PEL 251

ENVIRONMENT OF DEPOSITION AND STRATIGRAPHY OF THE URANIUM-BEARING STRATA AROUND BEAUFORT WEST, SOUTH AFRICA

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SAMEVATTING

Nagenoeg 50 monsters van uraanhoudende strata – en van hulle aangrensende onderste en boonste lae – rondom Beaufort-Wes, Suid-Afrika, is palinologies ontleed. Die resultate toon dat hierdie sedimente gedurende Laat Permiese tye in 'n wye, effens vlak delta afgeset is.

Die meeste van die sedimente is fluvio-deltaïes en die grootste hoeveelheid plantreste is van die noorde af vervoer, die hinterland in daardie tye. 'n Aansienlike deel van die mikrofossiele, bv. *Veryhachium* en hystrichospheres, is ongetwyfeld van marine-oorsprong.

Die voorkoms van marinemikrofossiele in die gebied, in vergelyking met dié met die land as herkoms, neem suidwaarts aansienlik toe.

ABSTRACT

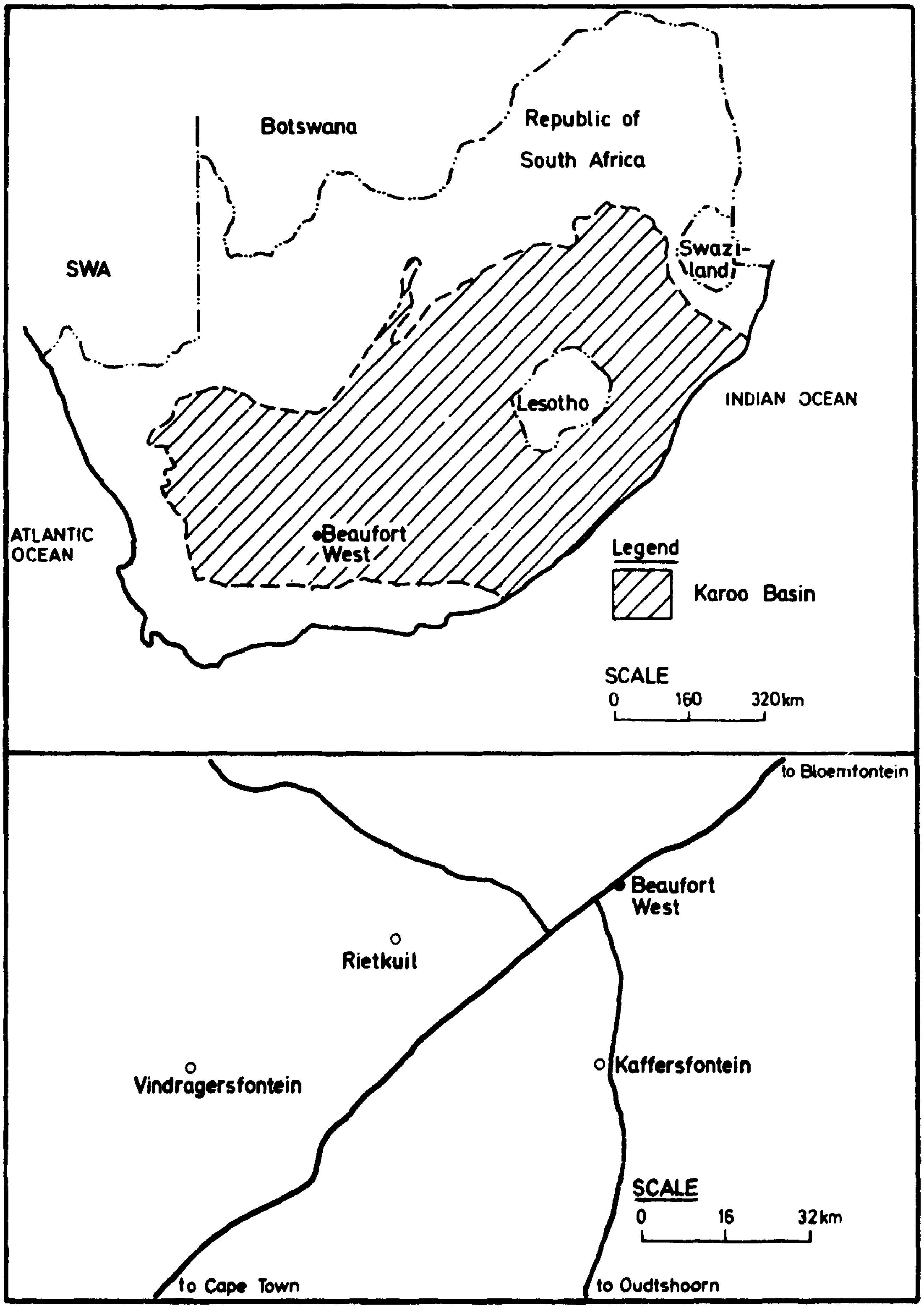
Palynological analyses of some 50 samples collected from uranium-bearing strata – as well as the layers immediately above and below them – around Beaufort West, South Africa, indicate that these sediments were laid down in a wide, rather shallow delta in Late Permian times.

Most of the sediments are fluvio-deltaic, and most of the plant remains were transported from the north, the hinterland in those times. A considerable percentage of the microfossils, e.g. *Veryhachium* and hystrichospheres, are clearly from a marine environment.

The occurrence of marine microfossils in the spectrum, as compared with those of terrestrial provenance, increases considerably southwards.

ACKNOWLEDGEMENTS

I am deeply indebted to Professor E.M. van Zinderen Bakker, Head of the Institute for Environmental Studies, University of the Orange Free State, who in collaboration with Dr. J.W. von Backström, Director: Geology Division of the Atomic Energy Board initiated and took the trouble to organize this study. I also wish to express my gratitude to the following: the Institute for Environmental Studies where the study took place, and the people working there who assisted me in every possible way, especially Mr L. Scott and Mrs Boutcher, the Union Carbide and Southern Sphere Mining and Development Companies and their field geologist who supplied me with the samples as well as the South African Atomic Energy Board who financed the research.



MAP 1: APPROXIMATE LIMITS OF THE KAROO BASIN IN SOUTH AFRICA AND LOCATION OF BOREHOLES AROUND BEAUFORT WEST.

1. INTRODUCTION

Sporadic uranium occurrences have been discovered during recent years around Beaufort West, approximately at the border of the *Tapinocephalus* and the *Cisticephalus* Zones (Kitching, 1970) of the Lower Beaufort Series of the Karoo Supergroup. The uranium minerals are disseminated in fine sandstone and occur in a number of horizons which are at present confined (von Backström, 1974) to the Lower Formation of the Beaufort Group.

The Lower Formation mainly comprises alternating sandstone, shale and mudstone layers, with some chert lenses. The bedding is irregular and facial changes are rapid. The uranium mineralization is associated with deposits formed along erosion channels, with bone debris and with carbonized material. The uranium-bearing rocks are mostly dense and non-porous. Up to now the only theory as to the origin of the ore (von Backström, *op. cit.*) favours "both syngenetic and secondary origin".

The present study, in which palynological methods were applied, aimed at discovering whether the uranium deposition was connected with any definite palaeo-environmental factors. In discussing this, a different working hypothesis is suggested, namely that the uranium is not a secondary, but a primary deposit carried by groundwater, that it was deposited under atmospheric conditions and was subject to environmental influences. In neither case is a source known or suggested for the uranium-bearing solutions.

In addition to a discussion of the environmental factors, the present study aims at a better stratigraphic age definition of the uranium-bearing strata in order to facilitate correlations with other rock units in which uranium might still be discovered.

Except for a preliminary report on the uranium finds (von Backström, *op. cit.*) and a general account of the stratigraphy of the entire Beaufort Group (Kitching, 1970), almost no previous studies have been published on this subject. The litho-stratigraphy and correlations of some deep boreholes in the vicinity were studied generally by Winter and Venter (1970), and a number of general geological accounts are also available. The only palynological study of the uranium-bearing strata was carried out by R.P. Stapleton (1975); however, this is only of a preliminary nature.

The Beaufort palynoflora was studied in more detail by Anderson (1975), but only in the northern part of the Karoo. The lastmentioned is a thorough and most detailed study of the palynoflora, and was of much help during the present work.

2. SAMPLING

Samples were collected from three areas, all in the vicinity of Beaufort West (Map 1).

2.1 Rietkuil

Samples were collected from boreholes and outcrops. The outcropping sequence, including the layers below and above the uranium-bearing horizons, was sampled in the field. About 20 samples were collected, ranging from clays to medium-grained sandstones. Particulars of these samples are not given here, since they did not yield any palynological material, most probably due to surface oxidation.

The boreholes, all of them continuously cored, were sampled in more detail. Altogether, 54 core samples were collected from nine boreholes. The depths at which samples were taken are given in metres below or above the ore horizon, which was taken as datum. The lithological descriptions, as well as particulars of the local geology, were provided by the field geologists of Union Carbide Co.

A list of the borehole samples follows:

Borehole No.	Sample No.	Elevation (metres)	Lithology
5097/c	1	−9,0	light-green siltstone
	2	−6,0	light-green siltstone
	3	−3,2	light-medium grey-green, fine to very fine sandstone
	4	−2,8	grey-green mudstone conglomerate
	5	+5,5	light-grey fine sandstone
	6	+8,5	light-grey fine sandstone
	7	+12,6	light-green silty shale
	8	+18,0	light-grey-green silty shale
	9	+23,0	light-grey siltstone
	10	+24,4	light-grey-green siltstone
5005/c	11	+14,4	medium-grey-green siltstone
	12	+11,4	medium-grey-green siltstone
	13	+7,9	light-grey sandy siltstone
	14	+2,3	light-grey sandy siltstone
	15	−1,7	medium-grey silty shale
	16	−5,2	light-grey-green shale
5009/c	17	+18,3	light-grey-green siltstone
	18	+8,4	light-medium grey-green very fine sandstone
	19	0	medium-grey fine to very fine sandstone
	20	−1,2	dark-grey fine sandstone
	21	−5,2	medium-grey-green siltstone
5037/c	22	+15,5	medium-grey-green siltstone
	23	+10,9	medium-purple-grey siltstone
	24	+3,4	medium-green mudstone
	25	0	dark-grey fine sandstone
	26	−3,1	medium-green shale
4969/c	27	+12,8	medium-green silty shale
	28	+8,4	medium-grey fine sandstone
	29	+4,3	light-green siltstone
	30	0	medium-grey-green siltstone
	31	−4,8	light-medium-grey fine sandstone
5033/c	32	+15,7	medium-purple-green siltstone
	33	+10,0	medium-grey-green siltstone
	34	+2,7	medium-green shale
	35	−1,6	medium-grey-green sandy siltstone
4913/c	36	+25,7	medium-green shale
	37	+22,5	medium-green siltstone
	38	+12,0	medium-green sandy siltstone
	39	+6,5	medium-green silty sandstone
	40	−1,4	light-grey-green siltstone
	41	−7,0	light-green shale
4861/c	42	+7,0	light-grey fine sandstone
	43	+5,0	light-grey fine sandstone
	44	+2,0	medium-grey-green sandy siltstone
	45	+0,5	light-green shale
	46	−0,5	light-green shale
	47	−4,7	light-grey-green siltstone
5041/c	48	+14,8	medium-green siltstone
	49	+6,0	medium-green shale
	50	+4,5	medium-grey-green siltstone
	51	+1,0	medium-dark-grey fine sandstone
	52	−0,7	light-medium-grey fine sandstone
	53	−2,3	medium-grey and green mudstone conglomerate
	54	−3,5	light-grey-green shale

2.2 Kaffersfontein

One borehole, designated by Southern Sphere Mining and Development Co, KF GG-21, was sampled from this locality. The borehole reached a total depth of 80,40 m and was sampled at approximately every metre.

The lithology (by H.F. Klingheil) is as follows:

Depth in metres	Description
0–17,34	Grey to grey-purple shale
17,34–23,07	Grey, massive, highly argillaceous sandstone; weakly calcareous mudstone; pebble conglomerate
23,07–60,00	Dark-grey to purple mudstone and shale
60,00–66,70	Grey, massive, argillaceous sandstone
66,70–69,00	Dark-grey shale and mudstone
69,00–76,53	Grey, massive to laminated, fine sandstone
76,53–80,40	Grey-green shale

2.3 Vindragersfontein

One borehole, drilled by Southern Sphere Mining and Development Co. and designated VD 286C, was sampled from this farm. The borehole reached a total depth of 77,5 m. From 15,73 m downwards to a depth of 77,00 m samples were taken at approximately every metre. The lithology (by R. Jackson) is generally grey siltstone and mudstones, with occasional fine sandstones and shales.

3. PREPARATION

All the samples, i.e. those from the outcrops as well as from the boreholes, were given the same treatment for separation of the palynomorphs. The process comprised crushing of the samples down to 2 mm particle size, dissolving in warm hydrofluoric acid for 48 h, washing in 10 % hydrochloric acid, mineral separation using a zinc chloride solution with a specific gravity of 1,9, and mounting in glycerin-gelatin.

The slides and residues are kept in the palynological collection of the Institute for Environmental Sciences, at the University of the Orange Free State, Bloemfontein. The analyses and microphotographs were taken with a "Zeiss" photomicroscope (No. 20291) of the same Institute.

4. RESULTS

4.1 Rietkuil

The outcrop samples were almost void of any organic remains, save for some specks of highly carbonized material.

The core samples were much better for analysis, due to a better preservation of the organic remains. The following account is therefore based only on the occurrences in the boreholes. Generally speaking, the state of preservation and the amount of analyzable sporomorphs are poor to very poor.

Most of the samples are very rich in carbonized organic material (Plates 2, 3, 4) and in remains of plant tissues (Plate 5). There is a medium degree of carbonization, and details of the plant tissues can be easily recognized. Samples rarely display a high degree of carbonization. The medium carbonization still allows for analysis of the sporomorphs, and sometimes even fine details are observed. Some of the samples (Plate 1) show considerable amounts of amorphous organic material. These contain almost no sporomorphs or other organic materials.

Palynomorphs are present in most of the samples, although in very low quantities compared with the rest of the organic material. Most of the palynomorphs are badly preserved, but this is always caused by breaking down and is not due to excessive carbonization, oxidation or bacterial activity. A noticeable phenomenon is the almost total absence of large sporomorphs, the spectrum comprising only the small forms. Rarely, some remains of large sporomorphs occur (plate 13, 1), but these are badly broken. The following sporomorphs were recorded:

Alete sporomorphs:
- Fungi spores
- *Perisaccus granulatus*, Klaus 1963
- Three different species of *Apiculatasporites*, one of which is probably *A. minimus* (Plates 16, 4–7).

Monolete sporomorphs:
- Three unidentified species

Trilete sporomorphs:
- *Gondisporites parvus*, Anderson 1975
- *Altitriletes densus*, Venkatachala and Kar 1968
- *Microbaculispora virkkiae*, Tiwari 1965
- *Maculatasporites indicus*, Tiwari 1965
- Three different species of *Gondisporites*
- *Leiotriletes* sp.
- *Apiculatisporites* sp.
- Two different species of *Acanthotriletes*.

Saccate sporomorphs:
- *Vittatina nonsaccata*, Anderson 1975
- *Vitreisporites pallidus*, Reissinger 1965
- *Vittatina* sp.
- *Taeniaesporites* sp.
- Two species of *Pityosporites*
- *Alisporites* sp.

Sporomorphs of uncertain affinity:
- *Tetraporina superba*, Mahesh and Bose 1969

Besides the sporomorphs, most of the samples also contain unicellular algal rests. These comprise up to 50 % of the total number of palynomorphs per sample. The algal rests are generally fairly well preserved, some of them even showing minute details of their spines and protrusions. The most common are a number of species of *Veryhachium*, among which could be identified:

- *Veryhachium hyalodermum*, Deunff 1958
- *V. tzutsii*, Horowitz 1974
- *V. reductum*, Deunff *ex* Jekhowsky 1961
- *V. longispinum*, Horowitz 1973

At least two different species of hystrichosphaerids were discerned, but an exact identification was not favoured because of their rather poor state of preservation and the lack of material for comparison.

A number of acritarchs are also present in most samples:

Two or three species of *Multisphaeridium*
Microhystridium parvispinum, Deflandre 1946
Solisphaeridium rossignolii, Glikson 1966

A general scanning of the slides indicated a relatively large number of spore and algal wall remains which are hopelessly broken, but for the most part non-carbonized.

4.2 Kaffersfontein and Vindragersfontein

Samples from these two boreholes and those from Rietkuil proved to be poor to very poor in palynological material. The assemblages recovered from both are very similar, and will therefore be treated as a single assemblage.

Characteristic of this assemblage is the predominance of acritarchs and hystrichosphaerids (Plates 9, 10), and the almost total absence of palynomorphs of any sort, except for some rare, small ones (Plate 16). The marine microfossils comprise some 98 % of the spectrum and are quite well preserved, with no signs of carbonization. On the other hand those of continental provenance are highly carbonized and their state of preservation does not allow their exact identification. The share of *Veryhachium* within the marine microfossils' spectrum is rather low, and most of them are acritarchs and hystrichosphaerids that could not be identified according to the available literature. They seem to belong to at least one new genus and two or three new species.

Plant tissues are quite rare, and those that do occur are very highly carbonized and rolled. The rest of the carbonaceous material, also highly carbonized, comprises only small to very small particles (Plate 4) which are much smaller in relation to those encountered in the Rietkuil samples.

5. DISCUSSION

Due to the relative scarcity and poverty of the material, and the rather limited stratigraphic span from which the samples were collected, it seems that each of the localities can be treated as a single palynofloristic unit. In addition, most of the samples from each locality show the same palynological characteristics, which further seems to justify this method of treatment.

The sporomorphs, mainly recovered from Rietkuil, and especially the monoletes, the triletes and the vesiculate forms (the *Tetraporina* may be included in this group as well), taken as a single assemblage, do not favour an exact palynostratigraphic allocation of the strata, due both to the poor number of species and to the lack of other palynostratigraphic studies of the area and the sequence. However, a comparison with the assemblages recovered by Anderson (1975) in the northern parts of the Karoo Basin, seem to point to the similarity between the spectrum now under investigation and the one described by Anderson from the *Tapinocephalus* and *Cisticephalus* equivalent zones, tentatively assigned a Late Permian age. Similar forms were also found in sediments attributed to the same age in Israel (Horowitz, 1973a), Australia (Glikson, 1966) and India (Kar, 1969, and others). The rather limited number of species and the majority of *striatiti* forms agree in general with the typical Gondwanan characteristics outlined in Hart (1970) and in Horowitz (1972). These characteristics most probably indicate a temperate to cool climate.

The presence of marine microfossils, especially the *Veryhachium* species and the hystrichosphaerids, surprises every student of the Karoo sequence. For many years this sequence of rocks was thought to have been deposited in a typical continental environment (du Toit, 1954; Truswell, 1970, and many others). The first indication, however, that marine hystrichosphaerids are present in the southern part of the Lower Beaufort was given by R.P. Stapleton (1975). Most of the forms found in the Beaufort West area during the present study are known from the Late Carboniferous, Permian and Triassic of Israel (Horowitz, 1973a, b; 1974). These microfossils seem to be of no significant stratigraphic indication in the Middle East, but of a great palaeo-environmental importance (Horowitz, 1974a). The assemblage, as it appears in the Beaufort West samples, of a rather varied speciation of *Veryhachium*, seems to indicate the outer part of a delta with a rather pronounced marine influence.

The greater prevalence of marine microfossils towards the south, in the Kaffersfontein and the Vindragersfontein samples (in which more and more acritarchs and hystrichosphaerids also occur), together with the absence of any large sporomorph and the carbonized state of the rare ones that do occur, indicate that the open sea lay in this direction during Lower Beaufort times.

The other characteristics of the palynofacies seem to corroborate this conclusion well: the wealth of plant and other organic debris in Rietkuil, all broken and rolled, diminishing considerably southwards; the prevalence among the sporomorphs, of the small types, and the scarcity of the large forms, together with the relatively large amounts of broken spore walls on Rietkuil and the almost total absence of sporomorphs in the other localities; the much better preservation of the algal and hystrichosphaerid material as compared with the sporomorphs, and the relative increasing poverty in sporomorphs as compared with the other carbonaceous particles towards the south. These point towards the long transport the allochthonous sporomorphs had suffered, and to the very high rate of deposition. Both factors are typical for an offshore sedimentation in a delta. The occurrences of highly rolled bone debris (von Backström, 1974) in the sediments, which was also observed in the field by the present author, also favours this assumption. It should be noted that Recent river-mouth sediments of Southern Africa (J.A. Coetzee, Institute for Environmental Sciences, University of the Orange Free State, personal communication, 1975) and of Pliocene to Recent sediments of the Nile Delta offshore of Israel (Rossignol, 1961; Horowitz, 1974a) also display the same characteristics.

The provenance of the allochthonous palynomorphs, which might also indicate the provenance of the sediments, lies somewhere in the far north. This is concluded from a comparison between the sporomorph assemblages recovered by Hart (1965) and by Anderson (1975) in the northern parts of the Karoo Basin. These assemblages are much richer in the number of species, in the number of sporomorphs per sample, and in the ratio of sporomorphs to other carbonaceous and vegetational debris. On the other hand, these assemblages do not contain marine algae. It must be emphasized in this connection that these authors have analyzed hundreds of samples without noting any marine microfossils. The rate of deposition in the north must have been much slower than in the south, as is indicated by the ratios between the numbers of recovered sporomorphs and the organic material. Also, the sequence is much more restricted in the north. It should be noted that the lastmentioned fact cannot be taken by itself as an indicator of the rate of deposition, since the area might have been strongly influenced by successive erosional phases.

With reference to the problem of uranium accumulation in the Beaufort West area, an important fact should be noted: uranium minerals, or at least some of them, are rather soluble in fresh water, much more than in saline solutions (von Backström, 1974); many uranium occurrences in the world are known along ancient drainage systems (*op. cit.*); the uranium occurrences of Beaufort West follow sedimentary structures that are reminiscent of channels (von Backström, 1974, and the present author's field observations). It is therefore suggested that the uranium minerals have been carried in solution by the river or rivers that contributed to the delta in the Beaufort West area in Late Permian times, and their contact with the seawater caused precipitation of the uranium. The idea brought forward in von Backström (1974) that the uranium was partly of epigenetic origin is hereby opposed.

6. CONCLUSION

The Beaufort West area was part of a large delta lying at the north or northwest shore of an oceanic basin in Late Permian times, into which rivers from the north drained. These rivers carried soluble uranium compounds that were precipitated upon contact with the saline environment.

7. SUGGESTIONS FOR FURTHER PROSPECTING

If the above assumptions are correct, every effort at delineating the ancient shorelines must be made. This should be done by connecting sedimentological studies with palynological methods. Due to the pronounced sea-level movements and changes during the Late Permian time through the Early Triassic time in the entire world, a number of shorelines could be traced. An exact age determination, and correlations with the Karoo strata in the central and northern parts of the Basin might show the direction in which the successive shorelines are to be found – whether transgressive or regressive. A correlation with the worldwide stratigraphy for these periods is essential, since it does not seem plausible that the Karoo Basin acted as an independent continental basin as was long suggested, but was rather connected with the global system of oceans that transgressed and regressed simultaneously.

Any further prospecting must be done along these shorelines, where uranium might have accumulated by the contact with the seawater.

The low to medium degree of carbonization and the high organic material content, especially the amorphous organic material, together with the very high rate of deposition, might also favour prospecting for oil in these areas. More extensive studies should be carried out in this connection.

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EXPLANATION OF THE PLATES

Plate 1 (Rietkuil): 1 – Amorphous organic material, Sample 49, Slide B-1-40.

2 – Amorphous organic material, Sample 42, Slide B-1-33.

Plate 2 (Rietkuil):

1 – Highly carbonized plant debris. Note *Veryhachium longispinum* in lower part of the photograph. Sample 44, Slide B-1-35.

2 – Carbonized and amorphous organic material, with some *Veryhachium* and small sporomorphs. Sample 45, Slide B-1-[illegible].

Plate 3 (Rietkuil):

1 – Carbonized and amorphous fine organic material. Sample 18, Slide B-1-9.

2 – Very fine carbonized and amorphous organic material, with plant debris and some small sporomorphs. Sample 26, Slide B-1-18.

Plate 4 (Kaffersfontein):

1 – 4 – Highly carbonized debris. Samples GG/21/52.50; GG/21/61; GG/21/97. Slides B-1-92; B-2-10; B-2-11.

Plate 5 (Rietkuil):

1 – 5 – Plant debris.

1 – Sample 45, Slide B-1-36.

2 – Sample 18, Slide B-1-9.

3,4 – Sample 18, Slide B-1-9.

5 – Sample 45, Slide B-1-36.

Plate 6 (Rietkuil):

1 – *Veryhachium hyalodermum*. Deunff 1958. Sample 18, Slide B-1-9.

2 – *V. hyalodermum*. Sample 15, Slide B-1-5.

3 – *V. tzutsii* Horowitz 1974. Sample 18, Slide B-1-9.

4 – *V. tzutsii*. Sample 18, Slide B-1-9.

5 – *V. reductum* Deunff *ex* Jekhowsky 1961. Sample 15, Slide B-1-5.

5 – *V. reductum*. Sample 18, Slide B-1-9.

7,8 – *V. longispinum* Horowitz 1973, Sample 15, Slide B-1-5.

Plate 7 (Rietkuil):

1–4 – Hystrichosphere. Sample 18, Slide B-1-9.

5,6 – Hystrichosphere. Sample 18, Slide B-1-8.

Plate 8 (Rietkuil):

1–3 – *Baltisphaeridium* sp. Sample 18, Slide B-1-9.

4 – *Baltisphaeridium* sp. Sample 15, Slide B-1-5.

5 – *Baltisphaeridium?* (or Hystrichosphere?). Sample 15, Slide B-1-5.

6 – *Microhystridium parvispinum* Deflandre 1946. Sample 14, Slide B-1-4.

7 – *Solisphaeridium rossignolii* Glikson 1966. Sample 15, Slide B-1-5.

Plate 9 (Vindragersfontein):

1 – 8 – Various *Veryhachium* (?) and acritarchs. Sample 286/212', Slide B-2-6.

Plate 10 (Vindragersfontein):

1 – 6 – Various hystrichosphaerids. Sample 286/212', Slide B-2-6.

Plate 11 (Rietkuil):

1 – Fungus (?) spore. Sample [illegible], Slide B-1-36.

2 – *Perisaccus granulatus* (?), Klaus 1963. Sample 19, Slide B-1-2.

3 – *Apiculatisporites* sp. Sample 15, Slide B-1-5.

4 – *Apiculatisporites* sp. Sample 18, Slide B-1-9.

5,6 – *Apiculatisporites* sp. Sample 14, Slide B-1-4.

7 – Monolete sporomorph. Sample 45, Slide B-1-36.

8 – Monolete sporomorph. Sample 18, Slide B-1-8.

9 – Monolete sporomorph. Sample 45, Slide B-1-36.

Plate 12 (Rietkuil):

1 – Large trilete, probably *Gondisporites* sp. Sample 45, Slide B-1-36.

2,3 – *Leiotriletes* sp. Sample 45, Slide B-1-36.

4,5 – *Leiotriletes* sp. Sample 45, Slide B-1-36.

Plate 13 (Rietkuil):

1 – Large trilete, probably *Gondisporites* sp. Sample 18, Slide B-1-8.

2 – *Microbaculispora virkkiae*, Tiwari 1965, Sample 15, Slide B-1-5.

3 – *Apiculatisporites* sp. Sample 45, Slide B-1-36.

4,5 – *Acanthotriletes* sp. Sample 15, Slide B-1-5.

6 – *Acanthotriletes* sp. Sample 15, Slide B-1-5.

7,8 – *Gondisporites parvus*, Anderson 1975. Sample 45, Slide B-1-36.

9 – *Altitriletes densus*, Venkatachala & Kar 1968. Sample 14, Slide B-1-4.

Plate 14 (Rietkuil):

1,3 – *Gondisporites* (?) Sample 45, Slide B-1-36.

2 – *Maculatasporites indicus*, Tiwari 1965. Sample 45, Slide B-1-36.

4,5 – *Tetraporina superba*, Mahesh & Bose 1969. Sample 14, Slide B-1-4. (2 different specimens).

Plate 15 (Rietkuil):

1 – A piece of *Taeniasesporites* sp. Sample 14, Slide B-1-4.

2 – *Vittatina nonsaccata*, Anderson 1975. Sample 12, Slide B-1-2.

3 – cf. *Vitreisporites pallidus*, Reissinger 1955. Sample 15, Slide B-1-5.

4 – *Vittatina* sp. Sample 15, Slide B-1-5.

5,6 – *Pityosporites* sp. Sample 45, Slide B-1-36.

7 – *Pityosporites* sp. Sample 15, Slide B-1-5.

8 – *Alisporites* sp. Sample 45, Slide B-1-36.

Plate 16 (Kaffersfontein):

1 – Highly corroded monolete. Sample 21/52.50, Slide B-1-92.

2 – Highly carbonized trilete. Sample 21/52.50, Slide B-1-92.

3 – Corroded vesiculate, probably *Pityosporites*. Sample 21/52.50, Slide B-1-92.

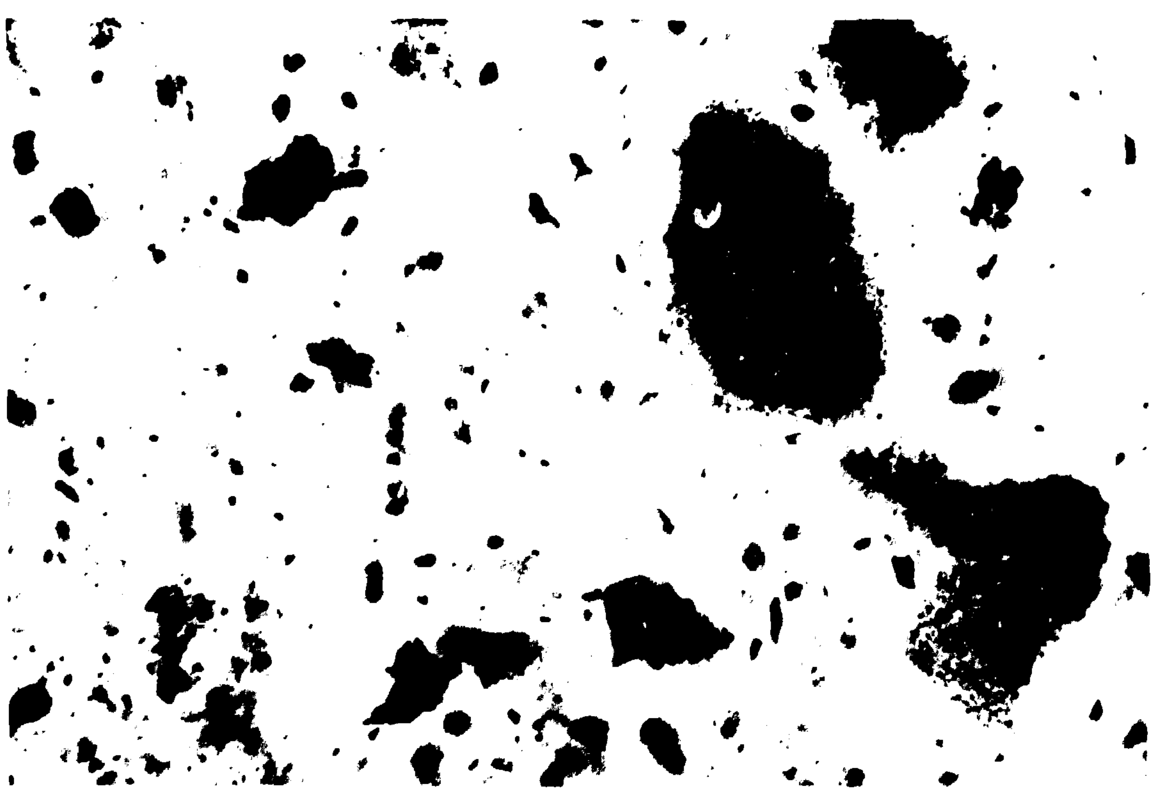
4–7 – *Apiculatisporites* cf. *minimus*. Samples 21/52.50; 21/61, Slide B-1-92; B-2-10.

Plate 1 (Rietkuil):

1 – Amorphous organic material, Sample 49, Slide B-1-40.

2 – Amorphous organic material, Sample 42, Slide B-1-33.

1



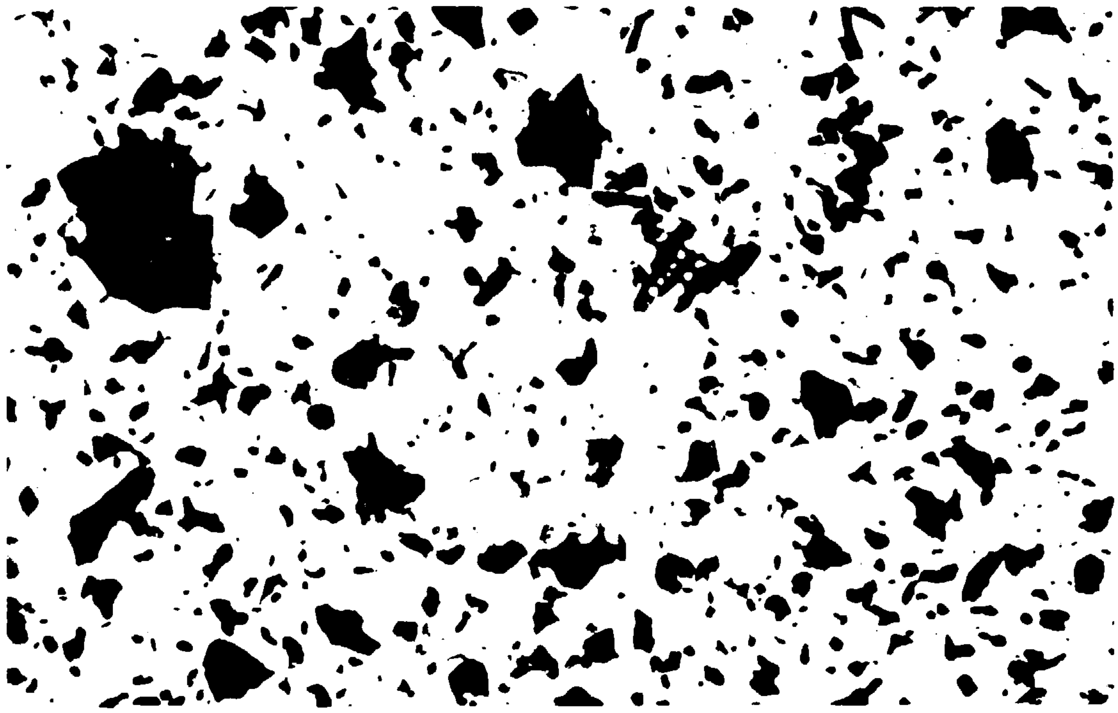
2

100μ

Plate 2 (Rietkuil):

1 – Highly carbonized plant debris. Note *Veryhachium longispinum* in lower part of the photograph. Sample 44, Slide B-1-35.

2 – Carbonized and amorphous organic material, with some *Veryhachium* and small sporomorphs. Sample 45, Slide B-1-36.



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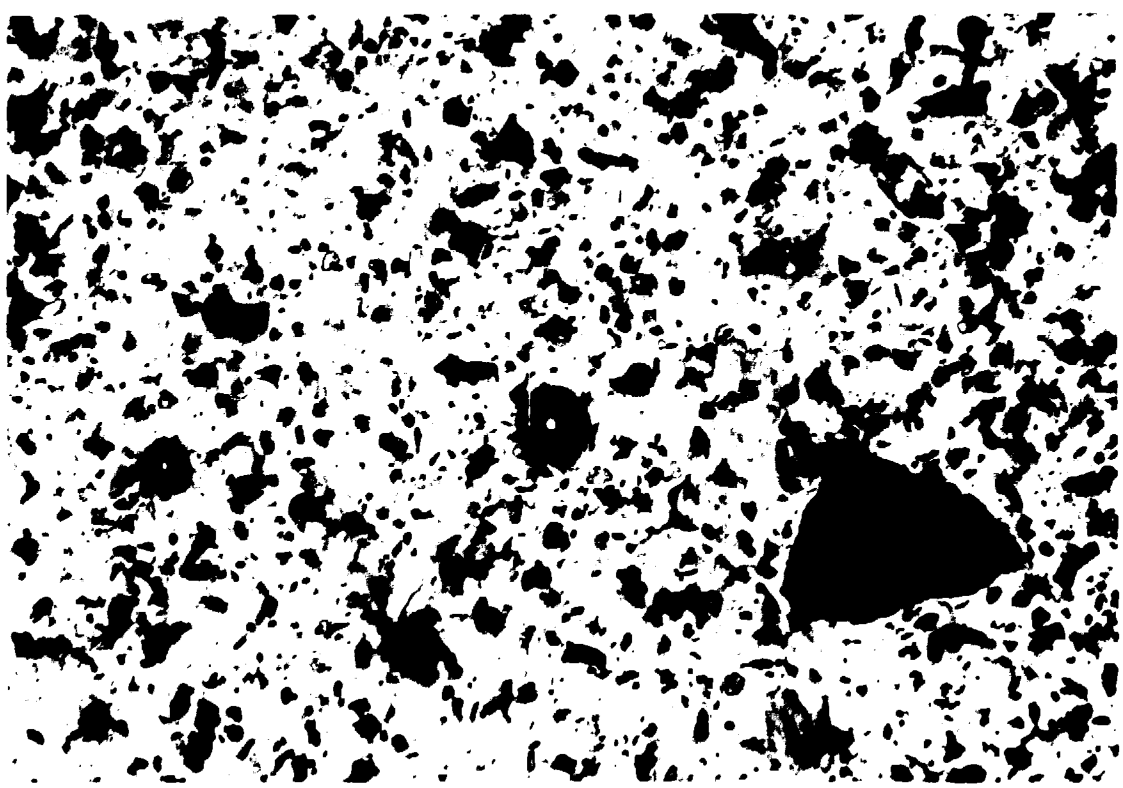


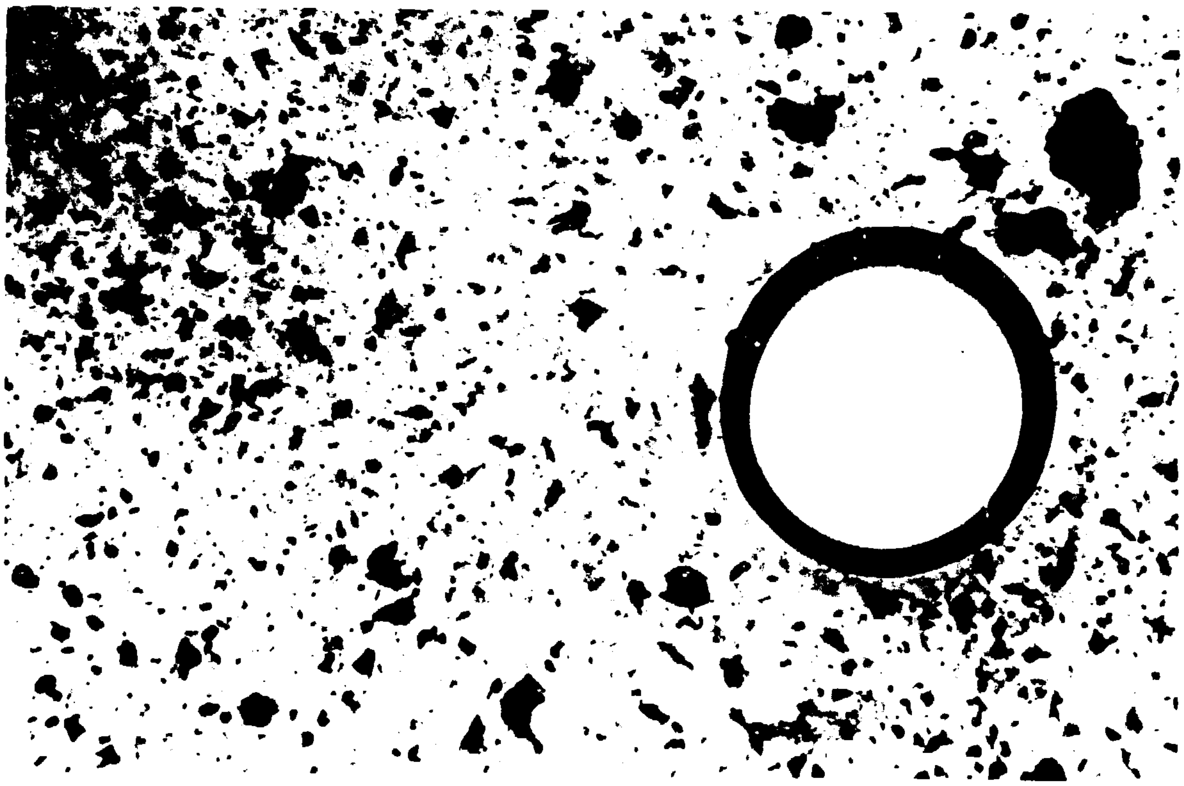
2

100μ

Plate 3 (Rietkuil):

1 – Carbonized and amorphous fine organic material. Sample 18, Slide B-1-9.

2 – Very fine carbonized and amorphous organic material, with plant debris and some small sporomorphs. Sample 26, Slide B-1-18.



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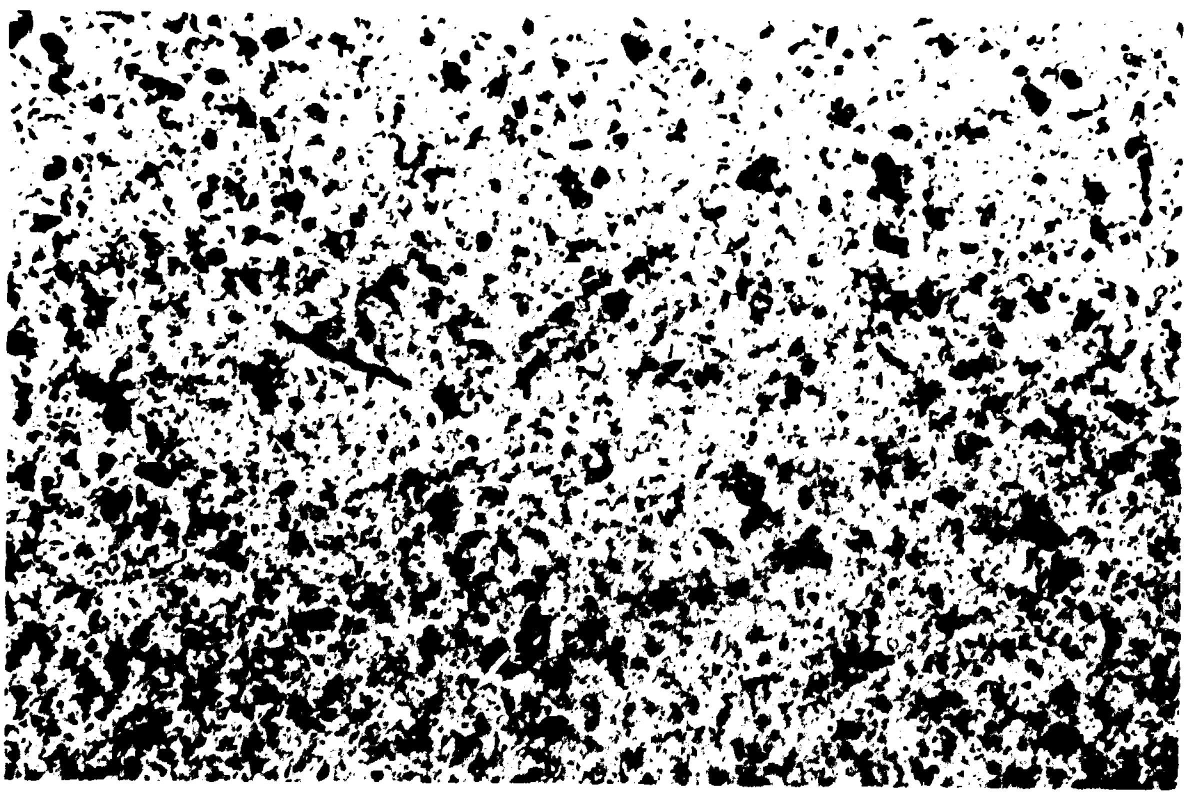


2

100μ

Plate 4 (Kaffersfontein):

1 – 4 – Highly carbonized debris. Samples GG/21/52.50; GG/21/61; GG/21/97. Slides B-1-92; B-2-10; B-2-11.

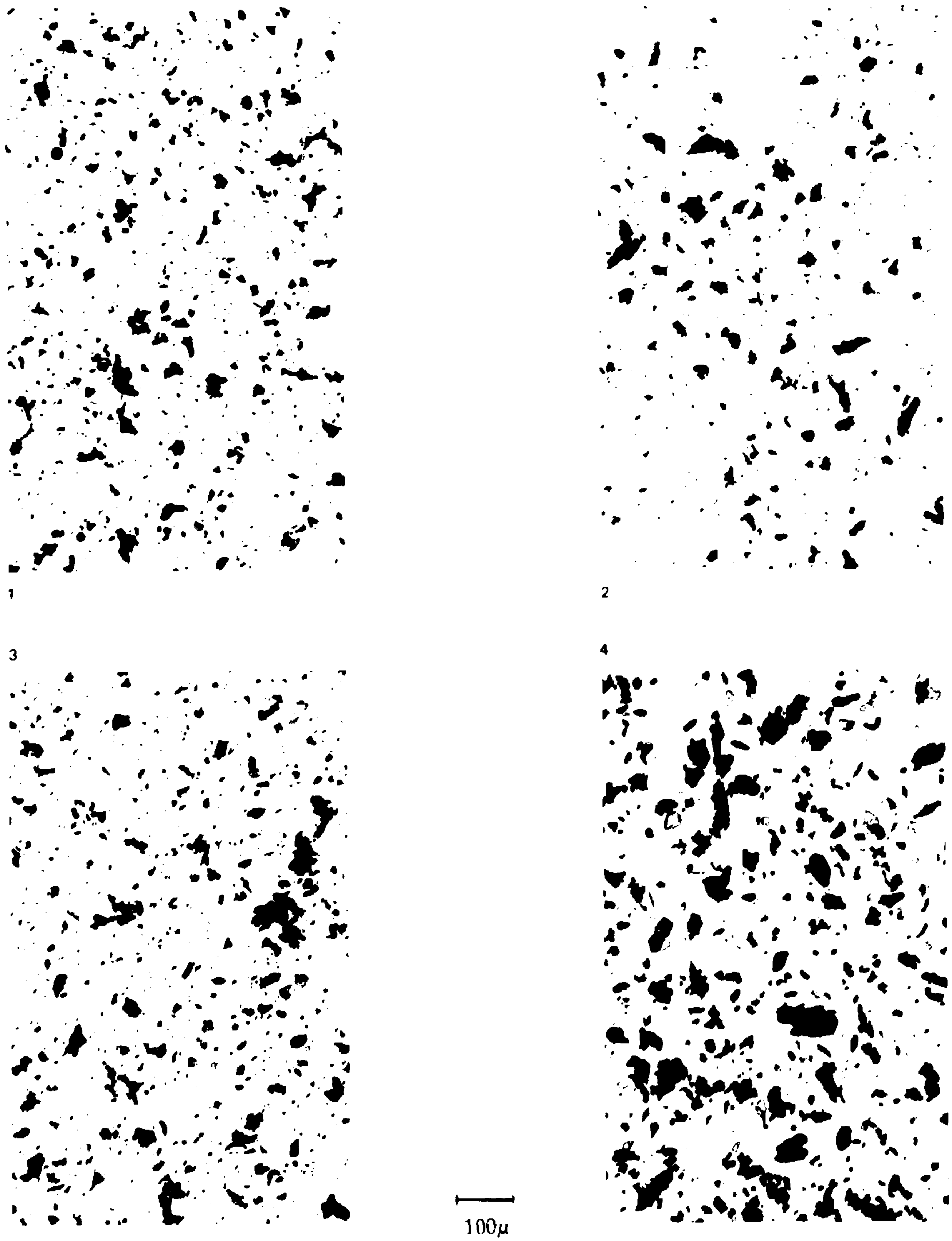


Plate 5 (Rietkuil):
1 – 5 – Plant debris.
1 – Sample 45, Slide B-1-36.
2 – Sample 18, Slide B-1-9.
3,4 – Sample 18, Slide B-1-9.
5 – Sample 45, Slide B-1-36.

financed the research.

Plate 6 (Rietkuil):

1 – *Veryhachium hyalodermum.* Deunff 1958. Sample 18, Slide B-1-9.

2 – *V. hyalodermum.* Sample 15, Slide B-1-5.

3 – *V. tzutsii* Horowitz 1974. Sample 18, Slide B-1-9.

4 – *V. tzutsii.* Sample 18, Slide B-1-9.

5 – *V. reductum* Deunff *ex* Jekhowsky 1961. Sample 15, Slide B-1-5.

5 – *V. reductum.* Sample 18, Slide B-1-9.

7,8 – *V. longispinum* Horowitz 1973, Sample 15, Slide B-1-5.

Plate 7 (Rietkuil):

1–4 – Hystrichosphere. Sample 18, Slide B-1-9.

5,6 – Hystrichosphere. Sample 18, Slide B-1-8.

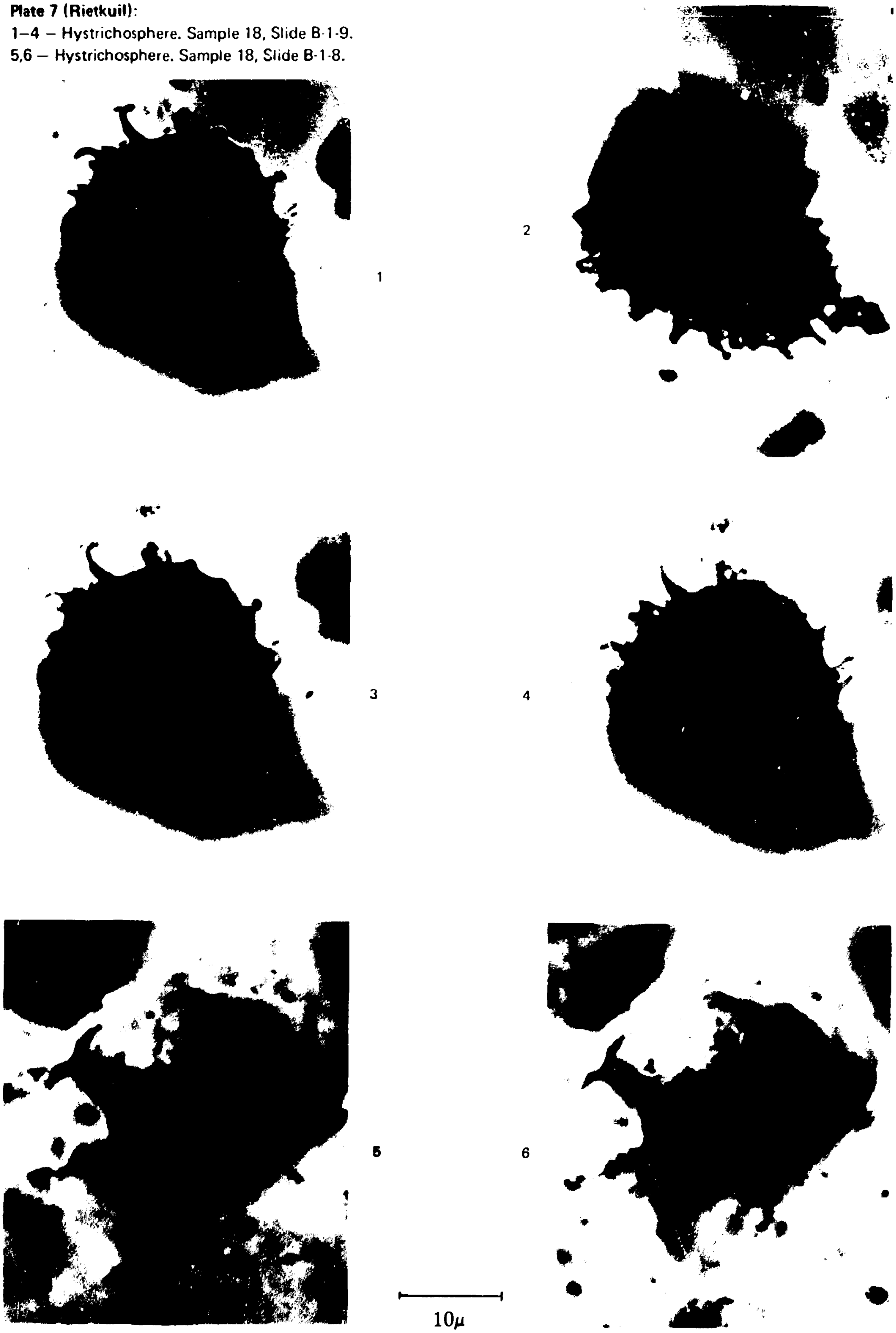


Plate 8 (Rietkuil):

1–3 – *Baltisphaeridium* sp. Sample 18, Slide B-1-9.

4 – *Baltisphaeridium* sp. Sample 15, Slide B-1-5.

5 – *Baltisphaeridium?* (or Hystrichosphere?). Sample 15, Slide B-1-5.

6 – *Microhystridium parvispinum* Deflandre 1946. Sample 14, Slide B-1-4.

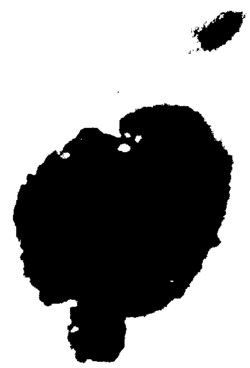
7 – *Solisphaeridium rossignolii* Glikson 1966. Sample 15, Slide B-1-5.

2

1

4

3



6

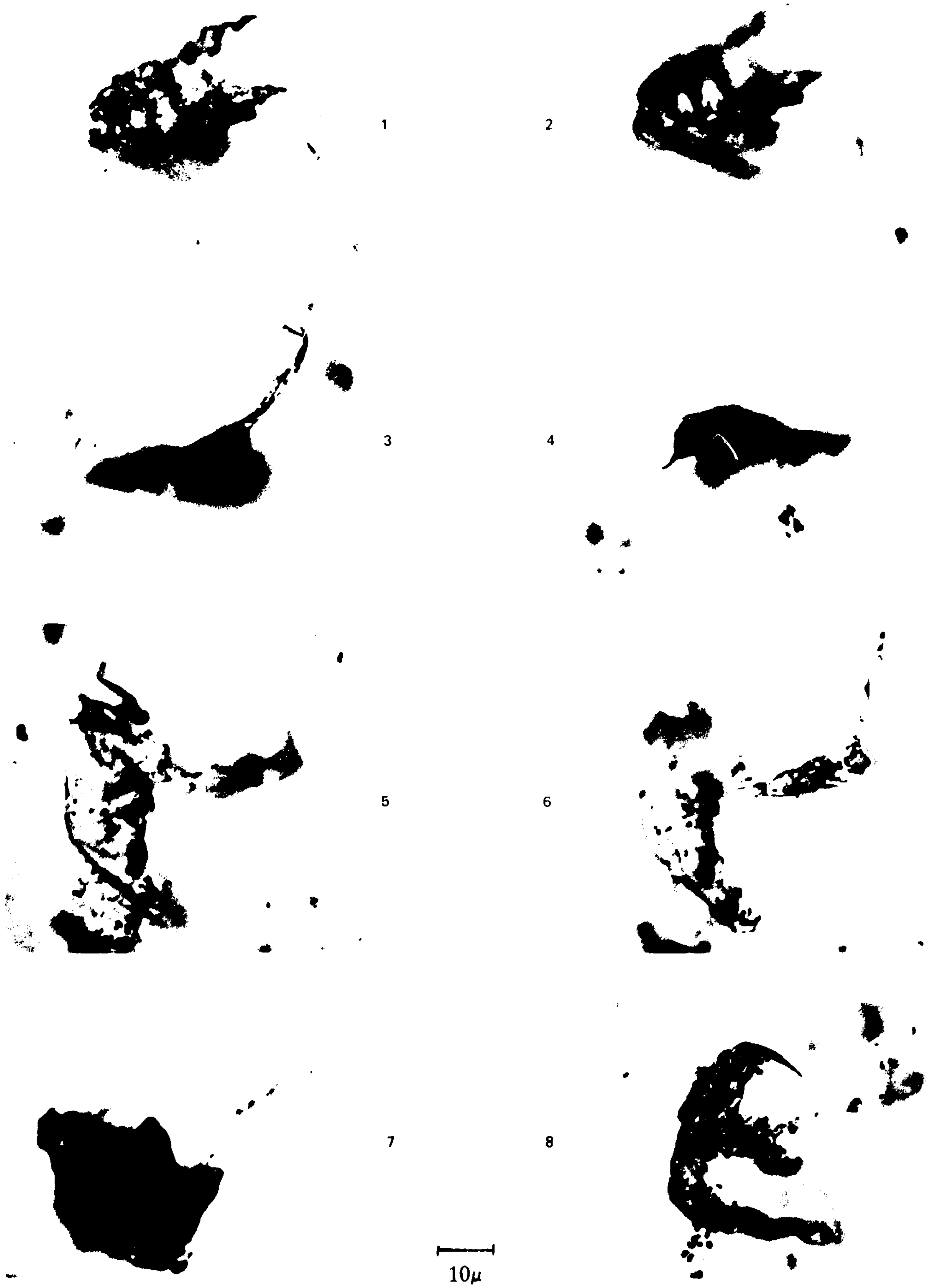
5

7

10μ

Plate 9 (Vindragersfontein):

1 – 8 – Various *Veryhachium* (?) and acritarchs. Sample 286/212', Slide B-2-6.



sporomorphs are poor to very poor.

V. longispinum, Horowitz 1973

Plate 10 (Virdragersfontein):
1 – 6 – Various hystrichosphaerids. Sample 286/212', Slide B-2-6.

1

2

3

4

5

6

10μ

Plate 11 (Rietkuil):

1 – Fungus (?) spore. Sample 45, Slide B-1-36.

2 – *Perisaccus granulatus* (?), Klaus 1963. Sample 19, Slide B-1-2.

3 – *Apiculatisporites* sp. Sample 15, Slide B-1-5.

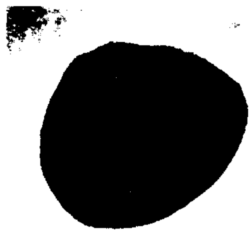
4 – *Apiculatisporites* sp. Sample 18, Slide B-1-9.

5,6 – *Apiculatisporites* sp. Sample 14, Slide B-1-4.

7 – Monolete sporomorph. Sample 45, Slide B-1-36.

8 – Monolete sporomorph. Sample 18, Slide B-1-8.

9 – Monolete sporomorph. Sample 45, Slide B-1-36.



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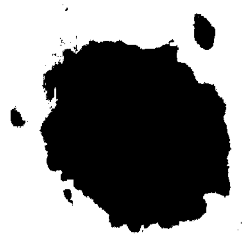


6

7

8

9

10µ

Plate 12 (Rietkuil):

1 – Large trilete, probably *Gondisporites* sp. Sample 45, Slide B-1-36.

2,3 – *Leiotriletes* sp. Sample 45, Slide B-1-36.

4,5 – *Leiotriletes* sp. Sample 45, Slide B-1-36.

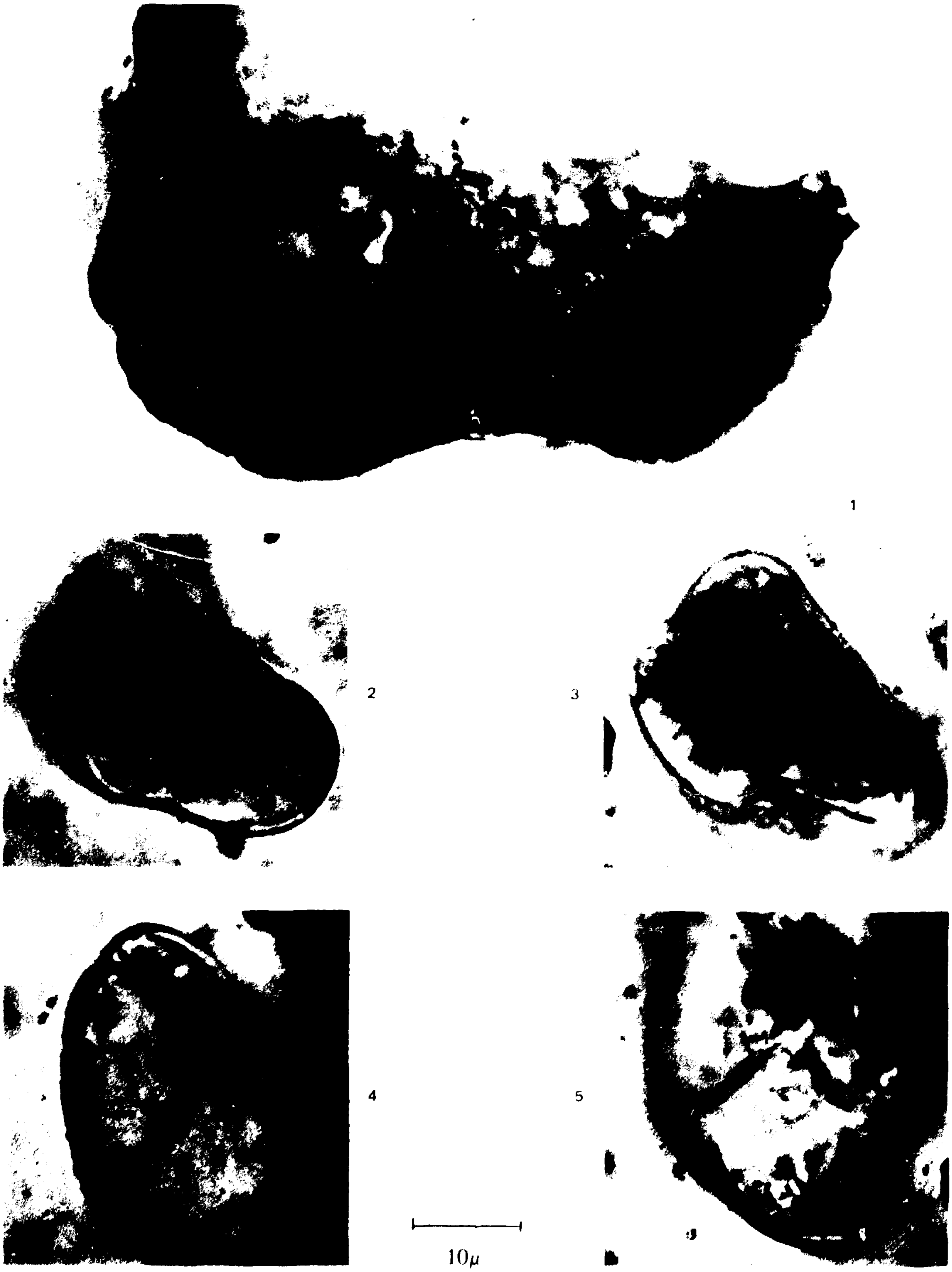


Plate 13 (Rietkuil):

1 – Large trilete, probably *Gondisporites* sp. Sample 18, Slide B-1-8.

2 – *Microbaculispora virkkiae,* Tiwari 1965, Sample 15, Slide B-1-5.

3 – *Apiculatisporites* sp. Sample 45, Slide B-1-36.

4,5 – *Acanthotriletes* sp. Sample 15, Slide B-1-5.

6 – *Acanthotriletes* sp. Sample 15, Slide B-1-5.

7,8 – *Gondisporites parvus,* Anderson 1975. Sample 45, Slide B-1-36.

9 – *Altitriletes densus,* Venkatachala & Kar 1968. Sample 14, Slide B-1-4.

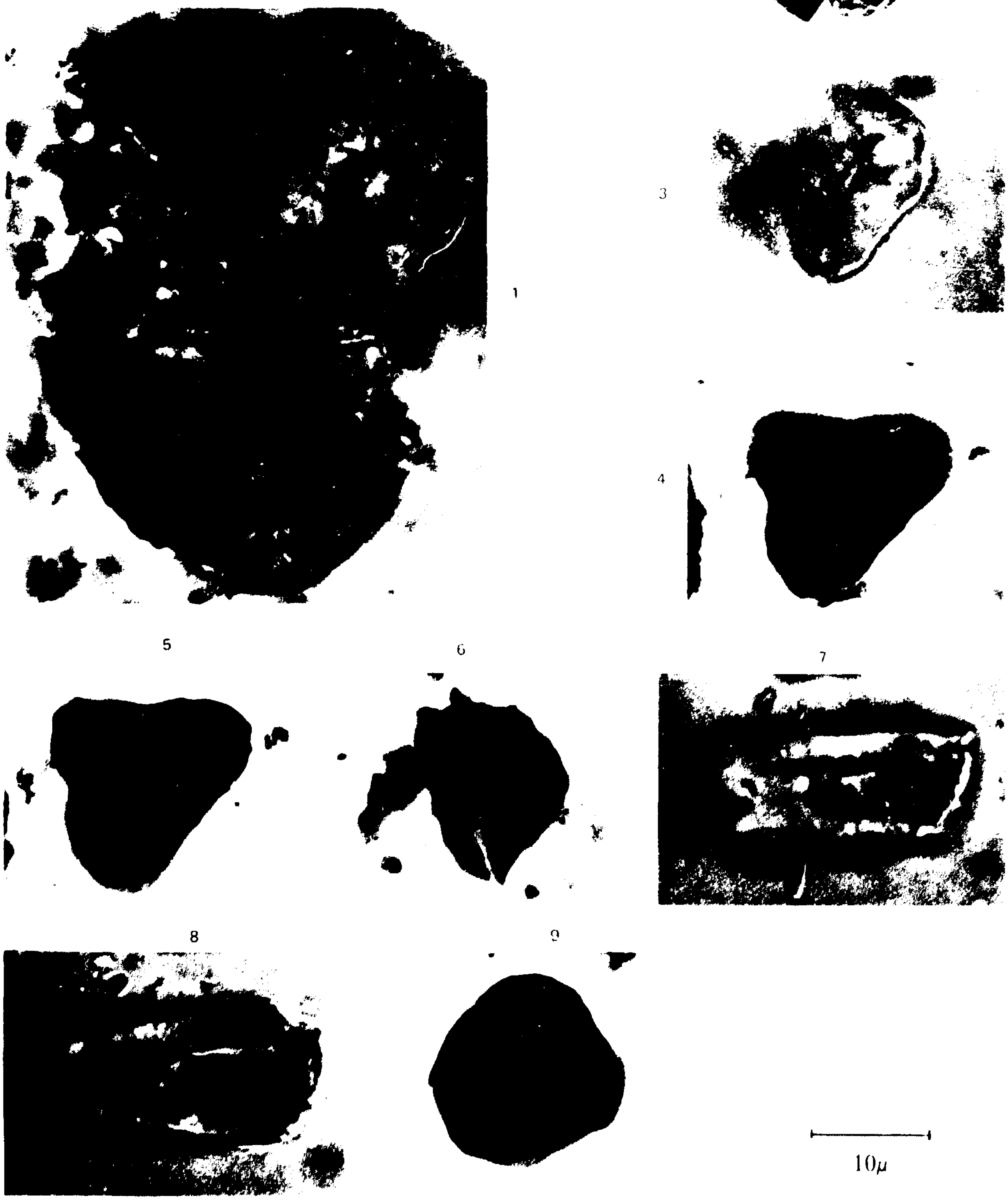


Plate 14 (Rietkuil):

1,3 – *Gondisporites* (?) Sample 45, Slide B-1-36.

2 – *Maculatasporites indicus,* Tiwari 1965. Sample 45, Slide B-1-36.

4,5 – *Tetraporina superba,* Mahesh & Bose 1969. Sample 14, Slide B-1-4. (2 different specimens).

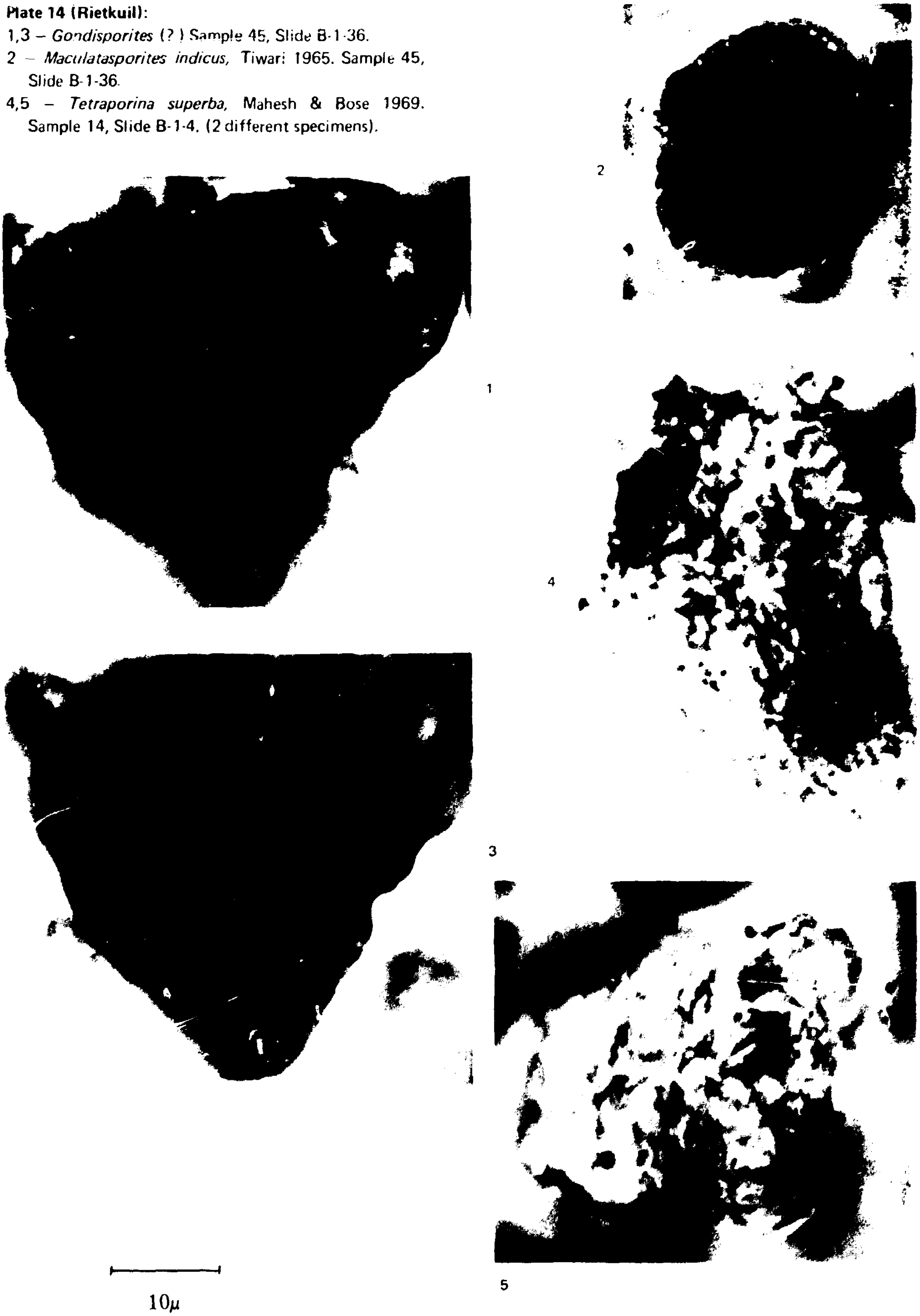


Plate 15 (Rietkuil):

1 – A piece of *Taeniasesporites* sp. Sample 14, Slide B-1-4.

2 – *Vittatina nonsaccata,* Anderson 1975. Sample 12, Slide B-1-2.

3 – cf. *Vitreisporites pallidus,* Reissinger 1955. Sample 15, Slide B-1-5.

4 – *Vittatina* sp. Sample 15, Slide B-1-5.

5,6 – *Pityosporites* sp. Sample 45, Slide B-1-36.

7 – *Pityosporites* sp. Sample 15, Slide B-1-5.

8 – *Alisporites* sp. Sample 45, Slide B-1-36.

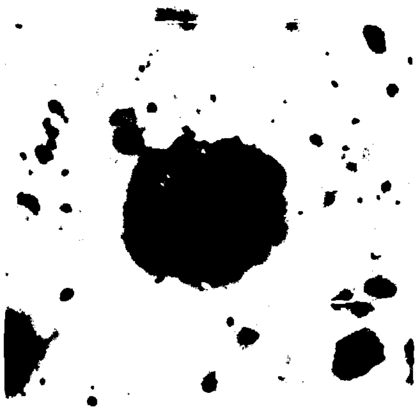
Plate 16 (Kaffersfontein):

1 – Highly corroded monolete. Sample 21/52.50, Slide B-1-92.

2 – Highly carbonized trilete. Sample 21/52.50, Slide B-1-92.

3 – Corroded vesiculate, probably *Pityosporites*. Sample 21/52.50, Slide B-1-92.

4–7 – *Apiculatisporites* cf. *minimus*. Samples 21/52.50; 21/61, Slide B-1-92; B-2-10.



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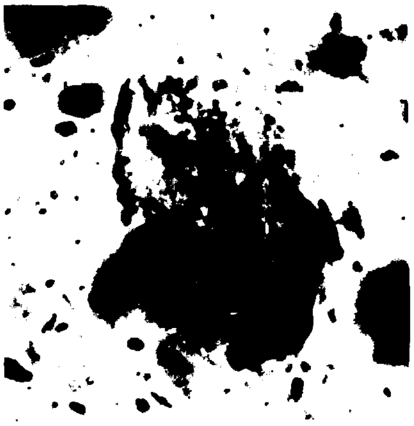

1

5

2

6

3

7

10μ