CONTACT INFORMATION
Mining Records Curator
Arizona Geological Survey
416 W. Congress St., Suite 100
Tucson, Arizona 85701
520-770-3500
http://www.azgs.az.gov
inquiries@azgs.az.gov

The following file is part of the

James Doyle Sell Mining Collection

ACCESS STATEMENT

These digitized collections are accessible for purposes of education and research. We have indicated what we know about copyright and rights of privacy, publicity, or trademark. Due to the nature of archival collections, we are not always able to identify this information. We are eager to hear from any rights owners, so that we may obtain accurate information. Upon request, we will remove material from public view while we address a rights issue.

CONSTRAINTS STATEMENT

The Arizona Geological Survey does not claim to control all rights for all materials in its collection. These rights include, but are not limited to: copyright, privacy rights, and cultural protection rights. The User hereby assumes all responsibility for obtaining any rights to use the material in excess of "fair use."

The Survey makes no intellectual property claims to the products created by individual authors in the manuscript collections, except when the author deeded those rights to the Survey or when those authors were employed by the State of Arizona and created intellectual products as a function of their official duties. The Survey does maintain property rights to the physical and digital representations of the works.

QUALITY STATEMENT

The Arizona Geological Survey is not responsible for the accuracy of the records, information, or opinions that may be contained in the files. The Survey collects, catalogs, and archives data on mineral properties regardless of its views of the veracity or accuracy of those data.

GSA, vol. 3, no. 7

such as Cellaria, have zooecial interiors characterized by distinct skeletal linings, but junctions between zooecia in adjacent linear series are indistinct and lack evidence of an intercalary cuticle.

Zoarial layers, most commonly in the superficial part of the frontal wall, may minimize or obscure external zooecial boundaries.

The diverse levels of individuality which result from combinations of these various factors will be useful in developing interpretations of budding patterns and modes of skeletal growth among cheilostomes.

ON THE RELATIONSHIP OF CERTAIN PRECAMBRIAN GOLD DEPOSITS TO IRON FORMATION

Sawkins, F. J., and D. M. Rye, Department of Geology, University of Minnesota, Minneapolis, Minnesota 55455

The association of a number of major Precambrian gold deposits with iron-rich sedimentary rocks is too impressive to be the result of coincidence. In North America the Homestake deposits occur in carbonate iron formation. A number of the deposits of the Kirkland Lake area, Ontario, occur in iron-rich carbonate rocks.

In South America the Morro Velho mine occurs in dolomitic carbonate iron formation. In Southern and Central Africa many similar examples can be cited including the Steynsdorp goldfield which shows a strong spatial relation to an auriferous iron-rich unit in the Onverwacht greenstone belt (Viljoen et al., 1969).

In Western Australia the close spatial association of many gold deposits with iron formations in early Precambrian greenstone belts is readily demonstrable. Furthermore, many aspects of the gold lodes in the Kolar district of Southern India suggest they may represent highly metamorphosed equivalents of their continuous chert-iron carbonate units.

Available details of the geology and stable isotope geochemistry of the above-mentioned areas, including new data on the Homestake, are consistent with the interpretation that the gold and associated sulfides were integral constituents of the iron-rich sediments during their deposition. Stable isotopic data, where available, further indicate that the ore-bearing and associated minerals have undergone varying, but generally limited redistribution, during later tectonic and metamorphic events.

This relationship between gold, sulfides, and the carbonate facies of early Precambrian iron formations should provide an important key to the exploration for gold deposits in Shield areas.

PLAGIOCLASE COMPOSITIONS AND DEPTHS OF MAGMA GENERATION BENEATH ACTIVELY SPREADING MID-OCEAN RIDGES

Scheidegger, Kenneth F., Department of Oceanography, Oregon State University, Corvallis, Oregon 97331

Petrographic, X-ray diffraction, and refractive index studies of the plagioclases from submarine volcanic ash layers and glassy rims of pillow basalts from the crestal areas of the Mid-Atlantic Ridge, the Gorda-Juan de Fuca Ridges, and the East Pacific Rise show that crystals in each sample are unzoned and usually have a 10-15% An range of compositions. Plagioclases from the slowly spreading Mid-Atlantic Ridge are significantly more calcic than those from the fast spreading East Pacific Rise. Plagioclases from the Gorda and Juan de Fuca Ridges with intermediate spreading rates have compositions between those of the Mid-Atlantic Ridge and East Pacific Rise samples. Thus, the average composition of plagioclase phenocrysts appears to be negatively correlated with the spreading rate of their source ridges.

Assuming similar geothermal gradients for the three ridges, plagioclase geothermometry yields apparent magma temperature which can be related to depth of magma formation from the mantle source rocks. It appears that magmas ascending beneath a slowly spreading ridge are signigicantly hotter and therefore, form significantly deeper than those beneath a fast spreading ridge. The inferred difference in average temperatures of plagioclase formation between the two areas roughly corresponds to a difference of 1 1/2-2 kms in the depth at which the magmas were formed.

SELECTIVE DISSOLUTION OF RECENT COCCOLITHS IN THE ATLANTIC OCEAN

Schneidermann, Nahum, Department of Geology, University of Illinois, Urbana, Illinois 61801

Selective species-preferential dissolution of recent coccoliths occurs in the equatorial Atlantic Ocean. Disappearance with depth of various species permits subdivision of the compensation zone into a series of dissolution levels. At about 3000m. depth a sharp decrease in the abundance of most caneoliths and cyrtoliths relative to their proportion in the living phytoplankton is observed. Below 4000 m. they comprise only about 1% to 2% of the assemblage. Below 5000m. the assemblage is essentially composed of five highly resistant placoliths: Emiliania huxleyi, Gephyrocapsa oceanica, Cyclococcolithina leptopora, Helicopontosphaera kamptneri and Umbilicosphaera mirabilis. The first two species take on a similar appearance after progressive dissolution of various structural parts of the shields. C. leptopora appears to be the most resistant of all modern species, and occurs in a good state of preservation (although as separate shields) at 5800 m. depth.

The dissolution occurs by means of selective removal of particular ultrastructural elements. Placolith tubes (rims) are more resistant than shields.

The calcium carbonate fraction of the lowermost 500 m. of the compensation zone is entirely comprised of the most resistant coccoliths. The resulting sediment is similar to the "mesolytic" facies described from the southern Atlantic by Leg III of the Deep Sea Drilling Project.

SOUTHERN BRITISH HONDURAS: LAGOONAL COCCOLITH OOZE

Scholle, Peter A., Cities Service Oil Company, Tulsa, Oklahoma 74150; Stanley A. Kling, Cities Service Oil Company, Tulsa Oklahoma 74150

The British Honduras carbonate depositional province contains a relatively narrow, deep, back-reef lagoon in which Recent fine-grained carbonate sediments are accumulating.

Examination of the finer fractions of these lagoonal muds by scanning electron microscopy reveals that a large proportion of the sediment (as much as 20 percent) is composed of coccoliths and coccolith fragments. Eight nannoplankton species have been described. Matthews (1965, 1966) failed to describe coccoliths and other fine-grained constituents in his study of British Honduran muds because he never

Technical Translations

Timofeev, V. I.

Vilyui gold-bearing basin

Razvedka i Okhrana Nedr
No. 6, pp. 1-5, 1965

J. D. SELL

Translated and Published by

Indian National Scientific Documentation Centre

Delhi

TT 68-50629

RAZVEDKA I OKHRANA NEDR
No. 6, pp. 1-5, 1965

TIMOFEEV, V. I.

Vilyui gold-bearing basin (O rossypnoi zolotonosti basseina r. vilyui)

Translated from Russian

Published for the U. S. Department of Interior, Bureau of Mines and the National Science Foundation, Washington, D. C. by the Indian National Scientific Documentation Centre, New Delhi.

1969

Printed and published by Insdoc, Delhi-12.

Vilyui gold-bearing basin

V.I. TIMOFEEV
Yakutiya branch, Academy of Sciences, USSR

The world gold mining practice shows that the richest auriferous deposits are associated with Precambrian conglomerates which are widespread in the South African platform. The world's largest gold deposits are confined to the Precambrian reefs of the Witwatersrand system. Gold mining commenced here in 1884, and the production was 112.3 metric tons [9] in 1961. Rich gold accumulations are associated with conglomerate layers whose thickness varies from a few centimeters to 12 meters. Their gold content is 7-20 gm/m^3 and U_3O_8 — from traces to 0.4 percent [5].

The Precambrian conglomerates of the Siberian platform have been very scantily studied and their gold content can be judged only hypothetically.

The South African and Siberian platforms are characterized by very similar composition of continental, magmatic and also metamorphosed sedimentary rocks. On the basis of these geological similarities, V.S. Sobolev expressed the opinion in 1939 about the probable occurrence of diamond-bearing Kimberlite pipes in the Siberian platform. This was later proved to be true.

The projections of Archean and Proterozoic crystalline basement of Vilyui tectonic depression (syneclise) of the Siberian platform and the projections of cupola of Archean crystalline basement of the South African platform (according to the terminology of Dyu-Toit) have many similar aspects with respect to their positions on the platform as well as their geological history. The Bredford cupola in South Africa and the Suntar anticline of Yakutiya are extended towards the platform borders; these are located in the respective platforms. The first one is located between the Karra and Bushveld depressions; and the Suntar anticline is confined within the Ygyattan and Kempendyai depressions (see Figure).

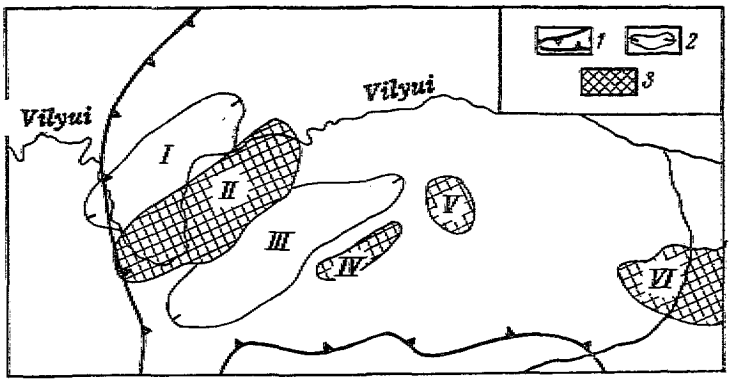


Fig. Schematic map of the projections of the basement of Vilyui tectonic depression (according to K.B. Mokshantsev et al. 1963).

I - Ygyattan depression; II - Suntar anticline; III - Kempendyai depression; IV - Upper-Sin anticline; V - Balnagai anticline; VI - Yakutiya anticline.

1 - Borders of Vilyui tectonic depression; 2 - Contours of depressions; 3 - Projections of the archeo-proterozoic basement of rocks.

According to A.K. Bobrov [3], a huge block of the basement [Suntar anticline] was uplifted even in the Riphean age in the southwestern part of the Vilyuĭ depression. Upliftment of Yakutiya and Upper Sinsk projections of the crystalline basement of the platform took place approximately in the Middle Paleozoic age. Apparently the transport of fragmented material from them continued uninterruptedly till the beginning of the Mesozoic era.

The projections of Archean crystalline basement of the Siberian and South African platforms are outcropping in the cores of the Aldan and Anabar anticlines, whereas in the Vilyuĭ tectonic depression (Yakutiya, Suntar, and probably, Upper Sinsk uplift), they are covered by terrigenous Mesozoic layers. Occurrence of placer gold in the valley of the Zolotink and Kenkema rivers testifies to the possible occurrence of gold in the older rocks of the basement of Yakutiya uplift.

Archean rocks of the Aldan and Anabar anticlines are bordered by thick molasse formations of early and late Precambrian rocks together with carbonate rocks of the Paleozoic era. Conglomerates are well developed in the southern margins

of the Siberian platform starting from the southern end of the Enisei mountain range and extending up to the outskirts of the Aldan shield in the Chara river basin, covering a distance of 2800 km. Auriferous deposits, associated with these, are well known, and their description can be found in the articles of Ivensen. Let us add that a recent assessment has further confirmed the existence of auriferous placers in the zone. An assay analysis of the reef conglomerate sample, collected by N.N. Gavril'ev from the Ennin formation of the Aldan shield (Bol'shoi Aim River) showed high gold content.

Gold content of the conglomerate layers in the slopes of Anabar shield has not yet been studied. However, depending on stray occurrences of gold in the basal conglomerates of Lower Cambrian and Mesozoic in the northeastern slope of the Anabar massif, there are possibilities of regional distribution of gold-bearing conglomerates in the slope of this massif. Frequent erosion of Archean and Proterozoic rocks, which were host rocks for auriferous rocks in the Riphean and Lower Paleozoic periods, served as favorable prerequisites for the occurrence of thick conglomerate layers.

On the analogy of historical development and formation of rich gold zone at Bredford, N.V. Cherskii put forward for the first time the suggestion about the possible placers in the Suntar anticline and its adjoining regions. Investigations carried out recently by the author showed the presence of two types of placer gold deposits in the Vilyui region: Vilyui and Baagin.

Thin flakes of gold having high assay value (970) belong to the Vilyui type. This gold is associated with the conglomerates occurring at the basal part of the Ukugut formation of the Lower Jurassic as well as in the sandstones of the Upper Cretaceous. The well-known placers occurring in the middle course of the Vilyui river and its tributaries have a high gold content. The Ukugut auriferous conglomerates and Cretaceous sandstones were formed as a result of the erosion of gold-bearing quartz veins and pyrite-marcasite veinlets. From the results of assay value it is known, that such highly auriferous pyrite-marcasite veinlets, filling up tectonic fissures, occur in the middle course of the Vilyui river. Some specialists consider that the main sources of such gold belong to the Upper Paleozoic age. Present day topography of the western Yakutiya, the peculiarity in the distribution of the stratigraphic horizons as well as the persisting erosion of the Cretaceous and Jurassic sediments by the

flowing water, lead one to suggest that the thinly dispersed placer gold in the eluvial deposits of the middle course of the Vilyuĭ river has been brought here from these intermediate places of accumulation.

The size of the gold of Baagin type deposit is slightly bigger than that of the Vilyuĭ, has a thin laminated form, and also differs in having a small content of impurities (assay 968). This type occurs in a limited area of the Tabasynd river and the Baag spring. Gold is contained in the sandstones of the Tabasynd formations of the Upper Triasic. The concentration of gold is not high. The Baagin gold is, perhaps, the redeposited product — after distintegration of old gold-bearing rocks of the basement of Suntar projection.

Moreover, the presence of gold in the rocks of Suntar anticline and Bredford cupola proves the similarity of their mineralogical composition. In 1962 the local inhabitants discovered a large nugget directly on the Suntar anticline.

A study of the region tells about similar discoveries at the end of the 19th century and the beginning of the 20th century. It may be suggested in this connection that the large commercial gold resources must be searched in the weathered products of gold-bearing rocks of the Archean and Proterozoic periods and in the direct neighborhood of the Suntar anticline; this can also be expected on the surface of older rocks buried under the Mesozoic rock cover.

As far as practicable, it is necessary to have a correct idea about the conditions and peculiarities of erosion processess in the anticline, and the mode of sedimentation in the adjoining regions. All these facts would help in drawing up the criteria for prospecting and finding out more prospective gold-bearing regions.

From the available geological information, this process, as we visualize it, occurred thus: As a result of an intense tectonic movement, there took place in the Lower Paleozoic an uplift of the Suntar anticline, in the form of a vast block of the basement. Simultaneously or a little later, two large negative structures developed in this very region. These are Kempendyai and Ygyattan depressions.

It is not improbable that there existed an uplift of the type of Suntar anticline in the present-day Patom upland region during the Paleozoic period.

This uplifted region comprised Archean rocks containing gold. Indirect proof for such a probable occurrence is afforded by the discovery of auriferous conglomerates in the core of the deeply eroded Urin anticlinorium [3].

During the Lower and partly in the Middle Paleozoic period, intensive erosion of the sedimentary rock cover took place on the top of the ridge; erosion of the basement rock took place later on. The elastic material, made up mainly of conglomerates, filled up deep depressions contiguous to the ridge. The process of accumulation of deposit is characterized by different degrees of intensity and by a not clearly defined cyclic nature, the presence of which is confirmed by the alternating conglomerate layers. The Witwatersrand auriferous deposits are associated with the sedimentary formation of this period.

Owing to the relative dying out of tectonic movements in the middle Paleozoic, levelling of relief took place over an extensive area. As a result of this, an equilibrium was established between the processes of accumulation and denudation; a favorable climatic condition helped in the formation of huge weathering crust not only in Carbonate rocks of the sedimentary cover but also in the uplifted portions of the Archean basement (Suntar anticline). Drilling of test pits showed that the thickness of weathered crust in the anticline was 53 m. Besides, in the individual ridges, the lower Mesozoic tectonic activation led not only to the complete destruction of the weathering crust of Archean rocks but to further intensive breaking of the compact Archean basement rocks.

It is apparent from the above-mentioned facts that the richest accumulation of placer gold should be associated with negative relief. This is in keeping with the flow of water of that period within the Suntar anticline as well as in its marginal parts. These ancient water streams, perhaps, flowed radially from the Suntar anticline. Therefore, the study of Premesozoic topography of the anticline is one of the most important tasks for proper organization of the prospecting and exploratory work. Because of the overall submergence of the Vilyuĭ tectonic depression in

the Mesozoic and wide occurrence of sandstone conglomerate layer in the Suntar anticline and other uplifted regions in the Lower Jurassic, gold placers associated with the erosion of the Archean - Proterozoic rocks were buried underneath.

Against the background of such an overall regional depression in the Jurassic period began the uplifting of Baagin, Sogolokh and Tabasynd structures of the Kempendyaĭ depression, apparently because of salt-dome tectonics. Owing to this upliftment, total erosion of the redeposited products of the Middle Paleozoic weathering crust of the Suntar anticline took place in the core of the above-mentioned folds. According to our observations, the weathered crustal relics were preserved only in their southeastern borders. At the same time, there might probably be gold-bearing regions, undergoing crustal weathering, in the Suntar anticline. It is beyond doubt that auriferous conglomerates were fully retained even in the Lower Paleozoic and were fully preserved in the adjoining anticlinal parts of the Kempendyai and Ygyattan depressions. Data obtained from trial pits show that the thickness of the Mesozoic cover on the Suntar anticlinal slopes is 368 m, whereas in depressions it goes up to 1500 - 2000 m. This fact clearly differentiates the said region from that of Witwatersrand where the cover of placers exceeds 3000 m at some places.

Thin layers of gravel-pebble conglomerates of the Ukugut formation, deposited in the Leias, follow only the borders of the Vilyui tectonic depression. Gold associated with them, perhaps, does not have any commercial importance. In the Cretaceous period, the intensive accumulations of terrigenous deposits continued mostly in the central regions of syneclise and its eastern part surrounded by Predverkhoyan depression. Apparently, gold of this period was associated with sediments and it was brought here from the edges of the tectonic depression.

Considering that Neogene deposits were localized only in the Aldan superposed depression and are absent in the territory under investigation, it may be presumed that the Vilyui valley underwent fracturing and erosion in the Neogene, and these effects continued even up to the Quaternary period. It must be emphasized that in the Middle Quaternary period the streams of the present Linde and Tyunga rivers joined each other somewhat towards the west and with the Vilyuĭ towards the south [5].

From these factors, we consider it necessary to make a search for auriferous conglomerates [of the Witwatersrand

type] in the most sagged part of the Kempendyai and Ygyattan depressions at a depth of about 1500 to 2000 m. It may be assumed that similar large deposits of auriferous conglomerates were preserved within the limits of these depressions in the vicinity of the anticline and at considerable shallow depths of the lower regions of the Paleozoic topography. It is also probable that considerable concentration of placer gold is found in the remnant weathering crust of negative type of topography adjoining the margins of Suntar anticline and at a depth of 370 m. It must be observed that the thickness of sedimentary cover at individual ridges can change quite considerably.

In the light of this information, the region of middle course of the Vilyui river must be considered as one of the prospective commercial gold-bearing regions of the Northeastern USSR. It must be grouped under separate gold-bearing provinces as suggested previously by Yu. A. Bilibin [2].

On this basis it may be recommended that a study of gold-bearing Vilyui tectonic depressions should be carried out by core drilling of the Upper Paleozoic weathered remnant crust at the uplifted parts of the Suntar anticline. Geophysical study of the area, adjoining the anticlinal regions of the depression, must precede drilling.

Literature

1. Bilibin, Yu. A. Metallogeniya Yakutskoi ASSR (Metallogeny of the Yakut ASSR) Izbr. Trudy, T. III, Izd-vo AN SSSR, 1961.

2. Balibin, Yu. A. Metallogenicheskie provintsii i metallogenicheskie epokhi. (Metallogenic provinces and metallogenic epochs) Gosgeoltekhizdat, 1955.

3. Du-Toit. Geologiya Yuzhnoi Afriki (Geology of the South Africa). Gosgeoltekhizdat, 1957.

4. Ivensen Yu. P. Mestorozhdeniya tipa zolotonosnykh konglomeratov i perspektivy ikh vyyavleniya na territorii SSSR (Deposits of the auriferous conglomerates and perspectives of its discovery in the territory of USSR).

In the book: 'Geokhimiya, petrografiya, i mineralogiya osadochnykh obrazovanii, ("Geochemistry, petrography and mineralogy of sedimentary formations"). Izd-vo AN SSSR, 1963.

5. Zol'nikov V.G., A.I. Popova. Paleogeograficheskaya skhema chetvertichnogo perioda ravniny Tsentral'noĭ Yakutii (Paleogeographical scheme of Quaternary period of the central Yakutiya plains). In the book: 'Materialy po izucheniyu rastitel'nosti Yakutii' (Materials for studying the vegetation of Yakutiya). Tr. In-ta Biologii, Vyp. III. Izd-vo AN SSSR, 1957.

6. Kolotukhina S.E. Osnovnye cherty tektonicheskogo razvitiya Afriki v dokembrii (Main features of tectonic development of Africa in the Precambrian). Izv. AN SSSR, ser. Geol., No.4, 1964.

7. Serdyuchenko D.P. Barito-gematitovye i sillimanito-korundovye mestorozhdeniya iz arkheiskikh osadochno-metamorficheskikh formatsii Yakutii i Yuzhnoĭ Afriki (Barite-hematite and sillimanite - corundum deposits from Archean sedimentary-metamorphosed formations of Yakutiya and South Africa). In the book: 'Geokhimiya, petrograpiya i mineralogiya osadochnykh obrazovanii (Geochemistry, petrography and mineralogy of sedimentary formations). Izd-vo AN SSSR, 1963.

8. Foss G.V. Zoloto (Gold). Gosgeoltekhizdat, 1963.

9. Cherskiĭ N.V. Bogatstva nedr Yakutii (Natural wealth of the Yakutiya) Yakutknigoizdat, 1957.

Technical Translations

Sysoev, F.A.

On the occurrence of large nickel deposits of the linear type in a small ultrabasite massif

Razvedka i Okhrana Nedr
No. 10, pp. 3-6, 1964

Translated and Published by

Indian National Scientific Documentation Centre

Delhi

TT 68-50628

RAZVEDKA I OKHRANA NEDR
No. 10, pp. 3-6, 1964

SYSOEV, F. A.

On the occurrence of large nickel deposits of the linear type in a small ultrabasite massif (O priurochennosti krupnykh nikelevykh mestorozhdenii lineinogo tipa k nebol(shim massivam giperbazitov)

Translated from Russian

Published for the U. S. Department of Interior, Bureau of Mines and the National Science Foundation, Washington, D. C. by the Indian National Scientific Documentation Centre, New Delhi.

1969

Printed and published by Insdoc, Delhi-12.

On the occurrence of large nickel deposits of the linear type in a small ultrabasite massif

F. A. SYSOEV

Ural Geological Directorate

All known commercial deposits of nickel in the Urals are connected with linear crustal weathering confined to massifs of serpentinized peridotites and dunites of peridotite formation which cover an area not exceeding 2 - 5 km^2. Only small deposits of the linear type have been discovered in the large massifs and their mining is economically unprofitable. The following may be named under such deposits: Anatol deposit occurring within the boundaries of the Tagil'sko - Krasnoural massif, Rogozhin and Itkul in the Ufaleĭ massif, Susan in the Alapaev massif and so on. Besides these, a good number of deposits, as for example, Kalinichev, Nizhne-Aleksandrov, Ul'yanov, Pereval'noe (Verkhneĭvinsk massif), Bruzyan and Kolyutkin (Klyuchev massif), with very limited reserves, are well-known. A number of small deposits have been located in the Ufaleĭ massif, as well as near Kyshtym lying to the south of Karabash, and so on.

In spite of the presence of a large number of mineralized ore bodies in such large massifs like the Tagil'sko-Krasnoural Verkhneivinsk, Ufalei, Klyuchev, and so on, systematic search did not result in the discovery of large commercial deposits. Prospecting was unsuccessfully conducted for a number of years in the Rezhev and Alapaev massifs. These also did not give any positive results.

The experience of prospecting for nickel deposits, which was confined within the crustal weathering of linear type, shows that more or less large deposits occur within the confines of small massifs of ultrabasites (area of outcrop 0.3 - 5 km^2). This has a great practical importance.

In spite of the complexity of circulating ground water in the region of hilly and undulatory topography, where the linear type crustal weathering occurred [6], the migration of nickel took place in a wet state from the top towards the bottom.

A massif of 400 - 800 m in height is sufficient to supply an adequate quantity of nickel necessary for the formation of an arc deposit. Total amplitude of positive epeirogenic fluctuations during the whole period of formation of the linear crustal weathering was quite large.

This relates to the predominant part of the geomorphological regions classified by A.P. Sirov [14] into: (1) detrital massifs - Upper Mesozoic-Paleogene denudation of the eastern surface of the foot hills of the Urals; (2) uplifted rock massifs of the Mesozoic denuded surface; (3) detrital massifs of Mesozoic denuded surface. Considerable uplifting was observed in different parts of the abraded peneplain.

Linear crustal weathering, as compared to the areal weathering, continued over a much longer period of time and perhaps started towards the end of the Paleozoic. The investigations of the geologists like N.F. Mamaev [2], A.A. Pronin [3], O.A. Nestoyanovaya and V.M. Sergievskii [2, 7] testify to the fact that the predominant part of ultrabasite massifs in the Upper Paleozoic were exposed to the surface and were subjected to weathering and erosion.

Relatively hot and moist weather at the end of the Carboniferous and beginning of the Permian [5] Periods, hilly and undulatory topography, abundant growth of vegetation - all these factors promoted the weathering of the rocks exposed to the surface as well as in the fracture zone. The weathering was specially effective at the tectonic contacts of the silicate rocks with limestones. Linear crustal weathering continued with varying intensity during the whole of the Mesozoic era. A supply of nickel in the crustal layers of marbles in a number of deposits was quite considerable even in the Paleozoic. In this period, the sedimentary ores containing nickel-bearing sulfides were formed in the Aidyrlin and Ufalei deposits.

Owing to the frequent uplifting of the Urals, huge rock mass was subjected to weathering and erosion. Nickel from the upper levels of the weathered crust was infiltrated into deeper levels. Depleted nickel of the eluvium of upper levels was gradually redeposited in the lower regions. Thus, in the process of uplifting, erosion, and weathering, the nickel concentration in the eluvium of linear crust increased. Frequent occurrence of relatively sharp rugged surface topography of substrata

activated deeper circulation of fissure water and assisted in the development of weathering into deeper horizons of the fracture zones.

Extension of each deposit took place along the length of fracture zone in the body of ultrabasite; its depth depended entirely on the topography. Moreover, the greater the region surrounded by fissure (vein) water above the points of their discharge, the greater were the depth and the intensity of the circulation of the water

The above-said occurrence of nickel deposits found within small massifs of ultrabasite is conditioned by three main causes:

1. Ultrabasites, like other intrusive bodies, are characterized by a large competence as compared to different kinds of shales. During the process of plicated tectogenesis, shales easily yield to folding. In such a case, small intrusive bodies as well as the ultrabasites, which are confined to shales, did not substantially increase their rigidity and they were subjected to grinding to a large extent during the fold movement compared to similar rocks forming large intrusives. Therefore, it is not known what is the available linear crust for mineralization in dunites and pyroxenites of the platinum-bearing belt, as it goes into the composition of large massifs of gabbro.

In all the known economic nickel deposits of the linear type of weathering, intensive longitudinal and transverse foldings are found. Shales are collected in acute folds; serpentinites and marbles are brecciated and broken into individual blocks.

The degree of grinding of small ultrabasites increases, in case the plastic country rocks are confined between large intrusives. For example, one of the largest deposits of linear type is confined to the massif of ultrabasites in the central Urals having an area of 3 km^2. In this place, layers of shales and marbles are confined between two large plutons; a massif of serpentinite occurs in the west, and that of a diorite in the east. Another such deposit, in the formation of which serpentinite, marble, and gniess take part and which is pierced through by a series of granite dykes, is surrounded by granitic intrusives from all three sides.

2. A small body of ultrabasites, confined in shales and subjected to strong grinding action, appeared to be quite favorable

for the development of directed hypergenesis in hydrodynamic conditions.

When shales occur in the hanging and footwalls of fragmented hyperbasites, the circulation of vein waters takes place in one direction, that is, along the strike of the tectonic zone of brecciation. Circulation of water in the transverse directions is stopped. In the hilly or undulatory topography, the hydraulic unit of the water table system is restricted at the foothill regions and at their edges by monolithic rocks of substrata, whereas in hanging walls they are confined within the layers of crustal weathering of rocks of argillaceous composition. These served as agents for the weathering and migration of chemical elements in the eluvial zone of tectonic faults at deeper zones. The depth often goes to hundreds of meters.

3. Small massifs of ultrabasite, as compared to larger ones, are frequently found in relatively complex hydrochemical conditions. The country rocks are highly schistose, sedimentary and volcanogenic modifications with abundance of disseminated pyrites and other sulfides in them. Water flowing through these rocks becomes not only acidic but also aggressive due to the decomposition of sulfides.

Within the boundaries of linear type deposits of crustal weathering and in their close vicinity, large ore bodies are frequently found. Sometimes huge granitoid massifs, as well as amphibolites, gabbro, marbles, gneisses, granite dykes, diorites, gabbro-diabases, and so on are also found.

In the fracture zones, which cut through various petrographical units, fissure waters of different compositions are formed. These waters get mixed up among themselves in succession while moving, and this increases their aggressiveness [1]. Besides, a relatively high level of aggressiveness of ground water is maintained for a longer time in the regions of complex geological structure than in the regions that consist of a single type of petrographical units. This is associated with frequent mixing of water of different composition during its movement along the zones of small fractures. Such cases are very rare in large massifs of ultrabasites where fractures extend over a considerable distance. Here, the intensity of weathering is weaker.

It would be incorrect to think that more or less large nickel deposits should always be associated with smaller massifs of ultrabasites. Owing to a number of reasons, many such massifs did not experience great dynamic actions, whereas others were subjected to crushing (fragmentation) during the course of the development of plicated tectonics. During weathering, linear crusts developed in them. Deposits could have been either very large or small. This depended on a number of factors: (1) the topography of a massif in question and its surrounding could have been relatively gentle and only planar weathered crust could be formed; (2) the topography was sharply broken; owing to considerable difference in the feeding levels of ground water above the points of discharge, the ground water penetrated to a great depth, and linear crustal weathering took place at deeper horizons; (3) erosion could have destroyed a considerable portion of the already formed deposit.

In summary, the following might be stated: Various types of nickel deposits of linear type having different magnitudes are formed under humid conditions of weathering in regions with hilly and undulatory topography and warm climate along the fracture zones in small massifs of dunites and peridotites. Under these conditions, only small and generally noncommercial deposits could form in large massifs.

Small massifs of serpentinized dunites and peridotites of peridotite formation, which differ from their analogous gabbro formation by possessing a much higher nickel content, are widespread. Generally, they are confined within an ultrabasite belt known in the Urals or can occur as diagonal bands in anticlinoria, connecting ultrabasite belts between themselves.

Groups of ultrabasite massifs occurring in the regions, where extensive marbleization of limestones has taken place, are of great importance. Such phenomena are found within the Murzinsko-Aduisk anticlinorium, in the southern and eastern margins of Verkh-Isetsk granite massif, in the south of Karabash, to the south of Syrostansk serpentinite massif, in the northern part of Kazbaev serpentinite massif, in the region of the Muslyumov group of ultrabasic massif as well as in many other regions. With the help of geogphysical methods, many new, small ultrabasite massifs may be discovered in the above-said regions.

Literature

1. Laptev F.F. Agressivnoe deĭstvie vody na karbonatnye porody, gipsy i betony (Aggressive action of water on carbonate rocks, gypsum and concrete). Tr. Vses. Kontory spets. Geol. Kartir., Vyp. 1. Izd-GONTI, 1939.

2. Mamaev N.F. Novye Dannye o vozraste giperbazitov na vostochnom sklone Yuzhnogo Urala (New data about the age of ultrabasites on the eastern slopes of the Southern Urals) Byull. Nauchn.-tekhn. Informats., No. 2/30, Gosgeoltekhizdat, 1961.

3. Pronin A.A. K voprosu o vozraste serpentinitov Urala (On the question pertaining to the age of serpentinites of the Urals). Izv — AN SSSR, Ser. Geol., No. 6, Izd. AN SSSR, 1944.

4. Sigov A.P. Osnovnye cherty geomorfologii Urala (Main features of the geomorphology of the Urals) From the book: 'Materialy po geomorfologii i novoĭ tectonike Urala i Povolzh'ya' T. 1. Izd-Bash. Fil. AN SSSR, 1962.

5. Strakhov N.M. Osnovy teorii litogeneza. (Principles of theory of litogenesis). T. 1. Izd. AN SSSR, 1962.

6. Sysoev F.A. K voprosu o genezise nikelevykh mestorozhdeniĭ vyvetrivaniya lineinogo tipa (On the question pertaining to the genesis of nickel deposits of linear weathered type). From the book 'Kora Vyvetrivaniya', Vyp. 5. Izd. AN SSSR, 1963.

7. Shumikhin E.A. O Vozraste Ul'traosnovnykh massivov zapadnogo kryla Magnitogorskogo sinklinoriya (On the age of the ultrabasic massifs of the western side of Magnitogorskiĭ synclinorium) From the book: 'Magmatizm, metamorfism, metallogeniya Urala'. Tr. Pervogo Ural'sk. Petrogr. Soveshch. Izd- AN SSSR, 1963.

Technical Translations

Prusevich, A. M.

Rich nepheline ores for use by the Aluminum Industry of Siberia

Razvedka i Okhrana Nedr
No. 11, pp. 7-11, 1965

Translated and Published by

Indian National Scientific Documentation Centre

Delhi

TT 68-50631

RAZVEDKA I OKHRANA NEDR
No. 11, pp. 7-11, 1965

PRUSEVICH, A. M.

Rich nepheline ores for use by the Aluminum Industry of Siberia (Bogatye nefelinovye rudy i ikh ispol'zovanie alyuminievoi promyshlennost'yu Sibiri)

Translated from Russian

Published for the U. S. Department of Interior, Bureau of Mines and the National Science Foundation, Washington, D. C. by the Indian National Scientific Documentation Centre, New Delhi.

1969

Printed and published by Insdoc, Delhi-12.

Rich nepheline ores for use by the Aluminum Industry of Siberia

A. M. PRUSEVICH
West-Siberian Geological Directorate

As a result of the geological prospecting work carried out in recent years in Siberia a number of deposits of nepheline ores were brought to light and prospected. These deposits can serve as a base for the development of an aluminum industry. One of such bases is Kia-Shaltyr deposits of nepheline ores (urtites) located in the northern part of Kuznets Alatau.

The deposits were discovered in 1957, and began to be exploited in 1962 after detailed prospecting. They were related to the huge central mass or to the ancient core of Kuznets Alatau, characterized by a typical multistage structure. The first structural stage is represented by Precambrian crystalline foundation. The second one is composed of layers of carbonate and effusive rocks of Sinian and Cambrian, which gave rise to huge gentle folds. Intrusion of alkaline gabbroids of Kia-Shaltyr massif occurs within this fold. The third structural stage comprises effusive and sedimentary strata of the Devonian. These occur in the basins formed by the systems of huge faults.

Carbonate complex of Usin (C_{m_2}) and Enicei (S_n) formations are represented primarily by bright-gray and gray marbleized stones with horizons of dolomitic limestones and dolomites, rarely quartzites, sometimes slates and effusives. Effusive-sedimentary complex of the second stage, provisionally brought under Kondom formation of the Lower Cambrian by P.A. Ponamarev (1961), contains metamorphic and sandy argillaceous slates, siltstone, sandstone, greenstone porphyrites and their tuffs with lenses and horizons of sandstone, quartzites and conglomerates.

Devonian deposits (D_{1-2}) occur negligibly in the region and are represented basically by effusive rocks dipping at low angle.

Kia-Shaltyr massif of alkaline gabbroids, intruding through the deposits of the Cambrian and the Sinian, is related to the ring structure and is an intrusion of the central type. The intrusion with 2.1 km^2 area has a stock form. Its contacts with enclosing rocks are steep, nearly vertical. Massif has been well differentiated. Its southern and southwestern parts are formed primarily of hypidiomorphic and granular theralite, and the northern and northeastern by trachytoid theralites which are very much similar to essexites in their mineralogical composition.

The rocks of ijolite-urtite series, namely urtites, ijolites, ijolite-urtites and melteigites are spatially situated in the marginal regions of the intrusion, forming a horseshoe-shaped ore body. Their contacts with the enclosing rocks and theralites are clear; these are typical of later formations. Rocks of ijolite-urtite series are characterized by gradual as well as sharp transitions between them.

The enclosing rocks of effusive sedimentary beds (plagioclase porphyrites, tuffs, clayey limestone) are intensively hornfelsic near the intrusion. Metasomatic hornfels and hornfelsic rocks form an aureole ranging in width from 100 to 400 m. Limestones subjected to marbleization are also clearly seen. In direct contact with intrusion, with urtites and ijolite-urtites in particular, skarns and skarnitized limestones have developed.

Contacts of ore body are steep, slightly sinuous, with a variation in the dip angle from 70° to 90° towards the southwest and northeast. In the southern part, the ore body dips steeply (70°-80°) to the southeast. Variation in the real thickness of the ore body at depth has not been established.

The rocks of the ore body are represented basically by bright-gray coarse-grained urtites, consisting of nepheline (85 percent), titanium-augite (15 percent) and slight admixture of apatite, titanomagnetite, and pyrrhotite. A sharp idiomorphism of nepheline is marked in relation to titan-augite. Secondary change in nepheline is insignificant and is evidenced by its alteration into cancrinite, liebenerite and zeolites.

The average chemical composition of urtites in percent is: silica, 40.63; alumina, 28.03; iron oxide (total), 4.75;

titania, 0.34; calcium oxide; 7.12; magnesium oxide, 0.95; sodium oxide, 10.77; potassium oxide, 3.01; gallium, 0.001. The constancy of mineralogical, petrographical and chemical composition is typical of urtite. Without any changes they are traced along the strike and across the width of the ore body, as well as through the entire depth of the wells drilled in the field.

Sometimes in those parts of the ore body which are near the contact, narrow belts as well as small schlieren bodies of ijolite-urtites are noted, which constitute about 5 percent of the total volume of the ore body. The schlieren of ijolites are unevenly developed in urtites. Often we meet them near the contact of the body of urtites with enclosing rocks as lenticles oriented along the ore body. These are isolated and steeply dipping; their thickness varies from 0.1 to 1 m, seldom reaching up to 1.5-4 m.

Ijolites are dark gray in color, coarse-grained, sometimes of pegmatitoid structure; they are composed of nepheline (50-60 percent) and pyroxene (40-50 percent). Apatite, titano-magnetite and pyrrhotite are present in negligible quantity. The average chemical composition of ijolites in percent is: silica, 40.32; alumina, 19.76; iron oxide (total), 12.20; calcium oxide, 12.68; sodium oxide, 7.25; potassium oxide, 2.18.

Ijolite-urtites in the southern and northern wedged out parts of the body form belts, ranging in breadth from 1-3 to 20-30 m along the contact of urtites with enclosing effusive-carbonate rocks. They have also been noticed in the eastern and northwestern parts of alkaline gabbroid intrusion at the contact with carbonate rocks. Ijolite-urtites are composed mainly of nepheline (64 percent) and pyroxene (35 percent); diopside, granate and calcite are present in a large quantity. The average chemical composition of ijolite urtites in percent is: silica, 39.96; alumina 23.97; iron oxide, 5.26; calcium, 13.84; potassium oxide, 2.56, and sodium oxide, 6.89.

A number of small crushed zones have been noticed in the ore body. Their thickness varies from 0.5 to 5 m. Within this range urtites are subjected to cataclasis.

Steeply dipping dikes (65°-85°) of diabase, porphyrites, camptonites, ijolite-porphyrites and nepheline syenites have intruded into urtites along the crushed zones as well as along

the zones of tectonic fracture. The thickness of dikes varies from 0.2-7 m, and they extend over 20-50 to 100-150 m. The chemical composition of dikes in percent is: silica, 40-48; alumina, 16-23; iron oxide, 8-16; alkali, 6-10. All the dikes differ sharply from the urtites in their external appearance. Because of this a major part of these can easily be removed by ore sorting.

Nepheline ores of the Kia-Shaltyr deposit are easily distinguished from the deposits of Nepheline-alumina raw materials, known in the country for their high content of economic components and lower content of unwanted materials (see Table).

Deposits and rocks	Content, percent				
	Alumina	Silica	Iron oxide	Calcium oxide	Total amount
Kia-Shaltyr urtites	28.0	40.4	5.0	7.2	13.6
Goryachegorsk (Krasnoyarsk region) theralite-syenites	22-23	44.4	10	8.3	9.5
Goryachegorsk partially de-ironed ore (concentrate)	23	45	6.5-7	8.9	9.8-10.7
Syenites-urtites of Kurgusul'sk (Krasnoyarsk region)	22-23	50.4	6.3	4.7	12.2
Nepheline-syenites of Tezhsar (Armenian SSR)	21	55	3.5	3	12.6
Ijolites of Kola peninsula	16.4	44.4	5.9	-	12.8
Nepheline concentrates of Kola peninsula	29-29.5	44-43.5	3.3-3.5	1-1.5	17.5-18

As is clear from the Table, the ores of Kia-Shaltyr field are more similar to Kola nepheline concentrates in their chemical composition. They are very much superior in quality to the concentrates of mechanical dressing, obtained from nepheline ore of the Goryachegorsk field in the Krasnoyarsk region, and can be used by aluminum industry for the manufacture of alumina without previous dressing.

The All-Union Aluminum-Magnesium Institute of the West-Siberian Branch of the USSR Academy of Sciences, USSR, and West-Siberian Geological Directorate, conducted technological tests of 24 samples of nepheline ores of Kia-Shaltyr deposit according to the method of baking with soda and limestone conforming to the scheme as practised in Volkhovsk plant. As a result of tests, a possibility was established for the successful treatment of nepheline ores (urtites) according to the aforementioned method, with the extraction of alumina ranging up to 85-92 percent and alkali, 85-89 percent.

The conditions of occurrence of the deposit enable us to conduct processing by open method with negligible expenditure for the removal of wastes. Mining and hydrogeological conditions of working off the Kia-Shaltyr field are favorable.

The Council of National Economy of Krasnoyarsk started the working of the mine in the Kia-Shaltyr field. This mine will be the first in the country, which would supply nepheline ore; ores will be treated at Achinsk alumina plant.

According to the estimates of the State Designing Institute of Aluminum and Siberian Scientific Research and Design Institute for Nonferrous Metals, Achinsk alumina will become one of the cheapest materials in the Soviet Union. Complex reprocessing of Kia-Shaltyr nepheline ores at the Achinsk plant facilitates obtaining, apart from the basic products (alumina), valuable waste products, such as soda products and high-quality cement, whose cost price is lower than at any of the newly designed large enterprises of cement industry. This also favorably affects the economy of Siberia.

In the northern part of Kuznets Alatau, in addition to Kia-Shaltyr, a few more fields of nepheline raw material have been brought to light. Of these the Goryachegorsk, Tuluyulsk and Kurgusul'sk fields in Krasnoyarsk region have great prospects. In the quality of ores the Kurgusul'sk field excels that of Goryachegorsk (less iron oxide and more alkali), and the latter might also become a big supplier of nepheline ores for the production of alumina in Siberia.

The areas of the growth of nepheline ores possess big sources of thermal energy and hydro-energy, which, in combination with the huge reserves of nepheline raw material

and high quality limestones, make them the principal centers of the aluminum industry of the Soviet Union. Undoubtedly, further study of this area will enable us to bring to light new fields of rich nepheline ores.

The genesis of nepheline rocks and urtites in particular is dealt with differently. Some research workers connect the formation of nepheline rocks with differentiation of granitoid and basalitic magma at great depths (O.A. Bilibin, A.N. Zavaritskii), others with metasomatic processes (L.S. Borodin) or assimilation of limestones by magmatic melt (popular hypothesis of Daly).

In the opinion of the author, urtites of the Kia-Shaltyr field are of magmatic formation and are an integral part of the complex of alkaline gabbroids of the central type, having been disposed in parts on its border. The differentiation of magma is clearly expressed on urtite and gabbroid, originated apparently in the deep magmatic hearth.

The following testify to the fact that the urtite portion of the magma was independent:

(1) The body of urtites is of elongated crescent-shaped form and in the northern part it is not in direct contact with theralites; it is separated from theralites by a narrow strip of skarns and skarnitized limestones;

(2) Urtites are characterized by nearly similar petrographical and chemical compositions over a large area;

(3) The body of urtites has clear contours, the contacts with the surrounding rocks are sharp, and in the contact points of theralites, these are somewhat enriched by nepheline, that is, affected by the process of nephelinization.

The presence of porphyritic texture in theralites and essexites suggests that the formation of the massif as a whole occurred in hypabyssal conditions in various tectonic setting. So, isotropic textures are typical of urtites and trachytoid textures, and banded and gneissic textures are typical of theralites and essexites.

According to the mineralogical and chemical composition, the igneous rocks of the Kia-Shaltyr massif are divided into two

branches. The one unites urtites, ijolites and melteigites, and the other unites theralites and essexites. These branches reflect the chemical evolution of two independent units of magmatic fusion that participated in making the massif: ijolite-urtite and essexite.

Nepheline rocks after reaching the earth's surface form positive reliefs. They are well preserved in drifted rocks and alluvium after erosion.

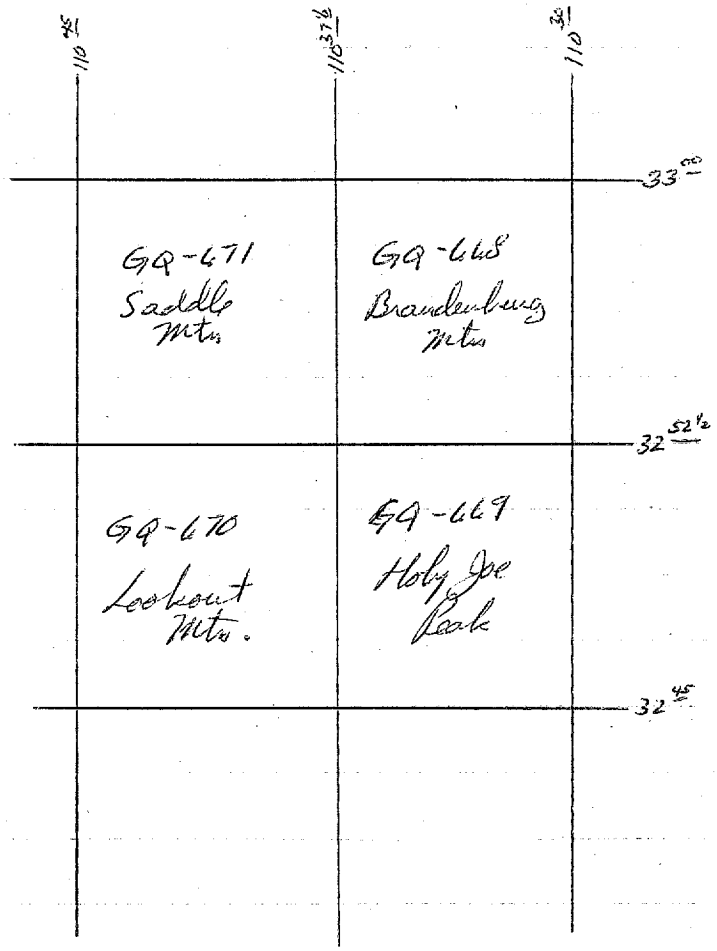
In prospecting for nepheline ores and in field identification of rocks, it is necessary to take into account the characteristic tetragonal and hexagonal forms of crystals of nepheline, and their greasy lustre as well as white or sometimes bluish or pinkish color. A particularly reliable sign that points to the presence of nepheline in the rock is the characteristic cavity, arising in the place of easily eroded crystals of nepheline.

The most effective method of prospecting for nepheline ores in poorly exposed areas and areas covered with turf is the river bed fragments. The fragments of nepheline rocks are found in alluvial deposits at a distance of more than 20-30 km from the original source. All small collateral tributaries directly leading to the original sources must be more carefully and uninterruptedly investigated. In this way it is possible to bring to light regions where the material under investigation comes from drifted rocks and river alluvium. Further search for the original field is effected by constructing routes along the slope and watershed of the river valley; this is the source of supply of useful mineral along the drifted rock fragments, which have formed quite extensively on the slopes of mountains. It is necessary to draw a geological map of the part on a scale 1:5000 or 1:10,000. The map must show the distribution and density of occurrence of ore fragments, insofar as the form of the fragment-ore fan depends on the form and position of the body of the useful mineral in relation to the relief of the locality. After delineation of the ore fragment cover, the ore body is stripped with the help of ditches and prospect holes which are laid transverse to the leading structures of the area.

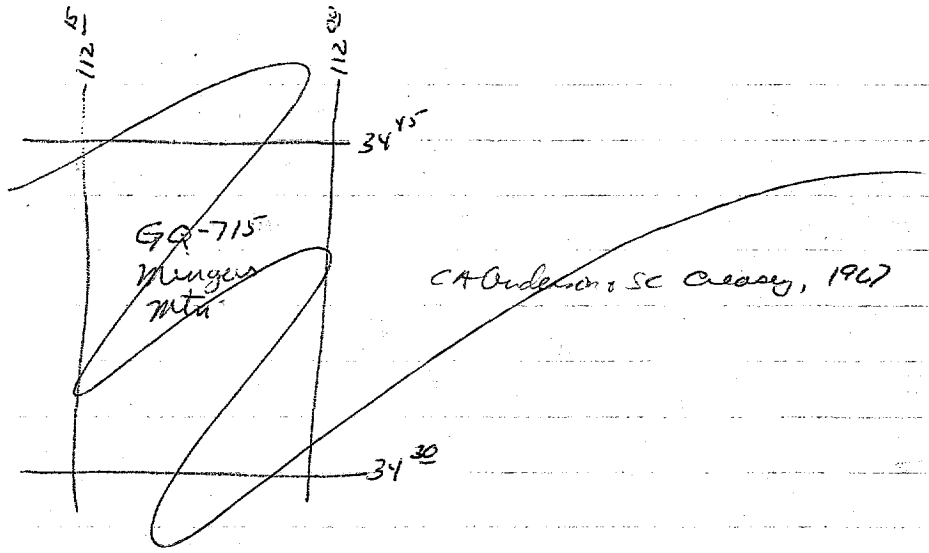
The application of the fragment-river-gravel method of search for nepheline ores in the northern part of Kuznets Alatau enabled within a short period the discovery of a number

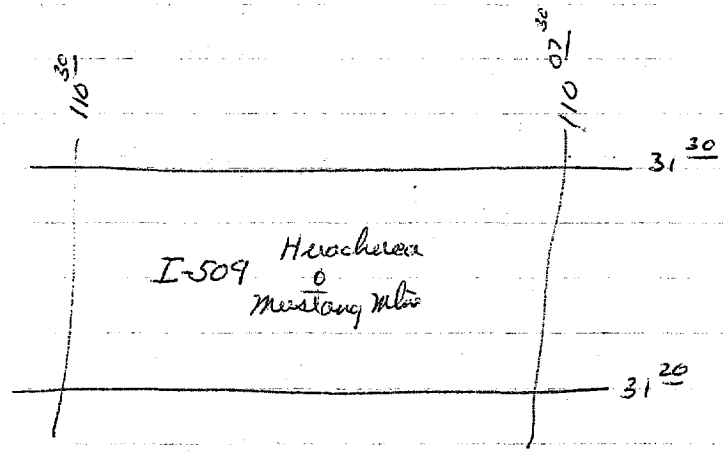
of fields of nepheline rocks, including those of Kia-Shaltyr; the total expenditure was not much.

Because of the notable growth of the aluminum industry in Siberia, the search for rich nepheline ores in this area remains, as it was in the past, one of the most important tasks of the geologists.

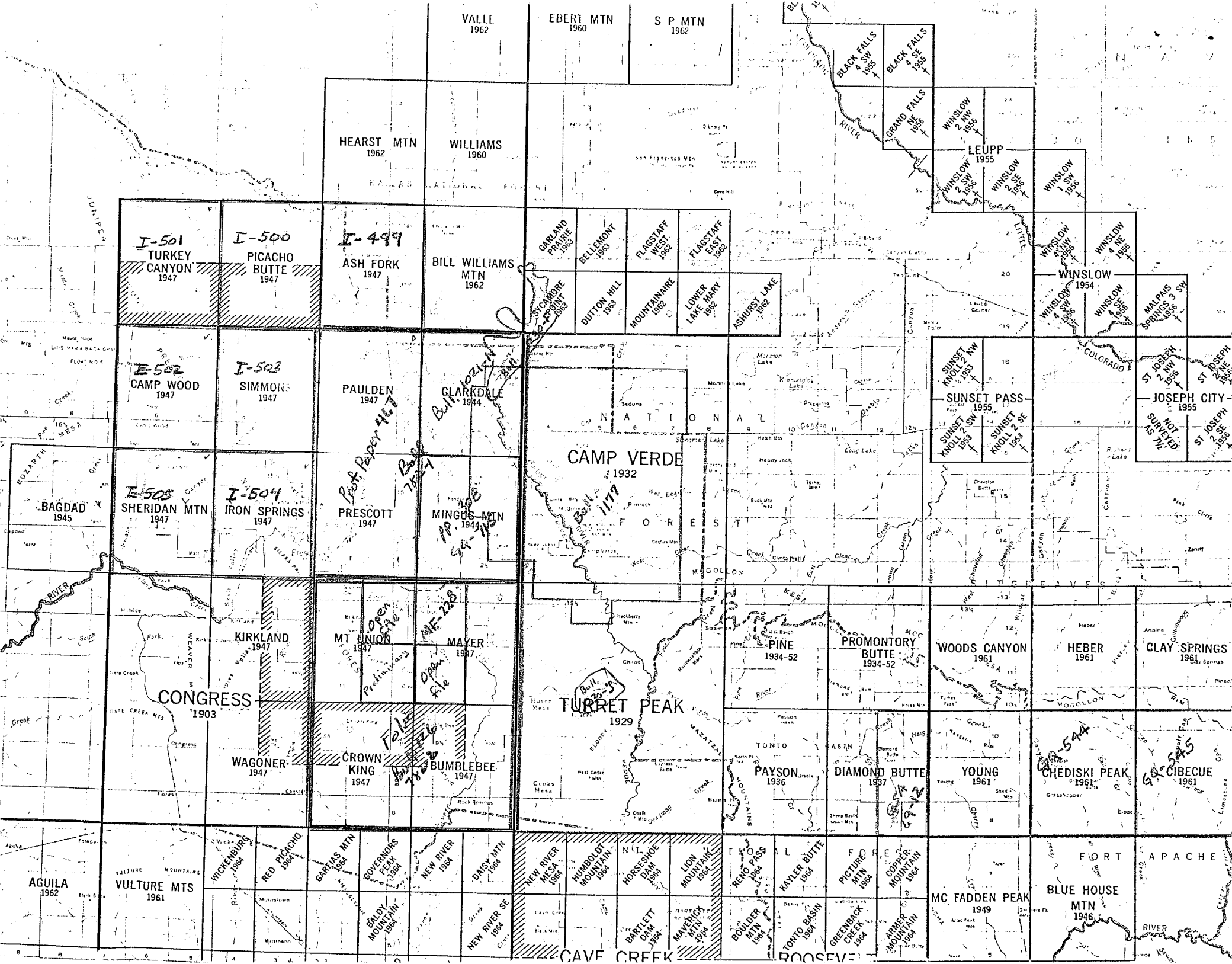


GQ, Geologic Quadrangle maps ~~in press~~ published.
Krieger, M.H., 1968.


112 45
112 00
34 45
GQ-715
Mungus
Mtn
CA Anderson, SC Creasey, 1967
34 30


110 30
110 07 30
31 30
I-509
Hexacheron
Mustang Mtn
31 20

Aa.0.0.18


VALLE 1962
EBERT MTN 1960
S P MTN 1962
BLACK FALLS 4 SW 1955
BLACK FALLS 4 SE 1955
GRAND FALLS NE 1956
WINSLOW 2 NW 1956
LEUPP 1955
WINSLOW 2 SW 1956
WINSLOW 2 SE 1956
WINSLOW 1 SW 1956
HEARST MTN 1962
WILLIAMS 1960
I-501 TURKEY CANYON 1947
I-500 PICACHO BUTTE 1947
I-499 ASH FORK 1947
BILL WILLIAMS MTN 1962
GARLAND PRAIRIE 1963
BELLEMONT 1963
FLAGSTAFF WEST 1962
FLAGSTAFF EAST 1962
SYCAMORE POINT 1963
DUTTON HILL 1963
MOUNTAINAIRE 1962
LOWER LAKE MARY 1962
ASHURST LAKE 1962
WINSLOW 4 NW 1956
WINSLOW 4 NE 1956
WINSLOW 1954
WINSLOW 4 SW 1956
WINSLOW 4 SE 1956
MALPAIS SPRINGS 3 SW 1956
I-502 CAMP WOOD 1947
I-503 SIMMONS 1947
PAULDEN 1947
CLARKDALE 1944
SUNSET KNOLL 2 NW 1953
SUNSET PASS 1955
SUNSET KNOLL 2 SW 1953
SUNSET KNOLL 2 SE 1953
ST JOSEPH 2 NW 1956
JOSEPH CITY 1955
NOT SURVEYED AS YET
ST JOSEPH 2 NE 1956
ST JOSEPH 2 SE 1956
CAMP VERDE 1932
BAGDAD 1945
I-505 SHERIDAN MTN 1947
I-504 IRON SPRINGS 1947
PRESCOTT 1947
MINGUS MTN 1944
KIRKLAND 1947
MT UNION 1947
MAYER 1947
CONGRESS 1903
WAGONER 1947
CROWN KING 1947
BUMBLEBEE 1947
TURRET PEAK 1929
PINE 1934-52
PROMONTORY BUTTE 1934-52
WOODS CANYON 1961
HEBER 1961
CLAY SPRINGS 1961
PAYSON 1936
DIAMOND BUTTE 1937
YOUNG 1961
CHEDISKI PEAK 1961
CIBECUE 1961
AGUILA 1962
VULTURE MTS 1961
WICKENBURG 1964
RED PICACHO 1964
GARFIAS MTN 1964
GOVERNORS PEAK 1964
NEW RIVER 1964
DAISY MTN 1964
NEW RIVER MESA 1964
HUMBOLDT MOUNTAIN 1964
HORSESHOE DAM 1964
LION MOUNTAIN 1964
RENO PASS 1964
KAYLER BUTTE 1964
PICTURE MTN 1964
COPPER MOUNTAIN 1964
MC FADDEN PEAK 1949
BLUE HOUSE MTN 1946
BALDY MOUNTAIN 1964
NEW RIVER SE 1964
BARTLETT DAM 1964
MAVERICK MTN 1964
BOULDER MTN 1964
TONTO BASIN 1964
GREENBACK CREEK 1964
ARMER MOUNTAIN 1964
CAVE CREEK
ROOSEVE

Recent Coverage.

Bull. 1021-N. Geol. of the Clarkdale Quad. (Lehner, 1958).

Bull. 1177. Geol. in the Verde Valley. (Twenter, 1963).

Bull. 1230-F. Mineral Resources – Sycamore Canyon. (Huff, 1966).

Bull. 1230-J. Mineral Resources – Pine Mountain. (Conney, 1967)

P.P. 308. Geol. of the Jerome Dist. (Anderson, 1958).

P.P. 447. Geol. of the Paulden-Prescott Quad. (Krieger, 1965).

GQ-544. Geol. of the Chalkiski Peak Quad (Finnell, 1966).

GQ-545. Geol. of the Cibecue Quad (Finnell, 1966)

MF-235. Prelim. Geol. of the NW 1/4 Mayer Quad (Anderson, 1959).

I-501. Prelim. Geol. of the Turkey Canyon Quad. (Krieger, 1967).

I-502. Prelim. Geol. of the Camp Wood Quad (Krieger, 1967)

I-503. Prelim. Geol. of the Simmons Quad. (Krieger, 1967)

I-504. Prelim. Geol. of the Iron Springs Quad (Krieger, 1967)

I-505. Prelim. Geol. of the Sheridan Mtn Quad. (Krieger, 1967)

Open file. Prelim. Geol. of the NE 1/4 Mt. Union Quad (Anderson, 1962).

GSA 69-12. Geol (E 1/2) of the Diamond Butte Quad. (Bell, v. 69, no. 12, p. 1495–(Gastil, 1958).

I-499. Prelim. Geol. of the Ash Fork Quad. (Krieger, 1967)

I-500. Prelim. Geol. of the Peacho Butte Quad. (Krieger, 1967)

Open file. Prelim. Geol. of the SW 1/4 Mayer Quad (Anderson, 1967).

GQ-715. Geol. of the Mingus Mtn Quad. (Anderson & Creasey, 1967).

Preliminary Geol (SE 1/4) Mount Union Quad., (P.M. Blacet, 1963) (Copy in ASARCO files)

Bull 782. Ore Dep. of Jerome (Plate 1) & Bradshaw (Plate 2) Quads. (Lindgren, 1926).

Folio 126. Bradshaw Mtns (Jaggar & Palache 1905).

Addendum:

17. 1909. Schrader. Mineral dep. Cerbat Range. Bull. 397.

30. 1914. Noble. Shinumo quad. Bull. 549.

51. 1923. Ransome. Geol of the Oatman gold dist. Bull. 743.

~~59. 1927. Lausen. Gold ore dep near Yarnell. Bull. 820.~~

67. 1928. Longwell. Geol of the Muddy Mts Nev. Bull. 795.

72. 1931. Lausen. Geol & ore dep of Oatman-Katherine. Bull 131.

77. 1933. Dry gold placers & placering. Bull 135-N2-160.

79. 1934. Hewett. Min. resources around Boulder Dam.

148. 1948. Koons. Geol of eastern Hualapai reserv. RME-2014.

155. 1949. Thomas. Ore dep. of the Wallapai dist.

178. 1951. Wing. Wallapai min dist. Bull. 978-E.

183. 1952. Hazzard. Dev & Mines rocks of Cang. PP. 233-D.

193. 1953. Thomas. Geol of the Chloride quad. GSA Bull. v 64, no. 4.

1945. McKee. Cambrian history of the Grand Canyon. Carnegie Inst Wash. Pub. 563.

1962. Twenter. Geol. Hualapai Ind. Reserv. WSP-1576-A.

Special: GCNHA. Geol. Bright Angel Quad.

Library Check:

(12) Davidson, C.F., 1940, The present state of the Witwatersrand controversy: Mining Magazine, vol. 102.

(22) Greenberg, R., 1963, Structure-gold relationships as revealed by some Witwatersrand mine plans: Bull. Instn. Min Metall., ~~#~~ no. 683, p. 1-10.

Davidson, C.F., 1957, On the occurrence of uranium in ancient conglomerates: Econ. Geol., v. 52, p. 668-693.

Liebenberg, W.R., 1955, The occurrence and origin of gold and radioactive minerals in the Witwatersrand System the Dominion Reef, the Ventersdorp Contact Reef and the Black Reef: Geol. Soc. South Africa Trans. and Proc., vol. 58, p. 101-227.

LUIS MARIA BACA FLOAT NO. 5
WHIPPLE BARRACKS MIL RES
MONTEZUMA CASTLE NATIONAL MONUMENT
Camp Verde
K A B A B
N A T I O N A L
C O C O N I N O
N A T I O N
F O R E S T
N A V A J O
S I T G R E A V E S
N A T I O N A L F O R E
T O N T O N A T I O N A L F O R E S T
Y A V A P A I
Yava
Hillside
Kirkland
Wagoner
Congress Junction
Octave
Wickenburg
Morristown
Nadaburg
Cave Creek
Young
Cibecue
Heber
Lake Mary
Mormon Lake
Richard Lake
Chuck Box Lake
Louse Lake
Buck Spring
Deer Lake
Bush Spring
St Joe Spring
GILA AND SALT RIVER MERIDIAN
Hassayampa
Santa Fe
Aguila
Ash Fork
Williamson
Verde
Fossil
Tonto
I N D I A N
Liscum
Fleming Spring
Mud Spring
Martin Spring
Mountain Spring
Sunrise Spring
Soldiers Lake
Red Lake
Allen Lake
Con Lake
Hay Lake
Moqui Spring
Spaulding Spring
Gentry Spring
Willow Spring
Coleman Lake
Turkey Spring
Fulton Spring
Dry Lake
Ashurst Lake
Walnut
Chino
Creek
Oak
Salt
Canyon
Diablo
Cottonwood
Wash
Sycamore
Mint Wash
Antelope

1. 1861 Newberry. Colo. River of the West.

2. 1876. Wheeler. Geol. atlas, Surveys west of the 100th meridian.

4. 1882, Dutton, Tert. history Grand Canyon.

9. 1903, Reagan, Geol of the Ft. Apache region.

12. 1905. Ransome & Palache, Bradshaw Mtns folio.

16. 1908. Lee. Geol of western Ariz. Bull 352.

20. 1910 Darton, Reconn. of part of NW N. Mex & N. Ariz. Bull 435.

25. 1913 Robinson. San Francisco volc. field.

36. 1915 Darton. Santa Fe guidebook.

39. 1914 Provot. Jerome mining dist.

49. 1922. Reber. Geol. & ore dep of the Jerome dist. (AIME vol. 66).

52. 1923. Jenkins Verde River lake beds.

58. 1925 Darton, Resume of Ariz. geol. Bull. 119.

59. 1925 Lausen, Gold-copper deposit near Payson. Bull. 120.

61. 1926. Lindgren. Ore dep of the Jerome & Bradshaw Mtns quad. Bull. 782.

62. 1926. Fearing. Some notes, geol. of the Jerome dist.

70. 1930 Lausen. PC greenstone complex, Jerome quad.

74. 1933. Gregory, Colo. Plateau region.

87. 1938. Butler. Some Ariz ore dep. Bull. 145.

92. 1937. Wilson. PC Mogollon revol in C. Ariz. GSA Bull, v. 50, no. 7.

94. 1937 Harrell. Ground-water resource, Holbrook region.

107. 1943 Gatchick. Rehwalt law of Yavapai Co.

145. 1948. Anderson. Street control, cu mineral, Bagdad.

157. 1950. Creasey. Geol of the Humboldt region & Iron Springs.

159. 1950. Price. Cenozoic gravels.

160. 1950. Ariz. Pb-Zn dep. Bull. 154 & 158.

161. 1950. Anderson. Alt & mineral - Bagdad.

174. 1951. Anderson Older PC street in Ariz. GSA Bull v. 62, no. 11.

187. 1952 Great Sunna 4-corner

205. 1954 Repenning. Bidahochi Fm

207. 1954. Fatt. Prelim report of springs.

246. 1956. Shay. Prelim. report - uran + gyp Cheny creek. RME-2036.

252. 1957. Metzger. Rec. water resources

Gold Mining on the Witwatersrand, by [illegible]
Vol I, pp. 1000 [illegible]. Vol II p. 1001-1821. The Transvaal Chamber of Mines 1946.

Chapter II - Geology, p. 34-75

The Witwatersrand System lies unconformably on the Ventersdorp System (Swaziland System) (Archaean & Archaean rocks)

The WS consists of shale, slate, sandstone, & chert conglomerates (Auriferous) and the upper part is mainly quartzite, grits, and pebble beds, among which are the chief gold bearing conglomerates of the Witwatersrand goldfield.

The Ventersdorp System is intimately related to the WS. In part the [illegible] the system are conformable but elsewhere [illegible] are definitely unconformable at the base [illegible] conglomerates.

The Transvaal System lies unconformably on the older systems which had been denuded to an even plain. The TS contains 3 Series. The conglomerates contain gold.

The [illegible] contain gold, chromite, zircon, carbon, osmiridium, and occasionally diamonds.
Gold is very abundant.

See p. 43 for Section of WS on the Central Rand
See p. 44-45 for Reefs Mined on Rand to date.

In the carbon bands reef lying just below the dense chlorite quartzite

called "the Green Bulwark" – carbon pyrite found in the pebble matrix, which commonly is more highly mineralized than the rest of the conglomerate, with quantities of pyrite, pyrrhotite and chlorite. The gold values are concentrated mainly in the bottom 6 inches of the reef, which will all assay, it is said, with the bulk of the mineralization contained "as minute flecks in fractured pyrite which, in such cases, usually present a satin-like granular appearance".

See p. 50-51 for "U.S.: Comparison Section."

See p. 52, for "Main Reef Characteristics" (Consolidated Barnes Congl!).

See p. 53 for "Consol. & the Main Reef Leader" (also not reproduced above this section).

See p. 54 for "Characteristics of the South Reef".

p. 58. Pyrite is abundant & is found sometimes in nodules or "buckshot" form. Calcite is also present, normally as a bottom seam.

The gold values are most commonly found associated with pyrite and rarely on the footwall (usually a carbon seam with a few inches of sheared quartzite below it); but they often shift from one horizon to another in reefs which tend to be continuous.

3/

See p. 63 for [illegible] for [illegible]

Primary minerals (p. 64):

Quartz, Sericite, Chromite, Diamond, Zircon, Ilmenite, Corundum, & Garnet.

Secondary minerals (p. 64). (metamorphism - metasomatism): Hydrothe

Pyrrhotite, Chalcopyrite, Sphalerite, & Galena

Sericite, Chlorite, & Chloritoid.

Pyrite, Calcite, Carbon, Tourmaline & Rutile,

Uraninite, Cobalt arsenide, the rare earth minerals, & traces of manganese, nickel, phosphorus, & vanadium.

Order of formation of minerals, p. 65.

Association of gold with other minerals, p. 66.

Distribution of gold in the conglomerate, p. 66

Origin of the Witwatersrand conglomerate, p. 69.

The Quest of the Golden Fleece OR
Argonauts - Novels W. Lewis Graves

Chapters:

1) The mineralogical gourmet.
2) The [illegible] adventure.
3) Finding the [illegible] in the human [illegible]
4) Sampling the human specimens.
5) Pursuing the light and a [illegible] in the deep.

Mineralogical parameters:

1) Gold

2) Uranium association

3) Other heavy metals or minerals? from crudal mass.

4) Other minerals (?) (non-metallic) characteristic of the depositional environ.

Geological parameters:

1) Age of depositional environment

2) Source area

3) Type of depositional environment; their characteristics.

T. H. McClelland, president,

ne 15, Endako paid off the of $1,662,000 owing on term loans and, on the same date, the any redeemed the $5,000,000 re-able preference shares out of the eds of a bank loan obtained on favorable terms.

ll expansion to a capacity of 22,000 daily commenced on Apr. 15 and June 30 construction was 40% plete.

oduction during the quarter was vely unchanged from the first d. Total molybdenum produced 3,447,066 lbs. compared with 3,509,349 n the first quarter.

venue amounted to $6,192,000 in the d quarter. After deducting expenses 3,547,000, estimated net profit for period was $2,645,000. Expenses in irst quarter totalled 3,206,000.

See ENDAKO Page 22

rpax Plans Deals r Two Properties

pax Nickel Mines is negotiating outside interests for further ex-tion on two of the company's prop-, the annual meeting was told.

olved in current negotiations are ompany's molybdenum property at Creek, B.C., held by Salal Molyb-n Mines (controlled by Norpax) and kel-copper property at Tiger Lake, ra district of Northwestern Ontario.

ly this year, Amax Exploration ed its option on the molybdenum after spending some $294,000 on ation there. "We are hoping that interests will take a working option e property," F. M. Fielder, presi-stated.

ks are going ahead with European sts, added Mr. Fielder, regarding er financing of exploration at the any's partially developed nickel-r property in the Kenora area. He bed these interests as a "major consumer," and expected nego-s to be completed shortly.

Iago Mines is to carry out an airborne magnetometer survey over two claim groups near Hope, B.C., according to D. G. McRae, president. On one of these, the 24-claim nickel-copper prospect, 10 miles north of Hope, diamond drilling was started recently.

Bulldozing and trenching have recently opened up the original nickel discovery on the 24-claim group to expose a nickel-copper bearing zone with a width of at least 60 ft. Only one wall could be exposed, as it would have been necessar. to cut through a government road to get to the other. A channel sample from the mineralized zone assayed 0.33% nickel and 0.08% copper. Selected grab samples returned 7.3% nickel, 3.1% copper and 0.3% molybdenite. Object of the diamond drilling is to check the size and potential of this mineralized zone.

The other group to get an airborne survey is Iago's 92-claim molybdenum-copper prospect, 15 miles east of Hope. Assays from the disseminated type of mineralization have ranged up to 0.102% molybdenite and 0.20% copper. "In the opinion of our engineers, results already indicate a very large low grade ore deposit is a distinct possibility", says Mr. McRae. A major molybdenum producer has expressed a wish to make a field examination of the property, and a second major company has also shown an interest.

Iago has other properties located near Osoyoos, B.C., and in nor:heast Washington State.

Madsen Net Higher

Madsen Red Lake Gold Mines earned a net profit of $255,155 or 7¢ per share in the first six months, compared to $178,495 or 5¢ in the same period last year.

The above profit was won from the milling of 136,461 tons of ore from which gold bullion worth $1,418,211 was recovered. Cost-aid brought an additional $270,000.

The company's working capital as at June 30th, 1967, amounted to $3,175,468, up from $2,704,829 at June 30 last year.

Rate of shipment of copper concentrates from Munro Copper Mines continued to accelerate during July, G. E. Smith, managing director, states. There were 14 railway carloads of copper concentrate grading 20% copper or better shipped from Matheson, Ont., during the month.

Munro Copper Mines property is in Munro Twp., approximately 22 miles east of Matheson. Copper concentrate is sold through British Metal Corp. (Canada) and is believed destined to Japan.

Reserves of broken ore underground are continuing to grow, Mr. Smith said, with stoping by the shrinkage method in practice. The mill has handled up to a maximum of 600 tons in a 24-hour period.

Commence Drilling At Dasson Copper

Dasson Copper Corp. this week is commencing a program of surface drilling on its Beauchastel Twp. property, about seven miles west of Noranda, Northwestern Quebec.

The first drill hole, a relatively shallow boring, is spotted to seek the downward continuation of a copper-bearing zone encountered in a surface showing. The original showing has been traced over a length of more than 200 ft., with widths ranging up to 30 ft., P. Poulette, president, states. Subsequent magnetometer and electromagnetic surveys have indicated anomalous conditions extending well beyond the limits of the showing, it is gathered.

The showing consists of chalcopyrite mineralization, coarsely disseminated or as massive fracture fillings up to one inch in width, in heavily altered and chloritized volcanic rocks, A. C. Lee, consulting engineer, states in a report on the occurrence.

The property is located a couple of miles northeast of Macanda Copper and about two miles west of the ground involved in an option proposal of Kennco Exploration (The Northern Miner, July 20). Drilling will be carried out by Groleau Bros. Diamond Drilling Co.

Press Search For Gold

Russians Employing Computers To Identify Favorable Areas

By V. Krasnova *

Throughout his existence man extracted from the earth 65 to 70 thousand tons of gold. Even considering that some has never been accounted for, the total figure will not exceed 100,000 tons. Generally speaking, this is not very much — a cube with a side of a little more than 55 ft. But even this quantity would make nearly 4,375,000 miles of gold wire 1.0 mm. in diameter.

For centuries the sources of gold in Russia were the so-called "gold-bearing areas" (the term itself is about 200 hundred years old). "Gold-bearing" seemed to imply that it was enough for man to stoop and pick the gold up. Here it was, right at the surface. This was how gold was obtained in Russia for centuries, the prospectors just stooped and picked it up. There was no need to take a look deeper down. But the gold reserves are gradually running out, and in some places they are even re-washing the gravels.

Radioactivity Helpful

The 1958 Geneva Conference on the peaceful uses of atomic energy gave geologists a new tool to prospect for auriferous ores. The point is that such ores as a rule contain uranium or thorium and, therefore, their radioactivity is relatively high. Thus, in localities with a high radioactivity count the chances for discovering gold deposits are higher. However, even this seemingly simple method meets certain difficulties. First, it requires special equipment for registering extremely low uranium concentrations; second, in the Soviet Union such gold reserves are concentrated mainly in Siberia whose

See EMPLOYING COMPUTERS Page 22

* From Novosti Press Agency, Ottawa.

BREWIS & WHITE
LIMITED
Underwriters and Financiers

Recent Underwritings
Candore Explorations Limited
Jameland Mines Limited
Pleno Mines Limited

Adelaide St. W., Suite 416
Toronto 1, Ontario
EMpire 4-7221

Domir
IN
DALE & C
I
44 VI
HALIFAX MONTREAL

J. T. DON
ASSAY
Mine Assays
Umpire Assays
Shippers' Representative
CTA
Main Labc
Branches: TC

PEÑARROY
Minin
and I
126 Rue Saint Pierr

700 CANAD
August issue features our
CANADIAN INDUSTRIAL STOC
which relates an easy graphic
your stocks. These charts a
plotted on logarithmic scale wh
WEEKLY PRICE RANGE, CLOSI
AND VOLUME FOR 2 YEARS.
exclusive distinct features incorp
CANADIAN CHARTS, FOR THE F
IN CANADA are the 200 DAY
AVERAGE AND THE RELATIVE
LINE. These two features may
your own BUY — HOLD — SELL
CANADA'S MOST
Please send $5, $6 or
FRASER RESEARCH

THOMSON K
THE TOR
2nd
368-3871
10-12 Ontario St., OSHA
Tel.: RA. 5-1104
KERNAG
Members The In

The Northern Miner, 53rd year (1915-1967) No. 19 (699) August 3rd, 1967. Section 2, page 17

[illegible]ite, [illegible]eding [illegible]dreds of [illegible]d in the [illegible]alous areas [illegible]gets. Drill-

are reported

Work [illegible] Claims

to continue [illegible]m property [illegible]e Little Long [illegible]rio.

[illegible]agnetic sur-[illegible] as well as a drilling.

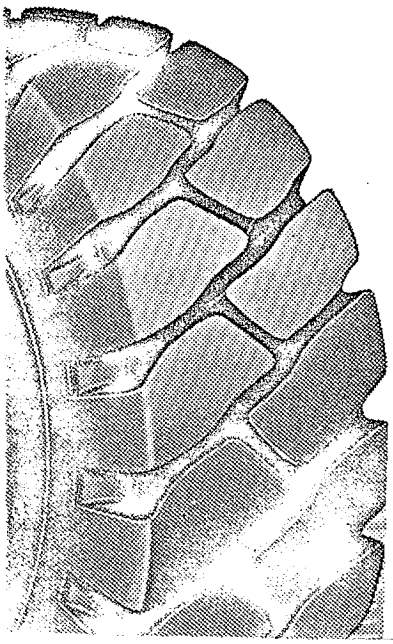
the company in staking the airborne geo-[illegible]nd magneto-

oned its 338 [illegible]rea of British

F. A. M[illegible]
MIN[illegible]
SHAFT S[illegible]
P.O. Box 517

HUDSC[illegible]
DEVEL[illegible]
The
Prope
Fiel
2
800 - [illegible]

[illegible] the large[illegible]
[illegible]mpany in [illegible]



(Continued from Page Seventeen)

territory measures millions of square miles.

It is true that if the main emphasis is concentrated on searching for primary deposits in conglomerates, the task is simplified to some degree. (Of particular interest are Precambrian conglomerates — pebble beds cemented by quartz, sericite and pyrite. It is in pyrite that the gold is contained.)

Conglomerate Areas

Seven large great conglomerate deposits are known throughout the world — three in Africa, one each in Canada, Brazil, Australia and several small points in Finland.

A band of Precambrian rocks fringes the Siberian Platform in a gigantic arc. It is within this arc that must be identified regions with increased radioactivity.

Well, suppose we did identify these regions and even estimated their gold tenor. What are we to do, now that we found that the area of a region with slightly higher radiation is 300 miles wide and 400 miles long. Where should one look for gold in so great an area? Where is the auriferous zone? Where should be put down a drill hole? Where should we sink a shaft?

The time when the geologist simply roamed the land with his haversack and with hammer are gone. Now one can no longer just walk about waiting to stumble upon something of value. Everything that lay on the surface has been found. Now the task is to find what is hidden deep in the interior of the earth. All over the Soviet Union more than 100 thousand certified geologists are searching for minerals. What a wealth of observations, what an ocean of facts. How should they be brought together and systematized?

Duplicate Conditions

Geologists believe that the formation of similar identical economic minerals all over the earth obeyed the same laws. If the geological map of an oil-bearing area of Canada and the geological map of an area in Siberia do not differ from each other, this means that geologists have reason to assume that the given Siberian region contains oil. But what yardstick should be applied for comparing two or more regions?

A major discovery based on the search for analogies in the historical development of two regions was made in 1934 by Academician V. S. Sobolev and A. P. Burov. Studying the trapp magmatism of Siberia and comparing it with the trapp magmatism of Africa, they concluded that the two regions had a similar geological history. In Africa this region produces diamonds from kimberlite pipes; therefore, diamond-bearing kimberlite pipes should be found in Siberia, too. They outlined areas promising for the occurrence of diamond. Fifteen years later their forecast came true.

Formula Devised

The method of comparison, though very effective, at present is beyond the powers of the human brain. Too great is the amount of information that must be processed. It would take man more than a single lifetime to do that since this involves billions of mathematical operations to choose the only correct way.

At the Siberian Branch of the Academy of Sciences this problem was attacked by a team of scientists of different specialities: F. Krendelev, Cand. of Geological and Mineralog. Sc., Y. Zhuravlev, Dr. of Mathematics, geophysicist V. Bobrov and junior scientist A. Dmitriev.

They succeeded in developing an original method for applying an electronic computer to the search for economic minerals by computing the relative importance of various geological features and the yardsticks for comparing various districts on the basis of study of geological maps. This was achieved by feeding coded information into the computer and applying discrete mathematical methods.

The task attacked by the Siberian scientists was to outline within the U.S.S.R. regions likely to contain a major gold deposit, one that would make it possible to create a real gold industry, a real "gold city" at the place of the discovery.

In the Soviet Union such a deposit is most likely to be found in conglomerates and this is what the Siberian team is trying to do.

Favorable Rocks Found

"Considering that in South Africa placers yielded 50 tons of gold, while the conglomerates of the same province contain about 50,000 tons of gold," says geologist Krendelev, "and assuming the same ratio holds true for Siberia (which has been amply demonstrated in the works of the Central Geological Research Institute), the gold reserves of the primary deposits of Siberia may be expected to run into still higher figures."

Using methods of discrete mathematics, Siberian scientists give the computer the assignment of identifying the geological features characteristic of gold deposits. Altogether such features number about 250.

To accomplish this task the computer has to perform a billion operations.

The use of discrete mathematical methods in the search for gold deposits is no longer confined to pure theorizing. Using the electronic computer, scientists at the Siberian Branch of the Academy identified the most interesting spots on the geological map of Siberia and went to look for ore at points indicated by the electronic prompter.

They checked their method in two regions. So far the first chunks of conglomerates have been found. They do not look like anything found in Siberia ever before, but compared with the African conglomerates they are as similar as peas in a pod.

Endako

(Continued from Page Seventeen)

For the six months to June 30, the company had an estimated net profit of $5,827,000, equal to 75¢ per share. In the six months of the company's last fiscal year (ended Oct. 31, 1966), the company reported a net profit of $5,414,000, or 70¢ a share. The company changed its fiscal year from Apr. 30 to Dec. 31.

Operating Statistics

	Second Quarter	First Six Months
Tons milled	1,606,000	3,139,000
Grade, % MoS	0.220	0.227
Recovery, %	81.58	81.93
Production, lbs.:		
Molybdenite	2,360,130	4,846,980
Molybdic Oxide	1,086,936	2,109,435
Estimated net profit	$2,645,000	$6,753,000
Net per share	34¢	75¢

Mogul Gets Oregon Group

Consolidated Mogul Mines has acquired, through a subsidiary, Harlow Wright Inc., a lease on a nickel prospect in Josephine and Curry Counties, Oregon. Mogul has paid $US50,955 for the lease which is [illegible]

DEPEND on DART UNIONS

TWO BRONZE SEATS, GROUND

The geochemical survey [illegible]erty, recommended by Dr. [illegible] consulting geologist, is [illegible] smoothly, Mr. Tait advises. [illegible] soil samples have been [illegible] field laboratory, and [illegible] are being mapped as drill [illegible]ing should begin this mon[illegible]

Several major companies [illegible] staking in the area.

Capri Plans More [illegible] On Geraldton Ar[illegible]

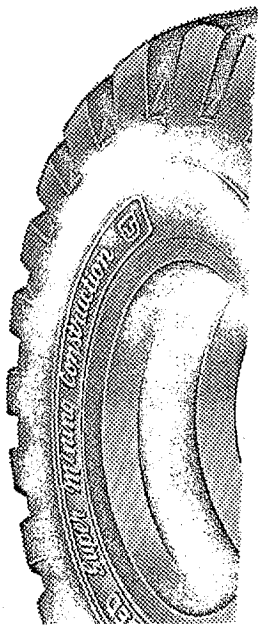
Capri Mining Corp. plan[illegible] exploration of its 500-c[illegible] northwest of Geraldton, in [illegible] Lac area, Northwestern On[illegible]

Geochemical and electro[illegible]veys have been recommende[illegible] limited amount of diamond [illegible]

During the past year [illegible] spent approximately $55,000 [illegible] claims, and in conducting a [illegible] physical survey, and a gr[illegible] meter survey.

The company has aban[illegible] claims in the Brenda Lake [illegible] Columbia.

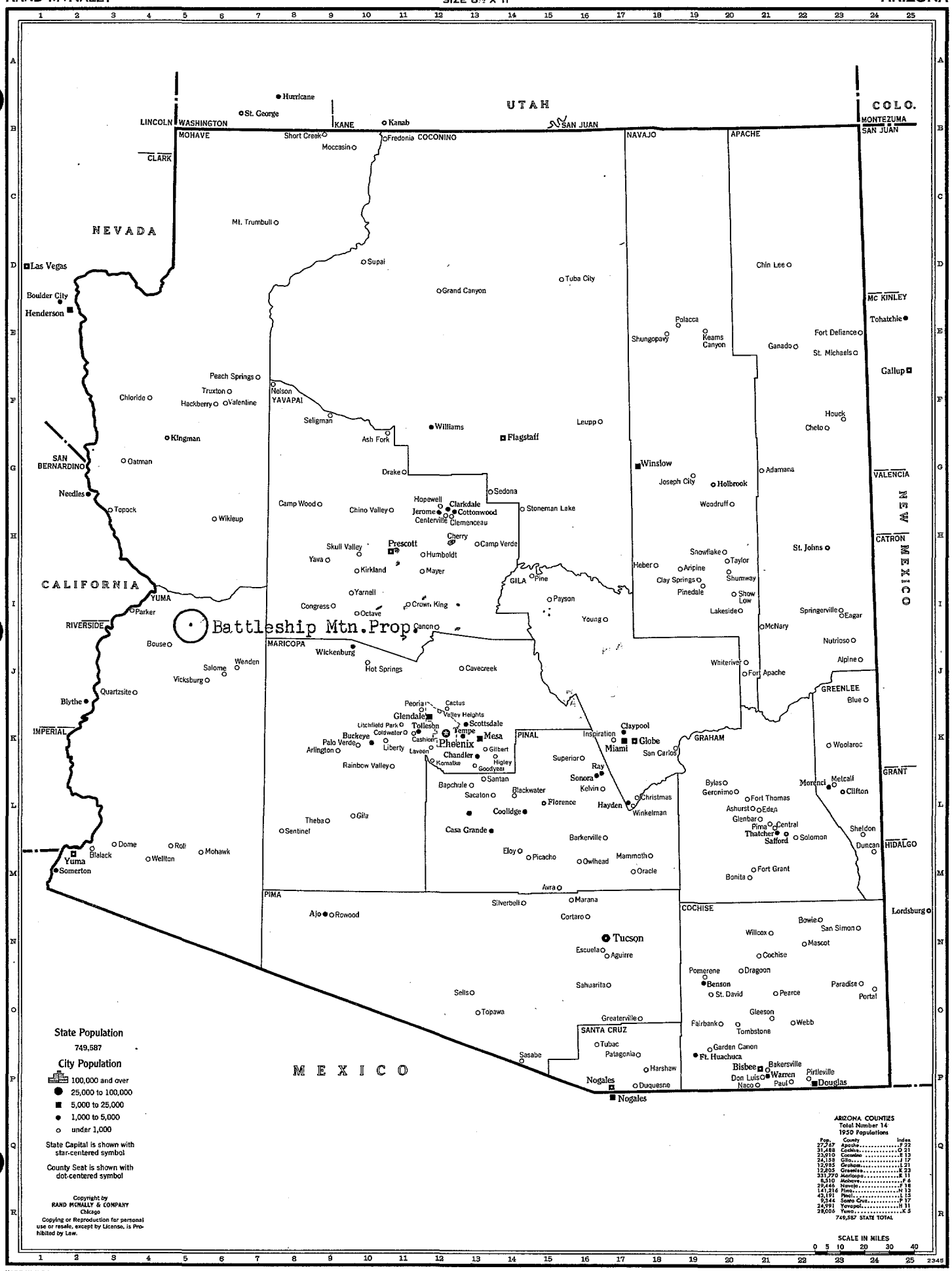
We ar[illegible]
tire co[illegible]



Check Precambrian gold production areas of Arizona — their possible projection under cover.

Check the extent of late Precambrian conglomerate development

Check the drainage trends et al.


UTAH
COLO.
NEVADA
CALIFORNIA
NEW MEXICO
MEXICO
LINCOLN
WASHINGTON
KANE
SAN JUAN
MONTEZUMA
MOHAVE
COCONINO
NAVAJO
APACHE
CLARK
MC KINLEY
YAVAPAI
SAN BERNARDINO
VALENCIA
CATRON
YUMA
RIVERSIDE
MARICOPA
PINAL
GRAHAM
GREENLEE
IMPERIAL
GRANT
HIDALGO
PIMA
COCHISE
SANTA CRUZ
Hurricane
St. George
Kanab
Short Creek
Moccasin
Fredonia
Mt. Trumbull
Las Vegas
Boulder City
Henderson
Supai
Grand Canyon
Tuba City
Chin Lee
Polacca
Shungopavy
Keams Canyon
Tohatchie
Fort Defiance
Ganado
St. Michaels
Gallup
Peach Springs
Truxton
Hackberry
Valentine
Chloride
Nelson
Seligman
Ash Fork
Williams
Flagstaff
Leupp
Houck
Cheto
Kingman
Oatman
Needles
Topock
Wikieup
Drake
Sedona
Winslow
Joseph City
Holbrook
Adamana
Woodruff
Camp Wood
Chino Valley
Hopewell
Jerome
Clarkdale
Cottonwood
Centerville
Clemenceau
Stoneman Lake
Cherry
Camp Verde
Skull Valley
Prescott
Humboldt
Yava
Kirkland
Mayer
Snowflake
Taylor
St. Johns
Heber
Aripine
Clay Springs
Shumway
Pinedale
Show Low
Lakeside
GILA
Pine
Payson
Yarnell
Congress
Crown King
Octave
Young
Springerville
Eagar
McNary
Parker
Bouse
Battleship Mtn. Prop.
Canon
Nutrioso
Alpine
Wickenburg
Hot Springs
Cavecreek
Whiteriver
Fort Apache
Salome
Wenden
Vicksburg
Quartzsite
Blue
Blythe
Peoria
Cactus
Glendale
Valley Heights
Litchfield Park
Tolleson
Scottsdale
Buckeye
Coldwater
Tempe
Mesa
Palo Verde
Liberty
Cashion
Phoenix
Arlington
Laveen
Gilbert
Chandler
Komatke
Higley
Goodyear
Rainbow Valley
Santan
Bapchule
Sacaton
Blackwater
Coolidge
Florence
Casa Grande
Superior
Ray
Sonora
Kelvin
Inspiration
Claypool
Globe
Miami
San Carlos
Hayden
Christmas
Winkelman
Woolaroc
Bylas
Geronimo
Fort Thomas
Ashurst
Eden
Glenbar
Pima
Central
Thatcher
Safford
Solomon
Morenci
Metcalf
Clifton
Sheldon
Duncan
Theba
Gila
Sentinel
Dome
Roll
Mohawk
Blaiack
Wellton
Yuma
Somerton
Barkerville
Eloy
Picacho
Owlhead
Mammoth
Oracle
Fort Grant
Bonita
Avra
Silverbell
Marana
Ajo
Rowood
Cortaro
Tucson
Escuela
Aguirre
Sahuarita
Sells
Topawa
Greaterville
Tubac
Patagonia
Sasabe
Harshaw
Nogales
Duquesne
Lordsburg
Bowie
San Simon
Willcox
Mascot
Cochise
Pomerene
Dragoon
Benson
St. David
Pearce
Paradise
Portal
Gleeson
Fairbank
Webb
Tombstone
Garden Canon
Ft. Huachuca
Bisbee
Bakersville
Warren
Pirtleville
Don Luis
Naco
Paul
Douglas
State Population
749,587
City Population
100,000 and over
25,000 to 100,000
5,000 to 25,000
1,000 to 5,000
under 1,000
State Capital is shown with star-centered symbol
County Seat is shown with dot-centered symbol
Copyright by RAND McNALLY & COMPANY Chicago
Copying or Reproduction for personal use or resale, except by License, is Prohibited by Law.
ARIZONA COUNTIES
Total Number 14
1950 Populations
Pop. County Index
27,767 Apache F 22
31,488 Cochise Q 21
23,910 Coconino E 13
24,158 Gila I 17
12,985 Graham J 21
12,805 Greenlee K 23
331,770 Maricopa K 11
8,510 Mohave F 6
39,446 Navajo F 18
141,316 Pima N 13
43,191 Pinal L 13
9,544 Santa Cruz P 17
24,091 Yavapai H 11
28,006 Yuma K 3
749,587 STATE TOTAL
SCALE IN MILES
0 5 10 20 30 40

884-1124
884-1943

(318)

Gold-Silver Production - Districts Table 10, Bull. 171.

			Millions of Au	Ag	Total Cu, Pb, Zn, Pb.
(Estimated)	San Francisco	1863-1951	47.33	2.05	49.91
	Pozo	1895-1939	2.54	8.00	10.53
	Big Bug	1867-1957	17.25	10.84	72.81
	Oro Blanco	1873-1957	2.63	2.80	10.53

Yavapai Co p 19, Bull 137 (Lode).

Ore Res of the Jerome-Bradshaw Mtns quad - Bull 782. (Lindgren).

Precambrian area: Cherry Creek, Bullwhacker, Jerseyville, Rich, Prescott, Yellow Aster or Lehman, and Minnehaha deposits.

Prescott dist - Bullwhacker

Cherry Creek Dist - Groom Creek dist.

A sketch of the geology & ore deposits of the Cherry Creek dist, Econ Geol vol. 1, p. 417-32, 1906 (Reid, J.A.).

Folio 124 by TH Jaggar & C. Palache.

Big Bull 131 - Ashman Hotham (Text), but provide (incl) modern paper & bibl?

Stoyanow: Paleozoic paleogeography GSA Bull., v 53, p. 1255-1282.

Large "hill" of Older PC (Mogollon Qtz) in S part of Paulden Quad. Possible current trap around the hill. Tapeats & Martin lay out on hill.

Uniformitarianism and Ore Genesis

Causam naturalem et assiduam quaerimus, non raram et fortuitam.

(*Playfair*)

C. F. DAVIDSON *

SINCE the days of Hutton, Playfair and Lyell, their doctrine that the present is the key to the past has grown to be the central tenet of the geologist's faith. Reviewing the progress of our science at the 150th anniversary of the Geological Society of London, L. H. Hawkes (1)[3] recently concluded that "on present evidence Lyellian uniformitarianism is applicable to the whole of geological time". In his *Grundprobleme der Geologie* the Russo-German geologist von Bubnoff (2) writes: "Serious investigation of the geological history of the earth is scarcely conceivable without the principle of actualism". Elsewhere H. H. Read (3) has pleaded: "We must cling to this great doctrine of uniformitarianism as long as we possibly can. If we relax, we may easily become anarchic—the deeper geology may pass into the higher lunacy". Nevertheless the doctrine has been attacked many times, and in recent years the assault has been particularly forceful in disputes relating to the origin of certain ore deposits. The purpose of this essay is to explore whether such dissensions from geological orthodoxy are well founded.

The Oldest Rocks

The most ancient rocks yet reported are basic to ultrabasic formations (norites, pyroxenites and peridotites) with ages in the range from 4,000 to 6,500 m.y., dated by the potassium:argon method (4). They occur in the Kola Peninsula, in Northern Karelia, and in the Aldan shield of Siberia; and they possibly represent the nearest approach yet known to the earth's primaeval crust. If we accept the yet undebated arguments advanced in support of the reliability of these determinations, the earth cannot be less than about 6,500 ± 500 m.y. old.

The earliest chapter of our geological record yet deciphered in any detail, however, is the Katarchaean period of some 3,500 m.y. ago represented by formations in the White Sea region of the U.S.S.R., where according to A. A. Polkanov (5) the rocks have the chemical and petrographical composition of normal paragneisses and meta-basalts, together with granites and granite-gneisses, indicating that in these early times "the processes of sedimentation, magmatism, and medium-depth metamorphism were already in operation". The dating of these Katarchaean complexes, again by the potassium: argon method, reflects the time of their high-grade metamorphism. But sedimentary and volcanic rocks almost equally old, and in considerable part free from the complications of granitization and high-grade metamorphism, are now known to be widely developed in Southern Africa. In Swaziland and in the Union of South Africa it is possible to recognize a lengthy succession of sedimentary systems of very great antiquity, the younger of which are so little altered that within living memory they were thought to be probably of Lower Palaeozoic age.

The succession is as follows:

Transvaal System	> 1950 ± 150 m.y.
Ventersdorp System	.. ..
Witwatersrand System (Upper Division)	.. ..
Witwatersrand System (Lower Division) (=Mozaan Series)	> 3070 ± 60 m.y.
Dominion Reef System (=Insuzi Series)	> 3100 m.y.
Swaziland System	> 3440 ± 300 m.y.

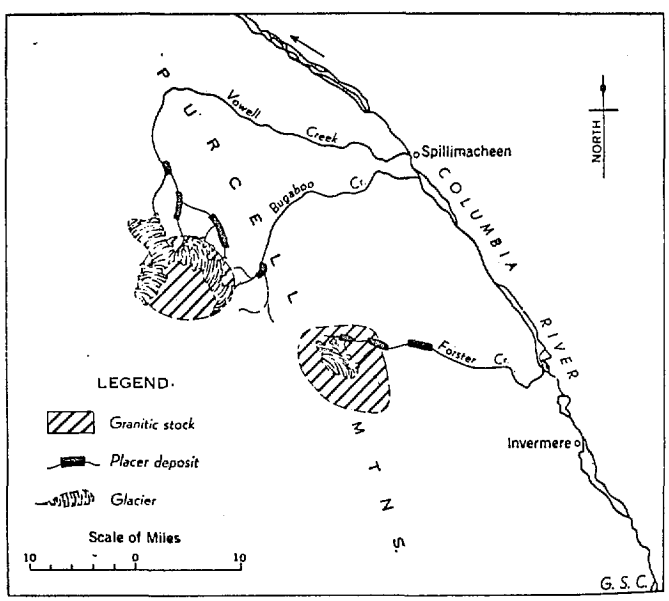


Fig. 1: Alluvial deposits with detrital uraninite are restricted to high-alpine streams draining glacier-capped granitic stocks. Map of Bugaboo Creek uraninite placers, British Columbia. (Geological Survey of Canada, 1963).

* Professor of Geology in the University of St. Andrews.

A lecture delivered at the Twelfth Inter-Universities Geological Conference, Sheffield, 16th. December 1963.

System Ages

The minimum age of the youngest of these systems is given by numerous concordant datings of the post-Transvaal intrusive rocks of the Bushveld Igneous Complex. A granite which intrudes the Mozaan Series of Swaziland, a 10,000-15,000 feet thick group of alternating shales, quartzites and conglomerates which is correlated with the Lower Witwatersrand sediments, has recently been dated by the rubidium:strontium method at 3,070 m.y. (6). These strata are younger than the Insuzi Series of Swaziland, a predominantly volcanic succession of much-altered rhyolites, andesites and volcanic tuffs customarily equated with the petrographically similar Dominion Reef System of the Transvaal (7).

The uraninite mineralization in the basal conglomerates of the Dominion Reef has been firmly dated at 3,100 m.y. (8).

Although this mineralization is demonstrably not syngenetic with the conglomerates, it may have been deposited by groundwaters which derived the uranium and gold by leaching the overlying rhyolites and acid tuffs; and since devitrification of such rocks, with release of uranium, usually occurs relatively soon after extrusion, on this hypothesis the age of the Dominion Reef is unlikely to be much more than that of its uranium ores.

Fig. 2: Primitive mining of these low-grade river placers in the upper Indus valley, West Pakistan, yields gold (about 0.05 ppm) with by-product uraninite (about 2 ppm). Uraninite has not survived in adjacent terrace gravels. (Photo: R. A. Khan Tahirkheli).

Swaziland System

The very old sediments of the ancient Swaziland System are intruded by a granite dated at 3440 ± 300 m.y. (6). The System is made up of the Moodies Series of quartzites and conglomerates, resting uncomformably on the Fig Tree Series of shales, cherts and jaspers, which is underlain by the Onverwacht Series of acid and basic volcanics. Probably there are granitic complexes of more than one age cutting these most ancient sediments and lavas.

This age pattern differs somewhat from that depicted by those South African geologists who accept that the Witwatersrand ores are of alluvial genesis—for example by Nicolaysen (9), whose recently published conclusions were arrived at prior to the critical announcement of the dating of the Mozaan Series. But in some important observations there will be no disagreement. It is clear that in southern Africa there are five or more major stratigraphical systems all over two milliard years old, with a combined thickness totalling at least 70,000 ft. and (the thickness of the Swaziland strata being unknown) probably much exceeding this figure.

In this region where the evidence is best preserved, there is therefore no support for the conclusions reached by some North American authors that the continents were built around a "continental nucleus", and that prior to two milliard years ago orogenesis occurred in some fashion different to that of normal geosynclinal development (10). Support for these views is also lacking in the prolific geochronological studies of the old rocks of the U.S.S.R.

It is also apparent that the sedimentary rocks formed well over three milliard years ago have a curiously modern aspect. In the Moodies Series we find current bedding, ripplemarks, mud-cracks, and rhythmic alternations of lithological types. In the Fig Tree Series of phyllites, greywackes, cherts and banded ironstones J. G. Ramsay (11) has lately found silicified spheroidal structures which closely resemble primitive algae. Manifestly the world's oldest sediments were laid down in water and hence at a temperature above freezing point. They display no obvious indications that the atmosphere when they were formed was markedly different from that of today; and they even exhibit problematical vestiges of life. It is against this background that we must evaluate some of the anactualistic hypotheses lately adduced in discussions on ore genesis.

Problems of Uraniferous Conglomerates

Paradoxically, the most clamant arguments advocating departures from uniformitarianism have originated in the very country, South Africa, where evidence of the principle is now most fully apparent. Disputes about the validity of the actualistic concept have mostly centred upon the great mining field of the Witwatersrand, which has yielded about a third of the world's cumulative production of gold. The rich concentrations of gold occur in occasional seams of quartz-pebble conglomerate known as banket, and in rarer pyrite-rich quartzites, developed in the Dominion Reef, Witwatersrand, Ventersdorp and Transvaal Systems; and the gold is consistently accompanied by uranium which is

present mainly as the mineral uraninite. From some half a million assays it has been demonstrated beyond question that the gold and uranium tend to vary sympathetically, so that whatever origin is claimed for one mineral must be attributed to the other also.

The close stratigraphical control of the banket orebodies has led most South African geologists to the conclusion that initially the gold and uraninite were deposited as alluvial detritus contemporaneously with the quartz pebbles of the mineralized conglomerates, and that later the sediments were modified by metamorphism. Those opposed to the alluvial hypothesis claim that the mineralization is a later, epigenetic, introduction deposited from hydrothermal fluids or from groundwaters.

The widely held belief that the world's greatest ore-field represents a series of gigantic placer deposits, stacked in one province throughout four geological systems with an age-span of a milliard years, has now become untenable within the limits of geological orthodoxy.

Among the many actualistic arguments advanced against this alluvial theory (12,13) there are two of special moment. First, there is irrefutable evidence that uraninite is found extremely rarely in modern placers and that in the few places where it does occur (under arctic or high-alpine conditions) it does not survive lithification; it is rapidly leached away by groundwaters, perhaps in favourable circumstances to be deposited elsewhere. Second, it is demonstrable by chemical analysis that the auriferous reefs of the Witwatersrand System are devoid of any greater concentration of common heavy minerals such as ilmenite, zircon, rutile and monazite than is found in the average sandstone. (The TiO_2 content in bulk samples of these bankets ranges 0·02-0·35 per cent and ZrO_2 0·04-0·05 per cent; analyses of more than 400 samples of the sandstones of the Russian platform (38), from Sinian to Recent in age, composited from over 6,000 specimens, show TiO_2 0·50 per cent average, 0·15-0·67 per cent range, and ZrO_2 0·08 per cent average, 0·01-0·11 per cent range.) The alluvial hypothesis thus demands the hydraulic concentration of gold and uraninite particles without any concomitant accumulation of those refractory heavy minerals which are ubiquitous in clastic sediments and which are widespread in the basement rocks whence the gold and uraninite were notionally derived. This requirement is plainly a physical absurdity.

Precambrian Ice Ages

To combat these arguments, geologists of the placerist school have of necessity postulated various departures from uniformitarianism, namely that (a) early Precambrian temperatures were very low, and the deposits accumulated under Ice Age conditions; and that either (b) the early Precambrian atmosphere contained no oxygen but was a reducing environment, or (c) the early Precambrian atmosphere was dominantly carbon dioxide.

The hypothesis that the mineralogical idiosyncrasies of the banket ores can be accounted for by their accumulation in an Ice Age environment has been advanced by many authors,

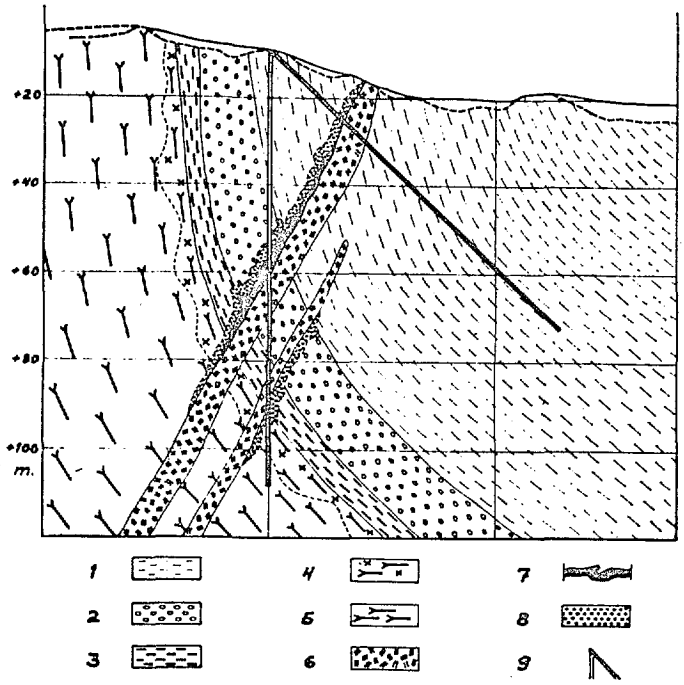


Fig. 3: The distribution of uraninite in the Proterozoic bankets of Paukkajanvaara in Finland is controlled by diabase dykes. 1, orthoquartzite; 2, conglomerate; 3, mica-quartz schist; 4, mica gneiss; 5, gneissose granite; 6, diabase; 7, uranium ore; 8, sub-ore mineralization; 9, drill hole. (Geological Survey of Finland, 1959).

all stimulated by the knowledge that today detrital uraninite is found only in deposits of alpine or arctic provenance. Conversely, other writers have accepted the bankets as fossil placers and have interpreted their peculiar mineralogy as an indication that early Precambrian times were characterized by near-zero temperatures. Circular arguments of this kind rigorously eschew any appeal to other geological evidence. It is well known that reputed tillites and other glacial sediments occur at numerous horizons in Precambrian strata, although lately the origin of many such deposits has been much disputed. A full review has just been published by Cahen (14).

On viewing all these observations within the framework of a radiometric time scale, however, it is apparent that the periodic incidence of Ice Ages was no greater in Precambrian times than within the Phanerozoic eras. One problematical tillite does occur within the Witwatersrand System, but it is not mineralized; and the mineralized conglomerates, which are characteristically oligomictic, are the petrographic antithesis of typical glacial sediments in that the latter are highly polymictic. A glacial origin does not help in any way to explain the abnormally low titanium:iron and thorium: uranium ratios of the auriferous reefs. Further, in these few Recent alpine alluvials in which detrital uraninite is found today, it can be shown that the mineral does not survive early diagenesis; and the mobility of uranium in glacial groundwater is also attested by the adsorbed radioactivity of mammoth remains found in Pleistocene permafrost gravels (13). There is therefore no support whatever, either from the lithological study of the oldest sediments or from investigations of ancient ore deposits, for the frequently advanced postulate of very low temperatures in the earliest geological times.

The Precambrian Atmosphere

A second anactualistic concept arising from studies of the banket mineralization is found in the hypothesis that these ores were formed prior to the development of atmospheric oxygen, when the earth still retained its primaeval reducing envelope. This departure from uniformitarianism was initially proposed to account for the presence of abundant pyrite in the gold-uranium ores, part of the pyrite being claimed by placerists to be unoxidized detrital debris. More recently Rutten (15) and Holland (16) have accepted the claims that these ores are alluvial deposits and, by *petitio principii*, have deduced that a transition from a reducing to an oxidizing atmosphere occurred somewhere between one and two milliard years ago. The hypotheses that the bankets are fossil placer deposits and that an anoxidizing atmosphere persisted more than half-way through geological time have thus become affectionately embraced in mutual support, each unable to stand on its own feet.

From the abundance of methane, hydrogen, carbon dioxide and carbon monoxide both in the gases contained in meteorites and in the gases encountered in mines where the mineralized host rocks are of mantle origin—diamond mines in kimberlite, apatite mines in carbonatite, and platinum mines in dunite (17)—it is a reasonable deduction that the earth's earliest atmosphere, derived from degasification of the mantle, was indeed of a reducing character; and it is of course important to establish at what stage in its history the earth lost this reducing envelope and acquired an oxidizing one. The deductions in this connexion based on the composition of the Witwatersrand bankets are however manifestly fallacious.

A reducing atmosphere would not make quartz pebbles any softer, or uraninite grains any less prone to attrition. It does not explain how uraninite, pyrite, sulphides and gold can become concentrated as heavy detrital minerals without any accompanying accumulation of the ilmenite, rutile, zircon and monazite which abound in black-sand concentrates from Archaean rocks and which are locally found as true alluvial enrichments in otherwise barren strata of Witwatersrand age. Further, in a great many early Precambrian formations from the very old Fig Tree Series of Swaziland onwards we find large deposits of stratified haematite-magnetite ores which have as good a claim to be regarded as sedimentary as the bankets; and since these all possess a ratio of ferric to ferrous iron much greater than is found in the average igneous rock or the average basalt, we cannot but deduce that they must have been formed either in oxygenated sea waters or in oxygenated ground waters, thus reflecting an oxygenated atmosphere at the time of their constitution.

Earliest Organisms

If therefore we accept the conclusion of some biochemists that living organisms first originated in a reducing atmospheric environment, we can deduce quite firmly from the geological evidence that life began before the earliest known sedimentary rocks of the earth's crust came into being about $3\frac{1}{2}$ milliard years ago, and that the primaeval reducing atmosphere was lost in still earlier, protogeological, times.

The notional carbon dioxide atmosphere proposed by yet other authorities (18) for early Proterozoic and Archaean times likewise fails to explain the mineralogy of the bankets, since in such an environment detrital uraninite would become quickly transformed to one or other of the many uranium carbonates. The only argued support for this hypothesis comes from workers who call upon a very much increased pressure of carbon dioxide in early eras to explain the more widespread development of dolomite in the older formations. (A carbon dioxide pressure of four atmospheres is required before dolomite will precipitate from water saturated with magnesium and calcium carbonates). Such arguments become irrelevant immediately it is recognized that dolomite is a metasomatic rock and that by virtue of their age the older limestone formations have become more subject to reaction with magnesium chloride brines.

That there was no significantly higher tenor of carbon dioxide in the Precambrian atmosphere is indicated (a) by the absence of a higher proportion of carbonate rocks among the oldest sediments; (b) by the geological evidence for occasional Precambrian ice ages—incompatible with an increase in carbon dioxide which would exercise a "greenhouse effect" and blanket in the radiation from the sun; and (c) by the existence of major deposits of organogenic phosphorites in old Archaean formations of the U.S.S.R. and China, the formation of such deposits being incompatible with any important increase in the partial pressure of carbon dioxide in sea water (19). One of these phosphate deposits, at Slyudyanka in the Lake Baikal region, is succeeded by between 10 and 20 kilometres thickness of Precambrian strata (20), and is obviously of great age.

Other Ancient Conglomerates

A more general argument adduced in favour of unspecified anactualistic conditions in so-called "Proterozoic" times rests upon the postulate that since these ancient uraniferous conglomerates are not paralleled among younger formations, they cannot have been formed by uniformitarian processes. In considering this claim it must be borne in mind that by no means all the ancient deposits are gold-uranium-pyrite assemblages like those of the Witwatersrand. The important bankets of Mounana in Gabon are uranium-vanadium-pyrite associations which, geochemically considered, are paralleled precisely by the ores in the Mesozoic and Tertiary sediments of the western United States, the latter forming the greatest uranium field in the world. Conglomerates and quartzites with uraninite, pyrite and small amounts of polymetallic sulphides are now well known in Variscan and Alpine ore-fields in Europe, though none is of much economic importance. A significant example has been described from Czechoslovakia (21).

Against this background, the relative magnitude of the uraniferous and auriferous banket resources of the Precambrian is therefore seen to be no more than a reflexion of the relative importance of other gold and uranium deposits in Precambrian rocks, explainable not by anactualistic conditions but by the more intensive metamorphism, migmatitization, and metasomatism which these ancient formations have undergone.

☐ *Uniformitarianism*

It can therefore be concluded that the anket ore deposits do not represent heavy-mineral concentrations of alluvial origin and that they furnish no evidence of departures from uniformitarian conditions. The corollary, that the metals have been introduced from groundwaters or other solutions, has lately been substantiated (22), showing that there is locally a causal relationship between structural fold features and intensity of mineralization. The ore deposition did not pre-date the folding and so must be of epigenetic origin.

How?

History of Evaporites

The first major evaporite deposits known in the stratigraphical succession are of Lower Cambrian age. Their greatest development occurs amid the undeformed sediments of the Siberian platform, to the north of Irkutsk, where locally a thickness of as much as 900 metres of rock-salt, together with potassium salts, is found in association with anhydrite and dolomite (23). In depth (2 km.) they give rise to dense intra-atal brines. Lower Cambrian evaporites of great thickness are also encountered at many other places in Asiatic Russia, in the Salt Range of Western Pakistan, and in Iran; and thereafter salt deposits are to be found somewhere or other in every period of Phanerozoic geological history. Throughout the vast territories of the U.S.S.R. the only system devoid of substantial evaporites is the Triassic, in contradistinction to Western Europe where large deposits are of Triassic age.

Only a few Precambrian occurrences of evaporites are on record, and these are all of quite minor significance. Pseudomorphs of salt crystals are found in the Sinian sandstones of the Aldan shield of Siberia and in the Beltian of North America, but apparently there are no recorded chloride or sulphate deposits of this age.

Many thin beds and lenses of anhydrite and gypsum are however to be seen in the Mines Series of Northern Rhodesia, which is older than 750 m.y., and in the contemporary copper deposits of Niari in Bas Congo; and small amounts of anhydrite have been found in the arkoses of the Lomagundi System of Southern odesia, probably of the same age. In the Grenville metasediments of New York State, metamorphosed around 1,000 m.y. ago, occasional bands of gypsum-anhydrite are interbedded with the marbles, which are also cut by veinlets of gypsum and halite.

All told, however, evaporite minerals are very rare in Precambrian formations, and we must therefore ask ourselves whether this reflects an anactualistic composition of the Precambrian seas.

History of Sea Water

The geological history of sea water has been discussed in an outstanding address by W. W. Rubey (24), who was probably the first to point out that, if the parts of the earth's crust which came into being in geological time are comparable in composition to the earlier proto-geological crustal formations (an assumption there is little reason to doubt), then although the cations of the salts dissolved in sea water have most probably been derived by the destruction of the rocks of the lithosphere, the chief anions (Cl', SO_4'', Br', etc.) cannot be in the main part the product of rock weathering since they are present in the ocean in an amount equal to or greater than the amount in the earth's crust as a whole.

The primary source of much of the anion content is to be found in the fumaroles, soffioni, and other exhalations of volcanic districts which every year bring vast tonnages of these elements to groundwaters and to the surface, derived ultimately from the degasification of the earth's mantle; and since the quantitative ratio of the anions in sea water bears a striking resemblance to the ratio of the same elements in volcanic gases, it is a reasonable deduction that the nature of volcanic activity has not changed with geological time.

The ratio of the mass of water in the hydrosphere ($0 \cdot 141 \times 10^{25}$g) to that of silica in the crust ($1 \cdot 32 \times 10^{25}$g) is about 1:10, and the average silica content of the crust is about 55 per cent. If, therefore, it is accepted that throughout geological time the average volcano has emitted about 5-6 per cent as much juvenile steam by weight as it has lava (at Paricutin the ratio was 16 per cent!) we can deduce that the size of the oceans has grown *pari passu* with the volume of the crust, and that there has been no progressive change in the composition of sea water throughout the earth's history.

A recent detailed discussion by D. A. Livingstone (25) comes to the general conclusion that the ocean should be regarded as a long-term steady-state system, with the intake of sodium from rivers balancing the loss of sodium as marine deposits are uplifted to form dry land. It is significant that the early Cambrian evaporites found on the stable platform of Siberia present a geochemical assemblage with dolomite, gypsum or anhydrite, halite and potassium salts which is quite modern in aspect.

On this reasoning the rarity of Precambrian evaporites cannot be attributed to a low salinity of the ancient oceans —even a brackish water will give salt deposits on evaporation—but is rather to be explained by the high solubility of these salts which makes them peculiarly liable to removal by intra-stratal leaching during the orogenic movements and metamorphism to which all Precambrian formations have been subjected.

As a corollary to this conclusion, it may be suggested that ore deposits in Precambrian rocks are less subject to intra-stratal reworking (solution, movement, and redeposition) than are those in younger formations, since (as shown later) there is reason to believe that such multiple migrations often take place by the agency of groundwater brines.

Significance of Laterites

The stratigraphical distribution of laterites and bauxites merits a brief comment. The earliest known bauxite deposits definitely identifiable with a lateritic crust of weathering are in the northern Onega district in the U.S.S.R., to the west of the White Sea (26). Here two zones rich in haematite and gibbsite, each several metres thick, have been located by recent diamond drilling work, and on apparently good stratigraphical evidence they are interpreted as laterites respectively of Upper Devonian and Lower Carboniferous age. The first development of lateritic ores can therefore be equated with the first invasion of the land by a forest flora, a coincidence which lends weight to the commonly held view that organic processes play an essential part in lateritization.

Bauxite deposits of potential economic significance are however on record from several earlier periods of earth history (26). In the Eastern Sayansk region of the Buryat Republic, a thick horizon of bauxite containing 25-35 per cent diaspore + boehmite is developed at a disconformity in dolomite between (?) uppermost Sinian and Lower Cambrian strata. The ores average about 40 per cent Al_2O_3 (locally reaching 54 per cent), 25 per cent Fe_2O_3 (locally 50-55 per cent), 4-30 per cent SiO_2, $0 \cdot 28$-$1 \cdot 80$ per cent CaO, $0 \cdot 83$-$2 \cdot 23$ per cent MgO, and contain typical trace elements for bauxite—P_2O_5 $0 \cdot 40$ per cent (average of 117 analyses), Cr_2O_3 $1 \cdot 0$ per cent, TiO_2 $1 \cdot 70$-$2 \cdot 35$ per cent, NiO $0 \cdot 10$ per cent. Similar deposits occur at an Upper Silurian—Lower Devonian discontinuity in the Novosibirsk region of Siberia, and in the Devonian of the Urals.

☐ *Uniformitarianism*

These unusual bauxitic ores, usually interbedded with dolomites, have long been considered to be marine precipitates forming aluminous analogues of oolitic iron ores, the alumina supposedly being derived from the weathering of nearby terrestrial formations under warm, humid, conditions; but the Lower-Middle Devonian deposits worked commercially in the Urals have recently been interpreted as continental, with the bauxite formed sub-aerially on the karst surface of Lower Devonian limestones.

In the descriptions of many such occurrences, however, it is reported that contemporary volcanic activity occurred not far away; and there are therefore grounds for suspecting that in some deposits the metals were supplied by submarine hot springs, the ores being genetically similar to the aluminous and ferruginous precipitates formed extensively today as a result of hot spring activity off the Kurile islands (27).

Quite the most ancient alumina-rich sediment in the geological succession is a deposit worked in a small way as a source of diaspore from the Insuzi Series of Swaziland, over 3,100 m.y. old. The bed of ore, 25 feet in thickness, is interbedded between mica schist and phyllite and consists of diaspore augen (up to 2 ft. across) in a matrix of pyrophyllite, andalusite and quartz (28). The geological history of this interesting meta-sedimentary orebody has not yet been unravelled.

Observations on Iron Ores

The immense volume of stratiform iron ore deposits in Precambrian formations has led many geologists to the view that these ores must have been formed in an environment which is quite without parallel in the seas of today.

No ironstones wholly comparable to the siliceous banded taconites of the Lake Superior region, the itabirites of Brazil, and the comparable oxide-facies iron formations found in all other Precambrian shields are known in the rocks of the Phanerozoic eras; and to explain the presumed simultaneous sedimentation of colloidal silica and iron oxides various authorities have postulated such departures from uniformitarian conditions as the existence of more acid oceanic waters, arising from an increased partial pressure of atmospheric carbon dioxide, from a greater proportional contribution of acid juvenile waters of volcanic origin when the oceans were smaller than they are today, and from more extensive volcanicity in Precambrian times.

Hitherto this problem has not been examined in a geochronological context. The earliest iron formations are the extensive deposits of the Fig Tree Series in Swaziland, dated at > 3,400 m.y. The younger of the two groups of Proterozoic taconites in Minnesota was metamorphosed around 1,600-1,700 m.y. ago, and the rocks are thought to be not much older than this.

The time spread of these ores is therefore roughly the same as that of the pre-Bushveld stratigraphical succession in South Africa, which has been already detailed; and since not as much as a fifth of this succession is made up of volcanic rocks, the hypothesis of more extensive volcanicity in Precambrian times is demonstrably unsound. The invalidity of the two other postulates has already been proven. Some other genetic interpretation of the Precambrian ironstones must therefore be found.

In this same geochronological context it is noteworthy that the bedded iron ores in the Pretoria Series (Transvaal System) of South Africa, which is at least 2,000 m.y. old, are principally haematite or magnetite chamosite oolites akin to the Ordovician Wabana ores of Newfoundland and to many later sedimentary formations.

Since these South African deposits are some 300-400 m.y. older than the siliceous taconite ores of the Lake Superior province, the mineralogy of the latter can scarcely be attributed to anactualistic conditions persisting at the time they were formed. Among other Proterozoic ironstones of Phanerozoic aspect may be mentioned the sideritic greenalite oolites of the Northern Territory of Australia (29).

The youngest ores of this kind are the very large fresh-water Oligocene deposits of Lisakovsk in Kazakhstan and marine Miocene deposits of the Kerch peninsula. The absence of modern analogues points to the diagenetic origin of the iron silicates.

Genesis of Ironstones

A cursory review of the immense literature on Precambrian iron ores leaves the overall impression that where there has been little regional metamorphism and where the beds are not strongly folded, the ironstones do not differ much from more modern sediments; but a much greater variety of ore types, mostly dissimilar from known sedimentary facies, is developed under more advanced tectonic and metasomatic conditions. In the huge ore fields of Krivoi Rog and the Kursk Magnetic Anomaly, which are more fully documented than any other deposits, the range of ore types—sedimentary, metasomatic, regional and contact metamorphic, and pyrometasomatic—is very great indeed.

Many rich haematitic ores are attributable to deep surface oxidation during former periods of weathering (though the primary "unoxidized" magnetitic quartzites of the K.M.A. average around 38 per cent Fe_2O_3, 14 per cent FeO, indicating an oxidizing environment at the time of their formation); but other changes seem to be due to migration of iron during orogenic events, often linked with granitization and doming in the underlying basements. A recent study of the Brazilian fields (30) concludes that "the high-grade haematites were formed by metasomatic replacement of siliceous and, to a minor extent, dolomitic itabirite by haematite mobilized from the iron formation as a whole by fluids . . . of hypogene origin, probably genetically related to the granitic gneiss. The replacement took place during the metamorphic epoch at elevated pressures and temperatures".

Evidence of the existence of hypogene ferruginous fluids in much more recent times is to be found in the many large siderite-ankerite ore deposits of Alpine age formed by metasomatic replacement of limestone and dolomite, some of which are mined extensively at Eisenerz in the Austrian Alps, at Rudnany in the Western Carpathians, at Djerissa in the Tunisian Atlas, and elsewhere.

Ferruginous Brines

The nature and origin of the metasomes which gave rise to such ore deposits are unknown; but since the transformation of limestone to dolomite and, exceptionally, to magnesite is generally accepted as having been brought about by the agency of magnesium chloride brines, it is reasonable to conclude that the metasomatism of limestone and dolomite into sideritic-ankeritic ores has resulted similarly from reaction with ferruginous brines. It may be suggested that these iron-rich solutions originate under orogenic conditions by base-exchange reactions between hot intra-stratal brines derived from the solution of evaporites on the one hand, and bedded iron ores of sedimentary or in some cases of exhalative origin on the other. On this explanation the emplacement of the mineralization may be related in time and place to granitization in depth without there being any direct genetic derivation from granitization.

To be concluded

Uniformitarianism and Ore Genesis

Causam naturalem et assiduam quaerimus, non raram et fortuitam.

(*Playfair*)

C. F. DAVIDSON *

Very large Proterozoic siderite deposits of this kind, developed as metasomatic replacements of dolomite, exist in the Bakal'sk field on the western slopes of the Southern Urals (31). It may well be that, in more siliceous environments, much of the reworking and mobilization of the iron in the great Proterozoic ironstone fields has occurred through the agency of heated groundwater brines.

This concept is of interest in relation to one remarkable metallogenetic feature of some Proterozoic banded ironstones—namely, the occurrence in these ore deposits of noteworthy concentrations of gold. Gold has been worked extensively both from the itabirite ores of Brazil and from the jasper bars of West Australia; and although the highest concentrations are found in haematite-rich zones of secondary enrichment, there can be no doubt (despite the lack of analyses) that gold is present in geochemically significant amounts in the parent rocks whence these supergene enrichments were derived.

One of the best natural solvents for gold is ferric chloride; and concentrations of the metal could thus be brought about wherever hot ferruginous brines have permeated feebly auriferous country-rocks. The banket ores of Ghana, where the gold-bearing conglomerates are very rich in haematite, are possibly explainable in a similar manner.

Exhalative Iron Ores

In recent years much prominence has been given to the hypothesis that many sulphide ore deposits of a strata-bound or pene-concordant habit have originated from the metalliferous exhalations of submarine volcanoes, notionally discharged into the sea by magmatic or fumarolic activity on the ocean floor, and quickly precipitated to form sedimentary ores nearby. Detailed concepts of this kind were first formulated by Schneiderhohn in Germany, both for the bedded haematitic iron ores of the Lahn-Dill region of Hesse, associated with Devonian diabases and keratophyres, and for the polymetallic sulphide ores of Rammelsberg and Meggen where eruptive rocks are less in evidence.

Among other geologists who have expressed comparable genetic views are C. Oftedahl for a great range of metallic deposits in Norway, V. I. Smirnov and associates for strata-bound deposits of lead, zinc and copper in the northern Caucasus and the Altai mountains, and R. L. Stanton for the lead-zinc and copper deposits of Mount Isa in Queensland. Somewhat similar opinions are held by K. C. Dunham, who suggests that hydrothermal springs of deep-seated origin may discharge metals into stagnant environments on the sea floor, so creating bedded orebodies of Kupferschiefer type. The actualistic evidence for these several postulates merits examination.

Present-day exhalative mineral deposits of marine deposition appear to be restricted to ores of iron and aluminium, the best examples of which are to be seen in the volcanic province of the Kurile islands (27). Here a number of small streams fed by acid fumaroles precipitate iron hydroxides either along their inland watercourses if the acidity is moderate (pH 4-5·5) or on mingling with sea water if their acidity is very high (pH 1-2). Thus the rivulet Yur'yeva arising from Ekebo volcano on Naramushir island, which debouches into the Okhotsk sea with a volume of 1·8 cubic metres per second and pH 1·72, daily brings 35 tons of iron and 65 tons of aluminium to the ocean waters; and at its mouth iron and aluminium hydroxides form a belt of thick yellow mud stretching seawards for three kilometres, with an average breadth of 300 metres and a depth of 2 metres.

Many smaller rivulets of the same kind are on record from the Kurile province, sometimes exhibiting a partition of hydrated ferric and aluminium sesquioxides developed with rising pH values. It is conceivable that phenomena of this kind could give rise not only to haematite and bauxite deposits but also, where the precipitates accumulated under sulphureous bottom conditions, to deposits of pyrite. Nevertheless it seems highly significant that in the Lahn-Dill ores the content of alumina is consistently very much lower than that of silica (Al_2O_3, average of 26 analyses, 4·14 per cent; SiO_2, average of 41 analyses, 16·77 per cent: exclusive of insoluble residue.). There is thus no free alumina as is found in the products of modern emanations, suggesting that in this instance the actualistic analogy may be invalid. This difference is not commented upon in a recent extensive study of the literature on this field (32). The iron ores may not have originated syngenetically with the lavas, as generally supposed, but may have been derived from them through their later lixiviation by hot saline brines. The sodic character of the host rocks (keratophyres and spilitic diabases) is in keeping with this explanation.

Polymetallic Ores

The polymetallic ores claimed to be of exhalative sedimentary origin are quite unparalleled in modern lava fields. It is true that specimens of copper, zinc and lead-silver minerals are to be found in many volcanic provinces; but to accept these selected specimens as quantitatively representative samples is repugnant to the most elementary principle of economic geology.

This is demonstrable, for lead and silver, by reference to the fumarolic products of the andesitic and basaltic volcanoes of Kamchatka (33). "From this extensive field eight different species of lead minerals have been recorded—perhaps more than from any other volcanic region. In examination of representative samples of the fumarolic products, however, silver was found in spectroscopic traces in only 6 sublimates

* Concluded from the March issue, page 185

out of 60 examined (in 5 of these only as weak traces) and is absent from 30 efflorescences and mofette deposits. Spectroscopic traces of lead were found in 21 samples out of 90, in all but two cases only as weak or very weak lines.

Where the metals are found (in these trace amounts) they are in association with chlorides and fluorides, and they are absent from solfataric phases. On actualistic grounds there is clearly no basis whatever for supposing that submarine volcanic exhalations can give rise to high concentrations of lead or silver on the sea floor" (34).

The inadequacies of the exhalative-sedimentary hypothesis as an explanation of the origin of strata-bound polymetallic ore deposits are accentuated if not only the pay minerals but also their gangues are considered. The type pene-concordant orebodies of Meggen and Rammelsberg contain vast quantities of barite; and in their geochemical make-up (high Ba with Pb, Zn, Cu) they are comparable to some of the largest barite deposits in the world, such as the pene-concordant bodies of Walton in Nova Scotia and Buchans in Newfoundland. Barium, however, is one of the rarest cations in volcanic emanations, because of the high insolubility of its sulphate; and to attribute a volcanic origin to the barium in these deposits is therefore absurd. By extrapolation, this becomes equally absurd for the associated polymetals.

A telling analogy may be drawn with the pene-concordant barite deposits which epigenetically replace bedded cherts and limestones of Palaeozoic age in the western United States (35). As noted later, a non-volcanic source of the barium may readily be envisaged.

Origin of Barite Gangues

Valuable evidence on the origin of such barium-rich fluids has been contributed by K. C. Dunham (36), who has drawn attention to the widespread presence of brines containing up to 2,676 p.p.m. of barium chloride, at depths below −1,000 ft. O.D., in parts of the Durham coalfield. Dunham interprets these brines as pockets of "fossil" hydrothermal waters which have been trapped since the Permo-Carboniferous epoch of mineralization. But such hydrothermal (*i.e.* hot water) fluids are not necessarily of juvenile (*i.e.* magmatic) origin, nor are they necessarily of Hercynian age.

In the diagenesis of evaporite deposits barium is released to local groundwaters on the anhydritization of gypsum and again on the secondary gypsification of anhydrite, in each case part of the trace elements present being rejected on recrystallization of the mineral; and a source of the barium brines of the Durham coal mines may therefore reasonably be sought in diagenetic processes occurring in the thick evaporite beds of Zechstein age nearby.

The correctness of this assumption seems to be borne out by experience in a coal mine near Essen-Borbeck in Germany, in which a vein of lead ore is invaded by warm saline water from a spring in the neighbouring Zechstein strata, the salt water containing as much as 6,200 p.p.m. of barium chloride (37).

Fig. 4: High-grade uranium ore (black, above group of men) in Eocene sands at the Petrotonics mine, Shirley Basin, Wyoming has been introduced by groundwater solutions.

It may be assumed that such waters have been encountered in coal mines solely because the latter have provided adequate accessibility for sampling: they may be much commoner in Phanerozoic rocks than is generally realized.

Authigenic Barite

In continental strata authigenic barite (often forming the cement of sandstones) is well known to be much more widespread than in rocks of marine deposition; and this may readily be accounted for if we recognize that evaporites characterize continental environments, and that the groundwaters of arid zones are more saline than those of humid regions as a result of the lixiviation and diagenesis of salt deposits.

In a recent study of the sandstones of the Russian platform, based upon the analysis of 460 composite samples of more than 6,300 specimens, it has been found that barite is ten times more abundant in strata deposited under arid conditions than in those of humid or glacial origin—0·38 per cent Ba compared to 0·03 per cent and 0·04 (38). It has also been shown recently that in the diagenesis of the modern evaporite deposits of Lake Eyre in South Australia, both barium and strontium, present normally in amounts less than 300 and 500 p.p.m. respectively, may build up into zones from one to six feet thick containing one per cent of one or the other element, though there is no parallelism in their distribution (39). That intrastratal brines deriving from the diagenesis of evaporites form a potential source of great barite deposits cannot therefore be gainsaid.

Similarly, since strontium is released to local groundwaters in large amount on the diagenesis of aragonite to calcite as well as on the diagenesis of sulphates, and perhaps in small amounts on the metasomatism of calcite to dolomite, an intrastratal source of strontium is readily available to account for red-bed celestine deposits like those of Yate in Gloucestershire without making recourse to such anactualistic unrealities as the strontium-rich rivers proposed in earlier geological literature. A metasomatic replacement origin for the somewhat similar celestine and strontianite deposits of southern California has been capably advocated by C. Durrell (40).

Submarine Barite

The hypothesis advanced by Dunham that "hydrothermal" barium-rich solutions may issue forth as springs on the sea floor can be supported by reference to the occurrence of barite concretions in modern submarine deposits situated along fault slopes, examples of which are known in the sea off California, Ceylon and Indonesia (41). But there is as little reason for supposing that such "hydrothermal" waters are of magmatic origin as there is for maintaining that the barite veins characteristic of fault zones in the Old Red Sandstone have been deposited from juvenile fluids. On uniformitarian reasoning it can be argued that mineralizing solutions of this kind are of diagenetic derivation, and that they are most likely to be met with in or close to arid-zone sediments.

The nodular or concretionary habit of modern barite deposits on the sea floor, with mineralization occurring only along or close to the fault-line where the

springs of barium chloride brine first [illegible] the sulphatic sea water, is quite dissimilar from the uniform but low-grade dispersion of barite found throughout deposits like the Marl Slate of Durham, for which a submarine exhalative origin has recently been claimed (42). The balance of evidence does not favour the hypothetical, anactualistic, juvenile origin of the barium, and one can therefore deduce that the sympathetic polymetals are not of juvenile exhalative origin either.

Fig 5: Cross-bedding of Eocene sands accentuated by epigenetic uranium oxides. Shirley Basin, Wyoming.

Red-Bed Copper Ores

The origin of the metals in ore deposits such as the red-bed coppers and the ore shales of the Central African Copperbelt, and in many kindred fields, is a topic which has given rise to an immense volume of argument between the syngenetic and epigenetic schools of geologists. Broadly speaking, the syngenetic concepts are based on the assumption that river drainage from a hypothetical metalliferous land mass would enormously increase the amount of polymetals in solution in the adjacent ocean, where the copper, lead and zinc would be precipitated in high concentration contemporaneously with the deposition of the sediments. But no support for these ideas is forthcoming from actualistic analysis. Modern rivers traversing heavily mineralized regions are not significantly higher in dissolved polymetals (*e.g.* copper) than rivers elsewhere, and they seldom have a tenor of copper as much as an order higher than the content in sea water. Most of the copper carried by the rivers of today is in an insoluble form held by the clay, the sesquioxides and the organic matter in such a manner that under normal fluvial or marine conditions it is inseparable from the other solid detritus.

T. S. Lovering (43) has referred to this reasoning as "a widespread misconception"; he admits that "ionic solution is an unimportant mechanism of copper transport in rivers", but believes that the metal is readily transported as soluble organo-metallic complexes. Unfortunately he has failed to observe that the actualistic argument (44) was based on chemical analysis not only of ionic copper but also of the dry residues from groundwaters around chalcopyrite and polymetallic deposits, thus taking colloidal organic (humate or chelate) copper fully into account.

In most provinces of strata-bound copper ores, mineralization is found in a wide variety of lithological formations within the same limited district—not only in marine shales like the Kupferschiefer but also in carbonate rocks and above all in desert sandstones. It is therefore a reasonable deduction that these various forms of pene-concordant mineralization occurring in regional proximity have a similar or closely related mode of origin.

Obviously the widespread introduction of pay metals into terrestrial formations with dune bedding and mudcracks was not brought about by submarine or sublacustrine precipitations; and it is thus the genetic interpretation of the red-bed copper ores, the commonest form of strata-bound orebody, which presents the greatest challenge. In this connexion it is suggested that insufficient attention has hitherto been given to a potentially genetic relationship between these copper sandstones and evaporites.

It has already been shown that Precambrian evaporite deposits are rare because of the tectonic and metamorphic state of the rocks; but in three of the four instances where relics survive—Southern Rhodesia, Northern Rhodesia and Bas Congo—they are found in association with copper sandstones. Adjacent to the first great salt deposits of Cambrian times, on the Siberian platform, is found the Upper Lena group of red-bed copper ores; and again in Devonian times the cupriferous sandstones of Minusinsk are regionally and chronologically close to extensive evaporite beds. The Dzhezkazgan Series (Upper Carboniferous—Lower Permian) of Kazakhstan contains not only the largest deposits of bedded copper ores in Russia, but also a sequence of gypsum and rock salt.

A further regional connexion between copper sandstones and evaporites of Permian age is to be found throughout most of the northern hemisphere—in New Mexico, in much of Western Europe, in East Germany, Poland, and as far east as the Urals. A similar association of Cretaceous age is to be found in Turkmenia; and numerous small deposits of Neogene age coexist in the Ukraine and Central Asia. The pattern of coincidence is too strong to be fortuitous; but since (unlike evaporites) no copper sandstones have ever been observed in process of formation today, it is permissible to conclude that the genesis of the latter takes place at some depth below the earth's surface.

Ores related to Evaporites

A genetic relationship between evaporites and copper sandstones may well exist if brines from the diagenesis and partial solution of these salt deposits have circulated at depth, become heated due to a high geothermal gradient, leached metals dispersed throughout their path, and deposited them locally in ore-grade concentration within the nearby country rocks.

Highly mineralized brines have been encountered at great depth in boreholes in many artesian basins; and it has been generally accepted that these waters rich in sodium and calcium chlorides are compositionally comparable to the so-called "hydrothermal" solutions found at depth in volcanic regions, of the kind from which ore veins are known to be deposited. Indeed, several authors (45) have attributed a volcanic or magmatic derivation to these deep brines. Certainly they are not of a simple

□ *Uniformitarianism*

connate origin, since they are sometimes ten times richer than sea water in their content of dissolved salts. In referring to them as "hydrothermal" solutions, however, a question of semantics arises, since the term "hydrothermal" means no more than "hot water", and is not synonymous with "juvenile" or "magmatic" as is too commonly supposed.

It is possible that the importance of volcanism or granitization in ore genesis rests, not in such processes being the source of most of the water or of most of the dissolved salts, but in the production of a high geothermal gradient which promotes the circulation of warm waters in depth, so bringing about the intra-stratal solution of buried evaporite deposits; and that the brines so created leach metals from the country rocks and thus become ore-forming fluids. If this happens, the regional association of evaporites with red-bed ore deposits finds a ready explanation. The gradual lixiviation of the evaporites can be expected to produce a chemical fractionation in the resultant intra-stratal brines, barium chloride solutions from the diagenesis of gypsum perhaps being formed at an early period, mixed chloride (K-Mg-Na-Ca) brines following as the more soluble salts are mobilized, and sulphate brines being the last to be formed. Possibly this fractionation may occasionally give rise to zoning in resultant ore deposits.

Liquid Inclusions

The extensive researches undertaken in recent years on the composition of liquid inclusions in ore-minerals and their accompanying gangue have given results not incompatible with these views, since these occluded fluids are for the most part highly concentrated $NaCl$-$CaCl_2$ brines. But as liquid inclusions in the minerals of granites are of a somewhat similar character, it may be suggested that so-called "hydrothermal" ores present a complete spectrum from deposits which have originated from truly juvenile fluids to those which have been created by meteoric brines, with a wide intermediate zone where the two types of solution have commingled.

Source of Metals

The source of the ore metals remains debatable. It seems unlikely from quantitative considerations that they came in major part from the evaporites—though in one of the bore-holes into the modern evaporites of Lake Eyre a concentration of 0·20 per cent zinc over 2½ ft. assay width was found, formed during diagenesis under surface conditions (39). Many uranium ore-fields occurring close to acid lavas and pyroclastics can undoubtedly be attributed to deep intra-stratal leaching of the country-rocks; but no such explanation is apparent for copper deposits in red beds and associated sediments.

The consistently high cobalt : nickel ratio of these deposits (except in some feebly mineralized shales) is, however, an indication that these strata-bound ores are of granitic parentage (46); and it can be deduced that a metallogenetic province is initiated, during a period of granitization or mantled doming of an old basement, by the introduction of metals of deep-seated origin into the immediately overlying sediments as a widespread but dilute dispersion. Later these feebly disseminated metals may be collected by deep brines and concentrated into ore deposits, either in favourable structures or by base exchange with the host rocks.

On this hypothesis it is possible to explain the origin of the Mansfeld Kupferschiefer without resorting to any anactualistic mechanism. Let us accept that this shale was laid down in Lower Zechstein times as a widespread horizon of carbonaceous silt with syngenetic pyrite. It was succeeded by the thick sequence of Zechstein evaporites and in due course by the Bunter, Muschelkalk and Keuper.

On uniformitarian grounds it can be postulated that highly saline brines were formed in depth, perhaps during Lower Bunter times, arising from the diagenesis and part solution of the Zechstein salt deposits; and that during their deep circulation these brines collected metals from feebly dispersed mineralization of Hercynian age. Later still, perhaps in Upper Bunter or Muschelkalk times, the brines migrated upwards and were intercepted by the Kupferschiefer, in which some of the polymetallic load was deposited by replacement of part of the pyritic iron.

In other words, the Kupferschiefer owes its metals to the same general processes as those which gave rise to the many small red-bed copper deposits and the occasional metallization of coal seams in the subjacent Rotliegende. Like the red-bed coppers, it betrays the origin of its metals by a cobalt: nickel ratio much higher than that of any known sedimentary rock. The discordant *Rucken* are, on this view, later "alpine-type" fissure veins into which the more mobile metals have moved by lateral secretion.

Strong support for this suggestion that the mineralization of the Kupferschiefer was effected by ascendant brines,

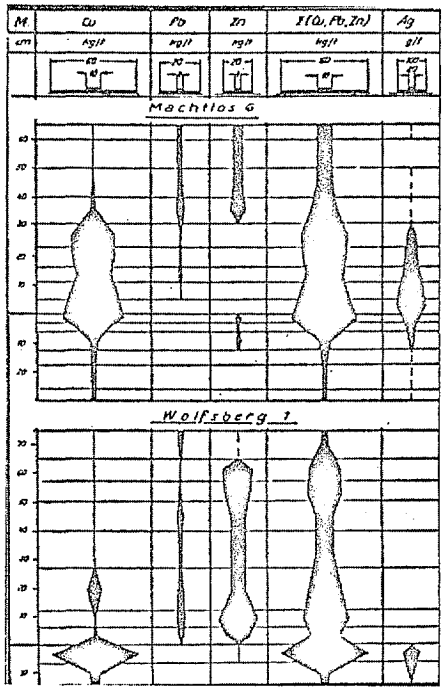


Fig. 6: Distribution pattern of polymetals in Mansfeld Kupferschiefer (two examples) showing zoning attributable to replacement of syngenetic pyrite by ascendant solutions.

bearing metals which replaced the iron in diagenetic pyrite, is to be found in the zonal distribution of the polymetals throughout the Mansfeld, Richelsdorp and Sangerhausen deposits. The pattern of metallization, with maximum silver and copper at the base of the mineralized sequence of strata, maximum lead at an intermediate level, and maximum zinc at the highest level (copper and zinc being strongly antipathetic) is in accord with the order of these metals in the Schürmann series; but the vertical position of copper and silver relative to zinc is the reverse of that seen in an ideal supergene sulphide deposit formed by metal-charged solutions descending from above, and is precisely what one would expect in a somewhat analogous replacement deposit fed from below.

The hypothesis that the mineralization arose through the pyritous Kupferschiefer intersecting a rising front of metal-charged brines thus readily accounts for this critical zonation, hitherto inexplicable on any other grounds. It makes it easier to explain why, although this marine shale formation has a very wide extent (an extent paralleled by that of the overlying evaporites), the mineralization is of highly variable intensity, most ore-fields having a post-sedimentation structural (synclinal) control. And, accepting that the brines derived their polymetals in depth by leaching disseminated mineralization of acid parentage, it interprets satisfactorily the abnormally high cobalt:nickel ratio in the more richly mineralized shales, which averages 4 : 3 over 38 analyses (50) and is highest in the richer ores.

☐ *Uniformitarianism*

Early in 1963 it was reported by D. E. White and associates, of the United States Geological Survey, that a well drilled for geothermal steam in the Salton Sea region of California had resulted in discoveries of quite unusual interest in relation to problems of ore genesis (47). The well in question is the world's deepest bore-hole in a high-temperature hot-spring province, with depth temperatures in the range 270 deg.-370 deg. C. It taps a highly saline brine of Na-Ca-K-Cl type (about 185,000 p.p.m. Cl), with exceptionally high potassium (23,800 p.p.m.); and it gave rise during a three month's production test to several tons of material deposited in the discharge pipe, this deposit consisting dominantly of amorphous silica with iron, manganese, and abundant bornite. Chemical analysis of this precipitate has revealed the astonishingly high content of about 15 per cent copper, 2 per cent silver, and notable arsenic, bismuth, lead, antimony, and some minor elements.

Initially it was believed that this brine formed the first known example of an "active" magmatic ore solution, derived from the same magma chamber as were the late Quaternary rhyolite domes of this region and representing an undiluted magmatic water residual after the separation of a more volatile phase manifested in shallow-depth hot springs nearby. More recent studies of the hydrogen isotope and oxygen isotope ratios have, however, revealed that the water is mainly of surface origin; and it has also been found that the metals are present principally as oxychlorides.

From these latest data White (48) has concluded that surface water has found its way deep underground, dissolved salts from evaporites and, heated by the high geothermal gradient in this volcanic district, has leached the metals from igneous rocks by base exchange or otherwise, so giving rise to a potentially ore-forming fluid. Apparently these heavy brines do not normally reach the surface because of their high density; but comparable studies of the tritium content of more dilute "hydrothermal" springs such as Steamboat Springs in Nevada, which deposit stibnite and cinnabar, have revealed that here also the water is principally of meteoric and not of juvenile origin.

These data suggest that the role of deep meteoric waters in the formation of hydrothermal deposits is considerably greater than generally supposed. On the Russian platform such brines with a temperature range of 100 deg.-374 deg. C. (*i.e.* up to the critical temperature) have been tapped by borings at depths of from 3·5 to 7·5 kilometres. Chukhrov (49) has suggested that the formation of molybdenum-tungsten ore deposits around the granitic intrusions of Kazakhstan is to be attributed to the mixing of magmatic and meteoric waters; and it is possible that in some instances such mixing may be the explanation of mineral zoning.

Although the efficacy of a brine in concentrating ore metals doubtless depends upon its strength and temperature, in some instances dilute aqueous solutions seem to have been quite effective in this respect. Reference has already been made to the now numerous well-authenticated instances of uranium deposits derived from the intra-stratal leaching of devitrified rhyolitic lavas and acid tuffs, the best-known example of which is found in the uraniferous coals of the Dakotas, consistently underlying sandy tuffs and bentonites.

Such associations suggest that many epithermal gold ores found in veins transecting propylitized rhyolites and andesites are similarly due to lateral secretion in heated groundwaters, and that for such deposits the views of Sandberger are nearer the truth than are those of Posepný. Again, without contradicting the liquation-differentiation hypothesis accepted for most copper-

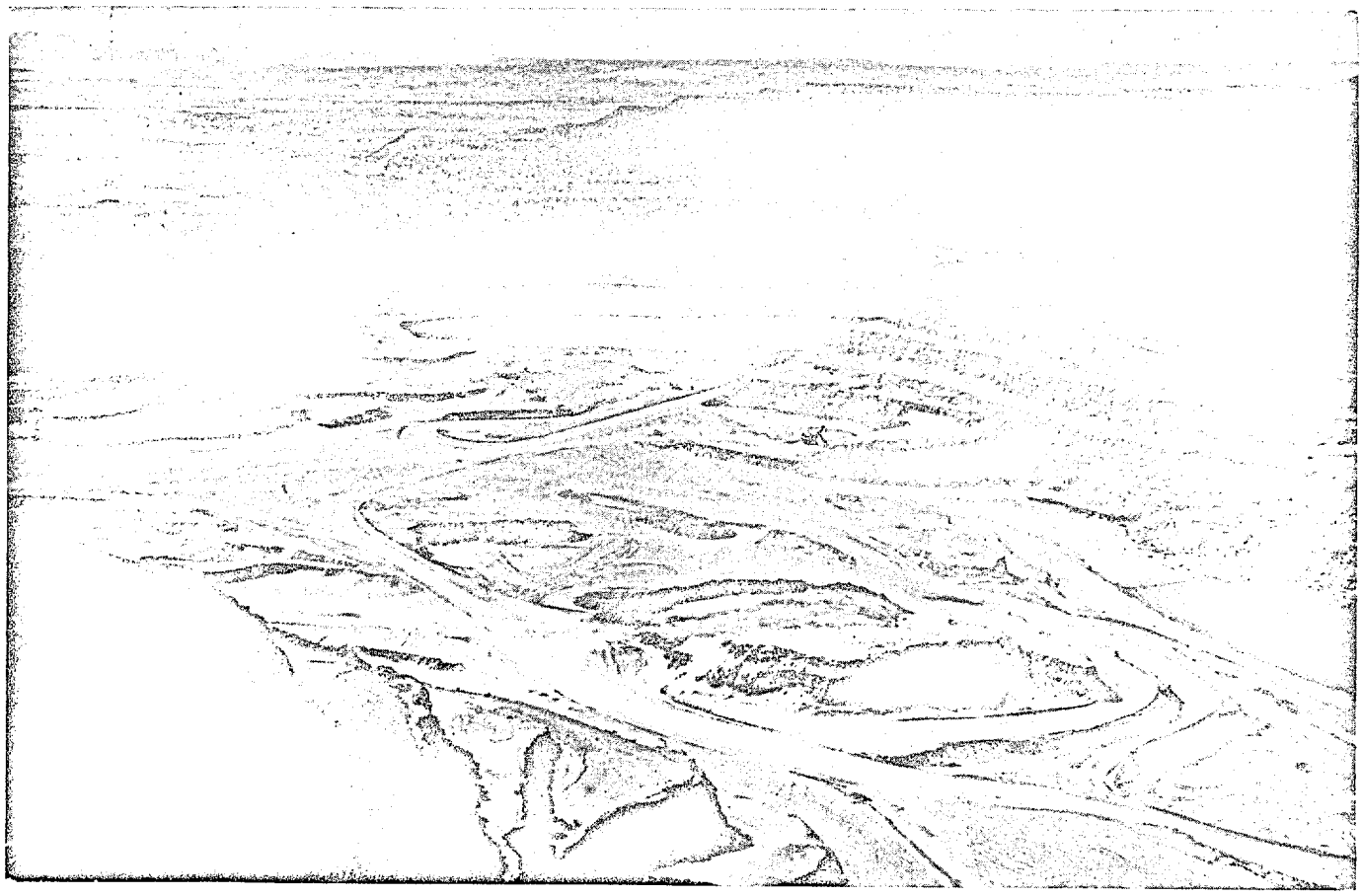


Fig. 7: The Jackpile uranium deposit, Grants, New Mexico. Mineralization in Morrison (Upper Jurassic) sandstone. Dakota (Lower Cretaceous) sandstone forms the higher ledges of the mine.

nickel sulphide deposits associated with norites and peridotites, it seems possible to conclude that some off-set sulphide ore-bodies of this kind may be attributed to the release of copper and nickel to groundwaters as olivine and pyroxene became serpentinized, uralitized and chloritized.

The brine of the Salton Sea borehole is very low in magnesium, in this being comparable to brines from the many salt lake (terrestrial) evaporites of California; but brines from the intra-stratal solution of marine evaporites will necessarily be high in magnesium. In the minerals of ore deposits, however, fluid inclusions generally (but not always) have a magnesium : calcium ratio of less than unity. This is readily explainable if the ore-forming brine is also the agent whereby dolomitization is effected in the country rocks around the ores.

From the discussion in the preceding pages it can thus reasonably be deduced that the various ore deposits attributed to anactualistic environments such as abnormal atmospheres, extraordinary volcanic exhalations, rivers of strange chemical composition, and other departures from uniformitarianism can all be accounted for, within the limits of contemporary experience, as being deposited at depth from saline groundwaters with or without juvenile additives. As was first said in 1761 by the German pioneer of actualism, G. C. Füchsel, *Die Art und Weise, wie die Natur bis zur heutigen Zeit wirkt und Korper hervorbringt, ist als Norm zu setzen; eine andere kennen wir nicht.*

References

(1) HAWKES, L. H. "Some aspects of the progress of geology in the last fifty years." I. *Quart. Journ. Geol. Soc.*, v. 113, pp. 309-321, 1957.

(2) VON BUBNOFF, S. *Grundprobleme der Geologie.* 3rd edn., Berlin, 1959. English translation by W. T. Harry, London, 1964 (in press).

(3) READ, H. H. *A. L. du Toit Memorial Lecture, Geol. Soc. S. Africa*, No. 3, 1953.

(4) GERLING, E. K., *et al*, in *Chemistry of the Earth's Crust*, v. I, pp. 356-373, Moscow, 1963 (Russian only).

(5) POLKANOV, A. A., and E. K. GERLING, in *Questions of geochronology and geology*, Moscow, 1961. p. 94 (Russian only).

(6) ALLSOPP, H. L., *et al.* "Rb-Sr age measurements on various Swaziland granites." *Journ. Geophys. Research.* v. 67, pp. 5307-5313, 1962.

(7) HUNTER, D. R. *The geology of Swaziland.* 104 pp. Mbabane, 1961.

(8) NICOLAYSEN, L. O., *et al.* "Evidence for the extreme age of certain minerals from the Dominion Reef conglomerate." *Geochim. Cosmochim. Acta*, v. 26, pp. 15-23, 1962.

(9) NICOLAYSEN, L. O. "Stratigraphic interpretation of age measurements in Southern Africa." *Buddington volume, Geol. Soc. Amer.*, pp. 569-598, 1962.

(10) SCHEIDEGGER, A. E. *Principles of geodynamics.* 2nd edn. Berlin, 362 pp. 1963.

(11) University of the Witwatersrand. *Economic Geology Research Unit. Fourth Annual Report*, for 1962. p. 22, 1963.

(12) DAVIDSON, C. F. "The present state of the Witwatersrand controversy." *Mining Magazine*, v. 102, 1960.

(13) DAVIDSON, C. F. "Uranium in ancient conglomerates: a review." *Econ. Geol.* vol. 59, 1964 (in press).

(14) CAHEN, L. "Glaciations anciennes et derive des continents." *Ann. Soc. Geol. de Belgique*, v. 86, pp. B 19 - B 83, 1963.

(15) RUTTEN, M. G. *The geological aspects of the origin of life.* Amsterdam, 1962, 146 pp.

(16) HOLLAND, H. D. "Model for the evolution of the earth's atmosphere." *Buddington volume, Geol. Soc. Amer.*, pp. 447-477, 1962.

(17) DAVIDSON, C. F. "The chemical history of the Earth." *Krishnan volume, Geophys. Soc. India*, 1963 (in press).

(18) OLEINIKOV, A. N., in *The significance of the biosphere in geological processes* (Trans. 5th-6th Sessions All-Union Palaeontological Society). pp. 117-121. Moscow, 1962 (Russian only).

(19) DAVIDSON, C. F. "Phosphate deposits of Precambrian age." *Mining Magazine*, v. 109, pp. 205-208, 1963.

(20) SOLOEV, A. I., *et al. Geological structure . . . of the south-east part of the East Sayansk massif*, Moscow, 1962. 154 pp. (Russian only).

(21) KANTOR, J. "Einige Bemerkungen zur Uranvererzung im Perm der Nordgemeriden Synklinale" *Acta Geologica Universitatis Comenianae*, no. 2, pp. 157-166, Bratislava, 1959.

(22) GREENBERG, R. "Structure-gold relationships as revealed by some Witwatersrand mine plans. *Bull. Instn. Min. Metall.*, no. 683, pp. 1-10, 1963.

(23) IVANOV, A. A., and LEVITZKII YU. F. *Geology of the halogenic deposits of the U.S.S.R.* Moscow. 1960, 425 pp. (Russian only).

(24) RUBEY, W. W. "Geologic history of sea water". *Bull. Geol. Soc. Amer.*, v. 62, pp. 1111-1148, 1951.

(25) LIVINGSTONE, D. A. "The sodium cycle and the age of the ocean." *Geochim. Cosmochim. Acta*, v. 27, pp. 1055-1069, 1963.

(26) BUSHINSKII, G. I., *et al. Bauxites, their mineralogy and genesis.* Moscow, 1958. 488 pp. (Russian only).

(27) ZELENOV, K. K., in *Contemporary sediments of the seas and the oceans.* Moscow, 1961. Pp. 65-72 (Russian only).

(28) HUNTER, D. R. *The mineral resources of Swaziland.* Mbabane, 1962, 111 pp.

(29) COCHRANE, G. W., and EDWARDS, A. B. "The Roper River oolitic ironstone formation." *Mineragraphic Investigations Tech. Paper* no. 1, C.S.I.R.O., Melbourne, 1960.

(30) DORR, J. V. N., and BARBOSA, A. L. M. "Geology and ore deposits of the Itabira district, Minas Geraes, Brazil." *Prof. Paper U.S. Geol. Surv.*, no. 341-C, 1963.

(31) BURGELYA, N. K., in *Reviews of the Metallogeny of sedimentary and sedimentary metamorphic rocks*, Moscow, 1962, pp. 14-122 (Russian only)

(32) FORMOZOVA, L. N., in *Volcanic-sedimentary and terrigenous formations*, Moscow, 1962, pp. 161-208. (Russia only).

(33) NABOKO, S. I. "Volcanic exhalations, their products and their reactions". *Trudy Lab. Vulkanologii*, vyp. 16 303 pp. Moscow 1959 (Russian only).

(34) DAVIDSON, C. F. Discussion in *Trans. Instn. Min. Metall.*, v. 72, pp. 381-3, 1963.

(35) KETNER, K. B. "Bedded barite deposits of the Shoshone range, Nevada". *Geological Survey Research* 1963, U.S.G.S. Prof. Paper 475 - B, pp. B38 - B41, 1963.

(36) DUNHAM, K. G. "Age-relations of the epigenetic mineral deposits of Britain." *Trans. Geol. Soc. Glasgow*, vol. 21, pp. 395-429, 1952.

(37) RAMDOHR, P. "Die orientierten Verwachsungen von Bleiglanz . . . bei Essen-Borbeck." *Abhandl. Deutsch., Akad. Wiss. Berlin*, no. 4, pp. 1-31 1947 for 1945-46.

(38) RONOV, A. B., *et al.* "Evolution of the chemical and mineralogical composition of sandstone rocks, in *Chemistry of the Earth's Crust*, v. I, pp. 201-252, 1963 (Russian only).

(39) JOHNS, R. K. "Investigation of Lake Eyre." *Reports of Investigations, South Australian Geol. Surv.*, no. 24, 1963.

(40) DURRELL, C. "Geological investigations of strontium deposits in southern California. *Special Report, Division of Mines, California.* No. 32, 48 pp. 1953.

(41) EMERY, K. O. *The sea off southern California.* New York, pp. 216-217, 1960.

(42) HIRST, D. M., and DUNHAM, K. C. "Chemistry and petrography of the Marl Slate of S.E. Durham." *Econ. Geon.* v. 58 pp. 912-940. 1963.

(43) LOVERING T. S. "Epigenetic diplogenetic, syngenetic and lithogene deposits." *Econ. Geol.*, v. 58, pp. 315-331, 1963.

(44) DAVIDSON, C. F. "The origin of some strata-bound sulphide ore deposits." *Econ. Geol.*, v. 57, pp. 265-274, 1962.

(45) KAPCHENKO, L. N. "The nature of abyssal chloride brines." *Intern. Geol. Review*, vol. 5, pp. 1137-1147, 1963.

(46) DAVIDSON, C. F. "On the cobalt:nickel ratio in ore deposits. *Mining Magazine*, v. 106, pp. 78-85, 1962.

(47) WHITE, D. E., *et al.* "A geothermal brine well." *Science*, v. 139, pp. 919-922, 1963.

(48) WHITE, D. E. Contribution to *Symposium on post-magmatic ore deposition.* Prague, 1963. Vol. II, (in press.)

(49) CHUKHROV, F. V. "On the possible influence of meteoric waters on mineralization of some hydrothermal deposits." *Geologiya Rudnykh Mestorozhdenii*, 1964 (in press). (Russian only).

(50) KNITZSCKE, G. Vererzung, Hauptmetalle und Spurenelemente des Kupferschiefers in der Sangerhäuser und Mansfelder Mulde. *Zeitschr. fur angew. Geol.*, v. 7, pp. 349-356. 1961

USGS Circular 560: USGS Heavy Metals Program Progress Report 1966 & 1967.

Geophysical studies near Fairbanks—Preliminary tests of magnetic and electrical methods as tools for exploration for gold placers and lode deposits were completed in the Fairbanks district.

Resistivity soundings give a reasonably clear picture of bedrock configuration below gravels despite problems posed by permafrost. At Wiseman, about 200 miles north of Fairbanks, resistivity measurements suggest that bedrock is too deep to reach with present-day dredges.

Efforts to detect narrow gold-quartz and sulfide veins on Cleary Dome north of Fairbanks were made using electromagnetic(EM) and induced-polarization (IP) methods. The veins apparently are too small to detect using EM, but both distribution and attitude of sulfide concentrations were established using IP.

Magnetic profiles failed to reveal any concentrations of magnetite such as might be associated with placer gold.

Reconnaissance studies in southern Brooks Range.—Geochemical sampling in the Chandalar and Wiseman quadrangles in the southern Brooks Range of north-central Alaska revealed a silver anomaly that extends the potential silver-bearing area around a known silver prospect. A gold anomaly was found along the Mikado shear zone 0.5 mile west of the Mikado mine at Chandalar Lake. Sampling of apparently favorable areas in the Table Mountain and Coleen quadrangles along the northeast border of Alaska yielded negative results.

Geologic mapping in Wrangell Mountains.—Geologic mapping of six 15-minute quadrangles in the Wrangell Mountains in south-central Alaska has been completed. These maps will provide a sound base for further study of the heavy metal potential of the region.

Gold in gravel of Kougarok River.—Small amounts of gold have been found in gravels of the Kougarok River in the western part of Seward Peninsula. Seismic profiles near the mouth of the river indicate a buried north-trending channel, possibly indicating a pre-gravel drainage direction. These gravels, formerly thought to be of Tertiary and Pleistocene age, are now believed to be entirely of Pleistocene age.

Gold veins at Nuka Bay.—Several quartz-arsenopyrite veins at Nuka Bay, at the southwest end of Kenai Peninsula, southwestern Alaska, contain as much as 10 ounces of gold per ton. The veins are short and discontinuous, and ore shoots are erratic, but small-scale mining may be feasible.

Arizona

Gold deposits of Gold Basin and Lost Basin.—Study of gold lode and placer deposits of the Gold Basin-Lost Basin area south of Lake Mead in northwestern Arizona has shown that alluvial placers of Pliocene(?) and Quaternary age on the flanks of the Lost Basin Range are the most promising. Small veins of quartz, sulfide minerals, and gold are abundant in Precambrian rocks of the region, and some contain coarse gold, but most are too small to be of economic interest. Placer deposits derived from Pliocene(?) pediment gravels have formed along arroyos on the east side of the Lost Basin Range over an area of 8–10 square miles. On the west side of the range, some placer deposits in Quaternary alluvial fans are being mined on a small scale. Potential resources may exceed 500 million cubic yards of gravel containing 0.01–0.02 oz gold ($0.35 - $0.70) per cubic yard. A sampling program is being planned with the U.S. Bureau of Mines.

California

Aeromagnetic map of part of the Mother Lode.—An aeromagnetic map of parts of the Mother Lode gold and Sierra Foothills copper mining districts in Calaveras, Stanislaus, and San Joaquin Counties, together with a geologic interpretation (U.S. Geol. Survey Map GP-561), shows that many of the ore deposits in this region are related to the Bear Mountains and Melones fault zones, which locally are intruded by ultramafic rocks that give rise to magnetic highs. Magnetic evidence suggests a similar buried fault zone 8–9 miles southwest of the Bear Mountains zone. Possible near-surface magnetite- and ilmenite-bearing sands, which elsewhere in the region are known to contain placer gold, also are indicated by the magnetic data.

Aeromagnetic surveys of the Mother Lode-Grass Valley area to the north in the Sierra Nevada have been completed. Some electromagnetic anomalies detected by aerial surveys have been checked on the ground; the conductive units appear to be black slates or phyllites and flat-lying volcanic rocks and gravels.

Tertiary gravels, Nevada County.—As an initial stage in the study of Tertiary gold-bearing gravels in the Sierra Nevada, the San Juan Ridge channel in Nevada County was traced for about 15 miles. The sinuous channel is ¼–1½ miles wide and along its axis is filled with 200–300 feet of gravel. Paleocurrent data show that the ancient river flowed from east to west. Twenty samples were collected for study and analysis. Much gravel was removed from this channel during hydraulic mining prior to 1885, but a large amount remains.

Field tests of six geophysical methods for studying possible gold-bearing Tertiary stream gravels in the Sierra Nevada were made north of Nevada City and are being evaluated. Seismic-refraction methods supplemented by gravity measurements appear to be best for determining bedrock configuration. Resistivity methods provide knowledge of conductive layers and may be able to locate the productive "blue lead" when other methods fail. Magnetic methods are useful if concentrations of magnetite-rich black sands are associated with gold, and induced polarization may detect disseminated sulfides that in places are associated with gold concentrates. Electromagnetic techniques do not appear promising at this preliminary stage.

Low-level (400 ft above terrain) magnetic, electromagnetic, and radiation profiles were flown across the

Metal-rich Cretaceous Asphaltic Sandstone near Durango, Colo.

Lenses of radioactive black "asphaltic" material in the Cretaceous Dakota Sandstone near Durango, Colo., are enriched in gold (as much as 0.16 ppm) as well as in thorium, titanium, and other elements. The metal-rich asphaltic material may be a form of thucholite.

Gold in Marine Sediments

The gold content of three marine samples has been determined by neutron activation. Results are:

Manganese nodules, Blake Plateau (composite sample), 0.2 ppb
Phosphorite, Blake Plateau (composite sample), 7.2 ppb
Metal-rich sediment, Red Sea, 130 ppb

The last figure is of particular interest inasmuch as these Red Sea sediments have already been reported to contain 0.9 percent copper, 2.6 percent zinc, 0.1 percent lead, 0.008 percent silver, and 0.002 percent tin.

Gold Content of Batholithic Rocks

Gold content of 8 samples from each of 3 batholiths was determined by neutron activation analysis. Results are as follows:

Southern California batholith, 0.2-4 ppb
Sierra Nevada batholith, 0.3-10 ppb
Boulder batholith, 0.4-3.3 ppb

Fossil Placer Deposits

Studies of ancient deposits of sand and gravel formed in environments similar to those of modern placers were started early in the program with the hope that some might contain gold deposits similar to those of the Witwatersrand in the Republic of South Africa. Work on sandstones and conglomerates in several western and midwestern states has been unsuccessful to date, but will continue as only a small part of the potential gold-bearing strata has been examined.

Precambrian and Paleozoic rocks

Great Lakes region.—Preliminary sampling and paleocurrent measurements were done in upper Precambrian and Cambrian clastic rocks in Minnesota, Wisconsin, Michigan, and New York, and in Devonian, Mississippian, and Pennsylvanian clastic rocks in Michigan, Ohio, Pennsylvania, and New York.

Selected samples from 22 localities were fire assayed for gold. Five of the 22 samples contained 0.027-0.050 ppm, the rest less than 0.025 ppm, the limit of detection of the analytical method. Samples with detectable gold were separated into light and heavy fractions and submitted for analysis, in order to test whether samples of these rocks can be effectively preconcentrated. Heavy minerals concentrated from pyritic conglomerates of the Precambrian Fond du Lac Sandstone contain 2.1 ppm gold. Inasmuch as the whole rock contained only 0.050 ppm gold, and the concentration ratio is only about 9, the heavy concentrate contains about five times as much as gold as would be expected; presumably the whole rock sample was not representative because of its relatively small size and the possible coarse nature of the gold.

Northwestern United States.—Samples of selected conglomerates of the Precambrian Belt Series from 11 localities in southwest Montana assayed less than 0.02 ppm gold. It seems likely therefore that conglomerates in this area of Belt rocks cannot be considered as potential sources of gold.

Of about 300 samples of quartzite from central Elko County, Nev., that were analyzed for gold, only one contained as much as 0.1 ppm.

Southwestern United States.—Of 70 samples of Precambrian and lower Paleozoic conglomerates collected during a reconnaissance study of possible fossil placers in central Arizona, only one contained more than 0.02 ppm gold, the limit of detection. A boulder conglomerate from the upper Precambrian Scanlan Conglomerate in the northern Sierra Ancha of Gila County had 0.1 ppm gold. However, the matrix of this conglomerate has small quartz-lined vugs possibly indicative of hydrothermal activity, therefore the gold may not be of detrital origin.

Quartzitic conglomerate from the basal conglomerate of the Precambrian Pahrump Group was sampled at eight localities between the Panamint and Kingston Ranges in southeastern California. These samples are to be analyzed for gold.

Conglomerates of the younger Precambrian Uncompahgre Formation in the San Juan Mountains, Colo., contain less than 0.1 ppm gold. Samples were taken from a basal conglomerate 3–8 feet thick and from 8 conglomerate lenses in a section of quartzite and slate 8,000 feet thick.

No gold was detected in four splits of heavy minerals concentrated from a 170-pound sample of Precambrian Vallecito Conglomerate from Vallecito Canyon on the south flank of the San Juan Mountains in southwest Colorado. Detection limits ranged from 0.3 to 0.02 ppm. The heavy mineral content of the conglomerate is very low.

Four samples of Precambrian conglomerate from the Las Tablas quadrangle west of Taos, N. Mex., contained less than 0.1 ppm gold. A heavy mineral concentrate from one sample also had less than 0.1 ppm.

Conglomerate beds in the Precambrian Ortega Quartzite in the Picuris Range near Pilar, Taos County, N. Mex., contain 0.05 ppm or less of gold.

Mesozoic Rocks

Analysis of 53 samples of black sands of Late Cretaceous age from the Rocky Mountain region reveals that only nine contain detectable gold (limit of detection, 0.1 ppm); the highest gold content is 0.3 ppm. Several samples earlier reported to contain as much as

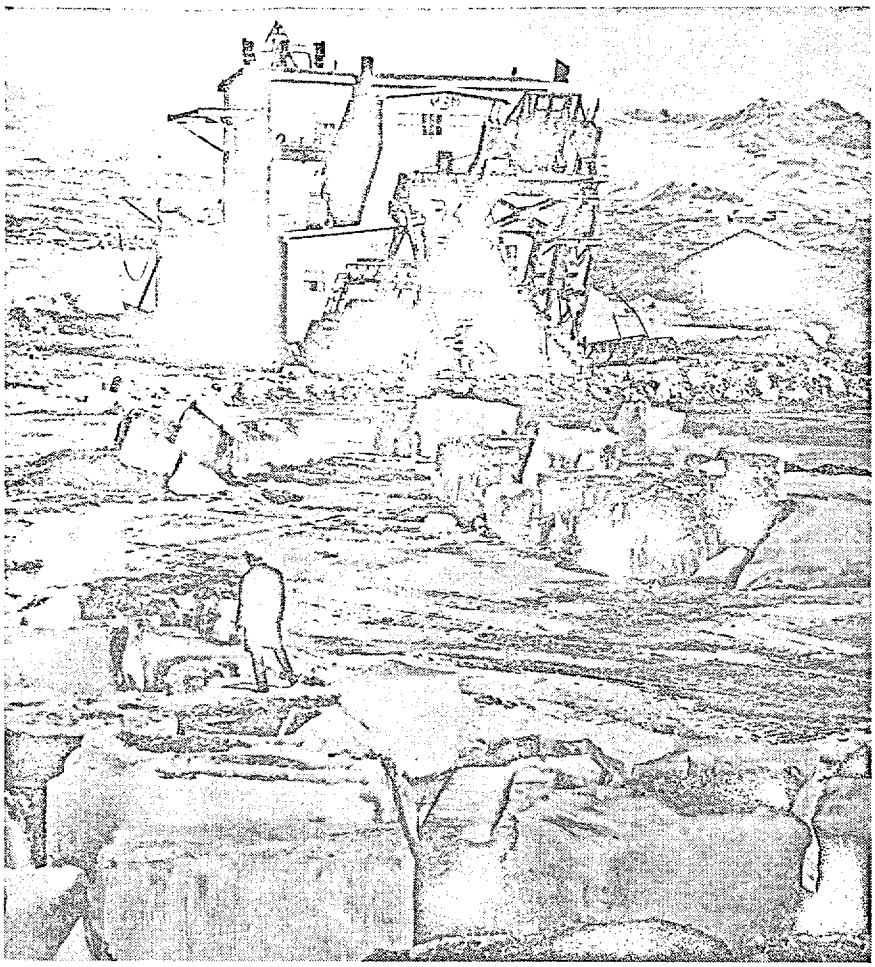


Photo by V. Pazdinikov for Novisti Press

EARLY SPRING start up for No. 80 dredge at the new Undinsky placer mine, Baleizoloto Combine, Trans-Baikal region is made possible by cutting the five-foot thick ice on the pond into blocks with a steam lance and then dragging them out of the pond. The arrow points to the new town buildings which were built to house the gold miners and their families.

How the Soviets use computers to prospect for Siberian gold

From 65 to 67 percent of Soviet gold output was mined from placer deposits as recently as 1964.[1] It has long been known that connected bucket line dredges recovered the largest proportion of this gold and the two pictures with this article illustrate the variety of dredging conditions under which this gold is produced. One of the pictures shows the start of dredging in a new district, Undinsky in the trans-Baikal area, where first output using what appears to be a dredge moved from another placer was recovered in the 50th anniversary year of 1967. Nevertheless, the placers are being depleted.

It is not surprising to learn that Engineer Valentina Krasnova reports that, "It was enough for a man to stoop and pick the gold up. There it was, right at the surface. This was how gold was obtained in Russia for centuries, the prospectors just stooped and picked it up. There was no need to take a look deeper down. But the gold reserves are gradually running out and in some places they are even re-washing the gravels."

Thus, the Russian geologists were faced with the problem of discovering unknown gold deposits so that gold output could be increased in the face of declining placer yields.

Engineer Krasnova reports in this special article for WORLD MINING how gold deposits are being searched for and located in Siberia.

Radioactivity Clue to Gold

The 1958 Geneva Conference on the peaceful uses of atomic energy gave geologists a new tool to prospect for auriferous ores. The point is that such ores as a rule contain uranium or thorium and, therefore, their radioactivity is relatively high. Thus, in localities with a high radioactivity count the chances for discovering gold deposits are better. However, even this seemingly simple method meets certain difficulties.

It is true that if the main emphasis is made on searching for primary deposits in conglomerates, the task is simplified to some degree. Of particular interest are Precambrian conglomerates—pebble beds cemented by quartz, sericite and pyrite. It is in pyrite that the gold is contained.

Seven large conglomerate deposits are known throughout the world—three in Africa, one each in Canada, Brazil, Australia, and several small points in Finland. All these are primary deposits where gold, uranium or both are, or have been, mined.

A band of Precambrian rocks

1 Geologiya Rossypei (Geology of Placers), edited by V. I Smirnov, 400 pages, Nauka, Moscow, 1965.

fringes the Siberian Platform in a gigantic arc. But where is the gold-bearing stratum to be sought here? Where is the auriferous zone? Where should we put down a drill hole? Where should we sink a shaft?

Geologists believe that the formation of similar identical economic minerals all over the earth obeyed the same laws.

A major discovery based on the search for analogies in the historical development of two regions was made in 1934 by Academician V.S. Sobolev and A. P. Burov. Studying the residual magnetism of Siberia and comparing it with that of Africa, they concluded that the two regions had a similar geological history. In Africa this region produces diamonds from kimberlite pipes; therefore, diamond-bearing kimberlite pipes should be found in Siberia too. They outlined areas promising for the occurrence of diamond. Fifteen years later their forecast came true.

The method of comparison, though very effective, at present is beyond the powers of the human brain. Too great is the amount of information that must be processed. It would take man more than a single lifetime to do that since this involves billions of mathematical operations to choose the only correct way.

At the Siberian Branch of the Academy of Sciences this problem was attacked by a team of scientists of different specialities: geologists, mathematicians, geophysicists.

They succeeded in developing an original method for applying an electronic computer to the search for economic mineral deposits.

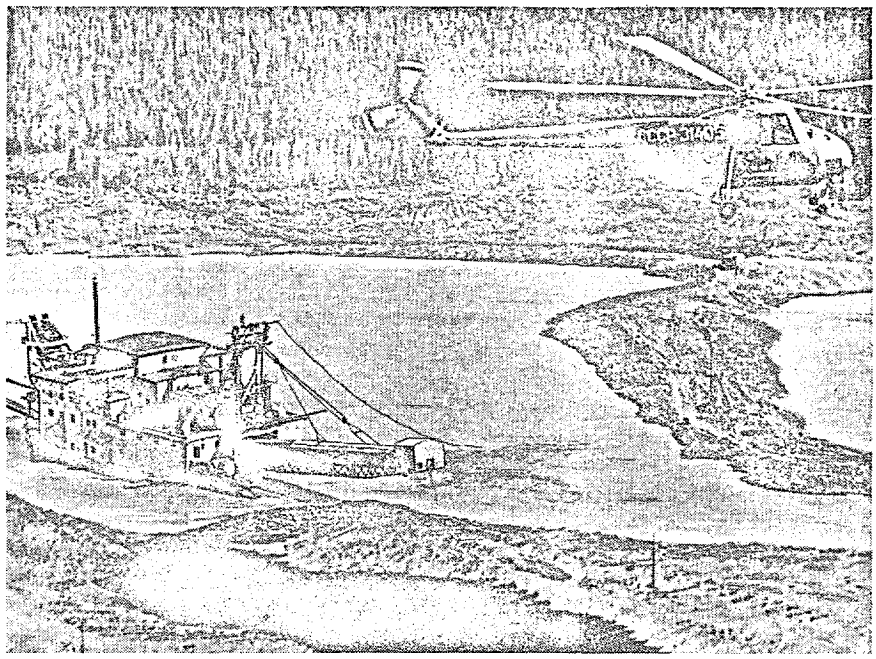
Outline Regions First

The task attacked by the Siberian scientists was to outline within the U.S.S.R. regions likely to contain a major gold deposit, one that would make it possible to create a real gold industry, a real gold city at the place of the discovery.

In the Soviet Union such a deposit is most likely to be found in conglomerates and this is what the Siberian team is trying to do.

A conference on the exploration for gold bearing conglomerates was held in Moscow in May 1966 when 22 papers were read before 100 Russian geologists and prospectors. Some results of the studies of Paleozoic and Proterozoic conglomerates in the Russian and Siberian shields, the Caucasus Mountains, and Kuznetsk Alatau have been published.[2] Apparently several basal beds (Krivoy Rog and Karelia) are uranium bearing, but the discovery of important gold resources is not listed. The conglomerates in the Baikal-Sayan region are lower in pyrite than those of the Witwatersrand and the gold content in only a few of several thousands of samples is as high as 1.0 gram per ton which is much less than in Witwatersrand ore.

Photo by V. Yakobson for Novisti Press



HELICOPTERS now provide fast transportation to the remote gold dredging operations in northern Siberia. This dredge is digging upstream in the Nizhnii Kuranakh River.

Using methods of discrete mathematics, the scientists give the computer the assignment of identifying the geological features characteristic of gold deposits. Altogether such features number about 250.

To accomplish this task the computer performs a billion operations.

The use of discrete mathematical methods in the search for gold deposits is no longer confined to pure theorizing. Using the electronic computer, scientists at the Siberian Branch of the Academy identified the most interesting spots on the geological map of Siberia and went to look for ore at points indicated by the electronic prompter.

They checked their method in two regions. So far the first chunks of conglomerates have been found. They do not look like anything ever before found in Siberia, but they look identical to the African conglomerates.

In one of 14 papers describing gold mineralization in the Far East[3], F. P. Krendelev indicates that fossil placers (conglomerates) are not ore grade, but that Jurassic age conglomerates have yielded picked specimens containing up to 11 grams of gold per ton. He further reports that a Witwatersrand type of quartzitic conglomerate contains gold in rounded and spider web forms, uraninite, brannerite, pyrite, and traces of other sulphides. The conglomerates do differ in some respects, however, from those of South Africa, as they contain potassic feldspathization and a little carbonate. A hydrothermal origin is advocated for mineralization in the basal conglomerates.

It is interesting to note the decline in placer gold output and the importance the Soviets place on maintaining, and, more importantly, expanding gold production. Russia has long ranked second in annual world gold output. Various estimates and guesses of yearly production vary from 4,000,000 to 6,500,000 ounces.

And the Soviets are not basing gold discovery solely on computers; Engineer Krasnova reports that, "All over the Soviet Union more than 100,000 certified geologists are searching for minerals".

[2] Zolotonosnye konglomeraty yuzhnoi okrainy Sibirskoi platformy (Gold bearing conglomerates of the Southern Border of the Siberian Plateau), 156 pages, Nauka, Moscow.

[3] Geneticheskie osobennosti i obshchie zakonomernosti rasvitiya zolotoi mineralizatzii Dal'nego Vostoka. (Genetic Peculaliarities and general Regularities of Development of Gold Mineralization in the Far East). Edited by E. A. Radkevich, 204 pages. Nanka, Moscow. END

Route: FTGraybeal F.T.G.
JDSell
File

AMERICAN SMELTING AND REFINING COMPANY
SOUTHWESTERN EXPLORATION DIVISION
P. O. BOX 5747, TUCSON, ARIZONA 85703

1150 NORTH 7TH AVENUE
TELEPHONE 602-792-3010

November 27, 1974

Mr. Paul A. Handverger
115 Sunset Boulevard
Clarkdale, Arizona 86324

Dear Paul:

It was agreed yesterday that you would undertake for Asarco a program of search for gold deposits in the Precambrian of Arizona. It was further agreed that you would spend approximately thirty field days in mapping and sampling to determine the distribution of gold in the various permissive units -- iron formations, tuffs, calcareous sediments, and where appropriate granites. A review of this data will determine whether to continue this program.

Mr. Stathis is hereby directed to supply you with the name of a firm to use for your analytical work.

Very truly yours,

Bill

W. L. Kurtz
Manager of Exploration

WLK:lb

cc: TCOsborne
JHCourtright
GJStathis

SOCIETY OF MINING ENGINEERS

P.O. BOX 625002, LITTLETON, COLORADO 80162-5002

PREPRINT NUMBER

88-187

PALEOPLACERS OF THE WITWATERSRAND BASIN

W. E. L. Minter

University of Cape Town
Rondebosch, C.P., South Africa

For presentation at the SME Annual Meeting
Phoenix, Arizona - January 25-28, 1988

Permission is hereby given to publish with appropriate acknowledgments, excerpts or summaries not to exceed one-fourth of the entire text of the paper. Permission to print in more extended form subsequent to publication by the Society must be obtained from the Executive Director of the Society of Mining Engineers.

If and when this paper is published by the Society of Mining Engineers, it may embody certain changes made by agreement between the Technical Publications Committee and the author, so that the form in which it appears is not necessarily that in which it may be published later.

These preprints are available for sale. Mail orders to PREPRINTS, Society of Mining Engineers, P.O. Box 625002, Littleton, Colorado 80162-5002

PREPRINT AVAILABILITY LIST IS PUBLISHED PERIODICALLY IN MINING ENGINEERING

Abstract. The most important Witwatersrand gold placers occur on extensive unconformity paleosurfaces that were produced during protracted periods of fluvial degradation. The erosional etches on what was generally unlithified substrate indicate that low sinuosity erosion patterns prevailed. The transport systems were dominantly braided fluvial with a minor debris-flow component. The placer sediments were non-cohesive sands and gravels which were evidently transported by fluctuating, yet perennial, discharges across extensive, low relief, braidplains, not far from littoral environments. Progress made in understanding heavy-mineral transport processes now emphasizes the importance that selective entrainment probably had in producing concentrations. Cognizance that these characteristics are not unique to the Witwatersrand should be taken into account when designing exploration models.

Introduction

Since the theme of this meeting concerns "surfaces", and because gold is so topical, it is appropiate that our knowledge of the ancient gold covered Witwatersrand "paleosurfaces" be reviewed. They are indeed giant fossil placers and their present output of 640 tons of gold per annum still overshadows all other sources of supply. Despite their long history of exploitation it was reassuring to deduce from the amount of research presented at the 1986 Conference, which celebrated the Centenary of the discovery of gold on the Witwatersrand, that the Witwatersrand deposits are still alive and well.

Geological Setting

Witwatersrand placers are practically confined stratigraphically to the Central Rand Group, which comprises the upper, more arenaceous part of the Supergroup. These sedimentary rocks are preserved in structurally downwarped or downfaulted parts of an extensive basin, 9750 km^2 in area, that extends from Johannesburg for 290 km to the southwest (Fig. 1). It overlies the more extensive West Rand Group that represents the lower part of the Supergroup, and which onlaps both the Dominion Group and the granite-gneiss and greenstone terrain of the Kaap-Vaal craton (Tankard et al., 1982) Only about ten percent of the periphery of the Central Rand Group outcrops, the rest being concealed by younger Proterozoic and Phanerozoic cover rocks. Recent dating of zircons by ion-microprobe analysis (Armstrong and Compston, 1986) has bracketed the age of the placers at between 3060 Ma for underlying Dominion lavas and 2708 Ma for overlying Ventersdorp lavas. These dates are by definition Archean although the style of Witwatersrand sedimentation clearly postdates cratonisation (Pretorius, 1976).

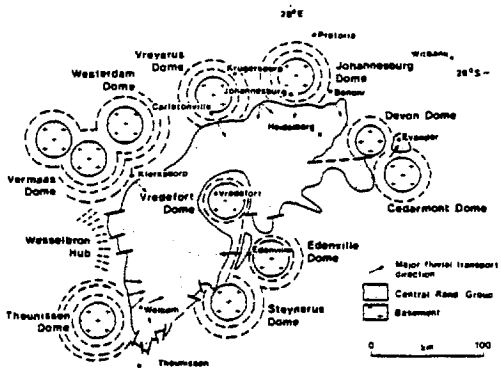


Figure 1. Outline of the Central Rand basin with younger cover rocks removed. Basement domes, marginal structures and paleocurrent distribution patterns of the major placers are shown.

The Paleosurfaces

Areal Dimensions

There are only two erosional regional paleosurfaces in the Central Rand Group that can be identified across the basin with any degree of certainty. These preserved surface areas may each encompass 9750 km^2 and are characterised by being associated with debris-flow diamictites. Their development may have been the result of particular regional climatic conditions.

The paleosurfaces with which the important placers are associated are more numerous, but less extensive. They are the erosion surfaces that separate unconformity bounded synthems in the Witwatersrand stratigraphy and their limits are defined by the lateral continuity of the placers. Using this criterion, they have been identified over areas of from 150 to 400 km^2.

Topographic Relief

The two regional paleosurfaces mentioned are also characterised by deeply incised channels of over 100 meters deep and in places more than a kilometer wide. Their courses are known to be sinuous and have been traced for tens of kilometers (Papenfus, 1957). Loadcasted podlike remnants and slumped sheets of reworked placer deposits, eroded and recycled from underlying placers, occur associated with the

diamictites in these erosion channels and have in some instances been exploited successfully. The topographic relief of the erosion surfaces bounding the synthems, on which placers generally occur, is much more subdued. For instance, although channelling of up to 6 meters deep in proximal reaches of the Steyn placer in the Welkom goldfield has been recorded (Minter, 1985), the average relief over 200 km^2 is 0.5 meters. In the Klerksdorp goldfield, the Vaal placer covers an area of 260 km^2, and along a paleostrike distance of 14 km the deepest channel encountered was 1m deep and 1000m wide (Minter, 1976). The Carbon Leader paleo-relief is similar to that of the Vaal placer over an area of 160 km^2 (Buck and Minter, 1985). In all of these more recently mined placers, systematic sedimentological studies have revealed that the drainage etches on the unconformities have a very low sinuosity. These drainageways would have had the form of braidbelts comprising shallow sinuous streams that transported and deposited the placer sediment. These aspects of areal extent, surface relief and drainage patterns resemble those of braidplains.

In rare instances where placer channels have eroded into siltstones, the cohesiveness of the substrate has resulted in discrete, steeply sided channelways, with more sinuous distribution patterns as in the B placer in the Welkom goldfield (Minter, 1978).

Stratigraphic Position

The two regional paleosurfaces discussed occur stratigraphically near the bases of both the Johannesburg and Turffontein Subgroups. The less extensive placer paleosurfaces, however, are located in discrete areas peripheral to the Central Rand Basin margin. They mark the unconformable boundaries between synthems composed essentially of sandstone, and are repeated stratigraphically, the placer sediments apparently being supplied repeatedly as it were from a geographically similar entry point. In the Welkom goldfield it is clear from isopach analysis that structural deformation occurred synchronously with sedimentation and that the stratigraphic stacking of placers represents intermittent tectonic rejuvenation of the basin margin (Minter et al., 1986). The tectonic activity at each entry point, however, when measured by the number of placer events recorded in the sequence, is different in each goldfield, and ranges from 1 to 8 or more. In detail, however, the position of major discharge points, and the sites of better mineralization, are related to the particular geometry and distribution of each placer deposit.

Correlation

Because many stratigraphic units in the lower part (West Rand Group) of the Witwatersrand Supergroup were deposited in an extensive shallow marine environment, and therefore can be readily correlated, numerous attempts have been made to correlate specific placers in the Central Rand Group from one part of the basin to another. But the number of synthems at each entry point of the basin, in this dominantly fluvial part of the sequence, are different because they are evidently related to different degrees of local tectonic activity. The sandstone packages comprising these synthems have subtly different lithological characteristics, different geochemical signatures and different paleocurrent distribution configurations. This all reflects the separateness of their local provenance areas. Even the Booysens Shale Formation, considered to represent a single lithostratigraphic horizon, is a compound unit. The chemical composition of this siltstone body displays significant differences at each entry point, probably reflecting compositional differences between each provenance area. Therefore, it is unreasonable to expect to be able to correlate individual placers beyond their own fan environments.

The Placer Sediments

The Central Rand Group sediments are up to 2880m thick in the Vredefort area and mostly comprise coarse-grained subwackes. Interbedded with these are units of conglomerate and quartz arenite that collectively total less than ten percent of the entire sequence. It is with these minor fractions of the succession that the placers are associated.

Gravel and Sand Fraction

The gravel facies in the placers comprise well sorted beds of small pebble to cobble size clasts that on average are well rounded and equant shaped, with a small proportion displaying ventifacts. These features are considered to indicate abrasion by dominantly fluvial processes with an element of eolian modification.

The clasts are composed of an oligomictic assemblage of vein quartz, chert and quartz arenite, with minor silicified shale and quartz porphyry components. This is a very mature assemblage and is identified with intensive erosion and considerable transport from a distant source. The chert component in particular generally comprises 10 percent of the suite, but in some cases is up to 50 percent of the total pebble population.

The placer sand size facies are light grey coloured, coarse-grained quartz arenites. The cement is mostly silica with a very small proportion of phyllosilicates in the matrix. The sand facies occurs interstitially in clast supported conglomerate, as the matrix of matrix supported conglomerates and also as beds interlayered with conglomerates. These arenites are, on the basis of the low phyllosilicate content, more mature than non-placer arenites either above or below the placers.

Geometry

The external geometry of the placers is generally tabular and sheetlike with a slightly irregular channelled base and a flat top. The basal channels represent an interconnecting system of broad, low sinuosity ribbon bodies up to 500m wide and 4.5km long (Minter, 1985). In some instances the placers are confined within channelways as discrete shoestring orebodies.

Internally, the gravel facies occur as single pebble layers on scour surfaces or as sheets that have accumulated in increments of up to 20cm thick. Although placer bodies average 0.5m in total thickness there are cases where thicknesses exceed 6m. The gravel facies also occur in planar and trough cross-bedded forms in a sandy matrix and the arenite is either horizontally or trough cross-bedded and rarely planar cross-bedded. Bedding planes in longitudinal exposures down the paleodip are crudely horizontal but transverse sections indicate irregular lenticular individual beds describing bedforms preserved within channels.

Deposition

The sequence of events recorded in the placers from scour surface to gravel unit and to crossbedded sand facies indicates both rapid and extreme variations in flow velocity from erosional flood stage to accumulation during waning flow. Grain size changes reflect lateral as well as vertical changes in the flow regime. The environment of deposition of the placer sediment appears always to have been of a fluvial nature in which unimodal transport by shallow transient streams prevailed (Smith and Minter, 1980).

Kerogen

Carbon seams are associated with some of the Witwatersrand placers. Spatially, it characteristically forms drapes and specks on channel floors and other scour surfaces, encapsulating gravel lag, on slipfaces of planar cross-beds (Minter, 1978), and draping gravel bars (Smith and Minter, 1980). It is composed mainly of hydrocarbons with organic sulphur and oxygen compounds (Zumberge et al., 1978). Rich concentrates of gold, uraninite and other detrital heavy minerals are associated with the kerogen, particularly on major scour surfaces, probably because these sites were surfaces of minimal aggradation on which heavy mineral traction carpets had had an opportunity to accumulate and upon which algal mats could develop without being killed off by rapid burial. Mossman and Dyer (1985), have also suggested that the kerogen was syngenetic and probably derived from prokaryotic microbial mats. They believe that bacteriological processes, such as the production of organic acids and / or sulphur cycle intermediates, may have played a role in the solution and redistribution of gold; whether from source rocks in addition to associated detrital grains is a mute point. Certainly, kerogen not associated with major scour surfaces are not well mineralised with gold. A preferred interpretation is that the role played by the kerogen is minor and localised. Areally, kerogen is more prevalent in the more sandy distal types of placers like the Vaal, Basal and Carbon Leader placers (Minter, 1978). Patches and disaggregated grains, however do occur in more proximal parts of placers but do not appear to have been as well preserved, probably because of the relatively higher turbulence that must have prevailed.

Heavy Mineral Fraction

About forty different detrital minerals have been identified in the Witwatersrand placers (Feather and Koen, 1975). The most common, or economically important, in order of abundance, are pyrite, chromite, leucoxene (after ilmenite), uraninite, zircon, gold and platinoids. They are concentrated in the placers on scour surfaces, particularly where trapped by pebble lags, and within clast-supported conglomerates (Minter, 1978). Also, on foreset and planar bedding surfaces in the sand facies. The bottom and top surfaces of the placer units are generally better mineralized, representing the lowest surface of degradation and the topmost winnowed surface. In relatively distal deposits, concentrations of zircon (400ppm), uraninite (1400ppm) and chromite (3000ppm) are common.

The relative proportions of these detrital placer minerals are generally related. The best documented ratios for example are those between gold and uranium, in which their log/log correlation exceeds 60 percent (Smith and Minter, 1980). Their respective ratios depend on the sedimentary facies in which they occur and also on their position in the depositional area. Uranium contents generally increase down

paleoslope. Furthermore, the log/log coefficients of correlation between gold and uranium appear to be different for each placer (Robb and Meyer, 1985). This is supporting evidence for a common placer origin and it seems likely that hydraulic sorting processes and specific original size distributions of the minerals supplied were important factors in each case.

Mineralogical research in recent years has focussed predominantly on the composition of allogenic pyrite, chromite, uranium minerals and gold. According to Hallbauer et al. (1986), and to Meyer et al. (1985), it seems that the Co/Ni ratio of detrital pyrites from the Barberton greenstone belt are an order of magnitude less than those from the Witwatersrand, but are more comparable with pyrite from the Murchison and Pietersburg greenstone belts and from the hinterland granites.

The detrital chromites display a range in composition from low to high Cr content but the frequency distribution of these varieties in the Central Rand placers indicates a dominance of ultramafic source rocks.

The high abundance of leucoxene after ilmenite in the placers is generally overlooked, and certainly represents the "missing" black sand component that is usually queried. The Ti-rich leucoxene played an important role in capturing remobilised uranium during the burial history of the placers but shows little sign of having been pyritised.

Uranium in the form of uraninite is better preserved in the kerogen but in the placer matrix it is coated by gersdorfite or titania, which outline their original shapes. These relic uraninites, authigenic uraniferous leucoxene, brannerite and coffinite all indicate that hexavalent uranium reacted with surface or ground waters (Smits, 1986). The repeated exposure of uraninite concentrates to weathering at positions of onlapping unconformities in the Welkom goldfield, demonstrates this process because the final placer of the sequence there is barren of original uraninite (Minter et al., in press).

The silver and mercury content of gold particles in the placers has also aroused interest. Mercury contents of between 1 and 5 percent in Witwatersrand gold is well above the trace amounts detected in Barberton gold but resembles that from the Murchison Belt, thus supporting conclusions concerning source terrain made from the Co/Ni ratios in pyrite. Oberthur and Saager (1986) contend that the mercury content has been derived from the host rocks during metamorphism and therefore that it does not have a bearing on provenance of the gold. The silver content of gold particles has also been used by Hallbauer in an attempt to fingerprint source areas but 1000 analyses of an extensive sample set across the entire Vaal Reef placer by Reid et al. (in press), indicates a complex heterogeneity of composition. Individual particles are homogeneous with respect to both silver and mercury content, but the variance between particles, whether within or alongside pyrite or quartz or kerogen is the same on both a local and regional scale. It will be necessary to establish what conditions prevailed within small cells before being able to understand the nature of the gold composition. What does seem clear, from the spatial distribution of gold particles in the placers, is that the gold has not migrated significantly away from surfaces where it was originally deposited.

Metamorphism

Early shale mineralogy studies by Fuller (1958), during which pyrophyllite was first identified in Witwatersrand sedimentary rocks, followed by numerous unpublished theses on Precambrian shales presented at the University of Cape Town, and more recent work by Phillips (1986), indicates clearly that the Witwatersrand rocks have reached a lower greenschist facies of metamorphism and that temperatures during burial probably reached 300 degrees Centigrade at 1 kb.

The effect fluids generated by dewatering and metamorphism had on mineralization has not been properly assessed. From the evidence described above it does not seem that the primary arrangement of the heavy mineral concentrates has been significantly changed. Indeed, it is a surprise to see how well the most detailed primary structures are preserved in such old rocks.

Structural Control

To date, no fault control on Central Rand sedimentation has been demonstrated. The faulting prevalent throughout the orebodies is all younger than middle Ventersdorp and postdates lithification of the strata.

It is quite clear at this stage, however, that a compressive model is valid (Minter et al., 1986), and that folding took place synchronously with sedimentation. In the Welkom goldfield this force was from the west and intensified during the deposition of the last Central Rand sediments, to the extent of overturning the strata.

Suggestions by Winter (1986), that the Central Rand depositary represents a cratonic foreland basin in a continental back-arc plate tectonic setting is partly based on the folding mentioned above. However, it has not been unequivocally demonstrated that the thrust faults invoked exist. The results

of current vibroseis surveys, once released and supported by diamond drilling, may well resolve these concepts.

Genesis

To appreciate the strength of the concept of a placer origin for the Witwatersrand gold and uranium orebodies it is necessary to understand in detail the sedimentary nature of the deposits. These characteristics are recognised in modern placers and have been reproduced experimentally in flumes. The dynamics of sediment movement are incompletely understood but significant progress is being made and many of the previously empirical relationships observed and the efficiency by which very high specific gravity minerals are concentrated can now be explained (Slingerland and Smith, 1986). Without a sound sedimentological approach to ore genesis, an examination for instance, of the present mineralogy in Witwatersrand ores, is frustrated by a confusing overprint of subsequent metamorphic events.

The source of such a prodigeous supply of gold is of course still an enigma. The clastic composition of the placer sediments clearly indicates a provenance dominated by Archean granitoids containing a significant component of greenstone. The variety of detrital minerals in the placers supports this concept and the chemical composition of the associated shales also indicates that both mafic and acid igneous rocks contributed to the sediment supply. Mineralogical research aimed at matching Witwatersrand gold and pyrite compositions with those in the Archean greenstones and granitoids have produced mixed results. It is not clear to what extent subsequent alteration has modified the original compositions. A notable concept that has emerged, however, is that granitoids adjacent to the basin may possibly have been altered by late hydrothermal activity during development of the Central Rand deposits and that roof zones enriched in gold and uranium were stripped by erosion and supplied to the basin (Robb and Meyer, 1985). The possibility that hydrothermal fluids may have produced sea floor pyritic, cherty, gold-rich exhalitive deposits associated with basaltic volcanism proximal to basin edge faults has been proposed by Hutchinson and Viljoen (1986) as an alternative source. Supporting evidence for their proposition is that iron-rich shales lower in the Witwatersrand stratigraphy, which would have been deposited distal to the basin margin, contain anomalous gold contents and may represent facies equivalents of the eroded proximal gold-rich units they propose. The main problem lies in accounting for the shear quantity of not only the gold, but also of the pyrite in the placers.

References

Armstrong, R. A., Compston, W., Retief, E. A., and Welke, H. J., 1986, "Ages and Isotopic Evolution of the Ventersdorp Volcanics," Abstracts Volume, Geocongress'86, Geological Society of South Africa, Johannesburg, pp. 89-92.

Buck, S. G. and Minter, W. E. L., 1985, "Placer Formation by Fluvial Degradation of an Alluvial Fan Sequence: the Proterozoic Carbon Leader Placer, Witwatersrand Supergroup, South Africa," Journal of Geological Society London, Vol. 142, pp. 757-764.

Feather, C. E., and Koen, G. M., 1975, "The Mineralogy of the Witwatersrand Reefs," Minerals, Science and Engineering, Vol. 7, pp. 189-224.

Fuller, A. O., 1958, "A Contribution to the Petrology of the Witwatersrand System," Transactions of the Geological Society of South Africa, Vol. 61, pp. 10-50.

Hallbauer, D. K., Klemd, R., and von Gehlen, K., 1986, "A Provenance Model for the Witwatersrand Gold and Uranium Mineralization and its Implications in the Recognition of Gold Distribution Patterns in Reefs,"Abstracts Volume, Geocongress'86, Geological Society of South Africa, Johannesburg, pp.133-137.

Hutchinson, R. W., and Viljoen, R. P., 1986, "Re-evaluation of Gold Source in Witwatersrand Ores," Abstracts Volume, Geocongress'86, Geological Society of South Africa, Johannesburg, pp. 145-148.

Meyer, M., Oberthur, Th., Robb, L. J., Saager, R., and Stupp, H. D., 1985, "Ni, Co, and Au Contents of Pyrites from Archaean Granite-greenstone Terranes and Early Proterozoic Sedimentary Deposits in Southern Africa",Information Circular No. 176, Economic Geology Research Unit, University of the Witwatersrand, Johannesburg, 11pp.

Minter, W. E. L., 1976, "Detrital Gold, Uraninite and Pyrite Concentrations Related to Sedimentology in the Precambrian Vaal Reef Placer, Witwatersrand, South Africa," Economic Geology, Vol. 71, pp. 157-175.

Minter, W. E. L., 1978, "A Sedimentological Synthesis of Placer Gold, Uranium and Pyrite Concentrations in Proterozoic Witwatersrand Sediments," in A. D. Miall (Ed.), Fluvial Sedimentology, Canadian Society of Petroleum Geologists, Memoir 5, pp. 801-829.

Minter, W. E. L., 1985, "Very Large Ancient (2.7 Ga) Fluvial Bed Forms in the Steyn Placer, Witwatersrand,

South Africa," Abstracts Volume, 3rd International Fluvial Sedimentology Conference, Colorado State University, Fort Collins, p. 29.

Minter, W. E. L., Hill, W. C. N., Kidger, R. J., Kingsley, C. S., and Snowden, P. A., 1986, "The Welkom Goldfield," in C. R. Anhauesser and S. Maske (Eds.), Mineral Deposits of Southern Africa, Vol. 1, Geological Society of South Africa, Johannesburg, pp. 497-539.

Minter, W.E.L., Feather, C. E., Glatthaar, C. W., (in press), "Sedimentological and Mineralogical Aspects of the Newly Discovered Witwatersrand Deposit that Reflects Proterozoic Weathering, Welkom Goldfield, South Africa,"Economic Geology.

Mossman, D. J., and Dyer, B. D., 1985, "The Geochemistry of Witwatersrand-type Gold Deposits and the Possible Influence of Ancient Prokaryotic Communities on Gold Dissolution and Precipitation," Precambrian Research, Vol. 30, pp.303-319.

Oberthur, Th., and Saager, R., 1986, "Silver and Mercury in Gold Particles from the Proterozoic Witwatersrand Placer Deposits of South Africa: Metallogenic and Geochemical Implications," Economic Geology, Vol. 81, pp. 20-31.

Papenfus, J. A., 1957, "The Geology of the Government Gold Mining Areas and New State Areas, With Particular Reference to Channel Sediments and the Origin of Minerals of Economic Importance," Unpublished Ph.D. Thesis, University of South Africa, Pretoria.

Phillips, G. N., 1986, "Metamorphism of the Witwatersrand - Fact of Fiction," Abstract Volume, Geocongress'86, Geological Society of South Africa, Johannesburg, pp.329-334.

Pretorius, D. A., 1976, "The Nature of the Witwatersrand Gold-Uranium Deposits," In K. H. Wolf (Ed.), Handbook of Strata-bound and Stratiform Ore Deposits, Vol. 7, Elsevier, Amsterdam, pp. 29-88.

Reid, A. M., le Roex, A. P., and Minter, W. E. L., (in press), "Composition of Gold Grains in the Vaal Placer, Klerksdorp, South Africa," Mineralium Deposita.

Robb, L. J., and Meyer, M., 1985, "The Nature of the Witwatersrand Hinterland: Conjectures on the Source-area Problem," Information Circular No. 178, Economic Geology Research Unit, University of the Witwatersrand, Johannesburg, p. 25.

Slingerland, R., and Smith, N. D., 1986, "Occurrence and Formation of Water-laid Placers," Annual Review of Earth and Planetary Sciences, Vol. 14, pp. 113-147.

Smith, N. D., and Minter, W. E. L., 1980, "Sedimentological Controls of Gold and Uranium in Two Witwatersrand Paleoplacers," Economic Geology, Vol. 75, pp. 1-14.

Smits, G., 1986, "The Mobility of Uranium During Witwatersrand Times,"Abstracts Volume, Geocongress'86, Geological Society of South Africa, Johannesburg, pp. 203-206.

Tankard, A. J., Jackson, M. P. A., Eriksson, K. A., Hobday, D. K., Hunter, D. R., and Minter, W. E. L., 1982, "The Golden Proterozoic," Crustal Evolution of Southern Africa, 1st ed., Springer-Verlag, New York, pp. 115-150.

Winter, H. de la R., 1986, "Cratonic Foreland Model for Witwatersrand Basin Development in a Continental Back-arc Plate-tectonic Setting," Abstracts Volume, Geocongress'86, Geological Society of South Africa, Johannesburg, pp. 75-80.

Zumberge, J. E., Sigleo, A. C., and Nagy, B., 1978, "Molecular and Elemental Analysis of the Carbonaceous Matter in the Gold and Uranium Bearing Vaal Reef Carbon Seams, Witwatersrand Sequence," Minerals, Science and Engineering, Vol. 10, pp.223-246.

SOCIETY OF MINING ENGINEERS

P.O. BOX 625002, LITTLETON, COLORADO 80162-5002

PREPRINT NUMBER

88-20

CHEMICAL AND STRUCTURAL BOUNDARIES, AND THE LOCALIZATION OF WITWATERSRAND GOLD

G. N. Phillips

R. E. Myers

University of the Witwatersrand
Witwatersrand, South Africa

For presentation at the SME Annual Meeting
Phoenix, Arizona - January 25-28, 1988

Permission is hereby given to publish with appropriate acknowledgments, excerpts or summaries not to exceed one-fourth of the entire text of the paper. Permission to print in more extended form subsequent to publication by the Society must be obtained from the Executive Director of the Society of Mining Engineers.

If and when this paper is published by the Society of Mining Engineers, it may embody certain changes made by agreement between the Technical Publications Committee and the author, so that the form in which it appears is not necessarily that in which it may be published later.

These preprints are available for sale. Mail orders to PREPRINTS, Society of Mining Engineers, P.O. Box 625002, Littleton, Colorado 80162-5002

PREPRINT AVAILABILITY LIST IS PUBLISHED PERIODICALLY IN MINING ENGINEERING

Chemical and structural boundaries, and the localization of Witwatersrand gold

G Neil Phillips* and Russell E Myers
Department of Geology,
University of the Witwatersrand,
Wits, 2050, S Africa.

*Current address: Box 1037,
Kalgoorlie, WA, Australia

Abstract The Witwatersrand reefs provide excellent examples of chemical and structural control on gold distribution. All mined gold appears to come from a carbon - gold association and/or Fe-S-Au association, and also from immediately above *or* below unconformity surfaces.

A total reliance on the current syngenetic model for Witwatersrand gold does not appear to be justified from the accumulated data and may be responsible for missed opportunities during exploration: consideration of other models is suggested especially where they better fit the data. The stratabound nature of Witwatersrand gold is critical to mining, but is emphasized in syngenetic models to the virtual exclusion of many other important observations. By analogy with other deposit types, stratabound character is probably a poor guide to genesis.

The placer model was reputed to predict gold distribution based on sedimentological parameters: such parameters are critical in our epigenetic model also, but for a quite different reason. Petrological studies of the Witwatersrand deposits suggest that sulfur and gold may have been introduced after burial, by fluids guided by faults, bedding planes, unconformities and other mechanical heterogeneities. In this epigenetic model, the original chemical nature of the sequence controlled deposition of gold, with zones rich in iron and carbon as preferred sites: these areas include carbonaceous matter, heavy mineral accumulations in conglomerates, and possibly Fe-rich concentrations on unconformity surfaces. The historic objections to an epigenetic model that include impermeability of rocks at the metamorphic stage, lack of adequate fluid flux, lack of alteration and inability of fluids to transport sufficient gold, may not be valid in the light of recent work.

As the future removal of reefs concentrates more on selective mining at marginal grade, the need for accurate geological models will increase: it is essential to commence a collection of the data that will discriminate alternative models.

Introduction

The Witwatersrand region has produced over 40,000 tonnes of Au since its discovery in 1886 by the prospector, George Harrison. This production not only represents 40% of all the gold ever mined, but also accounts for the Witwatersrand's pre-eminence as a gold producer for virtually all this century, and provides over $US 5 billion foreign exchange for South Africa annually. Current production of 680 tonnes Au comes from about 40 operating mines.

Gold is mined around the margins of the 200 X 100km Witwatersrand Basin from a several-kilometer thick package of metasediments dominated by quartzites and conglomerates, with minor shales and basalt. At very discrete positions within this package, gold is extracted from planar "reefs" of 0.1 to 2m thickness, and areal dimensions of 1-10km by 1-50km. Although grades are high in several mines (10-15ppm Au), it is the lateral and down-dip persistence of the reefs that allows the mining of grades of 5ppm Au and lower, at depths of 3-4km below the surface.

Groups of spatially-related mines exploiting common reef horizons form the basis of the subdivision into the main goldfields arranged concentrically around the Vredefort Dome (Welkom, Klerksdorp, Carletonville, West Rand, Central Rand, East Rand, Evander, Fig. 1); however, recent exploration outside these goldfields is demonstrating continuity between certain fields rather than confirming their individuality as originally proposed.

Historically, two origins have been supported for the Witwatersrand gold: a syngenetic origin (placer model) favoring deposition of gold at the same time as enclosing sediments, and an epigenetic origin ("hydrothermal") favoring later introduction of the gold. For many years the availability of rich and continuous reefs meant that genetic models played a negligible part during exploitation. The anticipation of decreasing grade leading to more selective mining in coming years provides the opportunity for more geological input into the direction of exploration and mining.

Mining engineers were some of the first to point out the similarity of Witwatersrand reefs to many known epigenetic ore deposits in the northern hemisphere. However, the placer model has been favored in recent years by most geologists, particularly those from South Africa. This conference session provides an ideal time to "re-discover" the chemical and structural controls displayed by Witwatersrand reefs, and reflect on their potential importance to exploration and mining.

This paper discusses the chemical associations in Witwatersrand reefs, and possible structural controls on the reefs. These data are discussed in terms of the syngenetic and epigenetic origins for the gold. Some implications for mining are contemplated.

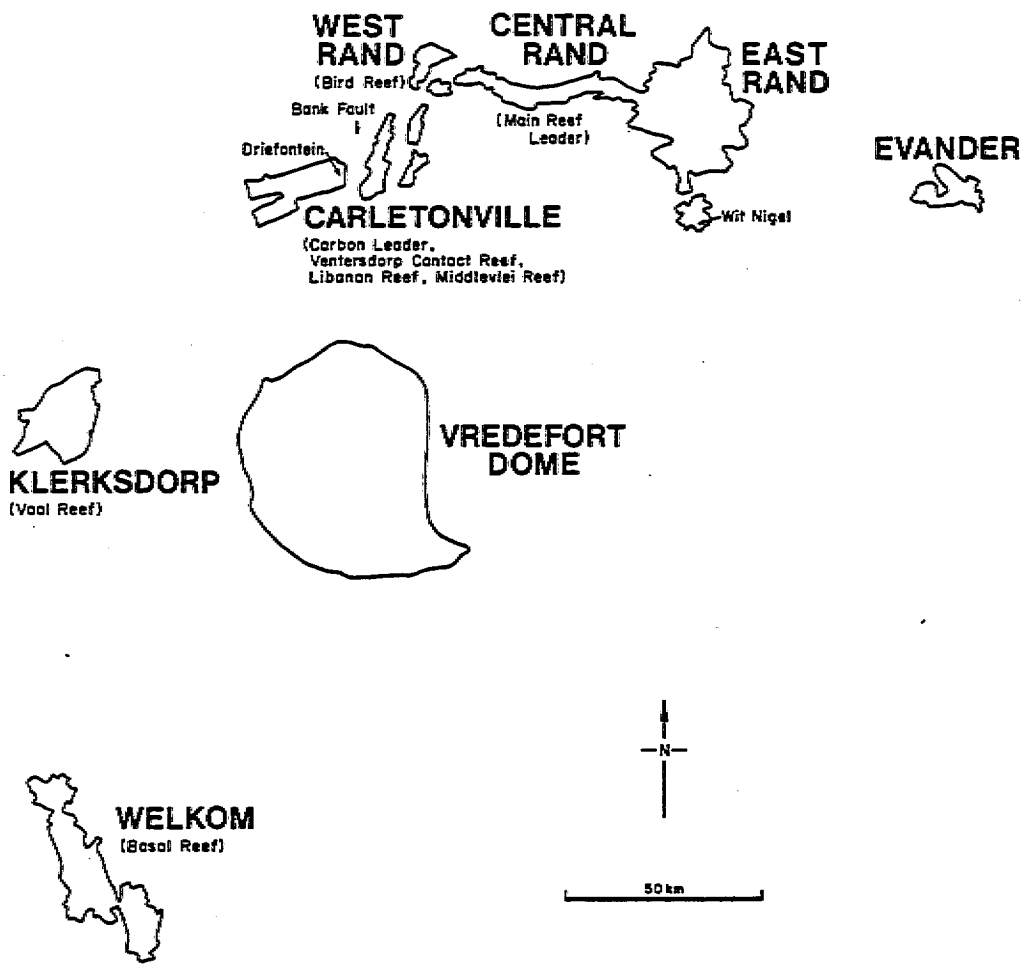
Geological setting

Given the age of the Witwatersrand Basin (around 2.7-2.8 billion years) and the thickness of overlying rocks (many km), it is not surprising that deformation and metamorphism have substantially modified the sequence after burial. Mineral assemblages indicate that temperatures of 300-400°C were widespread in all the goldfields during metamorphism at a time when the presently exposed rocks were 3-10km below the surface (Phillips, 1987).

Deformation has produced extensive faulting, shear zones, overturning of parts of the succession, folding and local brecciation.

Certain effects of the deformation are relatively easily removed during stratigraphic reconstruction (e.g. local faults), but most studies have not removed the influence of metamorphism. Temperatures in excess of 300°C provided the ideal opportunity for new mineral growth, the readjustment of existing mineral compositions, and the migration of aqueous fluids through the rock pile (Fyfe et al., 1975). The large-scale movement of elements at this stage is best recorded in thin shale horizons, but is being documented in all other lithologies.

Although some textural features such as grainsize and crossbedding are well-preserved through metamorphism, mineral compositions are easily reset and elements can readily migrate.



1. Map of the Witwatersrand Basin showing the major goldfields, the areas in which different reefs are mined, and location of mines mentioned in the text.

Without a detailed analysis of metamorphism, existing mineralogical studies are more likely to be documenting this metamorphic event rather than achieving their aim of characterizing sedimentary deposition.

<u>Witwatersrand reefs:</u> Witwatersrand "reefs", being the mined parts of the metasedimentary succession, include both quartz pebble conglomerates and carbon seams. These two reef types may occur on the one stratigraphic horizon and grade laterally into one another.

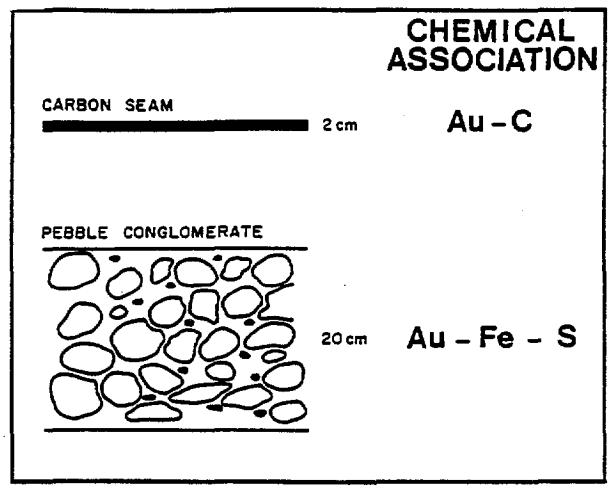
Many reef horizons form at the base of very distinctive lithological packages around 1-2m thick. The packages comprise all, or part, of: an unconformity surface overlain by a carbon seam, auriferous pyritiferous pebble conglomerate, highly mature quartzite and a shale or argillaceous quartzite. Examples that account for 75% of alltime Witwatersrand gold production, include: Basal Reef, Vaal Reef, Carbon Leader and the Main Reef Leader. The major exception is the Ventersdorp Contact Reef which is immediately overlain by mafic to ultramafic lavas of the Ventersdorp Supergroup, but is still on a major unconformity.

The auriferous quartz-pebble conglomerate reefs vary from extremely mature quartz-rich conglomerates such as the Vaal Reef, to rather immature conglomerates with 10-30% of lithic clasts in a mixed matrix (e.g. Steyn placer of the Basal Reef). The spectrum of lithological types covered by the conglomeratic reefs provides a virtually complete overlap with the thicker conglomeratic packages that are devoid of economic gold but form a significant part of the succession. Certain lithological characteristics are associated with economic conglomerate reefs within a single mine or reef horizon, but more importantly, no unique or special conglomerate type appears universally favorable for gold on the scale of the Witwatersrand Basin.

Although reef horizons thicken and thin in response to what are inferred as original channels, continuous stoping in many mines has demonstrated that economic gold may continue across these sedimentary changes (e.g. Krapez, 1985). The overall form of the reefs is distinctly planar, but within these planes there are linear zones of higher grade, referred to as payshoots.

Chemical associations within Witwatersrand reefs

The importance of chemical boundaries is emphasized by two chemical (and mineralogical) associations in



2. Summary of the chemical associations pertinent to Witwatersrand reefs: the gold - carbon association (top) is characterized by some extremely high gold grades and economic uranium, the gold-Fe-S association usually involves pyrite, but minor pyrrhotite is common in the Ventersdorp Contact Reef. The two associations are not mutually exclusive, and may grade into one another.

Witwatersrand reefs (Fig. 2). An Au-C association is well-displayed in the carbon seam reefs, whereas an Au-S-Fe association is typical of the pebble conglomerate reefs. These associations include less-well documented B and As enrichment, also.

The carbon-bearing reefs (Au-C association) are very thin planar sheets extending several hundred square kilometers and providing the most productive horizons in several goldfields (e.g. parts of the Basal Reef in Welkom, Vaal Reef in Klerksdorp, Carbon Leader in Carletonville, Main Reef Leader in the Central Rand). Although these carbon-bearing reefs grade across strike into conglomeratic reefs, in their best development they are not conglomerates at all, but rather carbon seams of a few centimeters thickness resting between footwall and hangingwall of quartzite. Disseminated carbon ("flyspeck" carbon) forming small blebs rather than a carbon seam may be intermixed with conglomerate.

The pyritiferous conglomerates are generally of lower grade and mined over greater thickness than the carbon-bearing reefs. A well-defined Au-S-Fe association is recorded basinwide, and although pyrite may not be directly correlated with gold, areas without iron-sulfide (or carbon, see above) are rarely if ever mined for gold, and conglomerates with high gold grades usually have abundant pyrite (e.g. the Ventersdorp Contact Reef at

East Driefontein mine has abundant pyrite and rich gold grades, whereas the subordinate reefs in the lower Witwatersrand succession at Afrikaaner Lease in the Klerksdorp goldfield have minor pyrite and marginal gold grades). Interestingly, the chemical associations extend to all other lithologies in the Witwatersrand: there appears to be a correlation between pyrite and anomalous gold in shales, quartzites, dikes and lava flows. Much of the pyrite in the upper Witwatersrand succession is idiomorphic ("recrystallized") and inferred by most workers to be metamorphic in age: the origin of the pyrite types in the reefs is more controversial.

One of the more important elements in the carbon seam reefs is uranium, and few if any occurrences are recorded of carbon without anomalous uranium, or uranium without carbon. The age relations between carbon and uranium still appear to be uncertain, regardless of one's preferred origin for the gold.

We know of no mined reef that does not exhibit a Au-C and/or Au-Fe-S chemical association.

Structural boundaries and their relation to reefs

Structural boundaries are manifest in several ways within the Witwatersrand reefs and their surrounding packages. Although some of these expressions, such as unconformities, have been recognized for several years, others are overlooked because of the methods of data collection (Fig. 3).

All the major Witwatersrand reefs lie on significant unconformities (Fig. 3a), and in places the erosion of many hundreds of meters of footwall can be demonstrated (e.g. Ventersdorp Contact Reef at the top of the upper Witwatersrand succession lies directly on lower Witwatersrand rocks in the Driefontein mines, representing the loss of kilometers of sequence). Because of these unconformities, the footwall lithology to reefs can comprise virtually any rock type in the succession; but footwall lithology appears to be related to gold grade in some areas (e.g. Kimberley Reef in Evander mines, Ventersdorp Contact Reef in Carletonville mines).

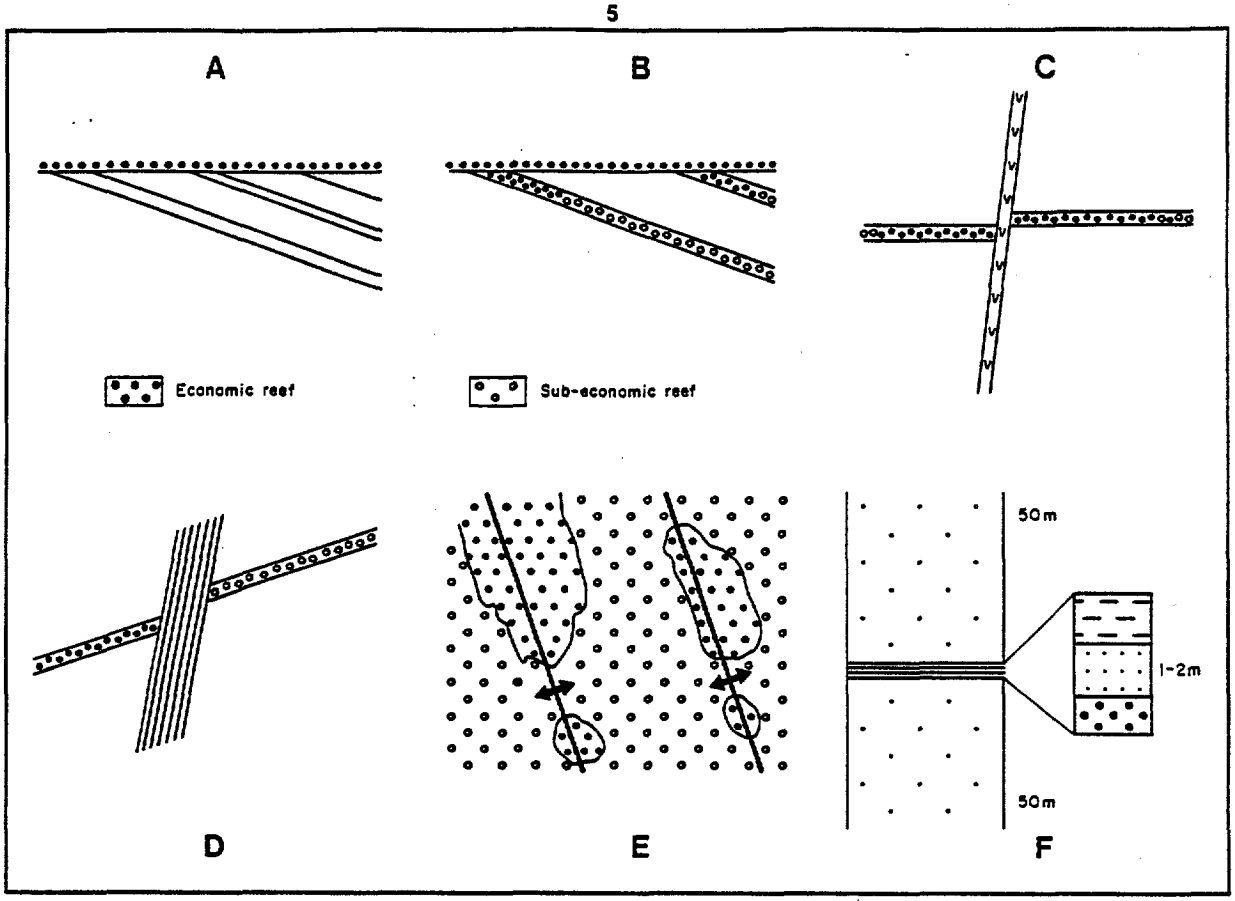
Unconformities that truncate reefs are important to the mining of certain horizons in the Carletonville goldfield (Fig. 3b). The Libanon reef is only economically mineralized within 100-200m of the overlying Ventersdorp Contact Reef and its unconformity. Libanon Reef is truncated by the base of the VCR and no major lithological changes have been documented downdip that coincide with the order-of-magnitude change in gold grade. This feature is so important on some mines that it influences mine planning and calculation of reserves, however it is hardly mentioned in the geological literature.

Dikes commonly mark changes in gold grade of certain reef horizons (Fig. 3c), and this is usually attributed to the remobilization effects of the hot magma. The extent of gold "redistribution" up to 30m from some 1-10m thick dikes suggests there may be more to the gold distribution pattern than simply thermal effects.

Major faults mark the transition of economic to uneconomic zones along several reef horizons. The Bank Fault separates highly mineralized Carbon Leader of the main Carletonville goldfield from a distinctly less mineralized to marginal Carbon Leader reef at the same stratigraphic horizon. On a smaller scale, we have noted examples of gold grade increases as reefs approach a fault or zone of intense faulting in more than half the mines (Fig. 3d).

Fold axes, especially in the East Rand goldfield, define linear zones that coincide with higher grade "payshoots" on certain reef horizons (Fig. 3e). Although many of these mines are now closed, at least one such fold is exposed at Wit Nigel mine, and demonstrates virtually no change in thickness of the conglomeratic reef across the anticline or adjacent syncline (0.5 to 1.5 m thick) even though an important pay shoot follows the anticlinal zone. Contrary examples of substantial thickness changes across folds are also known, and are interpreted as syn-sedimentary in origin. However, too often syn-sedimentary timing of folding is ascribed on the basis of anticlinal control on gold grades, rather than a more rigorous demonstration of timing based on thickness variations.

The reef packages represent highly heterogeneous intervals (2 m thickness of conglomerate, quartzite and shale) that are commonly the sites of preferential accommodation of deformation (Fig. 3f). The thin shaly units, in particular, are very high strain zones compared to the 10s to 100s m thick quartzite units above and below the reef packages. The reef packages have a considerably higher density of quartz veins, pressure solution features in the conglomerates, strong alteration of many clasts and bedding-parallel zones of foliation. Pseudotachylites, mylonites, shear zones and numerous smaller faults are regularly encountered in mining of these horizons, and suggest an important role of the reef packages as foci of strain and fluids during deformation.



3. Schematic summary of structural associations displayed by Witwatersrand reefs. (a) Unconformity surfaces are very strongly correlated with economic gold reefs; e.g. every major reef. (b) Subeconomic reefs may become economic within 200m of overlying unconformities; e.g. Libanon Reef below Ventersdorp Contact Reef. (c) Gold grades may increase considerably for many metres around narrow dikes; e.g. Middlevlei Reef. (d) Economic reef horizons may become sub-economic across minor or major faults, e.g. Carbon Leader Reef across Bank Fault, Bird Reefs across small faults in the West Rand. (e) Payshoots, as defined by better gold grades and/or selective stoping of a reef, have trends parallel to fold axes and maxima coinciding with anticlines; e.g. regional payshoot disposition in the East Rand parallel to NW-SE folds. (f) The lithological heterogeneity of the 1-2m thick reef packages between thick quartzite units makes them very important for the accommodation of strain during deformation; e.g. every major reef.

The overall importance of structural boundaries in the Witwatersrand Basin is not easy to test given the current geological data collecting methodology. Routine mapping is primarily concerned with solving fault offsets of reef, and maps superimposing gold distribution on structural features are rarely compiled. The "moving-point average" method of presenting gold grade data is smoothed with a bias and scale that eliminate much chance of noticing stope-scale relationships to structural features, and might be obscuring one of the most important features of the gold grade for any genetic discussions - its local variability and relationship to small-scale features. From a mining viewpoint this may not be important where a reef is consistently of economic grade, but becomes critical where a reef is marginal and requires selective mining.

The contouring of gold grade data is heavily influenced by sedimentological parameters, and rather than testing the validity of these parameters, assumes them. To provide a meaningful assessment of the role of structural boundaries, an important test would be to contour the same raw gold grade data with a strong structural input, and see if equally valid patterns emerge.

Discussion of the syngenetic origin for gold

The syngenetic (placer) model has much appeal in its broad similarity with modern processes occurring in fluvial systems, its simplicity, and the remarkably stratabound nature of most Witwatersrand gold. In modern river systems, gold and other heavy minerals are preferentially concentrated in the coarse detrital fraction represented by conglomerates; and the presence of anomalous gold in ancient conglomerates might have a similar origin.

The parallels between the Witwatersrand and modern placers are not enhanced by more detailed inspection, however. The shape of the Witwatersand reefs is planar as demonstrated by mining over hundreds of square kilometers; whereas modern gold placer deposits are typically linear and closely defined by river channels. This problem has been acknowledged, and the placer model proposes an alluvial fan for the Witwatersrand reef packages. Unfortunately modern analogues of this environment have not been the historic sites of placer gold mining, and instead, the old records suggest that degrading sections of rivers and even deeply incised valleys were favored by prospectors worldwide.

A further problem in drawing analogies between modern placers and the Witwatersrand is that of gold grade. Witwatersrand reefs are consistently above 1 ppm Au and commonly 10's or 100's ppm Au: these figures are 1-2 orders of magnitude higher than most modern placers (excluding local rich pockets). Even quartzites, shales and dikes are anomalous in gold at the > 1 ppm Au level in the Witwatersrand. Finally, modern systems do not provide a ready analogue for the very substantial gold accumulations in carbon seams.

The apparent simplicity of the placer model is mainly a function of it not addressing potentially conflicting data such as the chemical and structural controls on Witwatersrand reefs, and post-depositional modifications. Almost all syngenetic proponents regard the metamorphism and deformation as being peripheral to the present character of the Witwatersrand lithologies: this is not withstanding the fact that the minerals such as pyrophyllite, chloritoid and rare biotite have only been formed as a response to the elevated temperatures during metamorphism and are not detrital. Even minerals that might have detrital origins are being analysed as if their compositions *a priori* represent detrital compositions (see Phillips and Myers, 1987). If a placer model addressed post-depositional changes, the necessary readjustments to the model would be far from simple.

The stratabound nature of Witwatersrand gold, which is indirectly the historic strength of the placer model, might be re-interpreted (with considerable supporting observations) as a structural control related to unconformities. Current knowledge of the reefs suggests that unconformity surfaces may be far more significant than either the actual lithology enclosing gold mineralization or the exact stratigraphic horizon.

If a genetic model is judged by its predictive capacity, the lithological, stratigraphic and/or sedimentological predictions of the placer model based on sorting processes do have considerable value in the Witwatersrand, especially on the scale of a single reef and mine. There is no doubt that this usefulness has influenced the majority of workers, whose sphere of interest is usually a single mine or reef, to accept the placer model. With continuous reefs, there has been little incentive to determine if alternative models might be equally, or more, useful. It is the regional syntheses, however, that have neglected to adequately highlight the lack of universal applicability of any version of the placer model across the whole basin. Reef thickness, sorting, maturity, clast type and grain size parameters that have been developed successfully for one reef, are quite inapplicable for reefs in other goldfields (cf. the Steyn placer with 10-30% lithic clasts, and the Vaal Reef with < 1% lithic clasts - they are the most productive reefs on Unisel and Vaal Reefs gold mines, respectively).

The record to date of the Witwatersrand placer model when applied elsewhere in the world is far from encouraging, especially compared to porphyry copper, massive sulfide or greenstone gold models that find applicability in many terrains. This does not disprove the placer model, but should lead to a search for better alternatives.

In seriously evaluating the placer model, its apparent shortcomings and lack of generality contrast with what we suggest are universally valid features, namely the chemical associations and the relationship to structural boundaries suggested above.

Discussion of the epigenetic origin for gold

The epigenetic model has received support from textural studies of reef minerals, particularly gold; but has been challenged in the past on several aspects. These include a lack of fluid

channelways, a lack of alteration, lack of fluid flux and inability of solutions to transport enough gold.

Recent studies in the Witwatersrand Basin, however, have shown that large volumes of fluid were active during metamorphism, that temperatures and equilibrium with pyrite provided ideal conditions to transport gold, and that alteration appears to have affected every mine in every goldfield (Phillips and Myers, 1987). Studies in other terrains are demonstrating the considerable permeability of sequences during deformation and metamorphism, the importance of faults, bedding planes and dikes as fluid pathways, and the solubility of gold in hydrothermal solutions in equilibrium with pyrite (Seward, 1984). It would appear that these earlier objections to an epigenetic origin are very difficult to sustain.

There are enough examples of *stratabound* epigenetic mineralization around the world to suggest that this focal point of the placer theory also needs some reconsideration.

The strength of the epigenetic model is its ability to predict, not just explain, the chemical and structural controls on Witwatersrand reefs. Given temperatures during Witwatersrand metamorphism above 300°C, and virtually universal equilibration with pyrite, significant solubility of gold as a sulfur complex can be calculated (Seward, 1984). Areas of high fluid flux during metamorphism will reflect structurally-controlled fluid channelways, and gold deposition would be enhanced by host rock Fe destabilizing the gold-sulfur complex, and/or a reducing agent such as carbon precipitating gold.

Importantly, as the chemical association is determined by Fe and C distribution in the original succession, a stratabound deposit is actually predicted by our epigenetic model (cf. earlier "hydrothermal models" of Graton, 1930, and Davidson, 1953).

Implications for mining

During the era of Witwatersrand mining of persistent, rich reefs when reserves of a decade or longer were the norm, the need for geological models was rather subordinate to the techniques of mining. However, as high grade reserves are being depleted, and many mines turn to less persistent reefs, the need for accurate geological control increases considerably.

In marginal situations, an appreciation of structural controls could be used to effectively explore for economic patches in otherwise subeconomic horizons. Certain dikes and fault orientations might be favorable, although the data needed to test this hypothesis are not being currently collected. Further benefit could be gained from an understanding of the controls on the distribution of C and Fe (i.e. carbon and pyrite). Serious consideration should be given to the possibility that the pyrite, in particular, may not necessarily be an original component of conglomerates, but instead represents an original Fe concentration on unconformity surfaces.

Until the placer model can be properly evaluated in terms of its current deficiencies, and given the considerable predictive powers of the epigenetic model, a prudent mining policy would be to use a multiple working hypothesis, rather than adherence to one model alone.

Summary

The chemical associations of Au with C, and Au with Fe-S appear to be universal throughout the Witwatersrand Basin, and are far more general than any stratigraphic, lithological or sedimentological associations. Structural associations also appear to be significant controls on gold where they are specifically sought. However, the methods of routine data collection commonly prevent any structural associations from becoming apparent.

The strengths of the placer model have been its broad similarity to modern processes, apparent simplicity, and the stratabound gold distribution. However, there are significant divergences from modern processes in detail. The simplicity is deceptive as the model disregards important post-depositional processes, and stratabound character of ore deposits is not a critical guide to genesis.

The strength of the epigenetic model is its capacity to predict the chemical and structural associations: in contrast, the placer model would not predict these features, and has considerable trouble explaining some of them. Many of the criticisms of the epigenetic model appear invalid in terms of the current understanding of the role of fluids in metamorphic sequences.

We suggest that further collection of structural data might indicate that "unconformity-related gold" may be a reasonable description of Witwatersrand-type deposits.

Acknowledgments

Many colleagues have readily contributed their ideas to this study; not the least being Tony Cadle, Dieter Hallbauer, Sara Kerr, Judy Palmer, Kevin

Palmer, Zollie Ramos, Ray Smith and Richard Spencer. Anne Stewart drafted the figures. The support and cooperation of the Chamber of Mines and University of Witwatersrand are acknowledged. This study was only possible because the management and geologists of the forty gold mines were so accommodating during our underground visits.

References

Davidson, C.F., 1953, "The gold-uranium ores of the Witwatersrand", The Mining Magazine, February 1953, 73-85.

Fyfe, W.S., Price, N.J. and Thompson, A.B., 1975, "Fluids in the Earth's crust", Elsevier, Amsterdam, 382pp.

Graton, L.C., 1930, "Hydrothermal origin of the Rand gold deposits: Testimony of the conglomerates", Econ. Geol.,25, supp. to no.3, 1930.

Krapez, B., 1985, "The Ventersdorp Contact placer: a gold-pyrite placer of stream and debris-flow origins from the Archaean Witwatersrand Basin of South Africa," Sedimentology, vol. 32, 223-234.

Phillips, G.N., 1987, "Metamorphism of the Witwatersrand gold fields: conditions during peak metamorphism," Journal of Metamorphic Geology, vol. 5, in press.

Phillips, G.N. and Myers, R.E., 1987, "Mineralogy of the Witwatersrand reef components: a review and some implications for exploration", Recent advances in understanding Precambrian gold deposits. Geology Department & Extension Service, University of Western Australia, Perth, publ. 11, 341-354.

Seward, T.M., 1984, "The transport and deposition of gold in hydrothermal systems," Gold '82: The Geology, Geochemistry and Genesis of Gold Deposits. Balkema, Rotterdam, pp.165-181.