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COMPOSITE GRAINS IN MAAS (MEUSE) SEDIMENTS: A SURVEY AND A DISCUSSION OF THEIR OPAQUE COMPONENTS[1]

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ABSTRACT

Riezebos, P. A., E. B. A. Bisdom & O. Boersma (1978). Composite grains in Maas (Meuse) sediments: a survey and a discussion of their opaque components. Geol. Mijnbouw, 57, p. 417-431.

The opaque mineralogy of composite grains in acid-treated heavy-mineral concentrates from sediments of the river Maas (Meuse) was studied in reflected light and by SEM-EDXRA analysis. Secondary rutile, secondary ilmenite and hematite constitute the subtranslucent to opaque matter in these composites, which principally represent actual rock fragments. This suggests that the sediments investigated contain products of rather freshly disintegrated rocks.

The opaque components enable two important groups of rock fragments to be distinguished: a major group characterized by secondary rutile, secondary ilmenite and their intergrowths; and a minor group with exclusively hematite.

INTRODUCTION

Detrital material supplied by the river Maas constitutes a considerable part of the Quaternary deposits in The Netherlands. Sediment-petrographical examinations of these Maas sediments have resulted in the recognition of typical features by which they may be characterized and distinguished from other fluvial deposits (see e.g. VAN STRAATEN, 1946; ZONNEVELD, 1949, 1955; MAARLEVELD, 1956; RIEZEBOS, 1971; and DOPPERT ET AL., 1975).

The abundant presence of composite grains, consisting of more than one mineral species, in the heavy-mineral concentrates of rather recent and older Maas sediments (BISDOM ET AL., 1978) suggests that these grains may also be typical for detritus derived from the drainage area of the Maas river. In this previous study all composite grains were grouped as 'composites', this in spite of a varying appearance and the fact that some of them were recognized as rock fragments. For a more detailed description of the composites the reader is referred to BISDOM ET AL. (1978).

As opaque and semi-opaque minerals form an important part of the composite grains, ore microscopy and scanning electron microscopy combined with energy-dispersive X-ray analysis (SEM-EDXRA) were used for characterization of the opaque constituents. This paper presents the data obtained so far.

MATERIALS, PREPARATORY TREATMENT AND MOUNTING

The composite grains investigated are mainly from sub-recent Maas sediments (Betuwe Formation) and from sands collected from a pit near the village of Lerop. The sands from this pit were sampled for heavy-mineral analysis to a depth of 5.60 m (BISDOM ET AL., 1978). The results presented in Table I show the persistent presence of composites.

The chemical treatment of the samples for heavy-mineral analysis had to be rather intensive to remove the strong pigmentation and covering of the heavy-mineral grains with brown and black material. As no calcareous particles are

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Table I
Heavy-mineral compositions (in %) of sandy sediments in exposure near Lerop

Number	depth in cm	Fraction in μm	Tourmaline	Garnet	Rutile	Zircon	Anatase	Corundum	Sphene	Spinel	Total Accessory Minerals	Staurolite	Kyanite	Andalusite	Sillimanite	Topaz	Bright. Chloritoid	Total metamorphic minerals	Zoisite	Epidote	Saussurite	Pumpellyite	Total Epidote-Saussurite Group
1	16-28	210-150	19.8	6.0	0.3		0.3				0.6	4.0	2.0	1.7			0.3	8.0		13.3	8.3		21.6
2	42-50	210-150	17.0	5.3	0.3	0.3			0.3		0.9	3.3	1.3	3.3		0.3		8.2		11.3	8.3		19.6
3	84-91	210-150	15.8	1.0	0.7				0.3		1.0	1.7	2.0	3.0				6.7		7.3	14.3		21.6
4	104-113	210-150	22.3	1.0	0.7	1.3					2.0	4.3	2.3	7.5	0.3		0.3	14.4		9.3	6.3		15.6
5	165-174	210-150	21.3	1.0		1.0	1.0		0.3		2.3	2.0	3.1	3.3			0.7	9.1		11.0	16.0		27.0
6	193-209	210-150	12.4	1.0	0.7				0.3		1.0	1.3	0.3	3.3	0.7			5.6		12.7	15.3		28.0
7	223-236	210-150	13.4	1.7		1.0					1.0	2.3	1.3	2.7		0.3	1.7	8.3		15.3	5.3		20.6
8	287-299	210-150	5.0	0.3	0.7	1.0				1.0	2.7	1.3	1.3	3.3			0.7	6.6		20.3	5.7		26.0
9	347-350	210-150	21.7	7.3	1.0	0.3			1.0		2.3	6.3	3.3	5.7				15.3		12.0	6.7	0.3	19.0
10	450-460	210-150	10.3	5.0	1.7	0.3	0.3		0.3		2.6	2.0	1.7	2.7	0.3		2.7	9.4		3.3	10.0		13.3
11	480-490	210-150	17.0	7.8	1.7	0.3	0.3				2.3	5.0	2.7	2.0			2.3	12.0		5.3	9.3		14.6
12	510-560	210-150	17.3	3.0	1.0						1.0	4.3	3.3	5.3			3.7	16.6		10.7	10.7		21.4

present, a strong hydrochloric acid solution was used; a more diluted acid solution was insufficient for the removal of the dark-stained coatings.

The samples were split into two portions; the first was treated with H_2O and acid, and the second with H_2O_2. From both portions the size grades 210-150 µm were obtained by sieving and from these size grades the heavy minerals were separated using bromoform. The separation of the composites from the concentrates by hand-picking was very time-consuming and liable to errors. Therefore the entire heavy residue was mounted in polyester resin for the preparation of polished sections and polished thin sections.

ANALYTICAL PROCEDURE

A quantitative and qualitative inventory of the opaque constituents in the polished mounts was made by reflected light microscopy. Preliminary identifications were based on colour, anisotropism, bi-reflection, micro-textural features and other readily observable properties. Because an optical analysis in polished mounts also includes detrital particles made up entirely of opaque matter, additional analysis of polished thin sections was necessary to decide whether or not the opaque minerals recognized are equally spread over composite and opaque grains. Grains containing problematic mineral substances were recorded on microphotographs, which were used to locate these grains on the screen of the SEM. Thereafter, SEM-EDAX techniques were used for chemical element analysis from Na ($z = 11$) on. The *in situ* distribution of chemical elements in a certain area was indicated by X-ray images, while spectra of elements were obtained by point analyses (BISDOM ET AL., 1975).

However, the optical properties of goethite, lepidocrocite and hematite, and likewise those of rutile, anatase and pseudobrookite may show a great similarity. Therefore X-ray analysis[4] was performed on a heavy-residue subconcentrated with the Frantz isodynamic magnetic separator into portions of different magnetic susceptibility, in order to establish the presence or absence of these minerals in the same way.

[4] X-ray powder photographs were made and interpreted by Dr. S. W. H. Drucker. Geological Institute, University of Amsterdam

RESULTS

The results of some random samples are given in Tables II and III. Table II shows that goethite predominates in the untreated heavy concentrates. In the acid-treated residues goethite is absent or scarce, proving that the treatment was very effective. Here the opaque minerals are dominated by rutile, ilmenite and hematite. As shown in Table III these minerals occur in composite aggregates and in single-mineral grains. Microscopic observations show characteristic differences in mineralogy between the composite and single-mineral grains. First the opaque minerals found will be briefly discussed.

Green Hornblende	Brown Hornblende	Glaucophane	Total Hornblende	Augite	Hypersthene	Total Augite	Composites	Opaque
0.3			0.3				43.7	7.0
							49.0	12.0
0.3			0.3		0.3	0.3	53.3	13.0
							44.7	10.7
2.0			2.0				37.3	10.0
0.3			0.3				51.7	10.0
0.7			0.7	0.3		0.3	54.0	6.7
2.7			2.7				56.7	3.7
7.7	0.3		8.0	0.7		0.7	25.7	9.3
1.0			1.0	0.7		0.7	57.7	8.7
0.3			0.3				46.0	19.3
				0.7		0.7	40.0	8.0

Goethite and other iron-hydroxides

A large variation in colour, porosity, reflectivity, internal reflection, micro-texture etc. is shown by the goethite. These differences occur between the individual grains as well as within single ones (Fig. 1). In the X-ray images, a relationship between the iron distribution and changes in optical properties is seldom obvious (Fig. 2A and 2C) unless evident translucent inclusions occur. This suggests that the variation in optical features is primarily related to crystallinity, dehydration and possibly contamination with clayey material. The mineral often appears as aggregates of micro-crystalline and/or crypto-crystalline material (Fig. 1.)

Higher reflecting areas, layers or bands suggest the local presence of lepidocrocite and/or even hematite. On the X-ray films of the magnetic subconcentrates, however, no lepidocrocite reflection could be detected. Goethite pseudomorphs after framboidal pyrite were occasionally observed. Colloform banding indicative of colloidal deposition and especially concretionary zoning (oöliths) are frequent. Very often, however, the goethite appears without special textures. In view of the non-homogeneous nature of many of the aggregates which probably consist of intimate mixtures of goethite, hematite, lepidocrocite and amorphous material, the designation limonite could be more appropriate for many of the grains

The iron mineral was also found surrounding quartz and other transparent mineral grains of coarser grain-size, as a cementing substance between smaller grains and even occasionally as a constituent of evident rock fragments (Fig. 1). It has never been observed intergrown with other opaque minerals present in these sediments. This suggests that the majority of goethite or limonite grains must be of detrital origin, because it is difficult to see why opaque grains were excluded from oxidation, limonitization or cementation by goethite when these processes were exclusively of an authigenic nature. The presence of oölite fragments also illustrates this tentative conclusion. From this separate occurrence it can be further deduced that the majority of the goethite and the remaining opaque species may be derived from different source rocks.

Rutile

Two types of rutile are distinguished. The first type, rutile I, is almost exclusively found as individual opaque grains (Fig. 3A). It was observed in one instance attached to ilmenite in a single grain. As the mode of the intergrowth does not suggest a genetic relationship, this was considered as an accidental

Table II
Reflected-light analysis of the 210-150 μm size grades in polished mounts (200 grains). The untreated and acid-treated residues have been separated from the same field sample.

	Untreated heavy residue	Acid-treated heavy residue
Rutile I	1	12
Ilmenite I	1	16
Hemo-ilmenite	1	1
Ilmeno-hematite	1	3
Titanhematite	–	2
Ilmenite I altering in leucoxene	1	10
Rutile II	11	89
Ilmenite II	2	23
Ilmenite II altering in leucoxene	–	4
Leucoxene	–	16
Ilmenite I intergrown with rutile II	–	1
Ilmenite I intergrown with rutile I	–	–
Ilmenite II (+ leucoxene) intergrown with rutile II	2	17
Rutile II intergrown with leucoxene	–	3
Chromite	–	2
Magnetite	-	-
Martite	-	1
Goethite-limonite	178	-
Hematite (finely distributed)	2	-
Very fine hematite inclusions in altered (?) mineral substance	-	-

Table III
Reflected-light analysis of 800 detrital grains from an acid-treated residue (210-150 μm) in polished thin-section. The findings show the occurrence of the species distinguished in composites and opaques.

	Composite grains	Opaque grains
Rutile I	2	53
Ilmenite	-	32
Hemo-ilmenite	-	3
Ilmeno-hematite	-	3
Titanhematite	-	2
Ilmenite I altering in leucoxene	1	112
Rutile II	120	137
Ilmenite II	40	52
Ilmenite II altering in leucoxene	3	7
Leucoxene	3	33
Ilmenite I intergrown with rutile II	-	2
Ilmenite I intergrown with rutile I	-	1
Ilmenite II (+ leucoxene) intergrown with rutile II	42	40
Rutile II intergrown with leucoxene	10	8
Chromite	-	10
Magnetite	1	4
Martite	1	1
Goethite-limonite	–	6
Hematite (finely distributed)	48	
Very fine hematite inclusions in altered (?) mineral substance	11	15

phenomenon. Rutile I generally displays dark-coloured internal reflections, evident lamellar twinning and proportionally large polished surface areas of the grain sections.

These features are different or lacking in the second type of rutile, rutile II, which occurs in composite grains as well as in single-mineral grains. It is found as aggregates of needles, rods, lamellae, vermicular, granular or dotted areas of various shape and size (Fig. 4). Rather large section areas are usually porous and frequently a Widmannstätten texture is visible (see Fig. 4, middle photograph).

The different appearance of rutile II is accentuated by its frequent occurrence intergrown with other translucent and opaque minerals. According to the EDAX analysis the intergrown or enclosed translucent material is mostly made up of silicon suggesting that it must be silica (Fig. 5B). A special type of ilmenite (see below) frequently occurs closely associated with rutile II in opaque and composite grains (Fig. 6A, E and F.) It is obvious that rutile II represents relics of mottled, myrmekitic and orientated textured intergrowths and that other, originally intergrown, minerals were dissolved and replaced by silica.

The occurrence of rutile II with similar textural features in composites and in discrete opaque grains suggests that rutile II was formed in the source rock of the sediments and that also rutile II in discrete opaque grains must be considered as being inherited from these source rocks.

The similarity in the optical features of rutile and other Ti-bearing minerals has already been mentioned. The heavy-mineral analysis (Table I) shows only a small percentage of rutile, anatase and sphene grains. Also on the X-ray films of the magnetic subconcentrates, the reflections of rutile and anatase could be detected. Therefore it is quite possible that especially the fine-grained rutile II is in reality partly anatase.

Ilmenite

Two types of ilmenite were also distinguished in the optical analysis. Ilmenite I shows distinct bi-reflectance and anisotropy, a brown colour with a pinkish tint, occasionally twinning and hardly any translucent inclusions (Fig. 4). It probably represents ferrianilmenite according to the nomenclature of BUDDINGTON ET AL. (1963). Titanhematite intergrown with ferrianilmenite (hemo-ilmenite or ilmeno-hematite) is very scarce.

Ilmenite I, whether or not intergrown with droplets, small lenses or lamellae of hematite, shows alteration in leucoxene along crystallographic directions, a feature which has been described by several workers (e.g. BAILEY ET AL., 1956). The successive stages of alteration as frequently described in the literature, however, are not always clearly recognizable, because the amorphous iron-titanium substance, characteristic for the intermediate alteration stages, sometimes seems to be lacking or is hardly developed. The final product of the leucoxenization process usually mainly consists of very finely crystallized material, probably rutile, though anatase, brookite and pseudorutile have also been reported in the literature (Fig. 4). The alteration products show bright internal reflections and colours very closely resembling those of rutile II. When the textural features pertinent to this alteration process are unrecognizable, leucoxene is difficult to distinguish from fine-crystalline rutile II.

Ilmenite I and its alteration products were almost exclusively found in single opaque grains. As shown in Table III, intergrowth of ilmenite I with rutile II is rather exceptional, but intergrowths of rutile II with leucoxenization products are more common. It is, however, usually difficult to assess whether these products are derived from the alteration of ilmenite I or of ilmenite II (see below). In view of the more frequent association of ilmenite II with rutile II within discrete grains (Fig. 6A), the latter possibility seems more likely.

In contrast to ilmenite I, ilmenite II contains many, differently sized and shaped, translucent inclusions which only contain silicon (similar to the point analysis of Fig. 7F) or silicon, aluminium and potassium (Fig. 7D). In oil immersion under the microscope ilmenite II also has a light-brown co-

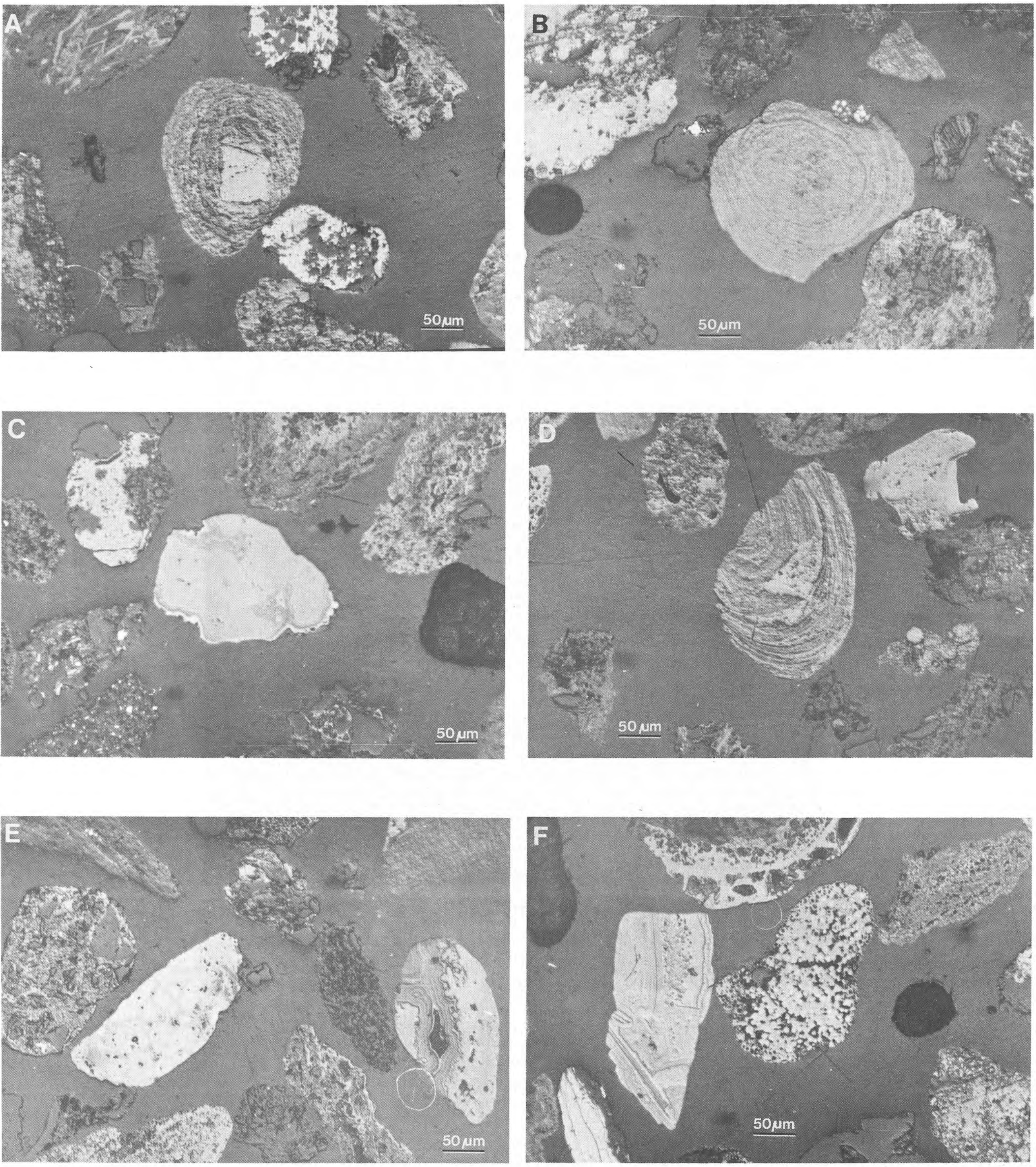


Fig. 1
Overall pictures of untreated concentrates (210-150 μm) in polished mounts. Reflected light, objective P.25/0.65 (oil), ocular Periplan 10 x.

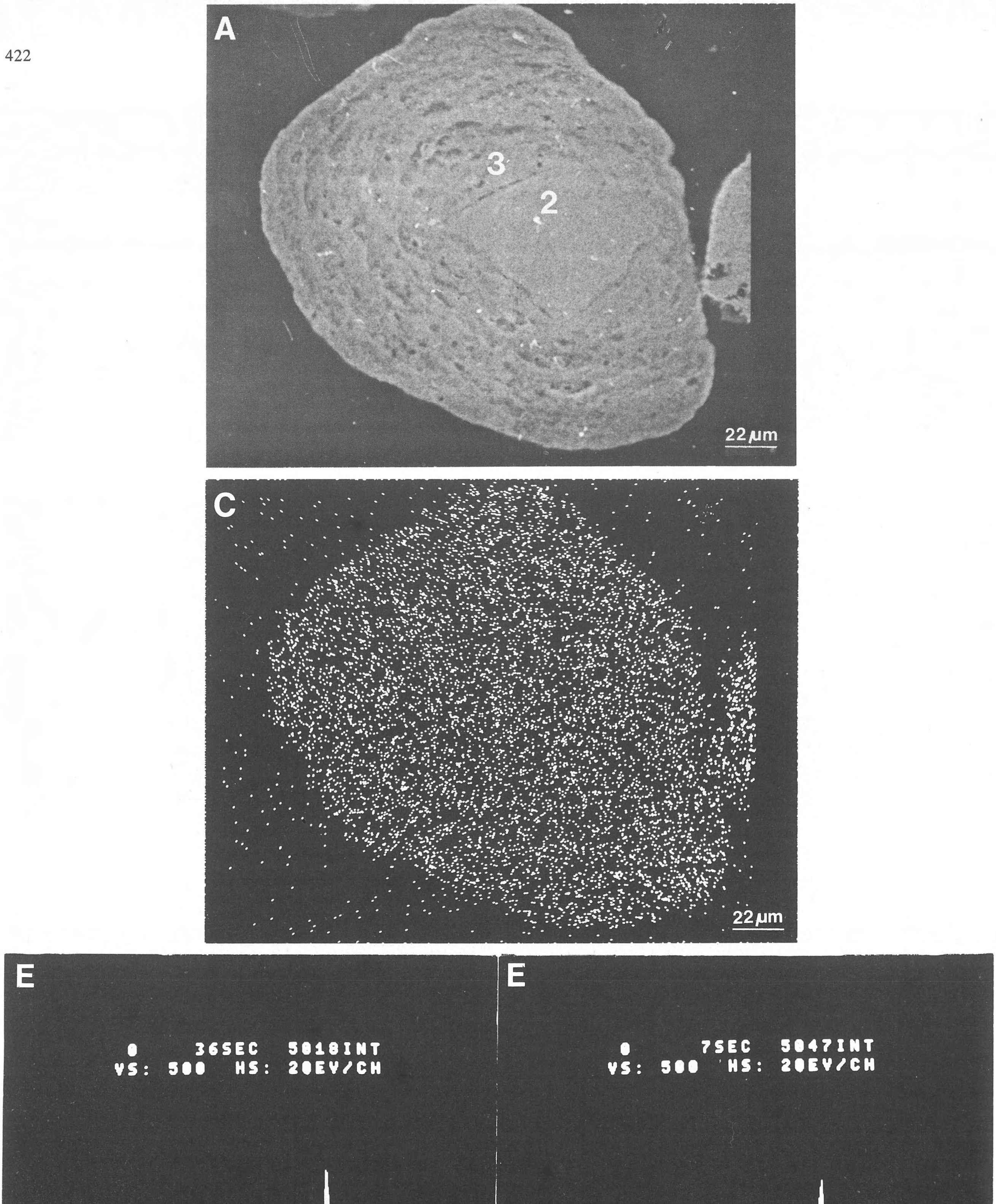
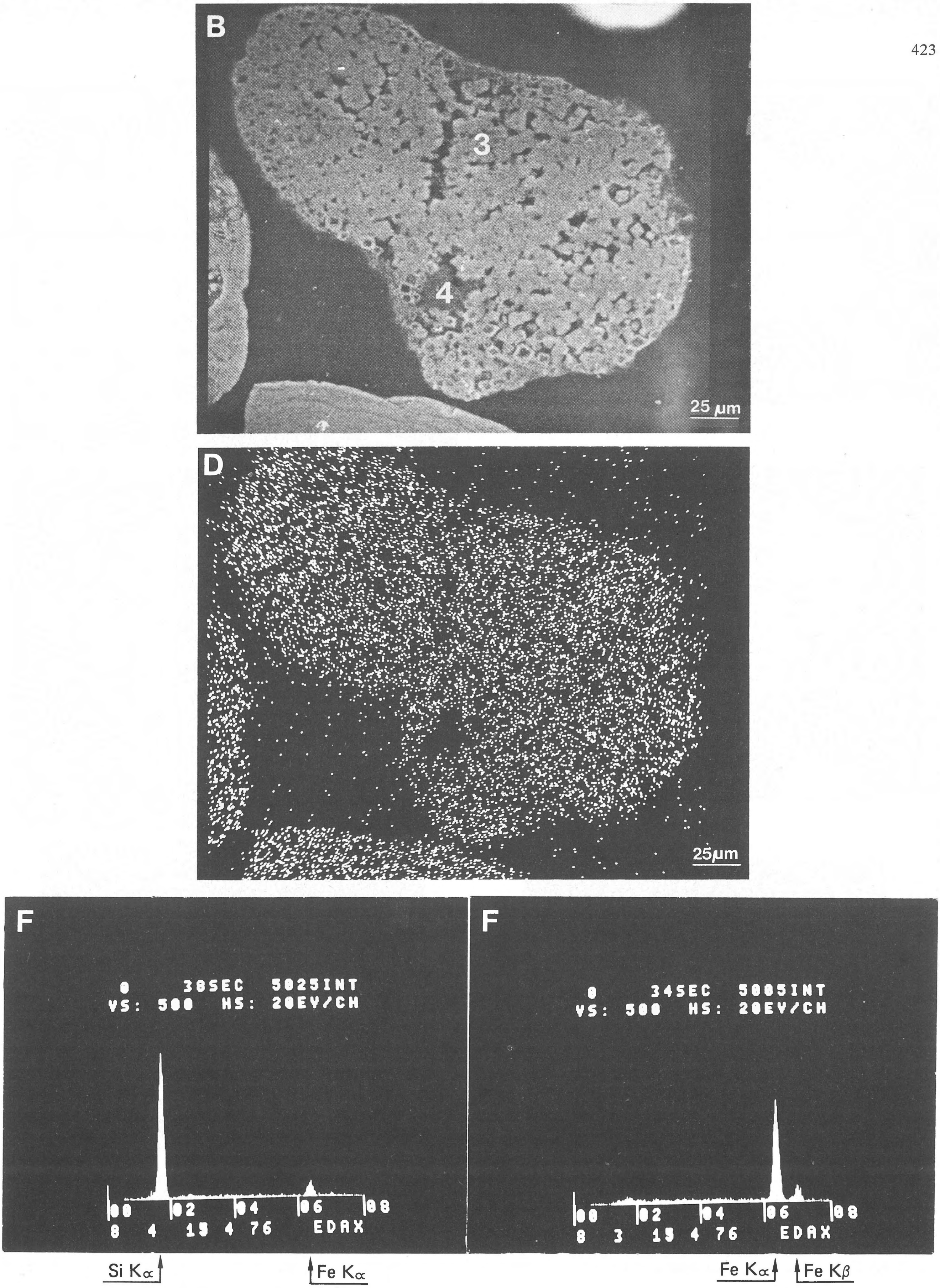


Fig. 2
A: Secondary electron image of the central goethite grain in the upper left photograph of figure 1.
B: Secondary electron image of the central goethite grain in the lower right photograph of figure 1.
C: X-ray image showing the distribution of Fe in A.



D: X-ray image showing the distribution of Fe in B.
E: Point analyses of sites 2 and 3 in A.
F: Point analyses of sites 3 and 4 in B.

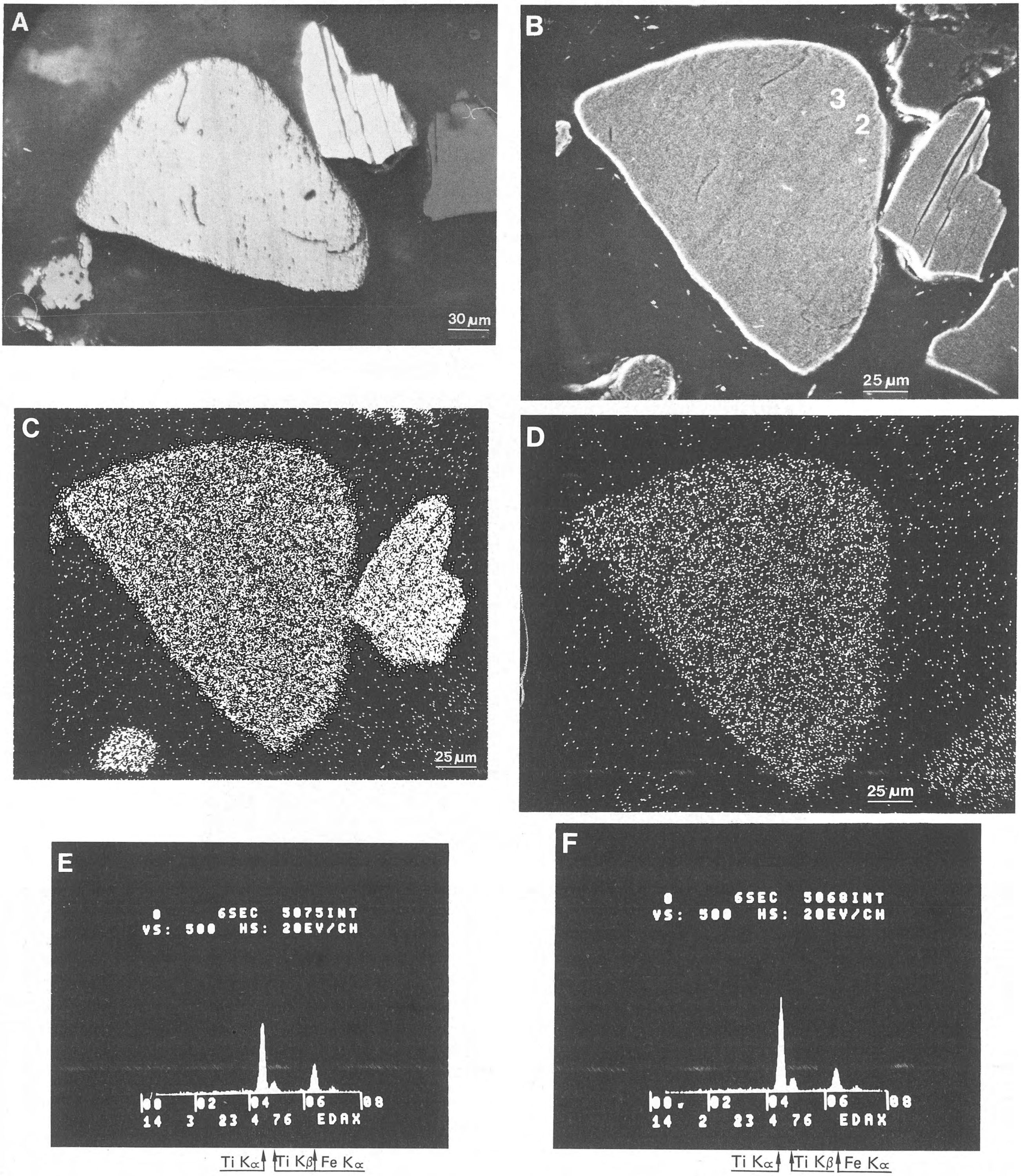


Fig. 3

A: Rutile 1 (white) and ilmenite I (greyish-white) showing roughly parallel to (0001) slight alteration into leucoxene. Reflected light, objective P.25/0.65 (oil), ocular Periplan 10 x.

B: Secondary electron image showing the sites of point analysis

C: X-ray image showing the distribution of Ti.

D: X-ray image showing the distribution of Fe.

E: Point analysis of site 3.

F: Point analysis of site 2.

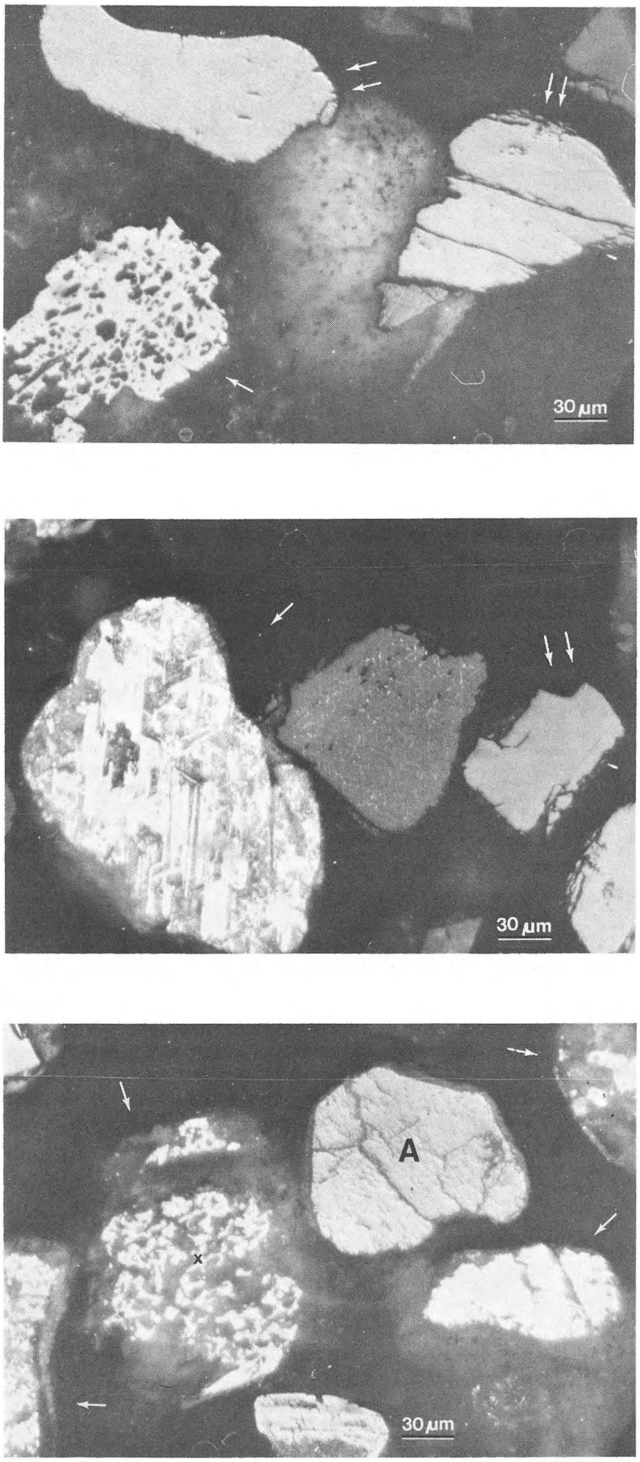


Fig. 4
Overall pictures of acid-treated residues in polished mounts displaying several types of rutile II aggregates (single arrow), unaltered detrital ilmenite I grains (two arrows) and a leucoxene grain (A). Reflected light, objective P.25/0.65 (oil), ocular Periplan 10 x.

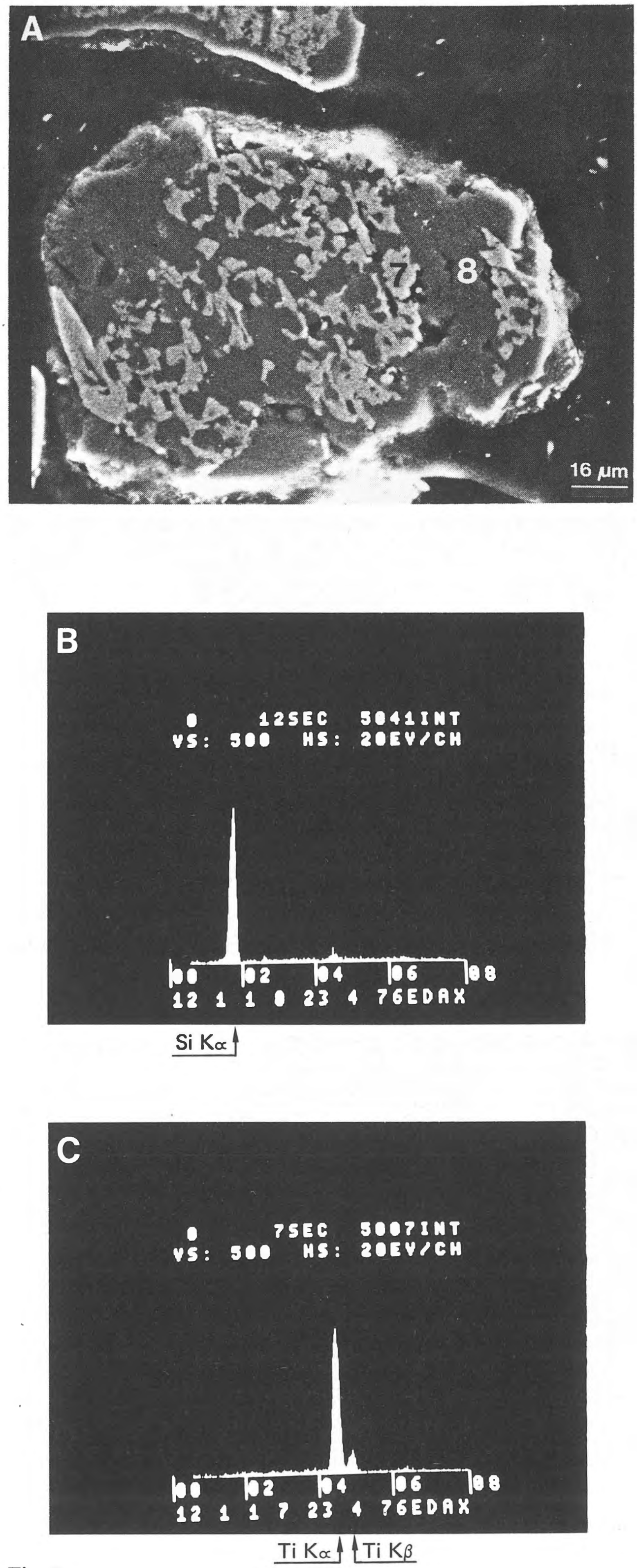


Fig. 5
A: Secondary electron image of the rutile II aggregate (X) from figure 4.
B: Point analysis of site 8.
C: Point analysis of site 7.

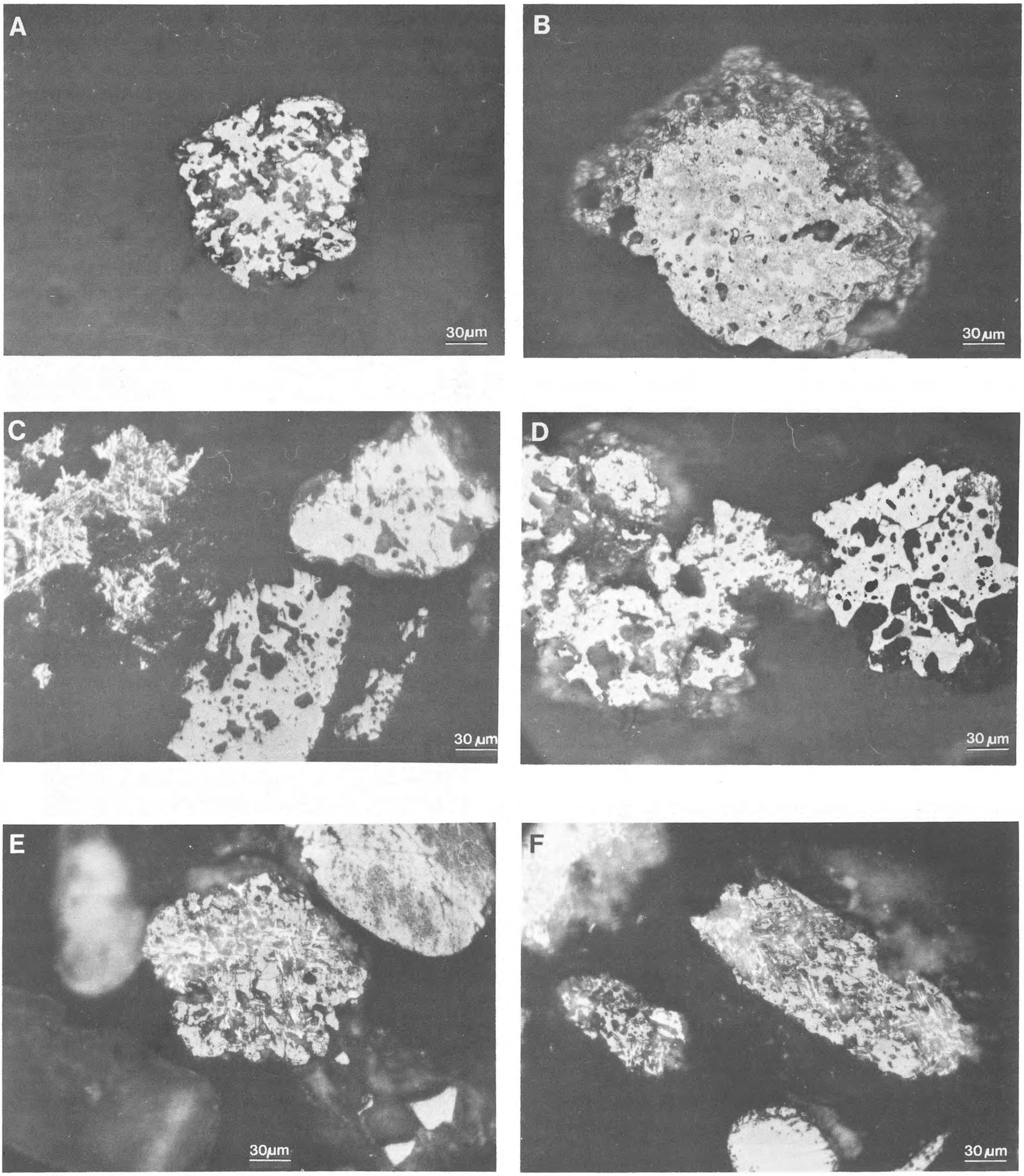


Fig. 6
Reflected-light micrographs of polished thin sections. Objective P.25/0.65 (oil), ocular Periplan 10 x.
A: Rutile II (white) and ilmenite II (greyish-white) within a single opaque grain.
B: Ilmenite II being replaced by coarse-grained leucoxene material.
C: Rutile II aggregate with a trellis texture in a composite (left), ilmenite II (middle) and rutile II (right).
D: Rutile II in a composite (left) and an individual ilmenite II grain.
E: Rutile II (white) with a trellis texture containing ilmenite II (grey) remnants.
F: Ditto, as a constituent of a composite.

lour, but instead of a pinkish tint a greyish tint has often been observed and in these cases bi-reflectance and other anisotropy effects are lacking or extremely weak. This material might possibly correspond with ilmenite in the first alteration stages as described by DIMANCHE & BARTHOLOMÉ (1976). But the seemingly isotropic character may also be due to orientation of the sections or to rather high magnesium or manganese contents. An alternative possibility is that the mineral may be magnetite. Therefore, some 'isotropic' ilmenite grains were investigated by SEM-EDXRA. The analysis indicated, in addition to iron, a high content of titanium and a little manganese in the greyish-brown ilmenite II (Fig. 7C). Ilmenite II is found as discrete grains and as a constituent of composites.

Ilmenite II is frequently intergrown with rutile II. Grains consisting of only ilmenite II or of only rutile II may show conspicuous resemblances in habit (Fig. 4 and 6D). Grains with a similar habit, however, may also consist of intergrowths of the two minerals (Fig. 6A), but there is always a sharp boundary line between them.

The alteration of ilmenite II is not the same as that of ilmenite I. Ilmenite II always seems to alter directly into aggregates of discrete small spherical grains with a 'polychromatic' appearance in plane-polarized light, showing white, yellow and red-brown internal reflections under crossed nicols (Fig. 6B). It does resemble coarse-grained leucoxene, but the amorphous iron-titanium substance was not observed and the alteration does not seem to be controlled by the crystal lattice of ilmenite.

Minor species

Hematite is the most frequent accessory opaque mineral but it occurs rather exceptionally as discrete grains. Textural features often indicate an origin by oxidation of magnetite (martitization) or by unmixing in the solid-solution series $FeTiO_3$ and Fe_2O_3 (ilmeno-hematite). However, it usually occurs as differently shaped and irregularly distributed small particles in rock fragments (Fig. 8). Baculiform hematite may show a clear seriate arrangement. It is also found in grains consisting of a dark reddish-brown to brownish-red, subtranslucent material which under the microscope sometimes seems to be amorphous. The latter grains are also found as components of rock fragments (Fig. 8).

Chromite has only been observed as opaque grains without forming intergrowths with other minerals. Once a grain with voids was observed, suggesting dissolution of an intergrown phase. Colour and reflectivity may vary, even within a single grain section. A mosaic or cataclastic texture is not uncommon.

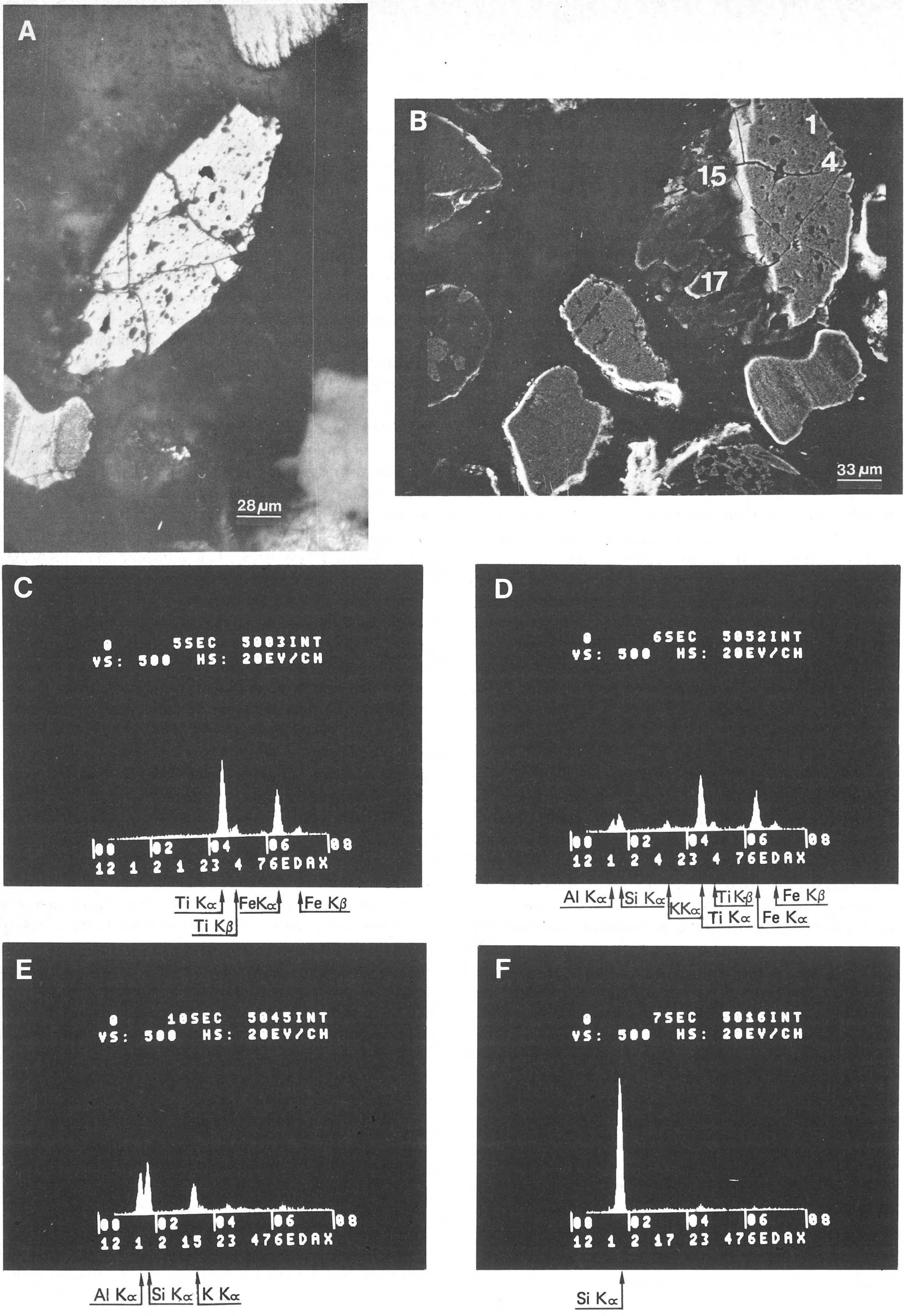
Magnetite is very rare. Replacement by maghemite has been observed.

DISCUSSION

It has already been suggested (RIEZEBOS, 1971) that a high goethite content could be characteristic of Quaternary Maas sediments. The large amount of goethite grains in the heavy residues of these fluvial deposits was considered to have derived from Jurassic rocks in Lorraine. A more recent investigation (MÜLLER & NEGENDANK, 1974) has shown that Pleistocene Mosel deposits also contain abundant goethite which is thought to have been provided by the Minette formation in the drainage area of this river. As far as the Maas deposits are concerned, the present results obtained from the untreated residues corroborate the previous findings (RIEZEBOS, 1971).

In the acid-treated concentrates the opaque minerals distinguished show a rather conspicuous distribution. The occurrence of rutile I, ilmenite I and its alteration products, chromite and magnetite is almost confined to discrete detrital opaque grains. Rutile II, ilmenite II and hematite are found in opaque as well as in composite grains. It is very likely that rutile I represents the high-temperature polymorph of TiO_2 while ilmenite I with its rare hemo-ilmenite and ilmo-hematite intergrowths is probably also a high-temperature member of the system FeO-Fe_2O_3-TiO_2.

It can be summarized that the opaque material in the composites is predominated by rutile II (anatase), ilmenite II (titanomagnetite) and hematite. Unfortunately, these minerals are very common constituents of various rock-assemblages, and thus provide rather poor information about possible source rocks. A significant characteristic is that the minerals are apparently of secondary origin. Also their textural features, as far as they have been preserved, are poor. The trellis texture displayed by rutile II is the only obvious one. It may suggest that this rutile has been formed by a transformation of ilmenite or ulvospinel lamellae oriented according to crystallographic directions of magnetite. This transformation may be attributed to an 'incongruent dissolution' of ilmenite (DIMANCHE & BARTHOLOMÉ, 1976) resulting in the formation of rutile; the cavities between the rutile are due to the complete dissolution of magnetite. It is important to realize that this process must have taken place in an environment where the activity of the ferrous iron was low. Another possibility is that these skeletal rutile II aggregates are remnants of original, regular rutile-hematite intergrowths which were formed by high-temperature oxidation of ilmenite. The aggregates may again contain rutile II or a reflecting material that resembles magnetite between the lamellae or needles (Fig. 6E and F). However, irregular aggregates consisting of only rutile II (Figs. 4 and 5) or of intergrowths of rutile II and the magnetite-like material are more frequent. In these aggregates no textural evidence for a possible derivation from ilmeno-magnetite or from ferrian-ilmenite can be recognized. According to RAMDOHR (1960) oxidation of Fe_2O_3-rich ilmenite may also result in irregular intergrowths of rutile and magnetite. SEM-EDXRA analyses of the magnetite-like



A
28 µm
B
1
4
15
17
33 µm
C
0 5SEC 5003INT
VS: 500 HS: 20EV/CH
00 02 04 06 08
12 1 2 1 23 4 76EDAX
Ti Kα
Ti Kβ
FeKα
Fe Kβ
D
0 6SEC 5052INT
VS: 500 HS: 20EV/CH
00 02 04 06 08
12 1 2 4 23 4 76EDAX
Al Kα
Si Kα
KKα
Ti Kβ
Ti Kα
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12 1 2 15 23 476EDAX
Al Kα
Si Kα
K Kα
F
0 7SEC 5016INT
VS: 500 HS: 20EV/CH
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Si Kα

material however, always show a high content of titanium and iron with some manganese (see Fig. 9). Similar SEM-EDXRA results were obtained from the individual 'isotropic' ilmenite II particles (see above). Further, the magnetite-like material occasionally exhibits the evident replacement by a coarse-grained type of leucoxene. Therefore, for the time being, it is indicated as ilmenite II, like the above-mentioned individual ilmenite II grains. It is realized, however, that this diagnosis rests on inconclusive evidence and that this ilmenite II may be partly composed of titanomagnetite. Magnetite, however, was not recorded in the powder diagrams of the X-ray films.

The alteration of ilmenite into leucoxene involves oxidation and progressive removal of iron under weathering conditions and this results in a product mainly consisting of TiO_2. As already mentioned, when seen under the microscope ilmenite I usually shows the pattern described by BAILEY ET AL. (1956), while ilmenite II usually exhibits the direct replacement by more porous, coarse-grained, leucoxene material (Fig. 6B). These phenomena suggest two ways of leucoxenisation. On the basis of the present findings, it is impossible to assess by which factors these two types of alteration are controlled, but in spite of some exceptions that have been found, it is not unlikely that they could be related to the two types of ilmenite and/or their different petrological history.

Hematite is mainly found as small euhedral to anhedral particles in composites that often exhibit a schistose structure of the associated transparent minerals. These composites are apparently schistose rock fragments. If developed in a lath-like or columnar way, hematite may occur parallel or subparallel to this schistosity (Fig. 8). Very minute hematite needles or grains are found in particles made up of a brownish to reddish, semi-opaque substance. The semi-opacity is probably due to finely-distributed iron-oxide. Such particles possibly represent the product of a thoroughly oxidized, iron-containing mineral. They occur as separate grains and as constituents of the schistose rock fragments suggesting a kind of spotted or maculose texture (Fig. 8).

In both ilmenite and rutile containing composites, the mutual arrangement of the translucent and opaque minerals is not as obvious as in the hematite-bearing specimens. The grain size of ilmenite, rutile and their intergrowths is usually considerably larger than that of the associated translucent grains, and idiomorphic outlines are rarely recognizable. Occasional grains with euhedral outlines seldom show an ar-

Fig. 7
A: Ilmenite II centre in a composite. Polished mount, reflected light, objective P.25/0.65 (oil), ocular Periplan 10 x.
B: Secondary electron image of the ilmenite II containing composite (upper right).
C: Point analysis of site 1 (see Fig. 7B).
D: Point analysis of site 4 (see Fig. 7B).
E: Point analysis of site 15 (see Fig. 7B).
F: Point analysis of site 17 (see Fig. 7B).

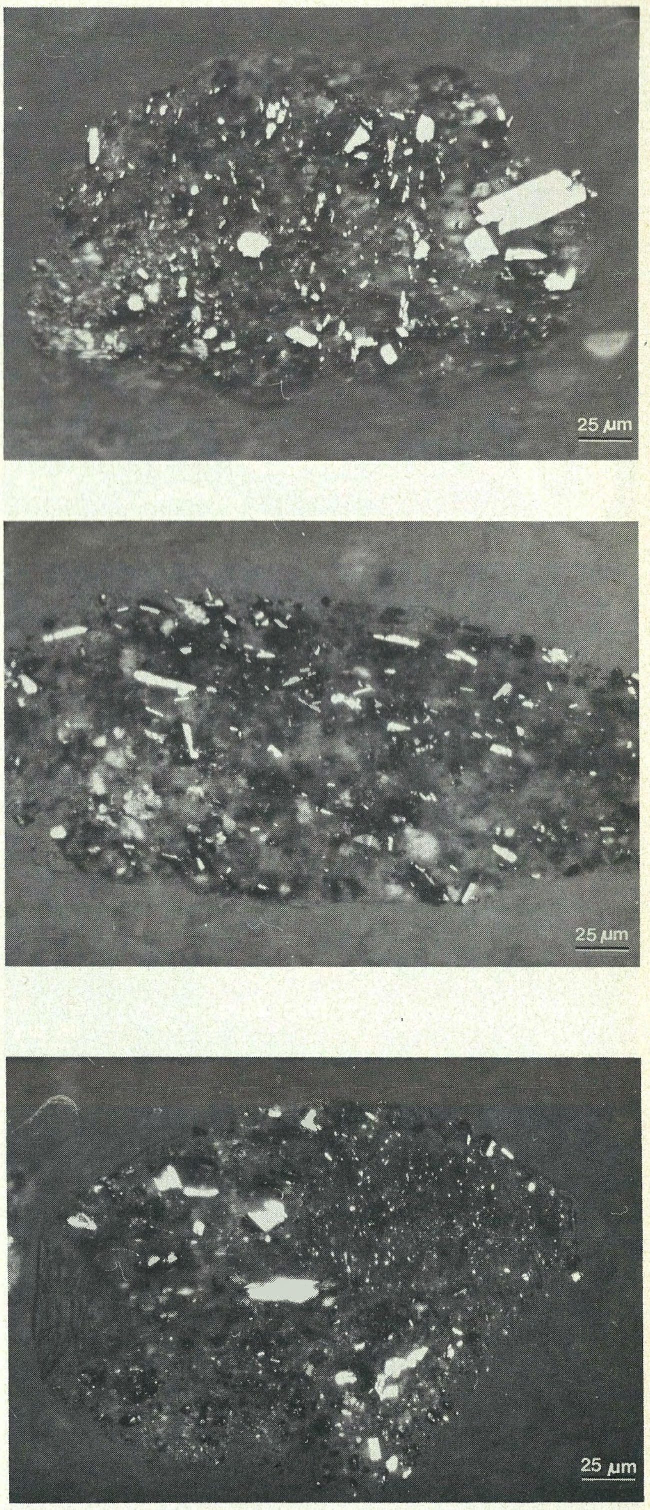

Fig. 8
Reflected-light micrographs of hematite-containing composite in polished thin sections. The specimen in the lower micrograph shows the presence of altered (?) mineral substances with extremely fine hematite inclusions (upper right and lower left part of the composite). Objective P.25/0.65 (oil) ocular Periplan 10 x.

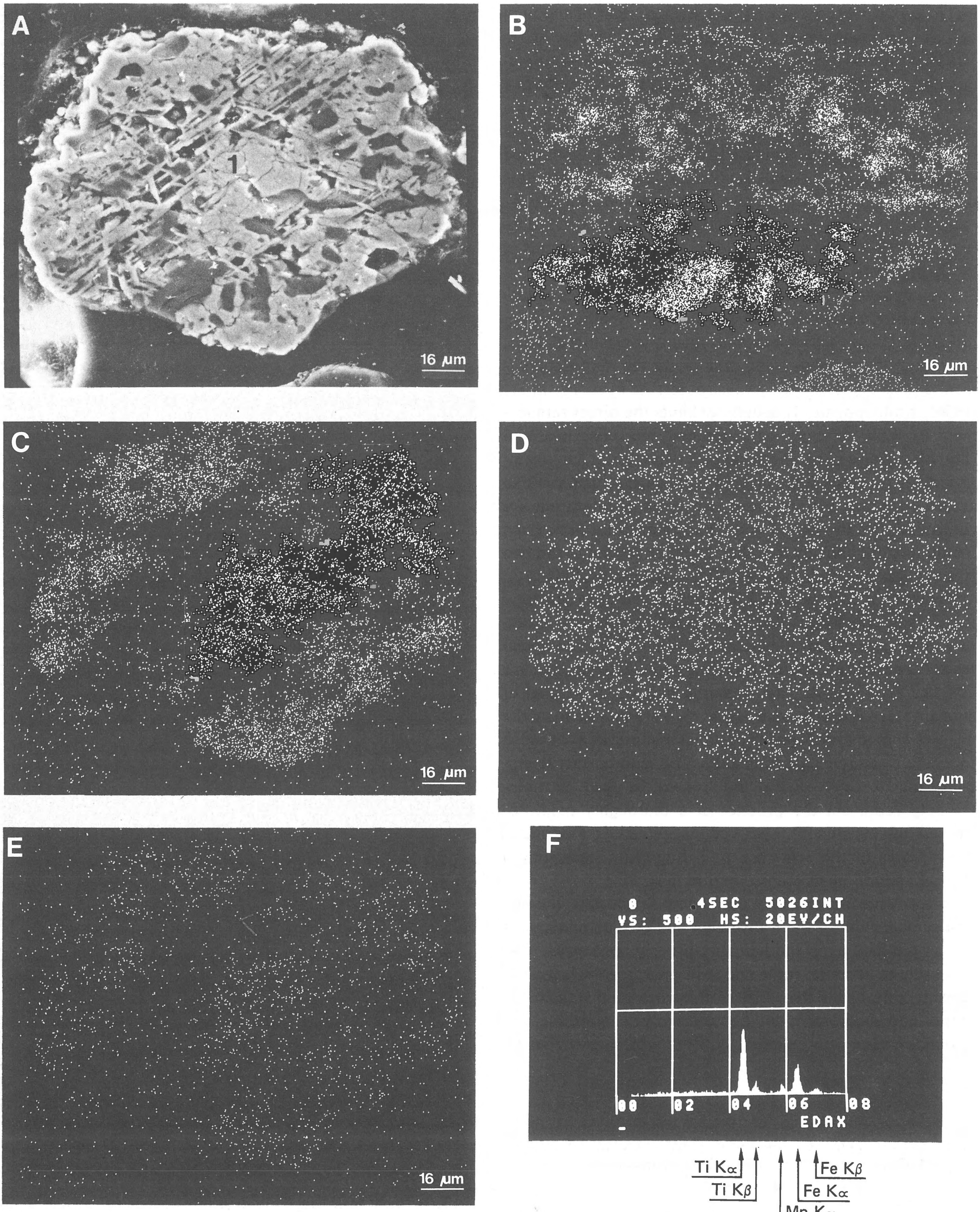

Fig. 9

A: Secondary electron image of the grain shown in Fig. 6E.
B: X-ray image showing the distribution of Si.
C: X-ray image showing the distribution of Fe.
D: X-ray image showing the distribution of Ti.
E: X-ray image showing the distribution of Mn.
F: Point analysis of site 1 (see Fig. 9A).

rangement parallel or sub-parallel to other prismatic or platy translucent crystals. Nevertheless, the majority of these composites may also be considered as rock fragments.

In an experimental study BOGGS (1968) pointed to the possible use of rock fragments in sedimentary petrology in order to assess the source rocks. However, because the areal dimensions of opaque minerals in the composite-grain sections are usually quite large and the remaining surface occupied by finer-grained translucent minerals small, the rock textures are usually neither distinct nor numerous enough to characterize the rock fabric. Moreover, the rock fabric just around the opaque minerals will probably not be representative of the original rock as a whole. From the ubiquitous presence of rock fragments in the heavy residues (BISDOM ET AL., 1978) it can be concluded that the investigated sediments of the river Maas partly consist of detritus that must have been mobilized rather recently on solid rocks in the drainage area.

CONCLUDING REMARKS

(1) The opaque, semi-opaque and subtranslucent minerals in the composites in acid-treated residues of the Maas sediments are mainly composed of secondary rutile (anatase), secondary ilmenite (possibly partly magnetite) and hematite.
(2) On the basis of the occurrence of these minerals two groups of composites can be distinguished. In the first group only hematite is found as opaque material, in the second group secondary rutile and ilmenite occur either together or separately.
(3) Although very probably all the composites are rock fragments, the hematite-containing specimens appear to furnish the most obvious instances.
(4) On textural grounds it can be assumed that ilmeno-magnetite and ferrianilmenite were the parent minerals for some of the secondary rutile and secondary ilmenite.
(5) In view of the fact that these secondary phases are found in composites (rock fragments) as well as in individual opaque grains, it can be concluded that the processes giving rise to these mineral phases did not take place in the present environment of the sediments, during their preceding transportation or during the disintegration phase of the original source rocks.
(6) The leucoxenization pattern of the secondary ilmenite found in composites seems to be especially characterized by a direct replacement of the ilmenite by rather coarse-grained leucoxenic material.
(7) On the basis of the opaque constituents it is not possible to relate the composites to distinct rock types.

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