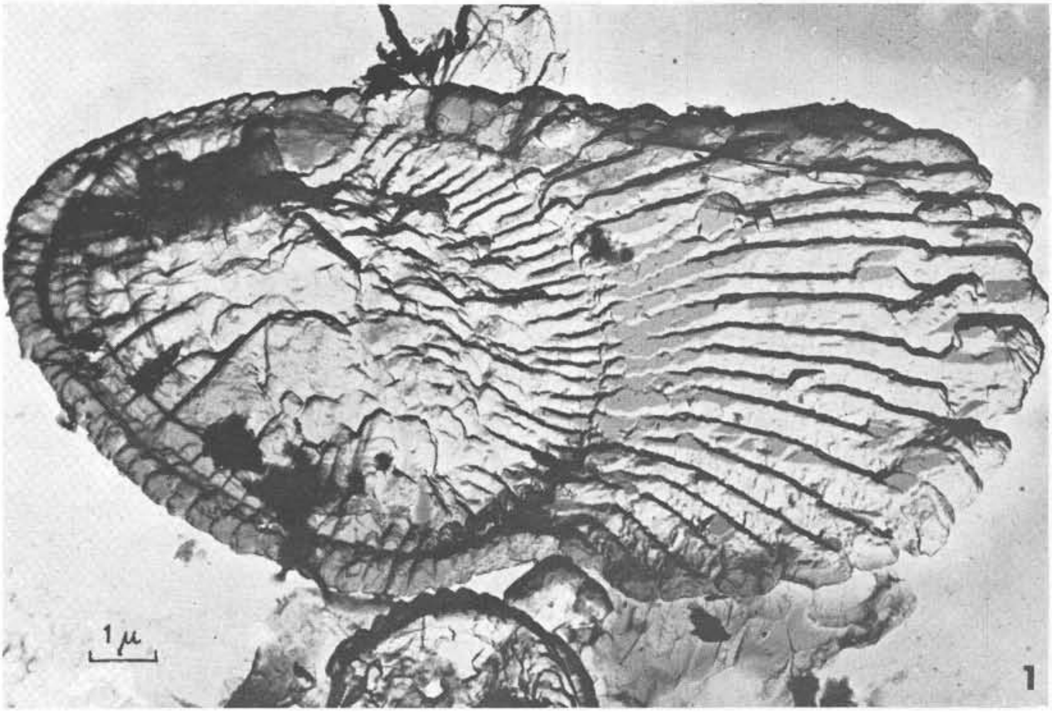

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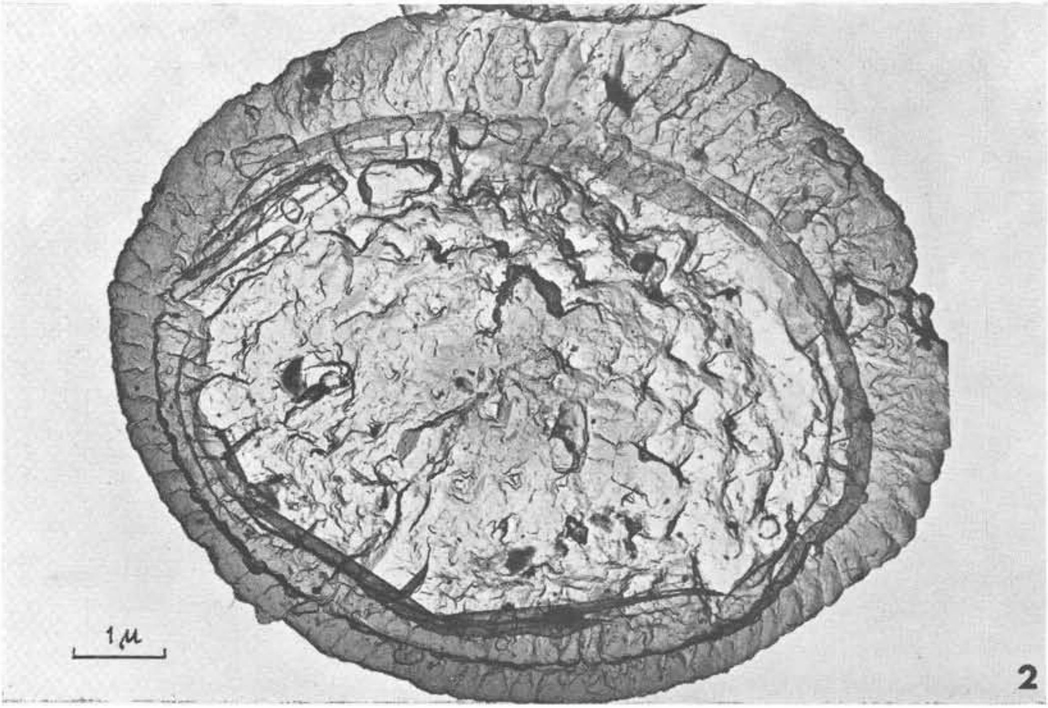

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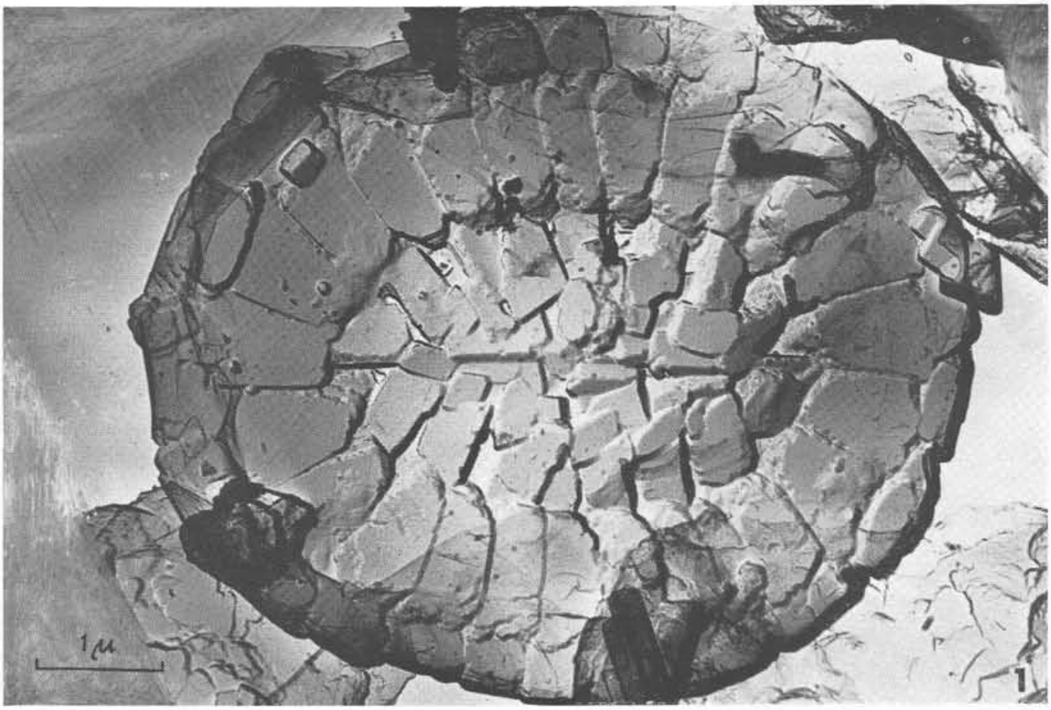

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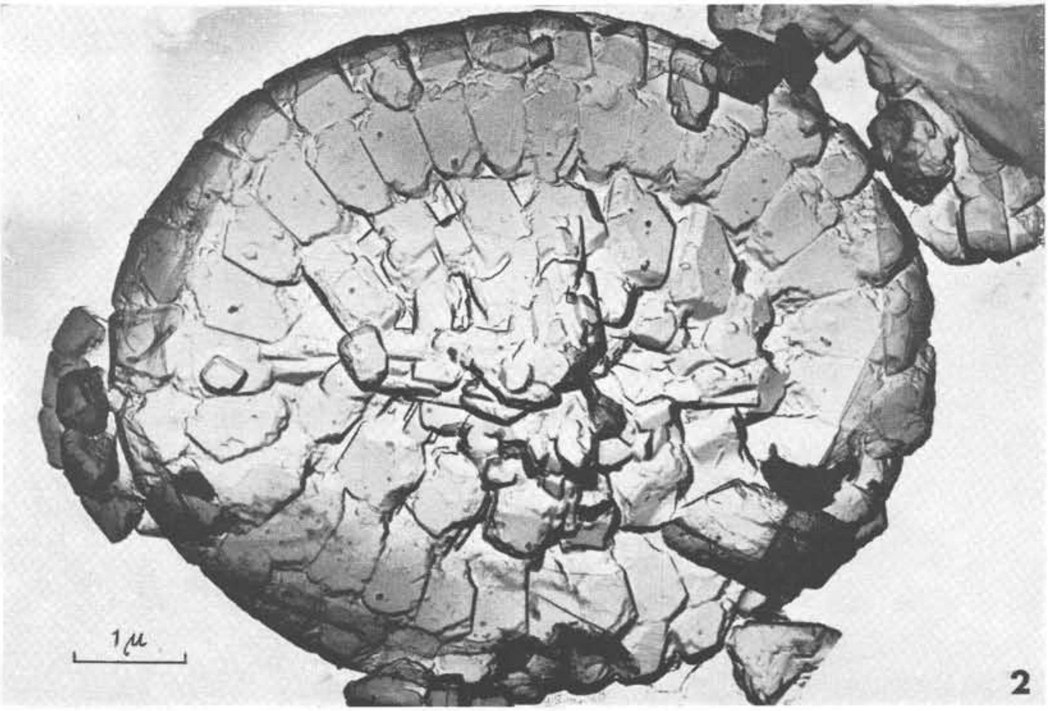

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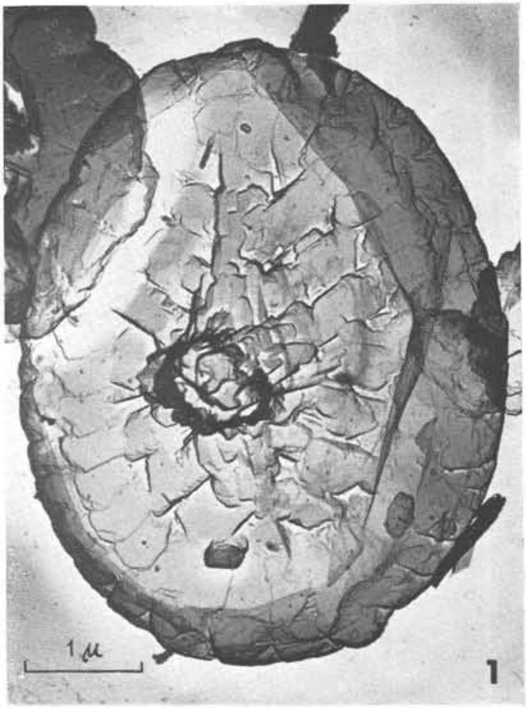

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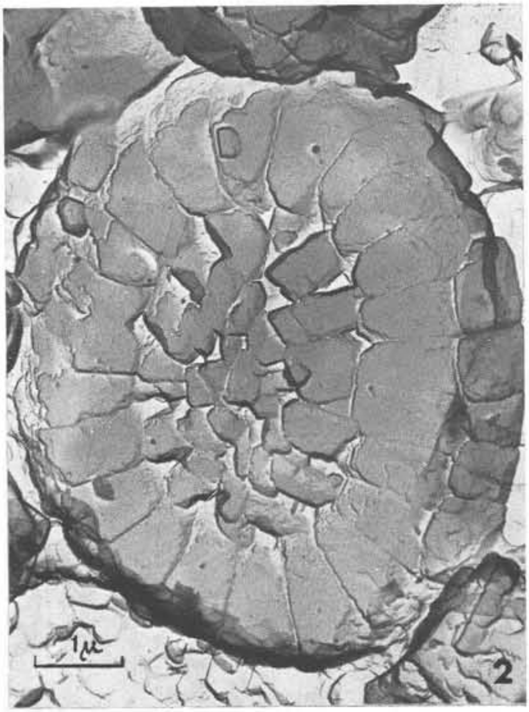

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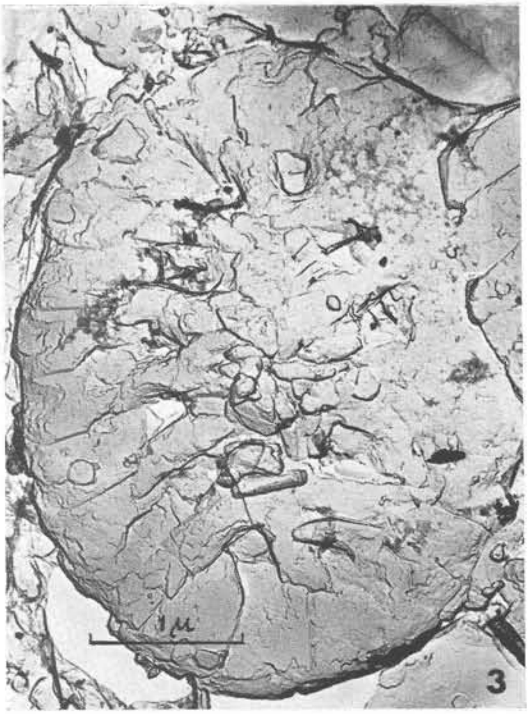

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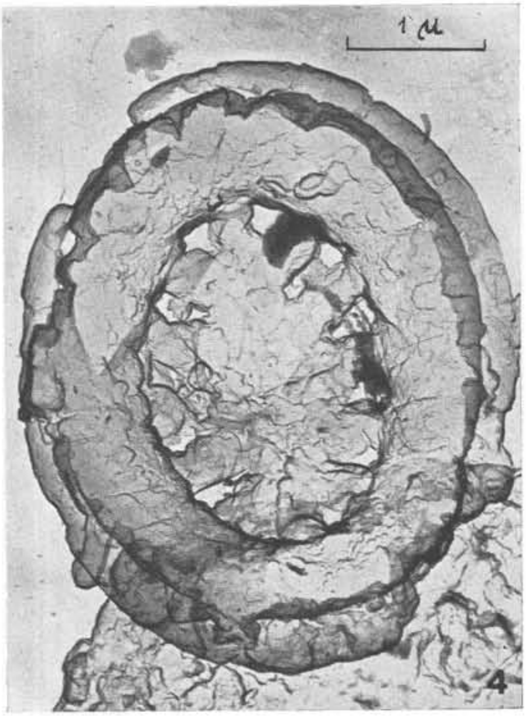

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PLATE 14

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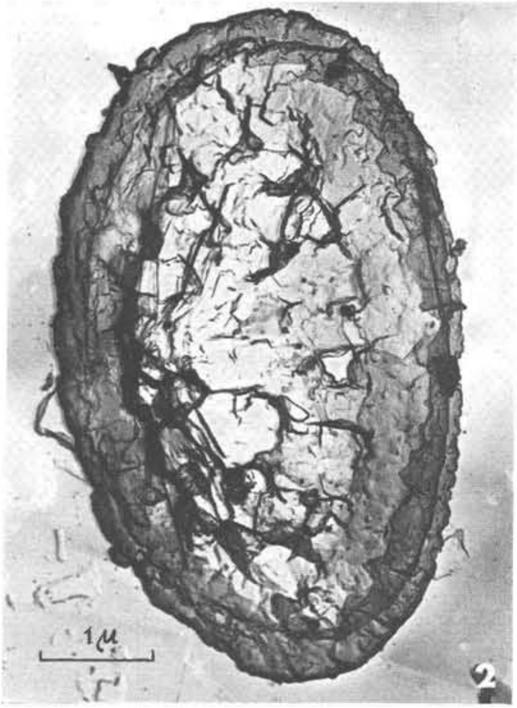

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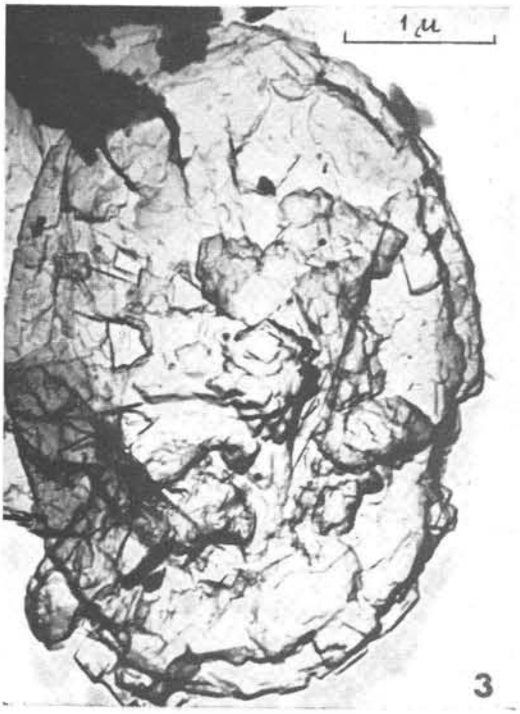

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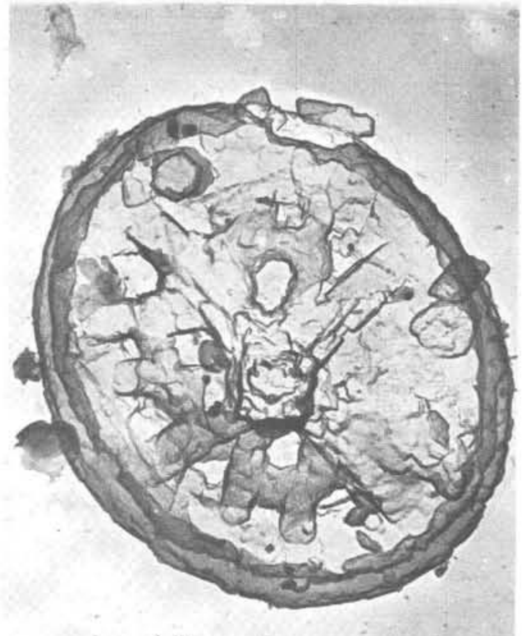

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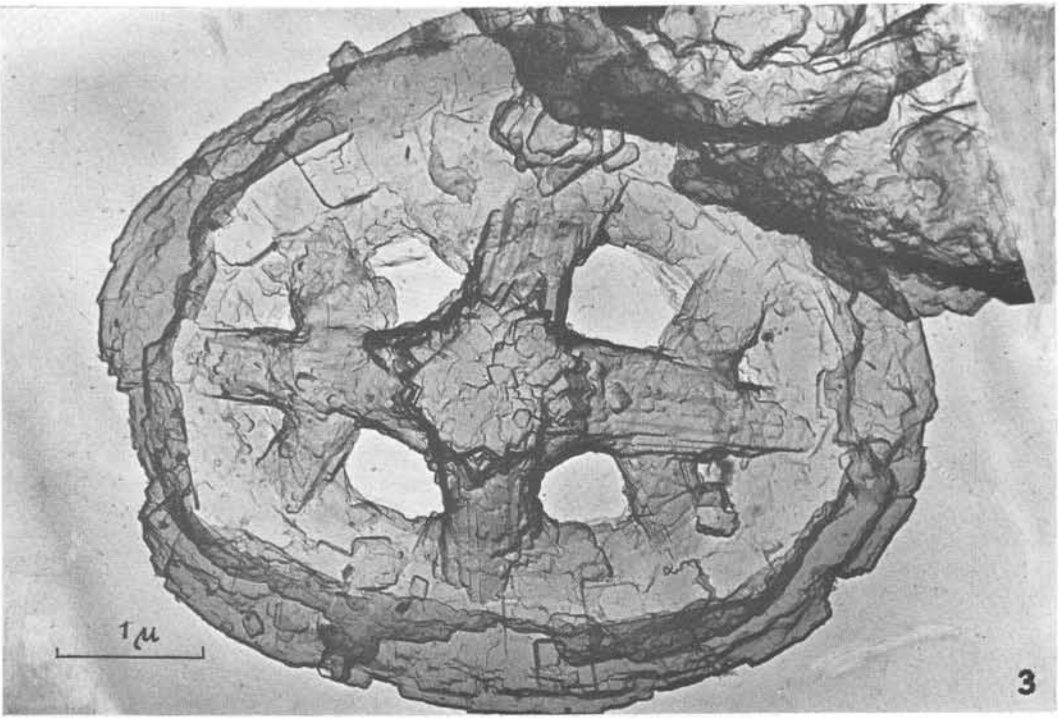

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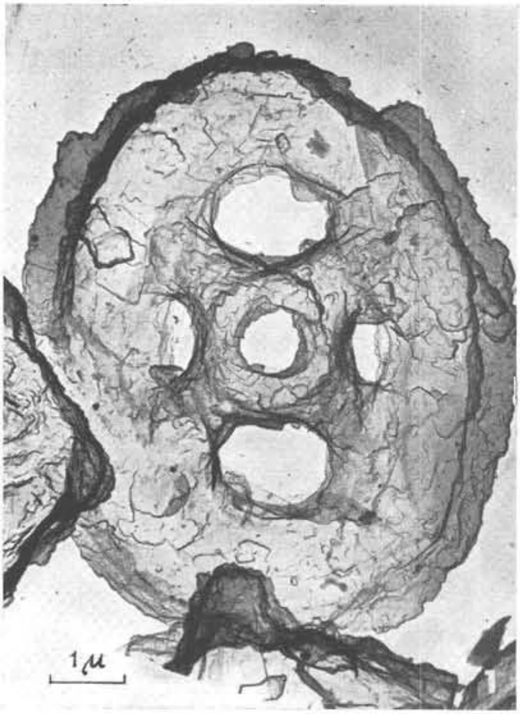

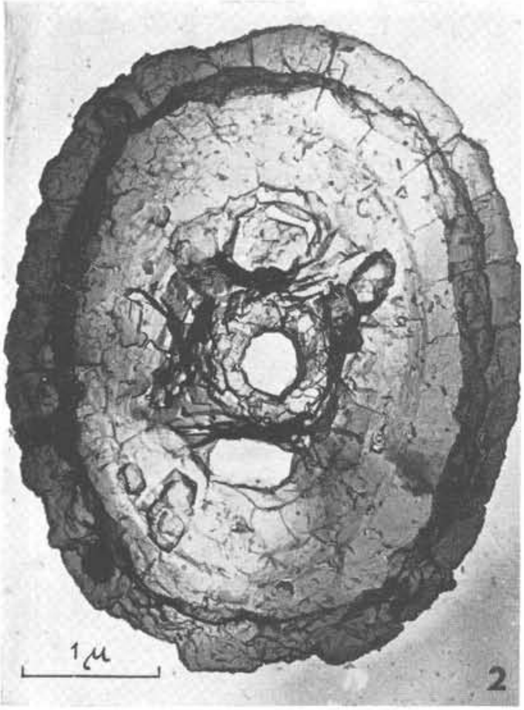

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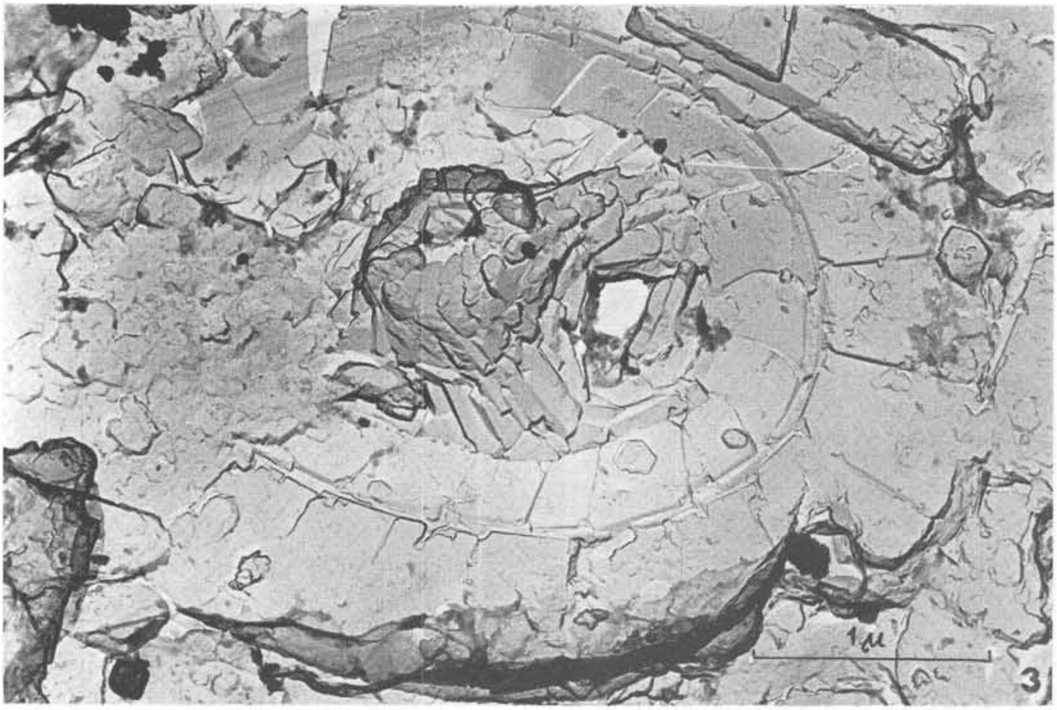

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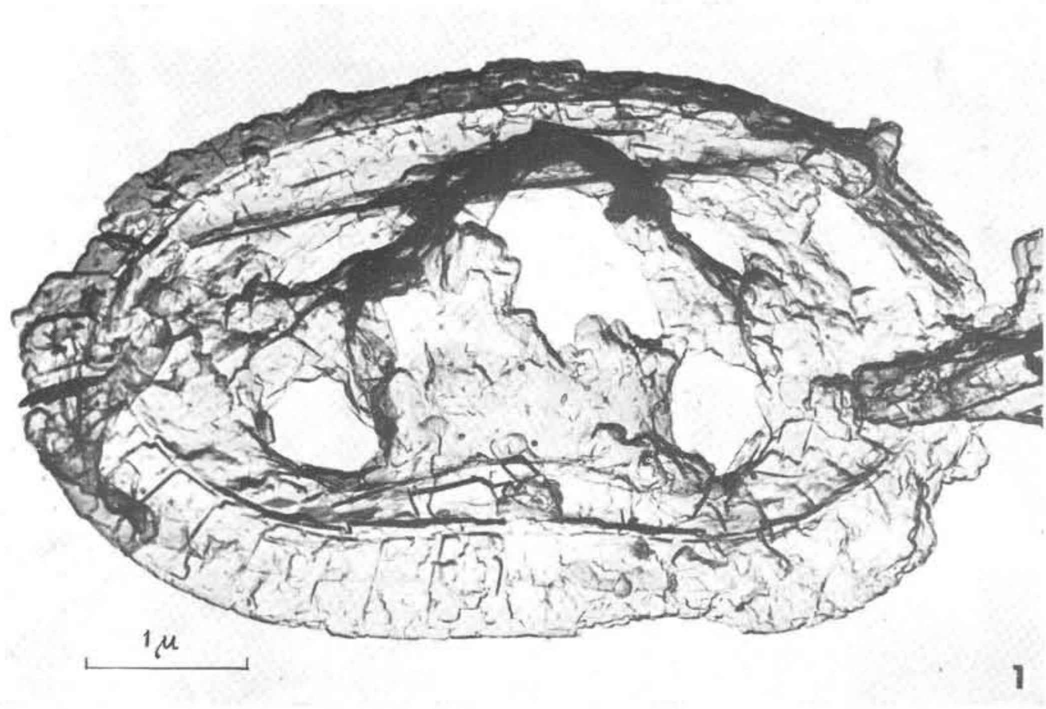
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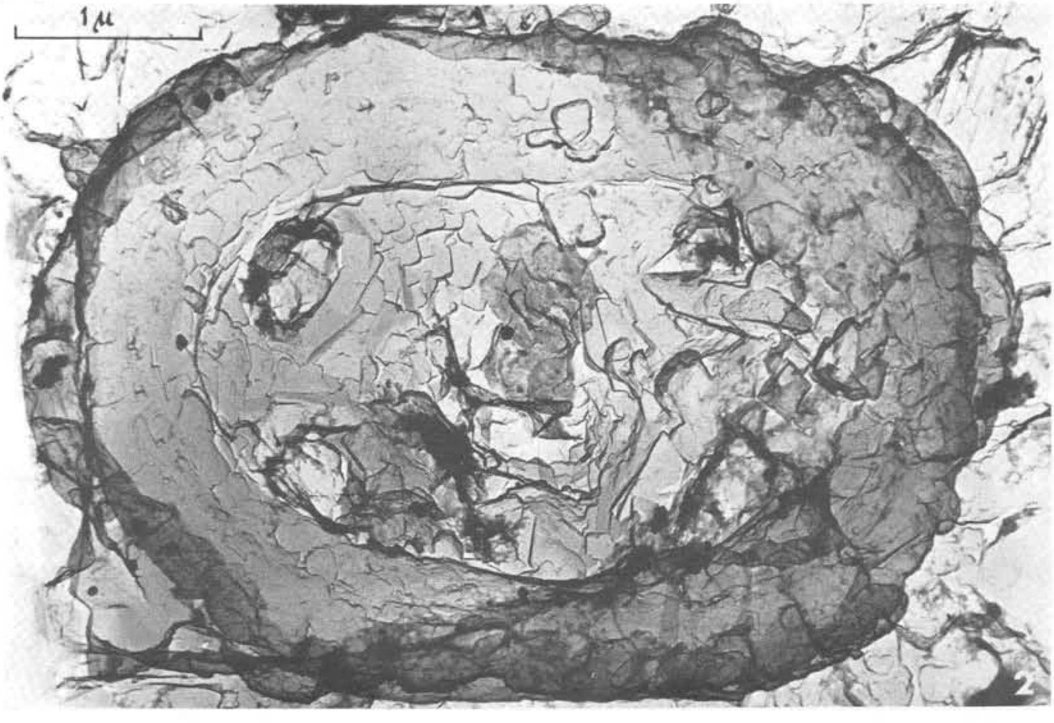
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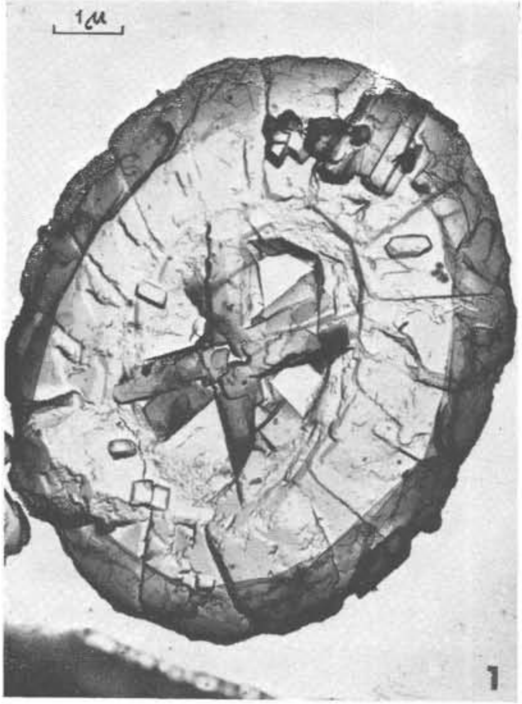

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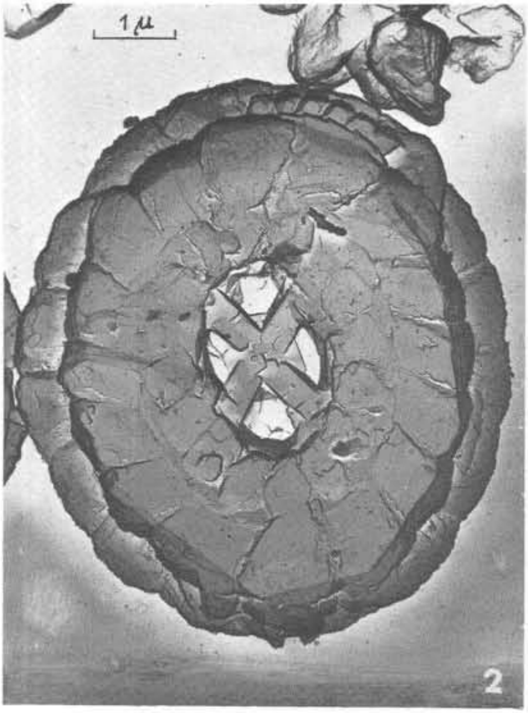

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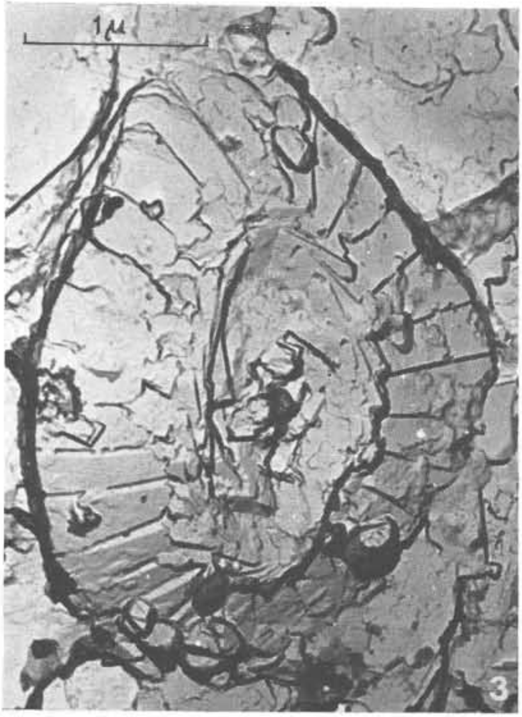

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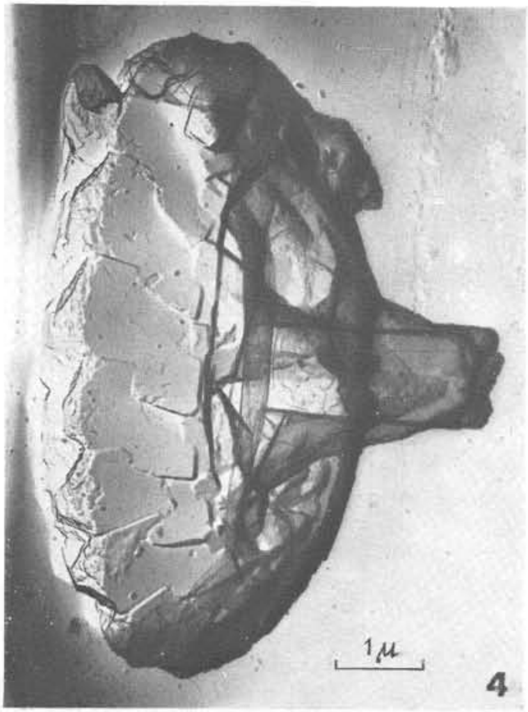

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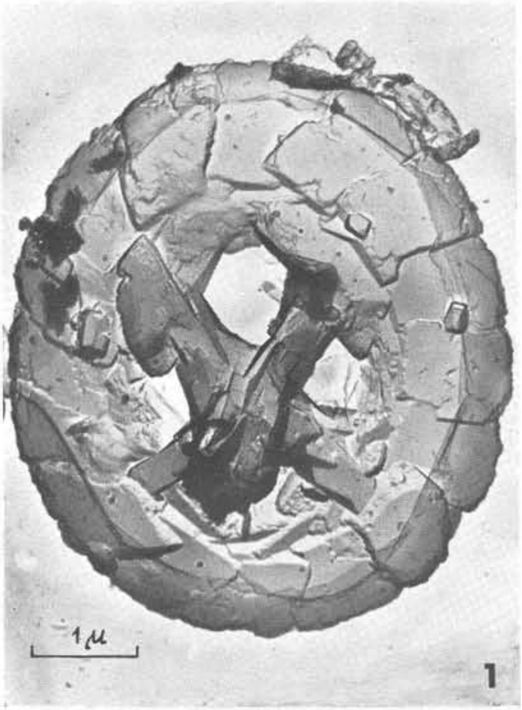

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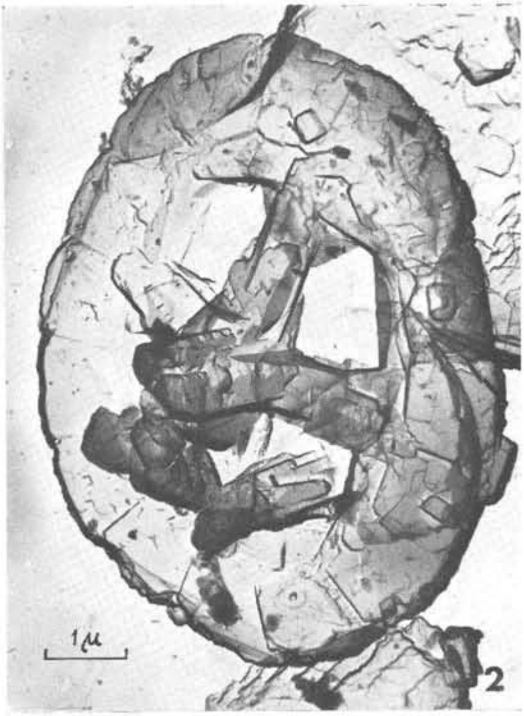

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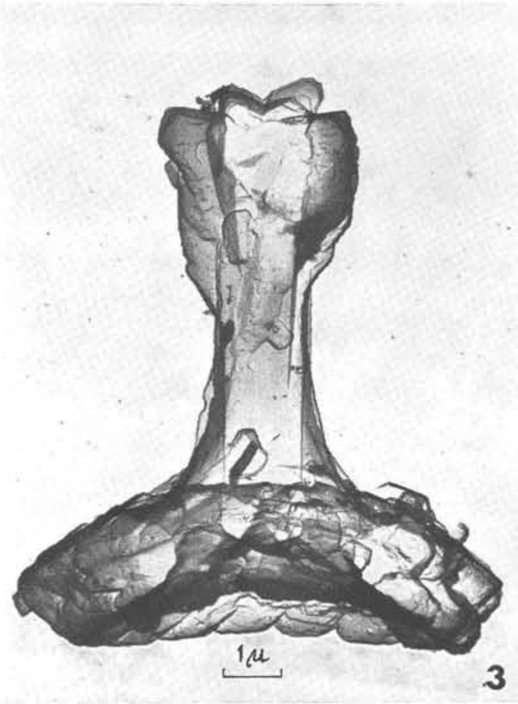

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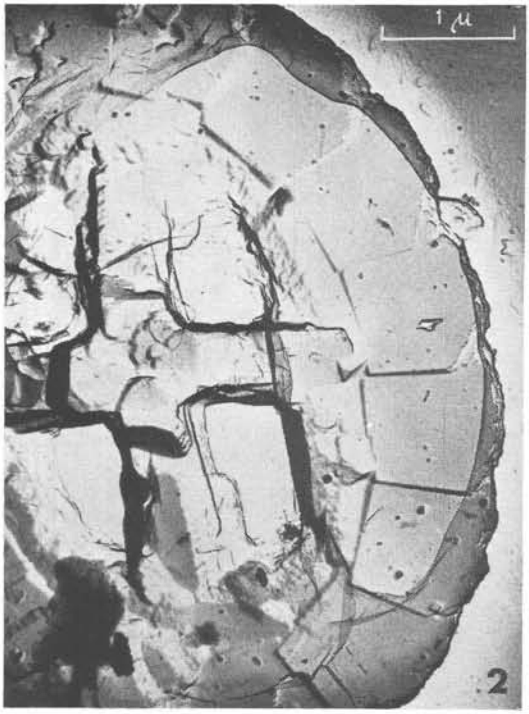
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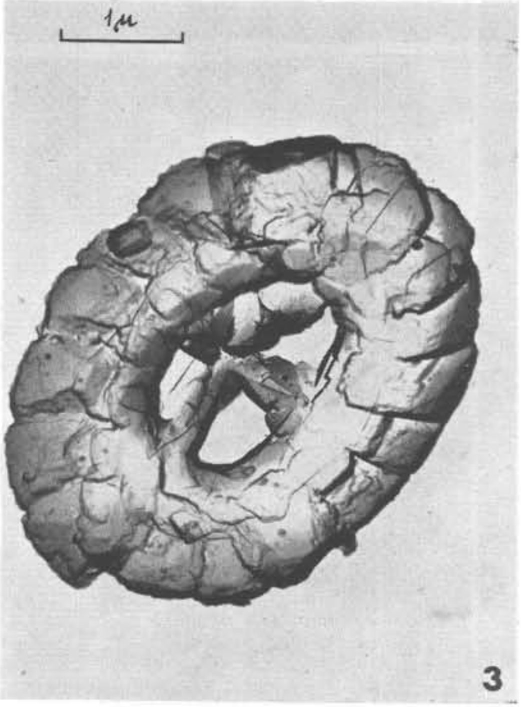
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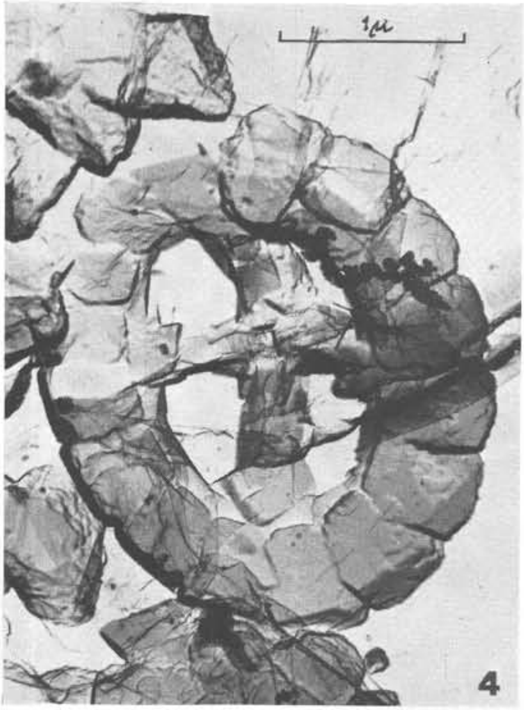
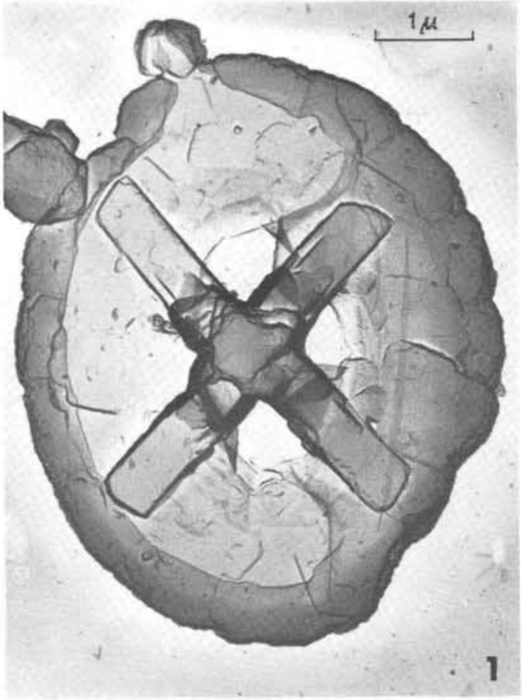

1μ
4



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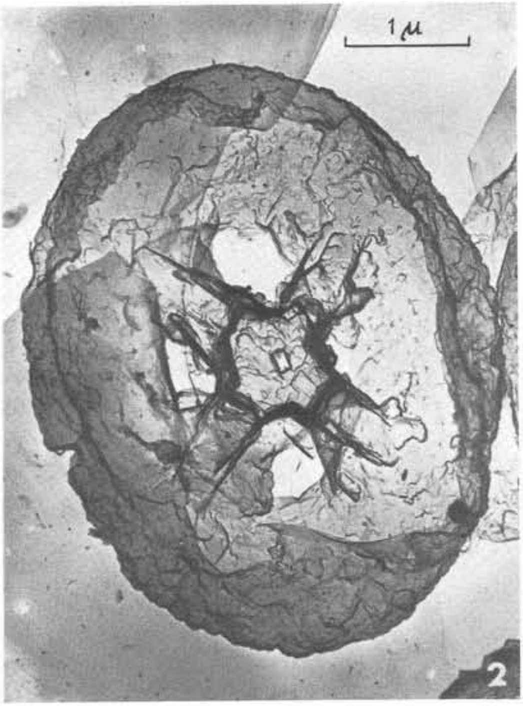

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3

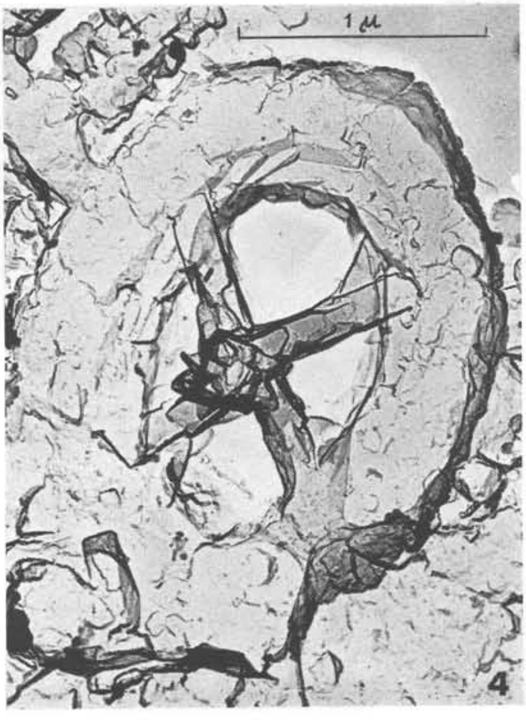

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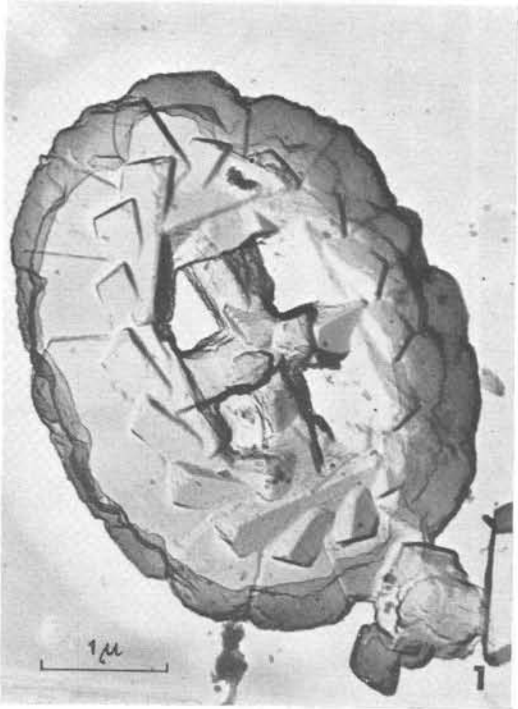
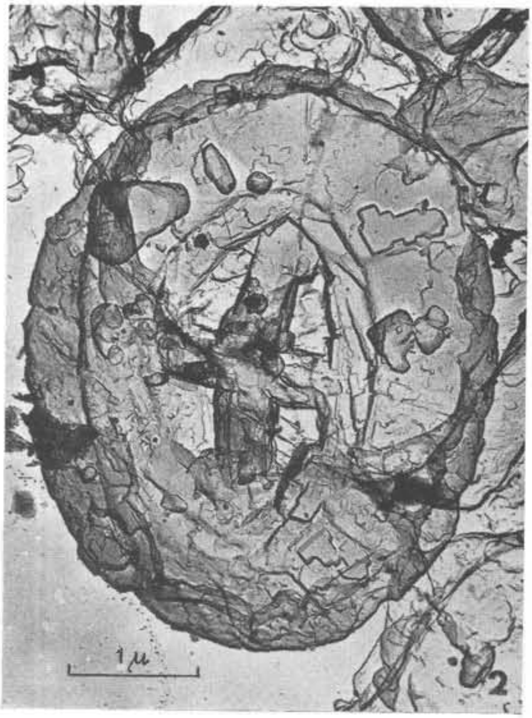
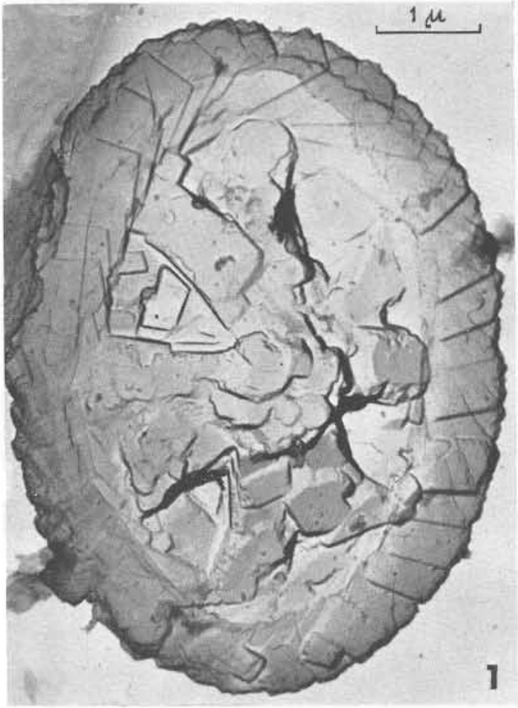
PLATE 22







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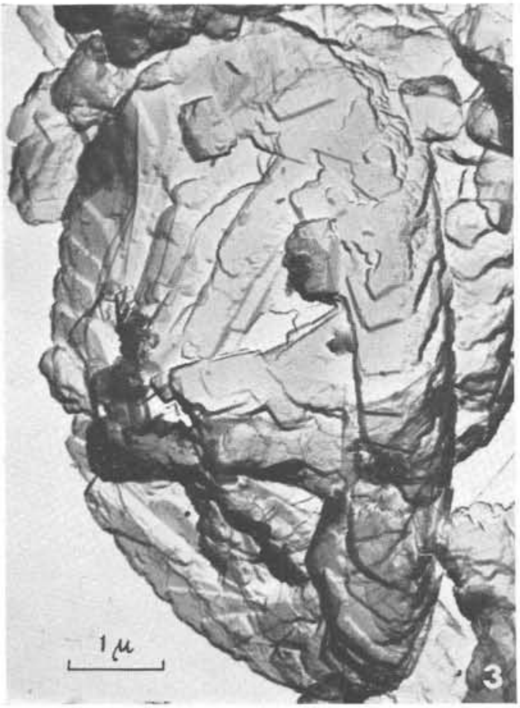

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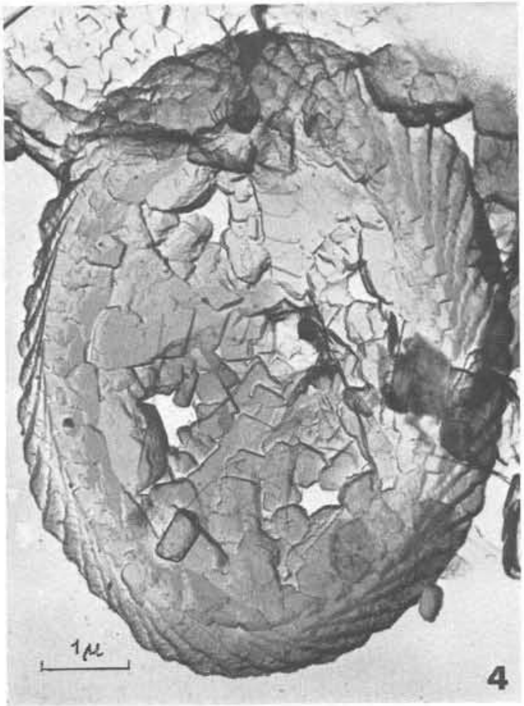

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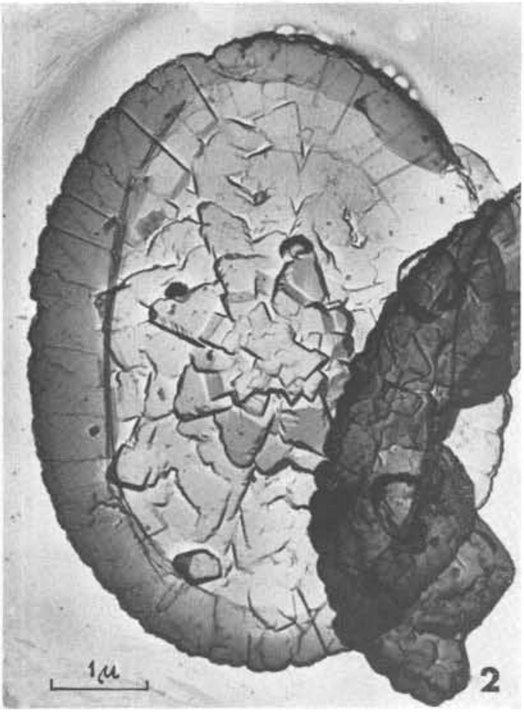
PLATE 24

1



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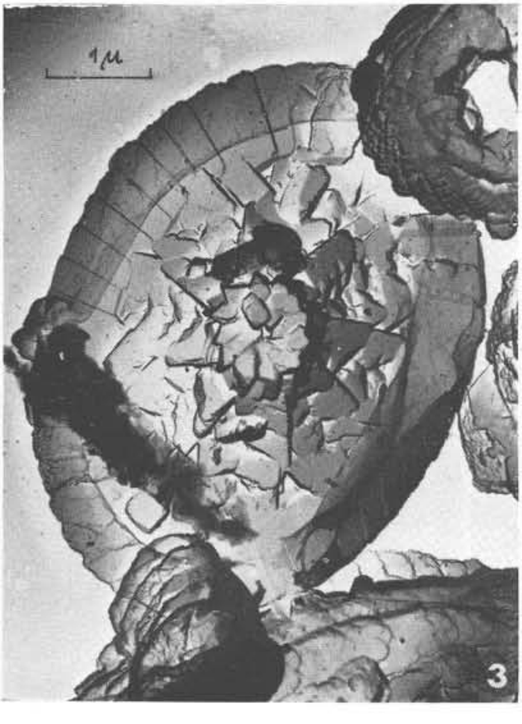

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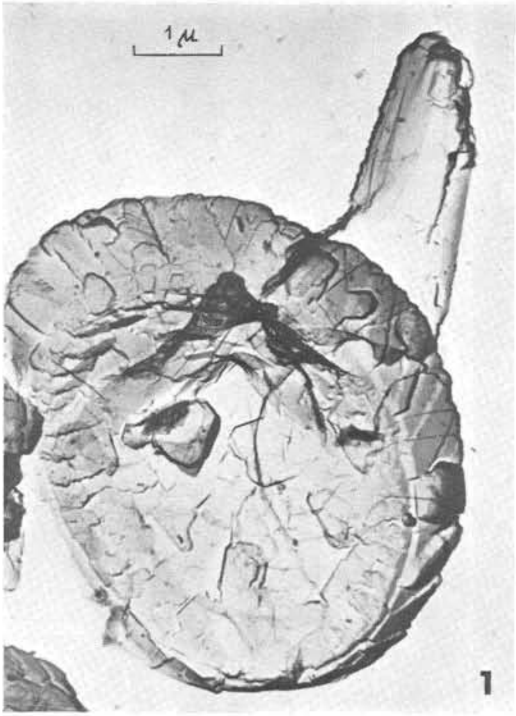
1 μ
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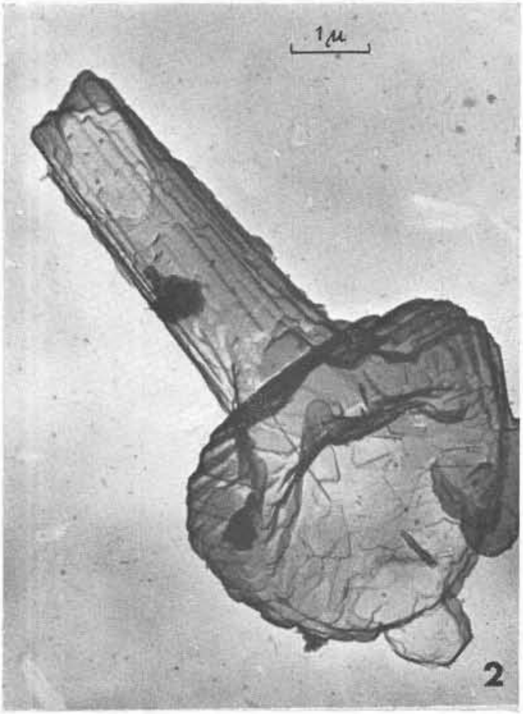
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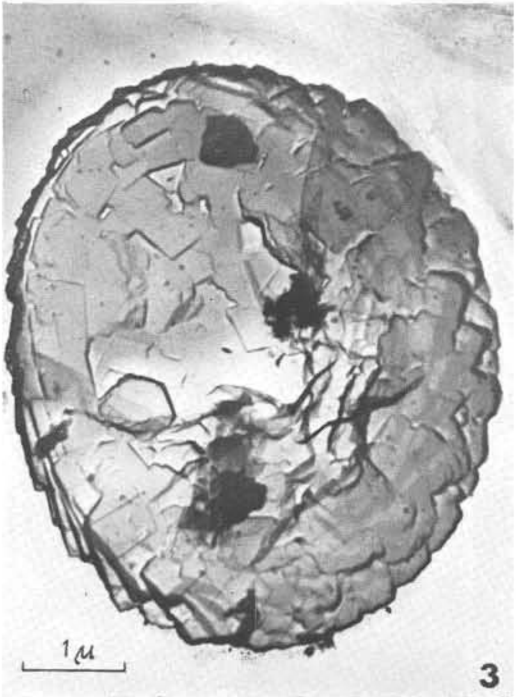
2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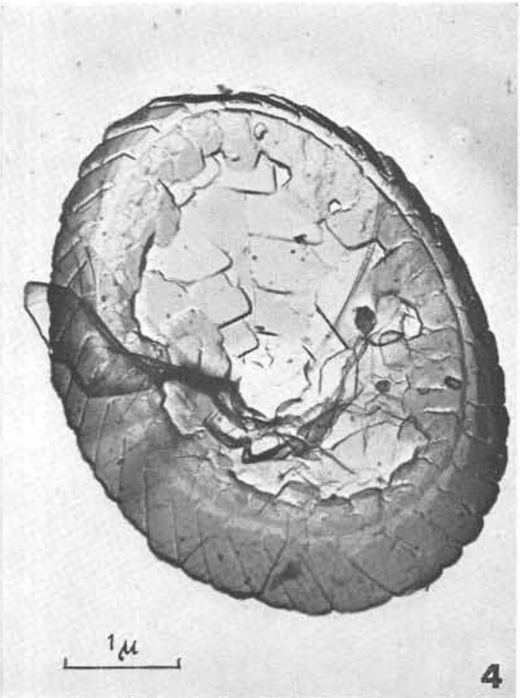
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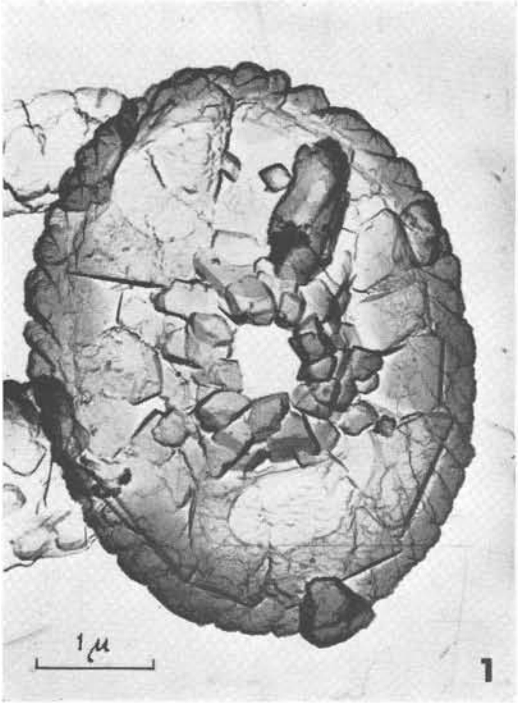
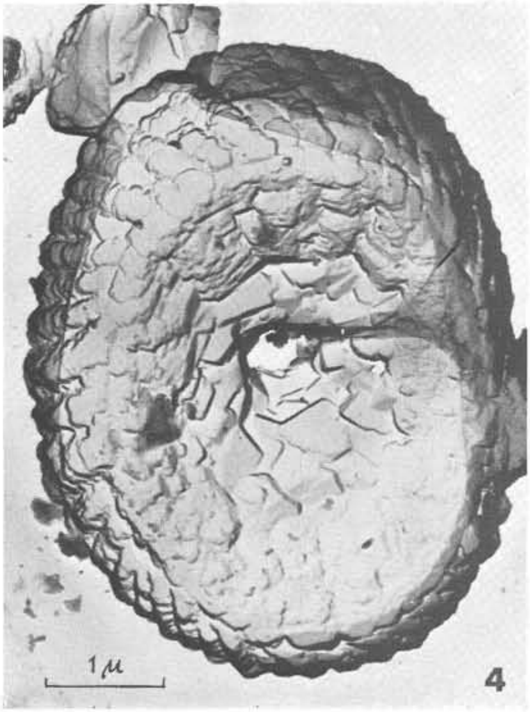

1μ
1


1μ
2


1μ
3


1μ
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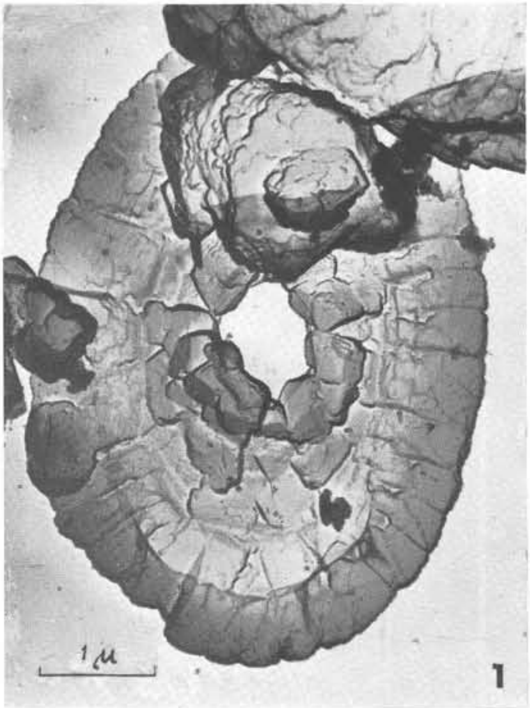
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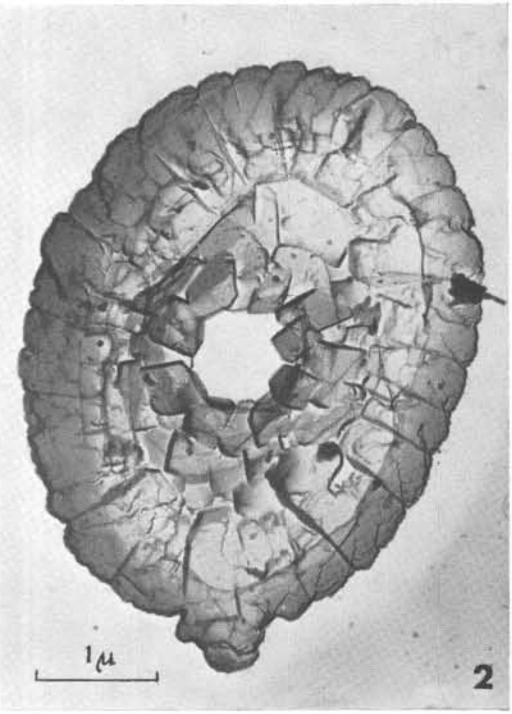
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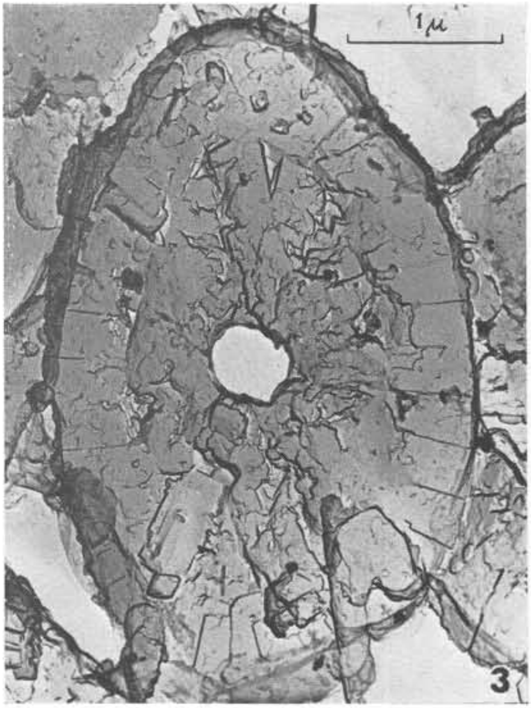
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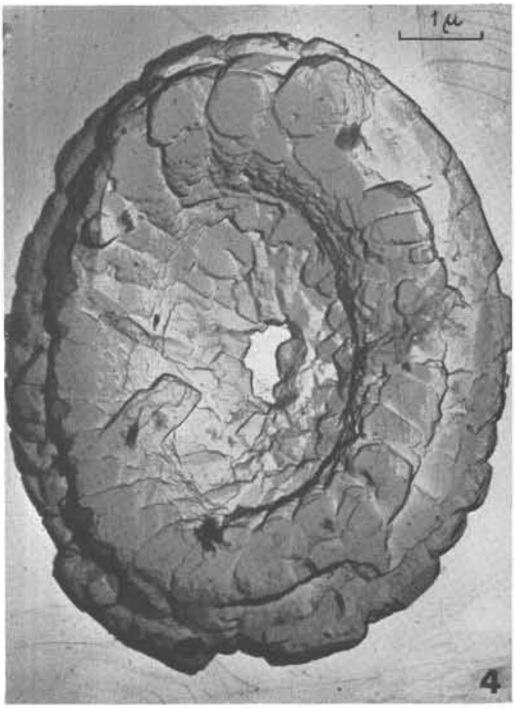
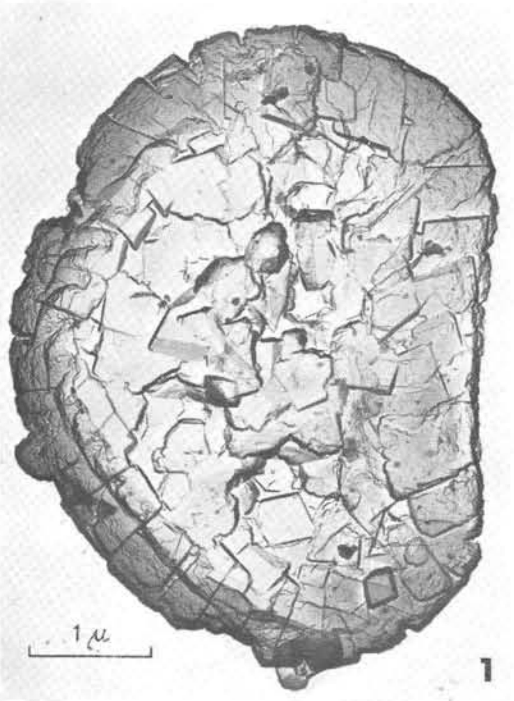

1 μ
4

PLATE 28



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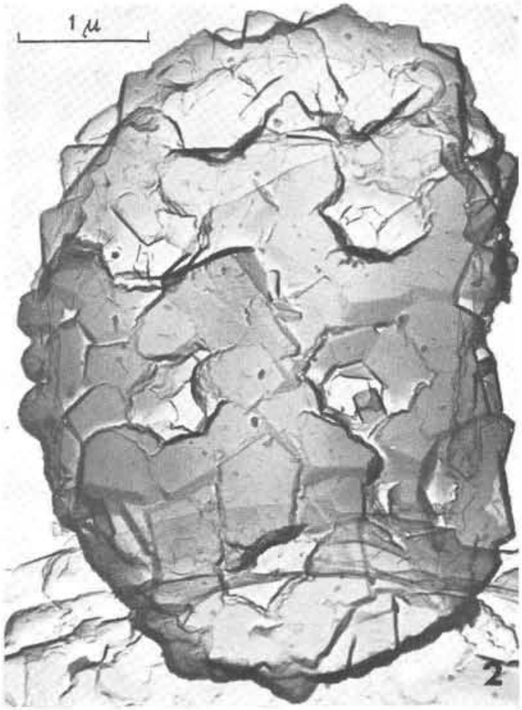

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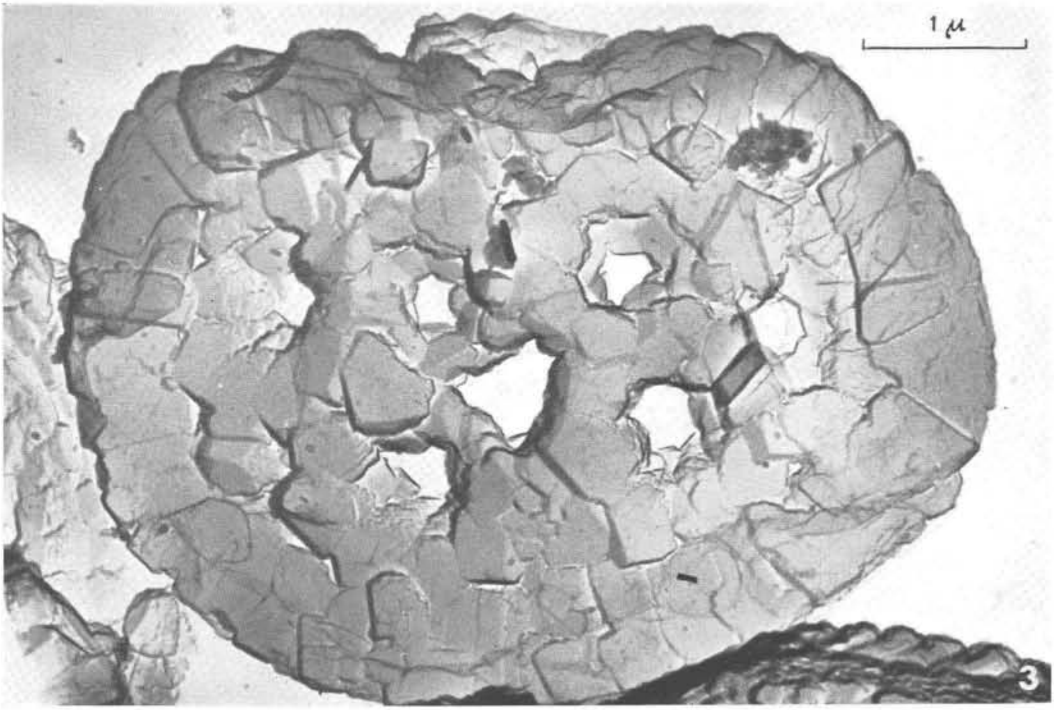

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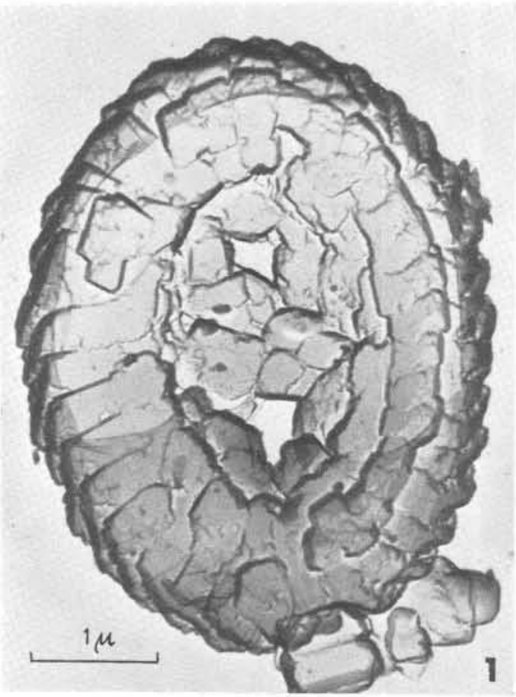
1μ
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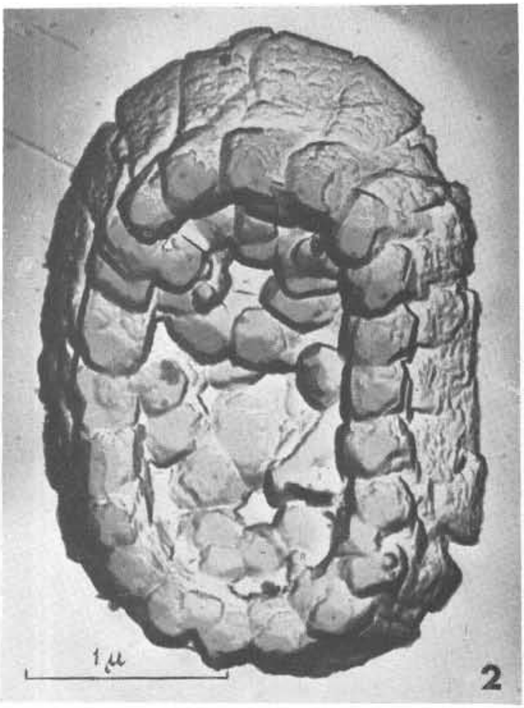
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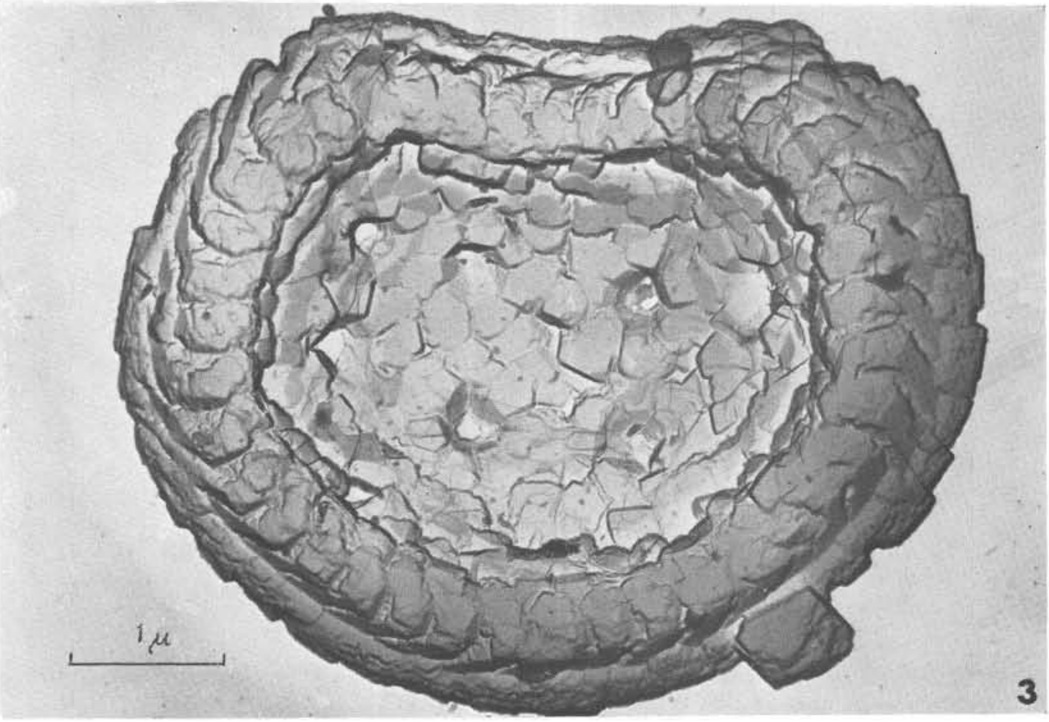
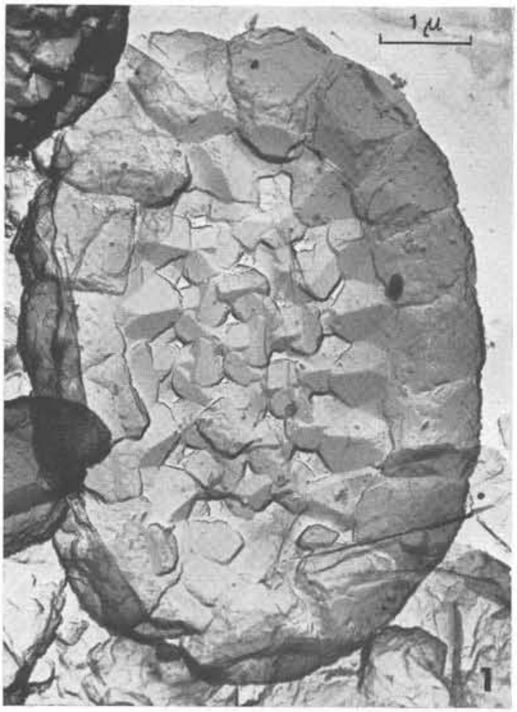

1μ
3

PLATE 30



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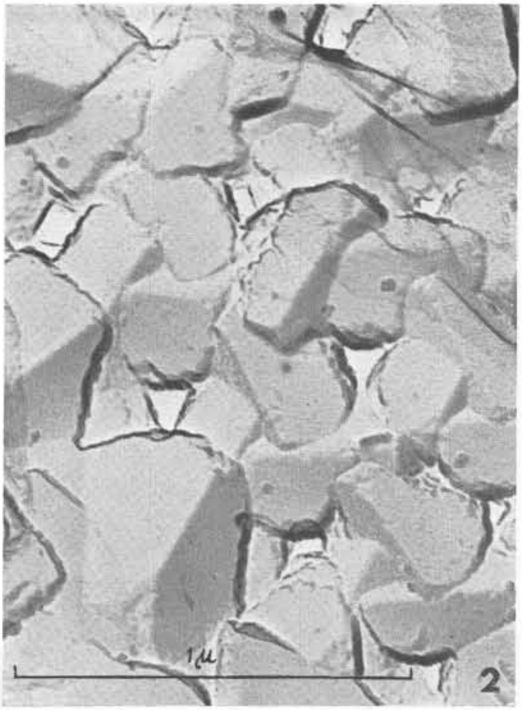

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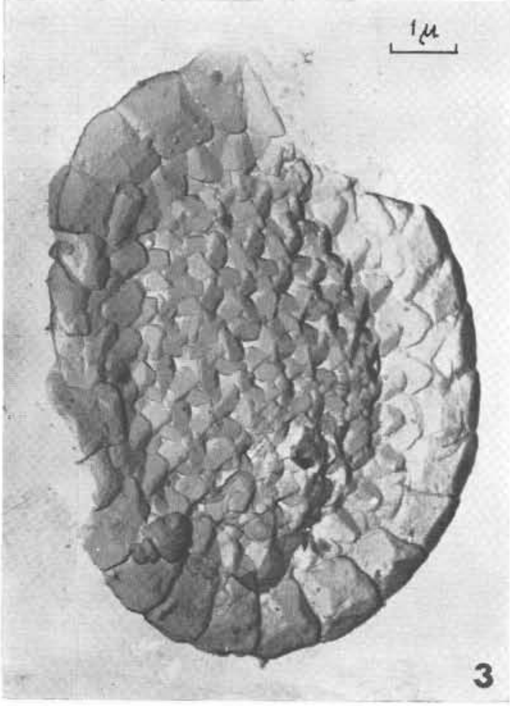

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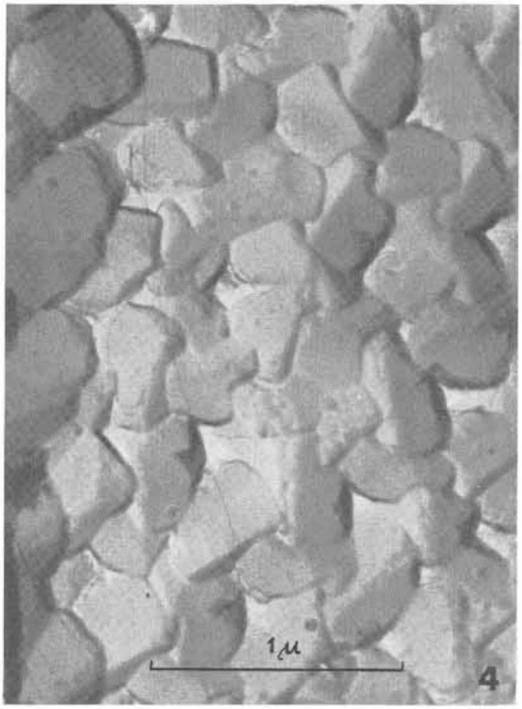

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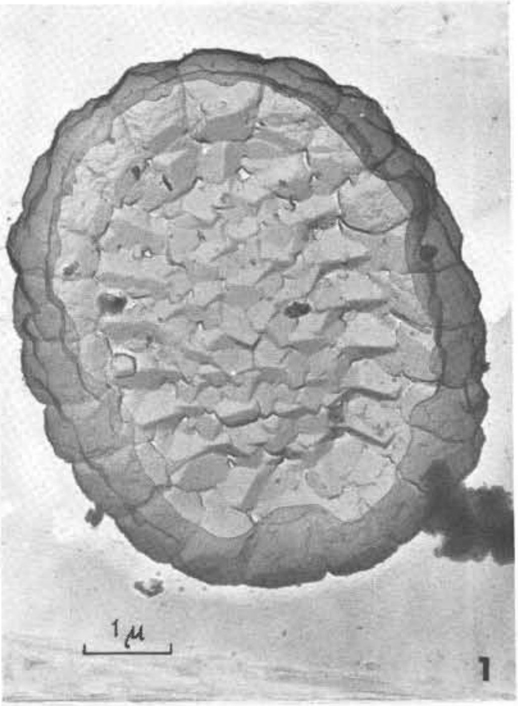

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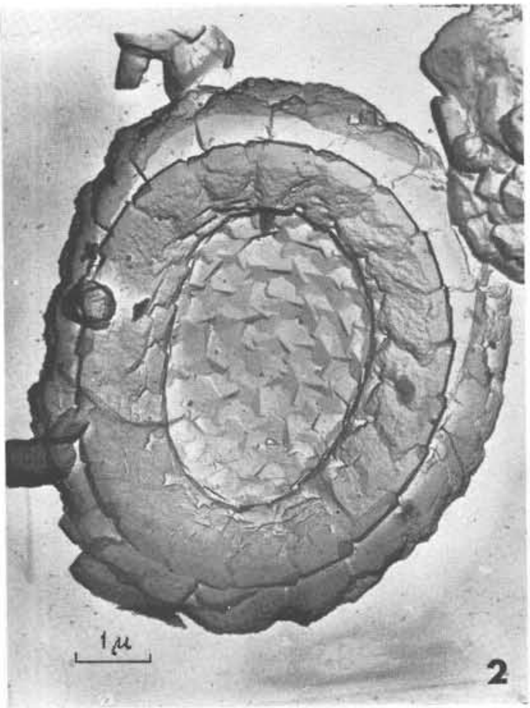

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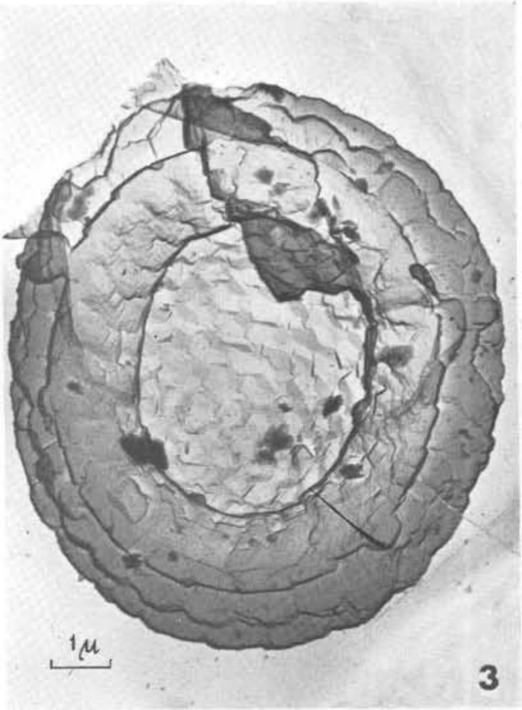

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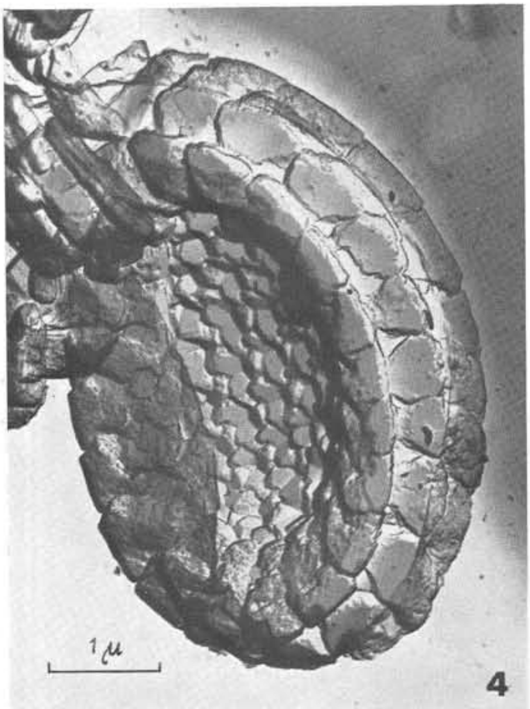

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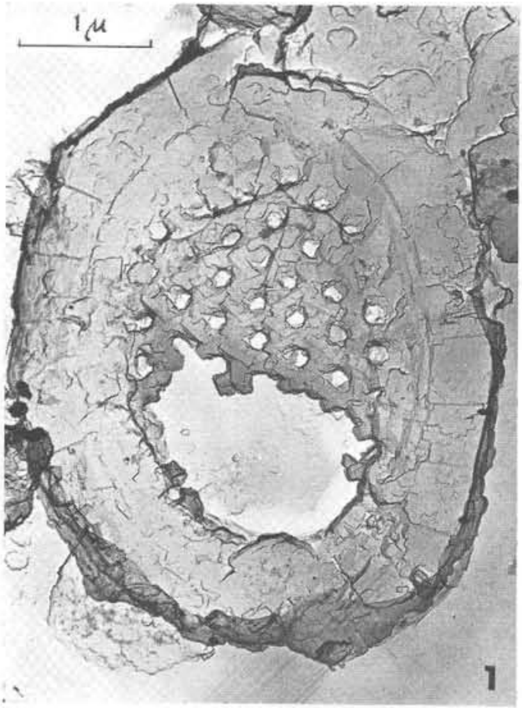
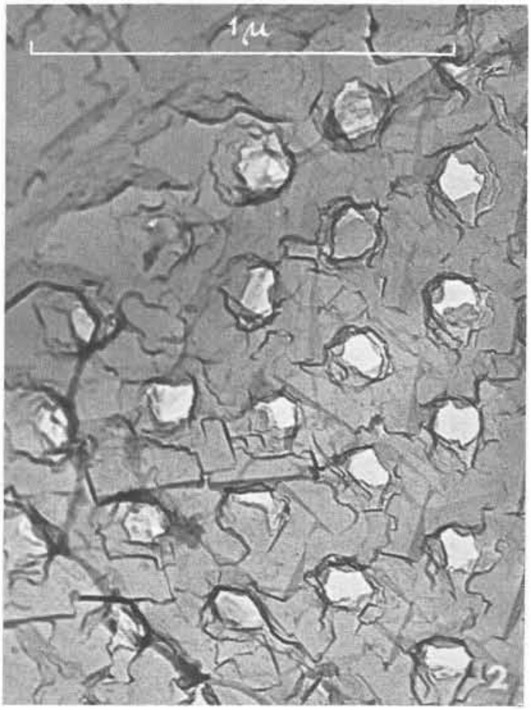
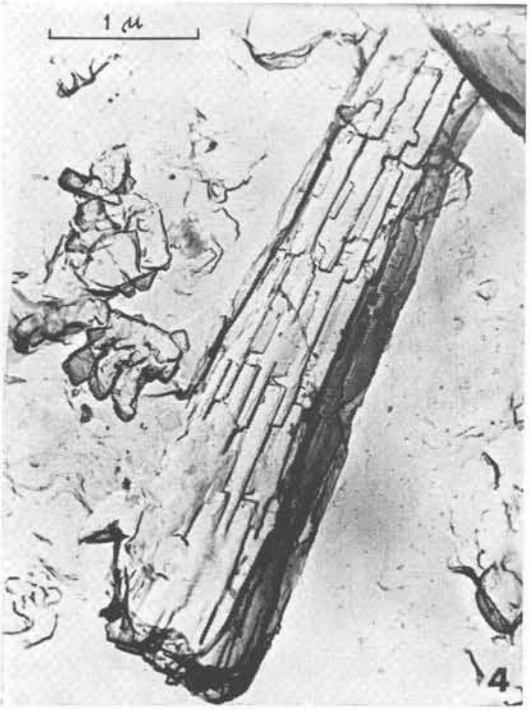
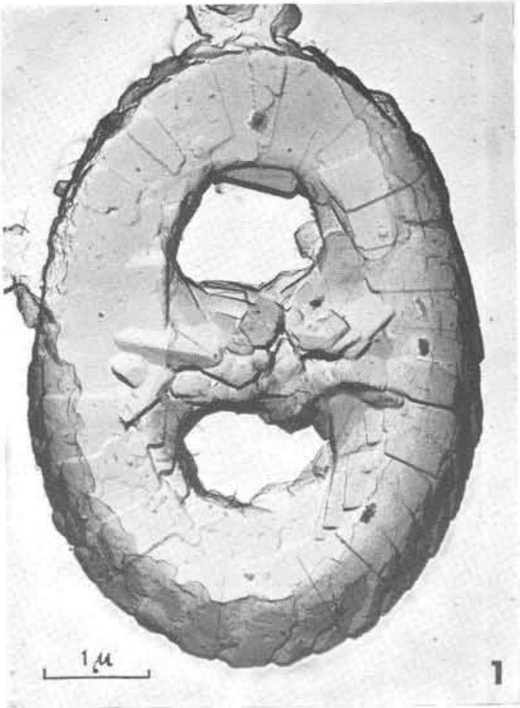
PLATE 32









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2

3

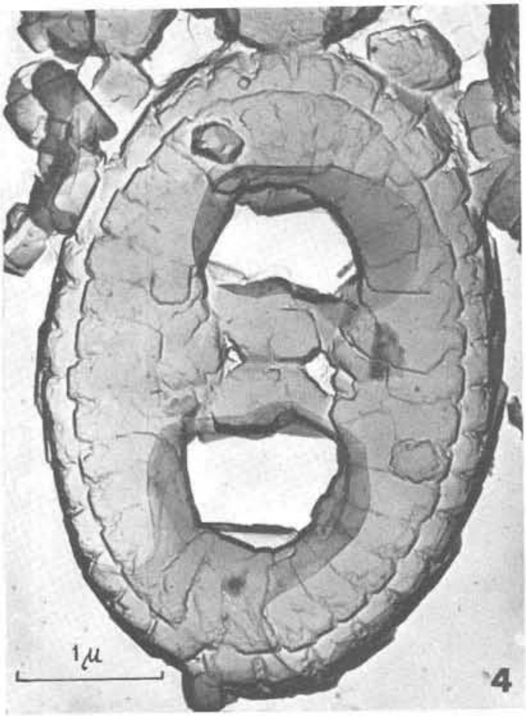

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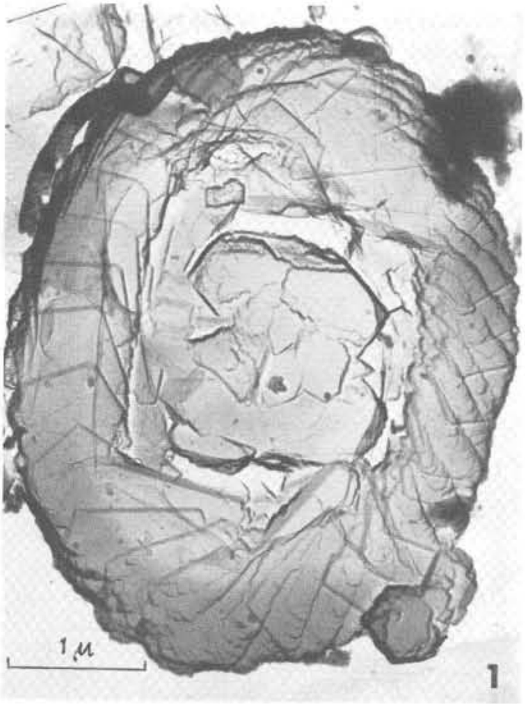
PLATE 34



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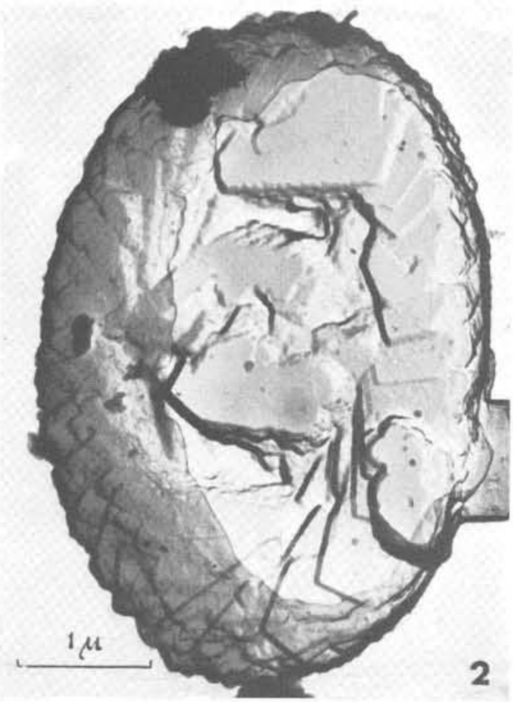

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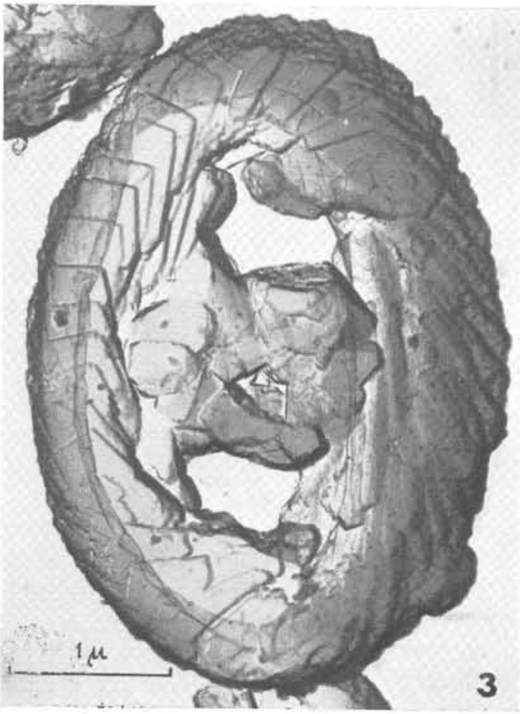

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4

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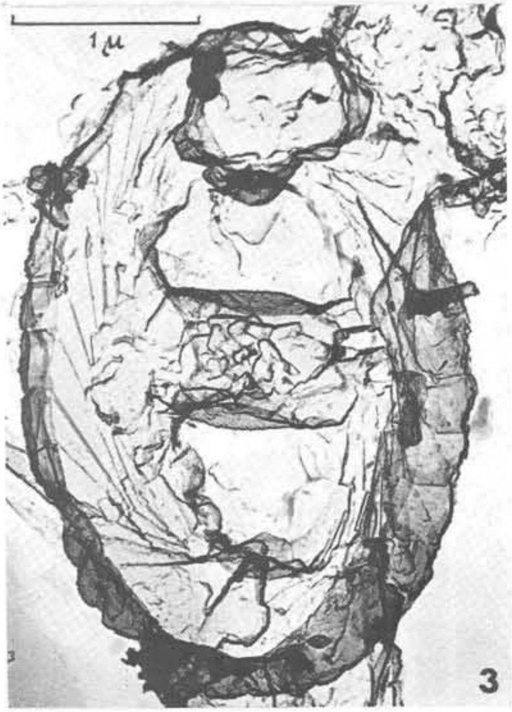

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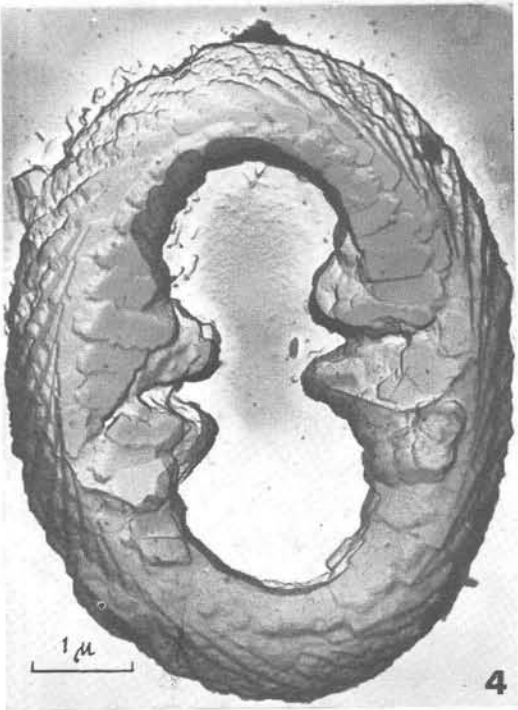

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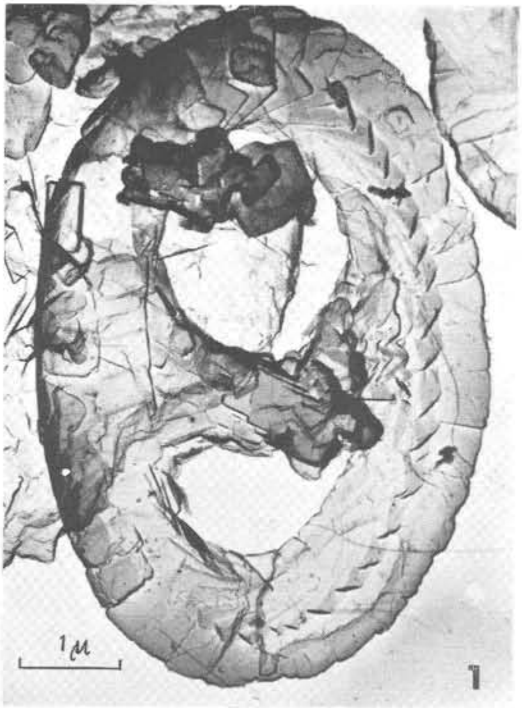

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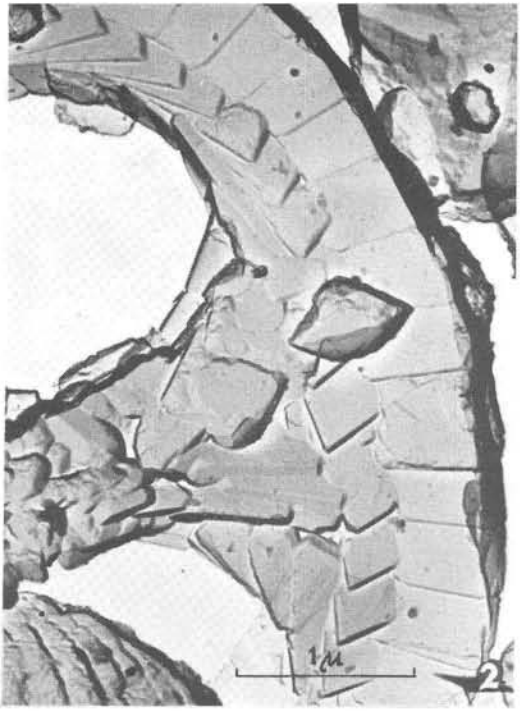

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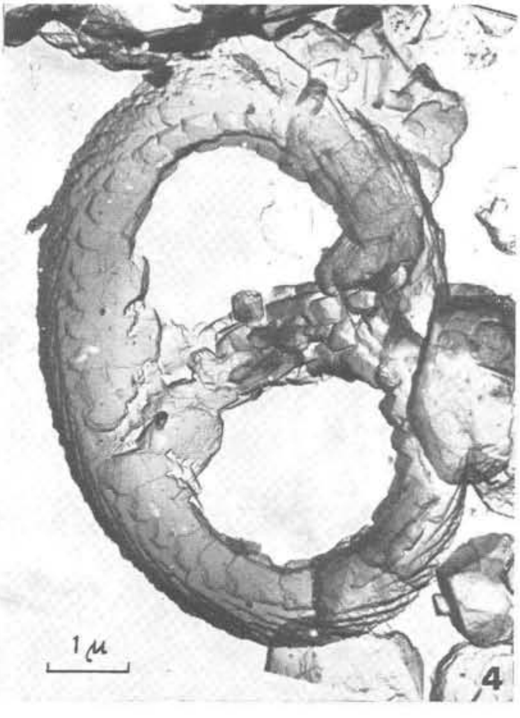

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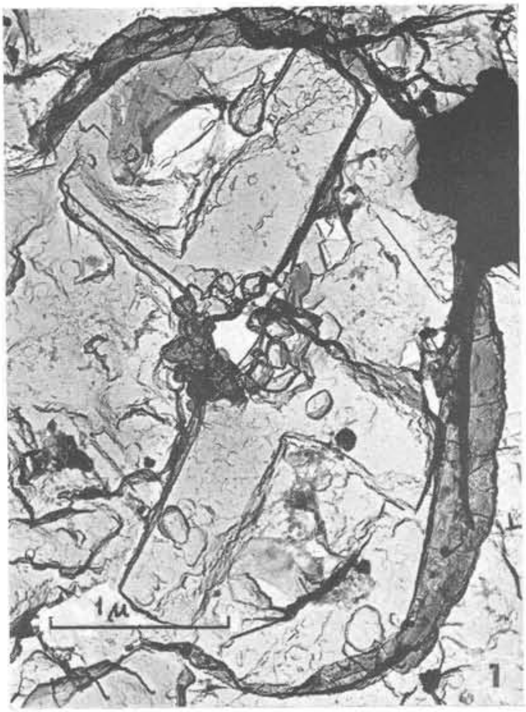
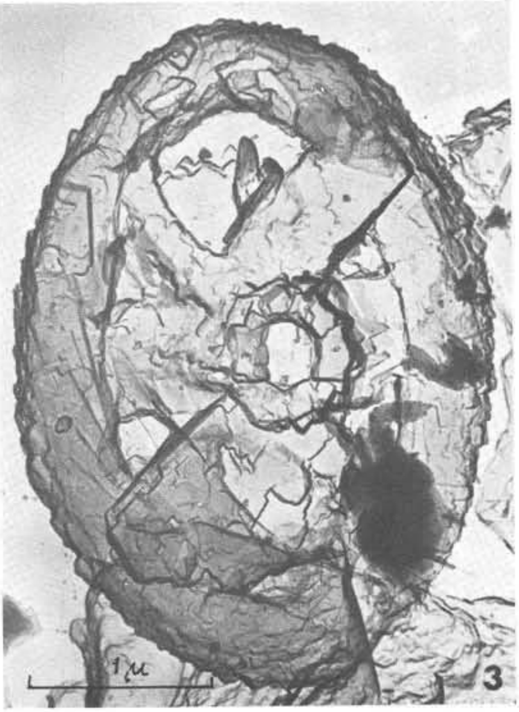
PLATE 37





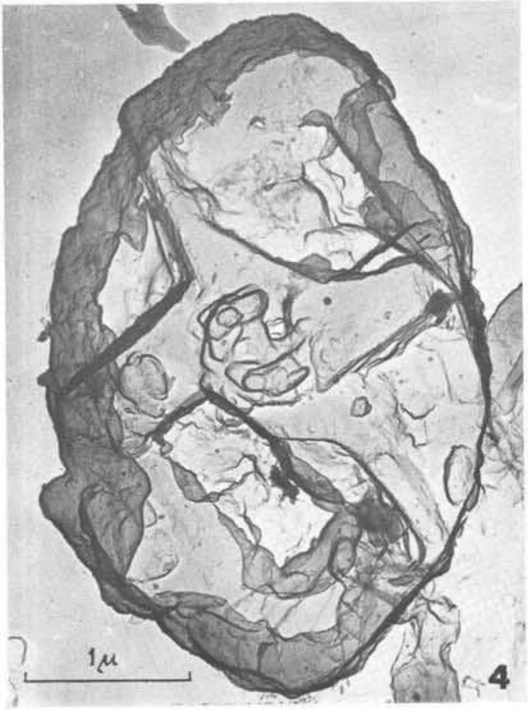
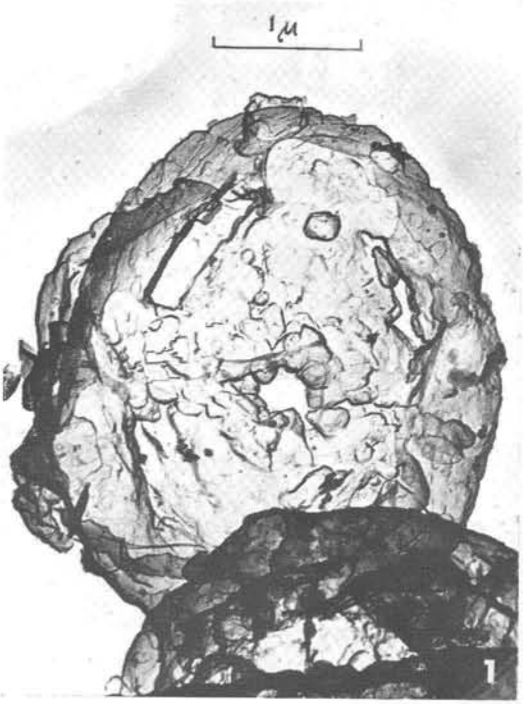
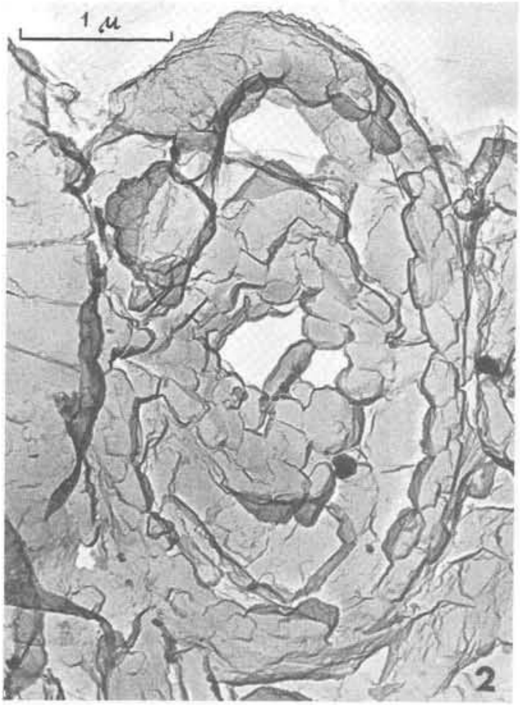
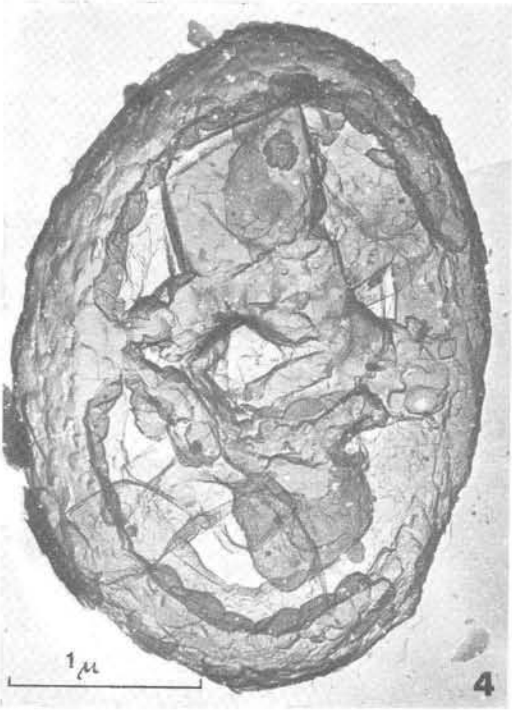


PLATE 38







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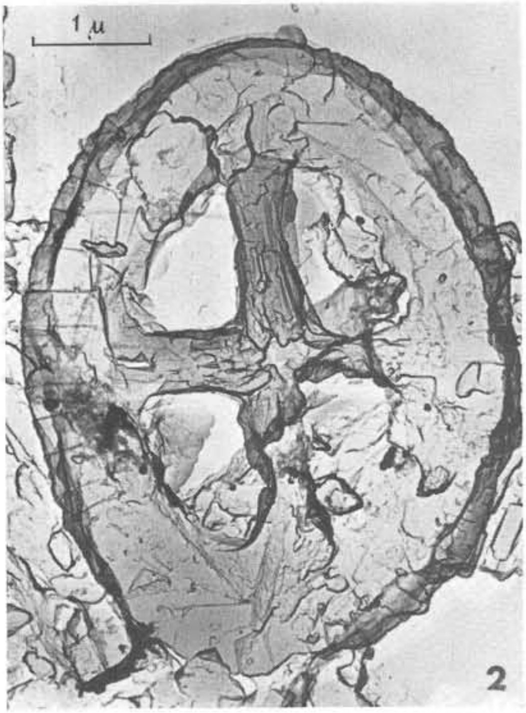

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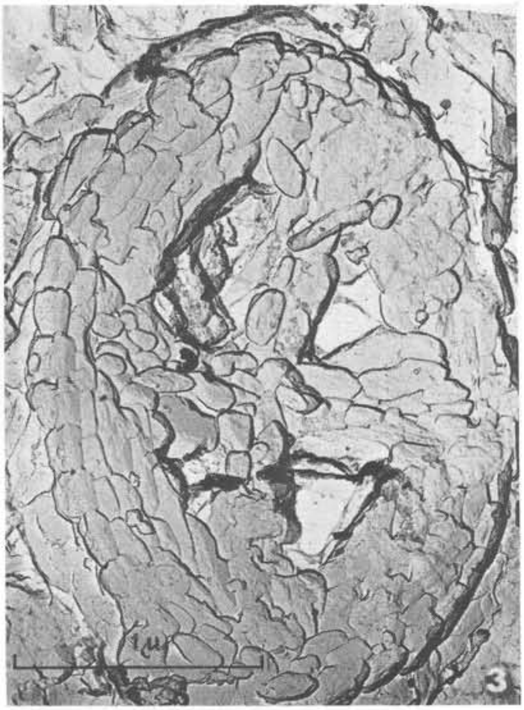

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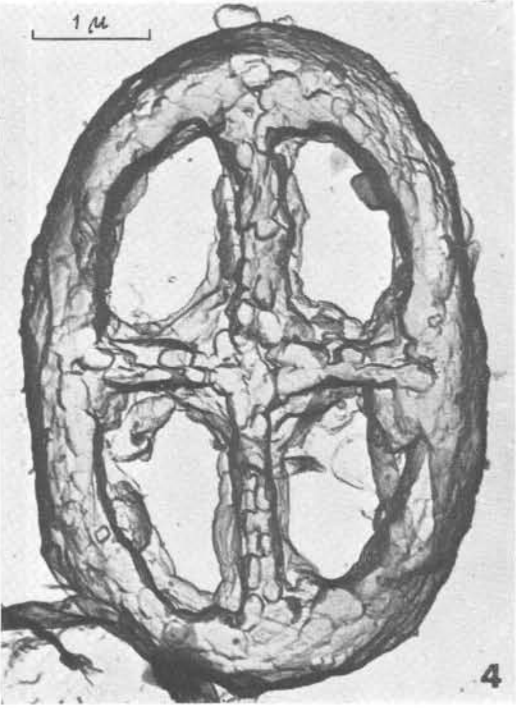

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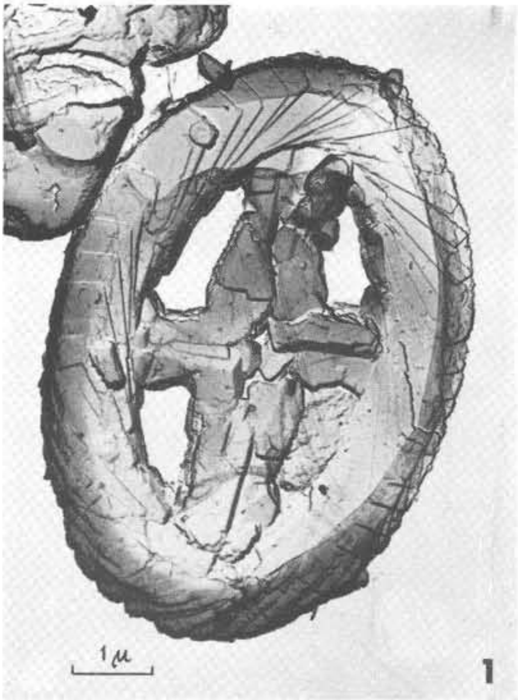

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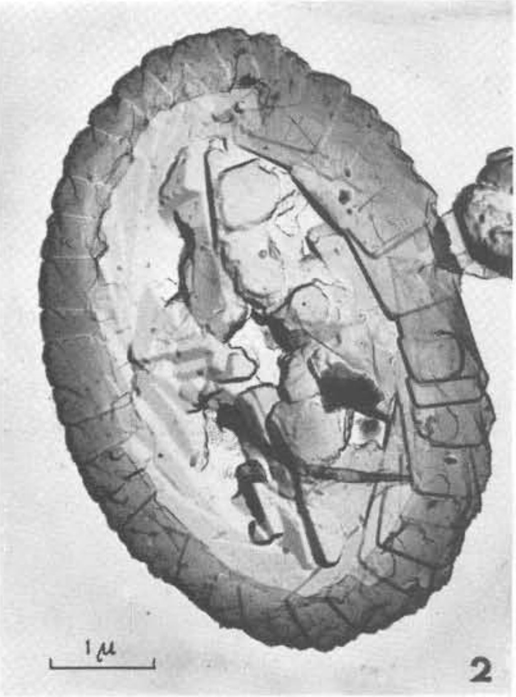

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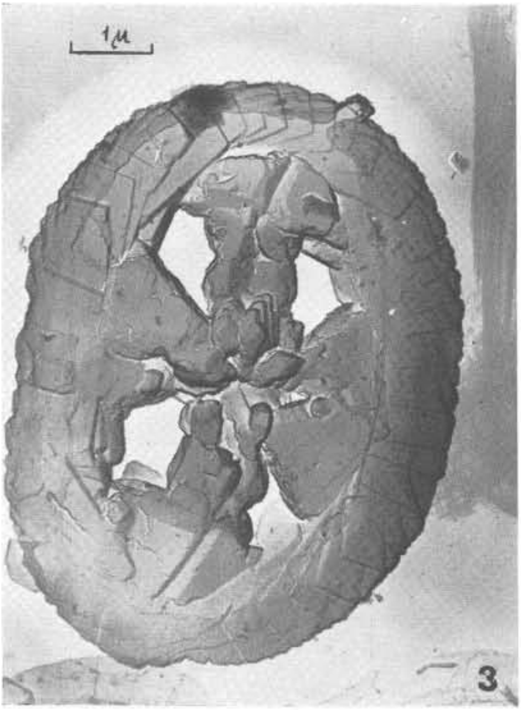

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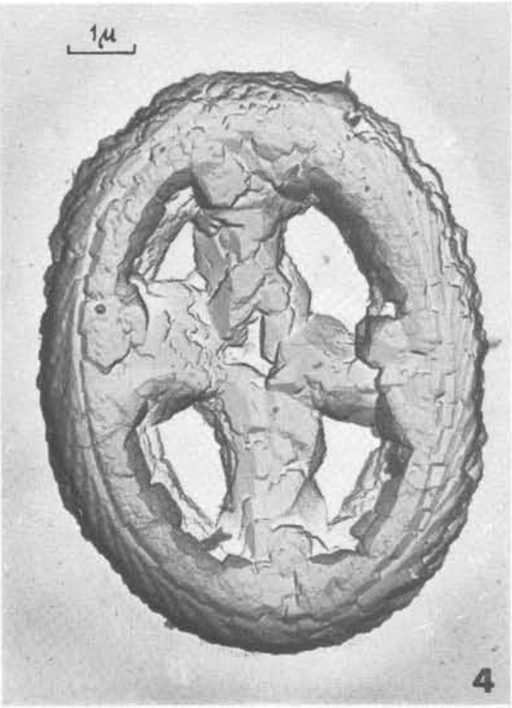

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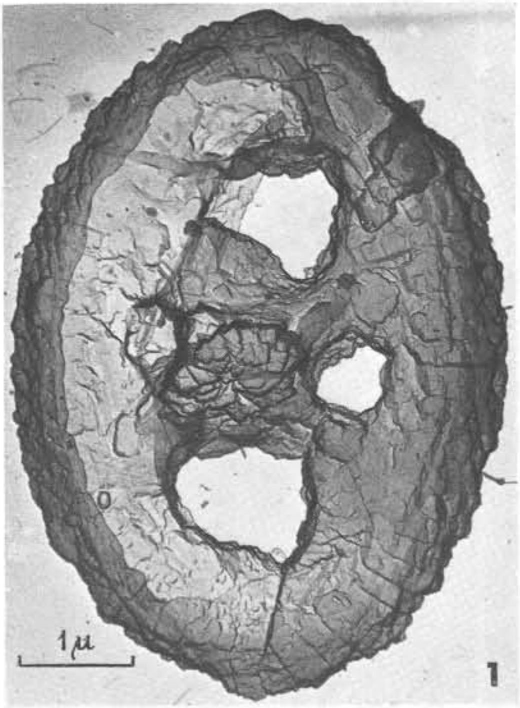
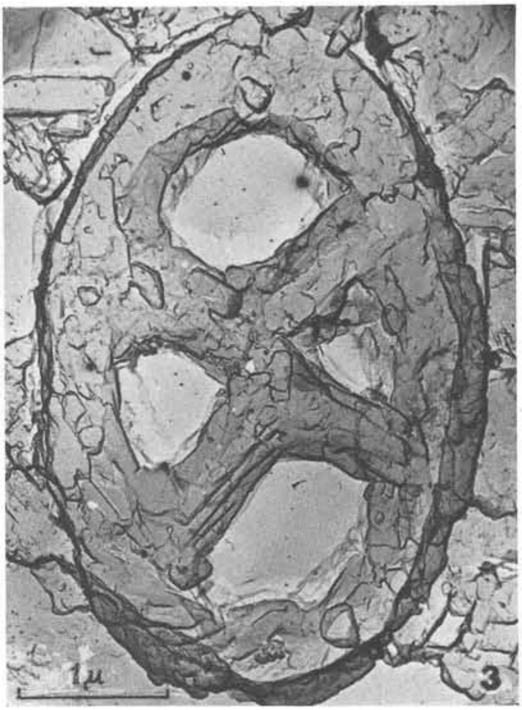
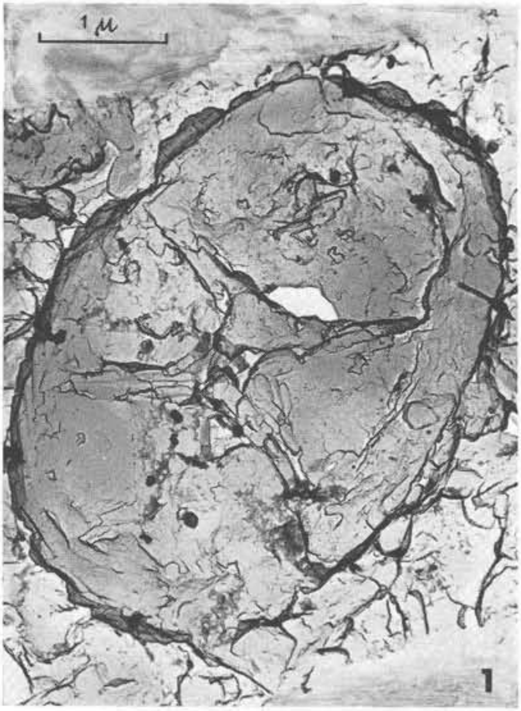
PLATE 41



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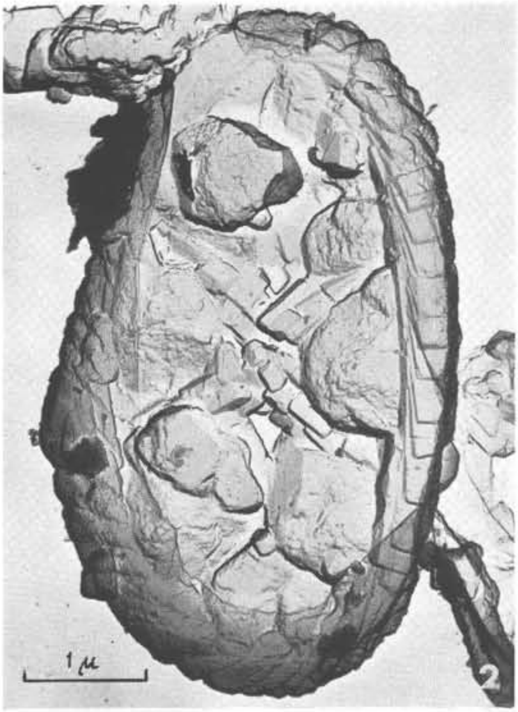
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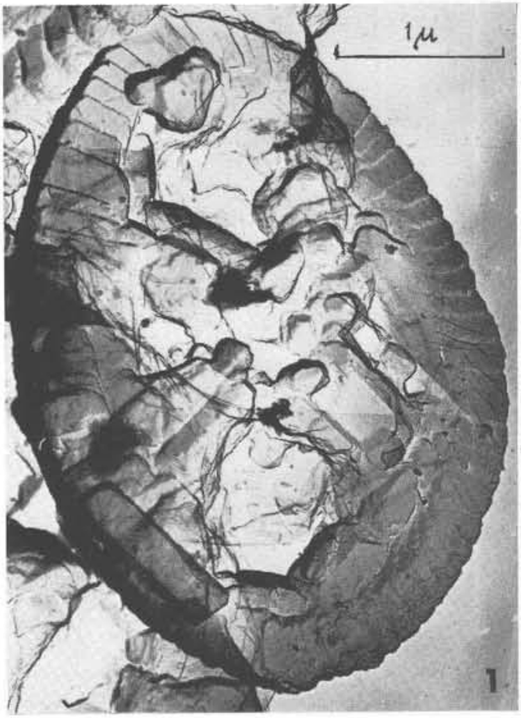
3


4



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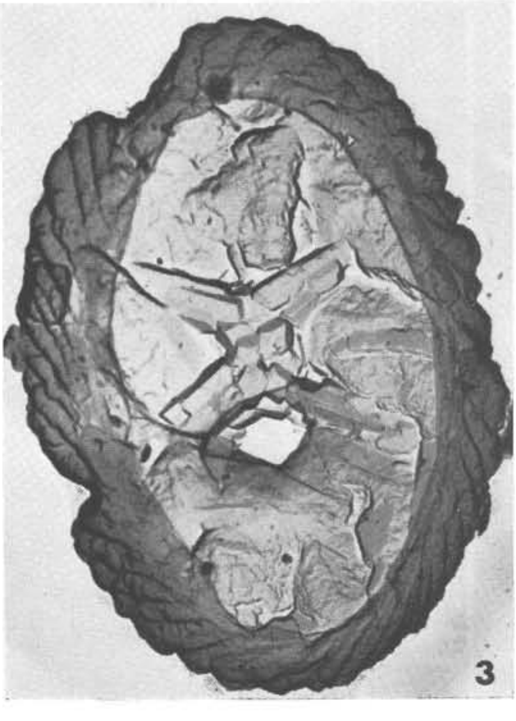

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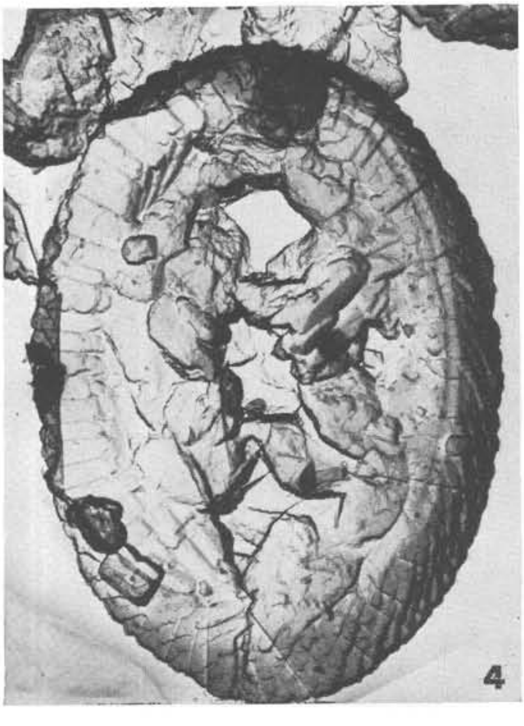
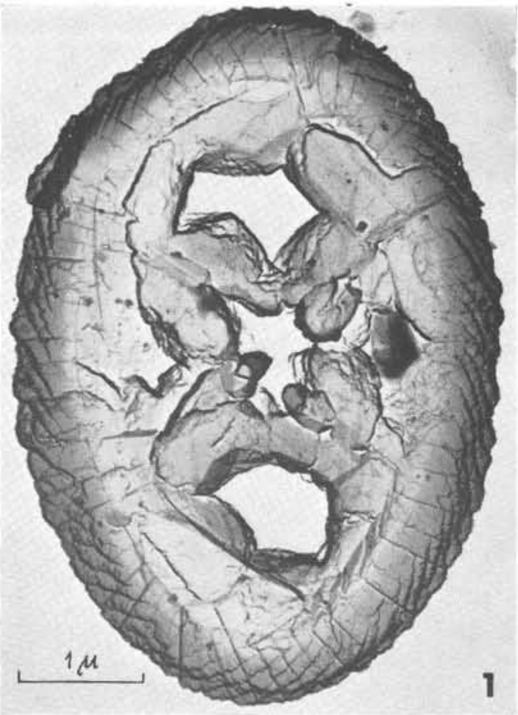
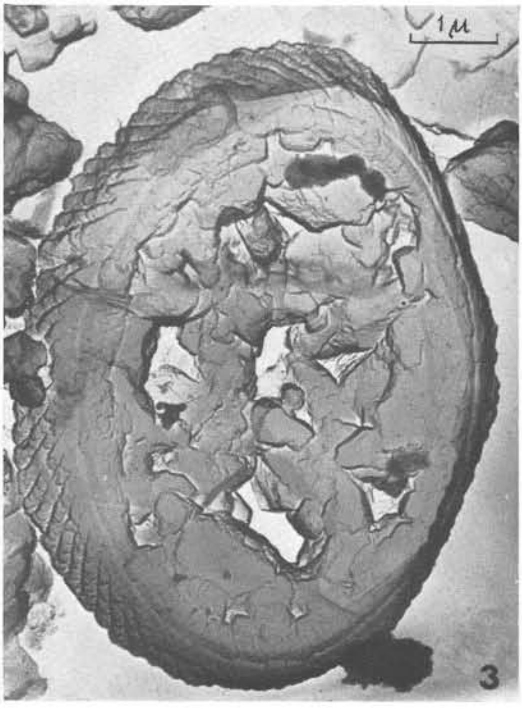


4

PLATE 44





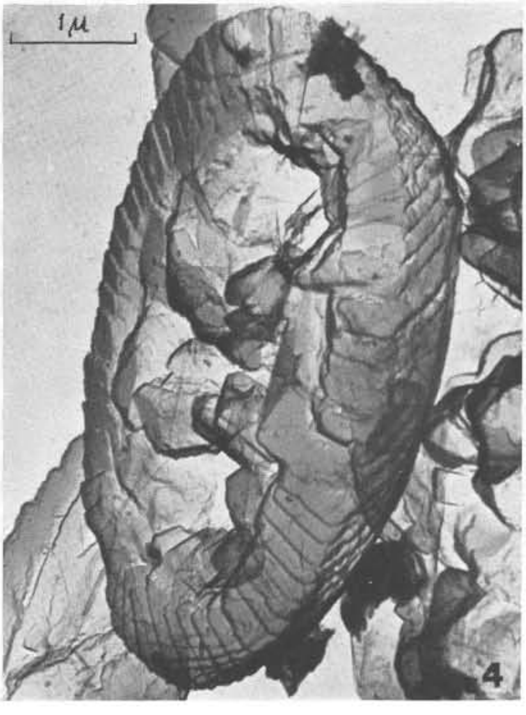
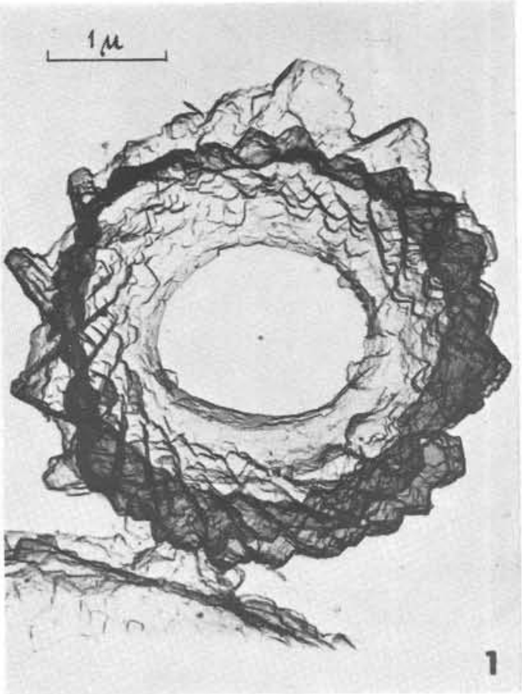


PLATE 45



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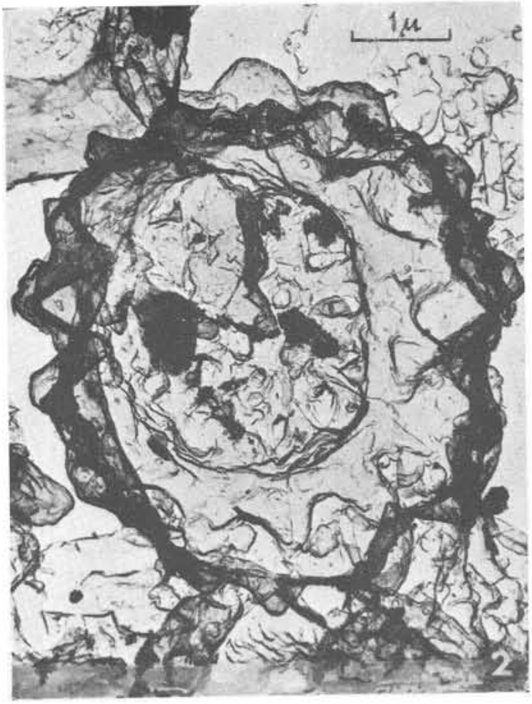

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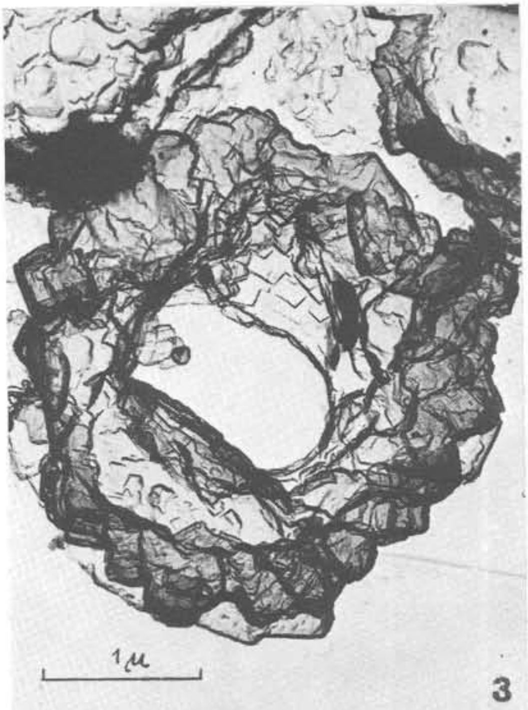

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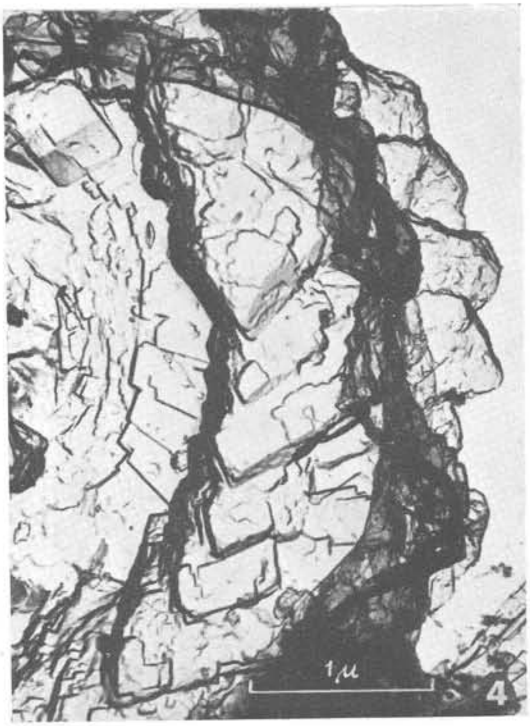

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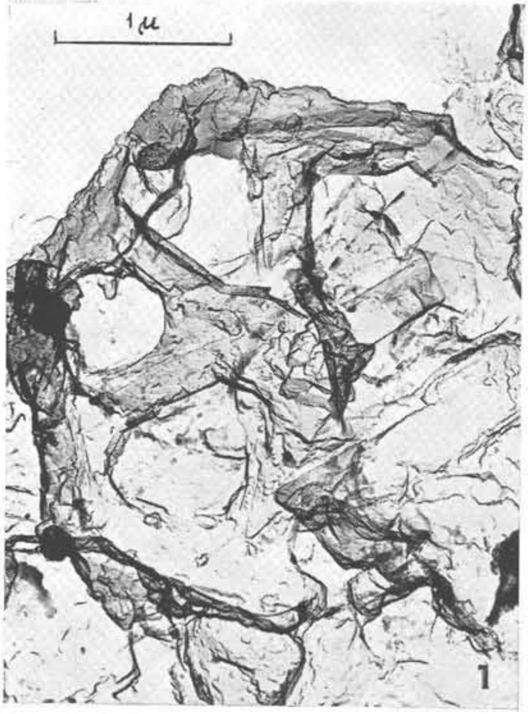
PLATE 46



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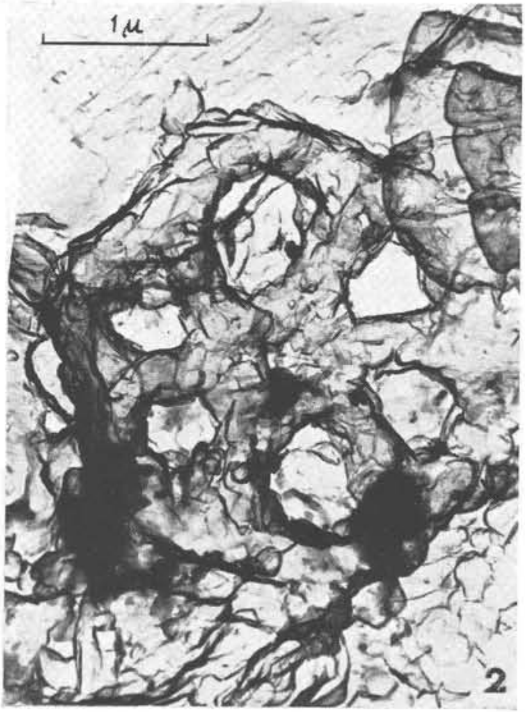

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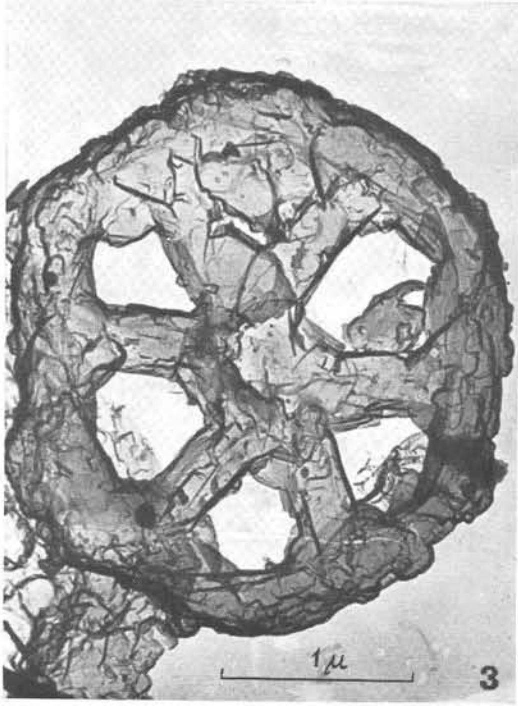

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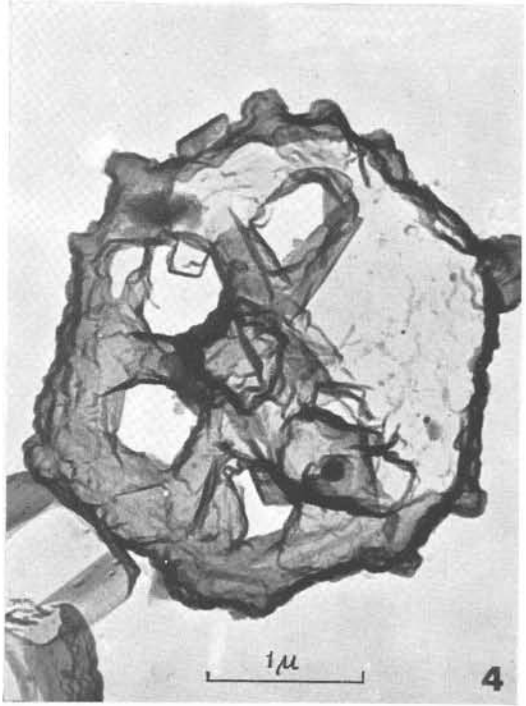

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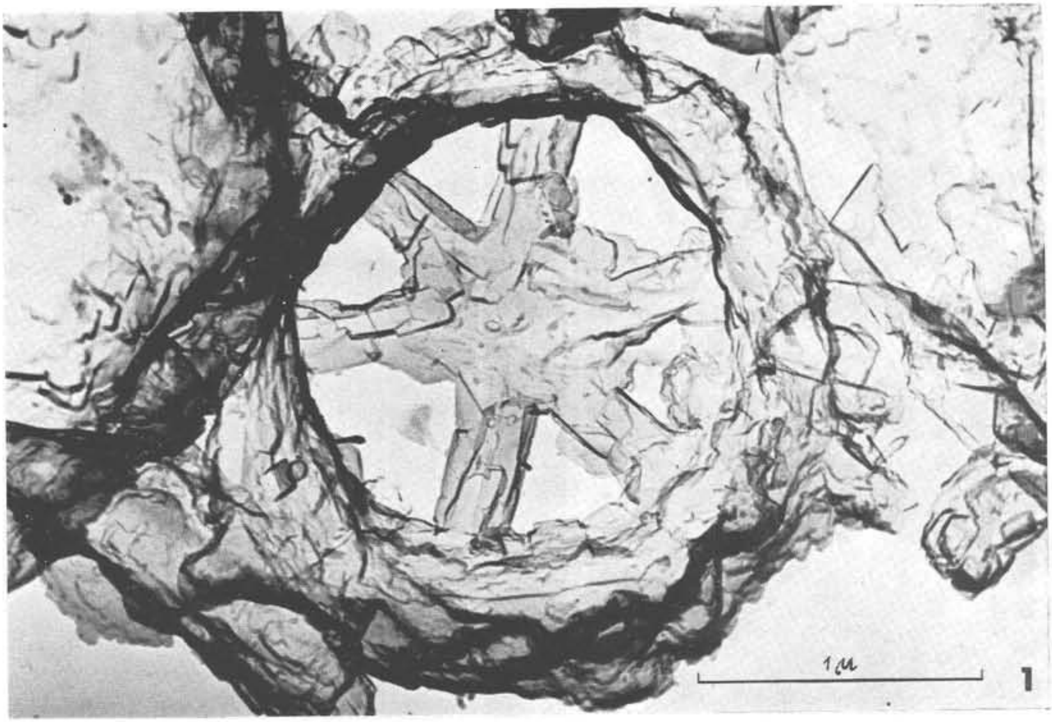
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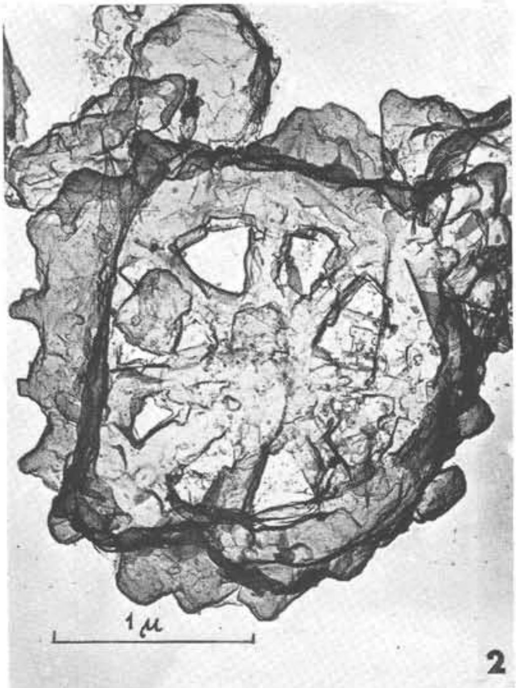
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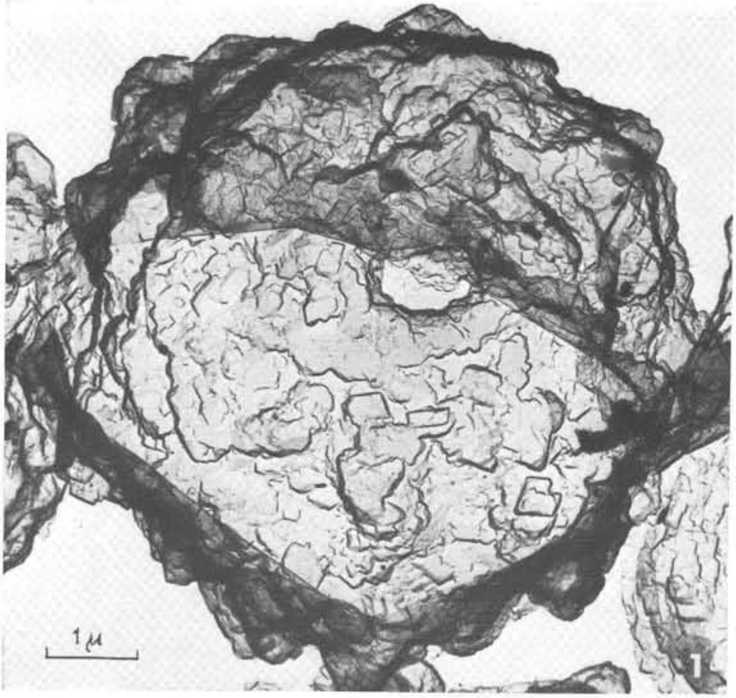

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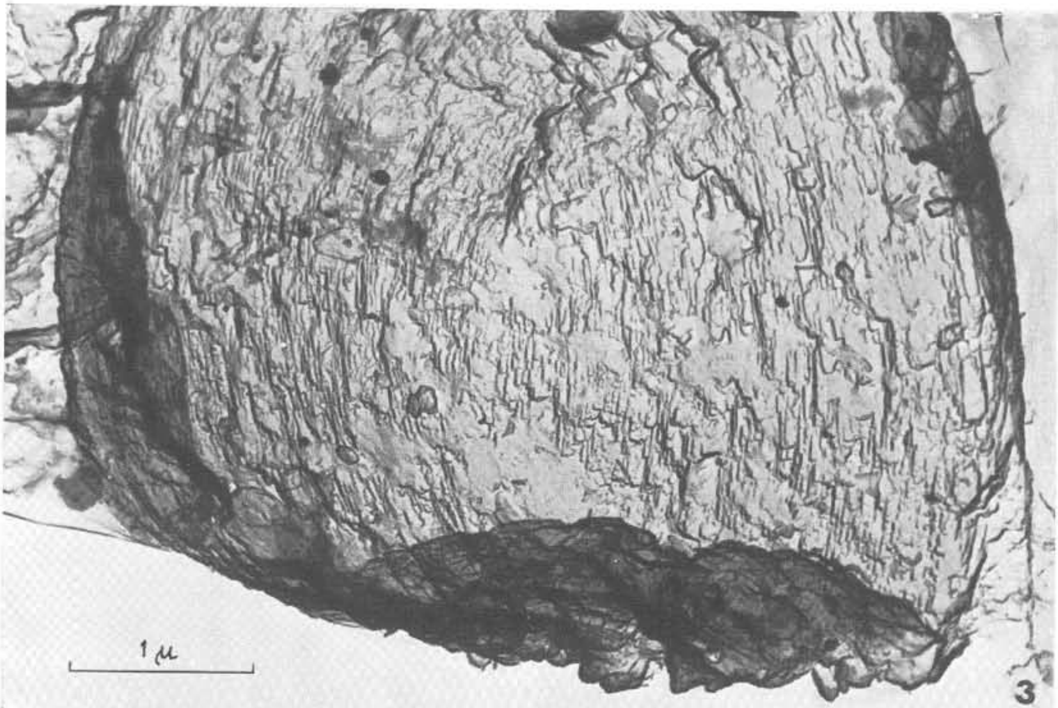

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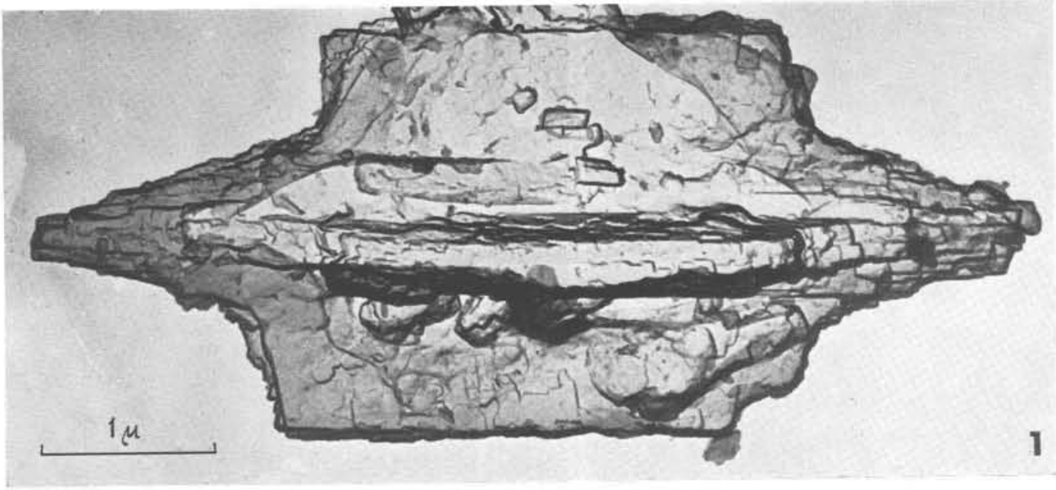

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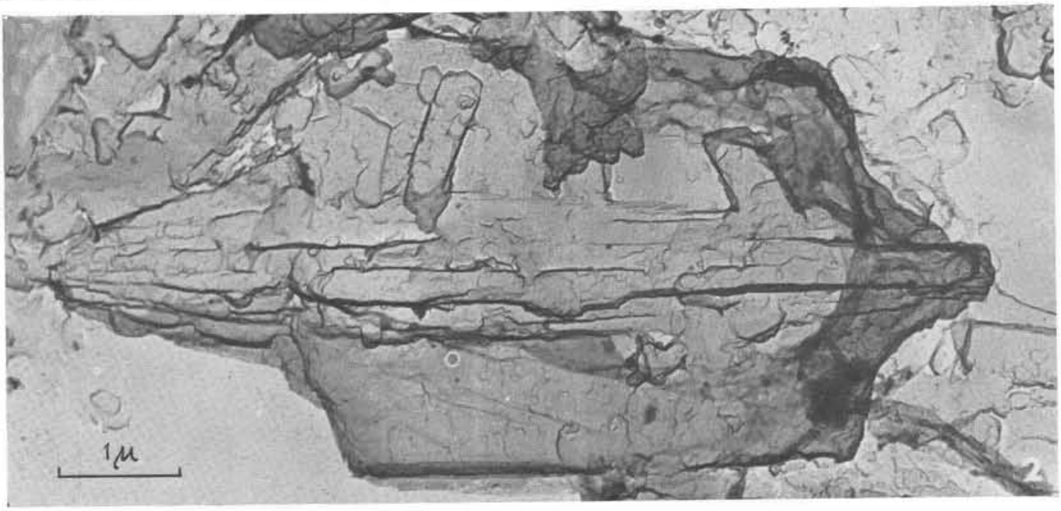

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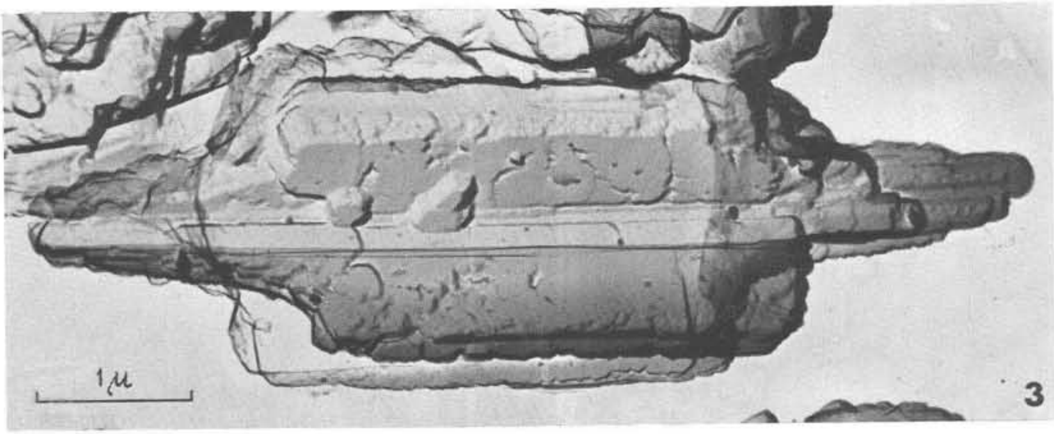

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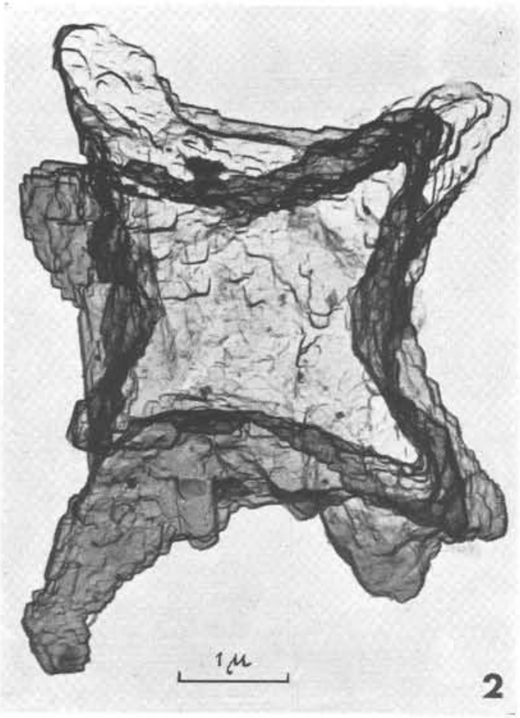

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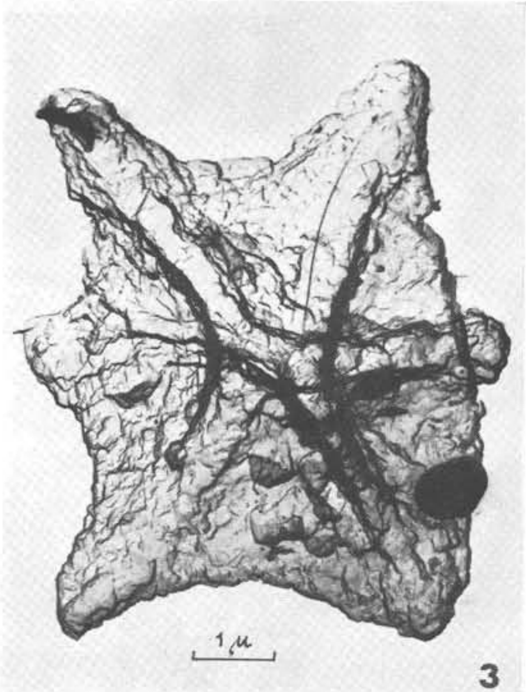

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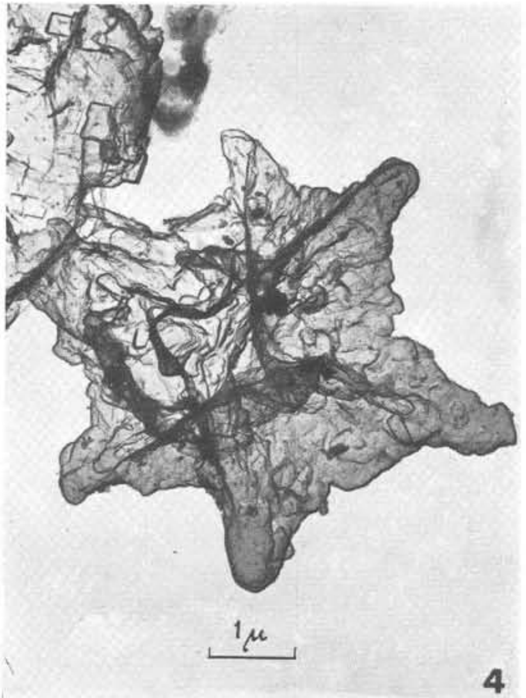

4

An Upper Maestrichtian Foraminiferal Fauna from Dörfles, Lower Austria

By SHAIBAN K. AL-SHAIBANI *)

With 3 plates

Abstract

This paper deals with the description of Upper Maestrichtian foraminifera. The foraminifera are picked up from one sample taken from marles in crevasses and fissures of Upper Tithonian of Ernstbrunn Limestone, quarry at Dörfles. 18 species have been found in this locality which have stratigraphic value for age determination; 37 genera which have long stratigraphic range have been identified too; only those, which have characteristic morphologic features have been identified to species. Stratigraphically Dörfles sample seems to be closely related to Upper Maestrichtian of Michelstetten due to many common species in both areas.

Introduction

During my stay in Vienna from September 9, 1968 till May 21, 1969 I have restudied foraminifera of some Upper Cretaceous samples, which I have collected from different stratigraphic sections in different localities of Austria during geologic excursions. The ages of these samples range from Cenomanian to Maestrichtian. Emphasis has been laid on two samples from Michelstetten section, which belongs to the Waschberg zone, and from the Gosau beds in Salzburg; both of them have already been studied and published.

In this paper I have worked out the sample brought from an old quarry at Dörfles, Lower Austria, which belongs to Waschberg zone. No former work has been done on the foraminifera of these marles, filling crevasses and fissures of Upper Tithonian of Ernstbrunn Limestone. The purpose of this study is twofold; to find out the age of this filling, which was thought to be of Upper Tithonian, and to correlate it with one of the mentioned Upper Cretaceous Sections. I had to limit myself to study one sample, due to the short time available.

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*) Department of Geology, College of Science, University of Baghdad; Baghdad, Iraq.

Systematic Descriptions

Family *GLOBOTRUNCANIDAE* BROTZEN, 1942

Genus *Globotruncana* CUSHMAN, 1927

Globotruncana arca (CUSHMAN)

(Plate 1, figure 1 a—c)

1926 *Pulvinulina arca* CUSHMAN n. p. — CUSHMAN, P. 32, Pl. 3, Fig. 1 a—c.
1926 *Globotruncana arca* CUSHMAN — HERM, P. 65, Pl. 7, Fig. 3.
1966 *Globotruncana arca* CUSHMAN — WILLE-JANOSCHEK, P. 96, Pl. 5, Fig. 1—6.

Description: Test subcircular, periphery lobate with double keels, dorsal side convex, ventral side slightly concave. Chambers forming the last whorl are six, increasing in size gradually as added. On the ventral side the umbilical margin of each chamber is with a strong lip, especially the last. Sutures an the dorsal side are oblique and curved, on the ventral side forming a loop-shape along with the umbilical lip and the ventral keel in each chamber. Almost all sutures are limbate and beaded. Aperture is not well preserved.

Dimension: Diameter 0.54 mm.; thickness 0.11 mm.
Occurrence: Common.
Range: Lower Campanian-Upper Maestrichtian.

Globotruncana mayaroensis BOLLI

(Plate 1, figure 2 a—c)

1951 *Globotruncana mayaroensis* BOLLI n. sp. — BOLLI, P. 198, Pl. 35, Fig. 10—12.
1957 *Abathomphalus mayaroensis* (BOLLI) — LOEBLICH & TAPPAN, P. 43, Pl. 11, Fig. 1 a—c.
1966 *Globotruncana mayaroensis* BOLLI — WILLE-JANOSCHEK, P. 111, Pl. 6, Fig. 5, 6.

Description: Test circular with lobate periphery, slightly convex on dorsal side and concave on ventral side. Six chambers in the last whorl, they are arranged obliquely to each other. The sutures on the dorsal side are curved and coarsely beaded, especially on the peripheral part, radial on the ventral side. The periphery is truncated by two keels, ventral and dorsal, which are strongly beaded. Aperture is not preserved.

Dimension: Diameter 0.78 mm.; thickness 0.24 mm.
Occurrence: Rare.
Range: Upper part of Maestrichtian.

Globotruncana gansseri BOLLI

(Plate 1, figure 3 a—c)

1951 *Globotruncana gansseri* BOLLI n. sp. — BOLLI, P. 196, Pl. 35, Fig. 1—3.
1963 *Globotruncana gansseri* BOLLI — VAN HINTE, P. 72, Pl. 3, Fig. 4.
1966 *Globotruncana gansseri gansseri* BOLLI — SALAJ-SAMUEL, P. 206, Pl. 22, Fig. 1, 2 a, b, c.

Description: Test semicircular, flat on dorsal side and inflated on ventral side. Chambers forming the last whorl are five in number surrounding the umbilicus. The sutures on the dorsal side are curved and finely beaded, ventrally radial and depressed. A very prominent beaded keel separates the flat dorsal side from the inflated ventral side. The periphery is slightly lobate. The wall of the ventral side is slightly rough and spiny. Aperture is not preserved.

Dimension: Diameter 0.27 mm.; thickness 0.100 mm.
Occurrence: Rare.
Range: Maestrichtian.

Genus *Rugoglobigerina* Brönnimann, 1952

Rugoglobigerina petaloidea petaloidea Gandolfi

(Plate 1, figure 4 a—c)

1962 *Rugoglobigerina petaloidea petaloidea* Gandolfi — Herm, P. 59, Pl. 2, Fig. 5.

Description: Test small, convex on dorsal side, concave ventrally with deep umbilicus. Four chambers on the final whorl, stout and compressed except the last, which is inflated to a certain extent. All chambers are covered by very fine pustules, the peripheral part is covered with fine spines. The periphery is petaloid with faint keel. Aperture is an interiomarginal low arch facing the umbilicus. This form has certain similarities with *Globotruncana citae*.

Dimension: Diameter 0.30 mm.; height 0.14 mm.

Occurrence: Rare.

Rugoglobigerina rugosa rotundata Brönnimann

(Plate 2, figure 1 a—c)

1957 *Rugoglobigerina rugosa rotundata* Brönnimann — Loeblich & Tappan, P. 43, Pl. 11, Fig. 2 a—5 c.
1962 *Rugoglobigerina rugosa rotundata* Brönnimann — Herm, P. 61, Pl. 3, Fig. 4.

Description: Test trochoidal in early stage, tending to be planispiral in later stage, subcircular, biconvex and umbilicate. In side view chambers are slighty elongate, five in the last whorl. Sutures are depressed and radial on ventral side. Periphery rounded and lobate. Wall covered by numerous papillae, which give the typical rugose appearance. Aperture is a low arch at the base of the last formed chamber facing the umbilicus.

Dimension: Diameter 0.35 mm.; thickness 0.24 mm.
Occurrence: Common.

Family *BULIMINIDAE* JONES, 1875

Genus *Reussella* GALLOWAY, 1933

Reussella szajnochae szajnochae (GRZYBOWSKI)

(Plate 2, figure 2)

1896 *Verneuilina szajnochae* — GRZYBOWSKI, P. 287, Pl. 9, Fig. 19 a, b.
1929 *Bulimina limbata* n. sp. — WHITE, P. 48, Pl. 5, Fig. 9.

Description: Test triangular in cross-section, has a general pyramidal shape with slightly curved edges. Chambers are clearly visible except the early ones, which are hidden by the backward projection of the later sutures, numerous and deeply excavated, due to the raised and twisted sutures. Sutures form prominent raised and twisted ridges. Aperture semilunar, situated at the base of the last formed chamber.

Dimension: Length 0.68 mm.; breadth 0.49 mm.
Occurrence: Rare.
Range: Part of Campanian and Maestrichtian.

Genus *Bulimina* D'ORBIGNY, 1826

Bulimina arkadelphiana CUSHMAN & PARKER

(Plate 2, figure 3)

1946 *Bulimina arkadelphiana* CUSHMAN & PARKER — CUSHMAN, P. 124, Pl. 52, Fig. 3, 4.

Description: Test spindle shape, tapering towards the proloculus. Number of whorls five. Chambers are numerous, not visible in early stage, later chambers are distinct and inflated. Sutures are distinct and deep. Except for the last three chambers, all covered with fine ridges, which are projecting as sharp spines at the margins of the chambers, especially in the early stage. Wall finely perforated. Aperture loop-shaped, situated at the side of the last formed chamber.

Dimension: Length 0.57 mm.; diameter 0.35 mm.
Occurrence: Common.

Family *BOLIVINITIDAE* CUSHMAN, 1927

Genus *Bolivina* D'ORBIGNY, 1839

Bolivina incrassata gigantea WICHER

(Plate 2, figure 5)

1962 *Bolivina incrassata gigantea* WICHER — HILTERMANN & KOCH in Leitfossilien der Mikropaläontologie, Pl. 312, Pl. 19, Fig. 51.

Description: Test stout, elongate, oval in outline, maximum breadth on the middle of the test, periphery is rounded. Chambers are biserial, six pairs, increasing gradually in size, slightly bending towards the proloculus.

Sutures are flush and curved. Wall smooth with fine perforations. Aperture elongate, oval with slight lip located on the side of the last formed chamber.

Dimension: Length 1.2 mm.; breadth 0.64 mm.; thickness 0.36 mm.
Occurrence: Rare.
Range: Maestrichtian.

Bolivina incrassata incrassata Reuss

(Plate 2, figue 4)

1899 *Bolivina incrassata* Reuss — Egger, P. 45, Pl. 16, Fig. 4, 5.
1946 *Bolivina incrassata* Reuss — Cushman, P. 127, Pl. 53, Fig. 8—11.
1966 *Bolivina incrassata incrassata* Reuss — Salaj-Samuel, P. 138, Pl. 2, Fig. 4 a, b.

Description: Test stout, moderately compressed, increasing in breadth gradually toward the aperture so that maximum breadth is near the aperture, periphery is rounded. Chambers are biserially arranged, eight pairs, gradually increasing in size, slightly bending toward the proloculus. Sutures are flush and curved. Wall smooth with fine perforations. Aperture elongate, oval with slight lip on the side of the last formed chamber.

Dimension: Length 0.62 mm.; breadth 0.19 mm.; thickness 0.10 mm.
Occurrence: Rare.
Range: Upper Campanian and Maestrichtian.

Genus *Bolivinoides* Cushman, 1927

Bolivinoides draco draco Marsson

(Plate 2, figure 6)

1951 *Bolivinoides draco draco* Marsson — Noth, P. 63, Pl. 9, Fig. 10.
1957 *Bolivinoides draco* Marsson — Loeblich & Tappan, P. 145, Pl. 33, Fig. 14—16.

Description: Test stout, rhomboidal, breadth and thickness increasing toward the aperture, periphery weakly carnated. Chambers are biserial throughout; curved toward the proloculus, increasing in size as added. Sutures are oblique and curved backward. Surface ornamentation consists of two nearly parallel median ridges, from which oblique secondary ridges branch toward the peripheral smooth surface. Aperture is a slit at the base of the last formed chamber.

Dimension: Length 0.38 mm.; maximum breadth 0.36 mm.; thickness 0.17 mm.

Occurrence: Common.
Range: Maestrichtian.

Bolivinoides peterssoni Brotzen

(Plate 3, figure 1)

1957 *Bolivinoides peterssoni* Brotzen — Hofker, P. 253, Abb. 305, 312.
1962 *Bolivinoides peterssoni* Brotzen — Hiltermann & Koch in Leitfossilien der Mikropaläontologie, P. 317, Pl. 50, Fig. 16.
1966 *Bolivinoides peterssoni* Brotzen — Salaj-Samuel, P. 140, Pl. 28, Fig. 1—2.

Description: Test stout, elongate, rhomboidal in outline, the thickest portion along the median line. Chambers arranged biserially, narrow and curved; the upper two or three pairs bearing spines. Sutures are curved and meet directly with the outer rim in an angle. Test covered with big sparse and overlapped nodes; very short ridges and fine granulations. The two sides of the test are straight. Aperture is loop-shaped.

Dimension: Length 0.52 mm.; maximum breadth 0.32 mm.
Occurrence: Common.
Range: Maestrichtian-Lower Danian.

Bolivinoides paleocenicus BROTZEN

(Plate 3, figure 2)

1957 *Bolivinoides paleocenica* BROTZEN — HOFKER, P. 253, Abb. 305.
1962 *Bolivinoides paleocenicus* BROTZEN — HILTERMANN & KOCH in Leitfossilien der Mikropaläontologie, P. 317, Pl. 50, Fig. 15.

Description: Test small, thin, rhomboidal in outline, almost as wide as long, the thickest portion along the median line. Sides in early stage are slightly vaulted, younger chambers are flat. Chambers are biserially arranged throughout, slightly curved, outside the periphery in the form of short spines, giving a jagged appearance of the periphery. Sutures are slightly raised and curved, they cut the periphery at an angle. Ornamentation as fine granulation throughout the test, the middle portion is covered by overlapping of very short ridges and nodes. Aperture is loop-shaped situated at the base of the last formed chamber.

Dimension: Length 0.30 mm.; breadth 0.28 mm.
Occurrence: Common.
Range: Maestrichtian-Lower Danian.

Family *ANOMALINDAE* CUSHMAN, 1927

Genus *Stensioeina* BROTZEN, 1936

Stensioeina pommerana BROTZEN

(Plate 3, figure 4 a—c)

1951 *Stensioeina pommerana* BROTZEN — NOTH, P. 71, Pl. 9, Fig. 12.
1957 *Stensioeina pommerana* BROTZEN — HOFKER, P. 353, Abb. 407.
1962 *Stensioeina pommerana* BROTZEN — HILTERMANN & KOCH in Leitfossilien der Mikropaläontologie, P. 327, Pl. 51, Fig. 11—13.

Description: Test trochoid, subcircular, plano-convex, hemispherical in shape; dorsal side flat, ventral side highly convex. Umbilicus is filled and smooth. Eight chambers in the last whorl, increasing in size, the last chamber is less ornamented than the previous ones. Sutures on ventral side are curved and flush, whereas on the dorsal side they are strongly raised and show to a certain extent some regularity with irregular short ridges in between;

they meet the periphery tangentially to form a continuous peripheral ridge. Aperture is an interiomarginal low arch.

Dimension: Maximum diameter 0.60 mm.; minimum diameter 0.48 mm.; thickness 0.32 mm.
Occurrence: Rare.
Range: Upper Campanian and Maestrichtian.

Family *NODOSARIIDAE* Ehrenberg, 1838

Genus *Neoflabellina* Bartenstein, 1948

Neoflabellina aff. numismalis (Wedekind)

(Plate 3, figure 5)

1962 *Neoflabellina* n. sp., aff. *numismalis* (Wedekind) — Hiltermann & Koch in Leitfossilien der Mikropaläontologie, P. 311, Pl. 50, Fig. 11.
1963 *Neoflabellina* aff. *numismalis* (Wedekind) — Van Hinte, P. 103, Pl. 13, Fig. 4—5.

Description: Test stout, deltoidal, flattened, periphery is truncated by two keels. Early chambers form a small planispiral portion of the test, later chambers are narrow, chevron-shaped extending backward on both sides of the proloculus. Sutures are highly limbate, curved and parallel to the periphery. Sutures along the median line of the test are divided to many parts, so that each one confines intersutural areas ranging from two to six in this sample. Ornamentation as intersutural scattered small nodes, especially near the periphery. Aperture terminal, rounded and smooth.

Dimension: Length 1.2 mm.; breadth 0.8 mm.; thickness 0.16 mm.
Occurrence: Rare.
Range: Upper Campanian-Maestrichtian.

Neoflabellina reticulata (Reuss)

(Plate 3, figure 6)

1929 *Flabellina reticulata* Reuss — White, P. 204, Pl. 28, Fig. 15.
1946 *Palmula reticulata* (Reuss) — Cushman, P. 84, Pl. 31, Fig. 1—6.
1962 *Neoflabellina reticulata* (Reuss) — Hiltermann & Koch in Leitfossilien der Mikropaläontologie, P. 309, Pl. 50, Fig. 13, 14.

Description: Test deltoidal, flattened, periphery is truncated. Early chambers form a small planispiral portion of the test, later chambers chevron-shaped, extending backward on both sides toward the proloculus. Sutures are limbate and very distinct, inbetween covered by an incomplete mesh of parallel raised ridges, which are at right angles to the sutures. Aperture is rounded a the end of a short neck.

Dimension: Length 0.91 mm.; breadth 0.57 mm.
Occurrence: Rare.
Range: Maestrichtian.

Family *HETEROHELICIDAE* Cushman, 1927

Genus *Planoglobulina* Cushman, 1927

Planoglobulina acervulinoides (Egger)

(Plate 3, figure 3)

1902 *Gümbelina acervulinoides* n. sp. Egger — Egger, P. 36, Fig. 14, 15, 16, 17, 18, 20, 21, 22.
1946 *Planoglobulina acervulinoides* (Egger) — Cushman, P. 111, Pl. 47, Fig. 12—15.
1966 *Pseudotextularia acervulinoides* (Egger) — Wille-Janoschek, P. 119, Pl. 8, Fig. 8.

Description: Test compressed, fan-shape and perforated. Chambers are subglobular, early stage is biserially arranged, later stages are scattered in one plane. Wall is ornamented by fine striations, they are well developed in early stage. Sutures are distinct and depressed. *Planoglobulina* is similar to *Ventilabrella*, but in *Planoglobulina* the early stage is much thicker than the early stage of *Ventilabrella*.

Dimension: Length 0.40 mm.; breadth 0.35 mm.; thickness 0.16 mm.
Occurrence: Rare.

In addition to the species described here in detail, the following genera and species were found too in the Upper Maestrichtian of Dörfles:

Ammodiscoides sp.
Ammodiscus sp.
Trifarina sp.
Asterigerinoides sp.
Allomorphina sp.
Bulimina sp.
Cibicides sp.
Cibicidoides sp.
Clavulinoides sp.
Dorothia sp.
Dentalina sp.
Eponides sp.
Eggerella sp.
Ellipsoglandulina sp.
Frondicularia sp.
Glomospira sp.
Hedbergella sp.
Gyroidina sp.
Globorotalites sp.
Gavelinella sp.
Gaudryina sp.
Lenticulina sp.
Lagena sp.
Marginulina sp.
Marssonella sp.
Nodosaria sp.
Pseudoglandulina sp.
Pleurostomella sp.
Ramulina sp.
Saracenaria sp.
Stilostomella sp.
Aragonia velascoensis Cushman
Biglobigerinella barri Bolli, Loeblich & Tappan
Marssonella oxycona Reuss

Acknowledgements

I would like to thank Dr. R. Oberhauser and Dr. M. E. Schmid of the Geological Survey of Austria, for their cooperation to write this paper. Special thanks to Dr. Schmid for reading the manuscript and his valuable criticism.

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PLATE 1

Figs. 1 a—c. *Globotruncana arca* (Cushman). 1 a, Dorsal view; 1 b, side view; 1 c, ventral view.

Figs. 2 a—c. *Globotruncana mayaroensis* Bolli. 2 a, Dorsal view; 2 b, side view; 2 c, ventral view.

Figs. 3 a—c. *Globotruncana gansseri* Bolli. 3 a, Dorsal view; 3 b, side view; 3 c, ventral view.

Figs. 4 a—c. *Rugoglobigerina petaloidea petaloidea* Gandolfi. 4 a, Dorsal view; 4 b, side view; 4 c, ventral view.

PLATE 1

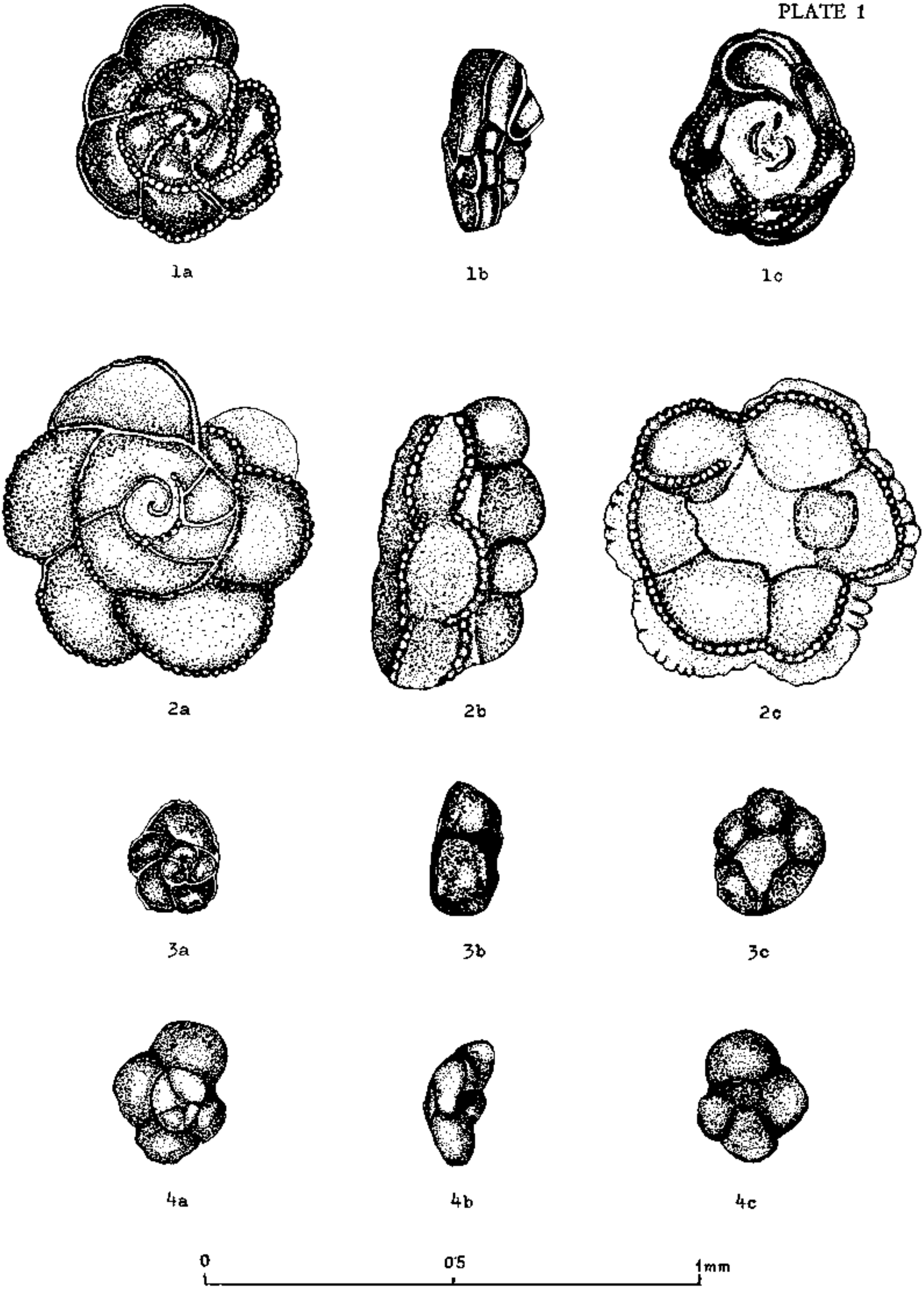

PLATE 2

Figs. 1 a—c. *Rugoglobigerina rugosa rotundata* BRÖNNIMANN. 1 a, Dorsal view; 1 b, side view; 1 c, ventral view.
Fig. 2. *Reussella szajnochae szajnochae* (GRZYBOWSKI).
Fig. 3. *Bulimina arkadelphiana* CUSHMAN & PARKER.
Fig. 4. *Bolivina incrassata incrassata* REUSS.
Fig. 5. *Bolivina incrassata gigantea* WICHER.
Fig. 6. *Bolivinoides draco draco* MARSSON.

PLATE 2

1a

1b

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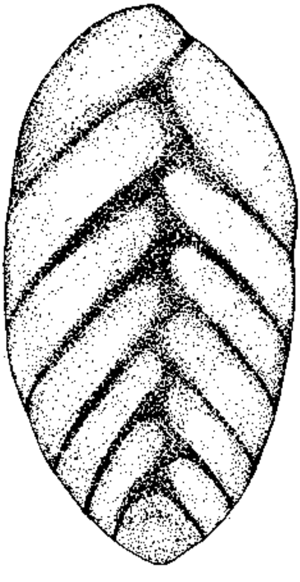

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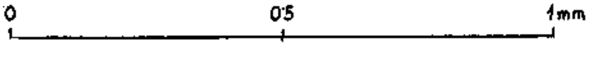

PLATE 3

Fig. 1. *Bolivinoides peterssoni* Brotzen.
Fig. 2. *Bolivinoides paleocenicus* Brotzen.
Fig. 3. *Planoglobulina acervulinoides* Egger.
Fig. 4 a—c. *Stensioeina pommerana* Brotzen. 4 a, Dorsal view; 4 b, side view; 4 c, ventral view.
Fig. 5. *Neoflabellina,* aff. *numismalis* (Wedekind).
Fig. 6. *Neoflabellina reticulata* (Reuss).

PLATE 3

1

2

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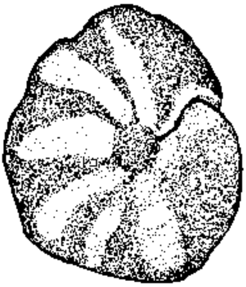
4a

4b



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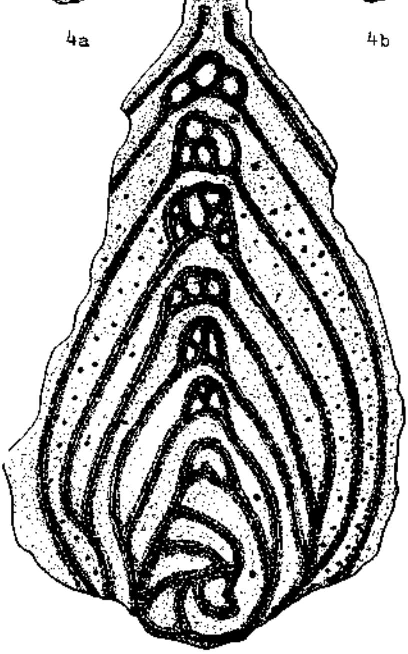

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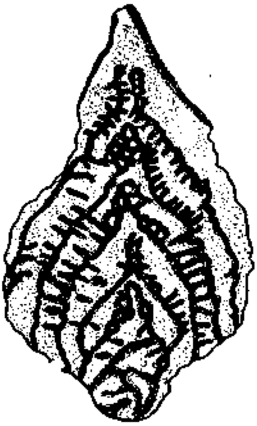

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Contribution to the Geology of the Area around Ober-Meisling (Krems Valley)

By G. O. KESSE *)

With 3 figures and 2 tables

Abstract

Thirteen working days were spent in the field mapping on the scale of 1 : 10,000 and the collection of 55 rock samples from a 6.74 square kilometres of land around Ober-Meisling (Krems Valley) located on the Moldanubian Series at the southern part of the Bohemian Massive and just 18 kilometres north of Krems, Lower Austria.

The main rocks encountered here are the highly folded, garnet, biotite and sillimanite rich paragneisses which are invaded by irregularly outcropping bodies and intercalations of amphibolites, calc-silicate gneisses, marbles, dioritic intrusions, linear dykes of lamprophyre, migmatites, pegmatitic and aplictic gneisses.

The presence and the abundance of hornblende, plagioclase, garnet and sillimanite in these rocks are all pointers to the typical mode of occurrence of high grade zone of amphibolite facies.

Most of these rocks are folded on large scale but the pronounced structural feature is the marked NE-SW regional trend with dips generally towards the SE.

The age of these rocks is almost earliest Proterozoic and the origin is of metamorphosed geosynclinal basin of pelitic material with occasional limestone layers.

Emphasis has been placed on the descriptive petrography of the rocks of this area since this has been the primary aim for the mapping of this particular area.

Introduction

Purpose

The geological mapping around Ober-Meisling on the Krems, Lower Austria, was undertaken as part of an eight-month post graduate further training of geologists from developing countries in Vienna, Austria. In this particular training, the curriculum is designed to cover the study of petrology of metamorphic and intrusive rocks and related problems. The main aim of this training is for Austrian geologists to impact some of their knowledge and experience to their fellow scientists from these various countries by assisting them, not only to accurately map an area and collect

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*) Authors adress: G. O. KESSE, Geological Survey, Kumasi, Ghana.

field data, but also to help them in correct assessment and interpretation of the data so collected. Emphases are placed on laboratory work and exercises during which time, apart from the ordinary examination of rock in thin section with polarizing microscope, universal stage methods for detailed examinations of rock sections and petrofabric analytic methods are taught. The laboratory work is also supplemented by specialized lectures of such-like topics as rock-forming minerals, feldspar investigations, geochemistry, ore-microscopy. X-ray methods which are geared to assisting the participant in his training programm in Austria and the subsequent utilization of the knowledge so acquired in the participant's own work in his home country.

The present work is the final report of this eight-month course which has been prepared under the guidance of our Austrian colleagues. Even though the report on the whole concerns the geology of the Krems Valley area around Ober-Meisling, understandably, emphasis has been placed on the petrography of the rocks in this area inasmuch as the whole course has been directed to this end.

It is also hoped that this work will contribute to the geological knowledge of this part of the Bohemian Massive.

Locality

The village of Ober-Meisling, with an estimated population of 500 people, is situated directly on one of the numerous bends on the Krems stream and is located almost at the centre of the mapped area (see Fig. 1) which lies between 48° 27′ 18″ North latitude and 15° 26′ 30″ and 15° 28′ 18″ Eeast longitude. The mapped area is almost 6.74 square kilometres in area.

It is easily reached from Vienna by driving west to St. Pölten (63 km) then north to Krems-on-the Danube (28 km) and finally northwest to Ober-Meisling (18 km) through the villages of Senftenberg and Unter-Meislng.

The only settlement of any significance in the mapped area is the village of Hohenstein which is about 4 km southwest of Ober-Meisling.

Fieldwork

The geological mapping of this area was started on the 9th of October, 1969 after 2 days of introductory geological excursions in the area and its environs. The fieldwork was completed on the 23rd of October, 1969. Thirteen days were but spent in the actual field mapping and the collections of 55 rock samples (see Fig. 1).

The mapping of the area was based on the scale of 1 : 10,000 or 1 cm.: 100 metres. Rock exposures were excellent especially along road cuttings and stream valleys and good fresh rock samples could be easily collected.

Physical features

Most of the mapped area is pine-forested hilly country ranging in height from 350 to 567 metres (see Fig. 2). Prominent hills in the area include Hulm (519 metres high) Wachtberg (540 metres) and Steinberg (567 metres) (see Fig. 1). These hills are often covered with soil or weathered products of the rock and decayed vegetation and not much geology could be observed except in places which have been cut down to make way for farms.

The only stream of any significance is the Krems which enters the mapped area from the west through the village of Hohenstein, meanders eastwards through the villages of Ober-Meisling, bisecting the mapped area into almost two parts. In certain portions of its bank, it is often bounded by steep cliffs whilst in other places there are flat plains and terraces intensively cultivated for vegetables.

The valleys separating the hills are steep and sometimes contain some water. In these valley, deeply weathered rocks, mostly covered with vegetation are common and these rocks could easily be studied.

Previous work

Probably, many Austrian geologists might have worked in this area but it would suffice to mention that F. Becke, F. Reinbold and L. Waldmann have done some geological work in this area.

Of late, A. Matura has been mapping this area although his work is yet to be published.

Acknowledgements

Grateful acknowledgement is due, in the first place, to the Government of the Republic of Austria, UNESCO and OAS who sponsored the course and have borne the financial aspects.

The writer is grateful to Professor H. Küpper, former Director of Austrian Geological Survey and Professor H. Wieseneder, Institute of Petrography, University of Vienna, for their interest and welfare of the participants.

Particular thanks are due to Dr. A. Matura and Dr. S. Scharbert, both of the Austrian Geological Survey, for their daily continued stimulus of helpful advice and critical discussions both in the field and in the laboratory.

The assistance given to the writer in the laboratory by two colleagues, Mr. Luiz Scheibe of Brazil and Mr. M. A. Takla of Egypt, is sincerely acknowledged.

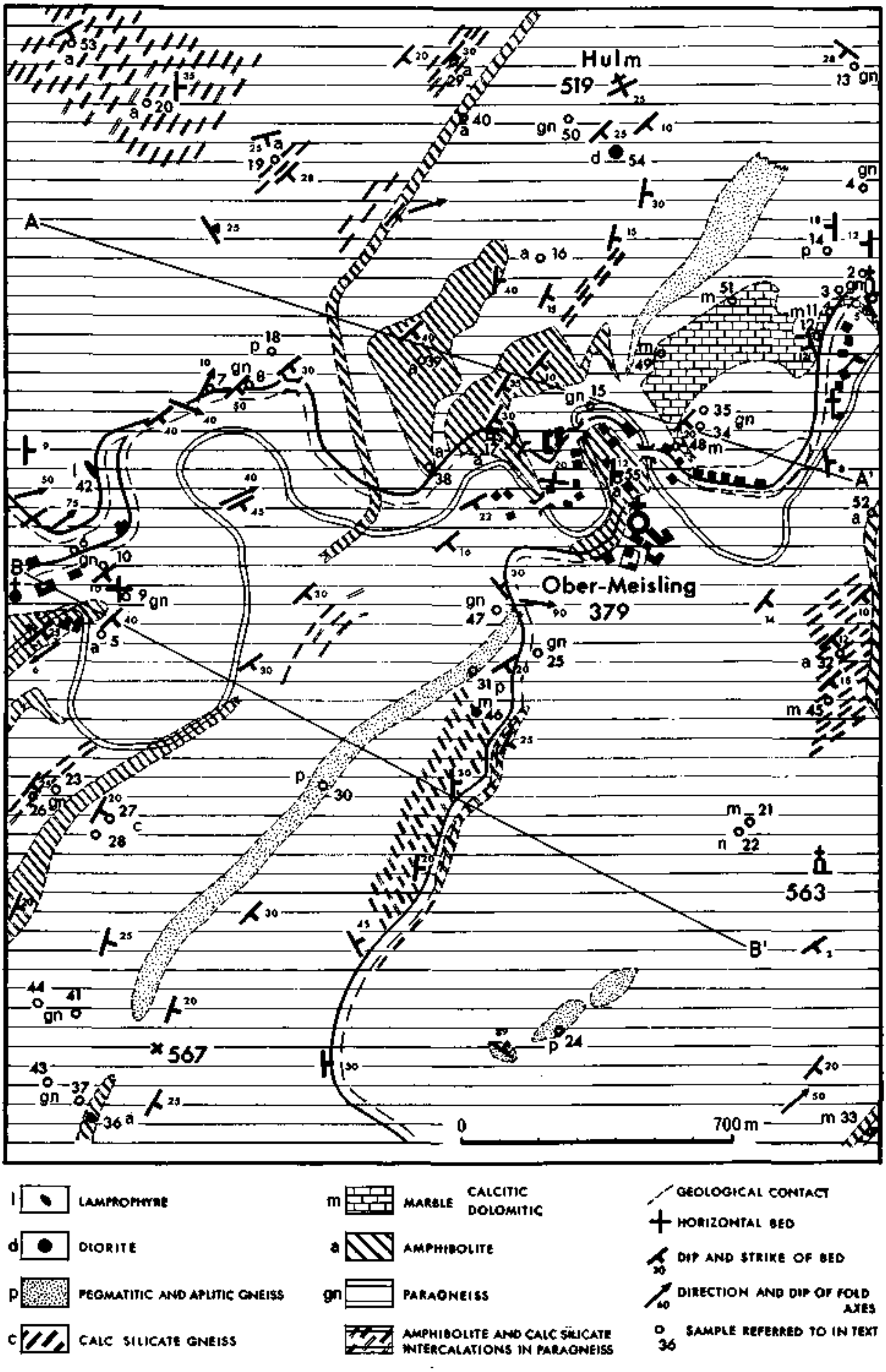

Fig. 1: Geological Map of the Area around Ober-Meisling.

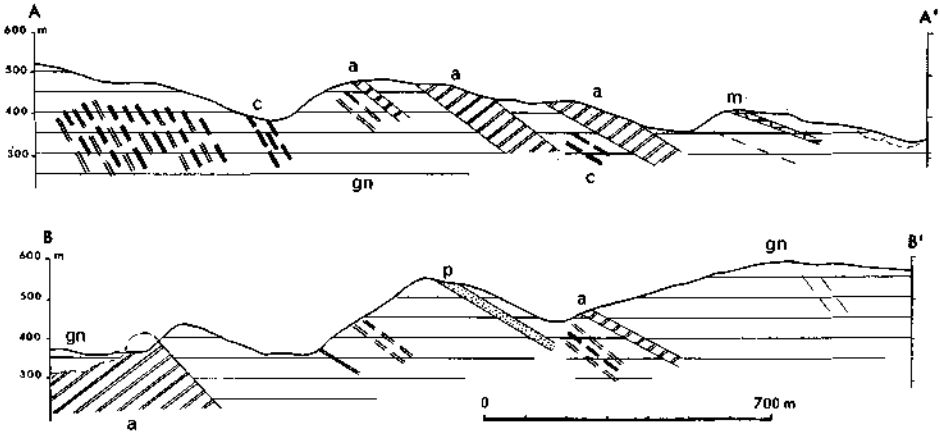

Fig. 2: Cross sections. Position see Fig. 1.

Geology and Petrography

General Geology

The rocks encountered in the mapped area are part of the variegated series of the Moldanubian Zone of the southeastern part of the Bohemian massive. The most prevalent rocks are the highly folded paragneisses which in turn are invaded by irregularly outcropping bodies and intercalations of amphibolites, calc-silicate gneisses, marbles, small dioritic intrusive bodies, lamprophyric dykes, migmatites, pegmatitic and aplitic gneisses.

The paragneisses are rather uniform in composition with the main constituents being quartz, oligoclase-andesine and biotite. In certain localities, garnet, sillimanite, alkali feldspar and cordierite are present.

Greyish to dark green amphibolites are rather widespread within these gneisses and are in intimate association with the gneisses. White or greyish marbles with varying amounts of impurities are also found. Sometimes, the silica minerals prevail and calc-silicate gneisses result.

A great deal of granitization or migmatization and general intrusion of granite rocks have taken place within the paragneisses. Dykes which are lamprophyric in character, as well as dioritic intrusives, do occur.

Quarternary deposits, consisting mainly of gravel, sand and alluvium derived from weathered rocks and deposition by the meandering Krems often cover the rocks. The most interesting deposit however is a thick deposit of loess found in the neighbourhood of Ober-Meisling (see Fig. 1).

The rocks have a general trend of northeast-southwest or northsouth strike with dips to the southeast and east. Most of the rocks are foliated with minerals like mica and sillimanite conspicuously oriented in planes and lines presumably as a result of directed pressure during metamorphism. Apart from the foliation which could be observed, these rocks are also prominently folded.

According to Svoboda (in Svoboda et al., 1966), the age of these rocks is generally regarded as a Pre-Cambrian, most probably, Early Proterozoic or Late Archean and were affected by intense pre-Palaezoic metamorphism. Numerous bodies of Variscian igneous rocks which later intruded these rocks resulted in the formation of migmatites and also of cordierite bearing gneisses.

A geological succession for the entire area is presented in Table 1, with the youngest rocks at the top of the table.

Table 1. Geological Succession.

Recent:	Superficial deposits i. e. gravel, sand, silt, clay and loess
Intrusives:	i. Lamprophyre
	ii. Diorite
Moldanubian Zone:	i. Pegmatitic and aplitic gneisses
	ii. Calc-silicate gneiss
	iii. Marble (a) Calcitic
	(b) Dolomitic
	iv. Amphibolite
	v. Paragneiss

Petrography

Paragneiss

About 80 per cent of the mapped area is underlain by highly folded paragneiss. These rocks actually form the bulk of the hills around Ober-Meisling and its environs, excellent exposures of which can easily be seen abounding the stream in the centre of this village and also at the northern side of the road cut located at about 2.3 kilometres west of Ober-Meisling on the Ober-Meisling-Hohenstein road.

These gneisses vary from the very fine-grained to medium-grained in texture. In colour, they vary from greyish-brown to dark brown. In some places, they are weakly, but at times, strongly migmatized. These gneisses commonly show strong compositional banding i. e. have a heterogenous structure with light layers (mainly composed of plagioclase feldspar) alternating with dark bands rich in biotite.

It is possible that most banding is inherited from original banding or bedding in the sediments and have been accentuated by subsequent metamorphism. The gneisses on Steinberg at the southwestern part of the mapped area; in certain places are characterized by excellent schistosity and those on Felling road are sandy. Some of them are still massive and structureless when there is not much mica in them.

The gneisses often contain bands of amphibolites, marbles, calc-silicate gneisses and quartzo-felspathic rich bands. The amphibolites, often are stretched but some display boudinage structures.

The s-surfaces of these gneisses are not planar but irregular. They are folded both on small and large scale, and have steep dips. In some areas, they are almost sub-horizontal and have varying attitudes even in the same general area.

The main rock types are the biotite, biotite-sillimanite, biotite-garnet gneisses. In the neighbourhood of Hulm, there are concentrations of poikiloblastic garnet in these rocks.

One outstanding characteristic of these gneisses is the monotonous sameness over large areas proving that, as a rule, metamorphic processes tend toward homogenization producing rocks more or less uniform both in structure and in composition.

A typical paragneiss is specimen M. 13 derived from a road-cut at the extreme northeast corner of the mapped area. This rock can conveniently be called a biotite garnet gneiss, for in hand specimen, this greyish black, fine-grained rock is foliated with quartzofeldspathic bands alternating with garnet crystals scattered throughout the rock.

Under the microscope, it is made up mainly of biotite, quartz, plagioclase, alkali feldspar, garnet sillimanite and opaques. These minerals are in mosaic arrangement with each other except the biotite and the sillimanite which are in some sort of alignment.

The biotite (25%) which is an iron-rich one occurs as roughly hexagonal plates showing strong basal cleavage. When fresh, it is light brown in colour with intense pleochroism. The flakes are in regular leaves and are oriented parallel to each other thus imparting and confirming the foliation as observed in these rocks. In certain parts of the section, biotite is seen to be readily altered into a light green chlorite, first, along the cleavage boundaries.

Quartz (23—25%) exhibits undulose extinction. It often builds irregular shaped grains sometimes interstitial to the feldspars but at times lobed into it in a manner suggesting replacement. Inclusions in the quartz are ubiquitous and are seen to consist of trains of minute bubbles.

The feldspars (35—40%) are of two kinds i. e. alkali feldspar and plagioclase. The alkali feldspar-microline (7%) does not display its characteristic twinning but like the plagioclase rather seem to have undergone an extensive alteration. The amount of plagioclase (35%) in these rocks greatly exceeds the amount of potassium feldspar, a common characteristic observed in these gneisses. Universal stage method reveals that the plagioclase has an anorthite content of 35% i. e. Andesine. Some of the large plagioclase fields have inclusions of biotite and other accessories such as zoisite.

The garnet (5%) of almandine variety, appears as spongy matrix anhedra haphazardly scattered throughout the rock. It is highly poikiloblastic and porphyroblastic with many inclusions of other minerals especially quartz.

Sillimanite (7%) is irregularly distributed as fibres in small bundels concentrated in discoidal felted masses and elongated in streaks usually intergrown with quartz or biotite. Some seem to bear no relation to the direction of schistosity and look like they have been formed late, replacing biotite. In certain parts of the section, sillimanite is in the process of being altered to sericite and present a „fluffy“ outlook.

Opaque minerals include magnetite and reddish brown rutile.

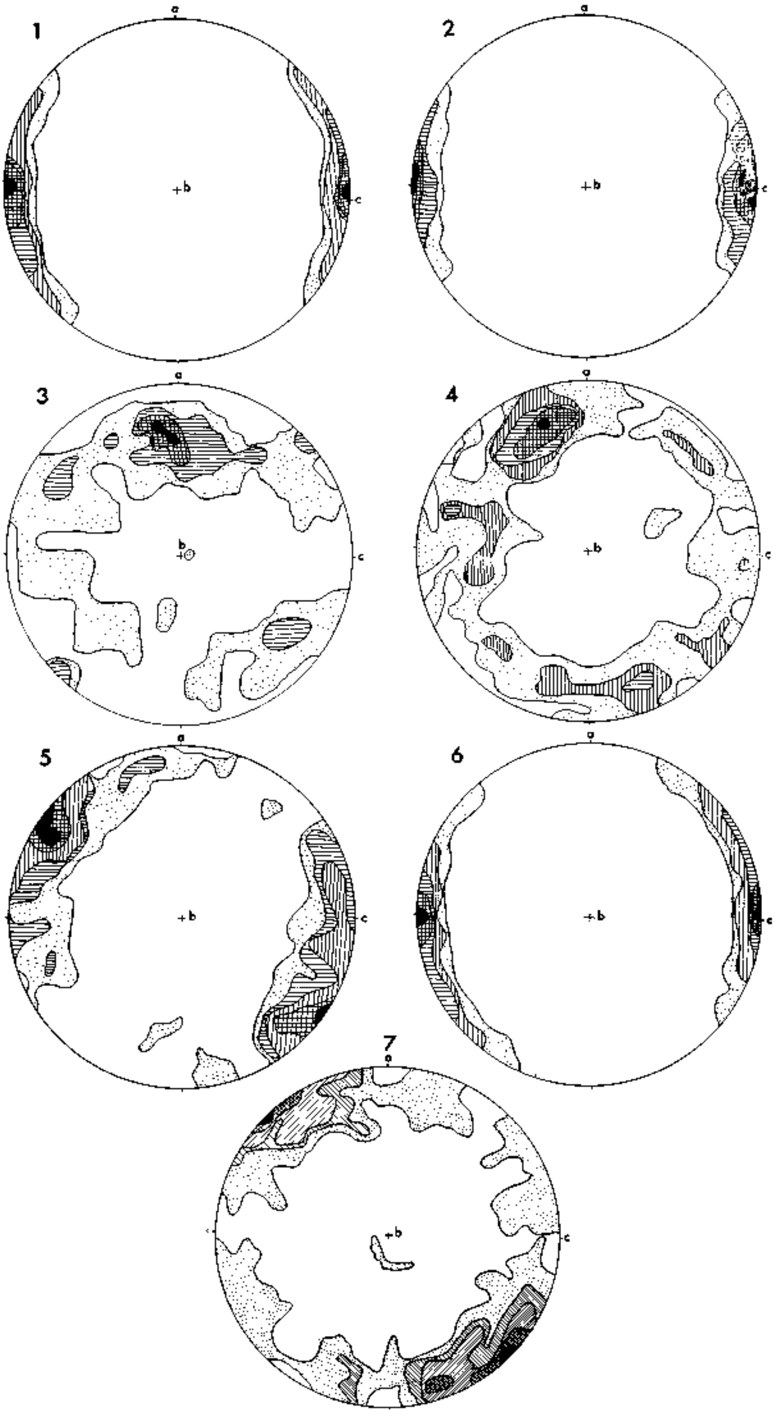

Fig. 3: Orientation diagrams. For descriptive legend see opposite page.

Specimen M. 41 also a sillimanite-biotite paragneiss taken from the southern part of Steinberg (see Fig. 1) is a fine-grained variety, greyish green in colour with sillimanite and biotite rich bands defining a foliation. The whole outcrop is intercalated with quartzofeldspathic rich bands.

The main minerals in these rocks are quartz (30%), biotite (25%), plagioclase (30%) with An 33 (i. e. andesine) alkali feldspar (6%), garnet (3%), sillimanite (5%), and accessory kyanite, rutile, zircon and graphite.

The interesting aspect of this rock is its high sillimanite content as compared with sample M. 13, and the abundance of myrmekite. The zircon present in biotite is surrounded by pleochroic "haloes" of extremely deep brown colour and intense pleochroism.

Descriptive legend for Fig. 3:

Diagram 1.

Sample M. 13. Paragneiss (Biotite Garnet Gneiss).
Orientation diagram for biotite: poles of (001) cleavage in 200 crystals.
Contours at 15%, 12%, 9%, 6%, 3% per 1% area.

Diagram 2.

Sample M. 43. Paragneiss (Garnet Cordierite Gneiss).
Orientation diagram for biotite: poles of (001) cleavage in 150 crystals.
Contours at 7.5%, 5%, 2.5%, 1% per 1% area.

Diagram 3.

Sample M. 1. Paragneiss (Biotite Gneiss).
Orientation diagram for quartz. Optic axes of 300 grains.
Contours at 4%, 3%, 2%, 1% per 1% area.

Diagram 4.

Sample M. 13. Paragneiss (Biotite Garnet Gneiss).
Orientation diagram for quartz. Optic axes of 250 grains.
Contours at 5%, 4%, 3%, 2%, 1% per 1% area.

Diagram 5.

Sample M. 43. Paragneiss (Garnet Cordierite Gneiss).
Orientation diagram for quartz: Optic axes of 200 grains.
Contours at 5%, 4%, 3%, 2%, 1% per 1% area.

Diagram 6.

Sample M. 46. Calc-Silicate Gneiss.
Orientation diagram for biotite: poles of (001) cleavage in 150 crystals.
Contours at 20%, 15%, 10%, 5%, 1% per 1% area.

Diagram 7.

Sample M. 46. Calc-Silicate Gneiss.
Orientation diagram for quartz. Optic axes of 200 grains.
Contours at 5%, 4%, 3%, 2%, 1% per 1% area.

Under the ore-microscope, traces of pyrite, often altered to limonite, could be observed. Ilmenite is a common occurrence is both twinned and involved in a "myrmekitic" intergrowth with garnet. Graphite occurs in laths and is also intimately associated with garnet. Magnetite is also present.

Specimen M. 43 is from th southwestern part of the field sheet. The rock is fine- to medium grained in texture, greyish brown in colour and contains transparent anhedral grains of cordierite showing alteration probably to muscovite. It occurs inconspicuously among the other constituents which, as usual, are quartz, alkali feldspar, plagioclase, biotite, garnet, sericite and accessory rutile, sphene and iron oxides.

Universal stage method used in the determination of the amount of Anorthite content in the plagioclase of some of these gneisses is set in Table 2.

Table 2. Anorthite content in paragneisses.

Sample No.	Anorthite content
1	33%
2	36%
13	33%
23	32%
35	35%
43	40%
	Average: Approximately 35% i. e. Andesine

The Table indicates that the characteristic plagioclase in these rocks is mainly andesine with an anorthite content of about 35% or An_{35}.

Orientation diagrams for biotite (0001)-poles in samples M. 13 and 43 (see Fig. 3/1 and 2) show that these poles form a well developed girdle of monoclinic symmetry with distinct singular maxima indicating the average position of the s-plane-pole. These diagrams proved that the micas are microfolded and confirms the well developed schistosity displayed by the biotite in these gneisses.

Orientation diagrams for quartz axes in samples M. 1, M. 13 and M. 43 (see Fig. 3/3, 4 and 5) show that the symmetry of the broadgirdle around B-axes is triclinic. There is a general under-population around B-axes co-ordinate in alle the samples, with the maxima near the A-axes. In sample M. 43 the under populated region in the B-axes is somewhat inclined to the AB plane.

In conclusion, it could be said that since these samples came from not too much distant areas, they have a tendency to develop the same mineralogical features with very minor local variations.

Amphibolites

These rocks occupy about 10 per cent of the mapped area outcropping mainly in the central and at the eastern parts of Hohenstein and in many other localities (see Fig. 1). These are greyish black, fine-grained rocks which represent the most frequent interlayers and are often in intimate association with the paragneisses. They form thin and up to several metres thick bodies in the gneisses and are often stretched or ruptured into pieces with respect to each other mainly by dilatation.

On top of Wachtberg, the amphibolites are fine-grained, greyish black rocks and finely lineated with the B_L 060/20. They also form boudinage structures within the paragneisses. Some of these rocks display a crude foliation but are mostly poorly foliated or hardly at all. They are peculiar rocks in that they sometimes carry biotite or at least altered product of biotite. In these biotite carrying rocks, the plagioclase content changes and although all these amphibolites are in intimate association two main types can be distinguished. These would be designated as (a) Amphibolite (in the true sense of the word) and (b) Biotite hornblende gneiss.

(a) Amphibolites

Specimen M. 39 taken from the centre of the mapped area (see Fig. 1) is a typical amphibolite. It is fine-grained, greyish green in colour, massive and structureless rock in hand specimen.

Under the microscope, however, it is seen to consist mainly of hornblende, diopside, plagioclase, chlorite, sphene, apatite, and opaques.

Hornblende (50%) is the greenish-brown variety, pleochroic from greenish to brownish green. Some of the grains are pseudomorphic after pyroxene but for the most part form characteristic prismatic grains with the grains interfering with each others.

Diopside (15%) is the commonest pyroxene. It is usually roughly equidimensional and may be subhedral to anhedral in form. Its association with the hornblende shows clearly that the hornblende follows the pyroxene or at least there is a replacement for one kind taking place, i. e. a clear case of uralitization in these rocks.

Plagioclase (20%) occupies large inter-spaces between the other minerals. It is mostly untwinned and forms even-grained mosaic pattern with other minerals. This particular specimen has a high anorthite content of 67% i. e. Labradorite but these amphibolites on the average contain about 45% Anorthite i. e. Andesine.

Chlorite (6%) probably as a retrograde product after biotite, occurs in erratically disposed flakes and is intergrown with the hornblende and/or pyroxene. Some of the chlorite could be determined as penninite.

Sphene (5%) in spindle and wedge-shaped forms is irregularly distributed in the specimen. Some of the large sphene crystals contain large inclusions of apatite, are pleochroic from brown to dark greenish brown and twinned.

Apatite (3%) is a abundant occurring as euhedral prismatic grains and also as six-sided prisms. It may be colourless but is often bluish and the crystals are often fractured across by a basal parting.

Under the ore-microscope, specimen M. 17, also a garnet amphibolite from the central part of the mapped area contains pyrite, magnetite, ilmenite, and limonite as products after pyrite.

(b) Hornblende gneiss

Specimen M. 5 taken from the southern part of Hohenstein is a typical example of these foliated amphibole-plagioclase rich rocks. It shows banding with alternating layers of hornblende (50%) and diopside (5%) versus plagioclase (35%) quartz (8—10%). The diopside is often concentrated in patches and streaks.

Summary: Near Hohenstein the amphibolites are folded (see Plate 6) with the fold axis measuring 06° towards the southwest.

The age relationship between the paragneisses and the amphibolites is not always clear in that they are in very intimate association.

Marble

X-ray analyses of the marble specimens collected during the field work showed that two main types of marbles occur in the area. The first type is mainly calcitic which is found outcropping at the northeastern part of Ober-Meisling and the second type (Specimen M. 33) is a dolomitic one found at the extreme southeastern corner of the mapped area. The marbles occur interbedded with the paragneisses and the amphibolites.

(a) Calcitic marbles

Specimens M. 11, 12, 48, 49 and 51 represent the calcitic marbles. Some of these marbles can be seen in a small quarry at the northern side of the road and about 100 metres from the cross at the extreme eastern part of the mapped area on Unter-Meisling—Ober-Meisling road. This outcrop is about 4 metres thick, has a strike of N 15° W and a dip of 12° towards the west. It is cut in places by thin bands of amphibolite and calc-silicate rocks. Ptygmatic veins of quartzofeldspathic material also cut the marble.

In hand specimen, the marble is massive, greyish white in colour but sometimes is cut by alternating light brown and reddish bands. The marble has a sugary or granular texture.

Under the microscope it consists mainly of mosaic pattern of calcite (90%) grains which are traversed by minute cracks appropriate to the rhombohedral cleavage of the calcite. In specimen M. 49 which appears slightly crushed, the grains show twin lamella.

Other mineral associated with the calcite are dolomite (2%), feldspar (2%), which is altered, quartz (2%), white or pale green diopside (3%), muscovite (1%) and scapolite. Accessory minerals include magnetite, sphene and iron-ores.

(b) Dolomitic marble

Specimen M. 33 consists predominantly of dolomite (90%) with minor amounts of calcite (2—3%) and other minerals such as quartz (3%). feldspar (2%), tremolite (1%), some few crystals of zoisite iron oxides opaque minerals. The dolomite crystals resemble the calcite crystals both in hand specimen and under the microscope.

Calc-silicate gneiss

These gneisses are not confined to one locality but are seen often as scattered boulders especially in the minor stream valleys and also as disjointed series of rocks both within the amphibolites and the paragneisses.

In general, these gneisses are commonly fine- to medium-grained, banded and vary from greyish green to deep green in colour. This banding is due to inhomogenous, anisotropic distribution of minerals but not to preferred orientation of these minerals.

Specimen M. 19 derived from the northwestern part of the map is a diopside-plagioclase rock with a granoblastic texture under the microscope, it is made up mainly of diopside, plagioclase, carbonate, quartz, chlorite, epidote which is altered to pistacite.

Diopside (30%) may be white or pale-green in colour and frequently contains rhombohedral crystals of sphene inclusions.

Plagioclase (35%) is often twinned and shows undulose extinction when not twinned. Some of the tabular prismatic crystals are partly corroded as a result of recrystallization of other minerals. Some of the untwinned crystals have been altered to sericite and kaolinite. Universal state method revealed that the plagioclase had an Anorthite content of 63% i. e. Labradorite.

The carbonate (10%) is twinned, rhombohedral in form and is often distorted or bent. This means that the rock has undergone some cataclastic effect.

Quartz (15%) forms large composite grains, has undulose extinction and carries some inclusions.

Most of the chlorite (8%), probably derived from biotite, is the penninite variety whilst the epidote group is represented by pistacite.

Accessory minerals include sphene, zircon, apatite, and poikiloblastic garnet. The ore-microscope shows abundant pyrite and limonitic alterations after pyrite. There are traces of chalcopyrite and ilmenite inclusions in the garnet.

Specimen M. 46 taken 2 kilometres in the valley just south of Ober-Meisling—Lechnerkreuz road contains quartz, biotite, plagioclase, garnet, alkali feldspar. The predominantly quartz grains are set in a mosaic of other minerals present.

Orientation diagrams for the biotite and quartz (see Fig. 3/6 and 7) reveal similar orientations for these two minerals as seen in the paragneisses (refer to Fig. 3/1—5). The only conclusion that can be drawn from these figures is that since all these rocks come from the same general area, there is little wonder that they have undergone similar metamorphic effects in their mineral orientations.

Pegmatitic and aplitic gneisses

Within the paragneisses and usually on top of some of the hills such as Steinberg, Buchberg and at the southeastern part of Hulm are found these fine- to medium-grained gneissic rocks which occur in two distinct forms. Firstly, as aplictic and migmatic quartzo-feldspathic rocks injected into the paragneisses as cross-cutting dikes, ptymatic or convoluted veins. Secondly, they occur as huge boulders with some measuring 2 or 3 metres in diameter on higher elevations but smaller boulders obviously derived from the huge ones, haphazardly scattered at lower elevations around and down-hill. Some of these boulders can conveniently be seen on the northeast trending trail from Lechnerkreuz near the top of Buchberg towards the cross at the eastern part of the area at an elevation of 563 metres.

Some of these rocks are gneissic in outlook but others are massive, coarse-grained, greyish white in colour, heterogenous and megascospically composite rocks, composed of magmatic portions as well as metamorphic parts. They usually consist of quartz, feldspar and few dark minerals, in which biotite predominates and seem to have preferred orientation. It is possible that these rocks intruded into the paragneisses absorbing some inclusions of the latter rock within them.

Within the paragneisses, these rocks are often folded into ptygmatic folds with strongly contorted structures and local enrichments often paralleling these s-planes of the paragneiss.

A typical aplictic gneiss is sample M. 14 taken from the northeastern part of Hulm.

In hand specimen, this rock is slightly foliated, light greyish yellow in colour, fine- grained with the mica grains defining the foliation.

Under the microscope, it is seen to be made up of mainly quartz, plagioclase, alkali-feldspar, muscovite, biotite and accessory garnet, apatite, zircon and epidote. Myrmekitic structures can also be observed. It has an allotriomorphic-granular texture.

Quartz (20%) some of which grow in the feldspar occurs as anhedral grains filling spaces between the feldspar and other minerals. It shows signs of recrystallization especially along adjacent grain boundaries.

Plagioclase (20%) occurs as both twinned and untwinned crystals with some appearing highly cloudy due to alteration to both sericite and kaolinite. Universal stage method proves 30% anorthite content for the plagioclase i. e. Oligoclase-Andesine. Alkali-feldspar (45%) mostly microcline is abundant. They occur as big individuals some of which are altered. There are also oriented inclusions in these feldspars.

The biotite (10%) is reddish-brown in colour and strongly pleochroic slightly aligned and defining some foliation. Some of the biotite have been altered to chlorite and penninite.

Muscovite (2%) occurs as an alteration product of potassium feldspar.

Apatite (1%) is seen as minute prismatic crystals.

Accessory minerals include zircon, poikiloblastic garnet and epidote which occurs as a vein mineral indicative of its late formation in this rock.

Sample M. 31 from the middle part of the mapped area has almost the same mineral composition as M. 14. The only difference between these two rocks is that M. 31 is massive, medium-grained, greyish green in colour with abundant myrmekite.

Diorite

This basic rock (sample M. 54) outcrops as an intrusive within the paragneiss at about 150 metres south of Hulm. It is but a small outcrop measuring only about one square metre in area and 0.6 of a metre high.

In hand specimen, it is a medium-grained, equiangular rock with greyish green colour.

Under the microscope, it has a hypidiomorphic texture and is seen to be made up mainly of hornblende, plagioclase, epidote, tremolite, apatite and accesory zoisite and pyrite.

Hornblende (45%) is the brown variety some of which have partly been altered to chlorite variety of penninite.

Plagioclase (45%) occurs as large individuals with some of the plagioclase twinned. Saussuritization in the plagioclase can be recognized by the greasy lustre, green colour, absence of cleavage and twinning in some of the plagioclase fields. Zoisite crystals are also seen embedded in the plagioclase. The plagioclase variety is oligoclase-andesine with an anorthite percentage of about 30% (An_{30}).

Apatite (5%) occurs as minute euhedral crystals of prismatic habit.

Alkali feldspar (3%), epidote and tremolite occur.

Under the ore-microscope, the rock is seen to be low in opaques. Only a few idiomorphic grains of altered pyrite can be observed.

Lamprophyre

Only one specimen (M. 42) of this rock-type is seen at the western part of the mapped area cutting the paragneiss as a narrow dyke, and measuring less than half a metre in width. It trends in a northwest-southeast-direction and has a steep dip to the northeast. In this area the paragneiss have been highly weathered, deformed and is sandy in places.

The dyke rock, in hand specimen, is a melanocratic, greyish green, fine-grained, massive and homogenous rock.

Under the microscope, it exhibits a panidiomorphic-granular (lam-(prophyric) tecture and consists mainly of subheral laths of plagioclase (50%), biotite (24%), anhedral quartz (10%), hornblende (15%), apatite with accessory iron ores and magnetite.

Examination under the ore-microscope reveals only tiny grains of pyrite with alterations to limonite and a few grains of magnetite.

Loess and other superficial deposits

A 7-metre thick deposit of loess is seen at the northern part of the road just at the eastern outskirts of Ober-Meisling. This material is soft, porous, pale yellow in colour with small capillary tubules. It is laminated in places and riddled with white calcitic material imparting to the outcrop an effervescene with dilute acid.

Examination with the handlens reveals that the minerals in the loess consist mainly of angular grains of quartz, mica flakes, calcite and minor felspathic grains.

It is most likely that this loess is of eolian origin.

The wide valleys near the Krems in particular, and the flat plains at the entrance to some of the valleys, are often covered by Recent or Tertiary deposits consisting in the main of quartz, gravel, brownish looking cobbles, soil and alluvium all mixed up together.

On top of the hills, superficial deposits of soil and alluvium usually serve as a mantle covering the rocks underneath.

Conclusions

The detailed study of these rocks, both in the field and under the microscope has shown that the main rock type in the mapped area is the paragneiss which is the oldest rock with intercalations of amphibolites, calc-silicate rocks, marbles, aplitic and pegmatitic rocks, cut in certain places by dioritic and lamprophyric dykes.

These rocks are hetrogenous, differing widely amongst themselves in composition, structure, texture and in distribution. They vary from the very fine-grained to medium-grained and pegmatite rocks.

They have a marked tendency to follow a northeast-southwest trend with dips generally towards the southeast.

Sometimes, contacts between the different rock types could be observed. At times, the contacts were so transitional and indefinite.

The paragneisses are more uniform in character and foliated types predominate over massive ones. The main constituents are quartz oligoclase-andesine, biotite. Garnet, sillimanite, alkali feldspar, cordierite may be found in the rocks.

Amphibolites are rather widespread within these rocks. Garnet, basic plagioclase and/or quartz have been seen in these rocks and presumably, the amphibolites were derived from sedimentary rocks or possible tuffaceous material. In some cases, these rocks are foliated and are then designated as hornblende gneisses.

Two types of marbles occur, i. e. calcitic and dolomitic. X-ray methods were used in separating these two groups. In these particular area, the calcitic marbles prevail over the dolomitic ones.

It seems likely that these rocks have resulted from a prolonged sedimentation in an unstable shallow geosyclinal basin.

The paragneisses then have developed as a result of regional metamorphism under increasing temperature and pressure during the Moldanubian Orogeny. It is likely that the sediments recrystallized according to the rules of several mineral facies, the complete sequence of events being a progressive change of the sediment by deformation, recrystallization and alteration through the greenschist facies — epidote-amphibolite facies and finally amphibolite facies. The limestone in the original sediments have now been turned to marble; the marls and clays to amphibolites. The calc-silicate rocks represent concretions enriched in carbonate. An intense metamorphism of the Moldanubian folding was accompanied by the penetration or mobilization of quartz feldspar solutions which gave rise to pegmatites, migmatites and aplitic dykes of metasomatic or anatectic origin. It is even possible that they formed synorogenically with the paragneisses.

The presence and abundance of green hornblende, plagioclase, garnet (almandine variety) and sillimanite in these rocks are all pointers to the typical mode of occurrence of the amphibolite facies which is in the high grade zone of progressive regional metamorphism. In these rocks derived from clastic sediments, almandine is widely distributed.

Epidote continues to remain stable through this facies however, not with albite but in paragneisses with oligoclase-andesine as the plagioclase in the paragneisses vary from about An_{30}—An_{40}. Saussuritization, chloritization and mylonitization could all be observed in these rocks.

A great deal of migmatization and intrusion of granite material has taken place in the rocks. The end of this period is marked by the intrusion of lamprophyric and dioritic dykes into the paragneisses.

Structure

A few words would be said about the geological structure of this area. The structure in the area has been dependent on the interaction of forces with operated during the Moldanubian metamorphics and its subsequent compressional effects on the paragneisses and its enclosing bodies of rocks. Due to these forces, the paragneisses and the amphibolites usually, in most places are extensively folded.

Although local variations exist, these rocks generally have a NE-SW or N-S regional trend with moderate dips towards the southeast or east. It is to be expected that these rocks have undergone, not one, but two or more periods of regional folding, which have resulted in the formation of anticlinal structures one of which could be observed in the locality just south of Hohenstein. This particular anticline has a fold axis in N 45° E direction and with a plunge of 6° towards the southwest.

The B_F or the direction and dip of fold axis in these rocks varies from 030/00 to 060/00 and two fold axes, at right angles to each other could also be observed.

The most complicated structure involved the relationship of the amphibolites and the paragneisses in the central part of the mapped area for these two rock types are in such an intimate relation that it was not easy to decipher the geology within the limited time on hand.

No major fault was observed but the possibility that some discordant faults are cutting these rocks cannot be ruled out in that mylonitized and slickensided rocks which are indicative of mobilized zones near these faults occur. The abrupt changes in dip and strike of the rocks at the northeast part of the mapped area, the elongated and streched habit of the quartz in the rocks taken from this area e. g. in samples M. 1, M. 2 and M. 3 were all indicative of a possible faulting in this area.

Jointing in the rocks is common. Whilst some joints are perpendicular to the foliation planes (i. e. cross joints) others are sub-parallel to the s-planes with the production of sheeting structure in the rocks.

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The Genesis of the Dobra and Krumau Complexes of the Kamp Valley in the Lower Austrian Waldviertel*)

With 3 figures and 3 tables

(Part 2: Mineralogy and Petrography)

By Mahmoud Khaffagy **)

Abstract

The mineralogy and petrography of the Dobra- and Krumau-rock-complexes are studied in detail. The zircons of the different gneissic varieties are investigated. The genesis of the different rock types is discussed; the clear ortho-origin for the Dobra (Spitzer) gneisses is declined. The parent rock of these gneisses is suggested to be a sediment derived in large part from pyroclastic-rich sources with or without graywackes, very often interlayered with considerable submarine acidic flows, intercalated with limestones, from which the newly detected marbles are derived. The regularly intercalated amphibolites are suggested to be formed from simultaneous intercalations of thin basic flows and sills. The Krumau complex is believed to be of clear para-origin, representing a regionally metamorphosed series of marine argillaceous, calcareous and arenaceous sediments, from which the para-gneisses, schists, marbles and quartzites were formed. The basic volcanic activity continued to the east to be responsible for the amphibolite bands intercalated in this complex.

Introduction

This second part represents the mineralogic and petrographic studies of the Dobra- and Krumau complexes (Spitzer gneisses and para-rock series) after Khaffagy (1970). The first part (Khaffagy, 1970) represents the geological and structural studies, while the third part (Khaffagy & Schroll, in press) will represent the geochemical studies of the same rocks.

The samples studied (200) represent the different rock types and varieties in a west-east cross-section through the area. Samples numbered 1 to 100 were collected from the Dobra-complex till the Genitzbach area including the contact zone; those with numbers 100 and above belong to the Krumau-complex till the eastern contact with the Gföhler gneiss body.

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*) The following is a somewhat shortened version of the original manuscript submitted by M. Khaffagy; the changes were jointly carried out and approved by Prof. H. Wieseneder and Prof. H. Küpper, Vienna, September 1970.

**) Dr. Mahmoud Khaffagy, Geology Department, Faculty of Sciences, Heliopolis (Ain Shams) University, Abbassia, Cairo. U. A. R.

1. Petrography of the Gneisses

On the basis of about 75 modal analyses it can be stated, that nearly all the gneisses of the area studied are mainly composed of plagioclase (oligoclas and andesine), quartz and potash feldspars (mainly orthoclase). The relative abundance of each of them differs according to the locality and gneiss type. Besides these three main constituents other minerals occur, sometimes also as main constituents as biotite, muscovite, sillimanite and augite. Accessories include garnet, sphene, hornblende, chlorite, tourmaline, apatite, iron oxides, allanite, zircon and calcite. As already previously indicated (part 1, KHAFFAGY, 1970), the gneisses could be classified according to their field occurences to two main groups; it is also possible to classify them into two main types.

Type I: includes the typical Dobra-gneisses, represented by samples No. 1, 3, 20, 24, 30, 36, 45, 51, 53, 60, 61, 73, 74, 80, 84, 85, 86, 87, 89, 96 and 99. This type represents the subvarieties of the Dobra-gneisses with the field names: biotite-bearing, biotite-free, banded and augengneisses. This type can be further subdivided to two other subdivisions, according to the knaf/plag (alkali feldspar/plagioclase) ratio:

Type IA: represents the gneisses with knaf/plag-ratio of more than 1, and includes mainly the augen gneiss variety; to this type belong the samples No. 3, 45, 61, 80, 84 and 99.

Type IB: represents the gneisses, in which the knaf/plag-ratio is less than 1, and includes the other three subvarieties represented by samples No. 1, 20, 24, 30, 36, 51, 53, 60, 73, 74, 85, 86, 87, 89 and 96.

Type II: includes the paragneisses, occuring in both complexes, it is further classified into two subdivisions according to their field occurrence:

Type IIA: represents the paragneisses of the Dobra-complex, to which the following samples belong: 14, 17, 26, 27, 31, 34, 37, 43, 44, 52, 56, 67, 83, 92, 93 and 95.

Type IIB: represents the paragneisses of the Krumau-complex. The samples belonging to it are: 100, 103, 113, 114, 115, 116, 117, 118, 119, 121, 124, 125, 127, 134, 135, 139, 140, 142, 145, 148, 154, 168, 170, 180, 186, 188, 191, 192 and 195.

The main compositional differences between the two types can be summarised as follows:

1. The quartz content in type I shows almost similar values ranging between 30 and 40%, with a mean value of 32.4% (33.0% for I A and 31.8% for I B); in type II, it shows a wider range from 2% (sample 17) to 50% (sample 34); highly quartzitic gneiss No. 83 has 69% quartz; the mean value of quartz in type II is higher than that in type I, being 37.25% (39.5% for II A and 35% for II B).

2. The absolute values and the relative abundance of both types of feldspars, show significant differences in both main types as well as in their subvarieties. The mean values of knaf show gradual decrease in types I A, I B, II A and II B, being 37%, 20%, 15.3%, and 16% respectively. A similar relation is also indicated by the knaf/plag ratios of these types, being 1.42, 0.47, 0.43, and 0.90 respectively. The amounts of plagioclases are behaving nearly in a contrary manner, with the exception, that Type I A, which represents the augen-gneiss-varietis, has a remarkable low plagioclase content (26.1%). This trend follows I B, II A, II B and I A, with the sequence 42.8%, 36%, 34.8% and 26.1%.

It is to be considered, that the values of the feldspars, in the individual samples show relative constancy in types I A and I B, when compared with types II A and II B. It is also remarkable that the augen-gneisses senso strictu occur only in the Dobra-complex. If any augen-variety does occur in the Krumau-complex, the augen are of plagioclase and not of knaf (near the contact to the Gföhler gneisses as in samples 188, 191 and 195).

3. Concerning the type, amount and distribution of the occuring micas, it is found that the most flourishing mica is the reddish brown biotite variety. Besides, muscovite is also occuring in considerable amounts. The biotite with its both varieties (reddish brown and greenish brown), is the only mica, occuring in the gneisses I A and I B, with an amount, very rarely exceeding 5% of the rock composition. The greenish brown variety is practically restricted to the samples 73, 80, 85, 87, and 89. On the other hand, both types of mica, the reddish brown biotite and the muscovite do occur, either separately or together, in the paratypes II A and II B, with amounts always exceeding 5% and very often reaching 20% of the rock composition.

4. Sillimanite shows particular restriction to the paragneisses of types II A and II B, occuring in both complexes. Its amount varies considerably, as it occurs in some samples only as accessory, while it reaches high values in others (36% in sample 17). Intermediate amounts are recorded with special predominance opposite to the Schloteinbach area and around Krumau/Kamp till Thurnberg Sperre.

5. Augite and diopside are practically restricted to the gneisses of the Krumau-complex (II B). Diopside occurs in a more restricted area between the Genitzbach and Krumau (samples 117, 118, 119 and 121 with amounts of 6%, 2.5%, 5% and 12% respectively). The augite is much more widely occuring in the Krumau gneisses and acquires higher values, reaching 40%, as in sample 115. Both pyroxenes do occur together in different proportions, as in samples 118, 119 and 121.

6. Amphiboles in the gneisses are encountered only as accessories and are restricted to type II B. Only samples 114 and 117 were found to contain 9.5% hornblende and 2.5% tremolite respectively.

7. Garnet is an ubiquitous mineral, as it occurs nearly in all the gneisses sometimes as accessory and as main constituent. It increases gradually in the Krumau-complex towards the Gföhler gneiss contact. In some garnetiferous mica schists it reaches aprecciable amounts, as in sample 118 with 19% garnet.

8. Titanite is like garnet, an ubiquitous accessory, but of wider distribution in all types of gneisses. Its amount is seldom 1%, except in three cases (158, 180 and 195) where it acquires 4%, 1.5% and 1.5% respectively. It shows in this respect some parallelism to both augite and garnet, as it also flourishes in the Krumau-complex, specially near the contact to the Gföhler gneiss.

9. The mineral tourmaline is only detected as accessory in the Krumau gneisses, it increases also in distribution to the east, starting by sample 95 near the Genitzbach. It reaches 1% and 2% in samples 116 and 170 respectively.

10. The mineral chlorite is always occuring as a parallel partner to biotite, being almost in all cases its alteration product. It is an accessory, but sometimes it reaches values from 3% to 18%, specially in type II (44, 56, 74, 86, 92, 115, 139 and 159).

The specific properties of the gneisses minerals

Quartz: The quartz occurs always in the form of xenoblastic grains, which differ considerably in their grain size. In the fine-grained varieties it ranges from 0.2 to 0.8 mm., while in the medium and coarse-grained varieties it reaches 3 to 8 mm. in diameter respectively. However, the most abundant grain size is that of the medium-grained varieties, which mostly ranges between 2.5 and 4.5 mm. In some varieties it occurs in the form of porphyroblasts; sometimes also as embedded finer grains in the ground mass. In varieties representing the predominant types, the quartz occurs in the form of xenoblastic grains mostly in a segregation crystallisation with other light-coloured minerals and shows a preferable allignment in the s-plane of the rock, thus enhancing the gneissose structure.

It is almost always deformed, showing undulose extinction from weak to strong. Some of these strongly deformed quartzes do not show any more the typical uniaxial character, it is sometimes pseudouniaxial to clearly biaxial with a 2 V ranging from 5—7°. Generally the mineral is obviuosly fresh and includes very often other minerals specially undeformed grains of biotite, and very rarely zircons (samples 43 and 52) and sillimanite, as in sample 26. Pores with liquid inclusions are not rare.

Plagioclase: The mean values of the plagioclases in the different types vary from 26.1% in type I A, to 34.8% in type II B, to 36.0% in type II A and 42.8% in type I B. The relative amount of the plagioclases in the gneisses is always exceeding those of the knaf, except only in type I A (the augen gneiss varieties of the Dobra-complex) where the ratio knaf/plag is more than 1.42. If the plagioclase content of the individual samples of each type is considered, it is noticed that the increase of the plagioclase content comes mostly on the expence of the knaf, due to the relative constancy of the quartz content together with other constituents (except in some mica schists and augite gneisses). The plagioclases vary from oligoclase (in types I A and I B) to oligoclase, oligoandesine and andesine (in types II A and II B). Anorthite content higher than 50% are extremely rare. The high values of 40—48% An were only observed in augite-bearing gneisses. The plagioclases occur almost always as xenoblastic grains forming with other minerals the main tissue of the rock. They occur sometimes as disseminated grains in the groundmass of the augen varieties, as well as crystallised segregations with other light constituents in the form of fine bands, alternating with other bands, richer in dark constituents. In rare cases, they occur in the form of porphyroblasts, which disturb the gneissosity of the rock (37, 48, 154, 188 and 192). In the fine-grained varieties they acquire a grain size, ranging from 0.2 to 1.0 mm., while in the medium — to coarse-grained varieties they vary from 1.0 to 3 mm. and from 3 to 5 mm. respectively. In some porphyritic varieties they can reach 9 mm. in diameter.

The reverse zoning of the plagioclases is frequent in type I with a core ranging in An content from 20 to 25% and a rim ranging between 25 and 30% (samples 1, 24, 45, 53 and 60). Less frequent is this zoning in Type II (samples 27, 44, 100 and 186). The aplitic, gneissic varieties do not show any zoning-structure of their plagioclases.

Polysynthetic twinning is almost always occuring in all the plagioclases of the studied gneisses, mainly after the albite-law. In some plagioclases, especially those of the porphyritic gneisses at the east end of the area, the twin lamellae are often bent at their ends indicating post crystalline deformation. It happens also in some zoned plagioclases, that the twinning is only restricted to the rim of the zone.

The majority of the plagioclases show a considerable degree of alteration, mainly sericitisation. The degree of alteration varies from one locality to the other, without any definite trend, except, that it is in type I of a lower degree and less predominant, than in type II. Also the aplitic varieties show relatively fresh plagioclases, while in some samples, especially those of type II, complete alteration and sericitisation of the feldspars is recorded, sometimes to an extent, where the differentiation between plagioclase and knaf becomes impossible (14, 17, 43, 44, 56, 86, 127 and 133).

Besides the fine inclusions of sericite in the altered samples, the plagioclases include also fine inclusions of other minerals. Some of these inclusions, especially biotite, exhibit an alignment parallel to the twin lamellae. In few cases the plagioclase contains grains of allanite, which produced radial cracks around them (87, 88 and 95).

The antiperthitic tecture is observed often in the plagioclases of the studied gneisses of both complexes. It occures in the form of clots and/or spindles of knaf in the plagioclase crystals, the spindles sometimes acquire a parallel alignment to the twin lamellae. This texture is relatively more frequent in type I than in type II. The aplitic varieties do not have antiperthetic texture, instead some perthitic intergrowths may occur. The myrmekitic texture occures more often than the antiperthitic and shows an equal predominance in both types of the gneisses.

Alkalifeldspars: These show a wide range of grain size, content, and distribution in the gneisses of the studied area. They occur as minor constituents in the gneisses of type II A, and as accessories in type II B (with some few exceptions), but comprise one of the main constituents in types I A and I B. In type I A they always exceed the plagioclases, while they are of comparatively less abundance in type I B, where the accompanying plagioclase predominates.

The main type of knaf is the orthoclase, which is sometimes perthitic. Near orthoclase, occurences of microcline are also recorded, especially in the highly aplitic varieties of both gneiss types, where it is the main alkalifeldspar occuring with weak cross-hatching twinning. In the aplitic varieties microline is the only knaf occuring, which is very fresh and sharply cross-hatched. Therefore we think, that such microcline occurences are local and secondarily recrystallised from the original orthoclase, wherever the temperature conditions favoured its recrystallisation.

The $2\,V_X$ measurements range from $-50°$ to $-72°$ according to the type of knaf measured. The extinction angle perpendicular to (010) is almost always 0° or with small deviations of 1°—3°, while that parallel to (010) ranges between 5° to 8°.

The orthoclase is often twinned after the Carlsbad law, especially the porphyroblasts. Less common is the twinning after the Baveno law. Generally the alkalifeldspars show a degree of alteration, which corresponds to that of the accompanying plagioclase. Normally they are kaolinised, with dusty appearance and rarely, in the highly altered varieties it is so sericitised, that differentiation between both feldspars is impossible.

As a further proof a the type of alkalifeldspar occuring and as an attempt to get some genetical indications, the or-content, as well as the degree of obliquity of the knaf were investigated by X-ray diffraction techniques.

The obliquity of knaf, which is defined as the degree of departure from monoclinic to triclinic symmetry, was determined after the method of GOLDSMITH & LAVES (1954 b) through the equation

$$\Delta = 12.5 \ d(1\bar{3}1) - d(131).$$

The obliquity is considered to be a direct measure of the statistical order-disorder distribution of the Al/Si atoms in the knaf unit cell. For $\Delta = 0$ the knaf is disordered and is monoclinic in symmetry (orthoclase), while for $\Delta = 1$ it is in complete order and is triclinic (microcline). MAC

Kenzie (1952, 1954) indicated, that the difference in 2 Θ between $(1\bar{3}0)$ and (130) reflections can be also considered as an expression of obliquity. It varies between 0.83° to 0.00° from monoclinic to triclinic symmetry respectively. However great care must be taken, in correlating these measurements with the degree of order, as it is certain, that the Na content can affect the $130—1\bar{3}0$ peak separation (Mac Kenzie, 1954).

The or-content of both the unmixed phase and the homogenised phase (after dry heating of the sampls to 1050° for 48 hours) was determined following the method of Orville (1958) through the equation:

$$Y = 166{,}39 — 92{,}31\ X.$$

Where Y is the or-content for the monoclinic phase, and

$$X = 2\ \Theta\ (20\bar{1})_{\mathrm{knaf}} — 2\ \Theta\ (101)_{\mathrm{KBrO3}}$$

For the triclinic phase the following correction must be introduced:

$$X_{\mathrm{mon.}} = X_{\mathrm{tric.}} + 0.015.$$

The samples Nos. 80 (Type I A), 53, 74 (Type I B) and 31 (Type II A) were subjected to these studies, the results of which are shown by Fig. 1 and Table 1. The knaf in all the samples (except 53) proved to exhibit a highly disordered distribution of their Al/Si atoms, hence acquiring the least degree of obliquity, i. e a domination of the orthoclase phase. It is clear that the (130) as well as the (131) orthoclase reflection peaks of these samples are well developed in the range around 23.40° and 29.74° respectively (technical corrections must be considered). The corresponding separate reflections of the microcline (130), $(1\bar{3}0)$ and (131), $(1\bar{3}1)$ when present, should appear at 23.14°, 24.04° and 29.36°, 30.16° respectively.

The sample 53 develops very badly such reflections which are neither typical for the triclinic nor for the monoclinic phases. The obliquity primarily estimated from these underdeveloped peaks ranges around 0.86. Cases similar to this were given by Goldsmith & Laves (1954 b), Mac Kenzie (1954), Richter (1965) and Da Costa (1967), where it is explained by the simultaneous occurence of both monoclinic and triclinic phases in the same morphology in the form of sub X-ray twinning and/or the occurance of microscopic to submicroscopic islands of both symmetries. Mac Kenzie, ibid., added, that different possibilities can occur, so that all gradations between the two extreme phases are possible. Consequently, the degree of development and sharpness of the peaks can be taken as a direct indication for the relative abundance for one phase over the other. Accordingly it can be concluded that sample 53 represents a predomination of the triclinic phase over the monoclinic phase.

It is here worth mentioning, that Heier (1957) indicated, that the knaf in the higher amphibolite facies, as well as in the granulite facies is a perthite with optical and X-ray monoclinic symmetry (there are indica-

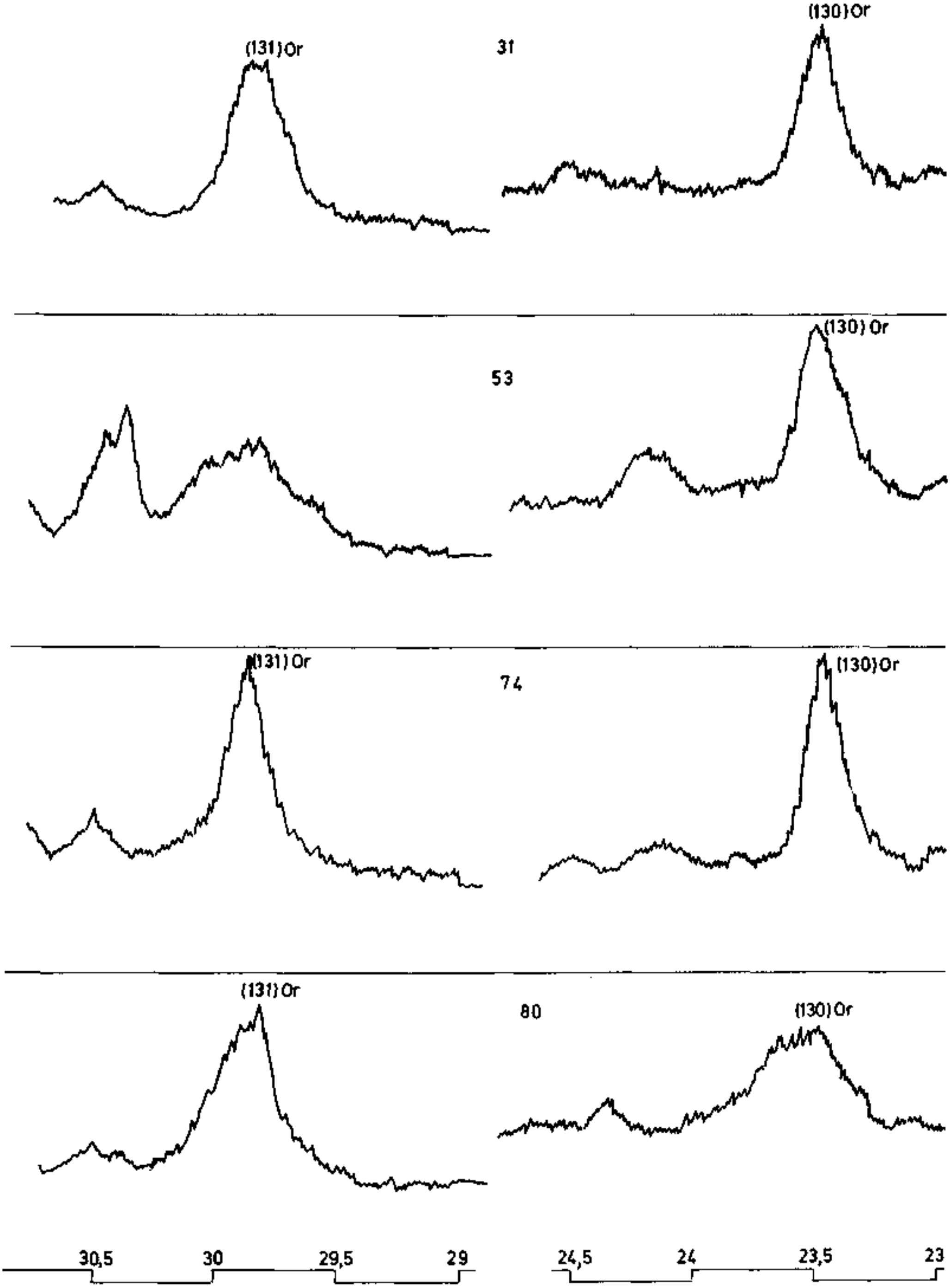

Fig. 1. The development of the peaks (131) and (130) in the unmixed and homogenised phases of the studied knaf samples.

tions for small deviations from monoclinic symmetry). A relation between obliquity and 2 V_X was indicated by HEIER (1961), as both of them increase parallel to each other. But in our case, where the studied Knaf of the orthoclase samples (Table 1) should acquire 2 V_X values near to each other, as they indicate similar degree of disorder, the differences in the 2 V_X are so big that such a relation does not exist. Similar cases were also indicated by MARFUNIN (1961) and H. G. SCHARBERT (1964), where it was explained by the fact, that X-ray data are not only dependant on the degree of order, but also on the sub-X-ray twinning, while the 2Vx is only dependant on the degree of order. On this basis the samples 31 and 74 can represent a highly disordered phase, while 53 and 80 must be having a sub X-ray twinning; then they would fall in the field of the "unbalanced twins" after MARFUNIN (1962).

Table 1.

Sample	Or% unmixed	Or% homogenised	2Vx°
31	88.72	87.00	51—58
53	93.93	86.31	62—67
74	87.14	79.85	53—60
80	89.77	86.08	

Concerning the orthoclase content of the unmixed and the homogenised phases no significant differences are detected. This is actually expected due to the low albite content, which is a reflection to the relative restriction of the perthitic structure.

Micas and Chlorites: Biotite and muscovite are the two mica types, occuring in the gneisses and schists of the studied area. Chlorite occurs mostly as accessory and mainly as an alteration product of biotite, garnet or sphene. The micas acquire a wide range of grain size from 0.2 mm, in the aplitic, mica-poor varieties (where the biotite is relatively fresh) to 6 mm long crystals, in the mica schists of both complexes. The most common grain size ranges between 1 and 3 mm.

In the Dobra gneisses both mica types are occuring. Actually type I (A and B) contains only biotite, while type II (A and B) can have biotite and/or muscovite.

In the typical Dobra Gneisses (I A and I B) the biotite content ranges normally around 5% of the total rock composition, mostly without any muscovite, which seldom occurs as accessory. In the other types II A and II B the biotite and/or the muscovite contents can be as much as 20 to 25% (samples 49, 95, 100, 117, 120, 170, and 180). In the mica schists the mica content can reach 60% (samples 46, 116, 132, 137, and 149).

Biotite occurs in the form of tabular crystals, which are always arranged parallel to the schistosity planes; in rare cases there are biotites crossing this direction. The most common biotite is pleochroic from x = light yellow to y = z = reddish brown. Less often the biotite acquires different colours and pleochroism mainly of the following varieties:

1. those, pleochroic from colourless or very light yellow to reddish brown, are represented by the samples 116, 118, 119, 120, 125, and 148; this biotite occurrence is often intergrown with muscovite laths.

2. those, pleochroic from brown to dark reddish brown (sometimes almost black), as in samples 93, 113, 145, 186, and 188.

3. those, pleochroic from light brownish green to dark green (sometimes also black); this is restricted to the samples 61, 73, 80, 84, 85, 87, and 89 of the Dobra-complex.

These biotites are altered mainly to chlorite with different degrees of alterations. In some highly altered varieties of types II A and II B the biotite is almost completely altered into chlorite, which still reserves laths of biotite, parallel to its cleavage that survived alteration. In others, which are less altered, the chlorites are found aligned parallel to the biotite cleavage, sometimes in optical continuity with them. Iron ores are often released as a result of this alteration and are mostly arranged in spots between chlorite and biotite. Chlorite is mainly of the pennine variety and seldom clinochlore. An other alteration product of biotite is sillimanite in the sillimanite-bearing varieties, as in samples 14, 26, 27, 31, 33, 37, and 168; only in sample 20 alteration to sericite is recorded. Pleochroic haloes around zircon, sphene and rutile inclusions are very frequent.

Biotite often has suffered post-crystallisation deformation and in some mica schists it is nicely microfolded, sometimes to be seen by the naked eye.

Muscovite is less abundant than biotite, being practically restricted in its occurence as a main constituent in types II A and II B; it shows some parallelism to the sillimanite in the sillimanite-bearing gneisses and schists; it is more frequent in type II B than type II A, with frequences from 5% to 22%, as in samples 95, 96, 127, 135, 140, and 170; in the muscovite schist No. 132 a muscovite content of 45% was observed.

The muscovite shows its normal optical properties, except in some samples of both types II A and II B, where it appears to be pseudouniaxial or with very small 2V angle, which never exceeds 7° (samples 52, 132, 140, and 149). It is quite possible that these muscovites are of the 3T or 2Ml polymorphs or even a mixture of both of them.

Sillimanite: Sillimanite is the index mineral, if it occures in considerable amounts, the para-character of the gneisses is indicated. Therefore its occurrence is practically restricted to the Types II A and II B of the studied gneisses; in samples 17, 27, 33, 44, of the type II A it acquires higher frequencies, as 36%, 5.5%, 8% and 9.5% respectively; in other samples of the same type it ranges around 4% and in some others it occurs only as accessory. In type II B it is of a wider distribution allover the area, as it occurs in samples 118, 120, 140, 154 and 168 with amounts of 18%, 8%, 31%, 14% and 30% respectively.

The sillimanite occurs mostly as acicular aggregates, arranged parallel to the schistosity planes of the rocks. They often show post-crystallisation deformation, being sometimes microfolded. Some of the sillimanite is the alteration product of biotite, when it occurs in the form of sheaves; sometimes it reserves some biotite laths, which survived the alteration.

Another occurence of sillimanite is in the form of colorless prismatic crystals, arranged with their c-axes parallel to the s-planes, observed only in two samples, Nos. 186 and 195.

The sillimanite is always accompanied by muscovite.

Pyroxenes: Pyroxenes in the gneisses studied are practically restricted to the Krumau-complex. They are mainly augite and in relatively seldom cases diopside, which sometimes accompanies augite in the same rock. The diopside shows a special predominance in the area between the Genitzbach and Krumau in samples 115, 117, 118, 119 and 121 with 40%, 6%, 2.5%, 5% and 12% respectively; in the two samples 118 and 119 it is accompanied by augite as accessory and with 35% respectively.

The augite occurs as main constituent in the augite gneisses, which occur mainly at the contact with the marbles of the Krumau-complex. Examples for these gneisses are given by the samples 119, 139, 148 and 191 with amounts of 35%, 15%, 35% and 28% augite respectively. In other gneisses of the same complex it occurs as an accessory with frequencies ranging around 5%. It ranges in grain size from 0.4 mm. in the fine grained varieties up to 7 mm. in the coarse-grained varieties; intermediate grain sizes are also occuring. In the gneiss No. 119 the augite occurs in the form of porphyroblasts with an average diameter of 5 mm., which include other minerals, especially biotite. The predominance of augite gives the rock a faint greenish, sometimes also greyish colour.

It is almost colourless to very light green in colour showing no pleochroism. The z-angle C ranges between 45° and 48° in most of the cases with $2V_z$ 58° to 61°, with relatively low birefringence. The diopside is always colourless with a z-angle C from 37° to 40° and $2V_z$ ranging from 58° to 60°.

A diopside-salite band (35 cm. thick) was found at the contact with a dolomitic marble layer near Krumau, which is identical to another salite band occuring in the Topnetzbachgraben, detected by Exner (1953). It is composed of prismatic crystals, about 3 cm. long and 1 cm. thick. They are milky white in colour and are according to Exner (1953) the product of reactions of siliceous solutions with the host carbonate rock.

Other Minerals: Other minerals occurring in the gneisses and schists as accessories are garnet, sphene, tourmaline, allanite, apatite, ores and zircon. Occurences of hornblende were recorded in the mica-hornblend schist No. 48 of the Dobra Complex with 18%, and in the Krumau Complex in sampels 100, 103 and 114 with amounts of 5%, 1.5%, and 9.5% respectively.

Garnet was recorded as a poor accessory in the Dobra gneisses, as in samples 20, 46, 52, 53, 56, 73, 74, 80, 84, 85, 89, 92, and 95. It occurs as idiomorphic crystals, sometimes rounded and ranging in grain size from 0.5 mm. to 0.9 mm.; it is often colourless and seldom light rosy in color, showing slight alteration to chlorite.

In the Krumau gneisses and schists, the garnet is of wider distribution. Moreover, it is one of the main constituents of the garnetiferous mica schists 118, 180, 186, and 95. In these schists it occurs in the form of big porphyroblasts, which distrub the schistosity of the rock, as they can attain a dimension of 7—8 mm. It is almost rather light rosy or rosy brown in colour, sometimes very sligthly anisotropic. Some crystals are riddled with inclusions of other minerals, as quartz and biotite and are slightly altered to chlorite.

Sphene is an ubiquitous accessory mineral in the majority of the gneisses and schists of both complexes, which never exceeds 0.5% except in some gneiss varieties of the Krumau-complex in the contact zone to the Gföhler Gneiss (159, 180, 195) with 4%, 1.5% and 1.5% respectively. In these three gneisses sphene occurs in the form of aggregates and clots of prismatic crystals, arranged with their c-axes parallel to the s-planes. Some of these crystals are zoned, some others are simply twinned.

Zircons: From the literature quoted before, about the Spitzer Gneisses and the Para-rock series, it is evident, that the work so far carried out, did not bring a satisfactory solution for the problem of their genesis and their relation to each other. It is also clear that no work was done on the accessory minerals as an additional tool to investigate the evolution of these gneisses and to participate in throwing some light on the problems of their petrogenesis.

The following zircon features are the mostly quoted: 1. habitus and terminal faces, 2. degree of rounding and corrosion, 3. elongation-frequencies, 4. color, zoning and inclusions and 5. growth trends of zircon crops.

The term "Abrasion Index" was firstly introduced by ALLEN (1944) to represent the percentage of zircon crystals in a given rock, that show no evidence of rounding. However, ECKELMANN & KULP (1956) noticed, that this terminology is unsatisfactory, as it indirectly suggests a meaning, contrary to that intended by the term. Therefore, they suggested the term "Rounding Index" to represent the percentage of crystals showing any signs of roundness. On the basis of this rounding index, they were able to differentiate between three types of granitic gneisses of igneous-(ortho)-origin and seven others of sedimentary-(para)-origin. POLDERVAART (1956) suggested, that a low rounding index of zircons is a strong evidence for their ortho-origin.

Also the elongation-frequency and length frequency curves of zircons in collaboration with their rounding index were very often used. POLDERVAART & BACKSTRÖM (1949) indicated that ortho gneisses have normally maximum elongation frequency above 2.0, while para gneisses have a value below 2.0. In most cases in which this maximum is below

2.0, nearly all the zircons show rounded terminations and the majority of the grains are well rounded.

Other properties like colour and inclusions can be quite helpful if they are conspiceous and common, specially for comparison and correlation purposes.

Zircon growth curves (Reduced Major Axis)

This technique is applied as it was firstly adopted by Larsen & Poldervaart (1957) in their attempt to differentiate between the Bald Mountain tonalites, Anthony Lake granodiorites and later intrusions.

Samples Studied and Techniques of Separation

For this study, 6 samples were subjected to statistical analysis. 5 samples of them are from the Dobra-complex, and the sixth is from the Krumau-complex. Sample No. 1 is an aplitic Dobra Gneiss variety, No. 2 is an augen gneiss variety, 3 and 4 are from the normal granitic Dobra gneiss, while the fifth is a sillimanite-bearing para gneiss intercalation in the Dobra gneiss. The sample No. 6 is also a sillimanite-bearing para gneiss, occuring in the Krumau-complex. The statistics for the first three samples were friendly offered by G. Deshpande (personal communication).

The sieved fraction of the crushed sample was carefully decanted with water and dried before being subjected to heavy liquid separation, using firstly tetrabromoethane (sp. gr. 2.90). The heavy concentrate obtained was washed by alcohol, dried, contaminations of biotite and other ore minerals were isolated, using a Franz isodynamic separator. The last concentration of the heavy mineral zircon was prepared by further separation using the Clarici solution (sp. gr. 4.2).

In this procedure attention should be paid to a common mistake, which often happens during the separation of zircons. This is the attempt to separate the biotite and other minerals of relatively higher magnetic susceptibility using the magnetic separator, before subjecting the sieved samples to heavy liquid separation. This seams actually logic; as, by getting rid of the magnetic fraction, the bulk volume will be greatly reduced, especially in biotite-rich rocks thus facilitating the heavy liquid separation which should follow. But it happens that, through this sequence of separation, the zircon escapes the fraction in which it is expected, that is the nonmagnetic light coloured fraction with quartz and feldspars, in spite of its pronounced low magnetic susceptibility. If such a nonmagnetic fraction is subjected to heavy liquid separation, practically no single zircon crystal will be gained. On the contrary, if the heavy liquid is firstly used to get rid mostly of the light fraction, then the magnetic separator to eliminate the magnetic fraction, an appropriate concentrate of zircon can be satisfactorilly obtained, by also using the Clarici solution.

As a result of our investigations the specific features of the different zircon crops are given in Tables 2 and 3. The figures 2 and 3 show their elongation frequencies and their RMAs respectively, which are discussed together with the other properties hereafter.

The zircons of these gneisses occur in the form of two significantly different types:

Type A: this is the type characterised by a high degree of roundness; its concentration in a gneiss variety gives rise to its "Rounding Index". The term "Rounding Index" is used here in the sense of ECKELMANN & KULP (1956), expressing the total percentage of the zircons, showing any degree of roundness. This Type A, occurs in the form of prismatic bipyramidal crystals with relatively simple form-combinations like [110], [111], sometimes combined with steeper bipyramids like [331] and very seldom recognised [100]. However the crystal forms were not easily recognised, due to the high degree of roundness and corrosion. Sometimes the crystals are highly corroded to an extent, so that they show extraordinary forms. A considerable proportion of this type is light coloured, from pale brown to pale yellowish brown; darker colors are very seldom; however, some dark brownish red crystals were also recorded.

Outgrowths and overgrowths are relatively seldom, not exceeding 11% in sample 6. Inclusions, in the form of fine needles and/or irregular, sometimes also globular forms of ores and other minerals, are not very rare. They are often difficult to identify, due to their extreme small size; zoning is absolutely absent.

Type B: This is relatively more idiomorphic than type A. The crystal faces and forms show better development, a relatively high proportion of them is euhedral with the prisms [110], [101] and the bipyramides [111], [321] and sometimes also [331] in different combinations. The crystalls are generally slimmer than in type A, seldom coloured,

Table 2. Statistics of the specific features of zircons.

sample s	1	2	3	4	5	6
strongly rounded %	10	9	18	15	70.5	85.5
subrounded %	38	47	37	36	23.5	13
rounding index	48	56	55	51	94	98.5
angular zircons %	52	42	54	49	6	1.5
out- and overgrowths %	15	7	26	14	10.5	11
zoned zircons %	21.77	14	25	23	—	—
RMAs Statistics:						
a	0.3696	0.3641	0.3293	0.3105	0.4948	0.5388
σ a	0.0148	0.0282	0.0174	0.0155	0.0268	0.0290
x mm.	0.1441	0.0999	0.1075	0.1589	0.1605	0.1466
y mm.	0.0521	0.0343	0.0383	0.0614	0.0787	0.0738
Sx mm.	0.0447	0.0332	0.0395	0.0373	0.0381	0.0348
Sy mm.	0.0164	0.0120	0.0129	0.0120	0.0188	0.0187
r	0.8739	0.9556	0.7719	0.7305	0.6672	0.6749
Dd	15.7	31.6	24.5	16.79	16.19	20.05
a°	20 15	19 50	18 15	18 10	26 20	28 20

Table 3. Statistical comparison values of the zircon crops.

sample pairs	Za	Zp	$Z\bar{x}$	$Z\bar{y}$
1 and 2	0.26	0.2724	9.68	10.735
1 and 3	1.81	1.94	7.5	8.114
1 and 4	2.2336			
1 and 5	4.09			
1 and 6	4.2835			
2 and 3	0.97	0.1654	1.785	0.402
2 and 4	0.4516	1.581	15.510	20.846
2 and 5	3.4293			
2 and 6	4.380			
3 and 4	0.4313	0.8193	12.28	17.073
3 and 5	5.1718			
3 and 6	6.1982			
4 and 5	2.73			
4 and 6	1.965			
5 and 6	1.1139	1.1197	0.3821	1.5776

being mostly colourless. Some of them are even water clear. Zoning in this type is frequent, reaching sometimes 25% as in sample 3. Zoning becomes more distinct, when the crystal lies with its lenghth parallel to the vibration direction of the polarizer. The zones follow the crystal outlines and increase sometimes in order from margin to core, which may be due to the increase in thickness or birefringence in this direction. Inclusions are common, either opaque of irregular shapes, or transparent in the form of fine needles with no special arrangement; some smaller zircons are often included.

Outgrowths and overgrowths are also more often in this type than in type A. They occur in the form of prismatic protrusions or cap-like overgrowths.

Genetical Indications

The zircon type "A", which is proved to be of pure sedimentary origin (ALLEN, 1944; POLDERVAART & BACKSTRÖM, 1949; ECKELMANN & KULP, 1956; POLDERVAART, 1956; KHAFFAGY 1964, and others) occurs alone up to 100% in the two sillimanite-bearing gneisses of the Dobra gneiss and the Krumau series; it also occurs in considerable proportions in the other Dobra gneiss varieties reaching sometimes 56% in the Augen Gneiss variety.

On the other hand, the zircon type "B", which according to literature appears to be of magmatic origin, occurs in equal abundance with type "A" in the Dobra gneiss varieties.

Considering the elongation-frequency distributions of these zircons, new data can be added; for the two sillimanite bearing gneisses, the maximum elongation-frequency lies between 1.5 and 2.0, being around 60% in both of them; besides this, about 10% of both zircon crops show elongations below 1.5.

For the other Dobra gneiss varieties, the maximum elongation frequency lies between 2.5 and 3.0. Still there is a considerable proportion

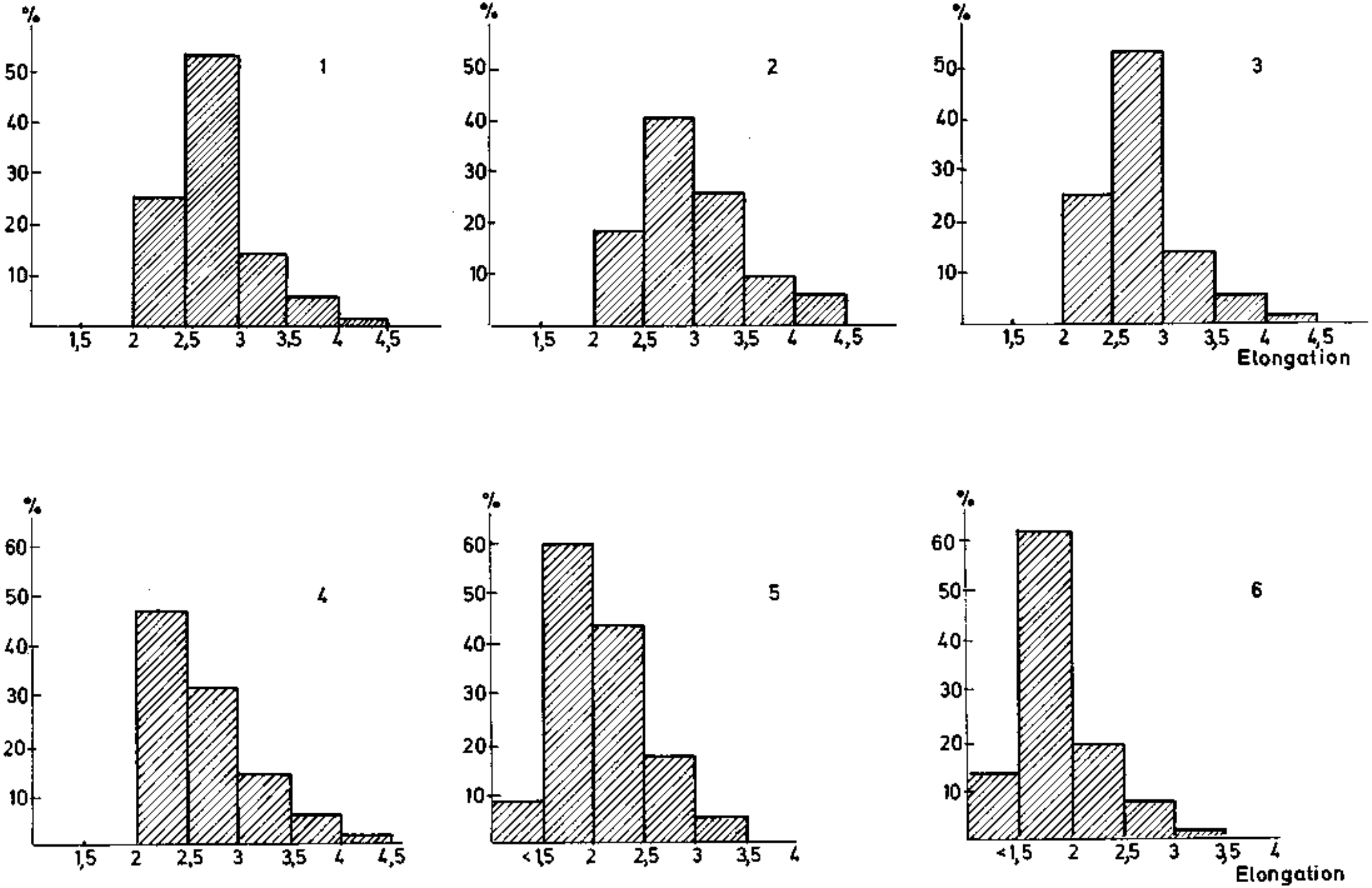

Fig. 2. The elongation frequencies of the zircon crops.

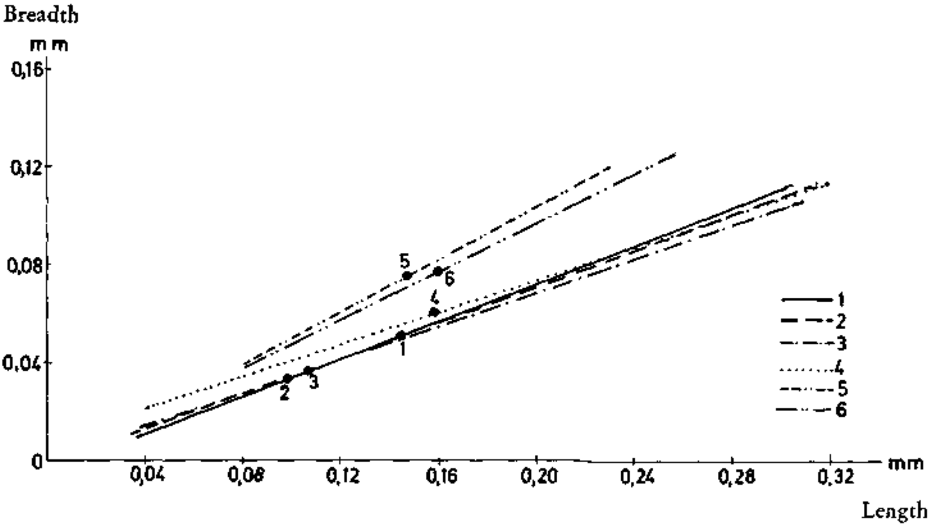

Fig. 3. The RMAs of the zircon crops.

of each variety, which has its elongation below 2.5. Also the RMAs-study separates very sharply between the two types of zircon crops. However, a glance to Table 3 where the different factors are compared on a statistical basis, shows, that the differences in slope between each of the two sillimanite-bearing gneisses and each of the Dobra gneiss varieties are, as expected, considered real. It is also clear that even between the Dobra gneisses themselves no complete harmony is recorded, concerning these differences. The difference in slope between 1 and 6 is considered real. Also, excluding the sample-pair 2 and 3, the other pairs of samples 1 and 2, 1 and 3, 2 and 6 and 3 and 6, are showing real differences in joint means Zx & Zy reaching sometimes very high values.

Considering these observations in connection with a discussion of the genetic problem of these rocks the following conclusions are submitted:

A. the definite sedimentary origin of the two sillimanite bearing gneisses, the one of the Dobra gneiss body and the second of the para-rock series is confirmed by:

1. the occurence of zircon type "A" in absolute majority in both of them;

2. the extreme "Rounding Index" of their zircon crops reaching 94% and 98.5% respectively.

3. the maximum elongation-frequency of their zircons lies between 1.5 and 2.0, being around 60% for both of them, and the occurance of about 10% of their zircons with elongations below 1.5.

A para-origin might be extrapolated for the other gneissic intercalations in the Dobra gneiss body, which are also sillimanite-bearing and/or mica-rich.

The occurrence of marble bands and calc-silicate rocks, together with these sillimanite-bearing gneisses in the Dobra gneiss body adds to the final proof, that their parent rock must have contained sedimentary material, and must have undergone sedimentary processes. This supports the idea of the existance of some sort of connection between the Dobra gneiss and the para-rock series, which was primarily indicated by the gradual transition along their contacts in the field.

B. concerning the other varieties of the typical Dobra gneiss body, the following conclusions are submitted:

1. the occurence of the zircon type "A" in nearly equal abundance with type "B" in these gneisses gives the impression, that the typical Dobra gneiss itself must have contained some kind of para- or sedimentary-material (from which type "A" was produced).

At the same time it must have also contained some kind of magmatic material, from which type "B" was derived. However the degree of this intermixing is not the same throughout the whole body.

2. the elongation-frequency maxima, being between 2,5 and 3,0 with percentages ranging from 40—50%, supports the just mentioned idea, that a high proportion of these zircons must have originated in a magmatic environment. On the other hand, if their considerable "Rounding Index" is taken into consideration, one could conclude, that even these zircons might have undergone at least one cycle of sedimentation, through which this rounding took place. Another explanation might consider the intermixing of this material with other sedimentary material, which contained the rounded and the subrounded zircons.

3. the relative harmony between the RMAs of these varieties, specially in the values of Za and Zp, indicates the existance of an intimate relation between them, having nearly the same origin and undergoing the same mode of formation. However, the two delicate tests Zx an Zy yielding very high values, up to 20,8 point strongly in the opposit direction. This can be only explained on the basis of the heterogenity and intermixing of different fource material of the Dobra gneisses in different proportions, thus giving rise to these different features.

From the foregoing discussion, it will be unappropriate to consider the Dobra gneisses (Spitzer gneisses) as typical Orthogneiss, as it always has been considered. It seems proven to be the metamorphic product of a heterogeneous mixture of Ortho- and Para-materials. Also its relation to the para-rock series cannot be easily neglected.

2. Petrography of the Amphibolites

The amphibolites occuring in both complexes, are mostly hornblend-andesine rocks, associated with quartz, whose amount does not exceed 6%. It normally ranges between 2% and 3%, otherwise it is a negligible accessory. Other minerals are biotite, titanite, garnet, chlorite, apatite, ores and zircon. The Dobra amphibolites are more biotite- and titanite-bearing, than those of the Krumau-amphibolites, which are more garnetiferous especially at the contact with the Gföhler Gneiss.

On the basis of 37 modal analyses the amphibolites can be classified into the following main types: —

Type I: Includes the biotite-bearing amphibolites, represented by the samples 7, 11, 47, 58, 63, 75, 79, 81, 88, 101, and 107. According to the biotite content of these amphibolites two subgroups can be recognised:

Type I A: with a biotite content less than 15%; this includes the samples 4, 11, 47, 58, 63, 75, 81, 88, 107 and 129;

Type I B: covers the biotite-rich amphibolites with biotite contents ranging from 15% to 32%, forming a minor group of intercalations, represented by the samples 7, 18, 79 and 101.

Type II: Includes the biotite-free amphibolites; it is the major type, occuring in both complexes. These are practically biotite-free or in very rare cases biotite occurs as traces of a minor accessory. This type is represented by samples 29, 40, 54, 57, 59, 102, 122, 126, 131, 157, 166, 167, 171, 172, 173, 177, 182, 189, 184, 187, 185 and 190; from these samples only 131, 157, 166, 167 and 171 are having biotite in negligible amounts.

Concerning the relative abundance of the two main constituents hornblende and plagioclase, some of the amphibolites show nearly an equal abundance, as in samples 11, 63, 88, 101 and 107 of Type I and samples 54, 129, 157, 173, 182, 185, 189 and 190 of Type II, ranging in their amounts around 40% of the total rock composition. Otherwise,the hornblende predominates the plagioclase, except in the two samples 11 of Type I and 157 of Type II, where the plagioclase slightly predominates the hornblende. In samples 4, 7, 18, 47, 58, 75, 81, 79, of Type I, and 29, 40, 57, 59, 102, 122, 126, 131, 166, 167, 171, 172, and 184 of Type II the hornblende predominates the plagioclase. Where its increase is almost always on the expence of the plagioclase. In the majority of the samples this excess in hornblende ranges from 20% to 30%. Greater differences of about 50—60% in amount are also detected as f. i. in samples 4, 7, 81, of Type I and 59, 102, 126, 131 and 184 of Type II.

Titanite and biotite show a certain parallelism in their occurence, being especially frequent in the Dobra amphibolites of Type I, where they are of less importance in the injection zone of the Gföhler Gneiss. Garnet occurres in detectable amounts only in the amphibolites at the contact zone to the Gföhler Gneiss, otherwise it occurs as a negligible accessory, except in the case of the two samples 102 and 107, where it acquires the amounts 2% and 3% respectively.

The amphibolites are almost fine-grained, mostly having a linear orientation of the hornblende prisms together with biotite (in biotite-bearing varieties) parallel to the s-planes, thus producing perfect schistose structure, which shows a complete concordance to that of the enclosing rocks. However some equigranular varieties, e. g. samples 29, 40 and 177 are obviously granoblastic, while samples 47, 57, 59 and 126 show a partial granoblastic structure. Coarse-grained amphibolites with hornblende prisms reaching sometimes about 1 cm in length are rare, except at the contacts of some aplitic injections. An example for this is sample 63, which is relatively rich in biotite (9%) and sphene (4%).

The hornblende, occuring in our amphibolites has a grainsize, normally ranging from 0,9—1,2 mm and is of the typically common green hornblende, pleochroic from light yellowish green to olive green in the majority of samples. Other samples of this hornblende are either lighter greenish or even brownish colours are not seldom. The amphibolites containing the typical green hornblende type are 4, 7, 11, 18, 101, 102, 107, 122, 182, and 185. Nearly all of this green hornblende is associated with dark brown biotite, pleochroic from light yellowish brown to dark brown, if the sample is biotite-bearing. Other amphibolites contain the brown variety of hornblende, which is pleochroic from light greenish brown to dark brown, associated with the previously mentioned brown biotite variety, they are represented by the samples 63, 173, 184, and 187.

Others with light green hornblende, pleochroic from light yellowish-green to light green, proved always to be accompanied by a light brown biotite variety. Examples of this type are the samples 47, 81, 131, 157, 166, 167, 171, 173, 177, 189, and 190.

Samples 57 and 59 (dyke- and sill-like occurances in the Dobra Complex) and the sample 126 (an occurence in the Krumau Complex) contain an almost colourless hornblende variety, pleochroic from nearly colourless to very light green, with z/C of 14,5° (in other hornblende varieties z/C ranges between 16—19°). These three samples are biotite-free.

Next to the hornblende and biotite the amphibolites include finer grains of other rock constituents, especially quartz, sphene, ores and zircons.

The zircons and sphenes are almost arranged with their c-axes parallel to the schistosity producing pleochroic haloes around them. Chlorites of the clinochlor and pennine types are the alteration product of both biotite and hornblende.

The plagioclases occur mostly in the form of xenomorphic grains, ranging in size from 0,6—0,9 mm. Greater grain sizes are relatively seldom and are only recorded at the contact zone with the Gföhler Gneiss, where they can reach 2 cm in diameter. They exhibit a wide range of An-content, ranging from 18—45%. Reverse zoning is frequent, nearly in all amphibolites, with a core ranging from 18—25 An % and a rim of 26—45 An %. They are polysynthetically twinned, mainly after the albite and pericline laws. In some plagioclases of the injected zones occurences of crystals with non-twinned cores are recorded, where the twinrims are generally bent. Completely individuals are frequent and occur everywhere.

The plagioclases are normally highly altered into sericite, except those of the aplitic injections, which appear to be relatively more fresh. Antiperthitic texture is very rare, observed only in the two samples 63 and 75. Inclusions of other minerals are often recorded, mainly hornblende, biotite, sphene and quartz.

The garnet seems to be preferable restricted to the amphibolites of the Krumau Complex, occuring only in samples 102, 107, 157, 166, 167, 171, 172, 173, 179, 184, and 185. However it shows special flourishing at the contact to the Gföhler Gneiss, thus developing the garnet-amphibolite varieties No. 166, 167, 171, 173, 184, and 185. Its amount ranges from 3% to 8% in the form of porphyroblasts of the almandine type, reaching a grain size of 7 mm, thus disturbing the schistosity of the rock. They are riddled with inclusions of other rock components. Some of them are irregularly cracked and are altered along these cracks into chlorite (mainly pennine). The garnet in the Dobra amphibolites is quite negligible, only occuring in the two samples 40 and 63 as a minor accessory.

The titanite on the other hand, shows its preferable occurence in the amphibolites of the Dobra-complex in samples 4, 11, 54, 63, 75, 79, 81 and 88. It ranges in amount from 2% to 10% and occurs in the form of idiomorphic sphenoidal crystals, which are almost always arranged with their c-axes parallel to the schistosity of the rock. Its occurence in the amphibolites of the Krumau-complex is relatively rare, being restricted to those at the contact with the Gföhler Gneiss, reaching sometimes 3.5%, sample 187. In the samples 102 and 107 with amounts of 2.5% and 2% respectively it occurs in the form of clot aggregates. It is sometimes altered into chlorite and replaced by ilmenite, especially in its core. The titanite is generally dark brown in colour, slightly pleochroic. In one sample (45) it is almost black.

Other accessory minerals as apatite and ores are ubiquitous and show a homogeneous distribution in the amphibolites of the whole area.

3. Petrography of the Marbles

Marbles occur in both complexes, they abound around Krumau till Thurnberg. However, the detection of the marble occurences in the Dobra-complex furnishes a good clue to the genetical problem, which so far remained puzzling and confusing for a long time.

Generally, our marbles are dolomite and/or calcite marbles, sometimes diopsidic, tremolitic, phlogopitic, or siliceous. Feldspathic marbles are rare except in the eastern contact zone of the Krumau-complex.

The samples Nos. 28, 32, 35, 38, 39, 68, and 82 were collected and investigated as typical for the marbles of the Dobra-complex (opposite to the Schloteinbachmündung, Franzen, Kamprohrbrücke and Schoerlberg); from the Krumau-complex the samples Nos. 108, 110, 111, 128, 136, 146, 152, 153, 156, 162, 163, 165, and 181 were studied, representative for the main varieties of this complex.

Our marbles are mostly fine- to medium-grained, ranging in diameter from 1—2 mm. Some occurences are also coarse-grained, reaching 4—5 mm. in diameter as in samples 28, 35, 110, and 136. They mainly consist of a mosaic of equal carbonate grains with lamellar twinning, closely packed and very often bent, which must be due to deformation.

Carbonate crystals are the main constituents of all the marbles, sometimes the only constituting mineral with few accessories. They may reach 95% of the total rock composition, as in samples 28, 110, 111, 136, 152, 162, and 165. Their percentages in other varieties, especially the siliceous No. 35, the tremolitic No. 82, and the diopsidic Nos. 38, 39, 68, 146, 163, and 181 range between 55% and 89%, according to the proportions of the other minerals.

An attempt was made to get an idea about the degree of dolomitisation in these marbles; they were subjected to X-ray diffraction method and a comparison of the peaks of the two reflections at 29.5° of the mineral calcite and 30.96° of the mineral dolomite was made. The results point to a relatively higher degree of dolomitisation of the marbles of the Dobra-complex, than those of the Krumau-complex, as indicated in Table 4.

Table 4. Degree of dolomitisation of the studied marbles as relatively indicated by X-ray diffraction method.

Sample No.	28	32	35	38	39	68	82	108	110	111
100% dolomite	×									×
dolomite calcite		×				×	×			
calcite dolomite				×	×			×		
100% calcite			×						×	

Sample No.	128	136	146	152	153	156	162	163	165	181
100% dolomite	×	×								
dolomite calcite										×
calcite dolomite										
100% calcite			×	×	×	×	×	×	×	

The origin of the dolomitic component of these marbles is less clear. However, the occurrence of the pure calcitic marbles of the Krumau-complex cannot be due to a "dedolomitisation" processes, since there is no appreciable concentration of minerals like tremolite, anthophyllite or talc, which could explain the refixation of the abstracted magnesia. Hence the other possibility of dolomitisation of actually calcitic marbles is more acceptable. Whether the dolomitic to partially dolomitic marbles were of primary syngenetic origin, or due to secondary dolomitisation processes, which should have taken place through the course of metamorphism presumably by Mg bearing solutions, remains purely speculative. It is also to be indicated, that no specific relation could be found, between the colour of the marbles and their degree of dolomisation. Pinger (1950) and Engel & Engel (1953), stated repeatedly, that the Frankline marbles and the marbles of northwest Adirondacks are predominently calcitic white, in colour, while local areas of dolomite are grey to dark grey. Our marbles, cover white as well as grey calcite- or dolomite-marbles.

The dolomitic and calcitic nature of the samples 128 and 163 was formerly detected by the U-stage measurements of the angle between the c-axes and the $(01\overline{1}2)$, for dolomite it is 62.5° and for calcite it is 26°.

Diopside occurs in samples 38, 39, 108, 136, 146, 162, and 181 in different proportions from accessory to amounts ranging from 10% to 30%. In the samples 39, 68, 146, and 181 it occurs with amounts of 30%, 29%, 10%, and 16% respectively, in the form of euhedral poikilitic crystals sometimes cracked, here calcite crystallises along these cracks; it is almost colourless with z/c from 39—40°.

Tremolite occurs in the sample No. 82 in considerable proportion of about 20% in the form of prismatic, colourless crystals, arranged parallel to the lineation of the rock; it occurs also in the two samples 128 and 136 as a minor accessory.

Phlogopite is recorded in all the studied samples (except 28, 35, 82, 128, and 181). In sample 38 it reaches an amount of 5%; in all the others its amount does not exceed 3%; also it was recorded in some of them as a minor accessory.

Graphite occurs in some marbles around Krumau, especially in those at the contact to the graphitic schists. Some of these marbles have a banded nature, graphite rich bands alternating with carbonate bands. The graphite is almost always accompanied by pyrite, in the form of euhedral crystals sometimes reaching 2 mm. in diameter.

Graphite was detected also in one marble variety (No. 35) occurring in the Dobra-complex opposite to the Schloteinbach mouth.

Forsterite altered into serpentine gives the marble variety No. 32 of the Drobra-complex a greenish spotted appearance; it is detected in considerable amount reaching about 15% of the rock compositon.

Quartz occurs as accessory mineral nearly in all marbles in the form of xenomorphic grains, which do not show the undulose nature. In the siliceous varieties 35 and 181 it occurs in amounts of 24% and 10% respectively.

Other accessories are muscovite, apatite, haematite, magnetite, and titanite. The last was detected only in the samples 153, 162, 163, 165, and 181. Zircon is observed in one sample No. 68 included in quartz.

4. Discussions and Conclusions

a) Degree and type of Metamorphism

The bulk of the metamorphic rocks, belonging to both complexes exhibit mineral assemblages of the almandine-amphibolite facies formed by regional metamorphism. According to TURNER & VERHOOGEN (1960), our mineral assemblages fall under the sillimanite zone of the almandine-amphibolite facies. According to WINKLER (1965), they fit mostly in the Barrovian almandine amphibolite facies, specifically into the sillimanite-almandine-orthoclase subfacies. The surviving of some muscovites of our gneisses and schists can be, according to WINKLER (1965), due to the highly pelitic nature of the parent rocks and/or the PT conditions of the sillimanite almandine orthoclase subfacies were not completely attained to transfer the whole muscovite present to sillimanite. He further adds that under high pressures more than 4000 bars (may reach 6 Kb), where almandine is generated instead of cordierite, 700° C would be surpassed so that muscovite may become unstable. For the parent rocks of such mineral assemblages, rocks as pelites, marls, shales, graywackes, sandstones, siliceous carbonates, and basic rocks can be taken into consideration.

Garnet is an ubiquitous wide-spread mineral throughout, and many of the gneisses are sillimanitic to highly sillimanitic. Also biotitic, muscovitic gneisses and biotitic amphibolites prevail in many localities. Most of these rocks are garnetiferous especially at the contact to the Gföhler gneisses, where the degree of metamorphism appears to have reached its apex. However, almost all the mineral assemblages of the paragneisses of both complexes appear to have been evolved in conjunction with extensive injections and soaking of the metasediments by magmatic fluids. Mainly alkali-siliceous liquids, locally aluminium-bearing, with iron and magnesium were introduced, from which reactions with the metasediments biotite, garnet and sillimanite were formed. They also clearly resulted in modifications in types and amounts of the occuring feldspars. Moreover the original composition of the metasediments involved in these interactions, undoubtedly varied appreciably at various parts of the sequence, and from place to place in the series, thus resulting in the diverse varieties mentioned before.

The amphibolites allover the area dominantly hornblende-andesine rocks with either biotite and/or clinopyroxenes as components. Titaniferrous and garnetiferrous varieties are recorded in the Dobra- and Krumau-complexes respectively and at the contact to the Gföhler Gneiss.

Most of the marbles contain diopside and tremolite. Only one variety contains forsterite, which does not seam to fit (as the case of muscovite) into this subfacies. This may suggest, that the rocks of this area lie in the transitional zone between the two subfacies.

The ubiquity of the assemblage quartz, biotite, oligoclase in the gneisses, as the oldest visible metamorphic assemblage is noteworthy. There are no clearly defined anticedent or relictminerals, suggesting a preceeding stage or step of lower grade of metamorphism. The chlorite as well as some of the sericite, recorded as minor constituents are products of superimposed retrograde metamorphism, which is only locally conspicuous. Thus the biotite is largely altered to chlorite, and the plagioclase are highly sericitised. Similar alteration to chlorite are also recorded for other minerals like hornblende, garnet and sphene.

b) Origin of the metasediments

The rocks of undoubted para-origin, occurring in the area, are the paragneisses, schists (Types II A and II B), marbles and quartzites. Concerning their origin, there ist no contradiction between the previous authors, who dealed with the area. It is considered, that the distinctly layered form of the paragneisses, quartzites and marbles of the Krumau-complex furnishes the first clue to their metasedimentary origin. They represent thus a series of marine sediments, originally laid down as alternating layers of shales, limestones, and sandstones, from which the gneisses and schists, marbles and quartzites were transformed, in the course of metamorphism. Before metamorphism, the rock may have been anything ranging from impure shales and sandstones to calcareous layers. Apparently here are important indications for sedimentary sequences commonly formed in fairly stable shelf environments, contrary to types formed on crustal segments of marked instability and appreciable local relief. These environment appears to have been marine, but with differences from place to place. An example is the marble-rich series around Krumau, which seems to have deposited in a large persistently negative, although not highly unstable basin. These thick, uniformly layered marbles and the associating quartzites lie stratified in the gneisses, are conformable with them.

These relations are in accordance with a concept, according which the gneisses are derived from shales or argillaceous sandstones, which themselves are the products of moderate to intensive residual weathering and good sorting. However the inferred premetamorphic features of the gneisses hardly point to a distinct type or origin of the parent sediment.

The pyritic and graphitic schist, undoubtedly has evolved from an argillaceous and somewhat calcareous sandstones, which may have contained much of the iron and sulphur combined in pyrite as sedimentary or diagenetic constituent.

c) Origin of the Amphibolites

Concerning our amphibolites, from the foregoing studies of the geology, distribution and petrology combined with their geochemical investigations, our basic conclusion is, that both the amphibolites of the Dobra- and Krumau-complexes might have the same parent rock, as no genetical differences between them are existing. The classification of the occuring amphibolites in both complexes into two types I and II, does not give an indication for any genetical differences, simply because:

1. the occurrence of both types in the Dobra- as well as in the Krumau-complex;

2. the equal distribution of both types all over the area;

3. the differences in these types concern mainly the occurrence or absence of some minerals as biotite, garnet and sphene, which can be due

to local changes in the degree of metamorphism (PT conditions), assimilation of parts of the country rock, or even due to post-metamorphic factors e. g. the case of the injected zone at the contact of the Gföhler gneiss.

It is worth mentioning to indicate that an ortho-occurrence of amphibolites can be taken into consideration, to which would belong the single dyke-like body of the Dobra-complex and related varieties previously discussed. These amphibolites are characterised by complete absence of biotite, the occurrence of the nearly colourless hornblende variety, which obviously predominates the plagioclase in amount, together with their granoblastic character.

Field observations and laboratory investigations, seem to suggest, that our amphibolites both of the thin sheet- and of the thick formation type, interlayering the gneiss complexes, have been emplaced, where they acquired their present composition during metamorphism; therefore they are either:

1. stretched and smeared-out fragments of basaltic flows, sills or dykes; or,

2. metamorphic differentiates derived from a sequence of basic fronts of mafic metasomatites.

Concerning the concept of the metamorphic differentiates, as a process contributing to or largely responsible for the formation of the amphibolites, it is possible, that the mafic elements, which are supposed to be expelled from the gneisses during metamorphism, have been selectively concentrated along certain bedding foliations and stratigraphic zones to form amphibolites. This hypothesis, if acceptable in our case, could be only as faint possibility considered for the thin amphibolite occurrences of the Dobra-complex, but certainly not for the thick formations of the para-series of the Krumau-complex.

This is on account of the minimum thickness of the amphibolites of the Dobra complex and also on account of their relatively smaller abundance (about 10% only), if compared with the enclosing gneisses. Here, the amount of the leached mafic elements from the gneisses could be sufficient to contribute in the formation of these thin amphibolites. On the other hand, the amphibolites in the Krumau-complex are nearly as abundant as the gneisses and they acquire bigger thicknesses reaching 200 m sometimes, which makes this hypothesis absolutely unrealistic. Even for the Dobra amphibolite sheets these metamorphic differentiation hypothesis is also rejected, as definite transitions between amphibolites and gneisses were not observed.

The above considerations lead to the conclusion, that the amphibolites allover the area have been derived from basaltic parent rocks. These could have been emplaced in the form of basaltic flows, sills, or as complex intrusive and extrusive types. These forms of occurrence might explain the thin sheets of amphibolites in the Dobra-complex, which could have been thinned and stretched by plastic flow of the rock sequences during the metamorphism. Usually in case of such basaltic flows or sills, complementary dykes and dyke-like occurrences are to be expected, which are lacking in our amphibolites except one single case of the Dobra-complex (KHAFFAGY, 1970). ENGEL & ENGEL (1965) and others (BOWN & ENGEL, 1956, and ENGEL, 1949) dealing with similar cases attributed this lack in dykes to tectonic processes, such as shearing out and rotation of fragments of the dykes into near conformity with metamorphically induced foliations.

The ortho-origin of the amphibolites may be inferred from:

1. the very sharp contacts of the amphibolites with the enclosing gneisses;

2. the common nature and the way of occurrence of the amphibolites in both complexes;

3. the consistenly fine-grained and the relatively more schistose margins of the thick bands and of the thin sheets of amphibolites, which may represent chill zones.

4. the discordant relation of the amphibolite occurrence in the Dobra-complex opposite to the Ruine Dobra.

5. the regular increase in abundance, frequency and thickness of the amphibolites from the Dobra towards the Krumau-complex.

As already indicated, the Krumau-complex is but the western limb of a regional syncline, whose eastern limb lies symmetrically east of the Gföhler gneiss. The volcanic center should thus have been situated somewhere under the Gföhler gneiss body. This position should have caused the basaltic flows, necessary for the formation of the amphibolites in the syncline. The fact that the Dobra-complet must be relatively older than (being underlying) the Krumau-complex suggests, that the thin amphibolite sheets intercalating it, represent the first eruptive pulses of this volcanic activity. These basaltic pulses should have been flown over long distances due to the high mobility of the basaltic magmas, which presumably helped in thinning these sheets. This volcanism should have been continued in the form of surface and/or subsurface eruptions; over different periods gradually increasing in intensity; it reached its apex with the eruption of the last basalts that correspond to the thick amphibolite bands of the Krumau-complex.

d) Origin of the Dobra Gneisses

The origin of the Dobra gneisses (Spitzer Gneis) is one of these interesting problems, that become the pivot for discussions, whenever the geology of the Austrian Waldviertel is concerned. This is perhaps due to the apparent contradictions between the ortho-origin suggested for these gneisses and their geologic and petrographic relations previously discussed. This ortho-origin was suggested mainly on account of the (granitic?) appearance and composition of some of the constituting gneiss varieties of this complex; which kind of ortho-origin and how it was formed, was no further explained.

EXNER (1953), in an attempt to pave the road to an approach to this problem, gave the following suggestions for the different possibilities for the modes of origin of these gneisses:

1. that the Spitzer gneiss is a magmatic intrusion in the neighbouring para-rock series;

2. that the Spitzer gneisses are but a granitised part of the para-rock series; or

3. that the para-rock series have been deposited over the Spitzer gneisses, here they have been later on folded together and been deformed through the same orogeny.

It is the author's opinion, that any origin suggested for the Dobra gneisses, should satisfactorily explain the following geologic and petrographic features:

1. the petrography and chemical composition of the different gneiss varieties;

2. their geochemical characteristics and the probable existence of an ortho-gneiss variety, together with typical sillimanite-, muscovite- and biotite-rich para-gneiss varieties;

3. the characteristics of their zircons, that lead to the final conclusion, that "The Dobra gneisses proved to be the metamorphic product of a heterogeneous mixture of ortho- and para-materials";

4. the coexisting intercalations of undisturbed amphibolites, with definite sharp contacts; besides, they are concordant with the enclosing gneisses and simultaneously folded with them;

5. the frequent occurrences of considerable marble bands, surrounded by typical paragneisses and schists, that follow the general trend of both Dobra- and Krumau-complexes.

6. the intimate geologic relation between the Krumau-complex and the Dobra-complex demonstrated by the gradual transition between them and the great similarity in the geologic trends and structures.

The mineral assemblage of our gneisses is composed of quartz, oligoclase-andesine and biotite, commonly accompanied by accessory sphene, muscovite, chlorite, apatite, (garnet and sillimanite) magnetite and zircon. The properties of the dominant minerals are remarkably constant, except in the case of biotite, where the greenish variety is observed only in some gneiss varieties near the contact zone with the Krumau-complex (samples 73, 80, 85, and 89). TILLY (1926), HARKER (1932), GILLULY (1936), AMBROSE (1936) and ENGEL & ENGEL (1960) noted, that the evolution of first greenish then brown biotite in successively more highly metamorphosed graywackes, is a gradual product during the dynamothermal "regional" metamorphism. Also Sugy (1935) described a reddish brown and a greenish brown biotite in metasediments and migmatites of north eastern Japan. He noted that the reddish biotite is the more highly metamorphosed facies with oligoclase and some garnet, where a mutual relation of metasediments and granitic components were instrumental in the evolution of the reddish biotite as well as garnet and sillimanite. Commonly the change in colour of metamorphic biotites from greenish brown to reddish brown is thought to reflect an increase in FeO.

The chemical analyses represented by Table 5 are remarkably similar in many aspects. However a main difference can be noticed concerning the values of the alkalies; while the Na_2O values of the authors analyses are 5.5% and 4.7%, that of the third analysis represented by Exner (1953) is only 2.84%; also the K_2O values show a reverse relation being 1.85% and 1.58% for the first two and 5.84% for the third. This might be due to the fact that the analysed sample of Exner is an augen gneiss variety (it is as such described by him) rich in Knaf augen. This naturally results in a remarkable difference in the Na_2O/K_2O ratios being 2.97 in the first two and only 0.59 in the third.

The question arises now whether the ratio Na_2O/K_2O may reflect a large scale abstraction of K_2O from the normal gneiss (Type I B) which should have been fixed in the form of Knaf augen in Type I A, or conversely the addition of soda after diagenesis and/or during metamorphism.

Table 5.

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	71.38	72.43	71.90	72.31	66.82	71.72	69.69	65.95	64.20	75.50	70.72
Al_2O_3	15.98	15.55	15.76	14.69	18.83	13.23	13.53	13.58	14.10	11.40	12.79
FeO	1.85	1.16	1.50	1.47	2.87	3.58		4.18			1.25
Fe_2O_3	0.49	0.81	0.65	0.66	2.58	0.30	0.74	1.94	1.00	2.40	0.22
MnO	0.06	0.03	0.04	0.04			0.10				0.73
TiO_2	0.29	0.25	0.27	0.24		0.35	0.40	0.55	0.50		0.26
CaO	1.97	2.53	2.25	1.99	2.76	1.80	2.00	3.10	3.50	1.60	1.20
MgO	0.66	0.54	0.60	0.53	0.67	1.81	1.95	1.88	2.90	0.10	0.34
Na_2O_2	5.50	4.70	5.10	4.35	2.11	2.72	4.21	3.73	3.40	2.00	3.80
K_2O	1.85	1.58	1.64	3.09	1.34	1.29	1.71	2.01	2.00	5.60	3.50
H_2O-	0.10	0.12	0.11	0.13		0.15	0.62		0.10		1.52
					2.13			3.13		0.60	
H_2O+	0.42	0.45	0.43	0.63		2.53	2.08		2.10		2.75
	100.55	100.15	100.3	100.13							99.08

1, 2 and 3. The analysed samples by Khaffagy with their avarage respectively.
4. The avarage of the three analysed Dobra gneisses.
5. Avarage of five graywackes, Balclutha, New Zealand (Turner & Verhoogen, 1960).
6. Avarage of three graywackes (Taliaferro, 1943).
7. Fresh Franciscan graywackes (Turner & Verhoogen, 1960).
8. Avarage of two analyses of graywackes, Marlborough, New Zealand (after J. Henderson, 1934/35).
9. Avarage of 11 graywackes of widely separated age and locality (after Pettijohn, 1957).

10. The avarage Arkose compositions (After Pettijohn, 1957).
11. Avarage of 20 lithoidal welded and unwelded tuffs, rhyolitic and latitic flows (after H. R. Cornwall, 1962).

It would seem possible, to conclude that the parent rock of the gneisses was a sediment derived in large proportions from sources rich in pyrolastics with or without graywackes, very often interlayered with considerable submarine acidic flows. The environment of deposition might have been exposed to some interrupting tectonical phases, involving also the deposition of limestones, from which marbles may have been produced.

The wohle series was simultaneously and regularly intercalated by thin basic flows and sills, responsible for the amphibolite formation, which possibly had its source in the east.

After the Dobra complex had been formed in this manner, gradual changes in the basin of deposition should have taken place, preparing for the deposition of the typical sedimentary facies, that covered the complex and from which the Krumau complex should have been derived (the pararock series). The varying nature of the paragneisses and schists, marbles and quartzites, which form this complex with its rapid lithological changes are infered to unstable conditions of deposition, under which great varieties of sediments rapidly, sometimes as intercalations must have been deposited. Sediments that could be responsible for the formation of this great variety of pararocks, could have been argillaceous sandstones, clays, marls, arkoses and pure sandstones, together with limestones, possibly intercalating each other.

The flourishing of amphibolites with their gradual increase in thickness towards east indicates, that the basic volcanic activities were not interrupted, but increased in intensity and frequency, thus producing more thick and more frequent flows and falls of basic material, which simultaneously interlayered the sedimentary sequence.

Both complexes, the Dobra-complex and the Krumau-complex will after deposition have undergone simultaneously the same events of regional metamorphism with the same degree of folding and deformation, through one and the same orogeny. This resulted in the major folding of them in the form of the now existing major syncline, whose western limb is represented by the Krumau-complex. The eastern limb of this major syncline exists east of the Gföhler gneiss body, which is supposed to be emplaced along its main axis.

That the Spitzer gneisses do not outcrop in the eastern limb of the Krumau-complex, may suggest, that this syncline is not symmetric or that the Spitzer gneisses are tapering and thinning out under the Krumau-complex in this direction.

Later on the Rastenberger pluton should have been emplaced at the western end of the Dobra-complex (Spitzer Gneisses) thus leading to the present state of the area studied.

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Zur Geochemie der Spitzer Gneise und der Paragesteinsserie des Kamptales, Niederösterreich

Von Mahmoud Khaffagy

(*Mit 6 Abbildungen*)

Geology Department, Faculty of Science, Heliopolis University, Cairo, Egypt, VAR
Aus dem Grundlageninstitut der Bundesversuchs- und Forschungsanstalt Arsenal

I. Einleitung

Um das genetische Problem der verschiedenen Gneise und Amphibolite im Gebiet des Kamptales/Niederösterreich, ihre Beziehungen zueinander und zu den anderen Gesteinstypen zu beleuchten, schien es notwendig, einige makro- und mikrochemische Untersuchungen vorzunehmen. Die Ergebnisse der geologischen Feldarbeiten und der petrographischen Untersuchungen sind bereits gesondert dargestellt worden (Khaffagy [1970]). Probleme der Petrogenese, vor allem aber der Metamorphite, können nicht nur auf Grund von Feldbeobachtungen und mikroskopischen Studien gelöst werden. Es bedarf vielmehr im besonderen auch des Einsatzes verschiedener Untersuchungsmethoden, wie der geochemischen Analyse von „Spurenelementen". Ein wesentliches petrogenetisches Problem ist die Unterscheidung von Ortho- und Paragneisen und Ortho- und Paraamphiboliten. Die Meinung des Autors ist, daß es ein „Amphibolit und Amphibolit-Problem" ebenso wie ein „Granit und Granit-Problem" gibt. Wilcox und Poldervaart haben (1958) festgestellt „under equilibrium conditions, ortho- and paraamphibolites would be indistinguishable if held at the same temperature and pressure". Auch Turekian (1963) war in diesem Punkt wenig optimistisch, ohne allerdings alle Möglichkeiten in Betracht gezogen zu haben, die die analytische Geochemie anbietet. Ortho- und Paragesteine auf Grund von geochemischen Untersuchungen zu unterscheiden, haben aber Leutwein (1939), Engel (1951), Taylor (1955), Snelling (1958), Lapadu-Hagues (1959), Evans & Leake (1960), Heier (1960) u. a. versucht (vgl. auch Taylor [1965]).

I. Janda, E. Schroll und Sedlazek (1965) haben darauf hingewiesen, daß man die Unterscheidung von Ortho- und Paragesteinen mit den Methoden und Techniken geochemischer Untersuchungen bis zu einem gewissen Grad lösen kann. Sie konnten am Beispiel von Amphiboliten des Waldviertels zeigen, daß die Projektionspunkte in den Korrelationsdiagrammen Ni—Co, Zr—Ni, Cu—Ni und Ni—Cr niedrigmetamorpher Orthoamphibolite die gleiche Lage aufweisen wie basische Magmatite, etwa Olivinbasalte und Gabbros.

Diese Gruppe schließt Orthoamphibolite, wie Gabbro-, Pyroxen- oder Anorthosit-Amphibolite, ein, jedoch auch „nicht durch Relikte gekennzeichnete Amphiboliteinlagerungen in Marmoren und manchmal auch solche in Paragneisen". Es wird festgestellt, daß „für Paraamphibolite im eigentlichen Sinn, die aus tonhaltigen Sedimenten entstanden sein sollen, keine Beispiele vorliegen".

E. Schroll (1966) stellt fest: „still premisses are lacking to solve some special problems", als er sich mit der Bearbeitung der seltenen Elemente in granitoiden Gesteinen beschäftigte. Den Spurenelementen kommt eine wichtige Schlüsselstellung zu, um petrogenetische Vorgänge zu charakterisieren und zu erklären. Der vorliegende Versuch, Ortho- und Paragneise auf Grund ihres Gehaltes an selteneren Elementen zu unterscheiden, ist als Vorstoß ins Neuland zu werten. Da kein ausreichendes statistisches Datenmaterial zur Verfügung steht, ist dieser Versuch selbstverständlich noch mit gewissen Unsicherheiten behaftet.

In der Folge werden die Ergebnisse geochemischer Untersuchungen des Dobragneises und seiner Amphiboliteinlagerungen sowie der Paragneise und ihrer Amphibolitvorkommen ausgewertet. Vier chemische Vollanalysen wurden von zwei Dobragneistypen und zwei Amphiboliten vorgenommen, die in den Dobra-Gneis eingelagert sind. 20 Gneis- und 16 Amphibolitproben, die etwa einem W-E-Profil durch das bearbeitete Gebiet entnommen worden sind, wurden auf Spurenelemente spektrochemisch analysiert.

II. Analysenmethoden

Bei den Gneisproben wurden die Elemente K, Ca, Ti, Rb, Sr, Sc, Y, Zr, V, Cr, Ni, Co, Cu, Ag, Yb, Mo, Zn, Tl, Sn, Be, Ca, La, Pb und Ba und bei den Amphibolitproben die Elemente K, Ca, Ti, Rb, Sr, Sc, Y, Zr, V, Cr, Mn, Ni, Co, Cu, Ag und Yb quantitativ analysiert. Elemente, deren Durchschnittshäufigkeit in den untersuchten Gesteinen auf Konzentrationen unter 100 ppm beschränkt bleibt, wurden mit Hilfe der optischen Emissionsspektralanalyse, die in größeren Konzentrationen vorliegenden Elemente röntgenfluoreszenzanalytisch bestimmt. Zur Kontrolle der röntgenfluoreszenzanalytischen Werte wurden auch flammenfotometrische und naßanalytische Methoden eingesetzt.

1. Probenvorbereitung

Das Probengut wurde in einem Laborbackenbrecher auf maximal 2 cm vorzerkleinert, geviertelt und anschließend in einer Schlagkreuzmühle auf maximal 2 mm vorgemahlen. Dann wurde die vorgemahlene Probe bis auf eine Menge von 100—200 g heruntergeviertelt und mit Hilfe eines Magneten etwaige stammende Stahlspäne entfernt. Danach erfolgte die Feinmahlung in einer Labor-Mörsermühle und schließlich händisch 30 Minuten in einer Achatreibschale.

2. Naßanalyse

Bei der Durchführung der Silikatanalysen wurde hauptsächlich nach Dittler (1935) und Jakob (1952) vorgegangen. Nur die Alkalien wurden nach Isolierung der Alkalien durch Ionenaustausch flammenphotometrisch und die Elemente Mn und Ti spektralphotometrisch nach Dittler (1935) mit einem Zeiß-Spektralphotometer PMQ II analysiert.

3. Emissionsspektrographische Analysenverfahren

Für die emissionsspektrographische Bestimmung der Elemente Sc, Y, Zr, V, Cr, Mn, Ni, Co, Cu, Ag, Yb, Mo, Zn, Tl, Sn, Be, La, Ga, Pb und Ba wurde eine Methode verwendet, die sich im spektrographischen Labor des Grundlageninstitutes der Bundesversuchs- und Forschungsanstalt Arsenal bewährt hat (siehe u. a. Janda, Schroll & Sedlazek, 1965).

Die Eichproben wurden aus Mischungen von Reinsubstanzen hergestellt und durch Referenzgesteinsproben (G 1 und W 1 des US National Bureau of Standards) kontrolliert.

Die Aufnahmebedingungen sind in Tab. 1 mitgeteilt.

Tabelle 1. Spektrographische Meßbedingungen für Gneise und Amphibolite.

Spektrograph 3,4 m — Ebert Gitterspektrograph Mark 4 (Jarell & Ash) mit 15.000 Linien/Zoll-Plangitter (Blaze 4000 Å)

	Amphibolite	*Gneise*
Ordnung	II.	I.
Blende	3,2 mm	3,2 mm
Fokus	200	180
Kamera	84	90
Sektor	$^{8}/_{100}$%	$^{8}/_{100}$%
Spaltbreite	20	20
Schaltung	anodisch	anodisch
Volt	220	220
Ampere	10	12
Belichtungszeit	180 sec	220 sec
Elektrodenmaterial	(Ringsdorff) RW 0	Ringsdorff/RW 0
Elektrodenform	RW 0055	S wie Grohmann (1965)
Gegenelektrodenform	RW 0090	RW 0090
Platte	Gevaert 34 B 50	Gevaert 34 B 50
Entwickler	Standard 224	Standard 224
Entwicklungsdauer bei 20° C	13 min	13 min

Zur Aufnahme wurden die Proben mit spektralreinem Graphitpulver (RW 0) 1 : 2 für Amphibolite und 1 : 1 für Gneise gemischt. Als interne Standards wurden 0,5% Pd für die schwerflüchtigen und 0,01% In für die leichtflüchtigen Elemente verwendet. Bei der Aufnahme erwies es sich als günstig, den Bogen zunächst bei 3 A zu zünden und erst nach 10 sec die Stromstärke auf den Normalwert von 10 A für Amphibolite, beziehungsweise 12 A für Gneise einzuregeln.

Die Auswertung der aufgenommenen Spektren erfolgte photometrisch mit anschließender Untergrund-Korrektur am Rechenbrett.

Ein Teil der Werte, wie Mo, Tl, Sn, Be und Ba, wurde durch Schätzen der Linienintensitäten im Vergleich zu Eichproben gewonnen.

4. Röntgenfluoreszenzanalytische Verfahren

Die Röntgenfluoreszenzanalyse wurde der vorliegenden Arbeit zur Bestimmung der Hauptelemente K, Ca und Ti und der Spurenelemente

Rb und Sr verwendet, wobei eine für die Spurenelemente Rb und Sr von Schroll, Skol und Stepan (1963) entwickelte Methode zur Anwendung gekommen ist (vgl. auch Schroll und Stepan, 1968).

Für die Durchführung der Analyse stand eine Philipsanlage mit Feinstrukturgenerator (1 KW), automatischer Registriereinheit und Vakuumspektrometer zur Verfügung. Die Meßbedingungen sind in Tab. 2 zusammengestellt.

Tabelle 2. Meßbedingungen der Röntgenfluoreszenzanalysen.

	für K, Ca, Ti	für RB und Sr
Röhre	Chrom	Molybdän
Stromstärke	18 mA	18 mA
Spannung	54 kV	54 kV
Impulszähler	Untersetzer: 16 (K), 64 (Ca), 8 (Ti)	Untersetzer: 32
Zählzeit	15 sec	15 sec
Kollimator	150	150
Strahlenweg	Vakuum	Luft
Kristall	PET	LiF
Detektor	Durchflußzähler	Szintillationszähler
Zählrohrspannung	1650 V	850 V

Die Gesteinsproben wurden nach sorgfältiger händischer Pulverung auf Analysenfeinheit im Achatmörser als Schüttproben unter Verwendung eines leichten Stempeldruckes in einem Probenhalter mit Mylarfenster eingebracht und gemessen. Die Eichkurven wurden mittels internationaler Referenzgesteinsproben (G-1, W-1, T-1, BM, BR, Syenit-1, GR) und künstlich angefertigter Eichmischungen erhalten. Es wurden jeweils drei Proben mit der Standardprobe W-1 gemessen, so daß eine Korrektur auf eine festgelegte Intensität der Standardprobe vorgenommen und apparative Schwankungen ausgeglichen werden konnten.

III. Analysenergebnisse

Die Analysenresultate sind in den Tabellen 3 und 4 zusammengestellt.

Tabelle 3. Chemische Vollanalysen.

	Vollanalysen der Dobragneise und der Amphibolite					
	Gneise			Amphibolite		
SiO_2	71,38	72,43	73,42	47,17	47,00	46,78
Al_2O_3	15,98	15,55	13,76	15,76	13,62	15,25
FeO	1,85	1,16	1,40	11,73	12,68	10,44
Fe_2O_3	0,49	0,81	0,69	1,55	3,70	2,53
MnO	0,06	0,03	0,03	0,22	0,26	0,03
TiO_2	0,29	0,25	0,18	3,66	3,96	1,95
CaO	1,97	2,53	1,49	9,27	9,06	9,73
MgO	0,66	0,54	0,38	6,37	4,70	7,35
Na_2O	5,50	4,70	2,84	1,90	2,10	2,66
K_2O	1,85	1,58	5,84	1,40	1,25	0,65
H_2O-	0,10	0,12	0,19	0,06	0,02	0,46
H_2O+	0,42	0,45	0,22	1,55	1,86	1,69
	100,55	100,15	100,04	100,64	100,21	99,52

Niggliwerte						
al	45	46	43	22	17	21
fm	14	12	13	48	52	48
c	10	14	9	23	24	24
alk	31	28	35	7	5	7
si	340	366	403	110	115	108
k	0,18	0,18	0,57	0,33	0,27	0,14
mg	0,32	0,33	0,26	0,46	0,34	0,53
si'	224	212	240	128	120	128
qz	116	154	163	—18	—5	—28

Anmerkung: Die Proben 1 und 24 passen zum trondhjemitischen Magmentyp (salisch, alkalireich bis intermediär, c-arm) bis zum natronrapakiwitischen Magmentyp.
Probe Ex 1953 gehört zum leukogranitischen Magmentyp (ausgesprochen salisch, sauer, alkalireich und c-arm) bis zum engadinitgranitischen Magmentyp.
Die drei Amphibolitproben entsprechen am ehesten dem gabbroiden Magmentyp (femisch, basisch alkaliarm und c-reich).

Tabelle 4. Instrumentelle Analysen.

a) Gneise

Nr.		1	17	24	27	31
%	K	1,7	1,8	1,3	3,25	1,02
%	Ca	1,65	3,0	2,0	0,54	2,30
%	Ti	0,14	1,72	0,17	0,29	0,27
ppm	Rb	37	52	48	145	41
ppm	Sr	400	36	850	255	720
ppm	Sc	16	24	<3	7,5	4,5
ppm	Y	67	10	10	16	13
ppm	Zr	160	1100	125	600	140
ppm	V	10	162	4,5	38	19
ppm	Cr	1,2	240	<1	16	<1
ppm	Mn	200	1300	70	115	120
ppm	Ni	<1	200	<1	29	5
ppm	Co	<2	55	<2	18	3,3
ppm	Cu	11	22	<1	15	<1
ppm	Ag	1,6	1,6	≦0,1	≦0,1	≦0,1
ppm	Yb	4,3	2,3	0,75	0,9	1,15
ppm	Mo	<3	3,6	3	3	3
ppm	Zn	≦100	1350	≦100	650	≦100
ppm	Tl	<3	<3	<3	<3	<3
ppm	Sn	<10	<10	<10	<10	<10
ppm	Be	4	3	3	3	3
ppm	Ga	26	60	23	40	40
ppm	La	47	<10	<10	31	47
ppm	Pb	14	47	13	38	10
ppm	Ba	430	730	550	1450	650
	K/Rb	459,5	346,1	270,8	224,1	248,8
	Ca/Sr	41,3	833,3	23,5	21,2	31,9
	Ni/Co	0,5	3,54	0,5	1,61	1,52
	Ca/Ti	17,86	1,74	11,76	1,86	8,52

Nr.		37	53	66	73	74
%	K	1,75	2,00	0,96	1,75	2,00
%	Ca	2,10	2,15	4,00	1,48	1,35
%	Ti	0,063	0,20	0,056	0,21	0,10
ppm	Rb	35	63	123	155	40
ppm	Sr	550	540	240	460	350
ppm	Sc	<3	<3	<3	7,5	<3
ppm	Y	14	12,5	20	22	18
ppm	Zr	360	125	110	180	320
ppm	V	6,8	15,5	4	47	21
ppm	Cr	1,6	<1	4,4	<1	<1
ppm	Mn	50	10	600	200	500
ppm	Ni	3	<1	1,8	13	<1
ppm	Co	<2	<2	<2	12	<2
ppm	Cu	11	<1	3,5	6	4,5
ppm	Ag	≦0,1	0,26	≦0,1	0,28	0,5
ppm	Yb	0,92	0,8	2,5	2,8	1,7
ppm	Mo	<3	<3	<3	<3	<3
ppm	Zn	120	≦100	760	≦100	≦100
ppm	Tl	<3	<3	<3	<3	<3
ppm	Sn	<10	<10	<10	<10	<10
ppm	Be	<3	<3	<3	≦3	<3
ppm	Ga	26	35	44	50	27
ppm	La	<10	28	<10	48	<10
ppm	Pb	6	13	40	17	21
ppm	Ba	800	720	570	440	850
	K/Rb	500,0	317,5	78,8	112,9	500,0
	Ca/Sr	38,2	39,8	166,7	32,2	38,6
	Ni/Co	2,0	0,5	1,0	1,08	0,50
	Ca/Ti	33,33	10,75	71,4	7,05	13,5

Nr.		86	99	80	121	134
%	K	4,45	4,10	2,75	1,82	0,73
%	Ca	0,76	0,90	1,70	3,6	1,38
%	Ti	0,184	0,26	0,172	0,55	0,49
ppm	Rb	205	122	60	110	28
ppm	Sr	157	190	665	355	57
ppm	Sc	5,8	8,9	7,5	20	7,5
ppm	Y	45	19	<10	28	38
ppm	Zr	260	215	170	100	260
ppm	V	22,5	38	8,5	104	80
ppm	Cr	1,8	6,3	<1	110	82
ppm	Mn	187	155	125	225	<10
ppm	Ni	<1	2,6	1,2	30	6
ppm	Co	2,6	4,0	<2	12	2,8
ppm	Cu	1,5	1,5	1,7	40	18
ppm	Ag	≦0,1	1,5	≦0,1	≦0,1	0,24
ppm	Yb	2,8	1,9	—	3,5	1,9
ppm	Mo	<3	<3	<3	<3	<3
ppm	Zn	670	475	100	700	650
ppm	Tl	<3	<3	<3	<3	<3
ppm	Sn	<10	<10	<10	<10	<10
ppm	Be	3	3	<3	5	4
ppm	Ga	21	24	30	52	26
ppm	La	90	85	58	<10	<10
ppm	Pb	27	65	20	5	15
ppm	Ba	660	850	2100	500	≦100
	K/Rb	217,1	336,0	458,3	165,5	260,7
	Ca/Sr	43,4	47,4	25,5	101,4	242,1
	Ni/Co	0,38	0,65	0,60	2,5	2,14
	Ca/Ti	4,13	3,46	9,88	6,6	2,8

Nr.		148	186	195
%	K	2,80	4,05	3,55
%	Ca	4,45	0,83	0,68
%	Ti	0,50	0,215	0,195
ppm	Rb	186	240	245
ppm	Sr	91	70	50
ppm	Sc	13	4,5	5,5
ppm	Y	30	63	75
ppm	Zr	<100	255	200
ppm	V	70	17	21
ppm	Cr	77	7,5	8
ppm	Mn	770	160	220
ppm	Ni	36	5	5
ppm	Co	17	3,3	3,4
ppm	Cu	12	6,5	15
ppm	Ag	<0,1	0,4	<0,1
ppm	Yb	3,9	3,6	5,5
ppm	Mo	<3	<3	<3
ppm	Zn	600	740	1100
ppm	Tl	<3	<3	<3
ppm	Sn	<10	<10	<10
ppm	Be	3	3	3
ppm	Ga	14	32	31
ppm	La	<10	42	<10
ppm	Pb	13	53	54
ppm	Ba	850	670	420
	K/Rb	150	168,7	144,9
	Ca/Sr	489,0	118,6	136,0
	Ni/Co	2,12	1,52	1,47
	Ca/Ti	8,90	3,86	3,5

b) Amphibolite

Nr.		4	11	18	29	40
%	K	0,90	1,20	1,27	0,56	0,55
%	Ca	6,8	6,35	6,5	7,0	6,5
%	Ti	2,15	0,80	1,42	1,08	1,55
ppm	Rb	38	52	58	<10	19
ppm	Sr	535	460	415	295	470
ppm	Sc	35	39,5	29	31,5	56
ppm	Y	58,5	42	48	48	53
ppm	Zr	266	254	2226,5	89	260
ppm	V	380	370	287	288	450
ppm	Cr	94	183	176	252	79
ppm	Mn	1270	1610	1770	1160	1370
ppm	Ni	46,5	81,5	79,5	73	55
ppm	Co	60,5	61	62	48,5	53
ppm	Cu	43	<3	49	42,5	30,5
ppm	Ag	2	—	—	0,56	0,85
ppm	Yb	—	—	—	—	3,6
	K/Rb	236,8	230,8	219,0	560,0	289,4
	Ca/Sr	127,1	138,0	156,6	237,3	138,3
	Ni/Co	0,77	1,34	1,28	1,51	1,04
	Ca/Ti	3,16	7,94	4,64	6,48	4,19

Nr.		54	59	75	102	107
%	K	0,72	0,52	0,97	0,42	1,19
%	Ca	6,40	7,4	6,45	6,80	5,85
%	Ti	2,30	0,94	1,16	1,57	1,61
ppm	Rb	22	16	38	17	78
ppm	Sr	530	273	422	127	525
ppm	Sc	38	38	36,5	57	32,75
ppm	Y	50	38	52,5	62	54
ppm	Zr	150	119	155	200	362,5
ppm	V	300	298	400	750	346
ppm	Cr	75	90	188	102	90
ppm	Mn	1314	1500	1365	1870	1875
ppm	Ni	40	360	72	65	24,5
ppm	Co	52	77	67	59	54,5
ppm	Cu	20	33	128	77	20,8
ppm	Ag	—	0,68	—	1,75	1,37
ppm	Yb	—	—	—	6,8	4,7
	K/Rb	327,3	325,0	255,2	247,1	152,6
	Ca/Sr	120,8	271,0	152,8	535,4	111,4
	Ni/Co	0,77	4,86	1,07	1,10	0,45
	Ca/Ti	2,78	7,87	5,56	4,33	3,63

Nr.		126	157	177	187
%	K	0,39	0,31	0,70	1,18
%	Ca	7,40	5,75	7,50	7,75
%	Ti	0,59	0,86	1,03	1,46
ppm	Rb	11	<10	14	41
ppm	Sr	300	385	550	228
ppm	Sc	25,5	25	43,5	57
ppm	Y	32	35	45	56
ppm	Zr	82	116	86	254
ppm	V	218	235	295	480
ppm	Cr	195	95	153	33
ppm	Mn	1300	1060	1210	1300
ppm	Ni	228	97	78	34,5
ppm	Co	67	49,5	49	60
ppm	Cu	21,5	70	<3	16
ppm	Ag	—	0,68	—	1,45
ppm	Yb	—	—	—	4,7
	K/Rb	354,5	310,0	500	287,8
	Ca/Sr	246,7	149,4	136,4	339,9
	Ni/Co	3,40	1,96	1,59	0,57
	Ca/Ti	12,55	6,69	7,28	5,31

IV. Diskussion der Ergebnisse

Die Auswertung der Ergebnisse wurde auf graphischem Wege mit Hilfe binärer Korrelationsdiagramme vorgenommen. Zur Ergänzung wurden auch Daten aus den Arbeiten von GROHMANN (1965), JANDA, SCHROLL und SEDLAZECK (1965) verwendet sowie auch andere unveröffentlichte Analysenergebnisse (SCHROLL, 1966, 1967). Die Diagramme enthalten auch Durchschnittswerte von Gesteinstypen, die im wesentlichen aus den Zusammenstellungen von TURKIAN und WEDEPOHL (1961) : (TW), GROHMANN (1965) : (G), CAMBEL und KUPČO (1965) : (CK), ENGEL und ENGEL (1965) : (E) entnommen sind. Beim Zeichnen der Korrelationsdiagramme wurde auf die bei HEIER (1962) und JANDA, SCHROLL und SEDLAZEK (1965) vorgeschlagenen Korrelationen Ni/Co, Cr/Ni, Ni/Cu und Zr/Ni zurückgegriffen. Außerdem wurden die Diagramme für K/Rb, K/Ti, Ca/Sr, Rb/Ba, La/Y, K/Zr und Ca/Ti entworfen sowie auch die Elementarverhältnisse K/Rb—Ca/Ti, K/Rb—Ca/Sr, Ni/Co—K/Rb in Beziehung zueinander gesetzt.

1. Ni/Co-Korrelationsdiagramm, Fig. 1 *)

Die Durchschnittswerte für alle Basite, auch die Mittelwerte von Gabbros und Amphiboliten der Kleinen Karpathen von CAMBEL und KUPČO (1965) fallen in das Orthofeld der Amphibolite. Von den in dieser Arbeit untersuchten Amphibolite sind aber nur ein Teil im sicheren Orthofeld zu finden. Es sind dies Amphibolite aus dem Dobra-Komplex (11, 18, 29, 59 und S_4) als auch Amphibolite aus dem Krumauer Komplex (126, 157 und 177). Alle anderen Proben fallen entweder in das Feld hochmetamorpher Amphibolite, verschieferter Amphibolite oder auch in das „Parafeld". Das soll nun nicht heißen, wie auch JANDA, SCHROLL und SEDLAZECK (1965) angeben, daß es sich tatsächlich um aus reinen Sedimenten hervorgegangene Gesteine handelt, sondern daß es sich nur um, durch hochgradige Metamorphose entartete Orthobasite oder aber um Alkalibasalte, tholeiitische Basalte, Tuffe, Tuffite, hydrothermal veränderte Basite und dergleichen handeln kann.

Mehrere Gneise des Krumauer Komplexes (121, 148) sowie auch die bei GROHMANN angegebenen Paragneise fallen in das Feld der sicheren Tongesteine. Die größere Zahl der Dobra-Gneise, aber auch Gneise aus dem Krumauer Komplexe ordnen sich um ein Ni/Co-Verhältnis von 2 an.

Die Orthogneise von GROHMANN konzentrieren sich, wie auch einige Proben der Dobra-Gneise (1, 24, 53, 74, 86 und S), am unteren linken Eck des Diagramms. Abweichend verhält sich die Probe 17 und Proben 27, 37, 66, 73 und 99. Die Probe 17 war überhaupt nicht mehr einzutragen, da sie außerhalb der Grenze des Diagramms zu liegen käme.

Die zwei von DESHPANDE untersuchten Proben von Spitzer Gneis (S_1 und S_2) liegen ebenso wie die Hornblendegranulite von Steingraben im Bereich tonalitoider Gesteine (Co $>$ Ni).

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*) Zeichenerklärungen S 191/192.

2. Cr/Ni-Korrelationsdiagramm

Einige der beim Ni/Co-Diagramm im Orthofeld befindlichen Proben (11, 18, 29, 59, S_4, 157 und 177) fallen hier in die Randzone des Konzentrationsfeldes der Orthoamphibolite. Die Werte zeigen eine stärkere Streuung als beim Ni/Co-Korrelationsdiagramm, wobei allerdings die Hornblendegranulite (E und F) und einer der Krumauer Gneise (134) sich anomal verhalten, während die große Zahl der Proben einem Cr/Ni-Verhältnis von 1 folgt.

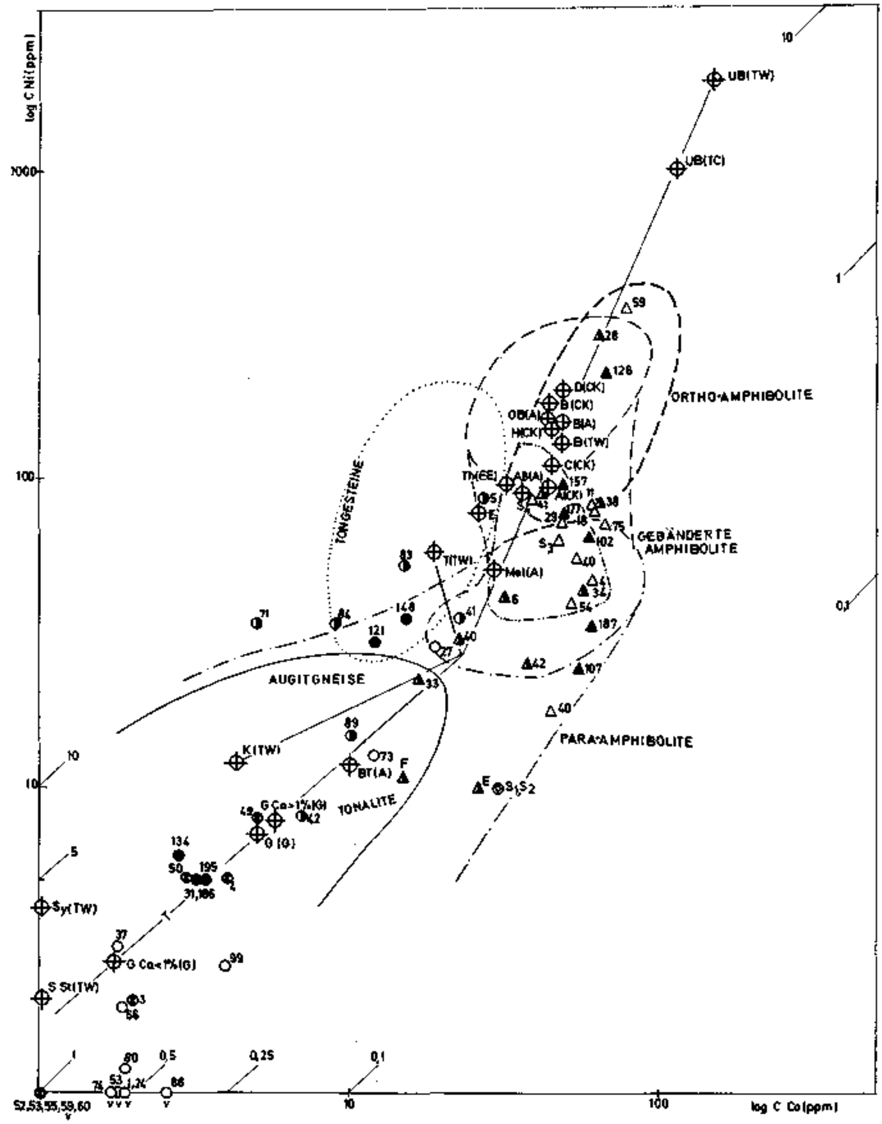

Fig. 1: Ni/Co-Korrelationsdiagramm.

Ein Unterschied zwischen Para- und Orthogneisen ist aus diesem Diagramm weniger gut ablesbar, außer daß die Paragneise höhere Absolutkonzentrationen aufweisen.

Von den Dobra-Gneisen häufen sich wieder die Proben 1, 24, 53, 74, 86 und 80 im Eck geringer Chrom- und Nickelgehalte. Abweichend verhalten sich die Proben (17, 27, 37, 66, 99, S_1 und S_2), die ein starkes Streufeld wie die Krumauer Gneise zeigen. Die Probe 73 verhält sich als Außenseiter.

3. Ni/Cu-Korrelationsdiagramm

Im Orthofeld sind die eindeutig als Orthoamphibolite bezeichneten Proben (59, S_4, 126 und 157) anzutreffen. Mit Ausnahme von Melaphyren und ozeanischen Tholeiiten fallen alle Durchschnittswerte in das Orthofeld. Der größere Teile der Krumauer Gneise liegt auch hier im oder in der Nähe des Konzentrationsfeldes von Tongesteinen, die sich aber eindeutig durch absolut höhere Ni/Cu-Werte von den Orthogneisen unterscheiden. Die Orthogneise sind wieder eindeutig — allerdings mit einer weiten Streuung (Ni/Cu 0,5) — im Bereich niederer Konzentrationen zu finden — wobei sowohl Ni > Cu oder auch Cu > Ni sein kann.

4. Zr/Ni-Korrelationsdiagramm

Das Zr/Ni-Diagramm bestätigt das Ergebnis der drei oben diskutierten Korrelationen. Die Krumauer Gneise, beziehungsweise die Paragneise nehmen ein lang gestecktes Feld ein, bei dem der Zr-Gehalt vom Ni-Gehalt unabhängig erscheint. Dazu gehört aber auch die zweite Gruppe der Dobra-Gneise, die sich in fast allen anderen Diagrammen zum Paramaterial hinordnen. Die erste Gruppe der Dobra-Gneise konzentriert sich deutlich bei niedrigeren Ni-Werten (um 1 ppm). Eine Erklärung wäre wohl, daß in den Dobra-Gneisen Paramaterial enthalten ist.

5. K/Rb-Korrelationsdiagramm, Fig. 2

Das K/Rb-Diagramm zeigt eine gute Korrelation zwischen Kalium und Rubidium, wies dies auch SCHROLL und GROHMANN (1965) angegeben haben. Bei basischen Proben konnten leider nicht überall Analysen durchgeführt werden, da der Rb-Gehalt oft unter der Nachweisgrenze der angewandten Analysenmethode gelegen war. Paragneise und Orthogneise zeigen im Bereich von K-Konzentrationen über 2% eine Koinzidenz. Das Feld der Paragneise setzt sich jedoch bei einem mittleren K/Rb-Wert von 170 bis zu einer K-Konzentration von fast 0,5% fort. Die Dobra-Gneise liegen in einem weiteren Streufeld, dessen mittleres K/Rb-Verhältnis mit 280 relativ hoch ist; nur die als Paragneise verdächtigten Proben 27, 66, 73, 86, 99 des Dobra-Komplexes tendieren zu niedrigeren K/Rb-Werten.

Die Amphibolite des Dobra-Komplexes kommen bei einem mittleren K/Rb-Wert von 300 im Feld der Basite etwa in der Verlängerung zu den Para- und Orthogneisen zu liegen. Die übrigen Amphibolite des Krumauer

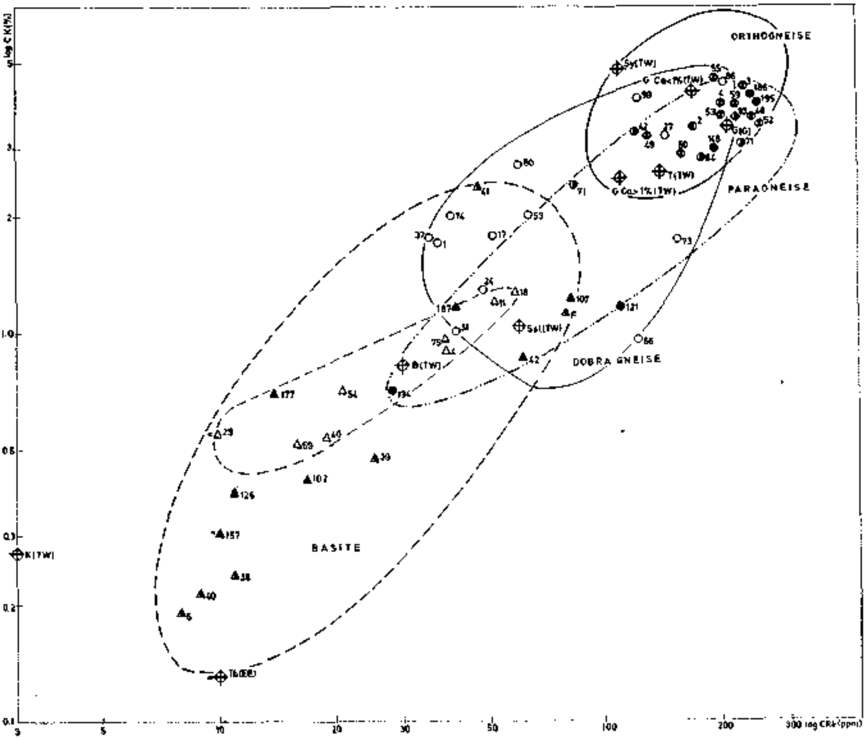

Fig. 2: K/Rb-Korrelationsdiagramm.

Komplexes zeigen ein etwas niedrigeres K/Rb-Verhältnis, so daß sich folgende Abfolge der K/Rb-Werte ergibt:

1. Dobra-Gneise.
2. Krumauer Gneise bzw. Paragneise.
3. Amphibolite des Dobra-Komplexes.
4. Amphibolite des Krumauer Komplexes.

Die K/Rb-Werte der Paragneise sind denen der Amphibolite aus dem Krumauer Komplex ähnlich.

Die Amphibolite des Krumauer Komplexes liegen fast durchwegs im selben K/Rb-Konzentrationsbereich wie Amphibolite aus den Ostalpen. Die K/Rb-Werte kommen denen des Dobra-Komplexes sehr nahe.

6. K/Ti-Korrelationsdiagramm, Fig. 3

Die Korrelation K/Ti trennt das Konzentrationsfeld von Basiten und Felsiten fast vollkommen auf, nur die Proben 134 und 17 liegen außerhalb des Gneisfeldes. Die Probe 134 ist ein Paragneis. Die Probe stammt aus dem Dobra-Komplex. (Die Probe 31 ist in bezug auf die Ordinate fehlerhaft eingezeichnet.)

Die Paragneise decken sich im K/Ti-Verhältnis zum Teil mit den Orthogneisen. Trotzdem wird ein beschränktes Feld von eindeutig erfaßbarem Paramaterial sichtbar.

Die Dobra-Gneise verhalten sich vollkommen anomal, wobei die Proben 1, 24, 37, 53, 66 und 73 sogar außerhalb der üblichen Ortho- und Paragneise liegen. Sie zeichnen sich durch einen niedrigen K- und einen höheren Na-Wert aus. Dagegen befinden sich die drei Proben der Dobra-Gneise 27, 86 und 99 im Feld der sicheren Orthogneise. Indifferent verhält sich die Probe 80, die aus einem Übergang zum Kraumauer Komplex stammt.

Recht auffällig ist, daß die Basite einer anderen Regression folgen als die üblichen sialischen Gesteine. Die Regressionslinie der Dobra-Gneise zeigt ebenso wie die der Basite eine positive Neigung, wobei allerdings der Ti-Gehalt erniedrigt erscheint.

7. K/Zn-Korrelationsdiagramm

Die Mehrzahl der Dobra-Gneise liegt als Orthogneise im Bereich der durchschnittlichen geochemischen Häufigkeit beider Elemente. Die untersuchten Krumauer Gneise fallen aber in ein eigenes Feld mit extrem hohen Zn-Werten.

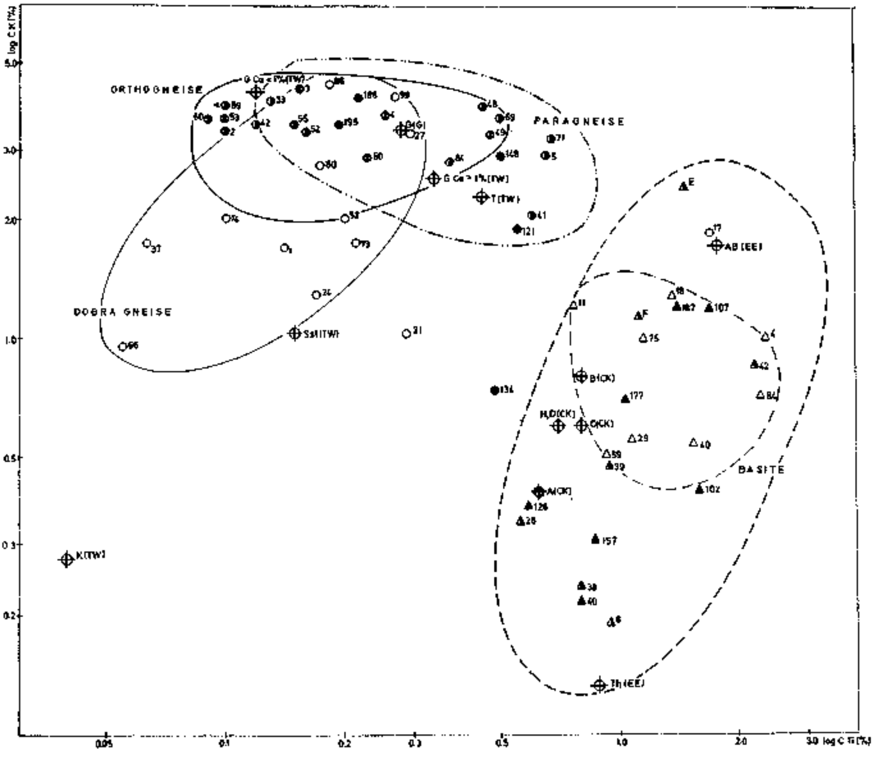

Fig. 3: K/Ti-Korrelationsdiagramm.

Von den Dobra-Gneisen fallen die Proben 27, 66, 86 und 99, auch die nicht mehr eingetragene Probe 17, in dieses Feld der Paragneise. Die Proben 66, 86 und 99 lagen in bisherigen Diagrammen vorzugsweise im oder in der Nähe vom Feld der Orthogneise; nur die Probe 27 verhielt sich in der Mehrzahl der Diagramme abweichend.

8. La/Y-Korrelationsdiagramm

Die Korrelation La/Y gestattet es ebenso, die Paragneise von den Dobra-Gneisen und Orthogneisen zu unterscheiden. Eine Ausnahme davon scheint nur die Probe 1 vom Dobra-Gneis zu machen. Die Dobra-Gneise unterscheiden sich von den Paragneisen durch niedrigere Y-Werte, die für gewöhnlich unter 30 ppm liegen.

9. Rb/Ba-Korrelationsdiagramm, Fig. 4

Auch die Korrelation Rb und Ba scheint trotz der geringeren Probenzahl zu brauchbaren Ergebnissen zu führen. Dabei nehmen die Gesteine der Dobra-Gneise und der Krumauer-Gneise charakteristische Felder ein. Auffälligerweise liegen die Zn-armen Dobra-Gneise in einem eigenen Feld. Eine Ausnahme davon macht wieder die Probe 17. Die Zn-reichen

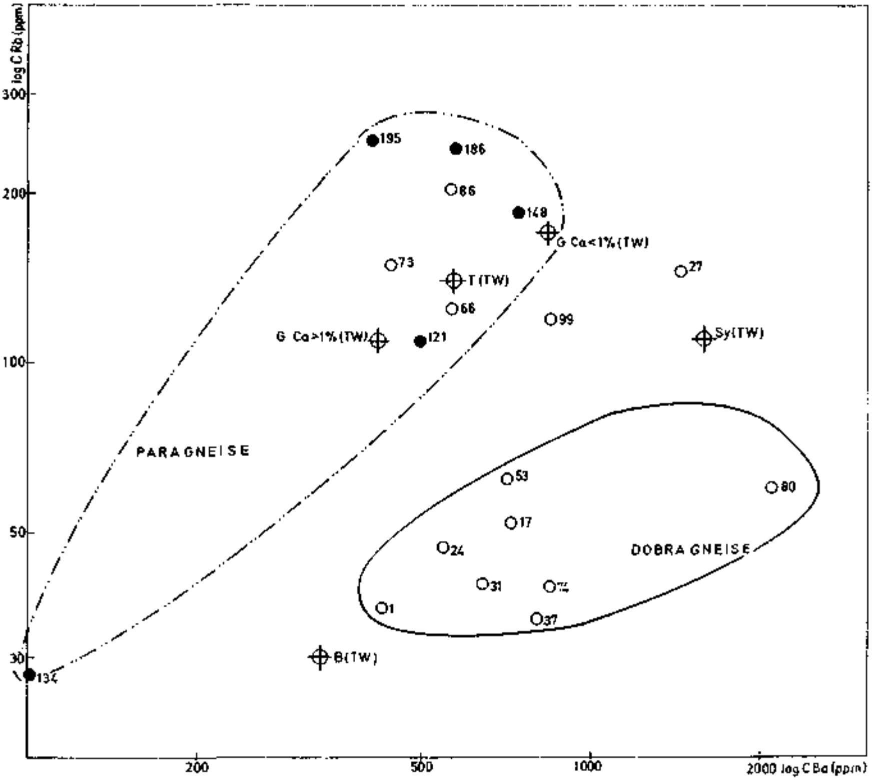

Fig. 4: Rb/Ba-Korrelationsdiagramm.

Proben, mit Ausnahme von 73, rücken näher an das Feld der Paragneise heran, bei denen für die Rb- und Ba-Werte die geochemischen Durchschnitte entsprechen. Bei durchschnittlichen Ba-Werten erscheinen die Rb-Werte der Zn-armen Spitzer Gneise extrem klein.

10. Ca/Sr-Korrelationsdiagramm, Fig. 5

Orthogneise und Paragneise unterscheiden sich nicht wesentlich. Die Dobra-Gneise nehmen wieder eine besondere Stellung ein, da ihre Sr-Werte zu höheren Konzentrationen tendieren. Dies trifft vor allem für jene Proben zu, die anomale K/Rb-Verhältnisse besitzen. Der Ca-Gehalt übt dagegen auf die Höhe des Sr-Gehaltes keinen Einfluß aus. Es ist zu vermuten, daß der Sr-Gehalt mit der Na-Konzentration korrelierbar erscheint.

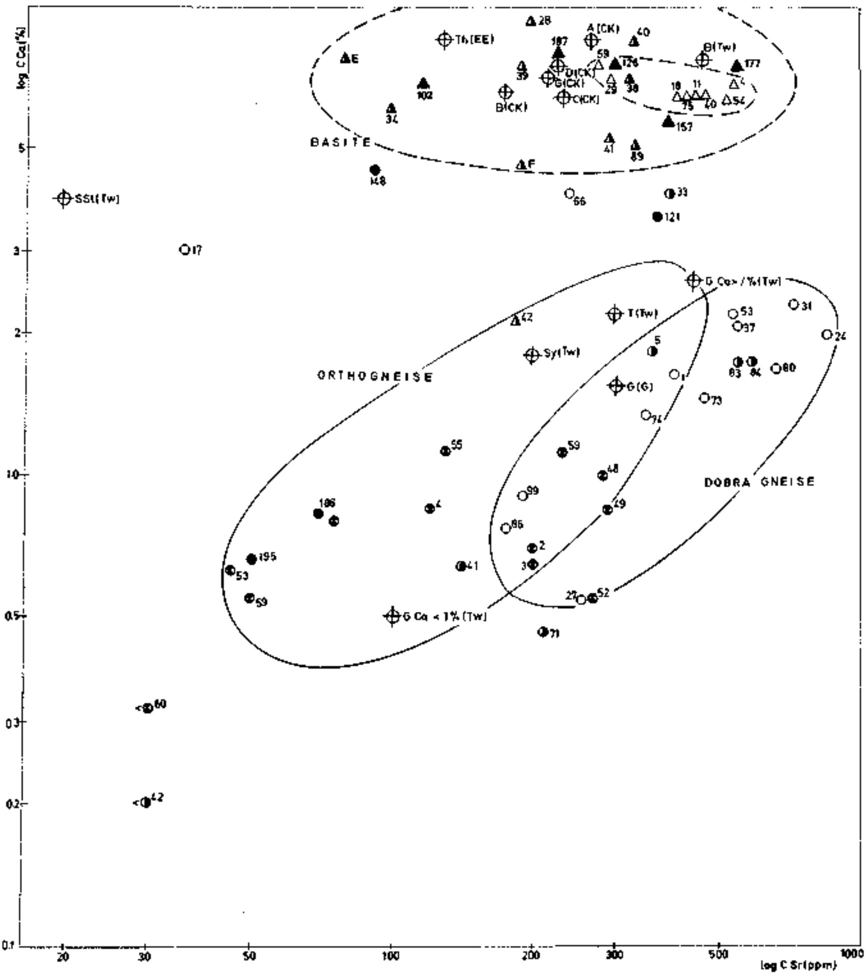

Fig. 5: Ca/Sr-Korrelationsdiagramm.

Im Gegensatz zu den sauren Gesteinen zeigt der Sr-Gehalt vom Ca-Gehalt der Basite keine Abhängigkeit. Interessanterweise liegen die Amphibolite des Dobra-Komplexes, im Gegensatz zu denen der Krumauer Gneise, in einem sehr engen Konzentrationsfeld, dessen Mittelwert etwa dem der Dobra-Gneise entspricht, wie dies bei K und Rb bereits angedeutet worden ist. Die Amphibolite des Krumauer Komplexes nehmen ein weiteres Konzentrationsfeld ein, das dem der Basite angepaßt ist. Auch die Krumauer Gneise zeigen ein sehr variantes Verhalten, wobei der Ca-Wert in Relation zum Sr-Wert ansteigt. Im Gegensatz zum Dobra-Gneis scheint es bei den Paragneisen keine Korrelation zwischen Ca und Sr zu geben. Das wäre vielleicht damit zu erklären, daß sich bei einem magmatischen

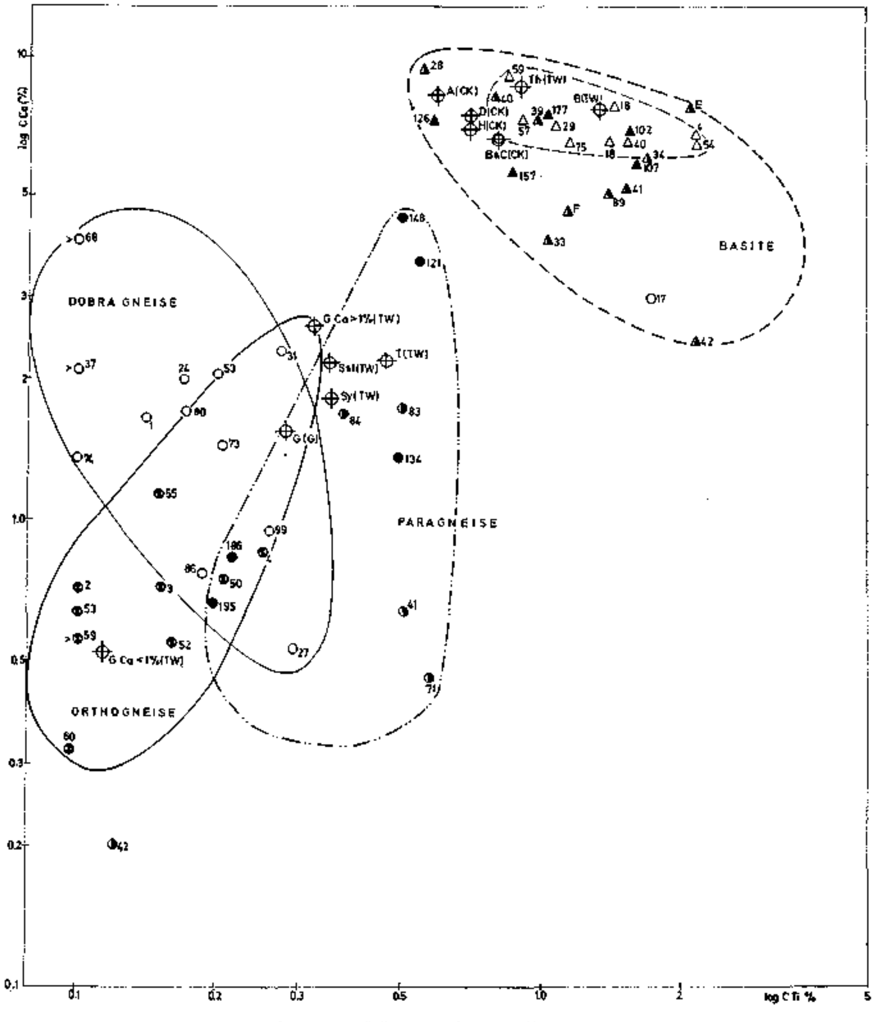

Fig. 6: Ca/Ti-Korrelationsdiagramm.

Differenziationsprozeß oder bei partiellen Aufschmelzungsprozessen ein Gleichgewicht einstellt, während das ursprünglich sedimentäre Material, das variable Mengen von Mineralen mit sehr unterschiedlichen Ca/Sr-Verhältnissen, wie Calciumcarbonate, Plagioklase usw., enthalten kann, im Verlauf der Metamorphose keine wesentliche Veränderungen erfahren hat.

Bei den Dobra-Gneisen sind allerdings wieder die Proben 17 und 66 Ausnahmen. Beide Proben tendieren zum Paragesteinsmaterial.

11. Ca/Ti-Korrelationsdiagramm, Fig. 6

Sowie das K/Ti-Diagramm zeigt auch dieses eine negative Korrelation der basischen Gesteine. Der Dobra-Gneis hat eine ähnliche Neigung. Orthogneise und Paragneise nehmen weitgehend getrennte Felder ein. Beide Felder durchschneiden das Konzentrationsfeld der Dobra-Gneise. Jene Dobra-Gneise, die zum Typ der Zn-armen Gneise gehören, liegen eher im Feld der Orthogneise. Von den Zn-reichen Proben liegen 27, 86 und 99 im Feld der Paragneise, während die Probe 66 eindeutig entartet ist und die Probe 17 überhaupt im Feld der Basite zu finden ist. Die Regressionslinien der Ortho- und Paragneise scheinen sich in der Regressionslinie der Basite zu schneiden. Die Amphibolite der Dobra-Gneise nehmen wieder ein relativ enges Feld ein.

V. Zusammenfassung der geochemischen Auswertungen

Für eine endgültige Aussage ist selbstverständlich die statistische Masse noch immer zu klein. Trotzdem zeigen die Diagramme für die Amphibolite, daß es sich auf keinen Fall um Paraamphibolite im klassischen Sinne handelt. Die Amphibolite aus dem Dobra-Komplex und die Amphibolite aus dem Krumauer Komplex lassen sich in ihrem Chemismus nicht wesentlich unterscheiden, nur daß die Dobra-Komplex-Amphibolite weniger variant sind als die des Krumauer Komplexes. Die Letzteren tendieren eher in das Feld der vorgezeichneten Orthoamphibolite, welches mit dem der Olivinbasalte oder Olivingabbros übereinstimmt. Diese Variation wäre vielleicht damit zu erklären, daß die Krumauer Amphibolite auch Tuffe und tuffitisches Material enthalten können. Ansonst müßte man annehmen daß die Differentiation ein stärkeres Ausmaß erreicht hat. Inwiefern die Amphibolite im Dobra-Komplex als Basalte, Diabase, Dolerite, Tuffe oder Tuffite aufzufassen sind, wäre zu erwägen.

Die Krumauer Gneise lassen sich von den Dobra-Gneisen mit größter Wahrscheinlichkeiten durch hohe Ni-, Co-, Cr-, Cu-, Y-, Ti-, Rb-, Zn-Konzentrationen unterscheiden, wobei vor allem die Werte von Ca/Ti, Ca/Sr, K/Zn, K/Ti, K/Rb, Rb/Ba, Ni/Co, Cr/Ni und La/Y nützlich erscheinen. Selbstverständlich dürfte ein Korrelationspaar nicht allein angesehen werden, sondern es müßten mehrere Elementpaare hiezu herangezogen werden, so daß die Wahrscheinlichkeit der Aussage erhöht wird.

Innerhalb der Dobra-Gneise dürften wenigstens zwei statistische Gruppen existieren, deren Kenntnis für deren Genese von Bedeutung sein dürfte.

Tabelle 5.

Proben Nr.	1	17	24	27	31	37	53
Ni/Co	1	2	1	2	2	2	1
Cr/Ni	1	(2)	1	2	1	2	1
Ni/Cu	1	(2)	1	2	(2)	2	1
Zr/Ni	1	2	1	2	2	2	1
K/Rb	1	2	1	2	1	2	1
K/Ti	1	1	1	2	2	(2)	1
K/Zn	1	2	1	2	1	1	1
Rb/Ba	1	1	1	2	1	1	1
Ca/Ti	1	2	1	2	1	2	1
Gneistyp	I	II	I	II	II?	II	I

Proben Nr.	66	73	74	80	86	99
Ni/Co	(2)	2	1	1	1	2
Cr/Ni	2	(2)	1	1	1	2
Ni/Cu	2	2	1	1	1	2
Zr/Ni	2	2	1	1	1	2
K/Rb	2	2	1	1	(2)	2
K/Ti	(2)	(2)	1	(2)	(2)	2
K/Zn	2	1	1	1	2	2
Rb/Ba	2	2	1	1	2	2
Ca/Ti	2	(2)	1	1	2	2
Gneistyp	II	II	I	I	II?	II

Die erste Gruppe der Dobra-Gneise dürfte aller Wahrscheinlichkeit nach magmatogener Herkunft sein. Sie zeichnet sich durch ein relativ hohes K/Rb-Verhältnis aus (250, maximal 500), womit sie sich vor allem von den üblichen Orthogneisen unterscheidet. Ihr Gehalt an Sr und Na ist wesentlich höher als der der üblichen Orthogneise. Wenn es sich dabei also um ein magmatisches Differentiat handeln sollte, so keinesfalls um ein kalireiches Spätdifferentiat, wie es in der oberen Kruste aufzutreten pflegt. Die zweite Gruppe der Dobra-Gneise ist weniger homogen und liegt in einem weiteren Streubereich. Das Ni/Co-Verhältnis erscheint in dieser Gruppe ebenfalls erhöht. Sowohl der Ni-Gehalt als auch die Cr-Konzentration erscheinen hoch. Auch der Zn-Gehalt kann anomal hoch werden, wie ein Teil der Proben (66 und 27) zeigt. Die Ti-, Sr- und Cu-Gehalte variieren stark und können vor allem in Zn-armen Proben sehr gering werden. Einige dieser Proben, wie z. B. die stark anomalen Proben 17, 27 und 66 sind wahrscheinlich auch als Paramaterial anzusprechen.

In Tabelle 5 ist eine Zuordnung der zum Typ 1 und 2 auf Grund der vorgelegten Diagramme vorgenommen. Die in Klammern gesetzten Ziffern sollen andeuten, daß die Zuordnung nicht sicher ausgesprochen werden kann. Danach gehören also, wenn etwa alle Kriterien entsprechen, eindeutig zum Typ 1: 1, 24, 53, 74 und 80 und zu Typ 2: 17, 27, 66 und

99. Mit noch hinreichender Wahrscheinlichkeit zum Typ 2 sind die Probe 73, während die Proben 31 und 86 eine Art Mischtyp unsicherer Zuordnung abgeben. Der Typ 1 scheint auf allen Diagrammen vom typischen Orthomaterial abgetrennt — während der Typ 2 stets in das Feld der Orthogneise, beziehungsweise in den Überschneidungsbereich mit Paragneis zu liegen kommt. Der Typ 1 dürfte aber trotzdem, wie oben erwähnt, als Orthotyp anzusprechen sein, der Na-Vormacht hat. Der Typ 2 kommt entweder in das Feld der Orthogneise, oft auch in das der Paragneise zu liegen, beziehungsweise zeigt extreme Streuwerte. Diese Gruppe ist wahrscheinlich genetisch nicht homogen. Ihr kann sowohl normales Orthomaterial mit Kalivormacht zuzurechnen sein, als auch vor allem Paramaterial. Hieher gehören alle extreme Proben, die bereits als Paramaterial ausgewiesen worden sind. Vor allem die Zn-reichen Proben charakterisieren das Paramaterial. Damit kann gezeigt werden, daß auch vom geochemischen Standpunkt der Dobra-Gneis nicht als eine genetisch-homogene Masse zu betrachten ist.

Die Ergebnisse der petrographischen und geochemischen Untersuchungen stimmen auch auffallend überein, wenn man die Proben 1, 17, 24, 27, 53, 74 und 80 in Betracht zieht (vgl. Tab. 5). Die Proben 31, 37 und 86, die petrographisch zum Paratyp (Typ 2) gehören, liegen im Übergangsbereich. Die Proben 66, 73 und 99, die megaskopisch granitische Merkmale zeigen und petrographisch dem Typ 1 zuzuordnen sind, weisen trotzdem alle geochemischen Merkmale für sedimentäre Herkunft auf (Typ 2).

Die vorliegenden Untersuchungen liefern den Beweis, daß es nützlich sein kann, systematische Untersuchungen und statistische Aspekte für petrologische Probleme heranzuziehen. Um zu einem vollen Erfolg zu kommen, wäre es zwar notwendig gewesen, von jeder Population von Gesteinstypen wenigstens 30 Proben zu untersuchen. Das wäre im vorliegenden Falle etwa 100 bis 200 Proben gewesen. Außerdem müßte die Elementverteilung in den sedimentären und magmatischen Ausgangsgesteinstypen noch besser studiert sein. Die vorliegenden geochemischen Beobachtungen unterstützen aber den Feldbefund trotzdem in ausreichendem Maße.

Nachtrag

Ohne Kenntnis der vorliegenden Arbeit hat Frasl (1970) folgendes festgestellt:

„Jedenfalls möchte ich für den Bitterscher Gneis und ebenso auch für den Dobra-Gneis ein hauptsächlich suprakrustales Ausgangsgestein annehmen. Nicht nur, daß die Einschaltung von vielen dünnen basischen Lagen bei vulkanischen Ablagerungen unschwer verständlich ist; auch die meist feinkörnige Beschaffenheit kommt bei Gneisen aus vulkanischem Ausgangsmaterial oft vor. Kalifeldspataugen passen ohne weiteres zu einer primären vulkanischen Entstehung, wenn sie wie hier in beiden Fällen bei optimaler reliktischer Erhaltung und schwacher Triklinisierung noch idiomorphe Zwillinge mit einem feinschaligen Zonarbau eines ganz bestimmten Typs erkennen lassen (vgl. G. Frasl: Jb. Geol. B. A. Wien 1954, Abb. 7, Taf. IX und p. 76 f. und 104).

Und schließlich wäre es schwieriger sich vorzustellen, wie eine so dünne Gneisplatte von 120 km Länge aus einem rundlichen Granitpluton ausgewalzt wird, als wenn das Ausgangsmaterial bereits etwa eine Porphyrplatte darstellt, z. B. das Ergebnis eines großen Lineargusses, wie dergleichen aus verschiedenen Ignimbritgebieten in der Literatur des letzten Jahrzehnts bekanntgeworden ist."

Danksagung

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Zeichenerklärung zu den Abb. 1—6

Amphibolite

△ Amphibolite aus dem Dobra Komplex
▲ Amphibolite aus dem Krumauer Komplex
◭ Amphibolite (Janda, Schroll u. Sedlazek [1965]), (Schroll, unveröffentlicht)

6-Maiersch, Bez. Horn — geb. Salitamphibolit
28-Elsenreith, Bez. Zwettl — Amphibolite eingelagert in Marmor
33-Halterberg bei Raisdorf, Bez. Horn — Fugnitzer Kalksilikatschiefer
34-Unterberg bei St. Corona am Wechsel. Steinbruch auf der Straße nach Aspang — Pyrit führender Amphibolit
38-Panzendorf, Osttirol, Halde des Kiesbergbaues — Amphibolit
39-Buckelkarsee, Schladminger Obertal, Stmk. — Amphibolit
40-Berliner Hütte, 1950 m — Femisches Relikt (Biotit, Hornblende, Epidot) im Migmatit
41-Berliner Hütte, 2000 m — Dunkler biotitreicher Anteil des Migmatites (mit Hornblenderesten)
42-Berliner Hütte, 1950 m — stärker injizierter Amphibolit
E-Steingraben, Hornblendegranulit
F-Steingraben, Hornblendegranulit

89-Diebsgraben am Wechselgebiet — Grünschiefer

Mittelwerte für Amphibolite

⊕ A . . . G (CK) = Mittelwerte für Amphibolite der Kleinen Karpaten (Cambel, Kupčo 1965)
A = 12 grobkörnige Gabbros, epizonal-metamorph. 40—55% Hbl.
B = 17 Gabbro-Amphibolite bis Hornblendit, schwach metamorph, 45—65% Hbl. Teilweise 80—90%.

C = 15 feinkörnige Amphibolite, retrograd und hydrothermal met. 45—55% Hbl.
D = 26 basische Amphibolite schwach metamorph 55—75% Hbl.
G = 70 Amphibolgesteine der Kleinen Karpathen

B = Basalte
AB = Alkalibasalte
OB = Olivinbasalte
Th = Tholeite
BT = Basische Tuffite
Mel = Melaphyre
UB = Ultrabasite
(TW) = Turkian und Wedepohl (1961)
(EE) = Engel, Engel und Havens (1965)

Gneise

○ Gneise des Dobra Komplexes
● Gneise des Krumauer Komplexes
◐ Orthogneise aus der Arbeit von Grohmann (1965)
2-Bittescher Gneis, Kamptal-Bundesstraße bei Schönberg
3-Spitzer Gneis, Stollen Dobra-Krumau, Halde bei Kamprohrbrücke
4-Gföhler Gneis, 4 km hinter Gföhl an der Straße nach Kronsegg
48-Granitgneis, grüner, Gauertal, Rhätikon
49-Granitgneis des Bilkengrades, Rhätikon
50-Granitgneis des Bilkengrades, Rhätikon
52-Granitgneis, Grimselpaß, Ende des Haslitales
53-Granitgneis, Grimselstraße, 2 km vorl. Stausee am Weg zum Grimselpaß
55-Granitgneis, Gamsboden, Furkaegg
59-Granitgneis, Tremola
60-Granitgneis, Antholzer Tal, Rieserferner-Gruppe

◑ *Paragneise aus der Arbeit von* Grohmann
5-Paragneis, Kamptal-Bundesstraße, 2 km nördlich von Schönberg
41-Paragneis, Kirchschlag bei Ottenschlag
42-Sillimanitgneis, Schneeberg, Kirchschlag bei Ottenschlag
71-Schiefergneis, Bruch der „Kärntner Granitwerke", Landskron bei Zauchen, Kärnten
83-Streifengneis, Radhausberg, Unterbaustollen, 1610 m
84-Streifengneis, Radhausberg, Unterbaustollen, 1225 m

⊕ *Mittelwerte für Gesteinsarten*
G = Granite
Sst = Sandsteine
K = Karbonate
(G) = Grohmann (1965)
(TW) = Turkian und Wedepohl (1961)
Sch = Schiefer
Sy = Syenite

Zeichenerklärung zu Fig. 1—6

▬ ▬ ▬ ▬ Orthoamphibolit
—··—··—·· Gebänderter Amphibolit
—·—·—· Paraamphibolit
——— Augitgneis
·············· Tongesteine
— — — Basalte

Heavy Mineral Content of Burdigalian and Helvetian Sediments of the Molasse Basin, Lower Austria

By Roberto C. Miró *)

Dirección Nacional de Geología y Minería, Buenos Aires, Argentina.

With 4 plates, 2 figures and 3 tables

Abstract

The mineral content of Helvetian and Burdigalian clayey-sandstones and shales from different core samples of the Molasse basin, Lower Austria, was investigated in order to give a characteristic petrographical profile of the area. Examination showed a total of 20 heavy minerals of detrital origin, the most common of them being chlorite, chloritoid, clinozoisite, epidote, garnet (by far the most abundant), ilmenite, magnetite, rutile and tourmaline. The light minerals are composed of large quantities of quartz and, in minor proportion, of different types of feldspars (acidic to intermediate plagioclase, microcline, orthoclase), and variable amounts of muscovite and calcite.

The shale units do not contain more than 4% of heavy minerals whereas the most sandy formations contain between 6 and 7,5%.

The tabulated frequencies of the heavy minerals show appreciable variations through the stratigraphical units. These variations, following an undulatory pattern, are evident when the minerals are tabulated as belonging to four main groups which are: 1) garnet, 2) more stable minerals (rutile, sphene, tourmaline, zircon), 3) alpine metamorphic minerals (chloritoid, clinozoisite, epidote, green hornblende), and 4) opaque minerals. The reasons for these variations are considered to be, 1) relative changes in the weathering rates in the different source areas, 2) sorting during transportation, and 3) post-depositional alteration.

The main source area of these sediments appears to be the alpine metamorphic rocks, the Limestone Alps and the Flysch. A minor contribution was probably derived from the igneous and metamorphic rocks of the Bohemian Massive in the north. Finally the underlying Tertiary might also have contributed to the sedimentary content of the basin.

1. Introduction

A general understanding of the relationship between the different rock types is known in the Tertiary basins of the northern part of Lower Austria. This knowledge is based mainly on the detailed faunistical studies

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*) The following is a somewhat shortened version of the original manuscript submitted by R. C. Miró; the changes were jointly carried out and approved by Prof. H. Wieseneder and Prof. H. Küpper, Vienna, September 1970.

carried out since more than hundred years (d'ORBIGNY, 1846; HOERNES, 1851; SUESS E., 1860).

The interpretation of the depositional environments and the paleogeographical distribution is also generally well known specially due to the numerous boreholes drilled for the purpose of oil exploration (more than 1700 boreholes in the Vienna basin alone). Regarding detailed petrographical studies, interesting results were obtained by WIESENEDER & MAURER (1958) in their study of the heavy mineral suites and their variations across the stratigraphical column in the Vienna basin.

The present study is of the heavy mineral suites of the Burdigalian and Helvetian sediments within the Molasse basin in Lower Austria. Samples were obtained from different boreholes in the area, drilled in the flat-lying Molasse.

2. Stratigraphy

The Tertiary formations in the regions studied are well known stratigraphically through the study of the outcrops and numerous boreholes. PAPP and others (1968) have summarized the stratigraphical classification

Table 1. Molasse Basin (North of the Danube) *).

Unit		Stage	Maximum thickness
2nd. Miocene Cycle	Local development in Hollabrunn and Langenlois	Sarmatian	70 m. Altenmark 1
	Grund Beds (Lower Lagenidian Zone)	Tortonian	100 m. Altenmarkt 1 130 m. Wildendürnbach 1
	Laa Formation	Upper Helvetian	730 m. Porrau 2 755 m. Wildendürnbach 4
1st. Miocene Cycle	Oncophora Beds	Lower Helvetian	290 m. Wildendürnbach 4 Wulzeshofen 2
	— — — — ? — — — —	— — — — ? — — — —	
	Eggenburg Formation	Burdigalian	580 m. Wildendürnbach 4
	Melk Formation	Aquitanian Chattian	

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*) For a comparison of older terms with the modern ones see A. PAPP et al. (1968).

of the Tertiary rocks. As it is pointed in this paper some difficulties arise in the location of the stratigraphical limits of the different rock units, because previous workers have not made a clear distinction between rockstratigraphic and biostratigraphic units (PAPP et al., 1968; pp. 25—26). It is beyond the scope of this paper to discuss the merits of the different stratigraphic classifications, here the Papp-classification is used (see Table 1).

3. Petrography

For the purpose of a detailed petrographical study samples were taken from six main wildcats. The location of these boreholes and their general stratigraphic limits are given fig. 1, see also BRIX & GÖTZINGER (1964), GRILL (1968). Samples were taken from the basal, middle, and top parts of each formation or unit.

Grain size analyses and heavy mineral-separation and -analyses were done after the conventional methods, KRUMBEIN & PETTIJOHN (1938).

As many as 20 different heavy mineral species were found. This number does not include the varieties of each mineral species. The opaque minerals were considered as a group for the purpose of counting, and some references are given about the individual species. The presence of chlorite group minerals and biotite was noted although they were not counted. Only 11 of the species are preponderant and their variations characterize the different mineral suites of the unit.

Table 2 shows the percentages by number distribution of all the heavy minerals of each sampled section.

The light mineral fraction represents more than 90% in weight of nearly all the samples. Therefore its importance in the sedimentary history of the units is evident. Fast counting showed no large variation of the components in the different samples throughout the stratigraphic column. For this reason the individual species are described and only a qualitative reference is made to their relative abundance, but the idea that interesting results could be found from its quantitative analysis is not disregarded.

4. Mineralogy

The description of the more common heavy minerals follows below. The relative abundance of the minerals is expressed in the scale given by EVANS, HAYMAN & MAJEED (1933).

Biotite is abundant and sometimes concentrated in the finer fractions. It occurs usually as basal flakes with irregular outlines with pale-brown to dark reddish-brown colour. Gas inclusions in biotite are very common, also in opaque material (Pl. 3, fig. 3). The major part of this mineral goes always with the heavy fraction. The iron-rich varieties are probably the most usual. In the Laa Formation biotite grains are very common, in the Oncophora Beds and the Eggenburg Formation there are but fairly common. Biotite appears also in samples from the Flysch (WOLETZ, 1951), it is present in the Helvetian and Pannonian, but is nearly absent in the Tortonian and Sarmatian of the Vienna basin (WIESENEDER & MAURER, 1958).

Chlorite is common to very common in the Laa Formation even in the clay fraction, and has with this a direct relationship. In the Oncophora Beds and the Eggenburg Formation sediments chlorite is fairly common. It occurs as pale-green to dirty yellow-green basal flakes with irregular forms. Its possible derivation as a diagenetic alteration product of biotite is here not indicated, because no transition stage was found in any of the grains; the grain-size distribution of chlorite points more to a clastic origin. It is more likely these are alteration products "in situ". The same idea has been expressed by WIESENEDER & MAURER (1958) for the chlorite present in the sediments of the Vienna basin.

Chloritoid is a fairly abundant mineral with a regular distribution in all the samples. The grains are lacking of inclusions but have usually cracks (Pl. 2, fig. 6, 7, 8, 9). Most of the chloritoid occurs as angular flakes with white-bluish to deep blue colours. Pleochroism of the grains is generally faint. Chloritoid is also mentioned by WIESENEDER & MAURER (1958) as a frequent mineral of Tortonian and Sarmatian sediments of the Vienna basin.

Clinozoisite is a fairly common to rare mineral component of the Laa Formation but a common component of the Oncophora Beds and the Eggenburg Formation sediments. It appears generally as colourless, elongate, euhedral crystals with anomalous bluish interference colours (Pl. 2, fig. 1, 3, 4). Clinozoisite has not a constant relationship in its content with that of epidote. In the samples of the Laa Formation the relation between both minerals varies from 6 : 1 to 4 : 1. In the samples of the Oncophora Beds and the Eggenburg Formation the ratio between clinozoisite and epidote is always less than 2.5 : 1.

Epidote, an abundant mineral in all units, is present in the form of equidimensional to elongate subhedral grains with angular to subangular outlines (Pl. 2, fig. 2). Most of the grains have a pistaccio colour which is peculiar to the iron-rich variety (pistacite) and a weak pleochroism. Corrosion of epidote is very pronounced and usually gives to the grains "cockscomb" terminations. The distribution of the corrosion along the surface of the grains is nearly homogeneous. The abundance of epidote in the samples of the Helvetian and Burdigalian sediments of the Molasse strongly contrasts with its rarity in the Vienna basin (WIESENEDER & MAURER, 1958). The importance of epidote together with those of the garnet and the opaque minerals is a common characteristic of the sediments of the Molasse basin (BRIX, 1960; JANIK, 1967).

Table 2.

			100% heavy minerals		100% non opaque heavy minerals														
Borehole	Units	sample number	opaque minerals	non-opaque minerals	garnet	epidote	clino-zoisite	chloritoid	green hornblende	staurolite	kyanite	rutile	tourmaline	zircon	titanite	monazite	apatite	percentage total heavy minerals	grains counted
Laa a. d. Thaya (type locality)	Laa Formation	21	28.5	71.5	66.4	9.6	3.5	8.5	1.2	1.8	0.5	4.0	2.2	1.7	×	—	0.8	3.6	386
		20	32.9	67.1	71.0	8.2	2.5	6.7	0.9	1.5	×	3.2	2.7	1.3	×	—	1.2	3.7	350
Altenmark 1 162—788 m.		19	27.6	72.4	74.4	7.5	2.1	6.9	0.7	0.8	0.7	4.0	1.5	0.7	×	×	0.4	3.2	412
		18	24.1	75.9	76.1	6.2	1.7	5.3	0.4	0.4	1.2	2.8	0.9	0.4	0.3	0.3	0.4	2.7	388
		17	22.2	77.8	78.5	8.6	1.6	4.5	0.3	0.4	0.9	3.2	1.0	0.4	0.4	0.4	0.4	3.6	325
Wulzeshofen 2 0—766 m.		16	23.5	76.5	85.2	5.1	1.9	3.1	0.5	0.4	0.4	3.6	0.6	0.4	—	0.4	0.4	3.7	325
		15	20.1	79.9	85.9	4.4	1.3	2.6	0.4	0.3	0.3	3.1	0.7	0.3	—	0.5	1.1	3.1	376
Porrau 1 660—1059 m.	Oncophora Bs.	14	19.6	80.4	78.2	7.5	3.8	4.1	0.6	1.6	—	2.2	0.9	0.6	—	×	×	3.6	416
		13	19.3	80.7	78.5	7.5	4.1	3.7	0.6	1.3	—	2.0	1.0	0.8	—	×	×	3.9	434
Altenmarkt 1 788—1070 m.		12	21.8	78.2	67.2	12.4	3.5	7.0	0.3	0.3	—	6.0	1.7	1.2	×	—	0.6	3.5	382
		11	24.0	76.0	65.0	13.8	3.9	6.8	×	×	—	6.7	1.6	1.0	×	×	0.5	4.2	390
		10	22.3	77.7	68.2	10.5	3.8	7.1	×	×	×	6.3	1.9	1.0	—	—	0.5	3.7	385
Porrau 1 1059—1332 m.	Eggenburg Fn.	9	28.1	71.9	54.2	6.8	4.5	6.5	×	6.5	×	7.5	10.7	2.8	×	0.5	×	5.6	450
		8	28.5	71.5	53.5	8.7	3.9	5.8	0.5	7.1	×	7.3	8.8	2.5	0.5	0.5	×	6.2	462
Wildendürnbach 4 1045—1620 m.		7	38.1	61.9	54.5	8.2	2.5	5.9	1.2	3.4	×	8.9	7.2	5.6	0.6	1.1	0.4	7.1	425
		6	35.4	64.6	54.7	10.1	3.5	5.7	0.6	4.4	0.3	8.8	9.5	4.9	0.3	0.6	0.4	6.5	422
		5	36.9	63.1	51.1	9.7	3.1	5.6	0.7	3.9	×	10.1	9.1	5.3	0.4	0.4	×	6.6	419
Porrau 2 1113—1421 m.		4	36.5	63.5	58.1	6.7	2.1	5.2	×	5.5	0.6	6.3	8.7	4.3	0.6	0.7	1.2	4.0	310
		3	36.2	63.8	57.2	6.9	1.7	5.6	×	4.6	0.4	7.5	9.2	3.9	0.4	0.4	1.4	4.4	307
Herzogbirbaum 1 1840—1865 m.	Glauconite Sd.	2	35.1	64.9	67.1	5.4	2.1	4.0	×	2.1	×	6.5	7.7	2.8	—	0.8	0.8	3.1	416
		1	34.7	65.3	66.5	5.8	1.7	3.5	×	2.5	×	7.3	6.5	3.1	×	0.8	1.0	2.9	441

× = One exemplar.

Garnet is the most abundant mineral of all the samples investigated. The maximum content is found in the Laa Formation, where garnet attains between 70 to 85% of the heavy minerals. Some lower content was observed in the Eggenburg Formation, about 54% of the heavy mainerals. The most abundant variety of garnet is a reddish-pink almandine. The presence of smaller amounts of pyrope was distinguished also from the X-ray data.

Garnet occurs in the form of angular inequal grains and, in minor amounts, as equal dodecahedral grains. The corrosion of garnet is strong, but shows differences in its intensity along the units, generally in relation with variations in the grain size of the sediments (Pl. 1, fig. 1, 2). The surface etching of the grains has the form of a mosaic with nearly regular edges (Pl. 1, Fig. 5). There were observed grains with numerous and regular conchoidal depressions, generally taken as percusion marks (Pl. 1, fig. 3). The inclusions in garnet are sphene, zircon, apatite. They are in some of the grains very abundant (Pl. 1, fig. 4, 6).

The abundance of garnet is a common characteristic of nearly all the Tertiary sediments of Lower Austria (WOLETZ, 1954; WIESENEDER & MAURER, 1958; BRIX, 1960; JANIK, 1967).

Rutile is a very common mineral in the samples of the Eggenburg Formation, but fairly common in the Oncophora Beds and in the Laa Formation. Two colour varieties were observed: golden-yellow and reddish-brown. The reddish-brown variety is weakly pleochroic. The grains are elongate subhedral with sub-angular to sub-rounded ends (Pl. 4, fig. 7); twinned crystals were also observed.

Rutile is present in higher amounts in the Vienna basin (WIESENEDER & MAURER, 1958) and in the Flysch sediments (WOLETZ, 1954).

Tourmaline is rare in the Laa Formation and Oncophora Beds, but common in sediments of the Eggenburg Formation. Three colour varieties of this mineral were distinguished: dark brown, blue and pink, all with strong pleochroism. Tourmaline grains are subhedral with well-rounded ends; spherical grains were observed in samples of the Eggenburg Formation. Inclusions of gas and liquid and, in few grains, of opaque material are common in tourmaline grains (Pl. 4, fig. 4, 5, 6).

Zircon is rare in samples of the Laa Formation and Oncophora Beds. In the Eggenburg Formation it is fairly common. The grains are prismatical euhedral with well rounded edges. Some spherical grains were also observed (Pl. 4, fig. 1, 2, 3). Zircon is generally colourless and contains few acicular inclusions.

Other heavy minerals were observed in the Tertiary sediments; they are scarce to rare and are listed below with some remarks.

Apathite occurs in euhedral prisms with rounded to sub-rounded ends. Some acicular grains were observed. The grains are relatively fresh and are carying from colourless to very pale blue (Pl. 2, fig. 5).

Barite is a fairly common mineral in the sediments of the Laa Formation, but rare in the Oncophara Beds and the Eggenburg Formation. It appears in grains of rhombic shape, its colour is varying from colourless to light blue (Pl. 4, fig. 8).

Green Hornblende is a rare mineral in all samples. The grains are green to pale green and elongate or irregularly shaped, having strong corroded ends (Pl. 1, fig. 7, 8, 9).

Kyanite is rare in samples of the Laa Formation and the Eggenburg Formation; it is absent in sediments of the Oncophora Beds; it occurs as elongate grains with marked rectangular outlines and common inclusions of opaque material (Pl. 3, fig. 4, 5, 6).

Monazite is rare to absent in all samples. However, a concentration of this mineral was found in the lower levels of the Eggenburg Formation. It appears as well-rounded grains with a reddish-brown colour.

Sphene is generally rare to absent, but it appears, as monazite does, in small concentrations in the Eggenburg Formation. The sphene grains are angular and contain abundant inclusions. In all the samples a pale yellow colour variety was most commonly observed.

Staurolite is a rare mineral in the samples of the Laa Formation and common in the Eggenburg Formation. The grains show faint pleochroism, varying from nearly colourless to yellow, with a common platy form and irregular outlines. The inclusions in staurolite are numerous and give a porous appearance to the grains.

The whole group of opaque minerals in the samples of the Laa Formation varies from 20 to 32%. In the Oncophora Beds the opaque minerals seldom attain more than 20%, and in the Eggenburg Formation the content varies between 35 to 38%. Three species were recognized: ilmenite, magnetite, and pyrite. For the purpose of the counting these species are considered as one group.

The most abundant of the opaque minerals is a black to darkish-gray ilmenite. The grains are not fresh and usually show conchoidal fractures. Magnetite appears also in abundant proportions as octahedral grains with rounded edges. Pyrite is fairly common in the finer fractions as dusty aggregates, usually associated with hematite.

The opaque minerals are abundant in all the Tertiary sediments of the Molasse basin. In the Lower-Helvetian sediments of the borehole Moosbierbaum 2 the opaque minerals form about 50% of the heavy minerals (Brix, 1960).

The light minerals are listed below in decreasing order of abundance.

Quartz is abundant in all samples in the form of angular to subangular grains with a dull surface. It is also present in the clay fraction. Quartz grains with undulatory extinction and anomalous biaxial figure are observed. Inclusions of zircon, graphite and apatite are common in most of the grains. Authigenic secondary enlargement of quartz was not observed.

Muscovite is abundant in the samples of the Laa Formation and Oncophora Beds; its grain size distribution in the sediments varies from the sand to the clay fraction. It appears as basal flakes with irregular outlines and frequent inclusions (Pl. 3, fig. 1, 2).

Calcite is a common to fairly abundant component of the sediments of the Laa Formation and of the upper part of the Oncophora Beds. In the Eggenburg Formation it is scarce to absent. It appears as angular to sub-angular grains, concentrated in the very fine sand and silt fraction.

Plagioclase is common to fairly abundant in all the Tertiary sediments and was observed in fresh or slightly to kaolinite alterated grains. With common zonal structure and multiple twinning, the most common of which is according to the albite law. By means of this twinning the composition of the plagioclase was recognized as acidic to intermediate (An 9—25). In the Laa Formation plagioclase is found associated with abundant small inclusions of microlites of sericite and clinozoisite. This inclusions are not taken as alteration products but as indication of retrograde metamorphism "in situ" of the alpine rocks (WIESENEDER, oral communication).

Microcline and orthoclase are rare to fairly common in all the samples in the form of flat grains with sub-angular outlines; the grains were observed fresh and twinned.

Glauconite was observed only in the Eggenburg Formation, particularly concentrated at lower levels, forming glauconite-rich sandstones. The grains are rounded with ovoid or polylobate forms, resembling foraminiferal crusts, and their dull surface is cracked. The authigenic origin of glauconite in the Tertiary sediments has not been completely proved. The derivation of this mineral could be expected from the underlying glauconite bearing sediments of the Cretaceous underground (BRIX & GÖTZINGER, 1963).

Some rock fragments, dominantly of sedimentary origin, as f. i. those of quartzites and siltstones, were specially observed.

$CaCO_3$ determinations have been made on different samples in order to find out its cement content. The uppermost lutitic Laa Formation and the Oncophora Beds are the most calcareous, and among these, very specially the samples of the type locality Laa a. d. Thaya. On the other hand, the Eggenburg Formation has a very small carbonate content. These results do well correlate with major induration and higher amount of limestone fragments in the clastic fraction in the upper units, and major friability in rocks from the Eggenburg Formation, with the exception of the well indurated Glauconite Sandstone.

The values are lower than those found by JANIK (1967) in samples of the Burdigalian "Schlier" of Linz (Upper Austria) and are similar to the lime content of the nearby Flysch rocks (NIEDERMAYR, 1966). The marly levels of the different units are not higher than 40% in carbonate content.

Table 3.

	Sample No	% $CaCO_3$		
(type loc.)	21	23.65	19.4	
Laa	19	9.9		
Formation	18	9.11	9.5	
	15	11.1		
Oncophora	13	5.78		
Beds	10	12.4		
Eggenburg	8	1.31	1.22	
Formation	6	8.04		
Glauconite	4	1.94	0.64	0.82
Sandstone	1	2.16		

The percentages are expressed in weight of $CaCO_3$.

5. Mineral Content of The Samples

The mineralogical composition of the Burdigalian and Helvetian samples of the flat-lying Molasse consists predominantly of quartz and feldspar. The quartz-feldspar relation is close to one in most cases, but rarely higher; the characteristics of the mineralogical species have already been mentioned, but we would again point out the predominance of the acidic to intermediate plagioclase among the feldspars, and the abundant occurrence of sericitic microlites (retrograde metamorphism). The biotite and muscovite content is equally high. This association of the light minerals, essentially arkosic, does not directly correspond to the association of heavy minerals, where a predominance of the metamorphic elements is observed. The heavy minerals do not represent more than 7% of the total weight in the analysed sandy samples. They have a high content of garnet and opaque minerals and a regular abundance of the alpine metamorphic minerals. The almandine is the predominant garnet species. The so called alpine metamorphic minerals consist of epidote, clinozoisite, green hornblende and chloritoid, which correspond to a varied range of metamorphic rocks of the Alps. Staurolite and kyanite are particularly scarce in the observed Helvetian sections. The so called more stable mineral group (zircon, rutile, tourmaline, monazite) appear in a scarce proportion and their textural characteristics generally show a grade of maturity between medium and advanced. The light fraction possesses a moderate to regular alteration, but the heavy association shows the effects of a sharp alteration (epidote, hornblende) and of a strong etching (garnet). This strong alteration of the heavy minerals is considered post-depositional, that is, due to diagenetic processes.

WIESENEDER & MAURER (1958) consider, that the chemical attack by means of salty waters might be so strong, as to provoke changes of the original proportions of the minerals in the Vienna basin (pg. 1169). In our case the sediments of the outcrops of the Laa Formation have been compared with corresponding Altenmarkt 1 and Wulzeshofen 1 boreholes. The differences observed do not correspond here to natural variations according to the relative solubility of the mineral species; therefore they may be attributed to factors of provenance or predepositional selection.

The analysed Burdigalian and Helvetian sediments have been compared by means of their heavy minerals to those belonging to adjacent basins.

The comparison with sediments of other areas of the Molasse is interesting; JANIK (1967) describes the Miocene of Linz with a mineralogy of the heavy minerals, which shows a marked similarity in its composition and proportions with that described by us. The same is the case with the mineralogical content of the Burdigalian sediments crossed by drillings in the Tulln basin (BRIX, 1960). The above examples do have a high content of garnet and a regular abundance of epidote, clinozoisite, hornblende and chloritoid. The Burdigalian and Helvetian sediments of the Vienna basin show a garnet-staurolite association (WIESENEDER & MAURER, 1958). Epidote and hornblende appears here in scarce proportions. This might be due to two reasons

a) post-depositional alteration, already mentioned;

b) delution in the mineral complex due to a higher proportion of staurolite and some stable minerals (zircon, tourmaline).

It is worthy of notice that the association garnet-epidote-hornblende is important in the outcroping sediments of the Burdigalian and Helvetian, and also in all the sediments of the Pannonian of the Vienna basin.

For the purpose of a further discussion of the origin, the data prepared by WOLETZ (1951) regarding the Flysch, have been included. The Cretaceous sediments of the Flysch have an equally rich association in garnet, but the stable minerals appear to be sometimes predominant over the alpine metamorphic minerals. The Eocene Flysch consists of, as far as translucent heavy minerals are concerned, almost exclusively zircon (over 65%), tourmaline, rutile and apatite, strongly contrasting with the Tertiary sediments of the Molasse.

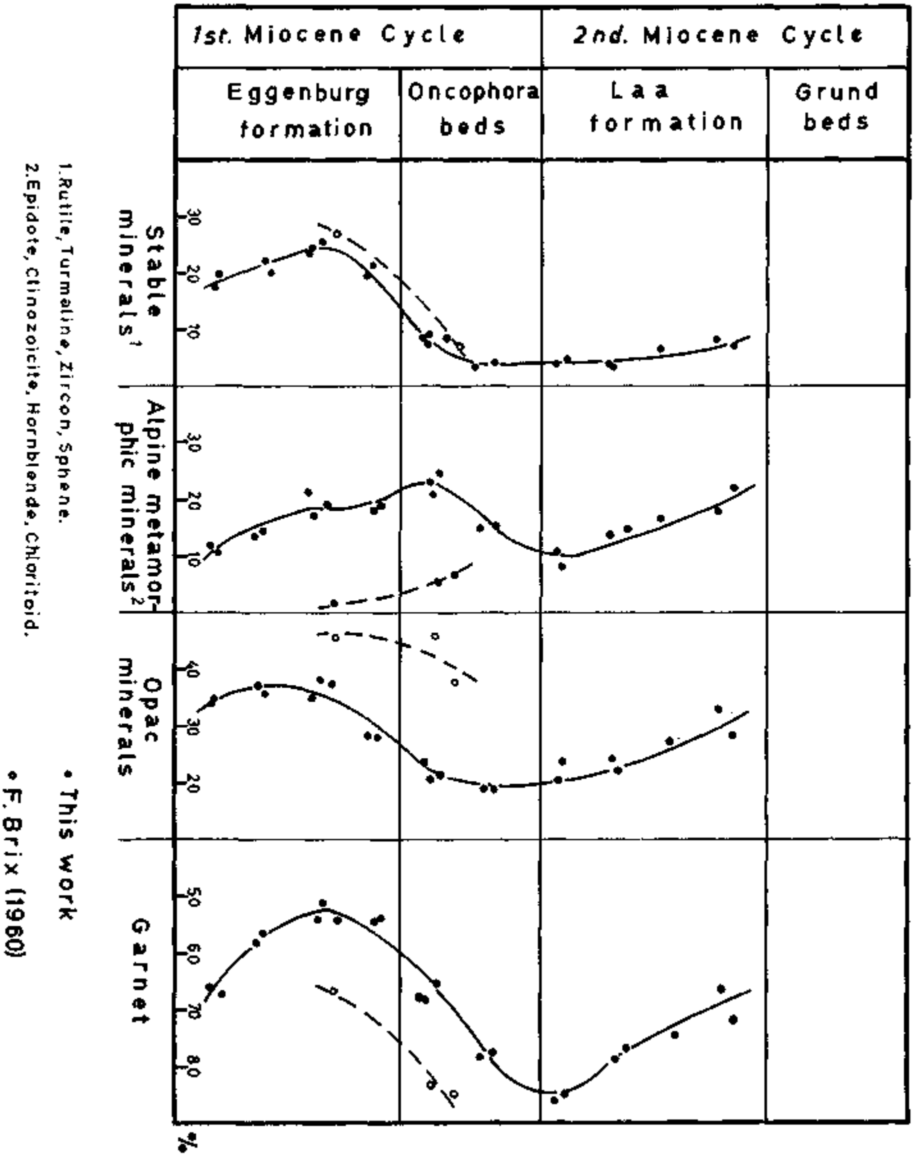
Therefore it can be assumed as a result of our studies, that the "Burdigalian" and "Helvetian" sediments of the northern Molasse zone are different from those of the Vienna basin of the same age on account of their heavy mineral content.

6. Variations Throughout The Stratigraphic Column

The comparison of the differences and similarities in the quantitative analysis of the mineral species leads to the following conclusions concerning the factors, that may influence these variations. For this purpose there have been included in a diagram (Fig. 2) the proportions of the four groups, into which the heavy minerals have been separated. The value of the different unit levels have been placed vertically, keeping an approximate equidistance. In order to point out the homogenity of the "undulations" in the variations of the components, the scale of the garnet rates has been invertedly placed.

In the Eggenburg Formation the heavy minerals represent between 4 to 7,1% of the total of the sand fraction. In the lower levels the pro-

fig. 2



1. Rutile, Turmaline, Zircon, Sphene.
2. Epidote, Clinozoicite, Hornblende, Chloritoid.

portion of the glauconite beds is not higher than 2,5%. As mentioned above, glauconite represents up to 40% and not less than 25% of the sand fraction. As an "a priori" estimate about the cause for the decrease of the rates of the heavy minerals in these levels, we think that in general it is accepted, that in environments of glauconite deposition the rate of sedimentation is slow and the sediments associated with the glauconite are characteristically mature (quartz-arenites, TRIPLEHORN, 1966).

In our case the mineralogical association of the heavy minerals garnet-rutile-tourmaline, would correspond with what is expected in mature sediments. This association rapidly changes towards the upper levels of the Eggenburg Formation, and here an increase of the alpine metamorphic minerals is observed.

In the medium levels of the Eggenburg Formation the association is garnet-epidote-rutile-tourmaline. Among the stable minerals, rutile as well as tourmaline are clearly predominant; both minerals appear in many varied mineralogical species and forms.

The opaque minerals, mainly formed by ilmenite, do not show variations in the different levels of the Eggenburg Formation. The content of staurolite increases progressively towards the upper levels of the formation, producing in its upper part, investigated in the borehole Porrau 1, a garnet-epidote-staurolite-rutile-tourmaline association.

The unconformity, which separates the Eggenburg Formation from the Oncophora Beds corresponds to a marked change in the relative proportions of the heavy minerals. We observed an inversion in the relative abundance of the stable minerals regarding the alpine metamorphic minerals. In the Oncophora Beds the latter represent 25% of the non-opaque heavy minerals, whereas the stable minerals do not exceed 8%. Another variation is the disappearance or rather scarcity of staurolite and kyanite. The opaque minerals diminish their proportions but are equally frequent and garnet is somewhat more abundant. These characteristics do not vary much through the Oncophora Beds, but at the top of the unit it is possible to observe a decrease of the proportions of the alpine metamorphic minerals, perhaps on account of an increase in the garnet proportions. Therefore the sediments of the Tulln basin show a decrease in the content of the stable and opaque minerals, and an increase of the garnet and the alpine metamorphic minerals through uninterrupted by the unconformity between the Eggenburg Formation and the Oncophora Beds. These trends are similar to those described in the sediments of the northern Molasse. Unfortunately the Brix data do not extend as far as to Upper Helvetian levels of the Laa Formation.

The alpine metamorphic minerals as well as the opaque minerals increase once again in their proportions above the contact between the Oncophora Beds and the Laa Formation. Garnet diminishes its relative proportions towards the youngest levels of the Helvetian. The stable minerals practically keep invariably their proportion of less than 10%. The variations, or their starting points correspond again to the boundary between two units. The fact that these variations in the content of the heavy minerals of the Burdigalian and Helvetian sediments correspond with the limits among discordant units, might be considered with view to possible tectonic implications. In this case the variation of the mineral content would correspond to relative variations of the relief surrounding the basin. The possibility that these variations may correspond to processes of post-depositional alterations seem to be less probable. The stable minerals increase effectively towards the top of the units, but so do the alpine metamorphic minerals, which correspond to species of higher chemical instability.

Provenance

The heavy mineral associations found in the different levels are the following:

Laa Formation: Garnet-epidote-chloritoid-rutile.

Oncophora Beds: Garnet-epidote-chloritoid-rutile.

Eggenburg Fn.: Garnet-epidote-chloritoid-staurolite-rutile-tourmaline.

Glauconite Sd.: Garnet-epidote-rutile-tourmaline-zircon.

These heavy mineral associations accompany a light mineral association, mainly formed by quartz and plagioclase, predominantly acid in almost equal proportions and, in smaller quantities, by muscovite and potassic feldspar.

As a whole the mineralogical associations of the Burdigalian and Helvetian sediments might originate from various metamorphic and intermediate igneous rocks. The state of textural maturity of zircon and, in some cases , of rutile and tourmaline, might indicate, that part of the contribution might originate from sedimentary rocks.

The N and NW margins of the Molasse basin are formed by the Bohemian Massif. The massif is formed by high and low grade metamorphic rocks (Moravian and Moldanubian zones), intruded by plutonic masses of diverse composition. An analysis done by Slavik (1952) during investigations of river deposits of the central region of Bohemia shows, the most frequent mineralogical species, that result from the weathering of petrographic types, varying from biotite granites to granodiorites. According to his observations, zircon and titanite appear in variable proportions between 15% and 35%, and only in two cases they represent about 65% of the total of the heavy minerals. The opaque minerals do not exceed 11% in all the cases, being generally below 6%. Apatite is found in variable proportions between 47 and 74%; in contrary to the two cases mentioned, zircon and titanite are particularly abundant; in the same samples the rate of apatite is les than 30%. Hornblende is very scarce, although one sample is described with a 30% content. Biotite is equally very scarce in all the samples (less than 0,5%). This low value in the biotite proportions would indicate, that the rates found should be considered with some reservation especially because some of the analyzed samples correspond to the product of weathering of biotite granites. It may be assumed that some samples have been collected in critical zones of differential sorting during transportation. The values found by SLAVIK (1952) as a result of weathering of the igneous masses of the Bohemian Massif would indicate that, at least partly, the arrangement of the stable minerals observed by us might have a similar origin. In this connection the scarce content of apatite, found in the sediments of the Molasse basin (Table 2) might be explained by the higher chemical instability of this mineral, as compared with other minerals.

As mentioned above the sediments of the Eocene Flysch are particularly enriched in zircon, rutile and tourmaline (WOLETZ, 1951). The fact that among the Burdigalian and Helvetian sediments of the Molasse there have been found thesesame minerals with characteristically mature textures, indicates, that Flysch constitutes a positive element adjacent to the basin, and that the products of its weathering might have been transported, at least partly, into it.

WIESENEDER in his very interesting study 1953 determined the principal possible origins of the different mineral associations present in the sediments of the Vienna basin. According to him the provenances could be grouped in two types: 1. alpine and 2. from granites. The sediments of alpine provenance have been subdivided, according to its mineralogical association in, 1 a) garnet-hornblende-epidote-staurolite-kyanite, or 1 b) garnet-hornblende-augite-epidote-zircon. The latter would correspond to the "Alpine province" but of high metamorphism. The association that might correspond to a granitic origin would be, zircon-tourmaline-apatite-biotite. It is evident that the sediments of the Molasse are of a very similar mineralogical association like those described by WIESENEDER (1953) as originated in the Alpine province. Taking into account that this association is predominant throughout the different analysed levels of the Molasse, it may be said, that alpine rocks were the main source of contributing material to the Molasse during its two Miocene sedimentary cycles. GRIMM (1957) has also recognized the mineralogical association epidote-clinozoisite-green hornblende-staurolite-kyanite in sediments of the Bavarian Molasse; he has considered it as originating from the same Alpine province.

Thus we might conclude, that the sediments of the Burdigalian and Helvetian of the northern Molasse basin might have originated as a result of the weathering of the high and low grade metamorphic rocks of the Alps; furthermore, they might have received considerably less contribution from the plutonic rocks of the Bohemian Massif and of the pre-existing sediments of the Flysch. In this connection the scarcity of apatite must be emphasized; for the rocks contributing do have a high content of this mineral and the apatite content found in the sediments of the Molasse basin is very low.

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fig. 1

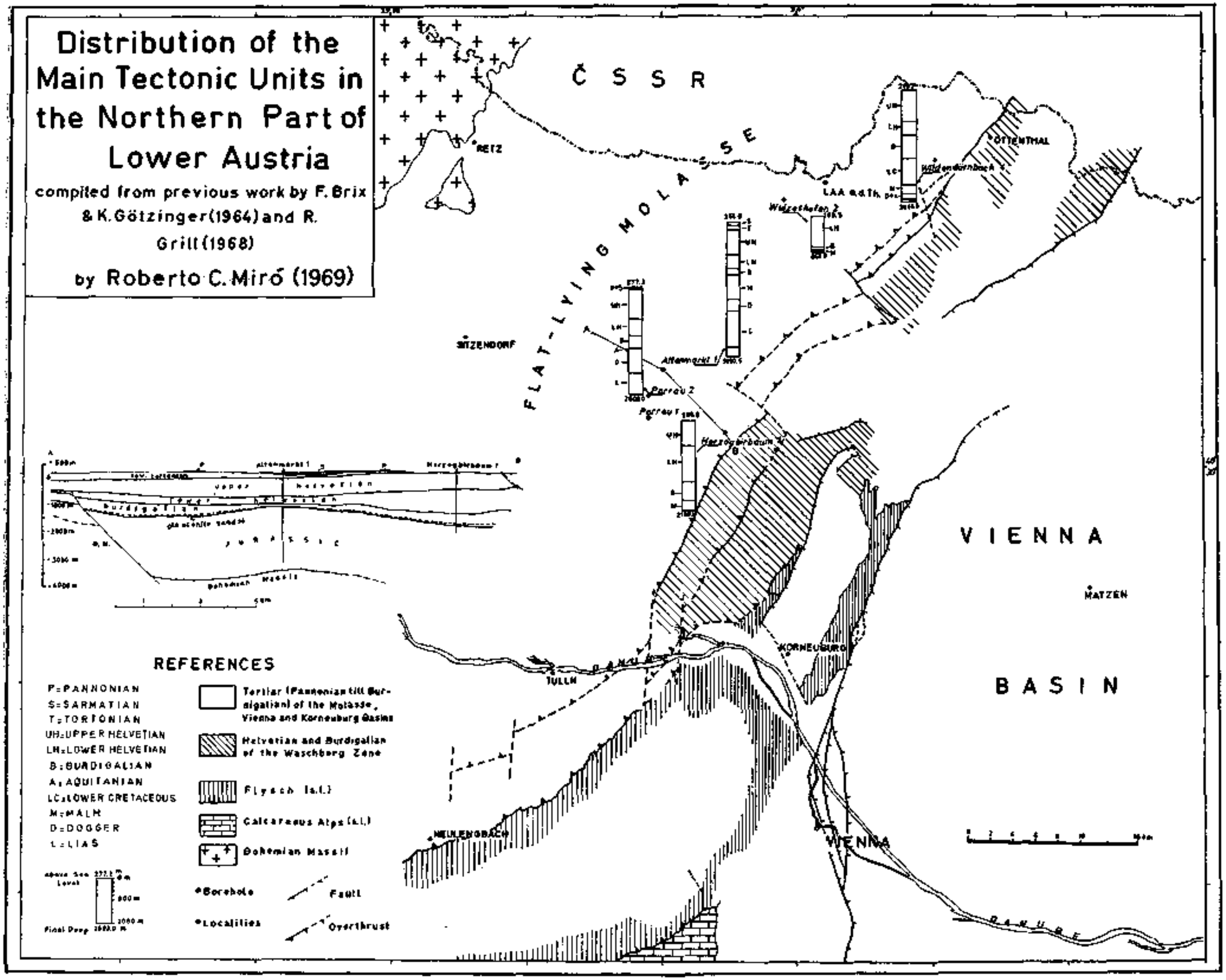

Distribution of the Main Tectonic Units in the Northern Part of Lower Austria
compiled from previous work by F. Brix & K. Götzinger (1964) and R. Grill (1968)
by Roberto C. Miró (1969)
ČSSR
FLAT-LYING MOLASSE
VIENNA BASIN
RETZ
SITZENDORF
LAA a.d.Th.
OTTENTHAL
Wildendürnbach
Wulzeshofen 2
Altenmarkt 1
Porrau 2
Porrau 1
Herzogbirbaum 1
A
B
TULLN
DANUBE
KORNEUBURG
MATZEN
NEULENGBACH
VIENNA
UH
LH
B
M
D
L
upper helvetian
lower helvetian
burdigalian
glauconitic sands
jurassic
bohemian massif
B.M.
+500m
-1000m
-2000m
-3000m
-4000m
5km
REFERENCES
P=PANNONIAN
S=SARMATIAN
T=TORTONIAN
UH=UPPER HELVETIAN
LH=LOWER HELVETIAN
B=BURDIGALIAN
A=AQUITANIAN
LC=LOWER CRETACEOUS
M=MALM
D=DOGGER
L=LIAS
Tertiar (Pannonian till Burdigalian) of the Molasse, Vienna and Korneuburg Basins
Helvetian and Burdigalian of the Waschberg Zone
Flysch (s.l.)
Calcareous Alps (s.l.)
Bohemian Massif
Borehole
Localities
Fault
Overthrust
Above Sea Level
277.1 m
0 m
1000 m
2000 m
Final Deep 2668.0 m

PLATE I

Figure 1, 2, 3, 4. Garnet. Laa Formation
5, 6. Garnet. *Oncophora* Beds
7, 8, 9. Hornblende. Laa Formation

PLATE II

Figure 1, 3, 4. Clinozoisite. Laa Formation
2. Epidote. Eggenburg Formation
5. Apatite. Eggenburg Formation
6, 7, 8, 9. Chloritoid. Laa Formation

PLATE III

Figure 1, 2, 3. Mica with sphene and opaque inclusions. Laa Formation
4, 5, 6. Kyanite. Laa Formation

PLATE IV

Figure 1, 2, 3. Zircon. Eggenburg Formation
4, 5, 6. Tourmaline. Eggenburg Formation
7. Rutile. Laa Formation
8. Barite. Laa Formation

PLATE 1


1


2


3


4


5


6

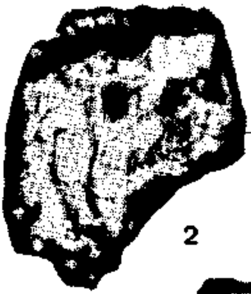
60 μ


7


8


9

1



2

3

4

5

60 μ

6

7

8

9

PLATE 3

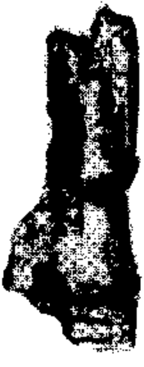
1

2

3

60 μ

4



5

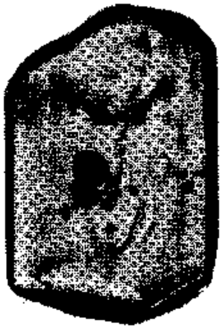
6

PLATE 4

1

2

3



4

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60 μ

Contribution to the Study of the Nöhagen Metadiorites

By Luiz Fernando Scheibe & Nizar Jaferali Maherali *)

1. Introduction

While mapping the area West of Hohenstein, the authors studied the northern part of a body of dioritic composition, described by F. Becke (1882, cit. Waldmann, 1963) as the "Körnigflaserig Dioritschiefer von Nöhagen". In this paper particular emphasis was put on the petrographic study of these rocks. This paper is a shortened text form of our final Unesco-course report which is equipped with figures and one geological map.

2. Location and Access

The Nöhagen Metadiorites occur near Nöhagen, in the Mautern Quadrangle, Lower Austria. The approximate geographical coordinates of the area are 15° 26′ E. W. and 48° 28′ N. The area is easily accessible by road and lies about 20 km NW of Krems.

3. General Geology

The area belongs to the Moldanubian Zone of the Bohemian Massive in Austria. The main geological units are coarse grained biotite-plagioclase-sillimanite gneisses; fine-grained biotite-plagioclase gneisses; amphibolites; calc-silicate rocks; pyroxene-plagioclase gneisses; marbles; and the metadiorites. These rocks are intensely folded, with dominance of NE directions. Ptygmatic folds as evidence of migmatization are common.

4. The Metadiorites

4.1. Occurrence

The part of the body which was studied occurs in Nöhagen and surroundings, and has an irregular shape which protrudes towards the NE, in the direction of the course of the River Krems. Best exposures are in the escarps of the valley of this river, but outcrops are common in top of the hills.

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Present adresses: L. F. Scheibe, Rua Joaquim Costa 37, Florianopolis (SC), Brasil, N. J. Maherali, P. O. Box 903, Dodoma, Tanzania.

The body is included in the coarse-grained biotite-plagioclase-sillimanite gneisses, and, near the contact with this rock, it occurs an intercalation of cordierite-garnet-biotite-plagioclase gneisses ("Kinzigites" described by WALDMANN, 1963, 1967), whose characteristics are discussed below.

4.2. Structure

The metadiorites show variations in the structure, from massive (in the coarse grained parts) to gneissose (in the fine and medium grained parts, towards the contacts). This fine-grained rock shows good orientation of the biotites and it was possible to trace some folding in it. The intercalated layers of cordierite-garnet-biotite-plagioclase gneisses show complex folding, with s-planes and fold axis whose attitude do not conform with the general trend of the area.

4.3. Petrography

The meta-diorites are dark green, sometimes spotted, with medium to very coarse grained texture, pegmatitic in places, also fine grained in others. The massive character of the rock makes a contrast with the gneisses of the area.

In thin section, plagioclase, hornblende and biotite are the dominant minerals, as shown in the following table:

Estimated modal composition of the Meta-diorites

	H-22	H-24	H-104	H-125	H-127	H-128	H-129
Plagioclase	40%	40%	50%	60%	20%	35%	55%
Hornblende	18%	40%	25%	10%	50%	50%	20%
Biotite	38%	15%	alter.	30%	15%	13%	20%
Quartz	tr.	3%	—	—	—	—	—
Sphene	tr.	tr.	2%	tr.	2%	tr.	tr.
Apatite	tr.	tr.	2%	tr.	3%	tr.	tr.
Zircon	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Opaque	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Microcline	—	—	—	—	10%	—	—
Epidote	2%	2%	tr.	tr.	tr.	2%	tr.
Chlorite	tr.	tr.	20%	tr.	tr.	tr.	tr.

Plagioclases were found (Universal Stage) to be of labradorite composition (55% An.), with normal zoning or with a "stained" feature, and complex twinning. In some samples, they are highly saussuritized.

Hornblende is pleochroic from light to dark green. Some samples contain relics of pyroxene, revealing that uralitization has taken place. The cleavage planes are sometimes accentuated by the deposition of opaque mineral, and sphene in rounded crystals is usually included.

Biotite is pleochroic from light yellow to reddish brown, and sometimes intergrown with the hornblende. Shows alteration to chlorite (penninite) with exsolution of sphene, and, in H-104, is completely altered. Other alteration products are epidote (weakly pleochroic from colourless to pale green, with high birrefringence, low extinction angle, length fast or length slow, and angle 2 V around 90°) and muscovite. Zircon as inclusions produces pleochroic halos.

Quartz was detected in one of the samples only (H-24), as some large fractured crystals. Microcline in large crystals occurs in the coarse grained diorite (H-127). Apatite occurs as an exsolution product and the opaque minerals show rectangular shape and alteration to limonite, beeing possibly pyrite.

5. The Cordierite-garnet-biotite-plagioclase Gneisses

These gneisses occur as layers in which the alignement of the garnets accentuates the banding. They include layers of seemingly amphibolitic composition, deformed giving "boudinage" features, as well as some carbonated layers. The garnet crystals are large and sometimes reach 6 cm in diameter. These cordierite-garnet-biotite-plagioclase gneisses are dark coloured, with a bluish tint.

In thin section these rocks show a cordierite content which ranges from 20%—40%. This mineral occurs in xenomorphic masses which include quartz, plagioclase, sphene and relics of biotite, an indication that the mineral is formed later than the others. Cordierite in places shows pseudohexagonal twinning and is partially altered especially along the cleavages and fractures to a yellowish mineral (faintly pleochroic, parallel extinction and 1st order interference colours — blue). Garnet occurs up to 20% and forms large porphyroblasts with oriented inclusions.

The quartz content amounts to 40% of the rock in one sample. Biotite is strongly pleochroic and is extensively altered to chlorite. The amount of andesine is reduced to 5%. Sillimanite, kyanite, apatite, graphite and zircon (inclusions with pleochroic halos in both biotite and cordierite) occur as accessory minerals.

6. Conclusions

The rocks of the area belong to the high temperature field of the amphibolite facies (SCHEIBE & MAHERALI, 1970), probably attained during the Variscian Orogeny. Possibly during this Orogeny occured the emplacement of the diorites. The syntectonic character of these rocks is evidenced by the orientation of the planar constituents in the contact zone of the body. The absence of orientation in its central parts, together with the lack of concordance of the structures indicate that the metadiorites did not suffer all the tectonic efforts which led to the formation of the gneisses of the area.

The formation of the cordierite-garnet-biotite-plagioclase gneisses, whose paragenesis is from the amphibolite-granulite transitional facies, could be related to a local temperature gradient due to the intrusion of the meta-diorites. However, a better study of these rocks is needed to make clear their origin and relationships.

The alteration of the biotites of the meta-diorites to chlorites, with exsolution of sphene, is one of the evidences of retrograde metamorphism which affected the crystalline rocks of the area, and which is possibly related to the Alpine Orogeny.

7. Acknowledgements

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