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"FLY-SPECK CARBON" IN CONGLOMERATES AND GOLD
IN BANDED IRON-FORMATIONS OF THE
PIETERSBURG GREENSTONE BELT : REFLECTIONS ON
THE FORMATION OF THE WITWATERSRAND DEPOSITS

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by

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ABSTRACT

The pyritic conglomerates of the Uitkyk Formation in the Archaean Pietersburg Schist Belt contain heavy mineral assemblages similar to those found in the Witwatersrand conglomerates. Carbonaceous matter, in the form of "fly-speck carbon", occurs sporadically in the conglomerates and represents the first reported occurrence of this type in South Africa outside of the Witwatersrand basin. The presence of carbonaceous matter indicates furthermore that advanced life-forms existed in suitable depositories other than the Witwatersrand basin and possibly appeared much earlier in the geological record than previously envisaged. The detection of carbonaceous matter in the Uitkyk Formation supports the interpretation that the Witwatersrand carbon represents the remains of primitive plants.

Archaean banded iron-formations from greenstone belts of the Kaapvaal Craton contain high gold values ranging from 4 to 667 ppb. These gold values are much higher than the values reported for the mafic and ultramafic volcanics of the same Archaean terrane (0,5 to 20 ppb). This suggests that Archaean banded iron-formations constitute another important primary source for the gold in the Witwatersrand deposit.

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I. INTRODUCTION

The early Precambrian crust of the Kaapvaal Craton in South Africa contains the largest known gold accumulations on earth. Gold occurs in two domains, firstly, in the Archaean greenstone terranes and, secondly, in the sediments of the Proterozoic Witwatersrand Triad. Of South Africa's gold production, the Archaean ores have produced 1,8 per cent of the total whereas 98,2 per cent has come from the Proterozoic Witwatersrand ores. The Witwatersrand goldfields undoubtedly constitute the world's most important gold deposits from which, up to present, more than 32 000 tons of gold have been mined. This represents about 55 per cent of all gold mined worldwide over the whole span of recorded history (Pretorius, 1975).

Most students of the Witwatersrand ores favour the "modified placer theory" as a metallogenetic concept for the formation of the deposits. In principal, this theory, which was first proposed by Mellor (1916), states that during diagenesis and regional metamorphism of the sediments, some of the detrital minerals - namely the sulphides and gold - were mobilized and reconstituted. This reconstitution caused many of the allogenic minerals to lose their detrital outlines thereby obscuring the typical sedimentary textures generally expected in placer ores. This suggestion eventually formed the basis of the well-known "Witwatersrand controversy" which raged for many years, particularly during the period 1928-1948 (Pretorius, 1975).

Based purely on the surface morphology of gold particles from different localities within the Witwatersrand deposits, Hallbauer and Utter (1977) maintained that "the Witwatersrand gold has retained most of its original detrital morphology, thus confirming the theory of placer origin of the Witwatersrand gold and ruling out large-scale recrystallization and mobilization". These authors, furthermore, postulate short transport distances for the gold, in the range of 10 to 30 km. Their conclusions contradict the findings of many workers including Liebenberg, 1955; Ramdohr, 1955; Brock and Pretorius, 1964; Saager, 1970 and 1973b; Schidlowski, 1970; and Feather and Koen, 1975, all of whom described recrystallization features in the Witwatersrand gold deposits.

According to most investigators who have studied uraniferous and auriferous pyritic placers, a non-oxidizing atmosphere appears to have been pre-requisite during the depositional history of such deposits. The main reason for this lies in the consideration that uraninite and pyrite generally cannot survive prolonged sedimentary transport under oxidizing conditions. However, in a recent paper, Simpson and Bowles (1977) suggested, on geochemical grounds, that an oxidizing atmosphere did exist during the early Precambrian, a conclusion that was further supported by Dimroth (in press) who undertook a macroscopic examination of Witwatersrand ores.

The question of the ultimate source of the Witwatersrand gold has attracted the interest of a number of researchers (Brock and Pretorius, 1964; Viljoen et al., 1970; Saager, 1973a, b; Köppel and Saager, 1974; Stumpfl, 1974; Hallbauer and Utter, 1977; Saager and Muff, 1978). All generally agree that the gold originated from an Archaean greenstone provenance area.

This paper represents the results of some of the research that has been carried out on a pyritic placer occurrence situated outside the Witwatersrand basin, and which may constitute a primitive fore-runner of the Witwatersrand deposits. These findings are offered in an attempt to clarify some of the questions that have recently been posed relating to the mode of formation of the Witwatersrand ores, the nature of the hinterlands, and the oxygen level in the early Precambrian atmosphere. For this reason, the pyritic placers in the conglomerates of the Uitkyk Formation, in the Pietersburg Schist Belt of the Northern Transvaal, were selected for study. In the past, several attempts have been made to explore the economic potential of these Archaean conglomerates on Mount Robert, resulting in the excavation of numerous prospecting trenches and shafts. All these undertakings have so far failed, possibly because of the erratic distribution of the gold, its low grade and the high development and access costs.

The Pietersburg Schist Belt was also chosen for study because it contains a number of well-developed oxide facies banded iron-formations in its lower volcanic units. The gold contents of these banded iron-formations were determined and the potential of the iron-formations as a possible source for the gold in early Precambrian placers was investigated.

II. GEOLOGICAL SETTING OF THE PIETERSBURG SCHIST BELT

The Pietersburg Schist Belt forms an inlier in the complex Archaean granitic basement of the Kaapvaal Craton. It is a strongly deformed greenstone belt correlated with the Swaziland succession. In common with other greenstone belts (Anhaeusser et al., 1969; Anhaeusser, 1971; Goodwin and Ridler, 1970), it is composed of a volcano-sedimentary rock-pile, the metamorphic grade of which generally falls within

the greenschist facies. The Pietersburg greenstone succession has a northeasterly strike and the rocks generally have a vertical dip. The Schist Belt is exposed over a total length of approximately 100 km and in the west it disappears under cover rocks of Transvaal age (approximately 2 200 m.y. old).

Anhaeusser (1972) and Viljoen and Viljoen (1969a, b) investigated and re-interpreted the geology of the Swaziland succession in the Barberton greenstone belt 250 km southeast of the Pietersburg Schist Belt. They divided this greenstone sequence into the four units shown diagrammatically in Table 1. The *Lower Onverwacht Group* (Tjakastad Subgroup), situated at the base of the sequence, consists mainly of mafic and ultramafic, often komatiitic extrusive volcanic rocks and is overlain by the generally tholeiitic and intermediate to acid sequence of lavas of the *Upper Onverwacht Group* (Geluk Subgroup). The *Fig Tree Group*, comprising argillaceous sediments with banded iron-formations, and the *Moodies Group*, comprising arenaceous sediments, overlie the volcanic units.

TABLE I

Lithostratigraphic Correlation of the Barberton Mountain Land
and the Pietersburg Schist Belt

		SWAZILAND SUPERGROUP (Barberton Mountain Land)	PIETERSBURG SEQUENCE (Pietersburg Schist Belt)	
Sedimentary Unit	Arenaceous	Moodies Group	Uitkyk Formation	
	Argillaceous	Fig Tree Group		
Mafic-to-Felsic Unit		Onverwacht Group	Geluk Subgroup	Eersteling Formation
Lower Ultramafic Unit			Tjakastad Subgroup	Landsberghoek Formation

(Modified after Anhaeusser (1976) and Grobler (1972))

Noteworthy geological accounts of the Pietersburg Schist Belt are those of Hall (1908), Willemse (1938), Van Rooyen (1947), Grobler (1972), and Saager and Muff (1978). Grobler (1972) recognized a far-reaching similarity between the geology of the Pietersburg Schist Belt and the Barberton Mountain Land. The stratigraphic correlation between the Barberton Mountain Land and the Pietersburg Schist Belt shown in Table I is based on Grobler's (1972) findings. Figure 1 represents a simplified geological map of the Pietersburg Schist Belt.

To date, no geochronological work has been carried out on rocks from the Pietersburg Schist Belt and all conclusions as to the age of the Pietersburg greenstone sequence must be deduced from the lithological correlations offered by Grobler (1972) and from age determinations performed in the Barberton Mountain Land, where Saager and Köppel (1976) investigated the lead isotopic composition of certain sulphide minerals from the lower units of the Swaziland Supergroup. They arrived at a maximum age of $3\ 810 \pm 70$, -30 m.y. and a minimum age of $3\ 450 \pm 20$ m.y. for this succession. Jahn and Shih (1974) obtained an age of metamorphism of $3\ 500 \pm 200$ m.y. for the Lower Onverwacht rocks using the Rb-Sr method.

The lowermost unit in the Pietersburg Schist Belt, which has been correlated with the Lower Onverwacht Group of the Barberton Mountain Land (Grobler, 1972), is the *Landsberghoek Formation*, and consists mainly of serpentinitized ultramafics with numerous intercalated oxide facies banded iron-formations.

The *Eersteling Formation* consists of metatholeiites and amphibolites together with ultramafic sills. The tholeiites constitute a rather massive volcanic pile and pillows are rarely preserved. Most abundant rock forming minerals of the metatholeiites are actinolite, quartz and chlorite, while albite, orthoclase and secondary carbonate minerals, as well as zircon, rutile, muscovite, epidote, apatite, and biotite, are of subordinate abundance.

By contrast with the sedimentary units in the Barberton Mountain Land, there is no argillitic unit developed in the Pietersburg Schist Belt. The Uitkyk sediments comprise mainly immature and poorly sorted sandstones and intercalated conglomerate banks and shale lenses. In the vicinity of the gold occurrences, the *Uitkyk Formation* forms an isoclinal syncline, its axial plane dipping to the south. Previously, the Uitkyk Formation was thought to overlie the Landsberghoek Formation unconformably. During these investigations, it was established that a thin horizon of intermediate volcanics, representing the Eersteling Formation, occurs on the southern slope of Mount Robert between the successions of the Uitkyk Formation and the Landsberghoek Formation.

As mentioned above, no geochronological data is yet available on the rocks of the Pietersburg Schist Belt and the surrounding basement-granites. An Archaean age for the Uitkyk Formation, as suggested

by Grobler (1972), thus remains uncertain and a correlation in age with the Witwatersrand sediments, as postulated by Van Rooyen (1947), must still be considered a possibility. The minimum age of the Uitkyk Formation is indicated by the Black Reef Quartzite of the Transvaal Supergroup which overlies all the rocks in the Pietersburg Schist Belt.

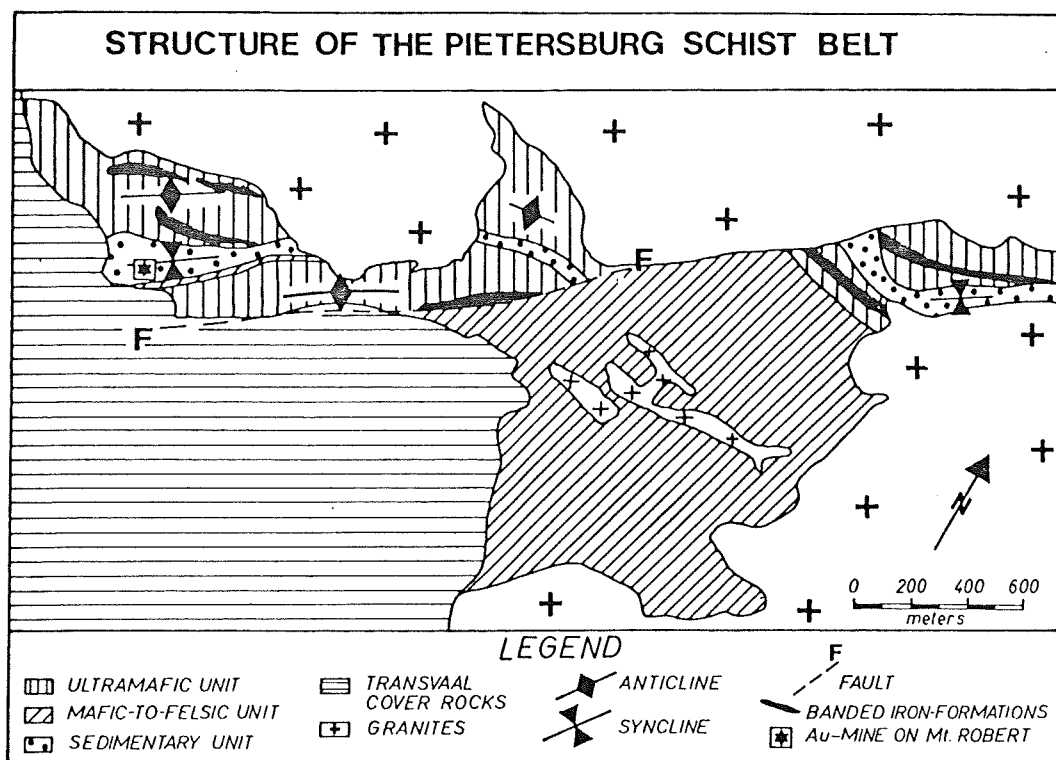


Figure 1 : Schematized geological map of the Pietersburg Schist Belt. Compiled from Willemse (1938) and Grobler (1972).

III. THE PYRITIC CONGLOMERATES

The prospecting trenches on Mount Robert are restricted to coarse-grained and poorly sorted conglomerates. The conglomeratic pebbles mainly comprise white vein quartz, banded chert, banded iron-formations, and intraformational shale and sandstone fragments embedded in a micaceous matrix. The pebble sizes vary between a few millimetres and 50 cm. A geological map of the Potberg gold prospect in the Uitkyk conglomerates at Mount Robert is shown in Figure 2. The conglomerates lie on a thick accumulation of sandstone and are succeeded by shale beds and siltstones which show erosion channels filled by coarse, well-sorted and cross-bedded sands. The siltstones and shales are capped by a massive pile of poorly sorted sandstone with a high percentage of angular chert fragments.

The extremely rapid facies changes within the conglomerate horizon of the Uitkyk Formation, the poor sorting and rounding, and the pronounced development of silt-filled scour channels and sandbars, suggest fluviatile deposition in a braided river milieu. Braided river and channel deposits of the type envisaged in this example have been described by a number of authors including Miall (1977), Pettijohn (1975) and Vos (1977). Alluvial fans, with braided rivers, developed in streams carrying an overload of sediments with respect to their transport capacity. The overloaded channels choke with their own detritus and tend to form longitudinal bars of sand gravel. Silt and clay material is subordinate and may fill abandoned channels.

The main minerals making up the sand and silt-sized conglomerate matrix are quartz, chlorite, sericite, porphyroblastic chloritoid, muscovite plates, and biotite needles. Chloritoid probably crystallized during metamorphism, and according to Winkler (1974), its formation requires a high Fe/Mg-ratio, simultaneously low contents of K, Na, and Ca, and relatively high Al contents. Furthermore, chloritoid is not necessarily a stress indicator, as has been thought of in the past. Work undertaken by Halferdahl (1961) showed that this mineral may grow both during and after the shearing stress which produces schistosity in the host rock.

Among the opaque minerals in the Uitkyk conglomerates, pyrite is most abundant and possesses the same morphological features as the pyrite encountered in the Witwatersrand sediments (Saager, 1970). The morphology of the Uitkyk pyrite has been discussed in detail by Saager and Muff (1978), Saager et al. (in preparation), and Muff and Saager (in preparation). Leucoxene is an alteration product of black sand

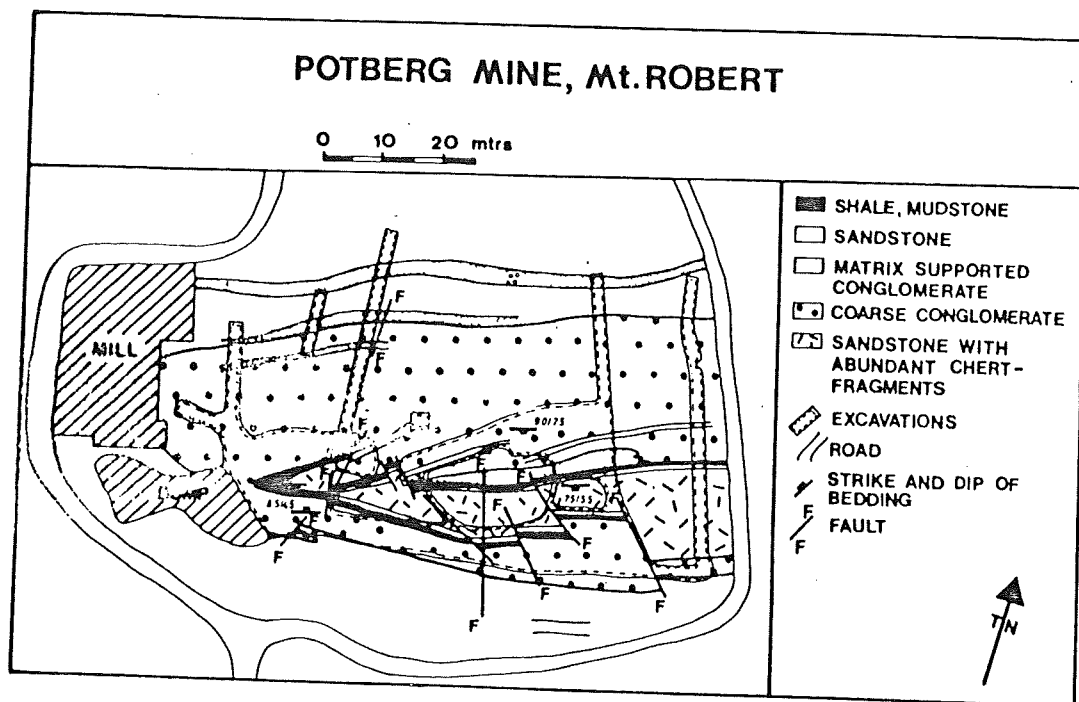


Figure 2 : Geological map of the gold prospect (Potberg Mine) on Mount Robert in the Utkyk Formation.

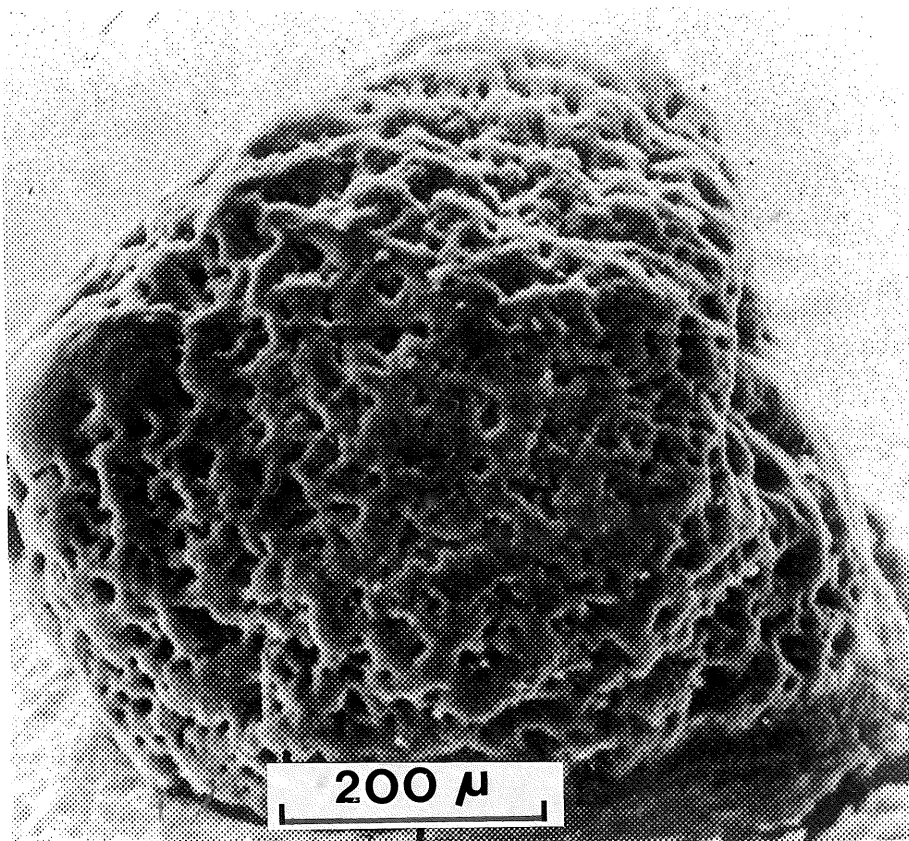
minerals and it frequently displays lamellae textures, suggesting that much of it formed from ilmeno-magnetite. All other ore minerals (chalcopryite, pyrrhotite, sphalerite, pentlandite, mackinawite and molybdenite) are rare. Gold occurs as sporadic detrital flakes in the conglomerate matrix. Zircon and chromite, as in the Witwatersrand sediments, are commonly encountered detrital constituents of the conglomerates. In polished sections some chromite grains display rims of higher reflectivity which could represent primary features, or the higher reflecting rims could have formed by *in situ* leaching. The chemical variation between the interior and rim of a chromite grain was determined by microprobe analysis (Table II). The rim and the core of the chromite grain studied differs markedly in that the rim contains more iron than the core and almost no magnesium. Furthermore, the rim of the grain shows a slightly higher aluminium content than the core, while the chromium content of the rim is slightly lower.

TABLE II

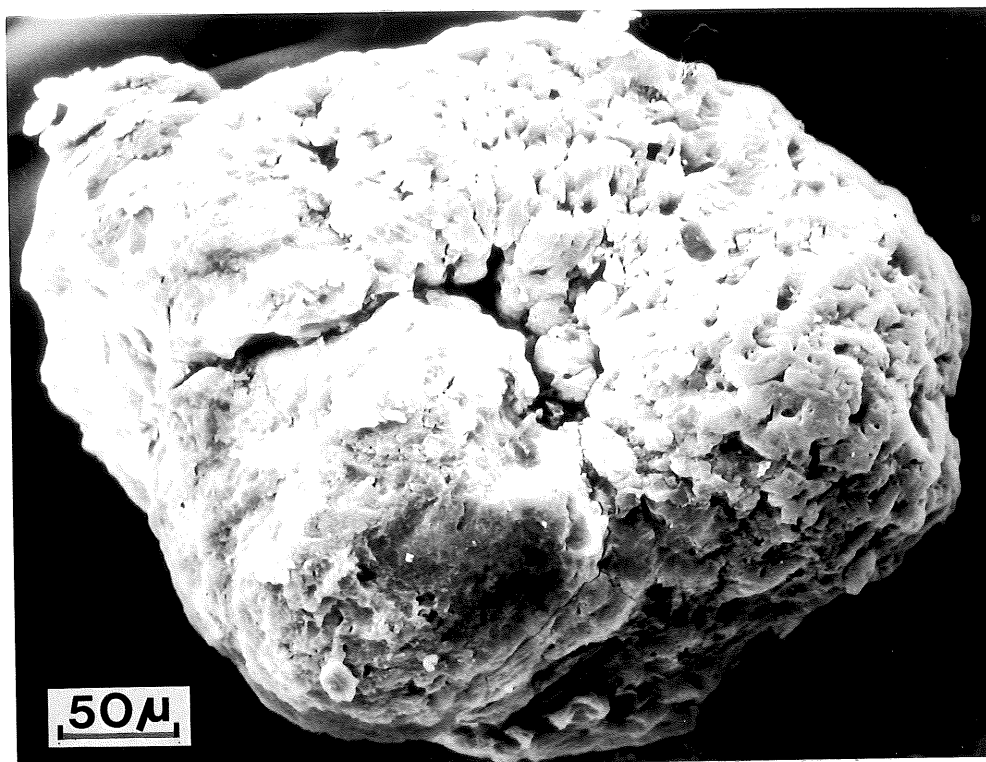
Microprobe Analysis of Higher Reflecting Chromite Rim on Dark-Coloured Chromite Core

	Core	Rim
TiO ₂	0,58	0,74
Cr ₂ O ₃	52,76	45,12
Fe (total)	21,6	32,77
Al ₂ O ₃	13,28	15,19
MgO	10,39	0,90
SiO ₂	0,14	0,0
MnO	0,29	1,07
Total	99,04	95,79

PLATE I



A : "Fly-speck carbon" from the Witwatersrand. Photo by Dr. D.K. Hallbauer, in Whiteside et al. (1976).



B : Scanning electron photomicrograph of "fly-speck carbon" from Uitkyk conglomerates, Mount Robert. The "fly-speck carbon" has been separated by treatment of whole-rock samples with hydrofluoric acid.

Mihálik and Saager (1968) investigated similar chromite grains in the Witwatersrand. According to their findings, the higher reflecting rims contain lower Mg and Al contents than the core, while the Cr and Fe content of the rim is clearly higher. They concluded that the rims developed *in situ* by leaching of MgO from the lattice and its replacement by FeO. It is suggested here that the same processes were operative in the Uitkyk chromites indicating that similar geochemical conditions may have prevailed in the Uitkyk and Witwatersrand conglomerates after their deposition.

Carbonaceous matter is a rare constituent of the conglomerates, although it may be concentrated in certain layers. It occurs as discrete, rounded aggregates, measuring 0,2 to 0,4 mm in diameter, and it is identical to the "fly-speck carbon" of the Witwatersrand ores.

Three varieties of carbonaceous matter have been reported in the Witwatersrand sediments (Hallbauer et al. 1977). These occur as :

- (i) *mats of carbon columns* which are arranged perpendicularly to the horizontal contacts of the mats. The individual columns of the mats possess diameters of approximately 0,2 mm, and their length varies from 0,5 to 5,0 mm. These carbon mats constitute the well-known carbon seams of the Witwatersrand.
- (ii) "*fly-speck carbon*" (0,2 to 1,0 mm in diameter); and
- (iii) apparently *amorphous material* in the Basal Reef of the Orange Free State Goldfield.

Liebenberg (1955) suggested that the carbonaceous matter of the Witwatersrand was formed by "irradiation of gases and/or liquid hydrocarbons by radioactive detrital minerals". Hoefs and Schidlowski (1967) supported Liebenberg's opinion. Later investigators detected amino-acid (Oberlies and Prashnowski, 1968), and alga-like structures (Snyman, 1965), in the carbonaceous material. Subsequently, a biogenic origin of the carbonaceous material, possibly from algae, became commonly accepted (Pretorius, 1966). From the fossil remains, Hallbauer et al. (1977) reconstructed primitive plants which they named *Thuchomyces lichenoides* and *Witwateromyces conidiophorus*. These plants supposedly existed during the deposition of the Witwatersrand sediments. Hallbauer et al. (1977) suggested that *Thuchomyces lichenoides* should be classified into a category of primitive, photosynthesizing fungi or filamentous bacteria and algae and not into a recent group of plants, and they considered the "fly-speck carbon" (Plate 1A) to be the vegetative diaspores of *Thuchomyces lichenoides*.

Several hundred grains of the "fly-speck carbon" from the Uitkyk Formation were isolated by hydrofluoric acid treatment of large rock samples (Neuerburg, 1975) and some grains were investigated by means of an electron microscope (Plate 1B). The surface of the carbonaceous matter from the Uitkyk conglomerates reveals pitted structures and morphological outlines identical to those observed on the "fly-speck carbon" from the Witwatersrand, where Hallbauer et al. (1977) emphasize the striking similarity between cortex-structures of living lichens and the fossil carbon grains.

In polished sections the carbonaceous matter from the Uitkyk Formation displays a dark grey colour and its Vicker's Hardness was found to vary from VH 50 to VH 130. The carbonaceous matter also shows oval-shaped structures between which small grains of pyrite can sometimes be observed. Electron microprobe investigations revealed that the interstitial material between the oval structures may contain up to 39,9 per cent uranium, 4,3 per cent thorium, and small amounts of titanium and lead (Saager et al., in press). The distribution pattern of these elements is, furthermore, almost identical to that of the same elements in carbonaceous matter from the Witwatersrand, reported by Feather and Koen (1975).

Despite a careful search during the investigations, the remaining two varieties of carbon which occur in the Witwatersrand sediments (viz., the columnar and amorphous carbon varieties) were not observed in the Uitkyk material.

If Grobler's (1972) correlation of the Uitkyk Formation with the Archaean Moodies Group proves to be correct, and if the "fly-speck carbon" of the Uitkyk Formation and the Witwatersrand succession are, in fact, remains of photosynthesizing life-forms, then such organisms must have existed some 3 000 m.y. ago. This is much earlier than commonly accepted. Such an early appearance of photosynthesizing organisms could possibly be attributed to the fact that the conglomeratic host rocks of the "fly-speck carbon" are among the oldest well-preserved continental shallow-water deposits known on earth. According to Pretorius (1976), the arenaceous Moodies Group heralds, in South Africa, the transition from Archaean-type crustal evolution to Proterozoic-type crustal development. With the first appearance of continental shallow-water deposition an entire sedimentary basin, with all its contained organisms, may have been exposed to prolonged and intensive solar radiation. Such shallow-water deposition, could, perhaps, have significantly altered the pattern and development-rate of subsequent biological evolution, leading to the evolution of primitive photosynthesizing plants.

If, however, the Uitkyk Formation is not of Archaean age but was deposited at approximately the same time as the Witwatersrand succession, then it is concluded that identical biological and depositional environments, containing similar primitive life forms, must have existed in areas distant from the Witwatersrand basin yet not directly connected with it.

Much older and smaller algal-like biological remains, with diameters ranging from 1 to 75 micrometers, have been described from the Swaziland sequence in the Barberton Mountain Land (Engel et al., 1968; Muir and Hall, 1974; Knoll and Barghoorn, 1977; Pflug, 1966). These microfossils occur, however, in what has been interpreted as a typical marine sedimentary environment.

IV. THE GOLD CONTENT OF ARCHAEOXIDIC BANDED IRON-FORMATIONS

As far as the authors are aware no one has yet offered the suggestion that the Witwatersrand gold may have been derived from Archaean banded iron-formations. In the Pietersburg Schist Belt, several horizons of oxide facies banded iron-formations occur in the volcanic rocks of the Landsberghoek and Eersteling formations. In the Pietersburg Schist Belt, a number of gold prospects were found to occur in the banded iron-formations and, for this reason, 19 samples of oxidic banded iron-formation were collected both from this area as well as from various greenstone belts of the Kaapvaal Craton. The samples were assayed for gold by neutron activation analysis and yielded values ranging from 4 to 667 ppb Au, with a mean value of 204 ppb Au (Table III).

TABLE III

Gold Contents of Various Banded Iron-Formations
from some Greenstone Belts of the Kaapvaal Craton
(Atomic Absorption Spectroscopy)

Sample No.	Locality	Remarks	ppb Au
77/49	Landsberghoek Formation *	-	192
77/50	Landsberghoek Formation *	-	151
77/51	Landsberghoek Formation *	very cherty	4
77/60A	Landsberghoek Formation *	-	173
77/60B	Landsberghoek Formation *	-	170
77/60C	Landsberghoek Formation *	-	157
PM 112	Landsberghoek Formation *	-	120
218767	Landsberghoek Formation *	-	88
218768	Landsberghoek Formation *	-	77
218764	Landsberghoek Formation *	-	495
PM 147	Landsberghoek Formation *	very cherty	80
77/2	Rhenosterkoppies, N.E. Transvaal	metamorphosed	150
77/112	Giant Reef **	metamorphosed	515
77/112 II	Giant Reef **	metamorphosed	356
77/117	Giant Reef **	metamorphosed	45
77/118	Giant Reef **	metamorphosed	105
77/92	Eersteling Formation *	limonitized	667
228761	Eersteling Formation *	-	145
228762	Eersteling Formation *	-	202

Mean = 204 ppb, standard deviation = ± 176 ppb Au.

* Pietersburg Schist Belt

** Sutherland Range

In polished sections prepared from these banded iron-formations, no gold particles could be detected optically with any certainty and it is concluded that the gold occurs as submicroscopic contaminations in either the oxide or the silicate minerals. Oxide minerals in the banded iron-formation samples studied include iron hydroxides and hematite. The microscopic texture of the hematite shows that it formed from martitization of magnetite, indicating that the primary iron oxide of the banded iron-formation was magnetite. According to James (1966), magnetite forms in the oxide facies of the banded iron-formations, under weakly oxidizing to weakly reducing conditions, while hematite develops under strongly oxidizing conditions.

According to Beukes (1973), the Rhodesian greenstone belts contain the best developed banded iron-formations, these generally occurring within the ancient volcanic units at the base of the greenstone successions. In the Barberton Mountain Land, however, the banded iron-formations occur throughout the stratigraphic column but are also found within the sedimentary units towards the top of the greenstone succession. In this respect, the Pietersburg Schist Belt bears greater similarities to the Rhodesian greenstone belts because the banded iron-formations are best developed in the lowermost volcanic unit, the Lapdsberghoek Formation. Applying the criteria established by Gross (1965), the banded iron-formations studied from the Archaean greenstone belts in the Kaapvaal Craton belong to the Algoma-type which are associated with volcanic rocks deposited in Archaean basins.

It is generally accepted that the silica and the iron of the banded iron-formations are chemically precipitated (James, 1966; Garrels et al., 1973; Trendall, 1965; Eichler, 1976; Dimroth, 1976; Cloud, 1973, and many others). For the banded iron-formations in the Rhodesian and South African greenstone belts Beukes (1973) proposed a volcanic origin for the silica. Subaquatic volcanic exhalations (Geijer and Magnusson, 1952; Goodwin, 1956) or subaquatic decomposition of lavas (Van Hise and Leith, 1911; Huber, 1959) are suggested as the sources of the iron.

Frapp (1976) investigated stratabound gold deposits in Archaean sulphide facies banded iron-formations in Rhodesia. He supported a volcano-genetic model, the sulphide minerals and gold having been syngenetically deposited with the banded iron-formations. Based on the findings of Henley (1973) and Fyfe and Henley (1973), Frapp (1976) proposed that downward percolating brines leached base metals and gold from the greenstone host rocks. These metal-bearing brines then moved upwards and precipitated their load in the vicinity of the 100°C isotherm, located above the sediment-water interface of the basin. Although not stated explicitly, one must conclude from Frapp's (1976) study that sulphidic iron-formations, containing gold mineralization, constitute potential hinterlands for auriferous placer deposits.

The Uitkyk, as well as the Witwatersrand, conglomerates contain, in places, numerous detrital banded iron-formation fragments. Because the samples studied from the various banded iron-formation horizons of the Swaziland succession showed high gold values (Table III), 17 banded iron-formation pebbles of the Kimberley Reef from the Evander Goldfield were assayed by neutron activation analysis for their gold concentration (Table IV). The values found in these pebbles of banded iron-formation ranged from 7 to 7 836 ppb Au, with a mean value of 827 ppb Au (Table IV). These values compare well with the gold contents of the 19 oxidic banded iron-formation samples collected in the Archaean greenstone belts.

TABLE IV

Gold Contents of Banded Iron-Formation Pebbles from the Kimberley Reef of the Evander Goldfield in the Witwatersrand

Sample No.	Remarks	ppb Au
810761	grey chert	2 447
26101	red pebble with pyrite replacement	235
8107611	-	360
15107635	black chert, pyrite replacement	854
15107666	-	7
261011	-	14
151085	-	7 836
14107633	-	127
28103	-	40
1510768	-	181
1410763	-	20
3113	-	6
1510767	-	60
1510763	-	66
110762	black chert, contains pyrite	74
15107688	-	1 711
1510765	-	17

Neutron activation analysis, reproducibility \pm 20%

Mean = 827 ppb Au, standard deviation = \pm 1 931 ppb Au.

A graphical Kolmogorov-Smirnov test (Miller and Kahn, 1965) was carried out on the gold values found in both the banded iron-formation pebbles from the Witwatersrand Goldfield and the banded iron-formation samples collected from various horizons of the Swaziland succession (Figure 3). The Kolmogorov-Smirnov statistic revealed that the two sample frequency distributions were drawn from the same population

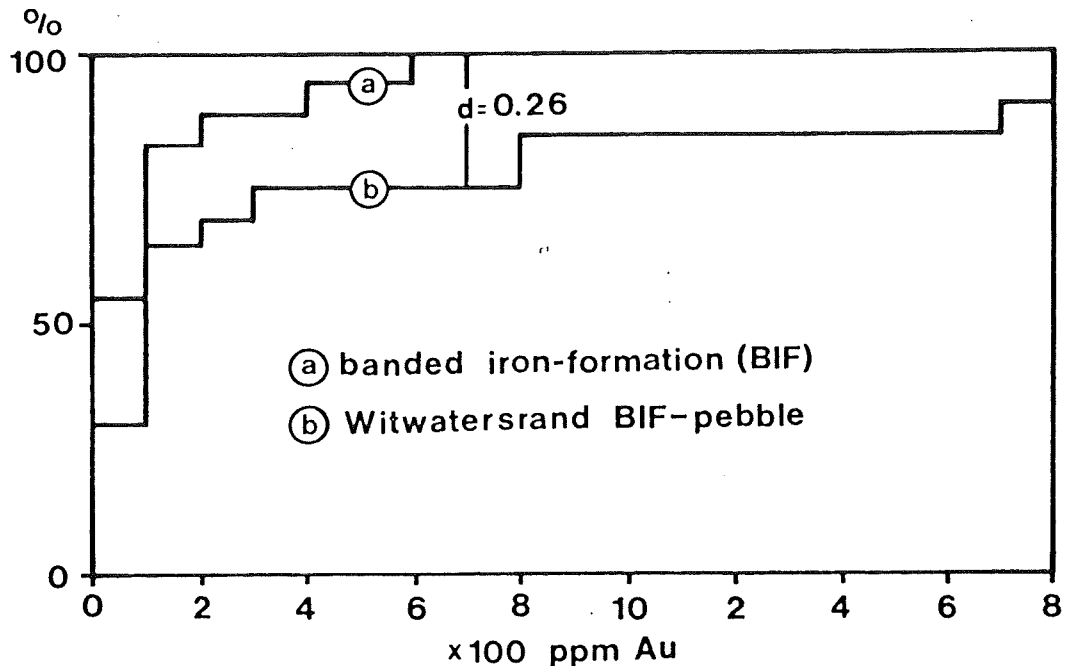


Figure 3 : Graphical solution of Kolmogorov-Smirnov test. d-value of 0,26 does not exceed the critical value of 0,46 at the 0,95 level of significance.

Thus, one can assume that the banded iron-formation pebbles in the Witwatersrand conglomerates originate, in part, from the erosion of "primary" banded iron-formation horizons similar to those investigated by the authors in the greenstone belts of the Kaapvaal Craton.

During erosion and fluvial transport, the "primary" banded iron-formations were variously fragmented and abraded. It is suggested that in the course of these processes gold was mechanically, and possibly chemically, liberated and thus became available for accumulation in sedimentologically favourable sites. Employing this model, it is concluded that some of the Witwatersrand gold, and probably also some of the gold in the Archaean placers, may have originated from oxidic banded iron-formations in the Archaean hinterlands.

V. SUMMARY AND CONCLUSIONS

The pyritic Uitkyk conglomerates studied by the authors exhibit rapid facies changes, well-developed scour channels and sandbars, and contain poorly sorted and rounded pebbles. These features point to a deposition in a braided river system on an alluvial plain. It is suggested that transport distances of the conglomeratic material were short and that the Uitkyk Formation was deposited in a narrow, elongated, rapidly subsiding trough. Signs of extensive transgressions and/or regressions were not encountered. The composition of the conglomerate fragments indicates that they were mostly derived from the underlying greenstones.

The Witwatersrand and Uitkyk conglomerates show close similarities with respect to the occurrence and distribution of the more abundant heavy minerals. For the Witwatersrand conglomerates, Pretorius (1976) suggested a regressive, intercratonic, basin-edge, as the depositional environment, with repeated reworking of the braided river deposits. This repeated reworking of the Witwatersrand sediments manifests itself by pronounced rounding and sorting of the conglomerate pebbles and by conspicuous sedimentological concentration of the heavy minerals. The detailed study of the Uitkyk conglomerates showed that most of these features are poorly developed, which is also indicated by the low gold grades of the Mount Robert ore.

The most striking difference in the mineralogical composition between the Witwatersrand and the Uitkyk conglomerates is the total absence of uraninite and the rare occurrence of other uranium-bearing phases in the latter. This observation can be explained either by the absence of uranium-rich high-volatile granites and associated uraninite-bearing pegmatites in the eroded hinterlands, and/or recent weathering with leaching of the uranium-bearing phases.

The concept of recent removal of uranium from the Uitkyk material studied here is favoured by the present authors for the following reasons :

- (i) the presence of zircon and molybdenite as detrital constituents in the conglomerates indicates that granitic rocks must have existed in the hinterlands which could have contributed uranium-minerals to the Uitkyk conglomerates; and
- (ii) high contents of up to 39,9 per cent uranium within the reducing micro-environment of the "fly-speck carbon" could represent retained traces of uranium from former uranium-bearing minerals in the Uitkyk conglomerates which had subsequently been completely leached-out by descending oxygen-rich aqueous solutions.

In the latter case, uranium contents in "fly-speck carbon", or other carbonaceous matter, of deeply weathered early Precambrian conglomerates, could serve as indicators for the presence of uraninite and other uranium-bearing phases in the conglomerates prior to their weathering. A clarification of this point would be of utmost interest to the uranium exploration industry.

"Fly-speck carbon" in the Witwatersrand is interpreted to represent diaspores of primitive plants (Hallbauer et al., 1977). The detection of similar microstructures in the Uitkyk Formation shows that these organisms also existed outside of the Witwatersrand basin. If the correlation of the Uitkyk Formation with the Archaean Moodies Group proves to be correct then this would imply that advanced life forms have developed several hundred millions of years earlier than was previously assumed. Irrespective of the Archaean age of the Uitkyk carbon, the authors believe that the new find of carbonaceous microstructures in the Pietersburg Schist Belt adds weight to the interpretation that the Witwatersrand carbon probably comprises the remains of primitive plants.

Simpson and Bowles (1977) suggested an oxidizing atmosphere during the early Precambrian and base their hypothesis on the bimodal distribution of uranium in the Witwatersrand sediments, where uranium occurs both as detrital thorian uraninite, and as fine uranium disseminations. According to these authors the uranium disseminations formed during sedimentation of organic-rich muds within the basin. Sulphate reducing bacteria probably assisted in precipitating uranium from solution. The transport of uranium in solution into the basin of deposition required, they maintained, the existence of an oxidizing atmosphere. To explain the occurrence of allogenic Witwatersrand pyrite and uraninite in their model, Simpson and Bowles (1977) cited the presence of these two minerals as detrital stable phases in recent gravels of the Indus River (Darnley, 1962; Miller, 1963).

Pre-Witwatersrand placers similar to those of the Uitkyk or Pongola conglomerates could well represent sedimentary links between the granite-greenstone provenance areas and the Witwatersrand basin. Conglomerate constituents of the Witwatersrand sediments were intermittently exposed to the atmosphere during sedimentary transport over a time period which, in any event, was probably much longer than the short geological history of the Indus River gravel. Therefore, to postulate a present-day atmosphere during Witwatersrand times from the presence of detrital pyrite and thorian uraninite in unconsolidated gravels of the Indus River, as was done by Simpson and Bowles (1977) using the principle of uniformity, is open to criticism.

Oxidic banded iron-formations from the greenstone belts of the Kaapvaal Craton were found to contain a mean gold content of 204 ppb (see Table III). This is approximately 15 times greater than the highest gold concentrations so far recorded in Archaean volcanic rocks that have been investigated for their gold contents. Viljoen et al. (1969) reported, for example, values lying between 5 and 20 ppb Au in komatiitic and tholeiitic material from the Steynsdorp goldfield. Later, Anhaeusser et al. (1975) analysed tholeiites and komatiites from a well-preserved section in the southwestern Barberton Mountain Land which yielded values in the range 0,3 to 3,4 ppb Au (mean value : 1,2 ppb Au). More recently, Muff and Saager (1978) examined tholeiites and komatiites from all the major greenstone belts of the Kaapvaal Craton and found values ranging from 0,1 to 31,5 ppb Au (mean value : 3,5 ppb Au). From these findings, as well as those reported in this paper, the authors suggest that oxidic banded iron-formations, in addition to other sources, may have constituted an important primary source for the Witwatersrand gold.

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