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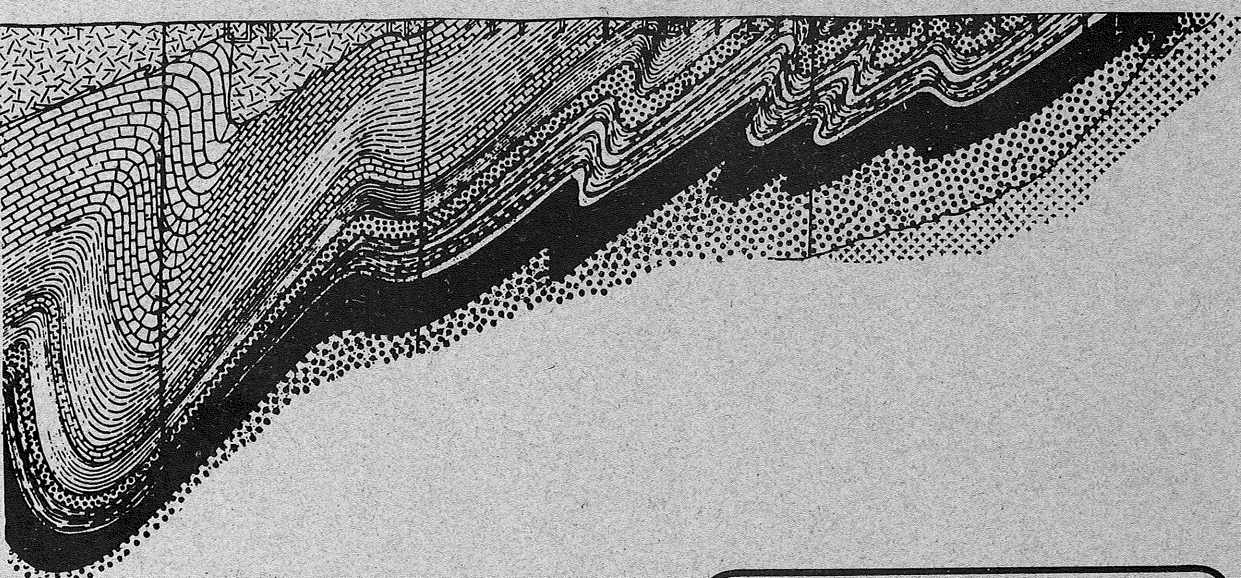

ECONOMIC GEOLOGY

RESEARCH UNIT

UNIVERSITY OF THE WITWATERSRAND.

JOHANNESBURG.

SILVER CONTENT OF GOLD

IN WITWATERSRAND CONGLOMERATES

by

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"It is clear that the facts in connection with the distribution of the silver in relation to the gold require a much fuller and more detailed investigation. It may be that these facts, if they were more completely known, might throw some light on the origin of the gold."

J.G. LAWN,

1924.

SILVER CONTENT OF GOLD IN WITWATERSRAND CONGLOMERATES

ABSTRACT.

Analysis of generalised data obtained from all producing mines associated with the Transvaal and Orange Free State Chamber of Mines suggests that in each Witwatersrand Reef the silver content of the bullion varies as a function of elevation: reef in shallow areas having high silver, reef in deep areas having low silver. In terms of the 'modified placer hypothesis' for the origin of the gold, such a composition gradient (if confirmed by subsequent experiments), would imply that considerable redistribution of silver relative to gold had taken place during the 'solution' stage. The available data are insufficient to suggest whether redistribution of silver might have occurred between reefs, or only within each reef as separate closed systems. Contrary to normal alluvial trends, the silver content of bullion from Contact Reefs (Ventersdorp Contact Reef and Black Reef) is usually similar to or higher than that in those underlying Witwatersrand reefs for which data are available. These underlying reefs are usually presumed to be the main source of the Contact Reef gold.

CONTENTS.

I. INTRODUCTION.

As part of the programme of research on the Witwatersrand System being undertaken by the Economic Geology Research Unit of the University of the Witwatersrand, it was considered desirable to accumulate systematically data on the silver content of the gold in Witwatersrand conglomerates. In response to a request made to the Chamber of Mines, information as to the silver content of the gold has since been made available by most producing mines in the Transvaal and Orange Free State.

II. HISTORY.

A significant variation in silver percentage of gold in mine assay samples was reported by LANE CARTER (1902, p.91) and DURES (1913, p.609). YOUNG (1917, p.77) observed that "...the purity of the gold appears to vary to some extent with the size of the particles in which it occurs in the rock, the coarser grained being the purer."

In the first major contribution to this subject, LAWN (1924) reported the results of detailed investigations into the silver percentage of gold in mine assay samples, and concluded (op. cit. p.27) "...in individual samples there seems a tendency for low silver percentage to be associated with high gold values, but the reverse not infrequently occurs."

PRENTICE (1939-40) reported much new detailed information as regards gold, silver and pyritic content of ore from eleven Witwatersrand mines, with the following results (op. cit. p.31):

1. "there is no obvious relationship between the pyritic content and the silver percentage in the ore"

2. "there is a definite correlation between the gold value and the silver percentage, the latter decreasing as the former rises and vice versa."

III. PRESENT STUDY.

Despite the variation in silver content of the gold

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as a function of grade of the ore (and possibly other local variations), it is apparent from previous studies that there is in some instances a significant variation between mines in the average silver content of the gold produced from one reef. The pattern of this variation, considered on a retional scale, seemed a promising avenue of investigation, and is the main subject of this report.

1. Quality of Data.

The data on silver content have been provided in reply to a questionnaire circulated to all producing mines in the Transvaal and Orange Free State. These data are in general the results of silver determinations made on collections of bullion beads from mine samples. For several reasons, however, the results reported from different mines are not necessarily rigorously comparable:-

1. Some mines reported the average result of determinations made at regular intervals over a considerable number of years; others reported on the results of only a few or a single test.

2. Some mines made tests on collections of all mine assay sample beads, regardless of their size; others sized the beads and determined the silver content in separate size ranges. With regard to the latter, in some instances no weight proportions were available and an arithmetic average was presented.

3. There is a possibility that there are slight differences in determinative procedures followed in different assay offices.

The errors resulting from these factors cannot easily be evaluated, and the compiled data are thus not rigorously standardized. However, the maximum variations in the average silver content reported from different mines are of such large magnitude (e.g. from 5.9% to 11.3% in Main Reef Leader of East Rand Basin) as to suggest that real differences between mines do exist. Furthermore, in determinations made at individual assay offices, differences in the silver content

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of gold from the same reef on different mines, and between different reefs on the same mine are recorded. Examination of the results on a regional scale was, therefore, considered to be warranted.

2. Results.

The data provided are compiled according to individual mining areas in the Appendix, with comments pertaining to the sampling procedure. Analysis of these data suggests several interesting relationships, which will be discussed under the following headings:

1. Variation of silver content of gold within individual reefs.

2. Silver content of gold in different Witwatersrand reefs.

3. Relationship between silver in Contact Reefs (Ventersdorp and Black Reef, and that in underlying Witwatersrand Reefs.

A. Variation in Silver Content of Gold within Individual Reefs.

For a particular reef in any one mining area, the average silver content of the gold appears to vary as a function of the present elevation of the reef in that area. Reef in "shallow" areas contains gold with a higher average silver percentage than reef in "deep" areas.

The tendency toward this relationship only became apparent on preliminary analysis of the silver data. In the original questionnaire circulated, no information was requested as to the average elevation of the samples used in the silver determination, and further enquiry revealed that for the silver values reported, such information is in most cases either unknown, or practically impossible to obtain. Thus the silver values reported by individual mines can only be evaluated in terms of the average elevation of the workings in each mine. This is obviously not altogether satisfactory, particularly for values reported solely on the basis of one determination. It is hoped

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that in the future silver data more rigorously controlled from the "elevation of sample" aspect might be obtained. Nevertheless, evaluation of the existing data in different mining areas, is as follows:

(i). <u>East Rand Basin</u>.

The data for the Main Reef Leader in the East Rand Basin (Appendix and PLATE 1, Fig. 1) are plotted geographically in Fig. 2 (PLATE 1) and contoured at intervals of 1% Ag from 6% to 10%. Generalised structure contours of the Main Reef Leader in the East Rand Basin, taken from CLUVER'S plan (1957, PLATE II) are presented for comparison in Fig. 3 (PLATE 1).

The similarity between the two contour patterns is conspicuous. It can be seen from the limited data in the Appendix that the pattern of variation of silver content of the Kimberley Reef in the East Rand Basin is generally similar to that in the Main Reef Leader.

Tests to determine the average silver content of Main Reef Leader samples have been made bi-annually throughout the greater part of the life of Marievale Consolidated Mines Ltd., these data are presented graphically in PLATE II.

A progressive decrease in silver content over the years is clearly apparent, which can reasonably be correlated with a progressive increase in average mining depth. The sharp rise in silver values between 1948 and 1950 coincides with a distinct drop in the average grade of ore mined over the same period (PLATE II). This change followed devaluation of the pound in 1948, whereby the economic grade cut-off was lowered. As a result, low grade reef not mined in the shallower levels was now extracted. Furthermore, with the lower grade limit, more low grade samples (with higher silver, see LAWN, 1924 and PRENTICE, 1939-40) would now be taken. Both of these factors would contribute to rise in average silver values, and are believed to account for the rise recorded between 1948 and 1950.

(ii). <u>Klerksdorp Area</u>.

The data provided by Hartebeestfontein Gold

Mining Company gave the first indication of an elevation control of silver percentage in this area. This mine reported results for the Vaal Reef in the "Shallow Area" - 14.7% Ag, and "Deep Area" - 11.2% Ag. These two areas are separated by the Kromdraai Fault. Data on the silver content as a function of bullion-bead size is available for all the Klerksdorp mines. To minimise errors due to variation in silver content as a function of sample grade (LAWN, 1924, PRENTICE, 1939-40), and to obviate the lack, in some cases, of information on weight proportions of the different size groups, the average silver content of 10-20 dwt. bullion beads on each mine has been used for purposes of comparison.

PLATE III shows generalised structure contours of the Vaal Reef in the Klerksdorp area* with the silver values inserted in the mined areas. A decrease in silver content with increasing depth on each side of the Kromdraai fault is again evident. The disparity on opposite sides of the fault is presumably in some way related to the displacement on the fault.

(iii). Central Rand.

On the Central Rand, mining on individual properties has extended from surface to depths exceeding 8,000 feet; as a result, the problem of evaluating the single values reported for each reef (Appendix) in terms of elevation is particularly acute. Furthermore, as most mines on the Central Rand extend along strike, with similar average working elevations, no great difference in average silver percentqge between mines due to differences in elevation of ore, could be expected.

Footnote:

*Compiled from borehole information in "The Handbook-Klerksdorp Area - Gold Mining and Prospecting", Technical Map Service, November, 1955.

On the whole, the silver values reported by Central Rand mines for the Main Reef group (Appendix) are comparatively uniform. Consolidated Main Reef Mines and Estate Ltd., (C.M.R.) is a conspicuous exception, but here, for some unknown reason, very low silver values are reported for <u>all</u> reefs.

Over the years, however, mining at any one property has become progressively deeper on average, and gold is produced from ore obtained at progressively greater depths. If an elevation control of silver does exist, supporting evidence should be found in the bullion records of individual mines.

Crown Mines was chosen as a test case, as their ore has been derived almost exclusively from the Main Reef group. Possible complications due to mixing of ore from different reef groups are therefore minimised. Data have been obtained on the silver content of the bullion produced at Crown Mines for the years 1922 to 1960* (Rand Refinery records), and are plotted chronologically in PLATE IV, Fig. 1. The expected general decrease is apparent for the years 1922 to 1954, followed by a sudden increase continuing to the present.

Detailed information as to the source of the ore mined at Crown Mines for the years 1950 to 1959 has been provided through the courtesy of MR. R.J. ROUILLARD (Manager) and MR. N. DENT (chief Surveyor). The results are presented graphically in PLATE IV, Fig.2.

It is immediately apparent that the increase in silver percentage starting in 1955 coincides with a substantial (and continuing) decrease in the percentage of ore obtained from the deeper levels (below 40 level) of the mine.

The reversal of the trend of variation of silver in the bullion, is therefore interpreted as being due to the increasing percentage of shallow level ore, with a higher silver content, fed to the mills.

*Note:- Bullion data for years before 1922 are not available.

(iv). Orange Free State.

No pattern of any sort is apparent in the data on silver content of gold in the Basal Reef (Appendix). The comparatively small differences in silver percentage between most mines (maximum 3.4%) may reflect similar average mining elevations. However, it can be appreciated that to test this hypothesis in a structurally complex area such as the O.F.S. goldfields, rigorous "elevation control" of the silver data is required. In the data available, the silver values reported come from tests made between 1950 and 1952 in the case of Welkom, and between 1957 and 1959 in the case of St. Helena. The relative elevation of the samples utilised in these tests is unknown, and thus no rigorous comparison can be made.

(v). West Rand.

With regard to variations in the silver content of gold in individual reefs, the situation in the West Rand is similar to that on the Central Rand, i.e. mines extend along the strike of the reefs, with similar average working elevations. Furthermore, there are substantial differences in the sampling and assaying procedures which were followed on the different West Rand mines to obtain the silver values reported. Attempts at comparing these data are considered futile, and they have therefore not been listed.

(vi). Far West Rand.

The reason for the relative difference in silver content of Carbon Leader gold reported by the three mines in this area (Appendix) is not obvious. Different sampling and assaying techniques, or samples collected at different relative elevations, may each or all be responsible.

B. Silver Content of Gold in Different Reefs in the Witwatersrand System.

The only areas in which sufficient data are available to warrant comparison of the silver content of gold in

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different reefs are the East Rand Basin, and the Central Rand.

(i). East Rand.

In the East Rand Basin, the gold in Kimberley Reef invariably contains more silver than gold in the Main Reef Leader, on each mine for which data on both reefs are available (Appendix).

(ii). Central Rand.

If allowance is made for the possibility of difference in average grade of the reefs (and consequent variation in average silver content), there is, on the whole, little difference in the silver content of gold in the different reefs of the Main Reef group on individual mines (see Appendix*). Comparing the major reef groups (Main, Bird and Kimberley), it would appear from the meagre data in the Appendix, that on individual mines, the silver contents of Bird and Kimberley reefs are increasingly higher than that of the Main Reef group. In this comparison however, the question of average grade of the ore is again important. The available data on the silver percentage of sized bullion beads from the different Reefs is as follows:-

Rand Leases**: Size of Bullion Beads:

	0-2 dwts.	2-3 dwts.	3-4 dwts.	4-5 dwts.	5-10 dwts.	10-20 dwts.
Main Reef	19.0%	17.7%	16.3%	13.9%	11.8%	9.6%
Main Reef Leader	20.9%	19.0%	16.3%	15.0%	11.7%	9.7%
Bird Reef	13.2%	16.4%	13.8%	11.7%	9.8%	-
Kimberley	20.6%	23.7%	16.7%	14.7%	13.5%	11.6%

Footnote:

*It may be noted (TABLE I) that for some unknown reason,) the silver content of gold in all reefs at Consolidated Main Reef Mines and Estate Ltd., (C.M.R.) appear substantially less than on any other Central Rand Mine.

** Rand Leases (Vogelstruisfontein) Gold Mining Company, Ltd. /9...

From these data it would appear that while the Kimberley Reef does indeed contain more silver than the Main Reef group (as in the East Rand Basin), Bird Reef samples contain less silver than those from the Main Reef group of equivalent grade.

PRENTICE (loc. cit. p.30) gives data on the silver content of different sized beads from different reefs at C.M.R. , - and an 'average' value for each reef, determined on a composite collection of all beads, regardless of size:

	Tr. to 2 dwts.	2-5 dwts.	5-10 dwts.	10-20 dwts.	over 20 dwts.	Average*
Main Reef	9.5%	11.1%	9.4%	8.4%	8.6%	9.5%
Main Reef Leader	9.0%	11.0%	9.1%	8.1%	7.8%	7.6%
South Reef	12.3%	11.3%	9.1%	8.5%	7.8%	8.2%
Bird Reef	9.3%	10.0%	8.3%	7.0%	8.7%	8.7%

In the 2-5, 5-10 and 10-20 dwt. size ranges, the Bird Reef again appears to contain less silver than the Main Reef group.

On the West Rand mines, the reported silver content of the various reefs in the Bird Reef group (in the neighbourhood of 20% Ag) is very considerably greater than that in the Main Reef group. However, in most instances, Bird

Footnote:
*The averages reported in the current data are less than those of PRENTICE, determined prior to 1939. This difference may be related to different working depths at the times of sampling.

reefs on the West Rand are mined primarily for their uranium content, and contain very little gold. It is most probable that the tendency toward increasing silver with decreasing grade (LAWN, 1924, PRENTICE 1939-40) accounts for the excessive silver content of the gold reported for these reefs.

(iii). Review.

If the possibility of elevation control of silver percentage in individual reefs is accepted, it can be appreciated that data suitable for the comparison of the silver content of gold in different reefs must be rigorously controlled from an 'elevation' point of view. With regard to the data available, the precise elevation at which the samples from different reefs were collected is not known. On the Central Rand, mining on all reefs started from the surface (i.e. the same elevation), but it seems probable that at present, younger reefs (stratigraphically) are being mined at shallower average depths than older reefs. This is almost certainly the case as regards Kimberley Reef and Main Reef Leader on individual mines in the East Rand Basin. Thus from the silver data alone, it could be considered that difference in elevation is the sole reason for Kimberley Reef gold carrying higher silver than Main Reef Leader gold.

However, the evidence of low silver in Bird Reef ore (at C.M.R. and Rand Leases), almost certainly obtained at shallower depths than ore from Main Reef group, contradicts such a conclusion.

For lack of rigorous elevation control, therefore, apparent differences in the silver content of gold in different reefs, must be accepted with reservation.

C. Relationship between Silver in "Contact" Reefs, and that in Underlying Witwatersrand Reefs.

The gold in the "Contact" Reefs - Ventersdorp Contact Reef and Black Reef - is generally considered to be derived by erosion and concentration of gold from the underlying sub-outcrop of one or more auriferous Witwatersrand conglomerates (DE KOCK, 1940, p.90 and 100; COUSINS, 1956 p.106). In an alluvial or eluvial process of erosion and concentration of gold, the gold should become purer by differential leaching of silver (see page 21). From the limited data available however, it appears that the silver content of Contact Reef gold is similar to or greater than that in the underlying Witwatersrand reefs. No data is available for other non-economic Witwatersrand Reefs which might be condsidered to have contributed gold to the Contact Reefs.

(i). Black Reef.

On Geduld Mine, the silver percentage in gold from Black Reef (and associated pyritic quartzites) is 15.6% (Appendix). This is substantially higher than that in the Main Reef Leader, and proportionately higher than that in Kimberley Reef on adjacent properties.

RICHARDSON, in his discussion of PRENTICE'S paper (1939-40 p.40), states: "The Black Reef at Government Gold Mining Areas contains an appreciably higher percentage of silver than the Main Reef Leader, and is more in the order of 13%." RICHARDSON (op.cit. p.40) gives some preliminary data on the silver content of Black Reef samples at Government Gold Mining Areas (Modderfontein) Consolidated, Ltd., in which the average silver content is 13.9%. The silver percentage of different sized bullion beads from Black Reef and Kimberley Reef samples at G.G.M.A. is reported as follows:-

	0-5 dwts.	6-10 dwts.	11-20 dwts.	21-50 dwts.	51-100 dwts.	over 100
Black Reef	15.97%	12.97%	12.50%	12.95%	-	11.60%
Kimberley Reef	14.08%	12.11%	11.19%	10.36%	9.61%	11.20%

(ii). Ventersdorp Contact Reef (V.C.R.)

The available data on the Ventersdorp Contact Reef in the West and Far West Rand are summarised below:-

	Ag % V.C.R.	Ag % Wit. Reef
Venterspost	11.0%	10.5% (Main Reef)
Libanon	9.0%	9.8% (Main Reef)
West Driefontein	10.7%	9.2% (Carbon Leader)
South Roodepoort	11.5% (10-20 dwts)c.f.	9.6% (10-20 dwts in Main Reef at Rand Leases)

With the exception of Libanon, the V.C.R. appears to be higher in silver than the underlying Witwatersrand reefs, although there is no conspicuous difference between V.C.R. and Witwatersrand reefs on any mine.

However, while the average depth of V.C.R. and Main Reef workings at Venterspost appear to be very similar (1 to 20 Level, Annual Report, 1959), it should be noted that at Libanon, the average depth of V.C.R. workings (9 to 14 Level, Annual Report 1959) is probably deeper than the average Main Reef workings (3 to 18 Level). An elevation control of absolute silver percentage common to both V.C.R. and Main Reef is possible.

In the Klerksdorp area, Western Reefs Exploration and Development Company report a striking variation in silver content as a function of bullion bead size, for Contact (V.C.R.), No. 5 Reef (Elsburg) and Vaal Reef (see below), but for size ranges greater than 10 dwts, the silver values are very similar.

	0-5 dwts.	5-10 dwts.	10-20 dwts.	20-30 dwts.	30 up
Contact	23.0%	18.0%	10.1%	10.0%	9.8%
No. 5	20.8%	15.2%	9.9%	10.7%	9.5%
Vaal	39.0%	16.0%	11.0%	10.1%	10.1%

While the average depth of Contact and No. 5 Reef workings are similar, these workings do not overlap those on the Vaal Reef, which are much deeper. The average for No. 5 Reef would appear less than that for the Contact Reef.

D. Silver Content of Composite Bullion Produced by Selected Witwatersrand Mines.

J.G. LAWN, in his discussion of a paper by FISHER (1934-35, p.391) stated that the average percentage of silver in the total bullion produced by all Witwatersrand mines had gradually decreased from 9.9% in 1904 to 8.8% in 1933. According to PRENTICE (1939-40, p.20), the average silver percentage in 1938 was 8.5%. This general evidence of decreasing silver content could likewise possibly be correlated with increasing depth of mining. After the fruitful analysis of the Crown Mines bullion data, it was obviously desirable to obtain similar data from other mines which in terms of long life and depth of mining might reasonably be expected to corroborate the trends indicated by the Crown Mines data.

On request, the Rand Refinery has provided data on the silver content of bullion from 12 mines for the years 1922 to 1960. These mines were selected bearing in mind the desirability of continuous production over a very long period (with concomitant assumption of substantial working depth range), and representative areal distribution. As a result, data have been obtained for mines situated between Nigel on the East Rand, and Blyvooruitzicht on the Far West Rand. These data are plotted chronologically in PLATE V.

When considering these data with reference to the hypothesis of elevation control of silver content, the following points should be remembered:

(a) There is uncertainty as to whether the chronological plot is consistently equivalent to a progressively deeper average working elevation. For various reasons, from economic to logistic, at intervals duri g the life of a mine it may have been preferable to mine available shallow ore rather than deep ore, for long or short periods. As ore reserves near exhaustion, reclamation etc., causes a retreat in the average working depth.

(b) Irregularity may be introduced due to sudden changes in the economic grade cut-off, whereby more or less low grade ore (with more or less silver) is milled.

(c) In many mines there is a probable irregular variation in the proportion of ore mined from different reef groups, and/or from different elevations.

However, on examination of PLATE V, it is clear that in the majority of cases there is a distinct, if sometimes irregular, decrease in the average silver content of the bullion as a function of time.

Nigel Mines was situated immediately up dip from Sub Nigel, and its gold had a distinctly higher average silver content. The sharp rise in silver values following 1948 is tentatively attributed to reclamation etc., prior to complete cessation of operations in 1958.

Sub Nigel, Simmer and Jack, Rose Deep, Crown Mines, New Kleinfontein, E.R.P.M., Robinson Deep, all show a progressive overall decrease in silver content. City Deep bullion shows a relatively constant silver content. However, this average is on the whole maintained by sudden sharp increases following gradual declines. This sharp reversal of a progressive downward trend is also evident in the plots for New Kleinfontein and E.R.P.M. and is conceivably due to sudden changes in mining policy or

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economics.

Luipaards Vlei is most irregular. Following a sharp rise between 1940 and 1942, there is a progressive decrease until 1954, followed by a sudden increase continuing up to the present. From examination of the plans in the annual reports of this company, it appears that intensive exploitation of the Bird Reef, for its uranium content, commenced in 1955. Apart from an indication that the development on this reef has mainly been extended up dip (hence progressively shallower working elevations), it also appears that the Bird Reef in this area carries very little gold, with the probability of a high silver percentage (LAWN 1924, PRENTICE 1939-40). Both these factors may contribute to an increase in the silver content of the bullion.

Venterspost and Blyvooruitzicht are both comparatively new mines, located on Reef which does not outcrop. Development and stoping from the shafts appears to have been extended as much up dip as down dip in the case of Blyvooruitzicht, with the possible result that a relatively constant average working elevation has been maintained up to the present. This may account for the constant silver content of Blyvooruitzicht bullion.

Venterspost shows a progressive increase in silver content. Two independent facts may contribute to this anomaly:

(a) From examination of mine plans, development and stoping from shafts appears to have extended more up dip than down dip.

(b) There appears to have been a progressive increase in the quantity of Ventersdorp Contact Reef (in proportion to Main Reef) ore mined.

On the whole, these data on the silver content of bullion are considered to support the hypothesis of elevation control.

E. <u>Distribution of Gold and Silver in Witwatersrand Ores.</u>

Gold, a siderophile element (GOLDSCHMIDT 1954, p.197)

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occurs in nature as the native metal, and as tellurides; in both these forms it tends to be associated with bismuth and antimony minerals, and with iron sulphides and arsenides (op.cit. p. 200-202).

Silver, on the other hand, is a chalcophile element, and in addition to the native form occurs abundantly in the form of sulphides, sulpho-salts and in halogen compounds. Silver is also prone to occur in solid solution with other sulphides - particularly galena (GOLDSCHMIDT, p.193).

Most of the gold in Witwatersrand conglomerates occurs as the native metal or alloy. YOUNG (1917, p. 77) noted an occurrence of gold telluride, but it has not been reported since. The intimate physical association of some gold with sulphides in the banket is well known (YOUNG, 1917, LIEBENBERG, 1955 p. 202 and others), but there is no evidence to suggest that gold does, or might, occur in solid solution in any of these sulphides. As regards the frequent association of small amounts of microscopically visible gold with iron pyrite, (GOLDSCHMIDT, 1954, p. 202) suggested that it might represent "exsolution from original solid solutions which have been formed at elevated temperatures". LIEBENBERG, however, (1955 p.161) specifically refers to the rare occurrence of gold inclusions in pyrite grains in Witwatersrand banket.

The bulk of the silver in Witwatersrand ores almost certainly occurs alloyed with gold. No silver mineral has ever been observed in polished sections of Witwatersrand banket, but there remains the strong possibility that silver occurs in solid solution or "captured" in other sulphides.

Several sulphides are known to be able to "dissolve" silver to varying degrees. GOLDSCHMIDT (1954, p.194) has arbitrarily classified some of the commoner sulphides in a sequence of increasing effectiveness in this respect:

1. Sphalerite, 2. Chalcopyrite, 3. Galena.

With regard to this sequence, GOLDSCHMIDT also states (p.194): "Below sphalerite is iron Pyrite which has never been proved to contain silver in solid solution." On the other hand, "the universal presence of silver makes galena the most important silver ore of the world" (GOLDSCHMIDT p. 407). GOLDSCHMIDT reports galena as commonly containing silver in amounts of the order of 100 to 1000 ppm and exceptionally amounts up to 10,000 ppm (1%) occur. With regard to the latter however,

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GOLDSCHMIDT states: "In such cases one usually observes segregations of metallic silver or silver sulphide as a result of unmixing at lower temperatures of the original solid solutions, but such phenomena are also observed with medium amounts of silver in galena." To the author's knowledge, no such exsolution phenomena have been observed in Witwatersrand galenas.

The presence of varying amounts of silver-bearing base metal sulphides has been invoked to account for the wide variation in silver percentage between individual samples by GRATON (1930) and FISHER (1939 p. 14).

Pyrite is the most common sulphide in Witwatersrand ores, but according to GOLDSCHMIDT (1954 p. 194), pyrite is not a significant silver carrier. PRENTICE (1939-40 p. 27) states that the bullion obtained from a sample of pyritic residue after amalgamation contained 13.3% silver.

In the Research Assay Office, East Geduld Mines Ltd., routine determinations of the gold content of sulphides in cyanide residues are made. The sulphides are concentrated by flotation, and then recyanided to remove any remaining free gold not enclosed in the sulphide grains. The results average from 1 to 2 dwts gold per ton of sulphide, (personal communication J.H. HARRIS, May, 1960). Through the courtesy of W.A. SINCLAIR, Chief Assayer, East Geduld Mines, Ltd., special tests were made with a view to determining the silver content of the sulphides. Pure silver was not added as a collector to the assay charge (the normal procedure for determining gold), and the resulting bullion beads were very clearly composed predominantly of gold. Because of the exceedingly small size of the beads, acid parting was not attempted, and no precise determination of the relative silver content could be made. However, by comparing the colour of these beads with artificially prepared 1 part Ag : 1 part Au bullion beads, it was estimated that the silver content of the bullion from the sulphide was not more than 25%. LIEBENBERG (1955, p.166) describes gold enclosed in grains of buckshot pyrite from the Black Reef as being paler than the free gold, indicating a higher silver content, but the alloy still consists predominantly of gold.

FRANKEL (1939, p.288) gives data obtained from Black Reef ore at the New Machavie Mine, in which a substantial difference in the Ag content of the coarse free gold (7.9%) and the pyrite bullion (up to 49.2% Ag) is indicated*

* Assay of the bullion obtained from two "general ore samples" (Black Reef) from New Machavie (FRANKEL, 1939 p.288) gave 13.2% Ag and 19.2% Ag respectively.

FRANKEL states: "The higher silver content of the locked up gold..........suggested that in addition to electrum, there might be other minerals rich in silver, such as argentite or a telluride. Careful search in polished section failed to reveal these minerals, and although repeated tests were made on pyrite concentrates, no tellurium was found".

Thus, while the particles of native gold enclosed in pyrite contain a higher percentage of silver than the free gold, there is no evidence that the pyrite contains a significant amount of dissolved silver.

With regard to galena, PRENTICE (1939-40 p.27) has given semi-quantitative analyses of two Witwatersrand galenas which suggest that the silver content is in the neighbourhood of 1000 ppm (i.e. 500-700 dwts per ton). On this evidence galena, although a very minor constituent of Witwatersrand ore, could substantially affect the silver percentage of individual conglomerate samples, particularly those low in gold.

No evidence is available concerning the silver content of other sulphides in the banket. However, with the exception of pyrite and pyrrhotite, sulphides are a very minor constituent. The pyrite content of the banket is generally considered to average around 3% (YOUNG 1917, p.62). PRENTICE, (1939-40 p.25-26) gives data on pyrite content averaging less than 2%.

With a view to estimating the effect of differential Ag in sulphide (for practical purposes, pyrite and pyrrhotite) on the average silver content of banket samples, let us assume that the average sulphide contains 2 dwts Ag per ton (equal in amount to the Au content). In a sample containing 3% sulphide, the sulphide would therefore contribute the equivalent of $\frac{3}{100} \times 2 = .06$ dwts Ag.

In a 5 dwt gold bullion bead, this would mean an increase in silver percentage of approximately 1% Ag. It is concluded therefore, that while silver in sulphides may significantly affect the silver percentage of individual low grade mine samples, it cannot be responsible for the variation of up to 6% in average silver content of hundreds of mine samples, recorded between different mines working the same reef at different elevations.

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F. Discussion of Results.

If the "random" nature of the data utilised in this report is borne in mind, the evidence of elevation control of silver percentage in individual reefs appears particularly striking. Nevertheless, before accepting this interpretation it would obviously be desirable to carry out an experiment designed to test its significance. Because, however, of the local and apparently erratic variations in the silver content of individual samples (LAWN, 1924) this is no easy task.* Ideally, it would be desirable (1) to segregate mine samples according to (a) restricted ore-blocks, on different reefs on individual levels (b) separate levels on individual mines, (2) to have such segregated samples collections made systematically on several mines operating at different levels, in an area such as the East Rand Basin, and finally, (3) to have the assaying of all samples performed at one single assay office. Such an experiment is beyond the capabilities of the Economic Geology Research Unit.

It remains possible, however, that investigations into the silver content of the reefs by different mines, or groups, may be designed in such a manner that the results could be utilised to test the hypothesis of elevation control of silver content, and simultaneously to establish more positively the relationship between reefs as regards their silver content.

It is hoped that this preliminary presentation of the data, and of the relationships indicated, will stimulate interest in the problems involved, and may perhaps elicit pertinent contributions from as many sources as possible. In this way, criticial data may be ultimately obtained which will confirm, deny or modify the hypothesis.

G. Potential Significance of Results.

There is much uncertainty as to the precise sedimentary and tectonic environment in which the Witwatersrand sediments were deposited. The System is known to be of great age, and to have been subjected to several periods of igneous intrusion and deformation since its formation. The current uncertainty as to the details of the origin of the Witwatersrand System, is in part at least, a direct consequence of its prolonged and complex geological history.

* See Appendix II.

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In this light it is, therefore, unreasonable to expect detailed investigation of any restricted aspect of Witwatersrand geology to point unequivocally to one sharply defined, primary mode of origin. With particular regard to the "bankets", some measure of ambiguity should be expected, as to whether observed or inferred relationships are primary, or manifestations of subsequent alteration - i.e. geological history. Many lines of evidence need further investigation and elucidation before a more complete overall picture of origin and history can evolve.

In spite of the uncertainties inherent in much of the data utilised in this study, and the necessity for much more systematic experiment, it is felt that already, 'elevation control' of the silver content of gold' is suggested to an extent sufficient to warrant preliminary consideration of certain of its implications.

It should first be commented that the inverse relation between gold content and silver percentage in individual samples, (LAWN 1924, PRENTICE 1939-40) while of genetic interest in itself, has no obvious bearing on the 'variation of silver content with depth' relationship to be considered here. The data utilised in this study represent in each case, the average silver content of the bullion obtained from a good many mine samples. It is the significance of the apparent variation of these average values with depth which needs explanation.

It may be contended that the decrease in silver content of the gold with depth in a reef might be due to some form of surface leaching or secondary enrichment at or below the outcrop or sub-outcrop. However, both these processes, under present atmospheric conditions, tend to result in purer gold nearer surface (MACKAY, 1944) the opposite of the present situation. Furthermore, the elevation control of the silver percentage in the Main Reef Leader of the East Rand basin apparently persists in areas of the reef far removed from any erosion surface, ancient or recent.

If supergene processes cannot account for the trend of variation in silver percentage, the pattern to be expected from a primary alluvial origin must next be considered.

The "fineness" of alluvial gold increases down stream from the lode source (LINDGREN, 1933, FISHER, 1934-35). This is attributed to a preferential leaching of silver relative to gold by water in the process of erosion and stream transport (LINDGREN, 1933, p.233) or to an electrolytic corrosion process, "which results in silver being removed from the gold-silver alloy and the associated gold being redeposited on the surface of the nuggets as a thin film of 'fine' gold" (FISHER, 1934-35, p.380). Thus, assuming the gold in the Main Reef Leader of the East Rand to be strictly alluvial in origin, one could expect some consistent pattern of decrease in silver content of the gold in the direction of transport.

The classic work of PIROW (1920) and REINECKE (1927, 1930) on pebble distribution and paystreaks in the Main Reef Leader of the East Rand basin was interpreted to indicate a northwest source for the pebbles composing the conglomerate. Recent measurement of cross-bedding in quartzites immediately overlying the Main Reef Leader on ten East Rand Mines (R.B. HARGRAVES, in preparation) likewise indicates a consistent South-easterly direction of transport of the sediment.

No such pattern of alluvial transport is suggested by the silver data. A radial introduction of gold would be more consistent with these results, but such an assumption is not supported by the sedimentologic evidence cited above. Furthermore, the apparent rise in silver content going westwards from Daggafontein over the present Springs monocline would militate against such an explanation.

Analysis of the pattern of silver variation in the Vaal Reef (Klerksdorp area) requires consideration of the nature of the Kromdraai fault (PLATE III). If it is a normal fault, then reversal of the movement would juxtapose reef with bullion averaging 11.2% Ag with reef averaging 14.7% Ag. This anomaly would appear to necessitate (a) redistribution of silver (b) <u>after</u> the faulting (i.e. after the elevation difference between the two blocks had been established). On the other hand, if the Kromdraai is primarily a tear fault, with right lateral displacement, then the Hartebeestfontein "shallow area" - Buffelsfontein reef block - might originally have been situated east or northeast of Stilfontein. The resulting pattern of silver variation would, on the assumption of purely alluvial origin, in part require a source of gold to the east or north east, which in the Klerksdorp area seems most unlikely.

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It may be considered that the gold in the banket was introduced to the basin by glacial agents, whereby the gold was protected from abrasion and leaching during transport. One might, therefore, conceive of a silver distribution pattern varying from irregular to homogenous, at least, within one conglomerate horizon. The fact that the actual distribution pattern appears to coincide with the present structural contours, can in no way be attributed to a primary "glacio-alluvial" origin.

The failure of supergene or sedimentary processes to account satisfactorily for the observed gold-silver distribution demands that other controls be sought.

The "modified" placer hypothesis invokes recrystallisation and/or solution and redeposition of alluvial gold, with the usual assumption that this took place more or less "in situ" (DU TOIT 1956, p.105). In which event, any primary alluvial trend in silver distribution might reasonably be expected to persist, and such is clearly not the case.

The evidence presented in this report suggests that the qualitative distribution pattern of silver relative to gold in the Witwatersrand conglomerates coincides roughly with the present structural elevation of the conglomerates. As such, the pattern would appear to be geochemical, and to have been imposed or superimposed by some physico-chemical process after the conglomerates were originally deposited.

The composition gradient or zoning appears to be manifested primarily in a vertical plane, which suggests that it is due to temperature or pressure varying in relation to a surface more or less parallel to the present horizontal. Considered by itself, this fact has no positive bearing on the question of the ultimate origin of the gold and silver, ("placer" versus "hydrothermal"). However, the pattern is such that to superimpose it on a primary alluvial pattern would involve substantial redistribution of silver relative to gold during the "solution" stage of the "modified" placer hypothesis.

There remains the important question of whether this geochemical distribution pattern was imposed blanket-fashion, effecting simultaneously the deposition of gold-silver alloy of a composition governed at any point only by the absolute elevation of each or any host conglomerate; or whether the

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pattern was imposed on each auriferous conglomerate individually, as separate closed systems. In other words, while one might concede that differential transfer of silver has occurred within reefs, has it occurred between reefs?

The progressive vertical increase in silver content from Main Reef Leader through Kimberley Reef to Black Reef, suggested by the data for the East Rand Basin, could be interpreted as indicating that transfer of silver between reefs has occurred.

On the other hand, the Bird Reef on the Central Rand appears to contain less silver than conglomerates of the Main Reef group situated vertically below it. This would suggest that the two reef groups were isolated one from the other when redistribution of silver took place. Furthermore, it could be interpreted to suggest that the absolute proportion of gold and silver now found in each Witwatersrand conglomerate varies as a function of original differences in provenance.

The fact that the percentage silver in gold in the Contact Reefs seems to be similar to, or greater than that in the associated underlying Witwatersrand Reefs, appears to be completely contrary to what could be expected on the assumption of derivation of the former from the latter by simple erosion, and reconcentration. However, there are insufficient data to indicate whether or not the silver content of gold in the Contact Reefs decreases with increasing depth as it does in the Witwatersrand Reefs. Thus the important point of <u>when</u> the composition gradient was established remains unknown. If it was only developed after the formation of the Contact Reefs, then in some way differential transfer of silver between these reefs and their principal source reefs would appear to have taken place. On the other hand, if the gradient was established before the Contact Reefs were formed, then the gold in those "higher" parts of the Witwatersrand source reefs (from which the Contact Reef gold was derived by erosion) would undoubtedly have been richer in silver than those "lower" parts now remaining. In which event it is conceivable that despite the increase in 'fineness' to be expected as a result of erosion and eluvial concentration, the resulting product might still be higher in silver than the gold in the uneroded source reef with which comparison is now made.

More data, to verify the hypothesis of elevation control, and with relevance to the alternative implications anticipated above, is clearly necessary.

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APPENDIX I

TABULATED DATA ON AVERAGE SILVER CONTENT OF BULLION FROM AURIFEROUS CONGLOMERATES IN WITWATERSRAND GOLD MINES.

TABLE I

EAST RAND

MAIN REEF LEADER

Mine	Average Ag.content reported:	Quality of Data	Time & frequency of tests	Kimberley Reef	Black Reef & Pyritic Quartzite	H.W. Leader	Foot-wall Reef
Brakpan	8.7	Single value given	Beads collected Dec. 1955 and Jan. 1956			9.6	12.6
Dagga	5.9	Arith.Ave. of * size data. Av. of 3 tests	Beads collected June 1959 to September 1960	8.4			
East Dagga	7.7	Av. of 4 unsized tests	Beads collected July - Oct. 1946	11.0			
S. A. Lands	m 8.5	Single Value given	No information				
Springs	8.2	Av. of 2 tests	No information				
Vogelstruisbult	10.2	Single value given	Tests every 2 weeks, value reported reasonably constant in M.R.L., variable in Kimberley	13.8			
Sub-Nigel	7.9	Arith. Av. of size data	Beads collected between 1957 and Jan. 1960				
Vlakfontein	7.4	Arith. Av. of size data	Beads collected between 1957 and Jan. 1960				
Spaarwater	6.5	Arith.Av. of size data	Beads collected between 1957 and Jan. 1960				
Geduld	11.2	Av. biannual unsized tests	1952 - 1959 Max. variation in 16 tests - 10.0% —11.9%		15.6		

* Note: The <u>maximum</u> variation in Ag. percentage as a function of bead size in the three Daggafontein tests is :- 7.4% Ag. (0-5 dwts.) to 4.7% Ag. (over 20 dwts.)

cont./E.Geduld

MAIN REEF LEADER

% Ag. in gold in other reefs

Mine	Average Ag.content reported	Quality of Data	Time & frequency of tests	Kimberley Reef	Black Reef & Pyritic Quartzite	H.W. Leader	Foot-wall Reef
E. Geduld	9.0	Av. biannual unsized tests	1950–1959 Max.variation in 20 tests – 8.5%—9.4%	9.5			
Grootvlei	8.4	" "	1950–1959 Max.variation in 20 tests: 7.9%—9.3%	10.1			
Marievale	9.7	" "	1950–1959 Max.variation in 20 tests: 9.1%—10.8%	10.9			
Van Dyk	9.5	Av. biannual unsized tests on M.R.L. & Kimb. combined (Proport. Kimb. beads probably minor)	1955 – 1959 Max.variation in 5 tests: 8.4%—10.6%				
G.G.M.A.	9.6	Lawn, 1924 bullion data		11.6 arith. av.	13.9 (Richardson 1939–40)		
Modder East	8.9	Estimated average of ore 'in situ' single value given					

TABLE I
KLERKSDORP

VAAL REEF

Mine	Average Ag.content reported	Quality of Data	Time & frequency of tests	Ag. content of 10-20 dwt beads from size data	
Hartebeestfontein Shallow	15.1	weighted Av. size data	10 tests, no dates	14.7	
Deep	10.8	" "	3 tests, no dates	11.2	
Buffelsfontein	13.4	Arith.Av. size data	No information	12.1	
Stilfontein & Ellaton	12.3	" " "	" "	11.8	
Vaal Reefs	8.7	weighted Av. size data	Av. 7 tests, 1957-59	8.6	
Western Reefs	17.2	Arith. Av. size data	No information	11.0	V.C.R. 10.1% Ag.

TABLE I

CENTRAL RAND

Mine	Main	M.R.L.	South	North	Bird	Kimberley	Comments :
Rietfontein	9.6		10.0	11.1			Unsized collection of beads, tests every 4-5 days values reported reasonably constant
Simmer & Jack	11.1	10.9	11.1				Arith. av. of size data; collections over 1 week each month, values reported reasonably constant
Robinson Deep		10.1					Arith. av. of size data; monthly collections values reported reasonably constant
Rand Leases 10-20 dwts	14.3 9.6	11.5 9.7			12.4	18.9 11.6	Weighted average of size data; 1 or 2 tests on 1 - 6 month collections
E.R.P.M.	10.5	12.2	11.5	composite 9.3			Approx. weighted average - estimated Ag. content of ore in situ, actual size data not available
Rose Deep	10.4	10.7	10.3		14.8		" " "
City Deep	12.0	8.5	9.3				" " "
Crown Mines	9.6	7.9	missing				" " "
C.M.R.	7.3	6.5	6.4		7.4	8.7	" " "
Durban Deep	9.4	-	7.9			11.2	" " "

<u>TABLE I</u>

<u>ORANGE FREE STATE</u>

<u>BASAL REEF</u>

Mine	Average Ag.content reported	Quality of Data	Time & frequency of tests	% Ag. in gold in other reefs
President Brand	11.3	Single value given	No information	
President Steyn	10.6	Single value given		
Western Holdings	9.9	Arith.Av. size data	Average of tests prior to 1956	
Free State Geduld	11.3	" " " "	" " " " " "	
Welkom	12.3	Weighted Av.sized data	Average 7 tests, 1950 - 1952	
Loraine	8.9	" " " "	Average 5 tests	B.reef 11.3 Elsburg Reefs 11.9
Virginia	10.9	" " " "	Average 6 tests	Leader 8.9
St. Helena	9.2	Average biannual unsized tests	Average 1957 - 1959	
Harmony	8.9	Single value given	Estimated average of ore 'in situ'	
Freddies Cons.	11.4	Arith. Av. size data	Tests every 2-3 months values reported reasonably constant	
Free State Saaiplaas	10.8	Single value given	Tests every 2-3 months value reported reasonably constant. New Mine.	

TABLE I

FAR WEST RAND

Mine :	Average Ag.content reported:- Carbon Leader	Main Reef	Quality of Data	Time & frequency of tests	V.C.R.
West Driefontein	9.2		Single value given	Monthly; values reported reasonably constant	10.7
Doornfontein	8.2		Arith. av. size data	Tests every 2 - 4 weeks, values reported reasonably constant	
Blyvooruitzicht	6.5		Single value given	Estimated average of ore 'in situ'	
Libanon		9.8	Single value given	Every 2 weeks; values reported reasonably constant in Main Reef, variable in V.C.R.	9.0
Venterspost		10.5	" " "	Every 3 months; values reported reasonably constant	11.0

APPENDIX II

RESULTS OF AN INVESTIGATION INTO THE VARIATION OF SILVER AS A FUNCTION OF REEF ELEVATION AT THE SUB NIGEL LTD.

APPENDIX II

Through the co-operation of MR. A.T. MOIR, Consulting Metallurgist, Goldfields of South Africa Ltd., a special investigation into the silver content of gold as a function of elevation was made at the Sub Nigel Ltd.

Five individual samples of high grade reef were taken at different elevations, ranging from 2,600 feet to 6,800 feet below datum. These samples were assayed and the silver content determined with extreme care (MR. J. DRABBE, Chief Assayer, The Sub Nigel Ltd.). The results are as follows:

Sample No.	Gold value, ozs./ton.	Feet below Datum	Percentage Silver
1	8.2	2,600	8.28
2	2.95	4,000	12.62
3	9.5	5,100	7.17
4	75.0	6,300	10.84
5	3.4	6,800	8.13

While the variation in silver content of these high grade samples is of interest in itself, it is obvious that the variations are in no way related to elevation.

On the other hand, the results of this test should be contrasted with the chronological plot of the silver content of the bullion produced at Sub Nigel from 1922 to 1960 (PLATE V). In the bullion data, an irregular, but on the whole progressive decrease in silver content is apparent. It seems most likely that this decrease is due to increasing depth of mining.

Whereas an erratic variation in the silver content of individual samples was demonstrated by LAWN (1924), the comparative uniformity in average silver content of Witwatersrand Bullion has long been acknowledged. (C.B. JEPPE, Gold Mining on the Witwatersrand, Vol.1., p.65, 1946).

The results of the Sub Nigel test are presented there-

(cont.)

fore, in order to emphasize the necessity for extensive sampling, in addition to careful assaying, in any experiment designed to test adequately the hypothesis of elevation control.

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