ECONOMIC GEOLOGY RESEARCH UNIT

University of the Witwatersrand
Johannesburg

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INFORMATION CIRCULAR No. 82

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by

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July, 1973

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ABSTRACT

Three suites of essentially argillaceous sediment from the Wolkberg Group and the Black Reef-Dolomite transition zone (Transvaal Supergroup) were analysed for gold, using instrumental neutron activation analysis. The average gold content of the argillaceous rocks was found to be 2,5 ppb, while the more arenaceous sediments carried, on average, some 22 ppb of gold. Sediment samples from the old workings on The Crags have an average gold content of 61 ppb; a value of 131,5 ppb was determined for one sample from these workings. The investigation showed that the background gold concentration in argillites is, on average, about 10 times lower than in more arenaceous sediments. An important exception is a carbonaceous silt-shale rock from the Dolomite-Black Reef transition zone, which carries nearly 90 ppb of gold. Such a sediment could act as proto-ore for gold-quartz reefs of the Pilgrims Rest-type, which are very often intimately associated with the carbonaceous shale beds in the Dolomite. On the basis of this study, a more thorough investigation of the gold content of shales in the Malmani Dolomite and in the lower portions of the Pretoria Group is recommended.

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INTRODUCTION

Gold deposits in the eastern Transvaal have diverse ages and geological settings, being found in Archaean greenstone belts, in Proterozoic basins, and in recent alluvial deposits. The deposits associated with the Proterozoic Transvaal basin (2100-2300 m.y.) are the subject of this study. Within the Transvaal basin, gold deposits are essentially of two types : fossil placer deposits and "hydrothermal" reef and vein deposits. The latter types have accounted for the major proportion of gold production in the Pilgrims Rest-Sabie Goldfield, which has recently ceased production after being exploited for nearly a century.

The "hydrothermal" gold-quartz ore bodies of the Pilgrims Rest-Sabie Goldfield are almost invariably associated with shale beds. Current theories hold that the shale beds acted as the loci of intrastratal slip, and that mineralizing solutions were afforded passage through these stratiform structural traps. Although intrastratal movement along shale beds has certainly taken place, the gold-quartz ore could equally well have been derived from the shale under the correct pressure-temperature and fluid conditions. Recent experimental work by W.S. Fyfe (personal communication) has indicated that mobile gold-quartz solutions can be produced at remarkably low temperatures (of the order of 200°C), under the correct pressure and fluid conditions.

Gold is known to occur as sub-microscopic disseminations in shale. An example of an economically-exploited gold-in-shale ore-body is the Carlin Mine in Nevada. Here, gold has been absorbed selectively by, or nucleated onto, surfaces of illitic clays, carbonaceous matter, iron sulphides, and quartz (Hansen and Kerr, 1968).

In the vicinity of The Crags (a farm in the Transvaal Drakensberg, northwest of Trichardtsdal), numerous quartz veins are found traversing argillaceous sediments of the Selati Formation (Wolkberg Group). The veins are auriferous, and were worked on a small scale early in the present century (Hall, 1914). The quartz veins, it was reasoned, probably formed by lateral secretion of silica into tensional sites, carrying with it the gold from the surrounding sediment. In the case of The Crags workings, the host sediments comprise carbonaceous shales, argillaceous quartzites, and some quartzites.

In this study, the gold contents of a variety of essentially argillaceous sediments from the basal portions of the Transvaal Supergroup were quantitatively determined. It is intended to extend the investigation stratigraphically upwards, to determine the gold distribution in argillaceous sediments through the whole of the Dolomite and the lower portions of the Pretoria Group.

The gold contents of specimens of gold-ore can usually be readily determined by the fire assay technique. In the case of the analysis of rocks, however, the low concentrations (ppb range) which are usually encountered present a problem to this conventional method. At such low levels, neutron activation analysis is particularly well-suited to gold determination, and has been used exclusively in this study.

In the first instance, the old workings on The Crags were sampled. A second suite was collected from a traverse across the entire thickness of the Selati formation (Wolkberg Group). Lastly, the upper portions of the Wolkberg Group and the Black Reef-Dolomite transition were sampled from a cored borehole, drilled at The Downs, a short distance west of the two previously mentioned sampling sites.

GEOLOGICAL SETTING

The area investigated (Figure 1) is situated in the northeastern Transvaal. It lies north-west of the settlement of Trichardtsdal, on the lower, east-facing slopes of the Transvaal Drakensberg.

The sediments studied form portion of the Transvaal Supergroup, currently considered to be some 2200 million years old. The supergroup was deposited on an Archean basement, composed of various

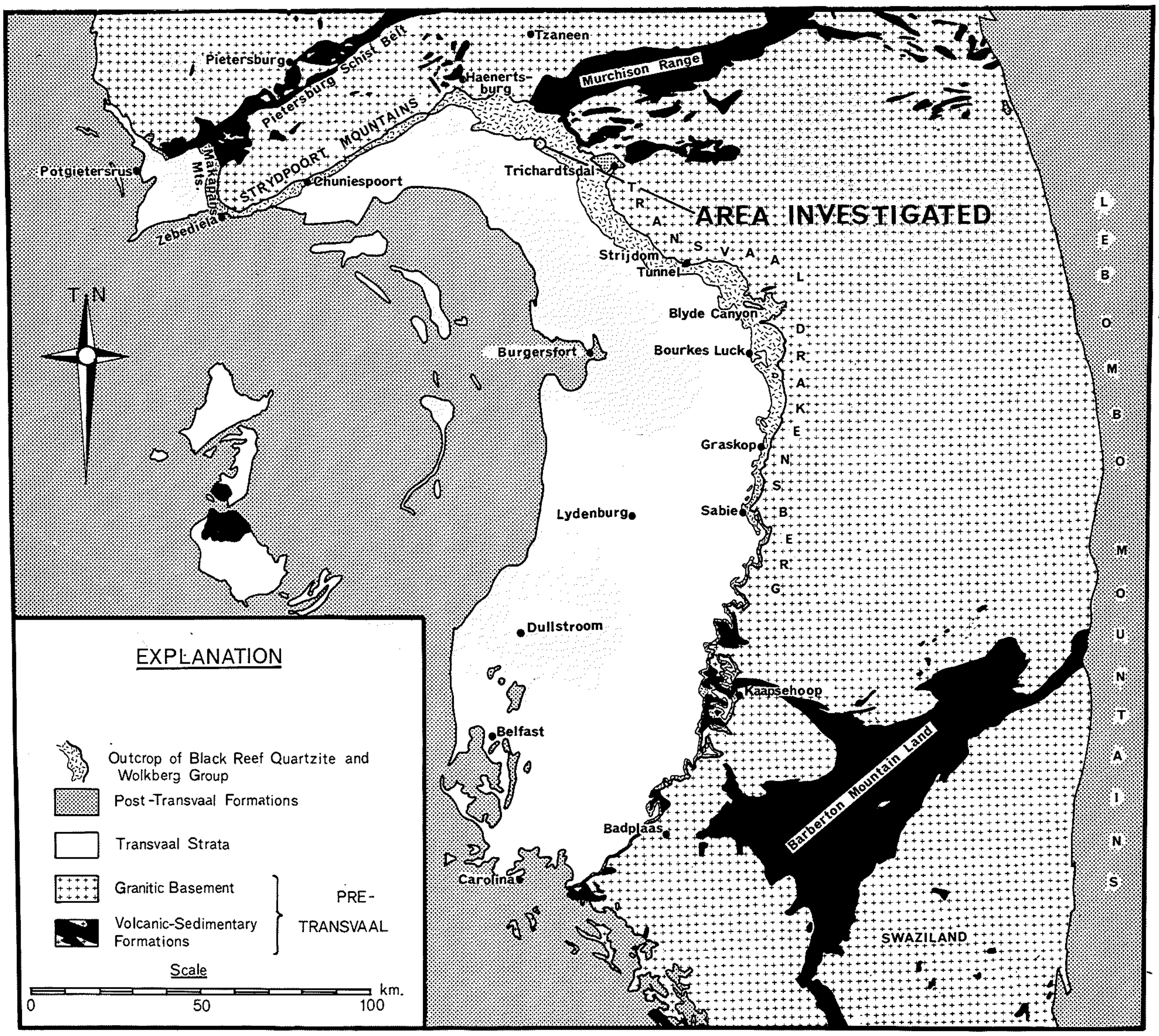


Figure 1 : Map showing regional geology and location of area studied (after Button, 1972).

granitic rocks with greenstone remnants. The earliest phase of Transvaal sedimentation, the Wolkberg Group, is limited in its distribution to the northeastern and eastern Transvaal, where it was deposited in a proto-basin of limited areal extent (Button, 1972). The Wolkberg Group grades upwards to the Black Reef Quartzite, except near the southern limit of the proto-basin, where it is overstepped by this unit. The Black Reef Quartzite passes upwards, through a transition zone, to the chemical sediments of the Malmani Dolomite. The largely argillaceous Pretoria Group rests, with an angular unconformity, on the preceding units of the Transvaal Supergroup. The former is overlain and intruded by the mafic and acid intrusives of the Bushveld Complex.

The sedimentary rocks analysed in this study were collected from the upper portions of the Wolkberg Group and from the Black Reef Quartzite-Dolomite transition zone. Purely arenaceous and volcanic formations were not systematically sampled, since the prime aim of this investigation was the determination of the gold contents of argillaceous fractions.

The Wolkberg Group commenced with the deposition of two arenaceous units, separated by a volcanic formation (Schwellnus and others, 1962; Button, 1972). These units were not sampled. The upper of the arenaceous formations grades upwards to the Selati formation, which, in the area under discussion, is some 800 metres thick. Here, the Selati Formation commences with about 130 metres of fine-grained argillaceous quartzite. The bulk of the formation consists of shales and mudstones, carbonaceous in places. Thin layers of fine-grained argillaceous quartzite are found here and there in the formation, being particularly abundant about halfway up in the unit. The old gold workings on The Crags are situated at approximately this stratigraphic level. The Selati Formation grades upwards, through a thickness of fine-grained argillaceous quartzite, into the overlying Mabin Formation.

The Mabin Formation is composed largely of quartzite and felspathic quartzite, with a thin medial zone of more argillaceous sediment. In the borehole drilled at The Downs, the formation consists of 34 metres of grey to dark grey, argillaceous quartzite, with frequent, thin intercalations of shale.

The Sadowa Formation, which is comprised predominantly of shale with interbedded argillaceous quartzite, occurs between the overlying Black Reef Quartzite and the Mabin Formation. Borehole samples of the Sadowa Formation, 113 metres thick at The Downs, were of dark grey shales, with minor interbedded argillaceous quartzite layers. At the top of this formation, an argillaceous quartzite horizon occurs which grades upwards into the overlying Black Reef Quartzite.

The Black Reef Quartzite attains its maximum thickness in the vicinity of the area studied. Here, together with its interlayered volcanic member, it is over 500 metres thick. It consists largely of mature, cross-bedded quartzite, with some thin pebbly and conglomeratic layers. The Black Reef Quartzite grades upwards to the Malmani Dolomite, through a transition zone, some 175 metres thick in the borehole at The Downs. This zone of transition is composed of a dark, chert-free dolomite, with layers of carbonaceous mudstone or shale and of quartzite.

THE OLD WORKINGS ON THE CRAGS

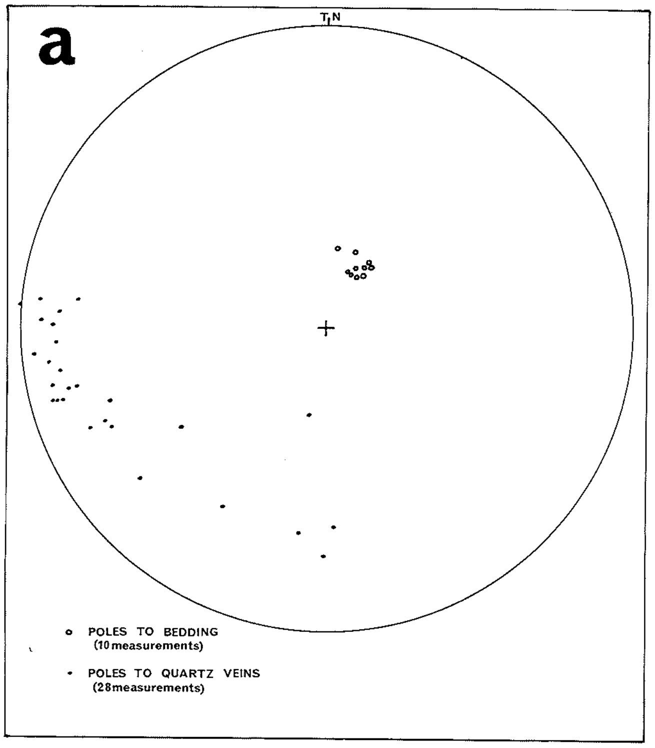
The old workings on the farm The Crags take the form of a few small pits and trenches and a large excavation, all lying broadly along a stratigraphic horizon about midway in the Selati Formation of the Wolkberg Group. In the workings, the Selati sedimentary suite is cut by numerous quartz veins, varying in thickness from less than 1 mm to about 10 cm. The veins are composed of white quartz, with occasional euhedra of hematite (pseudomorphous after pyrite) and mica flakes. In some instances, the quartz veins are stained green.

The host sediments are highly weathered, and appear to range from shales to quartzites. Most commonly, the sediment is a dark grey, very fine-grained, highly argillaceous quartzite which bleaches white. The white-weathering nature of the sediments is taken to indicate a carbonaceous composition. Within this suite, beds of medium- to fine-grained, crossbedded quartzite (ranging from 10 cm to 1 metre thick) are found. The presence of original pyrite specks is indicated by ferruginous mottling in the weathered sediments.

In the workings on The Crags, 10 measurements were made of the orientation of bedding planes, while 28 measurements were made on the orientation of quartz veins. An equal-area, pi-pole projection of the quartz vein and bedding orientation is shown in Figure 2(a). The contoured projection of these data is shown in Figure 2(b). It is apparent that, on average, the host sediments strike 124 degrees and dip at 18 degrees to the southwest. The maximum development of quartz veins strikes 172 degrees and dips 88 degrees east-northeast, approximately at right-angles to the bedding planes. There is also a minor development of quartz veins, striking 090 degrees and dipping 58 degrees north. In the vicinity of The Crags, the pre-Pretoria Group formations of the Transvaal Supergroup are deformed by a set of east-northeast-trending folds. If the folds are related to a north-northeast/south-southwest compressive stress, the major development of quartz veins lies approximately in the a-c plane of these folds. The minor development of quartz veins lies approximately in the a-b plane. The latter possibly represent fillings of tension fractures along the crests of folds.

SAMPLE COLLECTION AND PREPARATION

Eleven samples were collected on The Crags from a traverse across the old workings (Figure 3). The centimetre-thick surface layer of inwashed soil, coating the weathered outcrop, was removed, and the underlying unconsolidated argillaceous material was sampled. Each of The Crags samples was a composite of material, collected over a stratigraphic thickness of 2 metres and a width of approximately 5 cm. Two control samples were collected. The first consisted of a composite of



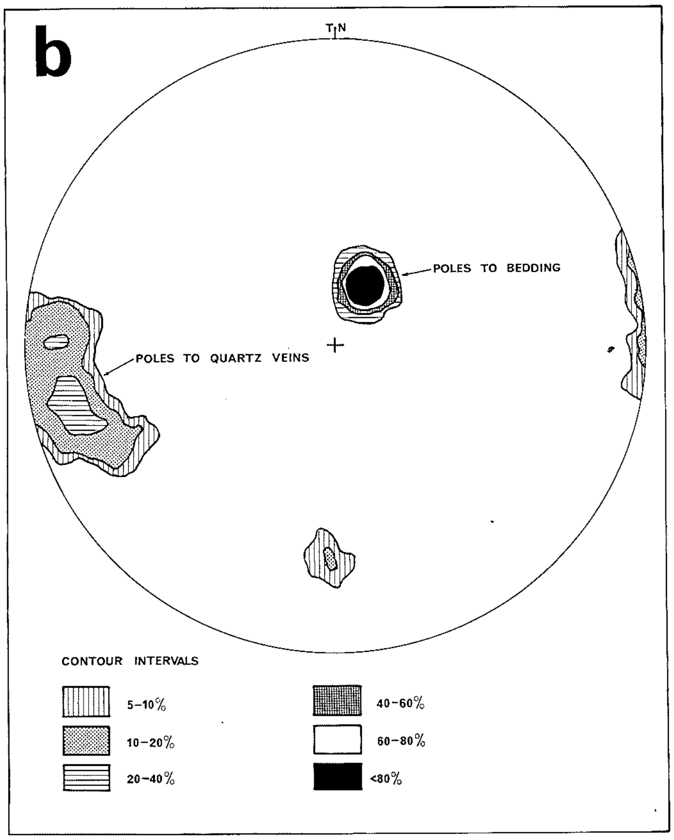


Figure 2 : (a) An equal area, pi-pole projection of quartz vein and bedding plane orientation from the workings on The Crags.

(b) A contoured, equal area, pi-pole projection of quartz vein and bedding plane orientation shown in Figure 2(a).

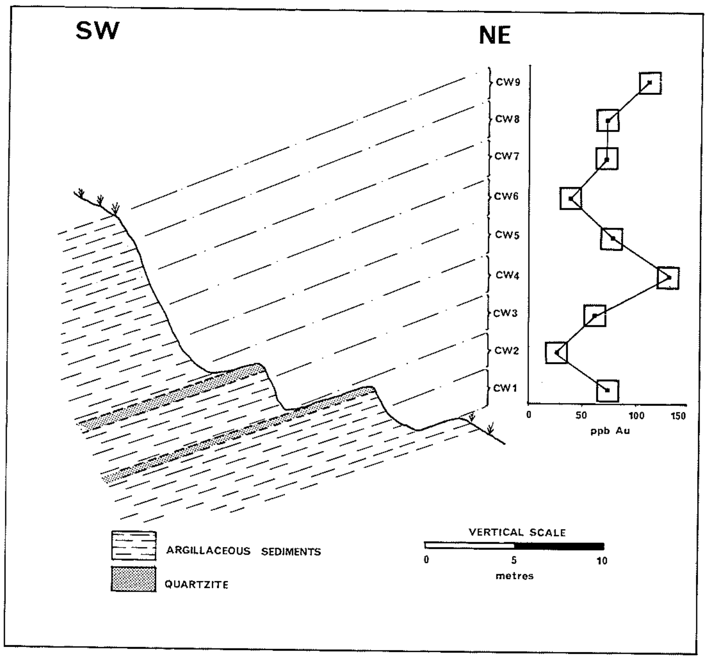


Figure 3 : A profile sketch of the old workings on The Crags. Sample positions and gold concentrations are shown.

argillaceous material, uncontaminated by quartz veins. The second was of quartz vein material, uncontaminated by argillaceous sediment. Fourteen composite samples were collected from a traverse (Kloof 12), across the entire thickness of the Selati Formation. These composite samples, each representing a stratigraphic thickness of 54 metres, were prepared by collecting six regularly spaced grab specimens of Selati sediment in each 54-metre intervals. Thirty-four samples were collected from the core of the borehole drilled at The Downs. These included specimens from the top of the Selati Formation, the Mabin Formation, the Sadowa Formation, and the Black Reef Quartzite-Dolomite transition zone. No samples from the Black Reef Quartzite or Serala Volcanics were analysed.

The degree of weathering of the samples varied widely. Samples collected from The Crags consisted of highly weathered, unconsolidated argillaceous material. The composite samples from the traverse across the Selati Formation varied from fresh to highly weathered. Samples from the borehole drilled at The Downs were all fresh. Due to the inertness of gold, the analysis of weathered specimens is generally considered permissible. Under special conditions of very high acidity and chloride ion activities, gold may be dissolved as the auric chloride complex in the zone of oxidation, but this behaviour is unusual (Kelly, 1969).

Prior to reduction of material for purposes of analysis, the borehole core samples (3,4 cm in diameter and averaging 10 cm in length) were longitudinally quartered. All samples were initially crushed in a jaw crusher and subsequently split into 200 g fractions. One fraction of each sample was further reduced to -120 mesh in a Siebtechniek centrifugal crusher using an agate bowl. Approximately 0,5 g of each powdered sample was then sealed in a high-purity quartz vial (length 4,7 cm, interval diameter 4,4 mm).

NEUTRON ACTIVATION ANALYSIS

(a) General

A flow-chart, in which the neutron activation analytical procedure is schematically represented, is shown in Figure 4. The basis of neutron activation analysis is the interaction of a neutron source with nuclides, giving rise to the production of radioactive nuclides, which emit characteristic radiation. A measure of this radioactivity reflects the concentration of the activated nuclide.

The nuclide ^{197}Au undergoes an (n,γ) reaction, resulting in the formation of the radionuclide ^{198}Au, which has a half-life of 2,70 days. The rate of formation of ^{198}Au, like other radionuclides, is dependent on the energy distribution of the neutron flux, and the cross-section (which varies with neutron energy). On removing the thermal component of the neutron flux (through cadmium shielding) the activation rate of some nuclides (amongst them ^{197}Au) relative to others is enhanced, as the former have higher cross-sections in the epi-thermal region (for example, Turkstra and others, 1972; Steinnes, 1970). This is an important factor in the determination of gold at very low concentrations. Interferences from other nuclear reactions such as (n,ρ), (n,α) and secondary reactions are not considered to be a serious source of error in the determination of gold.

(b) Irradiation

All samples, including the standard, were irradiated for 24 hours in cadmium containers in the poolside facility of Safari I, an Oak Ridge Research reactor of the Atomic Energy Board at Pelindaba. Different irradiation positions in the poolside facility were used.

A neutron flux gradient necessitated monitoring the flux. The total flux received by each sample was monitored by iron foils, which were wrapped around each vial. The method described by Rasmussen (1971) was used to normalize the neutron flux level to a standard value for all the samples.

(c) Counting Procedure

The counting of the γ-energy spectra of the activated samples was done with a 60 cm^3 Ge(Li) solid state detector-multichannel analyzer system. This system was coupled to an automatic

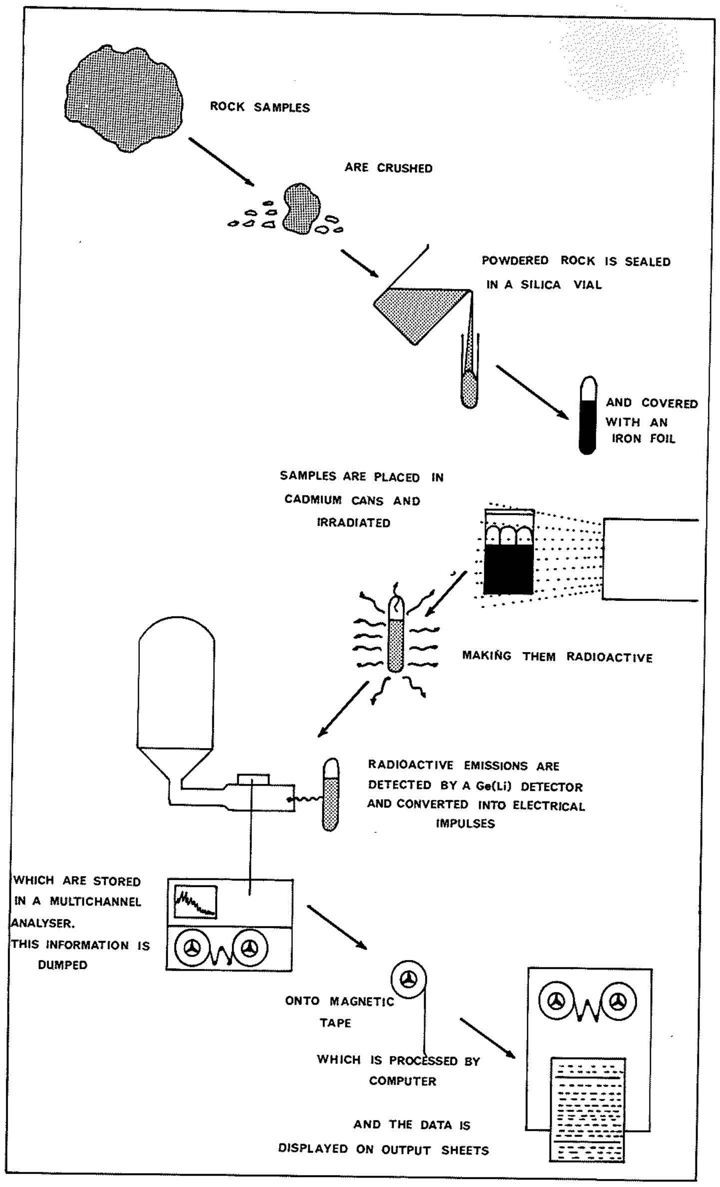


Figure 4 : A schematic representation of the neutron activation analytical technique.

sample transfer facility with a rotating sample holder. From a pilot study, it was established that best counting statistics were obtained 4 to 8 days after irradiation. All samples were counted twice for a period of an hour each.

The geometry of the sample relative to the detector face is critical to the reproducibility of the results. This was of particular importance to the present study since the samples analyzed were divided into three batches for convenience of irradiation and counting. Furthermore, the samples were counted at different distances from the detector face; the distance settings being governed by the activity of the samples.

All the γ-spectra recorded on the magnetic tape (incorporated in the counting system) were analyzed on an IBM 360/50 computer using a modified program developed by Yule (1969) to give integrated peak-areas of the energies corrected for decay, mass of sample, neutron flux variation and dead time. The integrated peak-areas for samples counted over a range of distances from the detector face were related to one another by an experimentally-determined distance correction factor.

Due to the presence of a prominent photopeak of ^{233}Pa ($t_{1/2}$ = 27,0 days) at 415,9 KeV, which in many spectra was not resolved from the 411,8 KeV peak of ^{198}Au, it was necessary to make a correction for the contribution of the ^{233}Pa photopeak.

(d) Standard

A NIM sample (Au S_4) which contains 0,24 ± 0,04 ppm Au was used as the standard in this study.

RESULTS

In this section, the results obtained are discussed under two sub-headings. The first is concerned with specimens from the workings on The Crags. The second deals with the stratigraphic distribution of gold, firstly in the borehole at The Downs, and, secondly, in the field profile across the Selati Formation.

(a) Old Workings on The Crags

The sampling pattern and the distribution of gold in the workings on The Crags are shown on the schematic diagram in Figure 3 and in Table 1, column (a). The same suite of samples was analysed by the fire assay technique, and the resulting gold values (in grams/ton) are listed in Table 1, column (b).

Table 1

Gold Values Obtained in Samples from The Crags

Sample Number	(a) * ppb Gold (1 x 10^{-9} µg/g)	(b) † grams/ton
CW 1	74,8 ± 4,2	1
CW 2	25,8 ± 1,8	Trace
CW 3	62,1 ± 3,4	Trace
CW 4	131,5 ± 5,4	Trace
CW 5	76,9 ± 3,4	0
CW 6	37,8 ± 1,3	0
CW 7	71,3 ± 2,4	Trace
CW 8	71,8 ± 2,9	Trace
CW 9	111,2 ± 4,2	0
CW10	9,6 ± 1,1	0
CW11	20,0 ± 1,3	0

[CW10 is the quartz-vein control sample; CW11 is the argillaceous-material control sample]

* Analyst : R.C. Minnitt

† Analyst : Union Corporation Group Laboratories

Sediment samples from the old workings on The Crags show an average gold content of 61,3 ppb (excluding control samples CW10 and CW11). This is nine times greater than the average for sediments from the non-mineralized sediments studied in this investigation.

One sample, which included a quartzite horizon approximately half-way up the sample traverse, carried some 130 ppb of gold. This was the highest value obtained from this suite. The

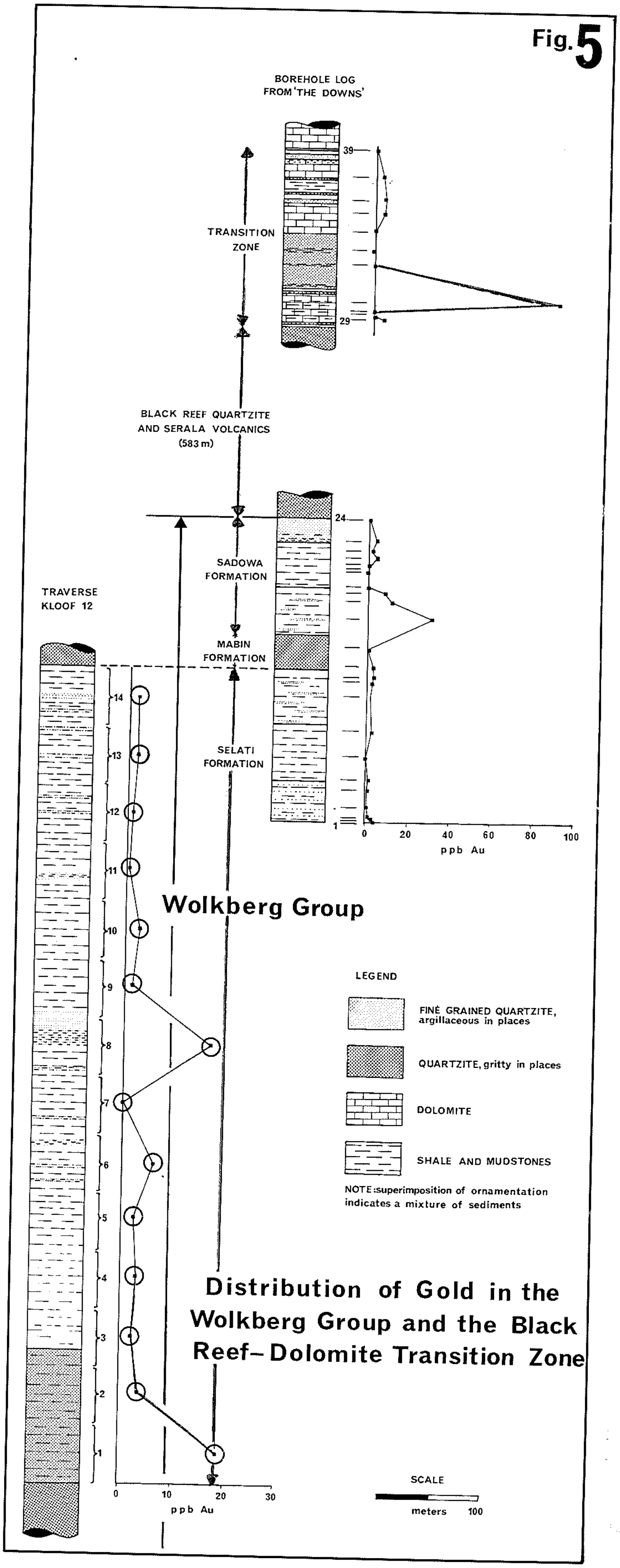


Fig. 5
BOREHOLE LOG
FROM 'THE DOWNS'
TRANSITION ZONE
BLACK REEF QUARTZITE AND SERALA VOLCANICS (583 m)
SADOWA FORMATION
MABIN FORMATION
SELATI FORMATION
TRAVERSE KLOOF 12
Wolkberg Group
39
29
24
1
0
20
40
60
80
100
ppb Au
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
10
20
30
ppb Au
LEGEND
FINE GRAINED QUARTZITE, argillaceous in places
QUARTZITE, gritty in places
DOLOMITE
SHALE AND MUDSTONES
NOTE: superimposition of ornamentation indicates a mixture of sediments
SCALE
meters 100
Distribution of Gold in the Wolkberg Group and the Black Reef–Dolomite Transition Zone

quartz vein control sample showed a gold content of 10 ppb, approximately six times lower than the average for the sample suite as a whole, while the argillaceous control sample with 20 ppb was three times lower. The gold contents of the control samples are, however, higher than the average for non-mineralized argillaceous sediments as determined in this study.

(b) The Downs Borehole and the Selati Formation Traverse

The gold distribution pattern in sediments sampled in the borehole drilled on The Downs is shown in Table 2 and in the upper part of Figure 5. The background gold content for the argillaceous sediments is 2,4 ppb. Four samples contain anomalous concentrations of gold. The first anomaly is present in the lower portion of the Sadowa Formation, where determinations of about 31, 11, and 7 ppb were recorded. The highest value is some 15 times greater than the background concentration in argillaceous sediments (2,4 ppb). The sediments in which these anomalous amounts of gold were found consist of fine-grained, dark-coloured carbonaceous quartzites. The second anomaly (nearly 90 ppb of gold) was encountered in the Black Reef-Dolomite transition zone. The rock-type which gave this value is a banded and laminated sediment, composed of alternating layers of black, carbonaceous shale and lighter-coloured quartzitic silt.

Table 2

Gold Values in ppb ($1 \times 10^{-9}\mu g/g$) Obtained in Samples From the Borehole Drilled on The Downs †

Sample Number	ppb Gold	Sample Number	ppb Gold	Sample Number	ppb Gold
DBH 1	4,3 ± 1,2	DBH 13	B.D.L.	DBH 29	3,7 ± 1,8
DBH 2	3,3 ± 0,7	DBH 14	31,2 ± 6,5	DBH 30	B.D.L.
DBH 3	1,2 ± 0,4	DBH 15	10,7 ± 5,0	DBH 31	B.D.L.
DBH 4	0,8 ± 0,5	DBH 16	7,0 ± 2,1	DBH 32	88,9 ± 47,7
DBH 5	0,4 ± 0,1	DBH 17	B.D.L.	DBH 33	B.D.L.
DBH 6	1,1 ± 0,5	DBH 18	B.D.L.	DBH 34	B.D.L.
DBH 7	B.D.L.*	DBH 19	B.D.L.	DBH 35	B.D.L.
DBH 8	2,1 ± 0,7	DBH 20	1,0 ± 0,8	DBH 36	3,5 ± 1,2
DBH 9	1,6 ± 0,8	DBH 21	3,8 ± 1,1	DBH 37	4,1 ± 0,9
DBH 10	B.D.L.	DBH 22	1,3 ± 0,5	DBH 38	3,3 ± 0,9
DBH 11	2,9 ± 0,9	DBH 23	3,3 ± 1,4	DBH 39	B.D.L.
DBH 12	2,4 ± 0,7	DBH 24	B.D.L.		

* Below Detection Limit

† Analyst : R.C. Minnitt

Samples from the traverse across the Selati Formation show a background gold concentration of about 2,7 ppb (Table 3 and Figure 5). The stratigraphic distribution of gold is plotted in this diagram. The argillaceous rocks (shales and mudstones) show uniformly low gold concentrations. Two anomalous samples were present in the Selati Formation. The argillaceous quartzite at the base of the Selati Formation carried some 19 ppb of gold, while that occurring half-way up the traverse showed a gold content of about 17 ppb. This second anomaly is situated at the same general stratigraphic level as the workings on The Crags.

Table 3

Gold Values in ppb (1 x $10^{-9}\mu g/g$) Obtained in Samples From the Traverse Across the Selati Formation †

Sample Number	ppb Gold	Sample Number	ppb Gold
SWS 1	18,8 ± 0,9	SWS 8	16,7 ± 0,9
SWS 2	3,7 ± 0,4	SWS 9	1,7 ± 0,7
SWS 3	2,0 ± 0,5	SWS 10	2,7 ± 0,1
SWS 4	3,0 ± 0,5	SWS 11	0,5 ± 0,2
SWS 5	2,4 ± 1,5	SWS 12	3,8 ± 1,5
SWS 6	6,1 ± 0,8	SWS 13	2,1 ± 0,7
SWS 7	B.D.L.*	SWS 14	1,8 ± 0,8

* Below Detection Limit

† Analyst : R. C. Minnitt

DISCUSSION OF RESULTS

It must, at the outset, be stressed that this paper represents the results of an initial investigation only into the gold content of argillaceous sediments in the Transvaal Supergroup. In the workings on The Crags, the average figure of 60 ppb gold (approaching 0,1 ppm) over a stratigraphic thickness of 18 metres represents a highly anomalous situation for fine-grained sediments. With a large tonnage, a 15 times concentration of The Crags-type grade would result in a deposit worthy of exploration.

It is impossible, at this stage, to decide whether The Crags gold is syn- or epigenetic. In the first instance, the physical distribution of the gold would need to be determined to ascertain whether it is associated with the clay fraction, or if it is in a coarser state, associated with detrital grains. If the gold is found to be absorbed on constituents of the fine fraction, more detailed sampling along strike should reveal whether the fines trapped gold locally along some structural zone, or whether the clays were uniformly mineralized by gold along a specific stratigraphic level, for greater distances along strike. A tentative conclusion is that the workings on The Crags represent a post-depositional concentration of the syngenetic gold found in the fine argillaceous quartzites and associated sediments near the middle of the Selati Formation.

In the Wolkberg sediments as a whole, gold tends to be concentrated in fine argillaceous quartzites rather than in mudstones or shales, the former carrying some ten times more gold (around 20 ppb) than the latter (between 2 and 3 ppb). This would suggest that the gold is an original constituent of both sediment types, but, being largely detrital, is preferentially concentrated in the coarser rock.

The Black Reef-Dolomite transition zone sees a fundamental change in the gold-distribution pattern. Here, nearly 90 ppb of the element were found in a carbonaceous silt-shale rock. This rock carries some 36 times more gold than its textural counterparts in the Wolkberg Group. This discovery is considered to be highly significant with regard to the genesis of the Pilgrims Rest-type gold ore-bodies. A shaly rock, such as the one described above, could act as a proto-ore for deposits of this type. Such a conclusion provides a stimulus for a more detailed investigation of the shaly sediments of the Dolomite and Pretoria Groups in the Pilgrims Rest-Sabie goldfield.

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Acknowledgements

The authors would like to thank : (i) National Institute for Metallurgy and the Atomic Energy Board for the financial aid provided, and, (ii) Professor J.P.F. Sellschop for placing the facilities of the Nuclear Physics Research Unit at our disposal. We wish to acknowledge the assistance and helpful suggestions made by members of the N.I.M.-WITS Neutron Activation Analysis Research Group, in particular H.W. Fesq, S.E. Rasmussen, and J.I. Watterson.

The Consulting Geologist of Anglo-Transvaal Consolidated Investment Company is thanked for making available samples from the borehole drilled on The Downs. Mr. T.M. Thalwitzer kindly granted his permission for the sampling of the workings on The Crags.

The idea of looking into the gold content of shaly rocks was suggested by Professor D.A. Pretorius, who drew the attention of one of us (A.B.) to the Carlin deposits in Nevada, and suggested that a similar situation could pertain in some of the Proterozoic basins of Southern Africa.

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Key to Figures

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