Bulletin de la Société belge de Géologie, T. 101 (3-4), 1992, pp. 153-171.
Bulletin van de Belgische Vereniging voor Geologie. Ed. 1993

SURFACE FEATURES OF HEAVY MINERALS FROM BELGIAN MESO-CENOZOIC DEPOSITS

by

Jan VAN DER SLUYS[1]

ABSTRACT

Surface features on garnet, epidote, amphiboles and tourmaline of Belgian Meso-Cenozic deposits have been investigated and described. Most features of mechanical origin are completely eliminated and replaced by corrosion features, except in the case of tourmaline, where impact marks have been well preserved.
Typical surface features on garnet are v-shaped, rhombic, triangular and hexagonal etching pits, mounds and occasionally "imbricate wedge markings". An evolution of v-shaped to rhombic pits and finally IWMs has been observed. Epidote and amphiboles show elongated etching slits.

KEYWORDS

surface features, heavy minerals, SEM

SAMENVATTING

Oppervlaktefiguren op granaat, epidoot, amfibolen en toermalijn van Belgische Meso-Cenozoïsche afzettingen werden onderzocht en beschreven. De meeste kenmerken van mechanische oorsprong zijn volledig uitgewist en vervangen door corrosiefiguren, behalve bij toermalijn, waar botsfiguren goed bewaard zijn.
Typische oppervlaktefiguren op granaat zijn v-vormige, ruitvormige, driehoekige en zeshoekige etsputjes, "mounds" en sporadisch "imbricate wedge markings". Een evolutie van v-vormige naar ruitvormige etsputjes en uiteindelijk naar IWM's kon worden vastgesteld. Epidoot en amfibolen vertonen eerder langwerpige etsspleten.

SLEUTELWOORDEN

oppervlaktefiguren, zware mineralen, SEM

1. INTRODUCTION

During the last decades, surface textures of sand grains have been a common field of interest to many sedimentologists. Most authors have been studying surface features on detrital quartz grains. Krinsley & Doornkamp (1973) and Le Ribault (1977) even published "atlases" of surface features on quartz grains. Fewer publications deal with heavy minerals, although one could expect a greater variety of features in this group.
Detrital garnet is the most commonly studied mineral. Already Sauer (1900) and Bramlette (1929) described textures of garnet grains, indicating chemical or mechanical action.
Undoubtedly of mechanical origin are the v-shaped indentations (impact pits). More problematic are the chattermarks. Whereas Folk (1975), Bull (1977) and

[1] Belgian Geological Survey, Jennerstraat 13 - B-1040 Brussels.

Gravenor (1985) interprete these trails of crescent-shaped indentations as purely glacial forms, Orr & Folk (1983) state that they could have originated from alteration as well.
Garnet shows a large variety of chemical features: etching pits of different shapes, mounds or hillocks, and imbricate wedge markings (IWMs) or faceted garnet. Especially the last texture has been a subject of discussion. Simpson (1976), Magaldi (1977), Maurer (1982) and Mader (1985) interpreted IWMs as overgrowths of authigenic garnet, based upon the argument of crystallographic similarities. Rahmani (1973) and Morton (1979, 1984) considered them as solution forms. Later, Hansley (1987), Salvino & Velbel (1989) and Morton *et al.* (1989) presented evidence speaking in favour of a solution origin of IWMs: experimental formation of faceted garnet by warm acid solutions, unlikeliness of garnet to form under diagenetic conditions, depletion of garnet with simultaneously increasing degree of faceting in deeply buried sandstones, occurrence of faceted garnet linked to mouldic secondary porosity, lack of compositional differences between grain core and facets.
Other heavy minerals have been studied in a rather sporadic way. Already Edelman (1931) mentioned hacksaw-structures on detrital amphibole and pyroxene grains. Setlow & Karpovich (1972) described features on different heavy mineral grains from littoral environments.
Recently, Wouters & Gullentops (1988) mentioned strongly etched garnet grains with well developped IWMs from Westphalian D Neeroeteren sandstone in a borehole of the Northern Campine Coal Basin (Belgium).

The aim of this paper is to present results and conclusions of a research on surface textures of heavy minerals in Belgian Meso-Cenozoic sediments. This research was part of a broad provenance study of Belgian Meso-Cenozoic sediments (Van der Sluys, 1990).

2. METHODS

Samples have been selected from the whole sequence of Belgian Meso-Cenozoic deposits. Consolidated calcareous samples were first treated with diluted HCl (0.5 N) before sieving and separating. Heavy minerals have been separated with heavy liquids (bromoform) from the sand fraction (1-4.3 ϕ), followed by magnetic separation and hand-picking for obtaining pure mineral fractions.
The grains were mounted on stubs and coated with a thin gold film, previous to examinations with a scanning electron microscope (Philips SEM 505). For each sample, 50-100 grains were investigated, and the surface features were compared to observations on grains from recent environments and to descriptions in literature.
Following minerals were studied: garnet, epidote, amphiboles and tourmaline. These minerals abound in many Mesozoic and Tertiary deposits, and they have different symmetry, physical and chemical behaviour. Eventually, these minerals are relatively easy to isolate. Table 1 gives a rough frequency distribution of surfaces features in every sample.

3. RESULTS

3.1. Garnet

Garnet grains from 55 samples have been examined, yielding a large number of observations. The following surface features have been recorded:

Furrows : linear or curved, of different size.
Impact or percussion marks : features due to grain collision, generally v-shaped, sometimes irregular, without orientation. Size: 10-20 µm (plate 1.a).
Scattermarks : flat, irregular pits with creviced surface. Size: < 100 µm.
Cleavage plates or blocks : platy- or block-like structures, often with broken edges .
Conchoidal breakage : typical shell-like surfaces, with curved arcs or edges (plate 1.b).
Etching pits : oriented pits, formed by solution phenomena. Different shapes and sizes have been described :

1. v-shaped pits, rather flat, < 10 µm, with a constant top angle (70-75°) (plate 1.c).
2. triangular pits, looking like a negative mould of a regular trigonal pyramid, deeper and larger than (1), 10- 20 µm (plate 1.d)
3. rhomb-shaped pits, sometimes very deep and small (2-3 µm), mostly flat and large (20-30 µm), with a top angle of 70-75° (plate 2.a,b).
4. hexagonal pits, less common, representing negative moulds of rhombododecahedral {110}. crystals. Initially developing in the center of a triangular etching pit, they enlarge (20-30 µm) (plate 2.c).

All these etching pits show an orientation, clearly influenced by the crystallographic lattice. A same grain sometimes may show differently shaped pits on different crystallographic surfaces.
Mounds or hillocks : spherical structures (5-10 µm) (plate 2.d).
Imbricate wedge markings (IWMs) : triangular, imbricated wedge-like features, in extreme cases giving rise to faceted grains. Top angle 70-75° (plate 3.a).

Generally spoken, garnet grains from Meso- Cenozoic sediments of Belgium are very poor in mechanically induced features. Impact marks are very scarce, as are well shaped cleavage plates, which is not surprising, considering the poor cleavage of garnet. Conchoidal breakage surfaces are the only commonly spread feature. Most observed textures are of chemical origin, although mechanical features (impact marks) are quite common on grains from comparable recent environments (Setlow & Karpovich, 1972 ; Magaldi, 1977). We therefore have no reason to presume that mechanical features would not originally have occurred on the grains of deposits under consideration. After deposition, corrosion must have rapidly removed or overprinted these features, because even in younger deposits mechanical features are rare. Only larger features, such as conchoidal breakage, have been preserved.

The most common chemical features are the etching pits. They are most abundant in sandy units. Also, in some deposits with very low garnet content (Diest Fm.), etching is very strong.
Other very common and striking features are the mounds (hillocks). These spherical structures, whose size is generally between 5 and 10 µm can cover complete grain surfaces. They are sometimes perforated by small rhombic etching pits, but usually mounds and etching pits do not occur on the same grain surfaces.
In some samples, more flattened mounds have been noticed, and in these cases, the structures were slightly imbricated, the narrow ends pointing in the same direction. Differences between these flattened mounds and IWMs were not very expressive (plate 3.b).
IWMs only have sporadically been observed. This confirms the conclusions of several authors, locating the formation of IWMs only at great burial depths (Morton, 1984, more than 2000 m).
There are striking morphological similarities between v-shaped and rhombic etching pits on one hand, and IWMs on the other hand : all features have top angles of 70-75°. On some grains, transition stages between rhombic pits and IWMs have been observed (plate 3.c).
One could think of three basic types of etching features, each evolving to different features with increasing corrosion:

1. v-shaped pits change into rhombic pits and eventually, if intrastratal solution becomes very strong, into imbricate wedge markings.
2. triangular pits evolve towards hexagonal pits.
3. mounds do not form out of etching pits. They are probably the result of a more steady solution of the grain surface, not located at crystal defects, as are etching pits.

In Belgian Meso-Cenozoic deposits intrastratal solution seems to be sufficient to form etching pits and mounds on a large scale, but conditions for the development of IWMs were seldom reached. Mounds and etching pits are therefore likely to be typical corrosion features on garnet in low to moderate burial depth conditions, IWMs are typical for deep burial.

3.2. Epidote

In total, 15 samples from Eocene, Oligocene and Neogene deposits were selected. Other units are very poor in this mineral.
Observations showed that surface features on garnet and epidote are different in many ways. The features on epidote are much more influenced by the good cleavage parallel to (100) and (001). Breakage blocks and cleavage plates are therefore well developed on many grains, and cleavage is often accentuated by solution.
Typical surface features on epidote have been recorded:

Etching slits : elongated pits, parallel to the c-axis (plate 4.b). These slits expand to form narrow, but very elongated furrows. In extreme cases, the grain is reduced to a bundle-like structure of needles (plate 3.d).
The v-shaped, rhombic or triangular etching pits, abounding on garnet, are very rare on epidote grains. This is also true for mounds and IWMs, which seem to be typical for garnet.
In general, mechanical features, such as furrows and impact pits are more abundant than on garnet grains in the same sample, although typical textures have not been observed (plate 4.a). This suggests that epidote is more resistant towards chemical corrosion than garnet.

3.3. Hornblende and actinolite

These two minerals have similar behaviour and characteristics and have therefore been considered as one group. Only 6 samples have been investigated, since amphiboles are very rare in deposits older than the Rupel Formation (Oligocene).
The behaviour of hornblende and actinolite is similar to that of epidote. There is a strong influence of cleavage direction (parallel to c-axis), accentuated by cleavage plates and etching features.
These features are narrow and elongated slits, parallel to [001]. Due to the lower stability, corrosion is much stronger, and often grains are skeleton-like bunches of needles. Consequently, mechanical features other than cleavage plates are totally absent.

3.4. Tourmaline

Tourmaline grains from 22 samples have been selected from the entire Mesozoic and Tertiary sequence. Observation shows that tourmaline grains almost exclusively bear features of mechanical origin, thereby proving the very stable nature of this mineral against weathering and intrastratal solution.
Typical cleavage-induced features are present: cleavage plates and blocks, furrows and parallel striation of the surface, directed along the [0001]-axis. In some cases, rounding of grains was quite advanced, and the cleavage features became less visible.
Unlike the other minerals examined, impact marks were frequently observed on tourmaline (plate 4 c,d; 5.a). They generally occur on convex faces of fairly to well rounded grains. Impact marks were v-shaped or curved (crescent marks), sometimes elongated and less regular. Larger impact marks, which we called "scatter marks", with upbroken, crater-like surfaces, have only been noticed sporadically. They seem to originate under high energy conditions, not occuring during deposition of Belgian Meso- Cenozoic deposits.
On prismatic grains, edges are often abraded, showing small crevices perpendicular to the edge (plate 5.b).
Chemical features, such as etching pits and mounds, are nearly totally absent.
Because of the stability of tourmaline, the possibility of inheriting older features on reworked grains is to be seriously considered. Their value for determining conditions of transport and deposition is therefore questionable.

4. CONCLUSION

Surface textures on heavy mineral grains are not very useful for determination of transport and sedimentation conditions of older deposits. On very stable minerals, like tourmaline, the mechanical features (impact features) are generally well preserved. Yet, these features are seldom indicative for a specific environment, since they can form under different conditions. Another huge problem is the possibility of reworking.
Minerals with lower stability, like garnet, epidote and amphiboles, are rapidly attacked by intrastratal solution or weathering. This causes a nearly complete destruction of previously formed mechanical features.
However, a detailed and quantitative study of the dissolution features might bring further understanding of geochemical processes in post-depositional weathering and diagenesis.
The most common surface textures on garnet are etching pits (v- shaped, rhombic or triangular) and mounds. In these features, there is an apparent evolution with increasing solution. Burial depth of Belgian Meso-Cenozoic sediments was too low to induce the formation of imbricate wedge markings.
Etching features on epidote and amphiboles are quite different from those on garnet: etching slits dominate, but hardly or no mounds and imbricate wedge markings are present.

ACKNOWLEDGEMENTS

Research for this publication has been carried as part of a N.F.W.O.-supported Ph.D. thesis. The author wishes to thank W. Bohyn and F. Martens (State University Ghent) for their assistance during the SEM work, as well as Prof. G. Stoops (State University Ghent) for critical reading and suggestions.

REFERENCES

BRAMLETTE, M.N., 1929 - Natural etching of detrital garnet. *Amer. Miner.*, **14**: 336-337.

BULL, P.A., 1977 - Glacial deposits identified by chattermark trails in detrital garnets : comment. *Geology*, **5**: 248.

EDELMAN, C.H., 1931 - Diagenetische Umwandlungserscheinungen an detritischen Pyroxenen und Amphibolen. *Fortschr. Miner. Krist. Petr.*, 16/1: 323-324.

FOLK, R.L., 1975 - Chatter-mark trails on glaciated garnets. *Proc. IX. Int. Congr. Sedimentol.*, Nice, Theme 1: 87-96.

GRAVENOR, C.P., 1985 - Chattermarked garnets found in soil profiles and beach environments. *Sedimentology*, **32**: 295-306.

HANSLEY, P.L., 1987 - Petrologic and experimental evidence for the etching of garnets by organic acids in the Upper Jurassic Morrison Formation, Northwestern New Mexico. *J. Sed. Petrol.*, **57**: 666-681.

KRINSLEY, D. & DOORNKAMP, J., 1973 - Atlas of quartz sand surface textures. *Cambridge University Press*, 91 p.

LE RIBAULT, L., 1977 - L'exoscopie des quartz. Editions Masson, Paris, 150 p.

MADER, D., 1985 - Diagenetic evolution of opaque and transparent heavy minerals reflecting colour genesis in Continental Fluvial Buntsandstein Red Beds of the Eifel (F.R. Germany). *In* : Mader, D. (Ed.). Aspects of fluvial sedimentation in the Lower Triassic Buntsandstein of Europe. *Lect. Notes Earth Sci.*, **4**: 531-560, Springer-Verlag, Berlin.

MAGALDI, D., 1977 - Microstrutture superficiali dei granati clastici in relazione all'ambiente di sedimentazione. *Boll. Serv. Geol. Ital.*, **98**: 117-128.

MAURER, H., 1982 - Oberflächentexturen an Schwermineralien aus der Unteren Süsswassermolasse (Chattien) der Westschweiz. *Eclogae geol. Helv.*, **75/1**: 23-31.

MORTON, A.C., 1979 - Depth control of intrastratal solution of heavy minerals from the Palaeocene of the North Sea. *J. Sed. Petrol.*, **49**: 281-286.

MORTON, A.C., 1984 - Stability of detrital heavy minerals in Tertiary sandstones from the North Sea Basin. *Clay Minerals*, **19**: 287-308.

MORTON, A.C., BORG, G., HANSLEY, P.L., HAUGHTON, P., KRINSLEY, D.H. & TRUSTY, P., 1989 - The origin of facets garnets in sandstones: dissolution or overgrowth ? *Sedimentology*, **36**: 927-942.

ORR, E.D. & FOLK, R.L., 1985 - Chattermarks garnets found in soil profiles and beach environments. Discussion. *Sedimentology*, **32**: 307-308.

RAHMANI, R.A., 1973 - Grain surface etching features of some heavy minerals. *J. Sed. Petrol.*, **43**: 882-888.

SALVINO, J.F. & VELBEL, M.A., 1989 - Faceted garnets from sandstone of the Munising Formation (Cambrian), northern Michigan : petrographic evidence for their origin by intrastratal dissolution. *Sedimentology*, **36**: 371-379.

SAUER, A., 1900 - Granat als authigenes Gemengtheil im Bunten Keuper. *Ber. Oberrhein. Geol. Verhandl.*, **33**: 42-46.

SETLOW, W.S. & KARPOVICH, R.P., 1972 - Glacial microtextures on quartz and heavy-mineral sand grains from the littoral environment. *J. Sed. Petrol.*, **42/4**: 864-875.

SIMPSON, G.S., 1976 - Evidence of overgrowths on, and solution of detrital garnets. *J. Sed. Petrol.*, **46/3**: 689-693.

VAN DER SLUYS, J., 1990 - Onderzoek naar mogelijke herkomstgebieden en studie van oppervlaktekenmerken van enkele zware mineralen uit Belgische Meso-Cenozïsche sedimenten. Th. Dr. Sc., n. publ., Gent, 110 p.

WOUTERS, L. & GULLENTOPS, F., 1988 - The sedimentology of the Westphalian D Neeroeteren sandstone, Kempen (Belgium). *Ann. Soc. Géol. Nord*, **CVII**: 191-202.

Manuscript received on 3 February 1992 and accepted for publication on 18 March 1992.

SAMPLE IDENTIFICATION	MECHANICAL FEATURES					CHEMICAL FEATURES				
	A	B	C	D	E	F	G	H	I	J
A. GARNET										
Triassic-Jurassic										
Arlon well/219E 254/-166 m Rhetian		*			*	*			•	
Arlon well/219E254/-99,5 m Sinemurian			*		*	*		•	*	
Arlon well/219E254/-53 m Sinemurian					*	***				
Cretaceous										
Thieu Weald-Thieu Fm.			*			*		*		
Bettrechies Cenomanian			*	*						
Autreppe Turonian			*	*	•	•				
Orp-le-Petit Maastrichtian		*	*	*		**			•	
Paleocene										
Gelinden Heers Fm.										
Chercq Landen Fm./Chercq Mb.			*	*		*		*	*	
Wansin Landen Fm./Lincent Mb.						**				
Lincent Landen Fm./Lincent Mb.			*	*		*		*		
Eocene										
Kortemark Ieper Fm./Vlaanderen Mb.				•		*				
Marke Ieper Fm./Vlaanderen Mb.			*			*		*		
Ieper Ieper Fm./Vlaanderen Mb.								*		
Hooglede Ieper Fm./Egem Mb.					*	*		**		
Hooglede Ieper Fm./Egem Mb.					*					
Mol well/31W237/-350 m Ieper Fm.			*			*		*		
Kallo well/27E148/-268,5 m Ieper Fm.			•		*					
Hooglede Mt.-Panisel Fm./Pittem Mb.			*			**		**	*	
Hooglede Mt.-Panisel Fm./Pittem Mb.						*		*	*	
Melle Mt.-Panisel Fm./Pittem Mb.			*		*	**		*		
Appels Mt.-Panisel Fm./Vlierzele Mb.					*	**				
Oedelem Den Hoorn Fm./Oedelem Mb.				*		*		*		
Aalter Den Hoorn Fm./Aalter Mb.			*		*	***		**		
Gobertange Brussels Fm.						**			•	
Braine-l'Alleud Brussels Fm.			*			•		•		
Balegem Lede Fm.			*		*	**		*		
Balegem Lede Fm.						•		•		
Meldert Lede Fm.			*			**		**	*	
Asse Kallo Fm./Wemmel Mb.								*		
Asse Kallo Fm./Asse Mb.					*	**		*	•	

SAMPLE IDENTIFICATION	MECHANICAL FEATURES					CHEMICAL FEATURES				
	A	B	C	D	E	F	G	H	I	J
Lokeren Kallo Fm./Ursel Mb.					**	**		*	*	
Asse Kallo Fm./Onderdale Mb.			*		*	•		•		
Asse Kallo Fm./Zomergem Mb.						*		•		
Waasmunster Kallo Fm./Buisputten Mb.				*		•		•		
<u>Oligocene</u>										
Watervliet Zelzate Fm./Bassevelde Mb.		*	*			*				
Henis Tongeren Fm./Neerrepen Mb.					*	***		**		
Pellenberg Tongeren Fm./Kerkom Mb.						***		*		
Pellenberg Tongeren Fm./Kerkom Mb.		*	*			*		***		
Boom Rupel Fm./Boom Mb.		**			*					
St. Niklaas Rupel Fm./Boom Mb.						**				
Rumst Rupel Fm./Boom Mb.					*	**		*		
Houthalen Voort Fm.			*		*	*		**		
<u>Miocene</u>										
Rumst Berchem Fm.					*	*				
Borgerhout Berchem Fm.					•	*			*	
Gelrode Diest Fm.						**		*		
Ramsel Diest Fm.					*	**		**		
Deurne Diest Fm.					*	*				
<u>Pliocene</u>										
Antwerpen Kattendijk Fm.			*			*		*		
Antwerpen Kattendijk Fm.					*			*		
Antwerpen Lillo Fm.			*	*	*	*		*	*	
Antwerpen Lillo Fm.						*			•	
Herentals Poederlee Fm.						*		*		
<u>Tertiary High-Belgium</u>										
Pessoux		*		•	*	***			*	
B. EPIDOTE										
<u>Eocene</u>										
Zwevegem Ieper Fm./Vlaanderen Mb.		*	*	*			*			•
Aalbeke Ieper Fm./Vlaanderen Mb.							*	*		*
Lendelede Mt.-Panisel Fm./Pittem Mb.	*	*	*	*						
Hooglede Mt.-Panisel Fm./Pittem Mb.				*	*	*				*
Appels Mt.-Panisel Fm./Vlierzele Mb.		*	*	•	*					
Woluwe Brussels Fm.			*	*	*	•	•			

SAMPLE IDENTIFICATION	MECHANICAL FEATURES					CHEMICAL FEATURES				
	A	B	C	D	E	F	G	H	I	J
Oligocene										
Watervliet		*		*	*	*	**	•	•	*
Hoeleden Tongeren Fm./Neerrepen Mb.			*				**	•		
St. Niklaas Rupel Fm./Boom Mb.			*	*	*	*				
Rumst Rupel Fm./Boom Mb.		*		•	*	*	*			*
Mio-Pliocene										
Rumst Berchem Fm.				*	*	•		•		*
Gelrode Diest Fm.		*	*	*	*	*				
Antwerpen Kattendijk Fm.		*	*	*	•					
Antwerpen Lillo Fm.			*		*					
Lichtaart Poederlee Fm.			*	*	*	*	**			
C. HORNBLENDE-ACTINOLITE										
Oligocene										
Henis Tongeren Fm./Neerrepen Mb.							***			
St. Niklaas Rupel Fm./Boom Mb.				***						
Mio-Pliocene										
Gelrode Diest Fm.				*			**			*
Antwerpen Kattendijk Fm.				*			*			
Antwerpen Lillo Fm.				*			*			
Herentals Poederlee Fm.				*			***			*
D. TOURMALINE										
Paleocene										
Racour Landen Fm./Lincent Mb.	*	*	*	*						
Chercq Landen Fm./Chercq Mb.				*	*					
Eocene										
Lauwe Ieper Fm./Vlaanderen Mb.		**		*	*					
Lendelede Mt.-Panisel Fm./Pittem Mb.		*		*	*					
Appels Mt. Panisel Fm./Vlierzele Mb.		*		*	*					
Braine-l'Alleud Brussels Fm.	*	**	*	*	*					
Halle Brussels Fm.		***		*	*					
Braine-le-Comte Brussels Fm.		***		**	*					
Nederokkerzeel Lede Fm.		**	*		*					
Balegem Lede Fm.		**		***	*					
Asse Kallo Fm./Onderdale Mb.		*	*	*	•					

SAMPLE IDENTIFICATION	MECHANICAL FEATURES					CHEMICAL FEATURES				
	A	B	C	D	E	F	G	H	I	J
Oligocene										
Waasmunster Zelzate Fm/Watervliet Mb.	*	*		•	•					
Watervliet Zelzate Fm./Watervliet Mb.	*	**	*	**	*					
Kerkom Tongeren Fm./Kerkom Mb.	*	**	*	*	*					
Hoeleden Tongeren Fm./Kerkom Mb.	*	***	*	•	*					
Pellenberg Rupel Fm./Berg Mb.		*		*	*					
Boom Rupel Fm./Boom Mb		*		•	•					
Houthalen Voort Fm.		**		*						
Mio-Pliocene										
Rumst Berchem Fm.		*	*	*						
Loksbergen Diest Fm.		*	*	**	*					
Antwerpen Kattendijk Fm.		*		*						
Lichtaart Poederlee Fm.		**		*	*					

Table 1. Surface features on heavy minerals.
A. Scattermarks - B. Impact marks v- or crescent-shaped - C. irregular pits - D. cleavage plates - E. conchoidal breakage - F. etching pits - G. etching slits H. mounds - I. IWMs J. hacksaw.

*** abundant
** frequent
* rare
• sporadically observed

PLATE 1

a. Garnet grain with different mechanical features: furrows (upper part), small v-shaped impact marks, crescent marks (right), scatter mark (center). Ile de Groix, Brittany, recent littoral sands (274 x)

b. Garnet grain with conchoidal breakage. Ciney-Pessoux, Tertiary deposits of High-Belgium (549 x)

c. Idiomorphic garnet grain with nicely developed v- shaped etching pits. Wansin, Landen Fm., Lincent Mb./U. Paleocene (1050 x)

d. Garnet grain with mounds and large triangular etching pits, developing to hexagonal pits. Limburg, Pleistocene Meuse Terrace Gravel (326x)

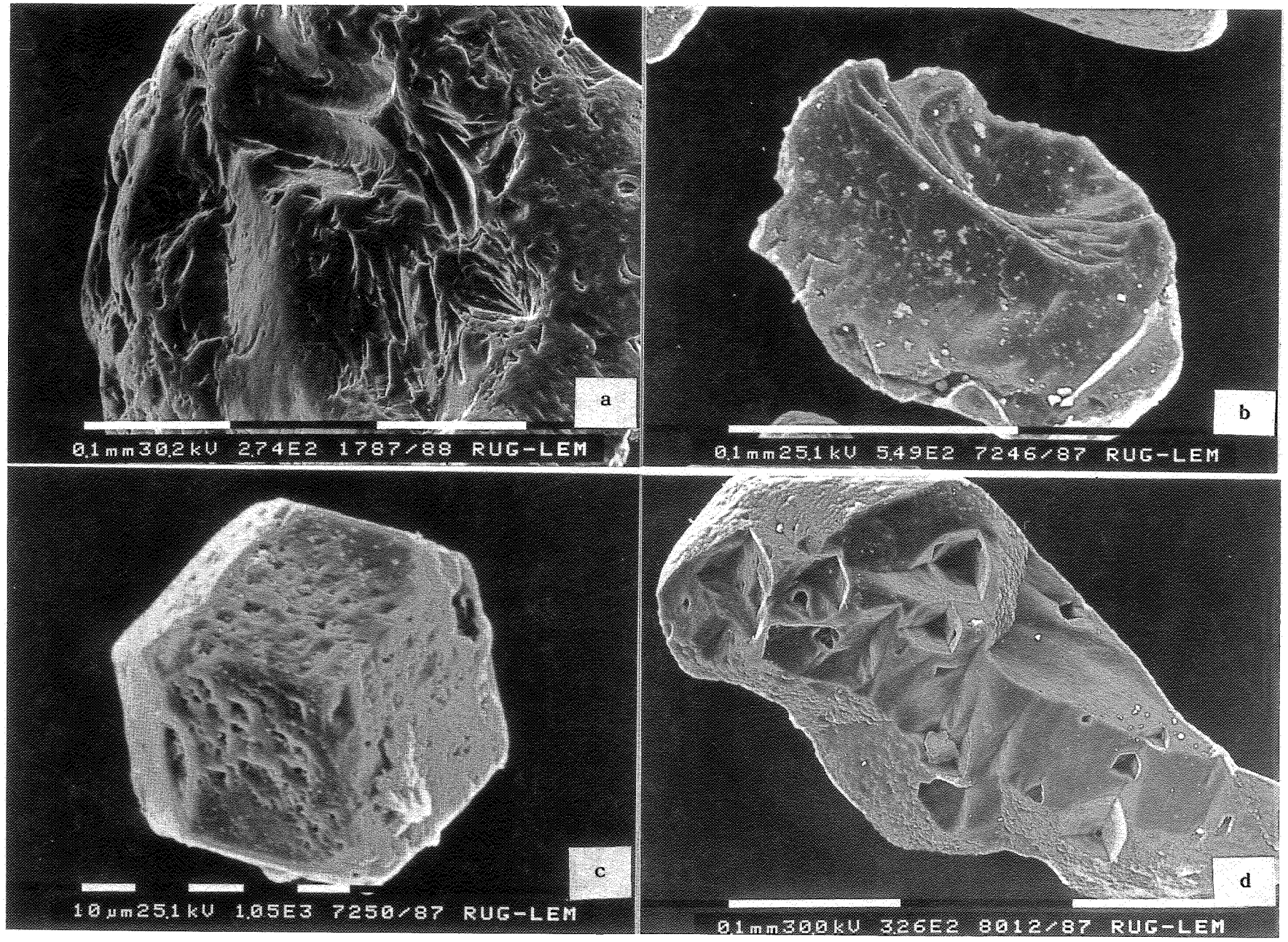

a
0,1mm30,2kV 2,74E2 1787/88 RUG-LEM
b
01mm25,1kV 5,49E2 7246/87 RUG-LEM
c
10µm25,1kV 1,05E3 7250/87 RUG-LEM
d
01mm300kV 3,26E2 8012/87 RUG-LEM

PLATE 2

a. Very small rhomb-shaped pits, mounds (right). Mol well (BGD 237, 349.9m), Ieper Fm./L. Eocene (1050 x)

b. Rhomb-shaped etching pits and mounds, neatly separated on different grain surfaces. Asse, Kallo Fm., Wemmel Mb./U. Eocene (1050 x)

c. Big hexagonal etching pit. Pellenberg, Tongeren Fm., Kerkom Sds. Mb./L. Oligocene (965 x)

d. Garnet grain covered with mounds. Pellenberg, Tongeren Fm., Kerkom Sds. Mb./L. Oligocene (1360 x)

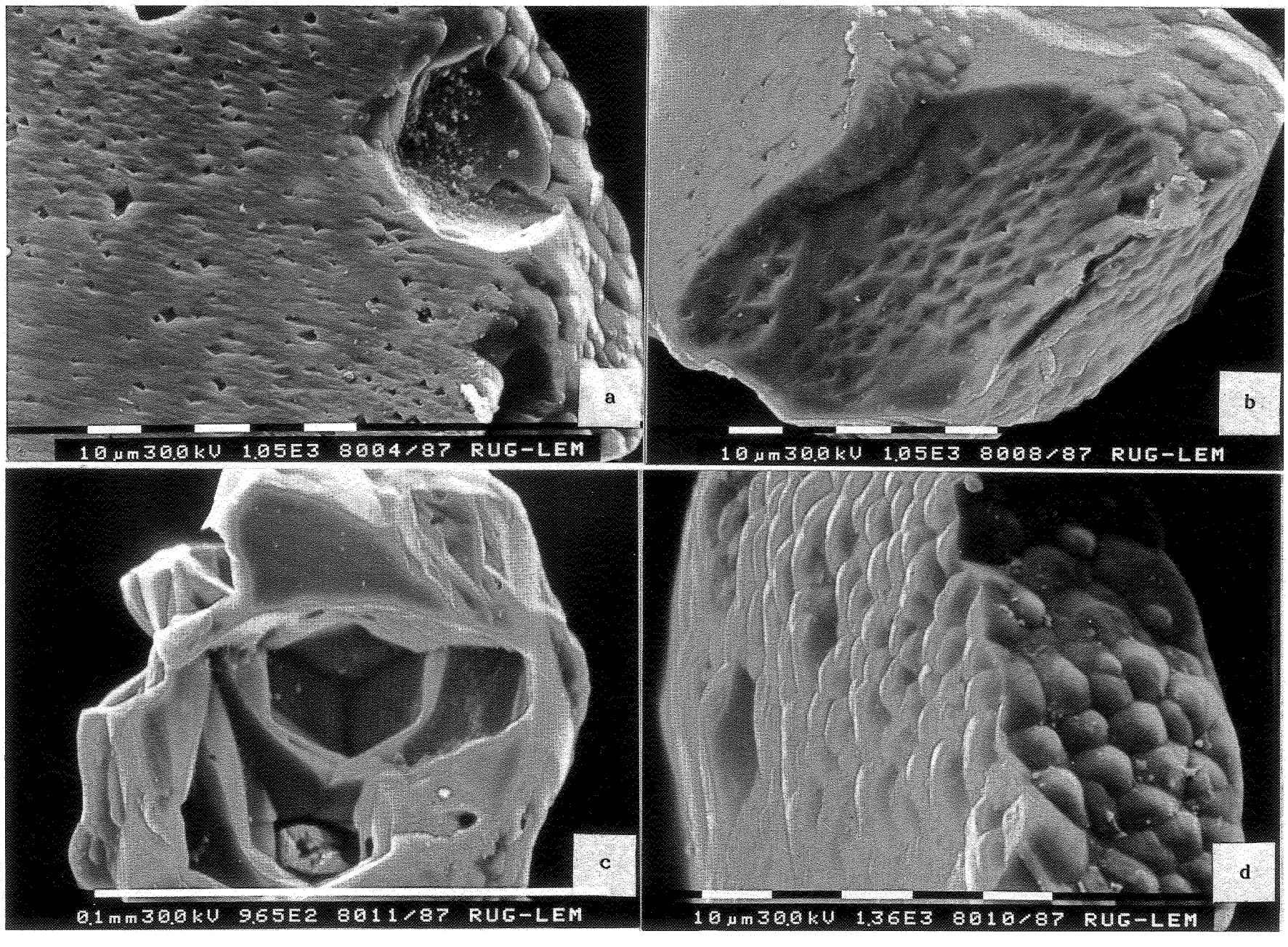

a
10µm30.0kV 1.05E3 8004/87 RUG-LEM
b
10µm30.0kV 1.05E3 8008/87 RUG-LEM
c
0.1mm30.0kV 9.65E2 8011/87 RUG-LEM
d
10µm30.0kV 1.36E3 8010/87 RUG-LEM

PLATE 3

a. Garnet grain with well developed imbricate wedge markings. Watervliet. Zelzate Fm., Watervliet Mb./L. Oligocene (820 x)

b. Garnet grains with flattened mounds, resembling imbricate wedge markings. Lokeren, Kallo Fm., Asse Mb./U. Eocene (1280 x)

c. Detail of an idiomorphic garnet grain, with rhomb- shaped etching pits, transforming to imbricate wedge markings. Orp, Maastrichtian, Upper Cretaceous (1450 x)

d. Epidote grain with typical etching pattern: elongated etching slits, parallel to cleavage. Aalbeke, Ieper Fm., Vlaanderen Mb./L. Eocene (420 x)

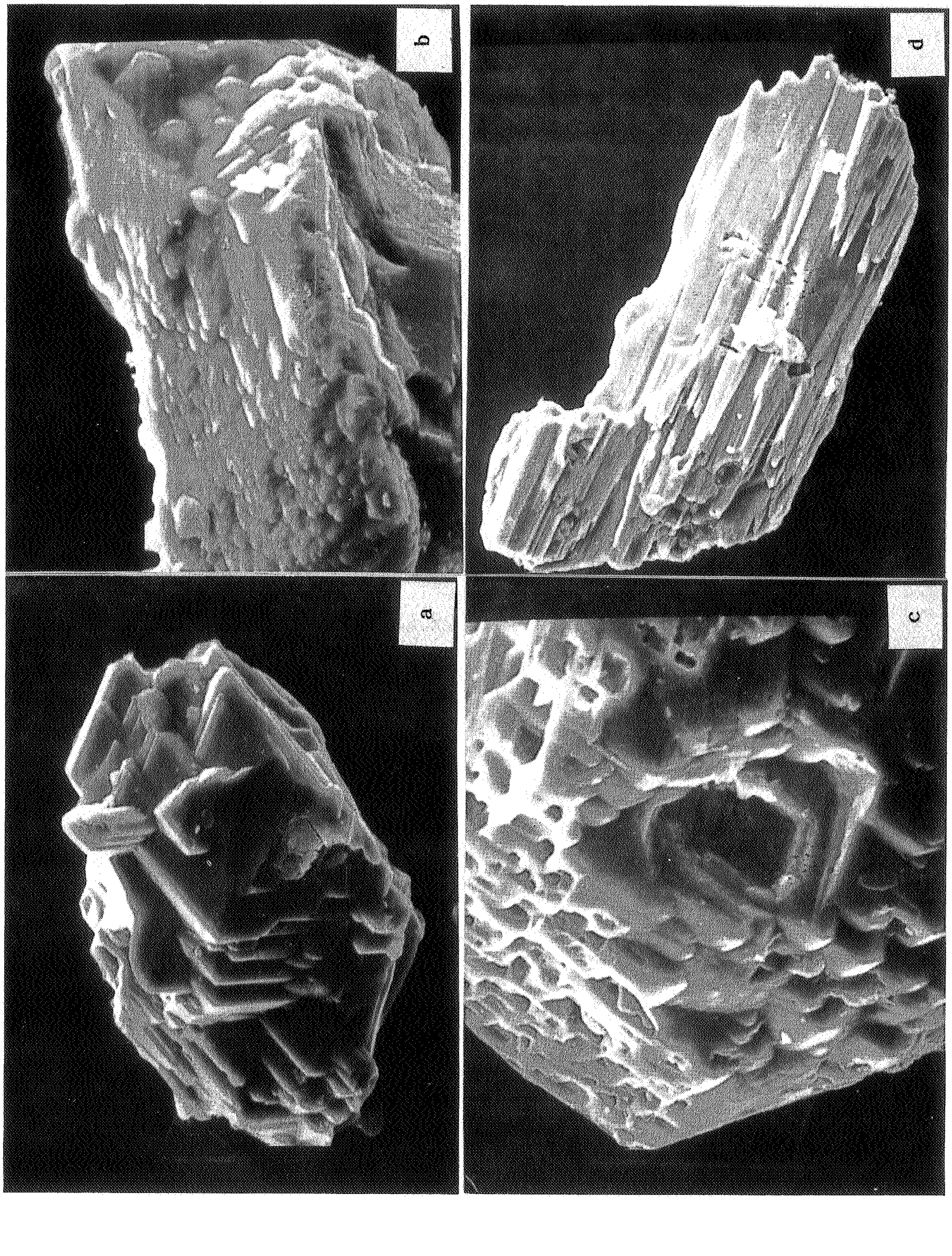

a
b
c
d

PLATE 4

a. Epidote grain with rough surface, breakage blocks, irregular pits of mechanical origin. Zwevegem, Ieper Fm., Vlaanderen Mb./L. Eocene (1300 x)

b. Epidote grain with small etching slits. Rumst, Rupel Fm., Boom Mb./M. Oligocene (1050 x)

c. Tourmaline grain with v-shaped impact marks and crescent marks. Lauwe, Ieper Fm., Vlaanderen Mb./L. Eocene (530 x)

d. Tourmaline grain with v-shaped and elongated impact pits. Braine-le-Comte, Brussels Fm./M. Eocene (450 x)

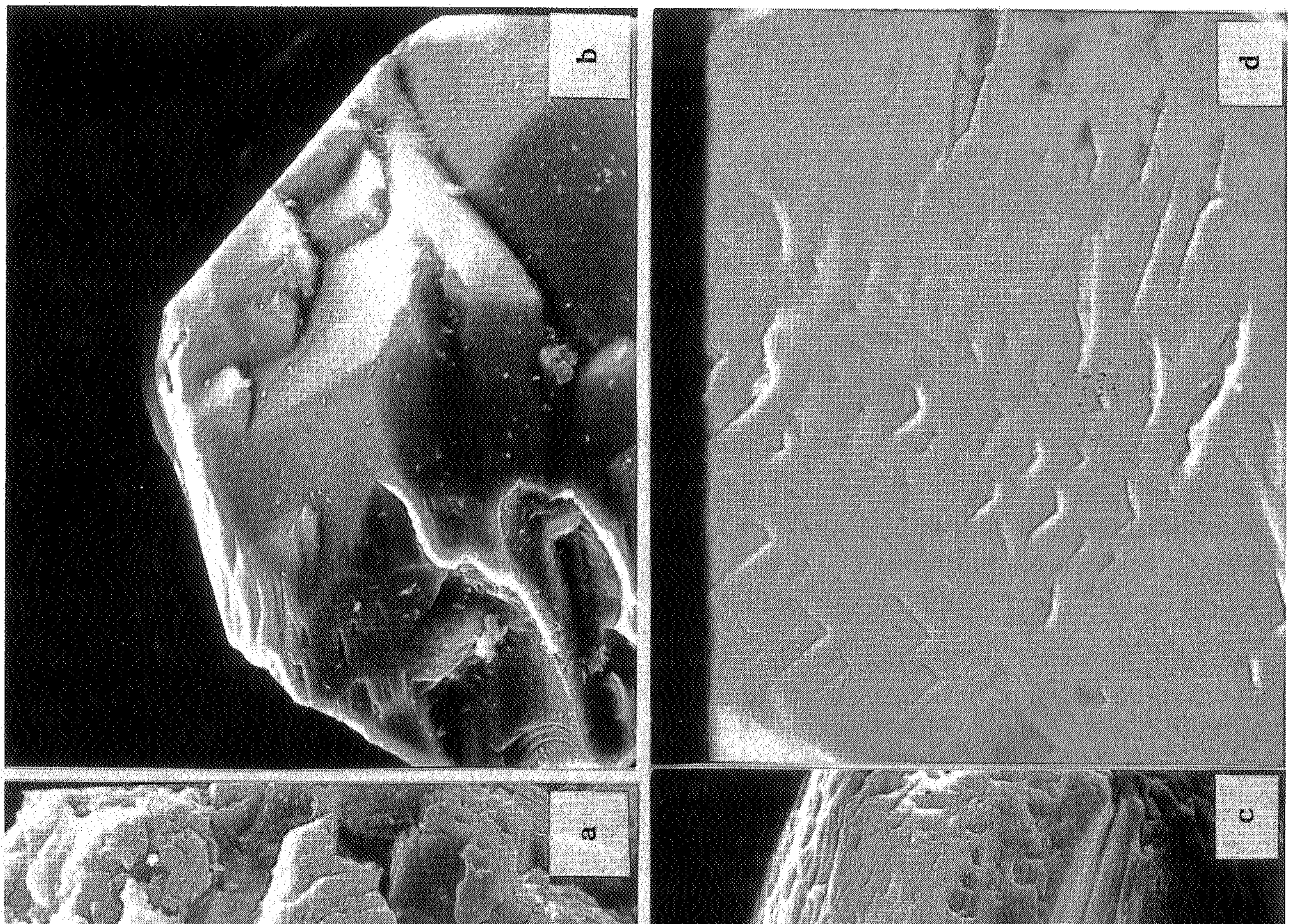
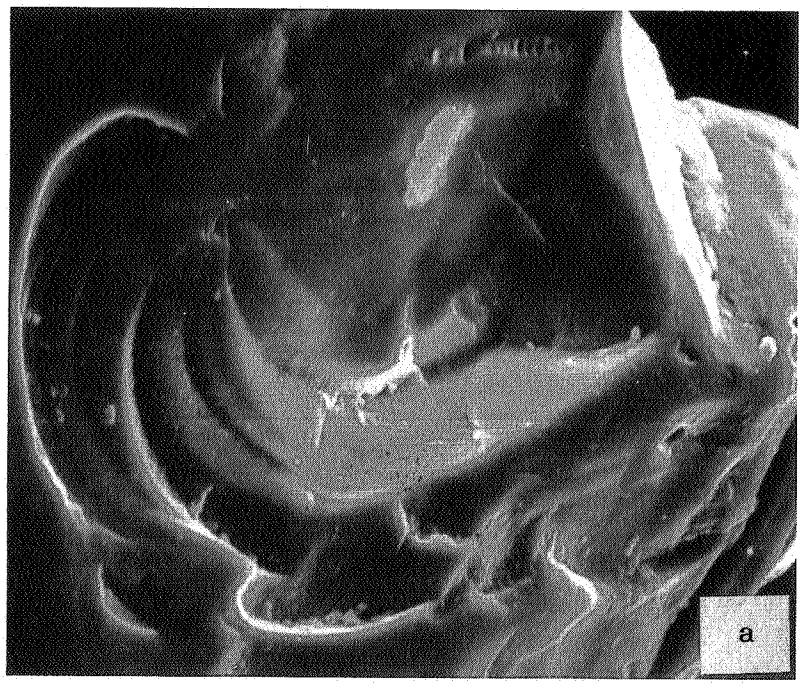
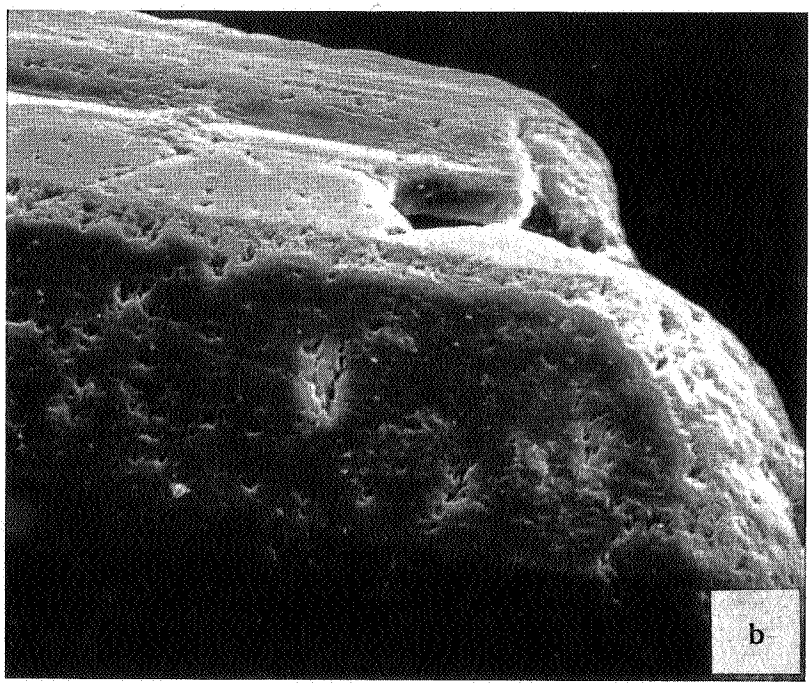

a
b
c
d

PLATE 5

a. Tourmaline grain with conchoidal fracture. Nederokkerzeel, Lede Fm./M. Eocene (700 x)

b. Prismatic tourmaline grain with broad edges, roughened by small, irregular crevasses. Antwerpen, Kattendijk. Fm./Miocene (870 x)


a


b