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ABSTRACT

Gold particles in systematically collected ore samples from the Proterozoic Carbon Leader Reef palaeoplacer were studied by ore microscopy and analysed for their silver and mercury contents. The majority of the gold was mobilized and reconstituted forming irregular jagged grains often intimately intergrown with authigenic sulphide minerals, while gold particles of detrital appearance are extremely rare. Mobilization and reconstitution took place as a result of compaction and metamorphic overprint. The element migration occurred over short distances suggesting that original sedimentary distribution patterns were not altered significantly.

Individual gold grains as well as gold grain concentrates obtained from individual ore samples possess uniform fineness values (silver contents). These uniform fineness values are considered to result from metamorphic homogenization processes. The assumption is made, therefore, that the silver contents found in the Witwatersrand gold particles are not those inherited from primary gold sources and provide, at best, limited information on the type of mineralization which existed in the provenance terrane of the sediments.

On a regional scale, fineness values of gold particles exhibit distribution patterns which cannot be correlated with known sedimentological facies. Consequently, studies of regional fineness distributions are of questionable value for grade evaluation during exploitation and exploration.

Mercury was found to be present in appreciable amounts in Witwatersrand gold particles (1,2-5,9%; $\bar{x}$: 3,1%). It is suggested that the major source of the mercury is the surrounding sediments from which the element was mobilized and subsequently amalgamated with gold as a result of metamorphism. The mercury contents of Witwatersrand gold particles, as with the silver contents, yield little information on the geochemistry of primary gold mineralization.

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I. INTRODUCTION

The oval-shaped Witwatersrand Basin occupies an area of approximately 52 000 km² in the Transvaal and Orange Free State provinces of South Africa (Fig. 1). The Witwatersrand succession, which is now largely covered by younger strata contains the greatest gold accumulation known on earth in the form of gold-uranium placer deposits.

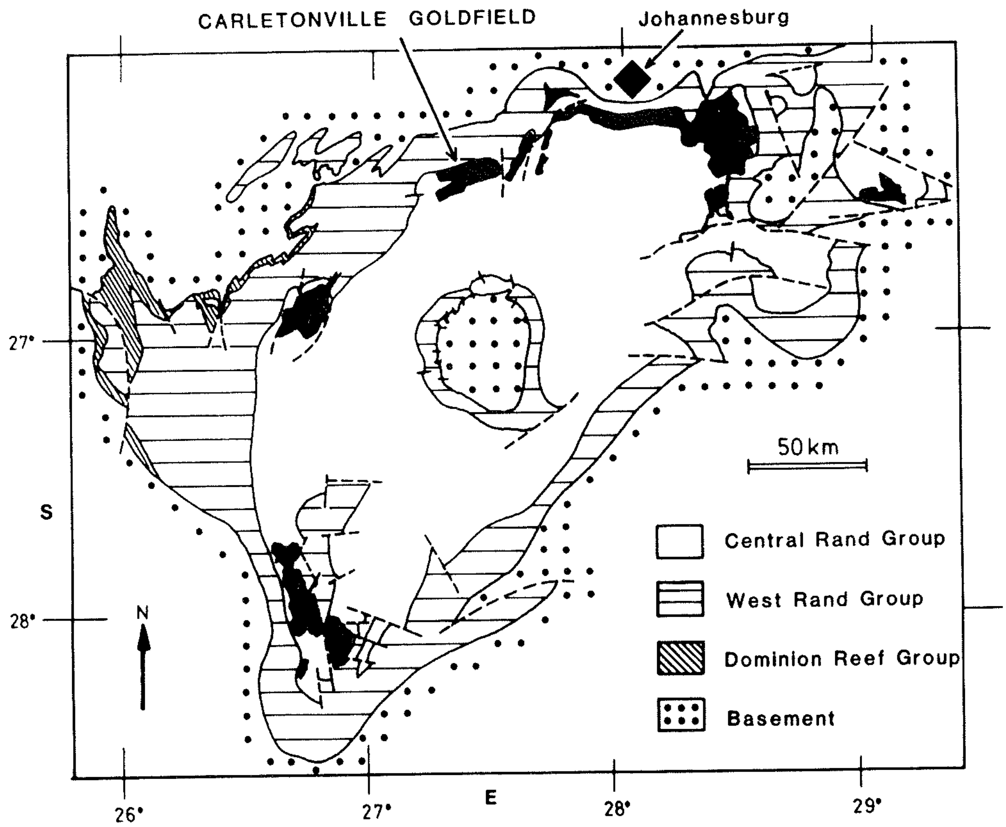


Figure 1 : Sketch map of the Witwatersrand Basin (younger formations removed) showing the principal mining areas (black) and the location of the Carletonville Goldfield.

The placers are part of the 2500 to 2600 Ma Witwatersrand Supergroup which is made up of interbedded fluvial, lacustrine, and marine sediments and, to a minor extent, of volcanic rocks (Pretorius, 1981). Lower greenschist facies regional metamorphism, coinciding with the intrusion of the Bushveld Igneous Complex about 2000 Ma ago (Wetherill, 1956; Burger *et al.*, 1962), affected the Witwatersrand strata.

Gold and other heavy mineral constituents of the placers are predominantly confined to conglomeratic beds which are interpreted to have been deposited in braided stream, deltaic, and lacustrine depositional environments (Pretorius, 1981; Minter, 1976, 1981).

The ore mineral assemblage, encompassing more than 80 minerals, exhibits detrital synsedimentary and, at the same time, hydrothermal epigenetic features. This constitutes the main reason for the *"Witwatersrand controversy"* which raged between the so-called hydrothermalists and placerists until the 1960's. Eventually, the dispute was resolved by the *"modified placer theory"* which envisages that during diagenesis and regional metamorphism some of the detrital constituents of the placers - mainly gold and the sulphides - were mobilized and reconstituted.

The purpose of this paper is to investigate the morphology and textural associations of Witwatersrand gold particles and to study the relationships of their silver and mercury contents with sedimentary and mineral distribution patterns. For this reason the Carbon Leader Reef of the Carletonville Goldfield (Fig. 1) was mapped and systematically sampled at the Doornfontein, Blyvooruitzicht, West Driefontein, East Driefontein, and Western Deep Levels gold mines.

Mineralogic studies using the ore microscope, scanning electron microscopy, and X-ray diffraction methods were carried out on most of the samples. The fineness of some 2500 individual gold particles from about 200 samples collected at 71 different underground localities throughout the goldfield was determined by microprobe techniques. The mercury contents of gold particle concentrates were analysed using atomic absorption spectrometry.

II. PREVIOUS INVESTIGATIONS

Various authors (e.g. Fisher, 1945; Gay, 1963: Stumpfl and Clark, 1964; Desborough, 1970; Schmid, 1973; Ramdohr, 1975) showed that alluvial gold commonly is poorer in silver than primary gold and attributed this to leaching of silver from gold particles during their sedimentary transport in surface waters. Accordingly, gold particles of recent placers often display silver poor marginal zones. Schidlowski (1968) and Saager (1969), however, observed that this phenomenon is typically absent in gold grains of the Witwatersrand ores.

Differences between the "apparent fineness" (fineness of ore samples) and the "true fineness" (fineness of individual gold particles) and their relation to the gold tenors of the Witwatersrand ores were discussed by Von Rahden (1965), Saager (1969), and Utter (1979) who concluded that low "apparent fineness" values encountered in low grade ores (with gold contents of less than 15 g/t) are caused by the presence of finely dispersed silver minerals and/or silver-bearing phases (galena, chalcopyrite, sphalerite) in addition to the silver alloyed with gold particles.

Variations of fineness values on a regional scale were investigated by Saager (1969). Working on samples from the Basal Reef horizon of the Orange Free State Goldfield Saager observed a decrease in apparent fineness values parallel to the main transport direction of sedimentary material. The true fineness of individual gold particles remained, however, conspicuously constant. Based on his observations Saager postulated that the Witwatersrand gold experienced three successive stages of silver depletion, namely:

(i) a relatively weak initial silver loss during the fluvial transport of the gold particles from the primary mineralization to the basin of deposition,

(ii) a second-stage silver loss during sedimentary reworking of the conglomerates in the littoral zone of the Witwatersrand Basin. This caused the observed decrease of apparent fineness values in the direction of sedimentary transport as reworking and, therefore, leaching of silver was less pronounced in areas covered by greater water depths (i.e. the littoral zones of the depository), and

(iii) a final, most conspicuous silver redistribution took place during metamorphism of the Witwatersrand sediments which resulted in a far-reaching homogenization of all reconstituted gold particles and obliterated all their pre-metamorphic features.

Contrary to the above concept Hallbauer and Utter (1977), Utter (1979), Hallbauer (1981), and Von Gehlen (1983) put forward the hypothesis that the Witwatersrand gold experienced no major geochemical changes either during sedimentary transport, deposition, diagenesis, or metamorphism. These authors concluded that the observed homogeneity of silver contents of individual gold grains is an indication of the geochemically unaltered nature of the gold and that their fineness values represent geochemical "fingerprints" inherited from primary sources. Furthermore, Utter (1979) and Hallbauer (1983) proposed that fineness distribution maps display a strong correlation with sedimentological distribution patterns and can, therefore, be used to delineate sedimentological facies within the conglomerates.

Hallbauer and Utter (1977) also compared the morphologies of gold particles from the Witwatersrand ores with those of gold particles from recent placers and proposed that most of the Witwatersrand gold retained its detrital character (i.e. it was not reconstituted after its deposition) and that transport distances in most cases were short and did not exceed 30 km.

Considerable quantities of mercury were discovered by Erasmus *et al.* (1982), in gold particles of the Witwatersrand ore. Using neutron activation techniques these investigators analysed some 60 samples which consisted of composites of 20 to 50 gold grains and which originated from 8 different reef horizons. The mercury contents ranged from 1,2 to 4,6 per cent. Another five gold particle concentrates from four conglomerate reefs were analysed by Von Gehlen (1983) using a microprobe. He found a similar range of mercury contents and observed single gold grains to be homogeneous in regard to their silver and mercury contents. He stated, furthermore, that the gold experienced "no major changes at all during transport and recrystallization". Von Gehlen (1983) accordingly assumed that the silver and mercury contents of the gold particles can be used to identify the types of primary gold mineralization occurring in the source terrane of the Witwatersrand placers.

III. GEOLOGICAL SETTING

The Carbon Leader Reef studied in the Carletonville Goldfield is the basal conglomerate of the Central Rand Group which represents the upper portion of the Witwatersrand Supergroup. According to the classification proposed by Pretorius (1981) the Carbon Leader Reef is a typical representative of the "carbon seam type ore". The Reef dips some 20 to 25° south-south-east, and, towards the north of the area investigated, it suboutcrops with a distinct angular unconformity against the Black Reef conglomerate of the Transvaal Supergroup (Fig. 2). Near the southern limits of current mining activities in the Carletonville Goldfield the Reef is found at depths in excess of 4000 m below surface. Actual mining takes place between about 800 and 4000 m and underground exposures of the Reef are accessible over an area of 20 km (along strike) by 6 km (down dip).

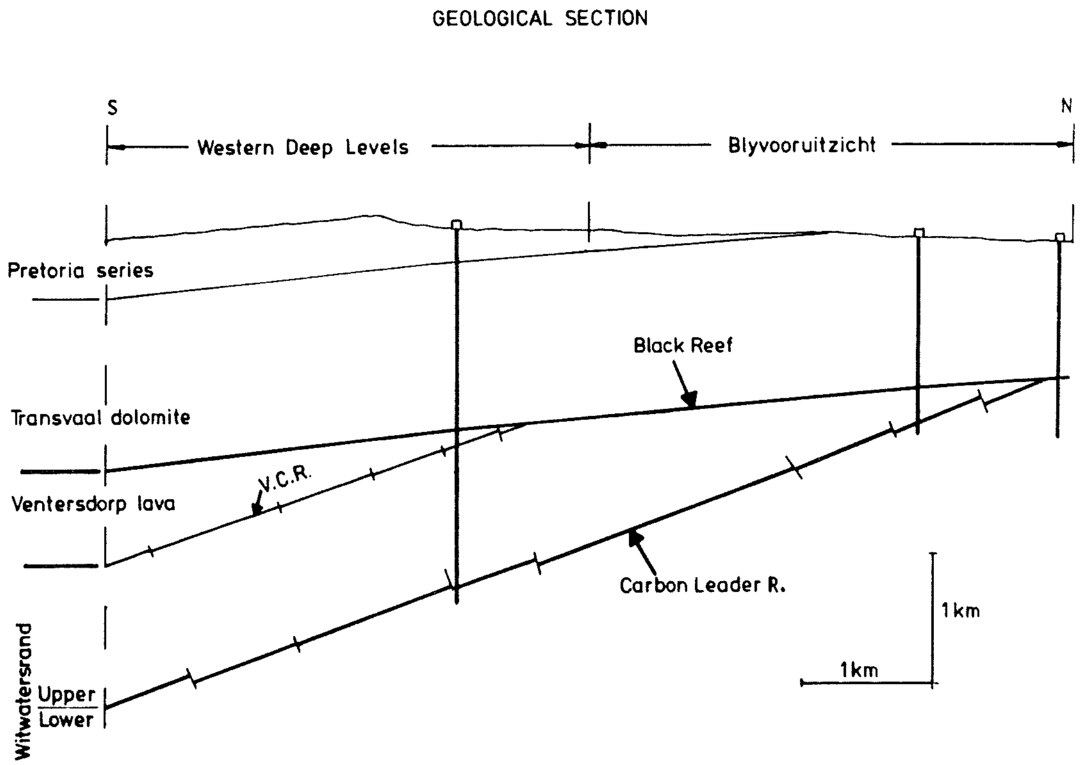


Figure 2 : Schematized geological section, Carletonville Goldfield, approximately N-S through the Blyvooruitzicht and Western Deep Levels mining areas (Lower Witwatersrand = West Rand Group; Upper Witwatersrand = Central Rand Group; V.C.R. = Ventersdorp Contact Reef).

The Carbon Leader Reef conglomerate rarely exceeds 10 cm in thickness. It is oligomictic in character: well-rounded quartz pebbles possessing mean sizes of 10 to 15 mm predominate while chert and quartzite pebbles are very rare (Oberthür, 1983). Practically all the gold and uranium of economic interest is confined to thin seams of carbonaceous matter and overlying conglomerate. Associated quartzites are virtually devoid of economic mineralization.

Detailed sedimentological investigations on Carbon Leader Reef exposures led Nami (1982) to assume that slight differences in the topography of the palaeo-surface have played a vital role in the concentration of gold especially that which Nami (1982) assumed to have been transported in suspension. Furthermore, he pointed out that the major fluvial activity was confined to channelized flow in depressions with higher interchannel areas being only flooded intermittently. Primitive life-forms (now represented by carbon seams) developed between the channels and physically entrapped and concentrated suspended gold particles which were washed over these areas during repeated stages of flooding (Hallbauer, 1975).

IV. ORE MICROSCOPY

A. General

The relative abundance of allogenic and authigenic ore minerals was found to vary widely from one sample studied to the other. Overall, however, allogenic constituents predominate. Generally, the ore minerals occur within the fine-grained, phyllosilicate-rich, conglomerate matrix. Pyrite, as the most common ore mineral in the Witwatersrand ores, is best studied (Ramdohr, 1955; Liebenberg, 1955; Saager 1970, 1973). According to these authors, three types of pyrite were distinguished in the Carbon Leader Reef samples, namely:

(i) detrital rounded pyrite. It constitutes the most abundant variety which originates from primary mineralization in the provenance areas of the Witwatersrand sediments,

(ii) rounded porous pyrite. This variety formed within the Witwatersrand Basin and comprises mudball pyrites (Hallbauer and Utter, 1977) and diagenetic concretions which both, due to their delicate structures, were only transported over very short distances or even developed *in situ*, and

(iii) authigenic pyrite. This pyrite formed as a result of diagenetic and/or metamorphic overprint and comprises overgrowths on detrital ore minerals, fillings of cataclastic cracks in detrital phases and conglomerate pebbles, and euhedral or irregular grains.

Detrital chromite, zircon, cobaltite, arsenopyrite, uraninite, and rutile are usually well rounded.

Recrystallized and mobilized ore minerals, exhibiting epigenetic textures, comprise (in approximate order of abundance) pyrrhotite, gersdorffite, chalcopyrite, rutile/leucoxene, brannerite, galena, mackinawite, and sphalerite (Feather and Koen, 1975). Noteworthy for the authigenic mineral paragenesis is the often encountered close association of remobilized gold and gersdorffite.

B. Gold

Gold particles are usually of microscopic size and range from 0,005 to 0,5 mm. In a manner similar to the pyrite the Witwatersrand gold particles are classified into the following varieties:

(i) individual gold grains possessing roundish or flattened outlines. These have variously been regarded as representing original *detrital grains* or *"nuggets"*. Using ore microscopy Ramdohr (1955) found this type of gold to be very rare and stated that "typical nuggets need not to be taken into account" as "even the placerists have long conceded that most of the gold is not present in normal placer form".

On the other hand, Hallbauer and Utter (1977), who studied individual gold grains by means of a scanning electron microscope, came to contrary conclusions and proposed that "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 based their conclusions on the observations of numerous randomly orientated scratches, plastic deformation features, and other surface textures on gold particles which Hallbauer and Utter (1977) considered to be a result of the short sedimentary transport. Other authors (Schopf, 1981; Feather, 1981; Saager, 1981) suggested that the surface markings on gold particles may also result from diagenetic compaction, metamorphic and tectonic overprint, mining activities, and possibly also from sample preparation,

(ii) *primary roundish-to-oval gold inclusions in detrital pyrite or cobaltite* were rarely found. Such gold inclusions, often combined with chalcopyrite and pyrrhotite, originate from primary mineralization from the source area of the placers. Noteworthy is the finding, reported by some authors (Ramdohr, 1955; Liebenberg, 1955; Saager, 1970), that primary gold inclusions possess higher silver contents than individual gold grains present in the conglomerate matrix of the same sample,

(iii) *reconstituted, authigenic gold* is the most common type of gold and in the Carbon Leader Reef typically occurs together with carbonaceous matter. In many instances gold associated with carbonaceous matter is visible to the naked eye. Microscopically it consists of irregular filaments reaching a length of up to 1 cm, but rarely exceeding a thickness of more than a few micrometres. Fibrous gold was found to be intergrown with other authigenic minerals such as chalcopyrite, galena, gersdorffite, and tucekite, but never with authigenic pyrite (Oberthür, 1983).

Authigenic gold occurs also as irregular, jagged, flaky-plate- or wire-like particles. It forms complex intergrowths with authigenic sulphides or fills cataclastic cracks of pyrite, cobaltite, or other phases. Remobilized gold may also be present as infiltrations in the marginal zones of rounded porous pyrite.

V. INVESTIGATION PROCEDURES AND RESULTS

A. Pressure Experiments

To study the influence of sediment compaction on the surface morphology of gold particles laboratory experiments,using a hydraulic press,were carried out. Spherical gold particles measuring 0,3 to 1,2 mm across, artificially produced from soldering gold, were embedded in quartz-sand (grain size: 1-3 mm). This mixture was placed in a steel cylinder and a pressure of 3 kb applied. After releasing the pressure, the gold grains were carefully separated. They were then studied by means of a scanning electron microscope and compared with untreated particles (Figs. 3 - 6).

The study showed that all gold particles used in the experiment were deformed to differing degrees by the pressure used, which more or less corresponded to the lithostatic pressure to which the Witwatersrand sediments were exposed. This demonstrates that observed surface textures on Witwatersrand gold grains may be the result of compaction, metamorphic overprint and/or tectonic deformation and cannot be solely attributed to sedimentary transport.

B. Fineness of Gold Particles

The fineness Au/(Au+Ag) x 1000 of individual gold particles, i.e. the *true fineness*, was measured in polished sections by microprobe analyses using a set of gold-silver alloys as standards. Precision of the obtained fineness values - checked by repeat spot analyses - was better than 99 per cent.

Fineness variations were studied in four ways, namely: (i) in individual gold grains; (ii) in gold grains occurring within separate polished sections; (iii) in gold grains of ore samples collected in specific mine stopes; and (iv) in gold grains of samples collected throughout the Carbon Leader Reef mining area of the Carletonville Goldfield.

(i) *Silver homogeneity in four individual gold grains* was probed by microprobe spot analyses (Fig. 7). From the results (Table I) it is apparent that individual gold grains possess extremely constant fineness values and do not exhibit any zoning with regard to their silver content. Distinct variations are, however, observed if the fineness values of the four samples are compared.

TABLE I

Fineness Data of Individual Gold Particles

Sample	Number of Analyses per Grain	$\bar{x}$	s	v
V 9	19	874,7	6,8	,76%
V 79	22	896,7	3,9	,43%
V 38	38	971,0	6,0	,62%
V 71	34	930,2	5,4	,58%

$\bar{x}$: arithmetic mean; s: standard deviation;

v: coefficient of variation

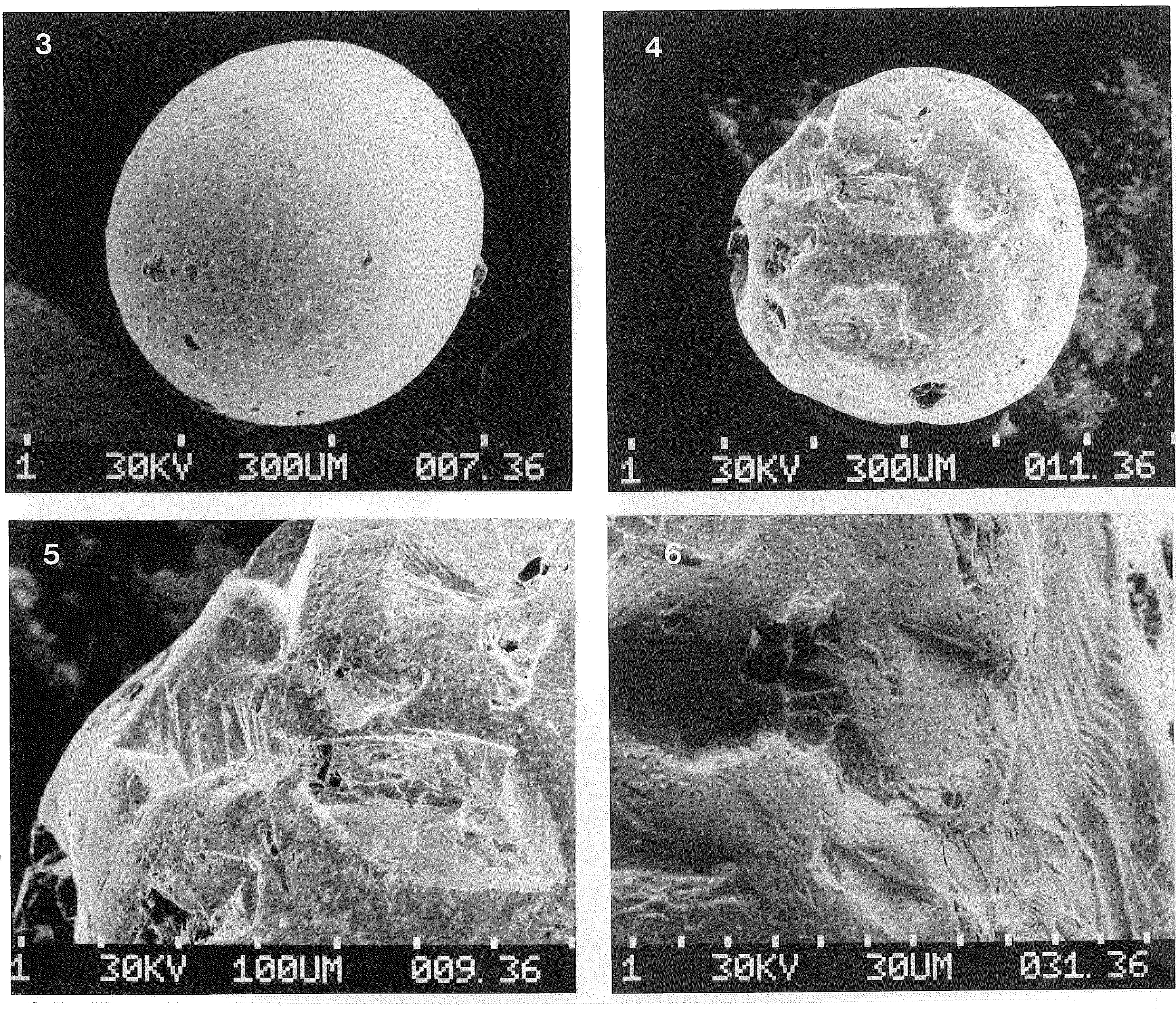
Figure 3 : *Spherical gold particle prior to pressure experiment.*

Figure 4 : *Spherical gold particle after pressure experiment (P = 3 Kb) showing deformation and indentations caused by quartz grains.*

Figure 5 : *Higher magnification of indentations shown in Fig. 4.*

Figure 6 : *High magnification of pressure indentations in gold grain. Note different sets of parallel aligned indentation marks caused by differential movements of quartz and gold grains during pressure experiment (P = 3 Kb).*

Figure 7 : *Authigenic, jagged gold particle. Numbers give fineness values measured at different spots by microprobe.*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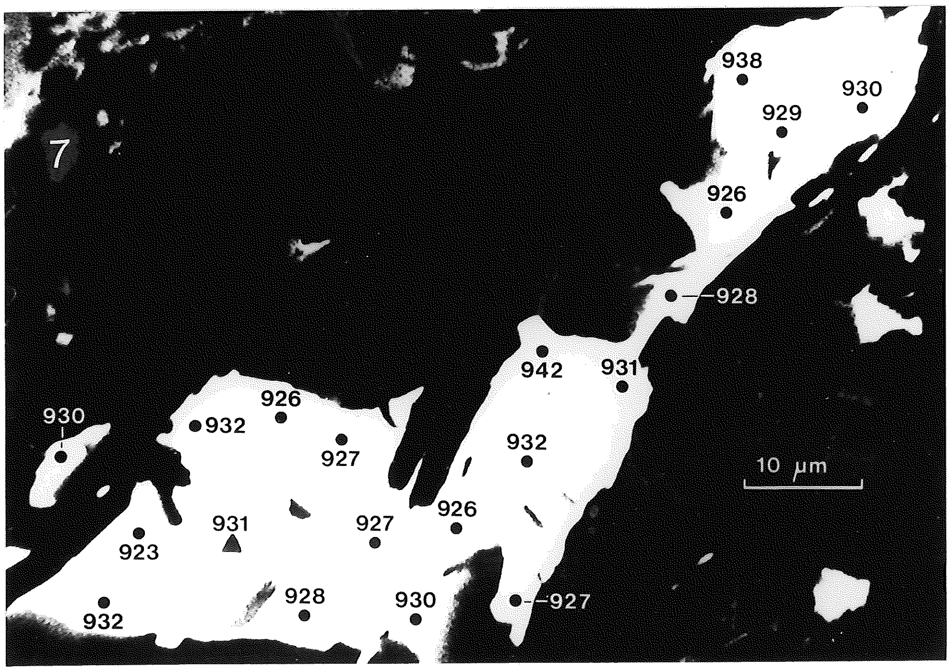
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(ii) *Fineness variations of gold particles present in individual polished sections* were studied in 12 separate samples obtained from various localities in the Carletonville Goldfield. In each of the samples up to 50 gold particles of differing mineral associations and intergrowths were analysed and the "true" fineness calculated (Table II).

Table II reveals that the fineness values of gold particles measured in each of the samples are normally distributed and possess extremely small dispersions. If the mean "true" fineness values of the individual samples are compared a considerable range of values is observed (894,8 to 974,2). This finding differs from earlier results of Schidlowski (1968, 1970) and Saager (1969) who observed conspicuously constant silver contents in gold particles analysed in samples collected over large areas of the Basal Reef in the Welkom Goldfield in the Orange Free State.

TABLE II

Fineness Data of Gold Particles Within Individual Samples

Sample	Number of Grains Analysed per Sample	$\bar{x}$	s	v
V 40	25	941,8	5,3	,56%
V 79	25	900,0	5,4	,60%
V 88	30	894,8	5,5	,61%
V 96	25	900,9	6,2	,69%
V 154	30	914,7	5,2	,57%
V 63	30	928,3	5,2	,56%
V 52	40	921,4	5,4	,58%
V 9	30	898,3	4,8	,53%
V 38	25	974,2	6,0	,61%
R 308	50	927,3	5,7	,61%
V 71	50	930,2	6,0	,61%
V 21	50	930,1	5,2	,56%

$\bar{x}$: arithmetic mean; s: standard deviation;
v: coefficient of variation

The present work revealed, furthermore, that the fineness values of single gold particles is neither influenced by their shape or grain size nor by their mineral associations and intergrowths.

(iii) The finding that gold grains of individual ore samples are of extremely constant fineness (Table II) prompted the writers to investigate whether narrow "true" fineness variations are also observable in samples collected some metres apart. For this purpose "*true*" *fineness variations within the area of a stope* at Blyvooruitzichy Mine were studied. Twenty-four samples were systematically taken from the Carbon Leader Reef along a total strike length of 152 m at intervals of 4 to 12 m (Fig. 8). In this stope the typically developed Reef consists of a 5 to 10 cm-thick conglomerate layer often underlain by a 1 to 15 mm-thick carbon seam. Ten gold particles per sample, or a total of 240 grains, were analysed and the results depicted in Fig. 8.

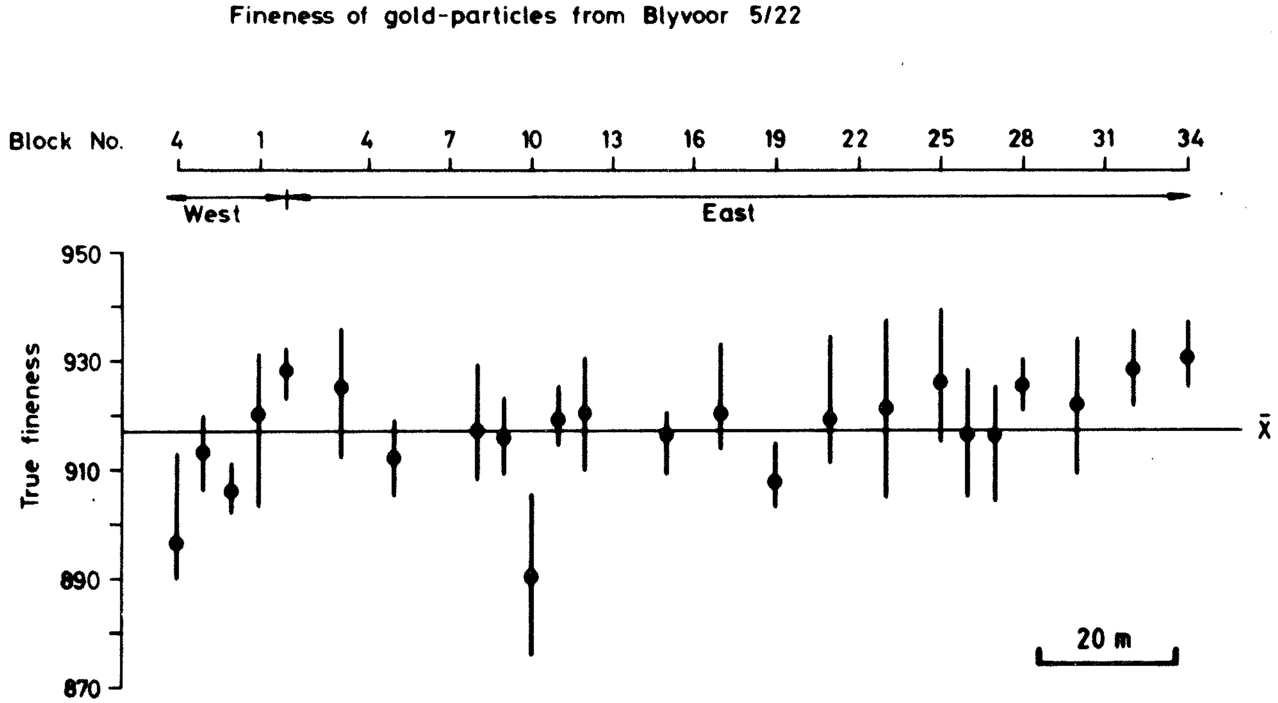

Figure 8 : *Ranges and mean fineness values of gold particles ("true" fineness) from 24 samples collected at Blyvooruitzicht 5/22 reef drive (experimental stope of the Chamber of Mines). Ten gold grains were analysed per sample.* $\bar{x}$: *= 917 (arithmetic mean of all 240 analyses)*

The fineness values of the measured gold particles range from 875 to 940 with an arithmetic mean of 917. For separate samples the mean values were found to vary between 890 and 930.

Fineness values of gold particles from individual samples exhibit the same type of distributions (normal and small dispersion) to those discussed above under point (ii) and listed in Table II. However, if the mean fineness values of the 24 stope samples are compared one observes, in a general way, a considerable and irregular variation of the values although a certain overlap is apparent if neighbouring samples are considered (Fig. 8).

Irregular "local" fineness variation was confirmed by a study of five samples collected at larger intervals (30-200 m) in the environs of the 100-3C drive at Western Deep Levels Mine (Fig. 9).

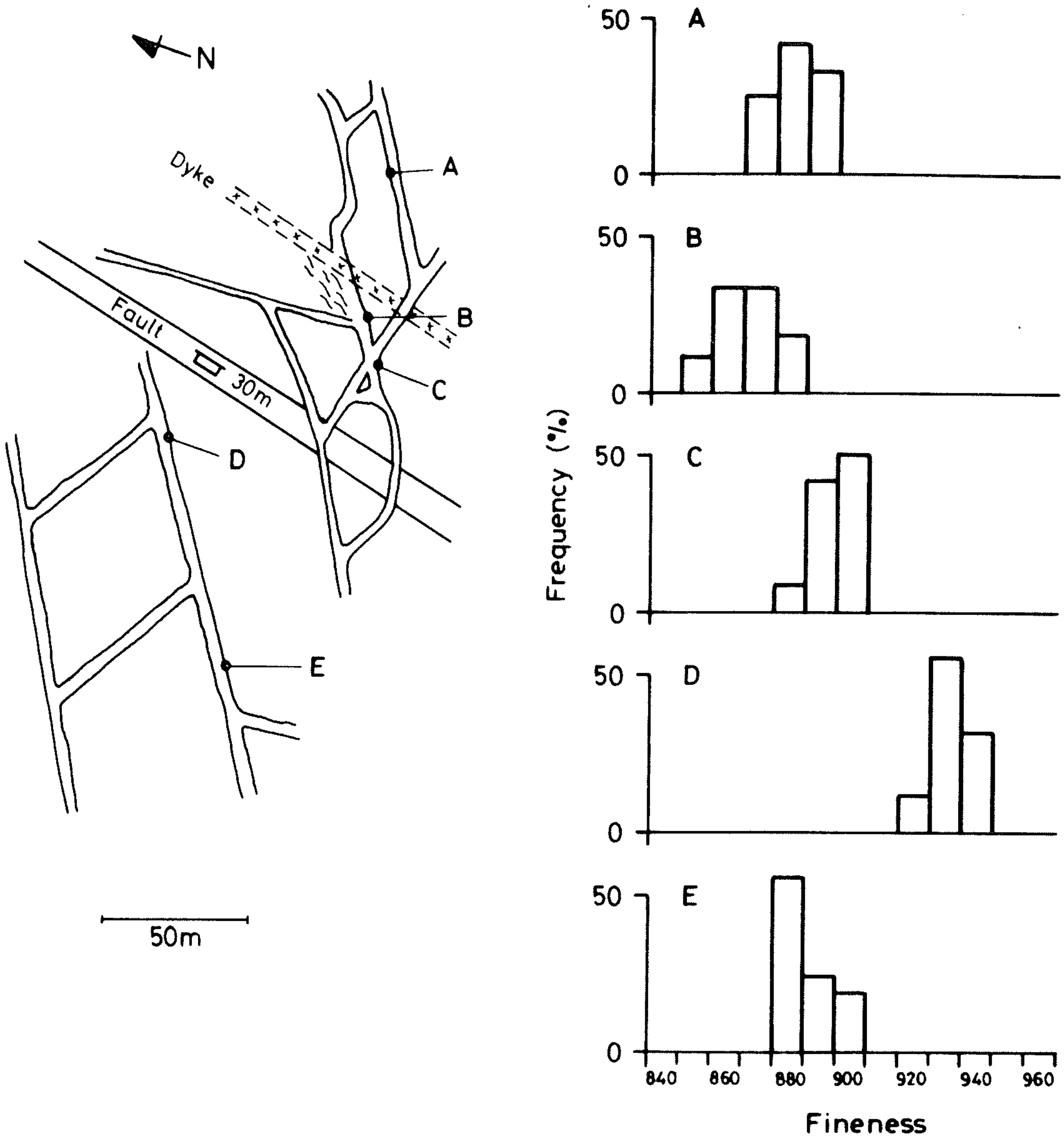

Figure 9 : *Sample localities of 5 samples taken from the vicinity of 100-3C drive at Western Deep Levels Mine (left hand side of figure), and "local" variation of "true" fineness observed in the 5 samples (A-E). Twenty gold grains were analysed per sample.*

(iv) *Regional variations of the "true" fineness over an entire mining district* were studied in a sample set of 71 ore specimens representing the mined Carbon Leader Reef of the Carletonville Goldfield (Fig. 10). Concentrates of gold particles were obtained from each sample of HF-treatment (Neuerburg, 1975) and in each concentrate 10 to 25 grains were analysed. This method was employed to ensure the availability of a maximum number of gold grains from each sample and at the same time it also permitted a study to be made of the morphology of individual gold grains by means of a scanning electron microscope.

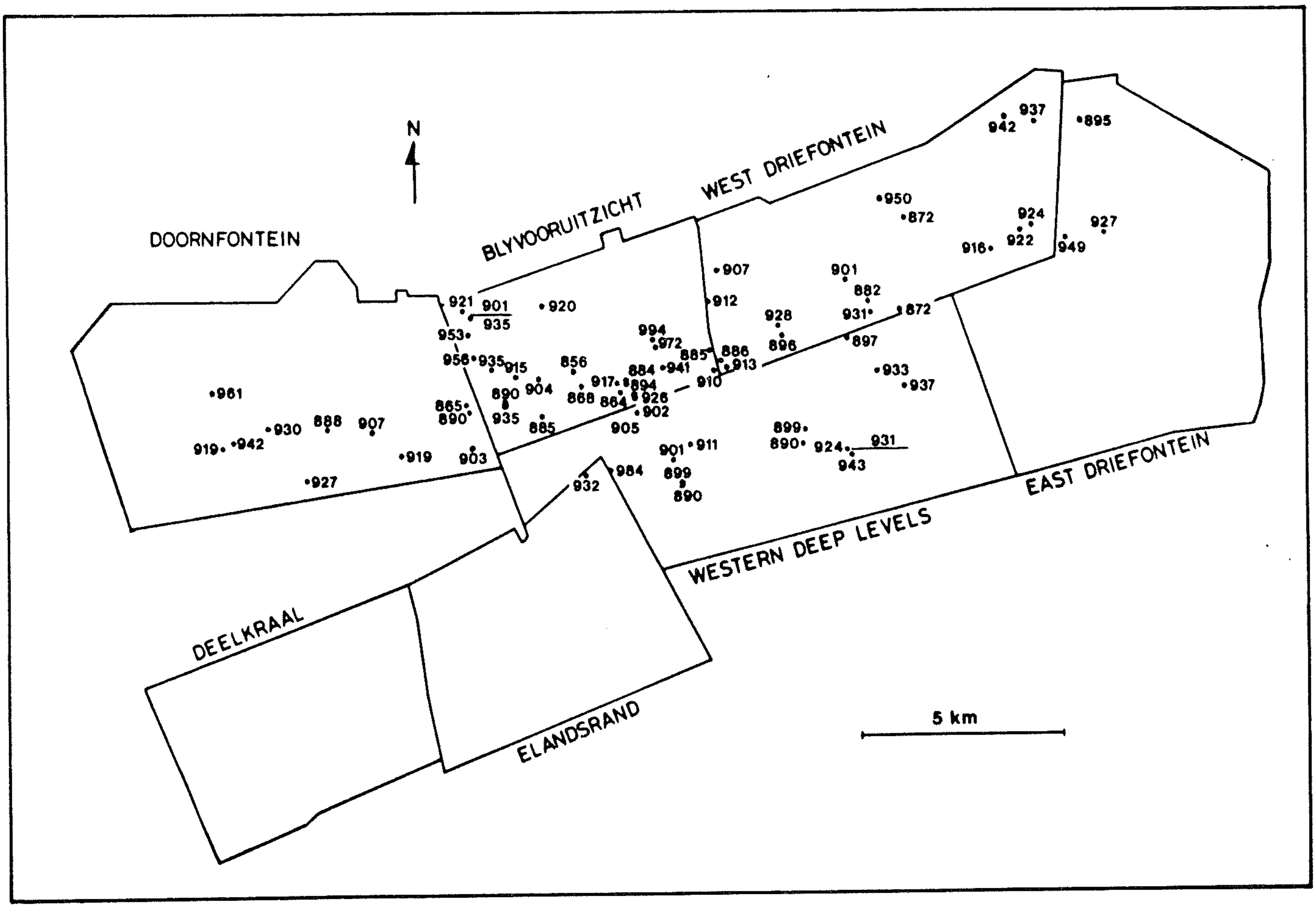

Figure 10 : *Sample localities and measured mean "true" fineness values in the Carbon Leader Reef of the Carletonville Goldfield. Ten to 20 gold grains analysed per sample.*

In total, 1209 gold grains showing a fineness range from 843 to 997 ($\bar{x}$=914,9; s=29,9; v=3,3%) were measured (Fig. 10). Concentrates of individual samples revealed extremely small coefficients of variation lying between 0,30 and 1,36 per cent. Regional distribution of the "true" fineness values obtained for each of the samples is given in Fig. 11 and shows an irregular, rather undefined, distribution pattern.

C. Mercury Content of Gold Particles

Gold particle concentrates were also studied by atomic absorption spectrometry for their mercury contents. Using sample sizes of 2 to 5 mg the analytical errors were less than 20 per cent.

Concentrates from 33 samples were analysed and the areal distribution of the data obtained is displayed in Fig. 12. The values range from 1,2 to 5,9 per cent mercury with a mean value of 3,1 per cent (s-1,0% Hg; v-32%).

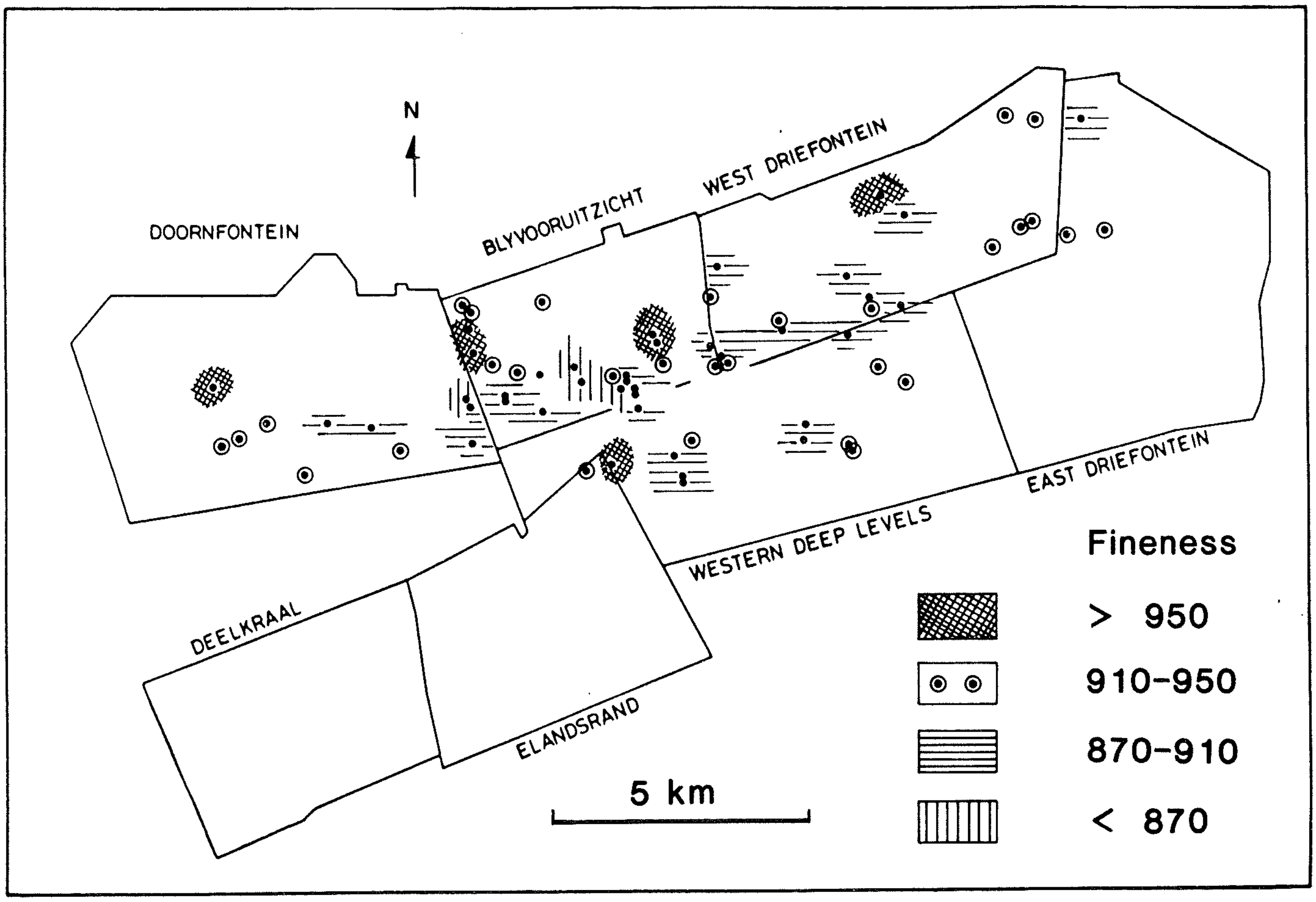

Figure 11 : Area distribution of "true" fineness values after grouping the data given in Fig. 10 into 4 classes.

Figure 12 indicates a general increase of mercury contents in gold particles in a direction towards the centre of the basin (i.e. towards the south-east). It indicates, furthermore, a lack of correlation with a fineness pattern found for the same area (Fig. 11).

Absence of correlation between the silver and mercury contents of gold particle concentrates is, furthermore, indicated by the scatterdiagram displayed in Fig. 13.

VI. DISCUSSION AND CONCLUSIONS

Sedimentological studies of Witwatersrand type ores (e.g. pebble size, pebble assemblage, pebble packing, and palaeo-current measurements) assisted considerably in understanding the genesis of these deposits. The investigations proved, furthermore, to be valuable for practical exploration and exploitation purposes, for instance, for the delineation of sedimentological facies and of pay-streaks. However, sedimentological studies, especially when used during day-to-day underground exploration, are very time and labour

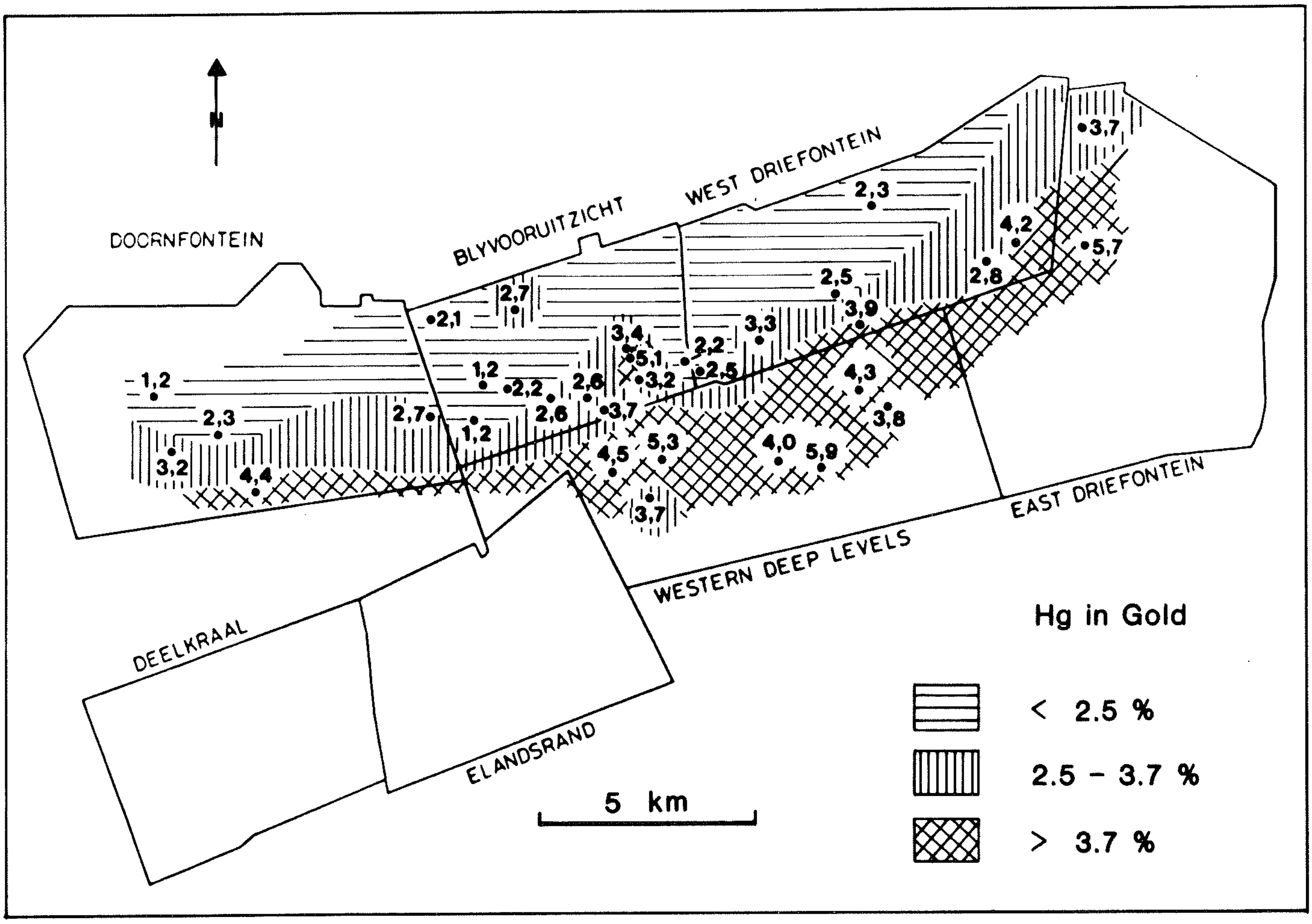

Figure 12 : *Sample localities and mercury contents of gold particle concentrates (Carbon Leader Reef, Carletonville Goldfield). Grouping of data and area trend are indicated by different hatching.*

consuming. For this reason several attempts were made to substitute them for much faster and easily applicable geochemical and mineralogical methods which were of invaluable importance in establishing the metallogenic concept of gold-uranium quartz-pebble conglomerates (Schidlowski, 1981).

Whole rock and trace element geochemistry, as well as mineralogical studies, provided little help in understanding gold distribution within Witwatersrand reef horizons. These predominantly negative results initiated the intensive search by Hallbauer (1983), Hallbauer and Utter (1977), Von Gehlen (1983), and others, to establish a relationship between the fineness of gold particles and gold distribution, i.e. the gold tenor of Witwatersrand reefs. For their studies the authors assumed that:

(i) gold is predominantly present in the form of *detrital particles* (Hallbauer and Utter, 1977)

(ii) *sedimentary transport distances* of the gold were short (Hallbauer and Utter, 1977) and

(iii) the Witwatersrand gold particles have retained their original *silver and mercury contents* (Hallbauer, 1983; Von Gehlen, 1983).

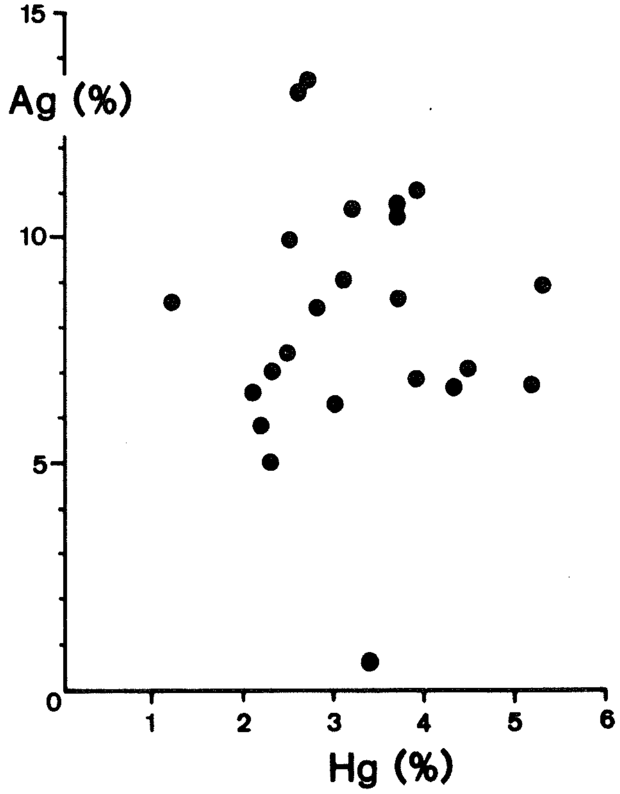

Figure 13 : *Scatterdiagram of mercury and silver values of 23 gold particle concentrates from the Carbon Leader Reef, Carletonville Goldfield. Both elements were analysed by atomic absorption spectrometry. Note absence of correlation.*

A. Detrital Nature of Gold Grains

Mineragraphic studies of the Witwatersrand ores have commonly been performed by ore microscopy and revealed the coexistence of detrital and mobilized minerals (Ramdohr, 1955; Liebenberg, 1955; Schidlowski, 1968, 1970; Saager, 1973, 1981, and many others). Regional metamorphic overprint is generally considered to be the most important factor for solution, mobilization, and reconstitution. In the case of gold the previously discussed pressure experiments showed that plastic deformation, a process already considered possibly by Sharpe (1955), was also of importance. However, migration of gold was of a very restricted nature and in spite of its epigenetic appearance, it still displays its original sedimentary distribution pattern (Saager and Esselaar, 1969).

A new method of mineralogic investigation was introduced and extensively used by Hallbauer (1974, 1983) and co-workers who recovered gold and other ore minerals by HF-treatment and studied them by scanning electron microscopy. In contrast to ore microscopy this method permits three dimensional investigations to be made of grain morphologies. Because HF-treatment generally destroys any relationships between the allogenic and authigenic ore constituents, including gold, this second method is not suitable for the investigation of intergrowth patterns and paragenetic relationships which are best studied *in situ* by ore microscopy. It is probably for this reason that Hallbauer and Utter (1977) failed to recognize the ubiquitous and predominant occurrence of mobilized reconstituted gold. Moreover, surface textures on Witwatersrand gold particles, as shown by our experiments (Figs. 3 - 6), cannot be employed in support of their detrital nature.

B. Sedimentary Transport Distances of Gold

Since interpretation of surface textures on gold grains is ambiguous they are unreliable aids to estimate distances of sedimentary transport. It must be noted that Nami (1982) has pointed out that gold probably was also transported in suspension during deposition of the Witwatersrand placers.

Furthermore, extremely short transport distances (Hallbauer and Utter, 1977) would cause a mass balance problem as the idea implies the occurrence of an extremely gold rich provenance terrane close to the basin of deposition. Such gold rich lithologies, however, have so far not been documented either from the exposed basement adjacent to the Witwatersrand Basin or from inferred model source areas, e.g. the Barberton Mountain Land of the Eastern Transvaal (Viljoen *et al.*, 1970).

C. Silver and Mercury Contents of Gold Particles

This study (Tables I and II) reveals that the regional metamorphic processes which caused the mobilization and reconstitution of the authigenic minerals, also induced homogenization of the gold. This process apparently affected all gold particles and resulted in uniform "true" fineness values. Such an explanation is corroborated by findings of Czamanske *et al.* (1973) who performed annealing experiments of gold-silver alloys and concluded that gold grains, subjected to metamorphism, should show no chemical inhomogeneities.

The presence of constant "true" fineness values in separate ore samples indicates that homogenization not only occurred within discrete gold particles, but is also observable over larger dimensions in the range of a few centimetres to metres (Figs. 8 and 9). It should be recalled that several authors (Von Rahden, 1965; Saager, 1969; Utter, 1979) proposed that in the Witwatersrand ores silver is present not only as an alloy with gold, but also in subordinate amounts in other, mostly authigenic silver carriers. The latter might have gained silver as a result of the homogenization process outlined.

Regional distribution of the "true" fineness in the Carbon Leader Reef of the Carletonville Goldfield (Fig. 11) exhibits an irregular pattern different from the sedimentary distribution pattern (Fig. 14) obtained from measurements of pebble sizes as well as chert/quartz, chromite/zircon, and arsenosulphide/pyrite mineral ratios (Oberthür, 1983). This lack of relationship may reflect pre-metamorphic areal differences of mean fineness, too pronounced to be masked by homogenization, or it may indicate local changes in the degree of metamorphic homogenization. Different modes of sedimentary transport (traction, suspension) of the various placer minerals may be an added reason for inconsistent distribution patterns (Figs. 11 and 14).

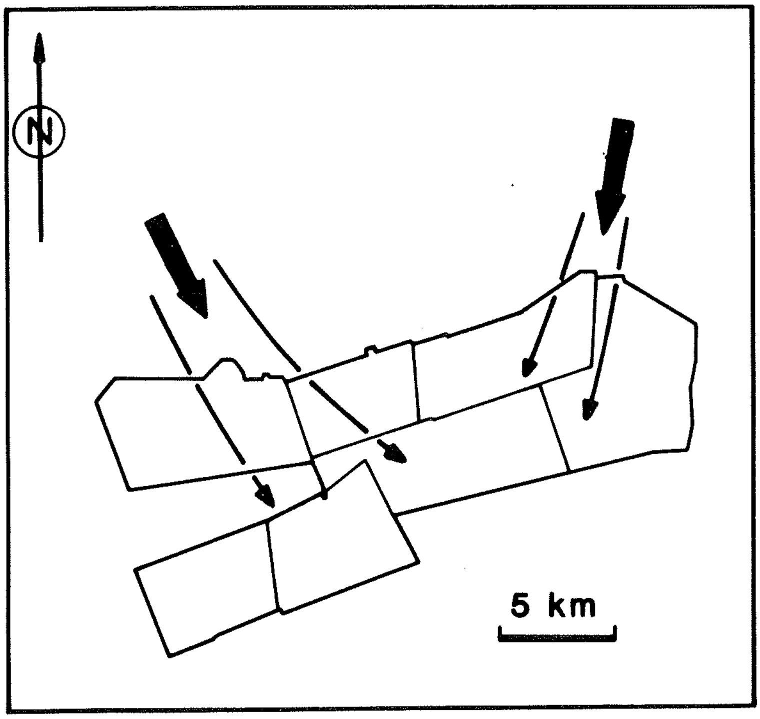

Figure 14 : *Model of sediment distribution and transport directions in the Carbon Leader Reef, Carletonville Goldfield, as inferred from mineral distribution studies carried out by Oberthür (1983).*

The distribution plot of the mercury content of gold (Fig. 12) reveals the existence of a well-defined regional pattern different from the patterns found for the heavy mineral assemblage (Fig. 14) and the fineness values (Fig. 11). In a general way, the mercury contents increase in a south-easterly direction, i.e. with depth of the Carbon Leader Reef (Figs. 2 and 12). Differences in sample depths range from 800 to 4000 m below surface corresponding today to a downdip rock temperature increase of about 50°C. The observed geochemical trend may reflect this thermal gradient and is explained in the following way:

> At greater depths and temperatures mercury, originally present at low concentrations in the Witwatersrand sediments, was more extensively mobilized and subsequently amalgamated with gold particles then close to the Carbon Leader Reef sub-outcrop where at lower depths lower temperatures prevailed. Turekian and Wedepohl (1961) reported average mercury contents of 40 ppb for sandstones and 300 ppb for shales, while Cameron and Jonasson (1972) found average mercury contents of 129 to 513 ppb for various Aphebian shales from the Canadian Shield. Similar mercury levels are also plausible for the Witwatersrand shales and quartzites.

On the other hand, if mercury is a primary constituent of the gold grains, an external heat source north of the Goldfield, inflicting a mercury loss on the gold particles, is required to explain the distribution pattern found. However, if such a heat source did not exist, and there are no obvious signs of it, a decrease of mercury contents in a north-westerly direction (opposite to the observed mercury gradient) would have to be expected.

VII. SUMMARY

1. Ore microscopy of samples collected systematically from the Carbon Leader Reef of the Carletonville Goldfield reveals that most of the originally detrital gold was mobilized and reconstituted and that gold grains of detrital appearance are extremely rare. Mobilization inflicted many epigenetic textures on the Witwatersrand ores and led to the neoformation of authigenic ore minerals. Element migration occurred over extremely small distances and, in general, did not alter sedimentary distribution patterns. Common intergrowths of gold and authigenic sulphides indicate that mobilization was a process which was chiefly initiated by regional metamorphism of the Witwatersrand sediments, i.e. it took place during the solution stage of the modified placer theory.

2. Pressure experiments (Figs. 3 - 6) carried out with gold particles demonstrate that their mechanical deformation and surface textures can be a result of post depositional events such as diagenetic, metamorphic, and tectonic compaction. In addition, mechanical deformation of gold particles may also be inflicted by mining activities, sample collection, and gold grain concentration. For these reasons surface textures and grain morphologies provide no unequivocal evidence for the detrital nature of the particles and should not be used to estimate distances of sedimentary transport of the gold.

3. Individual gold grains, even of different mineral associations, and gold concentrates of individual ore samples possess conspicuously uniform fineness values (Tables I and II), a geochemical feature which is related to metamorphic homogenization. The silver contents now observed in Witwatersrand gold particles are not, therefore, inherited from primary mineralization in the source area of the sediments. In samples taken from a single stope the fineness values show irregular variations, although certain overlaps occur among neighbouring samples (Figs. 8 and 9). This indicates that effects of homogenization are observable on a "local" scale, i.e. over distances of up to a few metres.

4. Regional distributions of fineness values exhibit a pattern lacking affinity to known sedimentological facies (Figs. 11 and 14). The discrepancies probably reflect pre-metamorphic areal differences of mean fineness values too pronounced to be blurred by metamorphic homogenization, or they are caused by local changes in the degree of metamorphic overprint. Accordingly, fineness distribution cannot be used in underground exploration to reconstruct sedimentological facies and predict related gold tenors.

5. On a regional scale mercury concentrations in gold particles now exhibit a down-dip increase which parallels the rock temperature gradient (Fig. 12). This finding makes it likely that mercury was mobilized from the Witwatersrand sediments and amalgamated with gold as a result of (burial) metamorphic overprint. At higher temperatures (greater depths) mobilization and amalgamation was obviously more effective than at lower temperatures (shallower depths). It follows, therefore, that the presently observed mercury contents of gold particles do not represent their primary compositions.

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