Heavy Mineral Content of Burdigalian and Helvetian Sediments of the Molasse Basin, Lower Austria

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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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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	

*) 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.

Borehole	Units	sample number	100% heavy minerals: opaque minerals	100% heavy minerals: non-opaque minerals	100% non opaque heavy 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.

G a r n e t 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).

R u t i l e 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).

T o u r m a l i n e 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).

Z i r c o n 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.

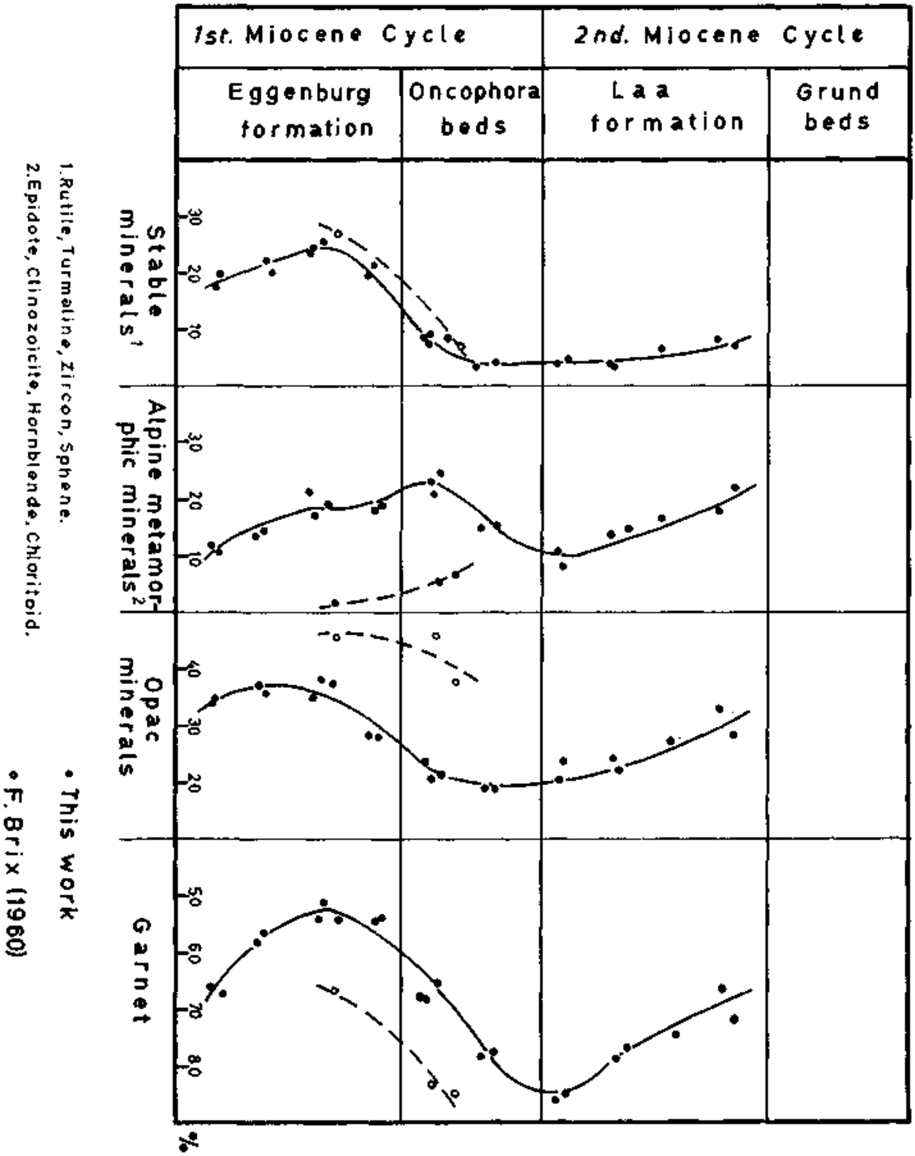
Therefore it can be assumed as a result of our studies, that the "Burdigalian" and "Helvetian" sediments of the northern Molasse zone are different from those of the Vienna basin of the same age on account of their heavy mineral content.

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



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

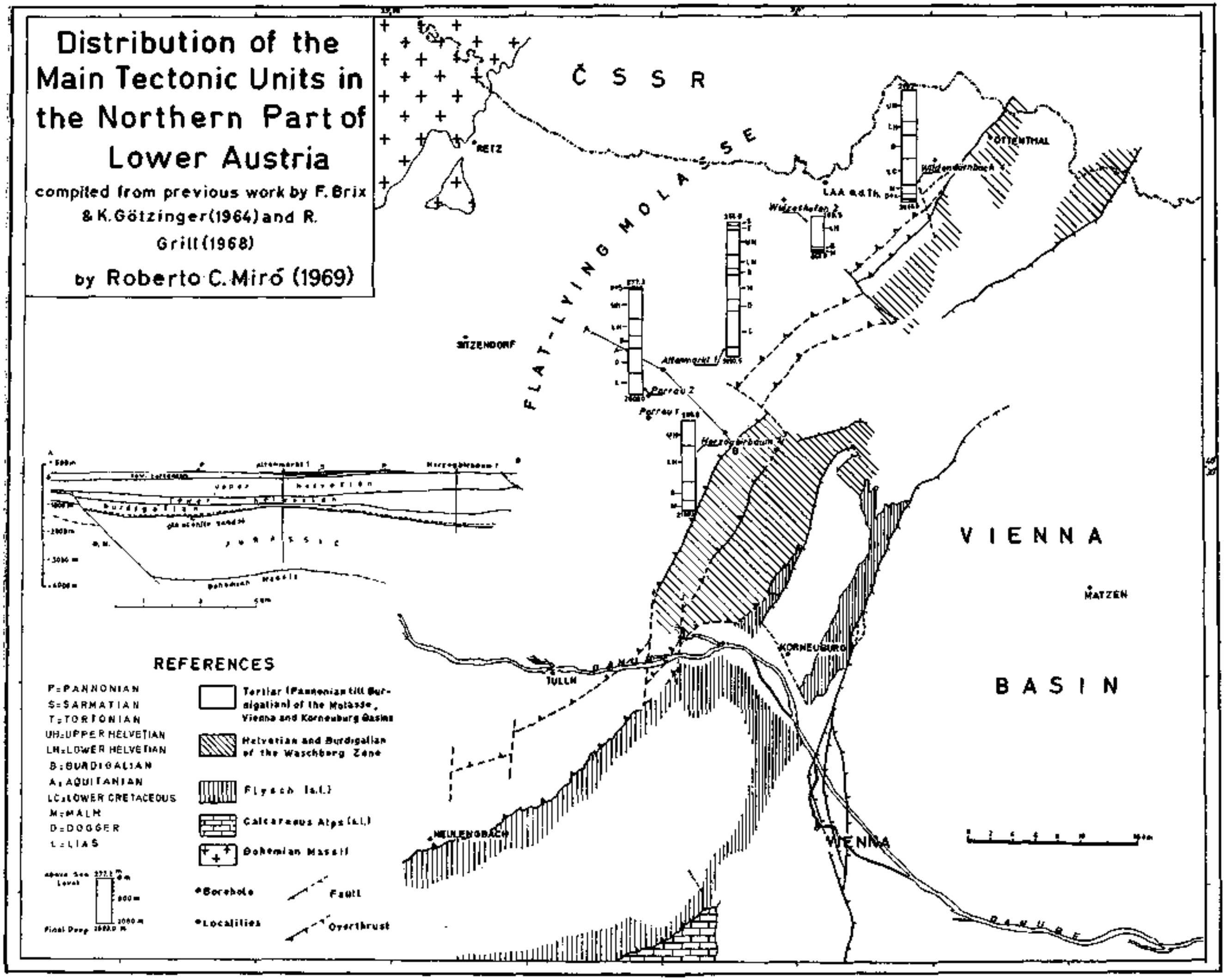
Distribution of the Main Tectonic Units in the Northern Part of Lower Austria
compiled from previous work by F. Brix & K. Götzinger (1964) and R. Grill (1968)
by Roberto C. Miró (1969)
Č S S R
FLAT-LYING MOLASSE
VIENNA BASIN
RETZ
SITZENDORF
OTTENTHAL
LAA a.d.Th.
MATZEN
KORNEUBURG
TULLN
NEULENGBACH
VIENNA
DANUBE
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
Final Deep
upper helvetian
lower helvetian
burdigalian
glauconitic sands
jurassic
bohemian massif

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

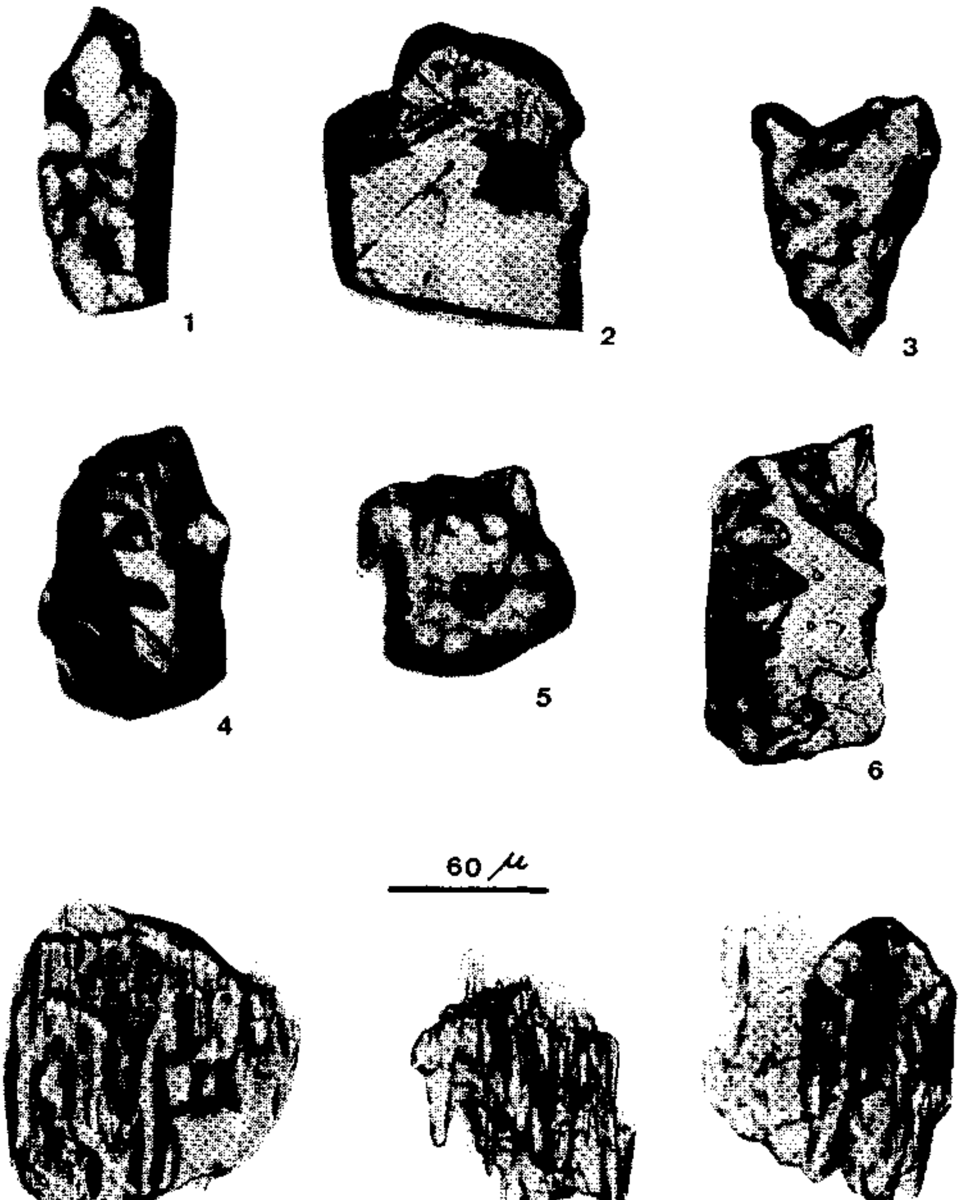

PLATE 2

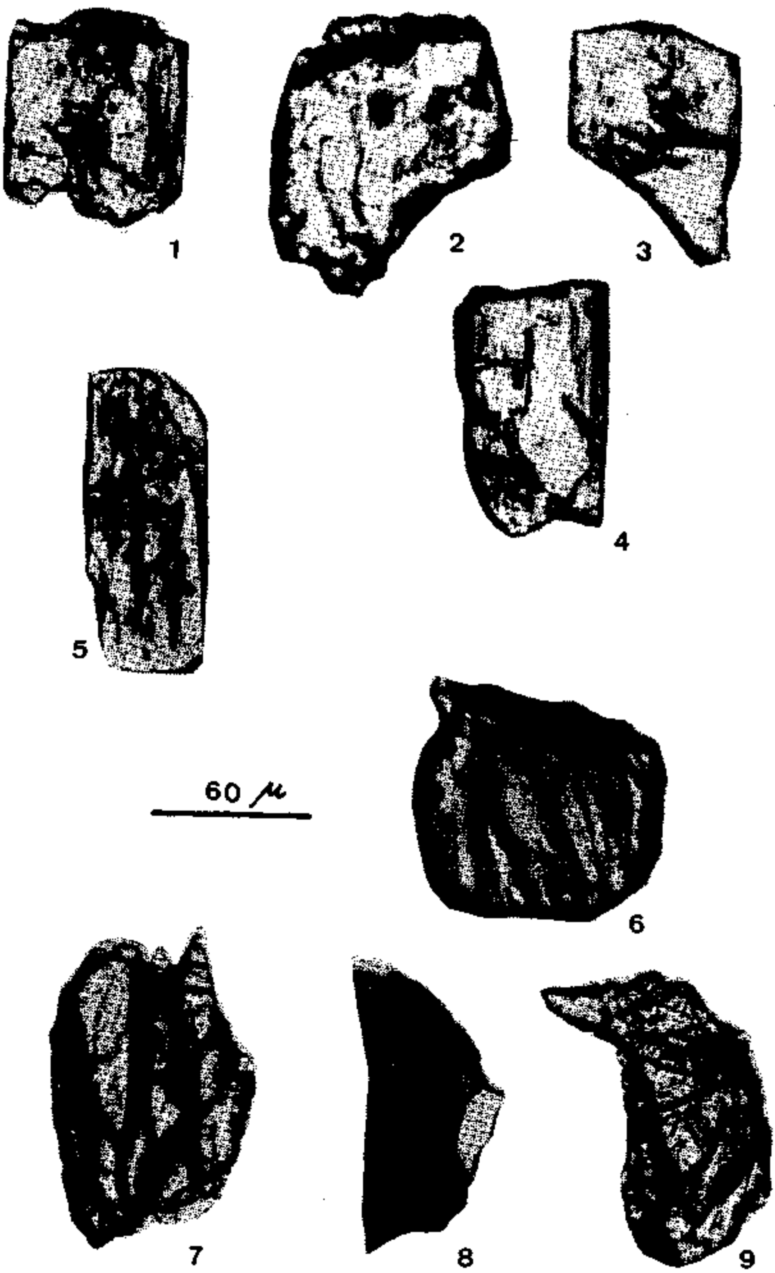

PLATE 3

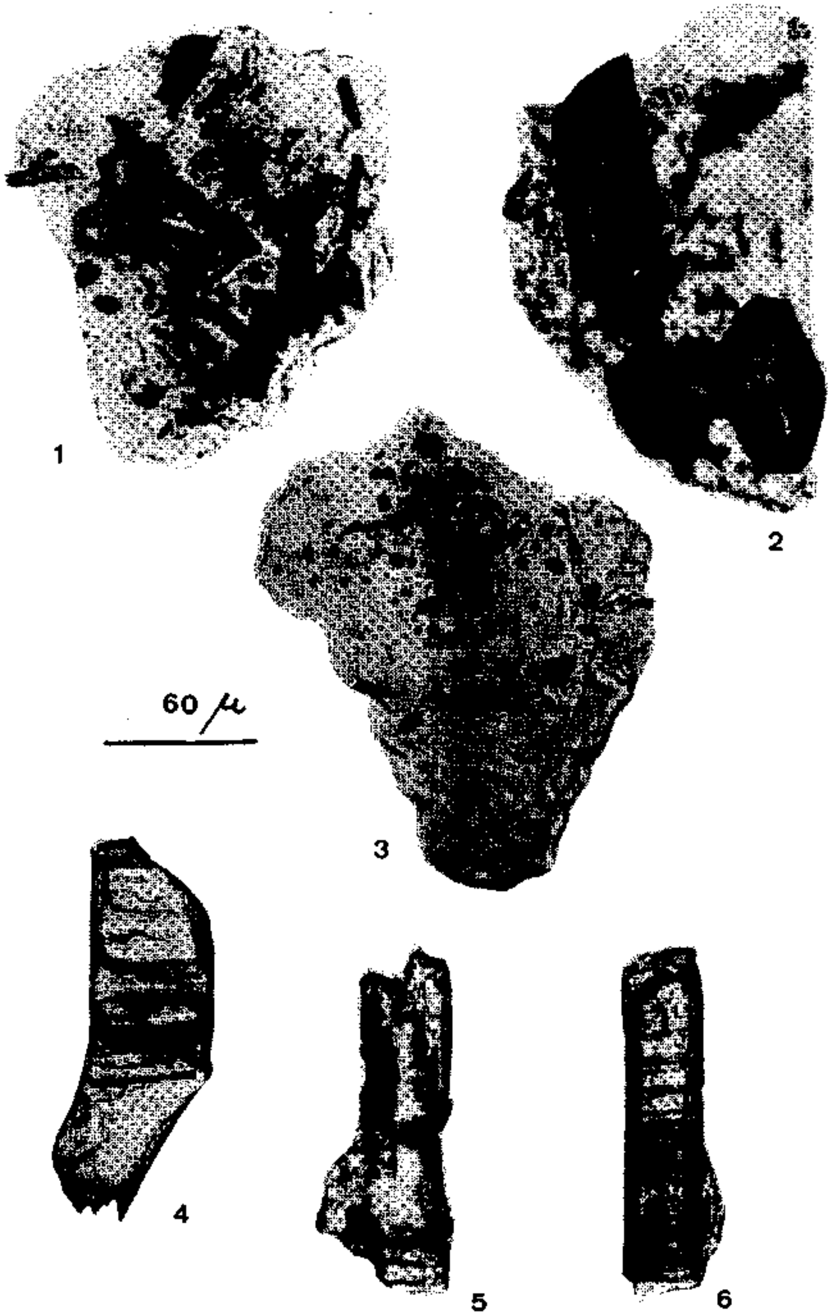

PLATE 4