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

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ASARCO

Southwestern Exploration Division

November 6, 1986

CONFIDENTIAL

F. T. Graybeal
New York Office

Precambrian Research, etc.
Gold

Dear Fred:

In reviewing the files prior to writing on the Mesquite Mine (10-27-86), I came across your letter of 9-1-82 to Jim Sell entitled "Cargo Muchacho Mountains Gold Prospect," concerning information in a George Stathis memo of 7-30-82.

Stathis proposed that the essentially trace gold obtained by Watson at Padre Madre was due to analytical error (Geochem Systems Lab, Orange, CA) ---- a problem which George had heard of (confirmed by Jim Briscoe during our recent AGS field trip). I suspect this may have been the reason Watson didn't file a report on samples that he presumably took from the Mesquite area ---- which he must have seen since he described bedrock and mineralization there (Report on Chocolate Mt. Placers, 6-14-68).

In a blind note to Kurtz in your above-mentioned letter to Sell, a literature search for aluminous horizons in the Precambrian was proposed. Since, as you state, aluminous schists are presumably the metamorphosed equivalent of acid hot springs systems, efforts to identify such in structurally or otherwise favorable environments would appear to be justified. Incidentally, I had not previously seen either your letter or the Stathis memo ---- perhaps your proposal was vetoed.

Under conditions of the past few years, wherein the exploration budget has been squeezed almost to the point of strangulation, essentially no funds have been available for examination of "new" prospects. Here I might mention that since May 1985, I have recommended field investigation of some 55 areas (for possible disseminated gold deposits adjacent to or near placers) in Western USA. In as far as I can determine from information obtainable here, only one (Wind River Fm., Wyo.) has been examined. Hopefully, more funds will be made available now that the Company has edged into the black.

J. H. Courtright

J. H. Courtright

(xtra)

September 1, 1982

Mr. James D. Sell, Manager
Southwestern Exploration Division
Tucson Office

Cargo Muchacho Mountains
Gold Prospects
Imperial County, California

Dear Mr. Sell:

I read the July 30 memo by Mr. Stathis on the above area with great interest. Mr. Stathis notes that Watson and Briscoe collected samples in the Padre Madre Mine area which showed no gold values. Mr. Stathis' conclusion that the negative response was due to laboratory error is significant, because as I recall we did a substantial amount of work in the Mohave region in the period 1965-1970. It might be useful to review all work done during this period of time, particulary work which involved the laboratory which ran the Padre Madre samples, to determine whether other areas of disseminated mineralization (pyrite or other sulfide) were encountered which later returned negative precious metal analyses.

Mr. Stathis also notes that mineralization at the Tumco Mine appears to be stratigraphically controlled. Stratigraphic control of gold mineralization is hardly new, but I'm not aware that this type of control is well documented in the Precambrian of the Mohave region. I note the Tumco Mine is 2½ miles northwest of the Newmont discovery at the Padre Madre Mine and I assume we have made a search of land status in this area to determine whether or not Asarco might become involved. Mr. Stathis suggests that the gold at Tumco, Padre Madre, and other gold prospects in this area may have been derived from syngenetic gold in Precambrian sedimentary rocks. He cites no particular evidence for this, but it might be of interest to him to know that I recall several odd-looking schists in the Yellow Aster pit at Randsburg (odd-looking because they were somewhat coarse grained and may have contained pyroxene and mica - an unusual assemblage) which contained disseminated fuchsite. The presence of fuchsite (or mariposite) is well established in many gold districts throughout the world and it occurred to me then that the Yellow Aster gold might have been derived from these

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of this
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EXPLORATION DEPARTMENT

mific-looking achists during emplacement of the Mesozoic granite which hosts most of the Randsburg mineralization (although I had no real evidence to support that brief thought).

Mr. Stathis also notes the presence of kyanite and pyrophylite-bearing schists in the Cargo Muchacho Mountains which he notes are geochemically barren. As you are aware, both of these minerals indicate a highly aluminous rock. Similar rocks have been mapped in the Piedmont in North Carolina, South Carolina, and Virginia, where they are interpreted to be the results of exhalative hot-spring activity. These aluminous beds have great lateral extent and are used to focus exploration work at specific stratigraphic horizons where exhalative mineralization containing massive base metals or disseminated gold might be found. Presumably, the aluminous schists are the metamorphosed equivalents of acid hot spring systems in which minerals of the advanced argillic alteration suite are commonly found. The presence of these aluminous rocks as well as Mr. Stathis' observation that some of the mineralization appears to be stratigraphically confined suggests to me that further research of this type of environment might be worthwhile. At the very least, it might be useful to review available literature for the presence of aluminous schists in the Precambrian of the Mohave region. I would be interested in your views on this subject as well as those of Mr. Stathis'.

Very truly yours

Original signed by
F. T. Graybeal

F. T. Graybeal

cc: WLKurtz

Blind Note for Mr. Kurtz - A literature review for aluminous rocks in the Precambrian of the Mohave would probably be a rather tedious job for most of the staff and I wonder whether you think Harold Courtright might be willing to pitch in on something like this. It hardly takes advantage of his vast knowledge of ore deposits but does take advantage of his careful and meticulous approach to virtually any geologic problem and I think that if he were briefed on the reasons for the search and given some literature (I can forward some data from the Piedmont) that he might develop an interest. In addition, perhaps we should extend it beyond the Mohave region to the Precambrian of all the Western USA, although I haven't discussed this with Balla, Smith, or Vikre. I like this idea better than having Harold try and recall the events which led to the discovery of Tocopala and other deposits, although Dick, who will see this blind note, might disagree. In any case, we can discuss it the next time we are in the field together. FTG

I agree and would add a similar review for other PE basins (quartzites) that might have Troy (Spar Lake) type copper-silver mi

ASARCO

Southwestern Exploration Division

July 30, 1982

To: J. D. Sell

From: G. J. Stathis

Cargo Muchacho (Hedges) Mining
District Evaluation
Cargo Muchacho Mountains
Imperial County, California

One hundred fifteen (115) rock chip and 18 rotary drill cuttings samples were collected May-June, 1982 by F. Michel and G. J. Stathis from subject district. The geochem assay results of these 133 samples were reported by Skyline Labs, Inc. of Tucson in reports dated June 28 (Job #TAJ-179), July 1 (Job #TAJ-183), and July 2 (Job #TAJ-182).

The geology of the district was discussed, in the early 1940's, by Paul Henshaw in a California Division of Mines Quarterly. The geology of the district is also discussed by Paul Morton in the 1977 Calif. Div. of Mines and Geology Report "Mines and Mineral Resources of Imperial County" (report #CR7). The Cargo Muchacho District is the site of intensive, on-going exploration activity by Newmont Mining Corp., who has at least one known gold discovery at the Padre Madre Mine area (NE¼, unsurveyed Section 19; T.15 S, R.21 E.). Mineralization occurs in Precambrian quartz-biotite-hornblende schist (Chuckwalla series?) and in quartz diorite. However, the bulk of the Newmont mineralization occurs in variably altered, well fractured, Fe stained (1 volume % or less oxidized, disseminated pyrite) schist. The schist contains gold-bearing quartz veinlets which generally parallel, rather than cross cut schistosity. At least 3 rock chip sample sites were collected in the late 1960's in the Padre Madre Mine area by ASARCO's Briscoe and Watson with no anomalous gold response. My guess would be that the negative response is probably due to lab procedure rather than sampling procedure.

Results of the 1982 reconnaissance, geochem sampling disclosed anomalous gold values at:

1. Newmont's intensive (25-100' spacing), shallow (< 100'?) drilled discovery area that trends northwest from the Padre Madre Mine. The drill area measures about 4000 by 1000 feet.

2. Tumco Mine area. Here precious metal mineralization is confined entirely to the Precambrian Tumco Fm. which strikes northeast and dips 35 to 45° southeast. Regionally, the Tumco Fm. is cut by numerous, irregular, Precambrian pegmatite dikes which range from < 1 foot to many tens of feet wide. At the Tumco Mine, mineralization is confined to certain,

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PRECAMBRIAN DISSEMINATED PYRITIC GOLD DEPOSITS

A NEW EXPLORATION MODEL

by

Phillip Anderson

1 March 1980

INTRODUCTION

During the first half of this century the U.S. exhausted all of its easily accessible gold reserves by mining small high grade veins; and, just as copper mining had to take a turn 20 years ago towards large porphry deposits, so too does the future of gold now lie in mining large, low grade deposits. The mineral exploration profession has not yet fully recognized the existence or significance of disseminated pyritic gold deposits as possible bona fide producible types of gold deposition, and that in the future they may be considered the most volumetrically and economically important source of gold in the world.

Recent escalation of gold prices has now brought these deposits well within the range of economic viability, to the extent that they may already be the most profitable type of deposit to mine. Exploration for gold has always been difficult because it is indirect, usually with the geologist substituting assays for observation. However, this need not be the case: the geologic settings and characteristics of disseminated pyritic gold deposits are highly distinctive, and a geologist aware of the significance of these earmarks can decisively explore for, and rapidly focus in on target areas in a logical, systematic and inexpensive exploration program.

The most important types of disseminated pyritic gold deposits are briefly discussed here in order to show why a detailed understanding of their depositional environments is essential to any successful exploration program for them, and that geologically blind, or by-chance exploration methods do not need to be tolerated with the application of these particular exploration concepts.

GEOLOGIC FEATURES OF THE DEPOSITS

Although some low-grade gold deposits are related to younger geologic units (Carlin, Carolina belt) the majority of the world's gold production, low grade and high grade, comes from Precambrian strata (e.g. Pretorius, 1976). In addition, some rock units which are an essential part of the disseminated pyritic gold deposit setting are most abundant in the Archean and Proterozoic sequences, background gold values are characteristically higher in Precambrian than younger rocks (M. J. Viljoen, pers. commun. 1979), and it is likely that most gold in the crust today is of Precambrian origin but has been recycled. All these factors indicate that the most logical approach in gold exploration is to concentrate on Precambrian rock sequences, recognizing that some younger environments are favourable for disseminated gold mineralization. The following discussion therefore refers to Precambrian deposits.

No pC in Nevada or under Mother Lode, in Phillippine Is, etc, etc

There are essentially three types of Precambrian disseminated pyritic gold deposits: (1) those stratigraphically confined to Precambrian volcanic rocks and directly related to the volcanic processes; (2) those in sedimentary or tuffaceous sedimentary sequences which are indirectly related to concurrent volcanic processes; and (3) those in sedimentary sequences seemingly unrelated to volcanic processes but formed by erosion of Precambrian volcanic, plutonic and sedimentary terrains. The first two types of deposits are closely analogous to proximal and distal massive sulfide deposits respectively, whereas the third type has no massive sulfide analogue because of the instability of base-metal sulfides in an erosional environment.

Each type of Precambrian disseminated pyritic gold deposit has a rock sequence or association that is highly characteristic of its occurrence, and in some cases the abundance of gold in the deposit is correlative to the abundance of a particular related rock type. For example, in the sedimentary recycled deposit, a distinctive type of igneous rock is required in the source terrain and a special conglomerate type needs to be the host before economic concentrations of gold are found. The distal-type volcanic-related, disseminated pyritic gold deposit usually has a highly characteristic array of sedimentary rocks, lithologically and geochemically, in which there always seem to be tuffaceous interbeds of a restricted composition. The proximal-volcanic disseminated pyritic gold deposit type is always found in a volcanic sequence whose components are lithologically and compositionally highly diagnostic and whose chemistry is almost invariable.

Such as

Such as

From these intimate rock associations it is clear that:

(a) the right rock associations can be used as a direct guide to the disseminated pyritic settings that are most likely to be rich in gold; and

(b) major element geochemical data spread throughout a volcanic sequence of potential interest, can also point directly to the most favourable strata for gold concentrations.

The depositional settings of the two volcanic-related disseminated pyritic gold deposits are such that it is evident that the volcanic processes themselves gave rise to the pyrite and gold mineralization in the volcanic and sedimentary rocks. In many ways the environment is similar to that depositing base-metal volcanogenic massive sulfide deposits in the volcanic build up to a fractionated, mineralized volcanic end product, except that the base-metal content of the pyritic gold stratigraphy is typically very low. Pyrite and gold substitute for the copper-lead-zinc silver association.

Known for at least 10 years

KNOWN AND PROSPECTIVE DEPOSIT EXAMPLES

A complicating factor in classifying known gold deposits or districts, but a highly significant one in reexploring them now for disseminated gold settings, is the fact that early mining worked only the vein structures that lie in the disseminated pyritic gold deposit setting, into which gold was remobilized to higher concentrations during deformation and metamorphism. A classic non-Precambrian example of this is the saddle reefs in the Bendigo-Ballaratt district of Australia, and a classic Precambrian example is the Yellowknife district, N.W.T., Canada; in fact many of the gold districts in the Precambrian of Canada are of this type.

Known for 10 years or more

Domestically, the Homestake mine, South Dakota, is considered to be a superb example of a distal-volcanic disseminated pyritic gold deposit (personal observation, 1971), whereas the Carolina slate belt may be a non-Precambrian example either of this same setting, or of the sedimentary-recycled type; published data from the area (Worthington and Kiff, 1970) does not provide enough information about the characteristic rock associations to make the choice.

But the attention is certainly a solid clue

When Goodwin (1965) and Hutchinson, Ridler and Suffel (1971) expounded the volcanogenic model for massive sulfide deposits in the Canadian Shield they clearly indicated the presence of gold intimately in the volcanic setting but accounted for it as veins rather than disseminated in pyritic strata. Although there are several Canadian examples of the proximal volcanic type of gold deposit there are few if any operating domestic ones. Perhaps the most interesting in this regard is the area around Ishpeming, Michigan where there is excellent potential for finding

They certainly had system in mind.

the proximal volcanic type setting, and possibly one or both of the other types of disseminated pyritic gold deposits. Mining of the Ropes gold mine concentrated on the veins that occurred in the favourable volcanic stratigraphy, so the real significance of the volume of gold mineralization that lies in the belt was missed (Broderick, 1945). The diagnostic volcanic rock associations all seem to be there (Broderick, 1945.)

The Ishpeming gold belt therefore has excellent potential for disseminated pyritic gold deposits of the proximal and distal volcanic type. Also, with the proximity of favourable Proterozoic or even younger Archean sedimentary sequences right in the same area, this may prove to be one of the few places in the world where all three types of Precambrian disseminated pyritic gold deposits could be found. Both the Archean of Minnesota and the Proterozoic of central Wisconsin are also extremely favourable hosts for the appropriate rock assemblages and therefore the disseminated gold deposits (personal observation, 1977). The central Colorado Precambrian volcanic belts, and possibly also the northern Colorado volcanic belt once again contain favourable earmarks for a disseminated pyritic gold deposit setting (personal observation, 1978). Since the metamorphic grade of parts of these belts are high, almost all early mining of gold was from high grade veins.

In central Arizona, the Proterozoic volcanic sequences contain the favourable geologic and chemical indications of the disseminated pyritic gold setting, the rocks are at lower metamorphic grades, so this is another prime area for exploration.

EXPLORATION MODEL

Geologic Aspects

I first encountered disseminated pyritic gold mineralization of the sedimentary recycled type in a non-Precambrian setting in British Columbia and developed between 1973 and 1975 the geologic criteria which seemed to correlate to gold concentrations. Since then I noted recurrences of this setting in Precambrian rocks of eastern Ontario and western Australia. Exploration of these areas at the time was based on hydrothermal concepts of epigenetically introduced gold, but application of these ideas is definitely misleading if the gold is syngenetic to the enclosing strata.

From detailed geologic and geochemical investigations of Precambrian in central Arizona between 1975 and 1979 it became apparent that the proximal and distal volcanic gold settings were equally if not more abundant in Precambrian terrains and equally as diagnostic from their rock associations. Major-element geochemical data I was generating during this time confirmed the geologic inferences and also indicated that the favourable rock sequences had distinct and systematic geochemical characteristics. With these criteria in mind, I investigated other Precambrian volcanic belts in the U.S., Canada and Australia and indeed confirmed that a characteristic pattern to disseminated pyritic gold deposits was emerging. There are almost as many geologic criteria to work with in disseminated-pyritic-gold exploration as we now understand are involved in the volcanogenic massive sulfide environment. There are as many criteria, however several exploration companies have been misapplying volcanogenic massive sulfide concepts to the search for disseminated pyritic gold deposits in recent years, because the types of criteria are different for the two metal assemblages.

Mining a Precambrian disseminated pyritic gold deposit consists of mining foliated schist with from 5 to 25% disseminated, fine-grained pyrite, and microscopic gold in amounts of 0.05 to 0.3 oz./ton. It is not uncommon to have gold grades higher than this (0.3 to 0.6 oz/ton) but they should not be relied upon for economic viability. Remobilized higher-grade veins within the disseminated pyritic gold-bearing stratigraphy definitely produces a richer bulk ore, but the presence of these veins usually indicates that metamorphism has reconcentrated the gold into veins from the adjacent strata, such that the aggregate of veins plus host rock is equal to the original grade of the host rock. There is usually no gross addition or subtraction of gold from the system, just redistribution. The particulate nature of the gold and its millability are not precisely known, but it must be in a free state (not encapsulated), because many earlier mining operations (e.g. the Ropes mine, Michigan) typically included the disseminated pyritic strata as "low grade" material.

Disseminated pyritic gold deposits by no means involve the mining of usual vein widths (10 to 20 feet). Most often the pyritic stratigraphy is upwards of 500 to 1000 feet wide with high gold values found only in portions of this width. Lengths are for as many thousand feet as the favourable strata are laterally continuous, and the depth of mining is almost always an economic rather than geologic cut off. Gross tonnage is therefore highly variable, but well into the millions to tens of millions of tons. Since flat lying strata are unlikely in Precambrian terrains, all potential mines would have to be underground operations. This factor should be viewed as a favourable one rather than a discouragement, because in all of the areas throughout the U.S. where the favourable rocks occur, without exception, an open pit operation would not be permitted.

Program

A mandatory first step in a logically constructed exploration program for Precambrian disseminated pyritic gold deposits is a thorough, extensive and on-going mining-data-base and literature-research investigation. More so than with any other metal, with gold, the distribution of early high grade operations is of paramount importance to the search for a lower-grade, large tonnage deposit. If not true elsewhere, it is certainly true in the western U.S. that the early gold prospectors were the most accurate and thorough gold geochemists our science has known. An exhaustive compilation of early mining and prospecting efforts is therefore an extremely valuable part of a disseminated-pyritic-gold exploration program. It is a necessary first step, but certainly no substitute for the geologic and geochemical work to follow it.

Concurrent with the mining data base-literature investigations, the second phase of exploration is best initiated. This consists of regional mapping of the Precambrian volcanic and sedimentary rocks, discerning primary stratigraphy and looking for the distinctive rock types and associations earmarking the favourable environment. This mapping phase needs to be supported by whole rock analyses and gold geochemical data, and all these results carefully integrated, in a discriminating fashion, with the results of the mining data base-literature investigation. From these results and the diagnostic rock associations, smaller target areas either will or will not immediately fall out of the analyses. If not, one moves to the next favourable volcanic belt to start phase 1 and 2 again. If target areas are found, only a modest amount of detailed mapping needs to be done to tightly define the most favourable disseminated-pyritic strata, after which the exploration program becomes entirely

geochemical and dimensional (gold assaying and drilling) on to the feasibility of production.

The role of geophysical methods in this program is important, especially in covered areas, however, the applications need to be viewed with considerable caution. A disseminated pyritic gold deposit may produce only a weak I.P. response which is less than the contrast between adjacent rock types. There will almost certainly be no strong E.M., or other electrical geophysical response analogous to that over a volcanogenic massive sulfide deposit. In fact, since all of the stratigraphy near the favourable zone may be weakly pyritic, and characteristic of that stratigraphic unit wherever it is, the ore deposit within it might give no anomalous electrical geophysical indication at all. Otherwise, magnetic methods may prove indirectly useful in helping to sort out the more hidden or obscure stratigraphy etc., as was so successfully done in the famous Witwatersrand region of South Africa.

CONCLUSION

Rising gold prices have now made exploration for Precambrian disseminated pyritic gold deposits feasible. A systematic set of geologic criteria are available to logically explore for these disseminated gold deposits. Without the criteria one would have to undertake a widely dispersed, expensive, hit-or-miss geochemical exploration program, but with them favourable gold settings could be quickly and decisively found through a relatively modest geologic-geochemical-literature research program.

Favourable environments for the Precambrian disseminated pyritic gold setting are known through the Precambrian of the U.S., particularly in upper-peninsula Michigan, Wisconsin, Minnesota, Colorado and Arizona. Adjacent favourable settings are also anticipated in parts of New Mexico, Wyoming, Montana and Idaho. Non-Precambrian favourable settings are expected or known in the Paleozoic of the eastern Appalachians (e.g. Maine, Carolina) and the early Mesozoic of the western U.S. (W. Idaho, E. Washington, E. Oregon, N.W. Nevada, N.E. California). From the last to the first, these are listed in what I believe at this time to be the order of increasing favourability.

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Hutchinson, R. W., Ridler, R. H. and Suffel, G. G., 1971, Metallogenic relationships in the Abitibi belt, Canada: A model for Archean metallogeny : Canadian Inst. Min. Met. Trans., v. 74, p. 103-115.

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Worthington, J.E. and Kiff, I. T., 1970, A suggested volcanigenic origin for certain gold deposits in the slate belt of the North Carolina Piedmont : Econ. Geol., v. 65, p. 529-537.

Appendix

Resumé

PHILLIP ANDERSON 30, single

Born: 16 February, 1949, Sydney, Australia

Education and Degrees:	Prep.	School certificate, Australia	1961-1967
		High school diploma, Canada	
	B.Sc.	Honours in Geology with high distinction	1971
		University of British Columbia	
	M.S.	equivalent from University of Arizona	1974
	Ph.D.	pending, University of Arizona	1979

Standing: graduated first in Geological Sciences out of 120; grade average 90%; grade point average 4.000.

Training in:

Petrology	Mineral Deposits	Stratigraphy
Mineralogy	Structural Geology	Geomorphology
Geochemistry	Photogrammetry	Geophysics
Geochronology	Mineragraphy	Surveying

Advanced training in:
Igneous and Metamorphic Petrology
Methods in Structural Analysis
Optical and X-ray Mineralogy
Ore Deposits and Sulphide Mineralogy
Remote Sensing Analysis and Mapping
Plate Tectonics and Structural Synthesis
Thermodynamics of Water-Rock Interactions
Rubidium-Strontium Dating
Quantitative Analytical Geochemistry
Theories of Ore Deposition, Massive Sulphides

Positions:	1971-1972	Teaching and research assistant, University of British Columbia
	1971-1973	Geological Consultant, British Columbia
	1973-1974	Research associate, University of Arizona
	1973-1978	Ph.D. candidate, Univ. of Arizona; consultant

Professional Organizations:
Geological Society of America
Geological Association of Canada, Fellow
International Union of Geologists, 1976

Honours: Honours in Geology with High Distinction, University of British Columbia, 1971.
Third place for Governor General of Canada's gold medal award, 1971.

B.Sc. Thesis: Geology, Petrology, Origin and Metamorphic History of the Eagle "Granodiorite" and Nicola Group, Southern British Columbia, 201 p.

Ph. D. Dissertation: The Precambrian Geology of Arizona, in prep.

Field Experience in Economic Geology

1968: Copper Exploration:
summer geologic and geochemical reconnaissance of porphyry deposits in the Okanagan Batholith, southern B.C. (Giant Mascot).

1969: Massive Sulfide Exploration:
summer regional evaluation of stratiform lead-zinc mineralization in lower Paleozoic limestones, from Yukon Territory to S.E. B.C., including evaluation of Bluebell mine, B.C. (Cominco).

1970: Porphyry Copper Geology:
summer detailed study of porphyry copper mineralization-alteration and peripheral vein mineralization near Princeton, B.C. in conjunction with thesis study (Semco).

1971: Porphyry Copper Exploration:
Exploration in the volcanic-intrusive environment of southern B.C. for Cordilleran porphyry copper deposits. Detailed geochemical, microscopic and X-ray studies of porphyry copper mineralization-alteration zoning and paragenesis. Airphoto studies of ore deposit structures (consultant). Visits to several western U.S. porphyry copper deposits.

1972: Porphyry Copper Evaluation:
Exploration of syngenetic Cu mineralization in Triassic Volcanics; detailed geologic mapping and evaluation of syenitic "porphyry copper" deposits near Afton, B.C.; supervision of two exploration-drilling programs in B.C. (consultant).

1973: Precious Metal Exploration:
Examination and evaluation of porphyry-gold, vein-gold and vein-silver deposits in the Cariboo district, central B.C. and the Premier district, northern B.C. (Consultant).

1974: Precious and Base Metal Exploration:
Detailed study of disseminated and lode gold mineralization in the Ladner slate belt, B.C.; synthesis of porphyry copper deposits of southern B.C. into regional structural and tectonic setting;
Study of massive sulphide and other Precambrian deposits in the Abitibi belt, Ontario, including Noranda-Rouyn district, Timmins, Kirkland Lake, Cobalt, Kidd Creek, Sudbury and Elliott Lake (consultant).

1975: Massive Sulfide Exploration:
Regional and detailed mapping of massive sulfide deposits in central Arizona in relation to Precambrian stratigraphy.

1976: Base Metal Exploration:
Detailed mapping of Precambrian geology in central Arizona and evaluation of massive sulfide deposits; Remote Sensing Consultant on oil and gas potential of the Sacramento valley, and on distribution of base metal mineralization in the western U.S.
Field study of massive sulfide, stratiform iron and nickel deposits in the Archean Yilgarn block, western Australia.

1977: Massive Sulfide Exploration:
Regional mapping of Proterozoic geology in Arizona, Colorado and Wisconsin and evaluation of massive sulfide potential.
Visit to the major base metal mines of Peru, Chile, Bolivia and Brazil.

1978: Massive Sulfide Exploration:
Regional mapping of Proterozoic geology in Arizona, Colorado and northern New Mexico, and evaluation of massive sulfide potential.

Summary of Principal Economic Experience (decreasing order of expertise and interest):

1. volcanogenic massive sulfide deposits
2. Cordilleran porphyry copper deposits
3. gold-silver-lead-zinc vein deposits
4. southwest U.S. porphyry copper deposits
5. stratiform lead-zinc and iron deposits
6. nickel and porphyry-gold deposits
7. replacement skarn deposits
8. molybdenum deposits
9. oil and natural gas deposits

Professional References:

Dr. J.M. Guilbert	Professor, Department of Geosciences, University of Arizona, Tucson, Arizona, 85721.
Dr. W.R. Danner	Professor and Dean, Department of Geological Sciences, University of British Columbia, Vancouver.
Byron S. Hardie	Exploration Manager, Newmont Exploration Ltd. 200 West Desert Sky Road, Tucson, Arizona, 85703.
E. Sherbon Hills	Professor and Vice Chancellor, The University of Melbourne, Melbourne, Victoria, Australia
Dr. Doug Dunnet	Precambrian geologist, Anaconda Company, 1849 West North Temple, Salt Lake City, Utah, 85116.
Dr. S.R. Titley	Professor, Department of Geosciences, University of Arizona, Tucson, Arizona, 85721.
Dr. L. K. Lepley	Remote sensing consultant, 8841 N. Calle Loma Linda, Tucson, Arizona, 85704.
Dr. W.R. Dickinson	Professor, Department of Geology, Stanford University, Stanford, California.
Drs. E.P. Meagher & A.J. Sinclair	Professors, Department of Geological Sciences, University of British Columbia, Vancouver, B.C.

Research

Past and Current Research:

1. Plate tectonic evolution of southern British Columbia (b)
2. Significance of Jurassic metamorphism in southern B.C. (a)
3. Volcanogenic gold mineralization in the Ladner arc-trench gap site, southwest B.C. (a)
4. offset on the Hope-Straight Creek fault, Cascade mountains, B.C. and Washington (a)
5. Syenitic "porphyry copper" mineralization-alteration, B.C. (c)
6. Petrologic evolution of rhyolites and the genesis of massive sulfide deposits (b)
7. Unusual volcanogenic metallization tracing a Precambrian suture through Arizona (b)
8. Precambrian tectonic and petrologic evolution of Arizona (b)
9. Geochemical characteristics and evolution of Proterozoic island arcs in Arizona (a)
10. Occurrences of Precambrian oceanic crust in the U.S. (b)
11. Major-element chemical composition of the Precambrian crust, Arizona (b)
12. Cordilleran - Precambrian tectonic interactions — a model from Arizona (b)
13. Problem of deformation of Precambrian volcanic belts (c)

(a) = manuscript prepared or in preparation; publication expected within one year

(b) = publication of study anticipated within the next two years

(c) = study may or may not result in publication

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GEOLOGICAL AND CHEMICAL CONTROL OF STRATABOUND PROTEROZOIC PRECIOUS METAL MINERALIZATION IN CENTRAL ARIZONA

P. F. O'Hara

Kaaterskill Exploration
Prescott, Arizona

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Abstract

Stratabound Proterozoic precious metal mineralization in central Arizona is associated with felsic and adnesitic to mafic volcanic rocks and sediments derived from these rocks. Hydrothermal fluids associated with felsic volcanism form gold mineralization within hotspring vent complexes or within asymetric basins, which flank the vent complexes and are filled with tuffaceous sediments. Massive to semi-massive sulfide copper-zinc systems associated with felsic volcanism may locally contain small gold occurances either laterally or vertically zoned from the ore.

In andesitic to mafic rocks, zinc-lead-gold-silver-copper bearing mineralization and gold mineralization are both associated with feruginous sulfide bearing cherts.

The partitioning of gold into these specific geologic environments may be related to variations in temperature and composition of the hydrothermal fluid and the depth of the seawater-sediment interface below sea level during the mineralization event.

Introduction

Gilmour and Still (1968) first proposed a strataform origin for mineralization at the Iron King Mine. This pioneering paper was followed by Anderson and Nash (1972), who proposed a stratabound origin for concordant lenses of mineralization at Jerome. Since these papers were published many deposits and mineralized systems within central Arizona have been identified as stratabound deposits. (Figure 1)

The purpose of this paper is to summarize geological and geochemical data which has been generated in the past twenty years within industry and academia and to suggest that these deposits have a more complex origin than was previously recognized.

Proterozoic Stratigraphy

Yavapai Series

Metavolcanic and metasedimentary rocks of the Yavapai Series (Anderson and Creasey, 1958) crop out within the area described in this study. These rocks were originally subdivided into the Ash Creek Group and Alder Group (Anderson and Blacet, 1972c). istopic data led Anderson and others (1971) to rename the Alder Group the Big Bug Group, which includes all the rocks of the Yavapai Series exposed in the area described in this study.

Big Bug Group. The Big Bug Group is divided into three formations. From oldest to youngest they are: (1) Green Gulch Volcanics, (2) Spud Mountains Volcanics, and (3) Iron King Volcanics (Anderson and Silver, 1976). The Green Gulch Volcanics do not host any of the deposits included in this study, therefore, they will not be discussed. The thickness of the Big Bug Group cannot be measured with confidence because of the probability that unrecognized small folds on the flanks of major folds duplicated the section and because of probable thinning and thickening of units during deformation (Anderson and Blacet, 1972c).

The following description of the Spud Mountain and Iron King Volcanics is taken from the report by Anderson and Silver (1976, p. 17). for more detailed information the reader is referred to the many articles coauthored by C.A. Anderson listed in the references.

The lower part of the Spud Mountain Volcanics is characterized by andesitic-rhyolitic breccia containing interbeds of crystal tuff, tuffaceous sandstone, and siltstone. Clasts in the breccia range from 3 to 50 cm in diameter, and individual breccia beds range from 3 to 10 meters in thickness. The dominant rock type forming clasts is porphyritic andesite containing phenocrysts 4 to 8 mm long; clasts of rhyolite may be absent in many beds and abundant in others. The breccia beds form the core of an overturned anticline in the northeastern corner of the Mount Union quadrangle (Figure 1). In the southern part of the Mount Union quadrangle, the breccia beds are thin and appear as interbeds in thickly bedded and massive crystal tuff containing stubby crystals and clasts of quartz and albite.

The upper part of the Spud Mountain Volcanics is dominated by andesitic tuffaceous rocks, locally containing rhyolitic flows and tuffs. Zircons from one of these flows exposed north of the Big Bug Mesa gave an isotopic age of 1775 - 10 m.y. (L. T. Silver, cited in Anderson and others, 1971) This date suggests that a large part of the Big Bug Group is younger than the Ash Creek Group.

In the northwest corner of the Mayer quadrangle, the andesitic tuffaceous rocks in the Spud Mountain Volcanics contain ferruginous cherts that intertongue with the Iron King Volcanics. Southward in this quadrangle and west of the Shylock fault zone, light-colored, sandy and silty tuffaceous rocks become dominant.

The Iron King Volcanics is a thick sequence of pillow and amygdaloidal andesitic and basaltic flows, locally containing thin interbeds of rhyolitic tuffs and flows. The youngest unit is a mixed andesitic-rhyolitic tuffaceous rock that crops out in the trough of the overturned syncline.

Isoclinial folding obscures the original stratigraphy (Anderson and Blacet, 1972; DeWitt, 1976, 1979; Anderson, 1978; O'Hara and others, 1978); therefore, the only way to develop a stratigraphy is to fit the lithologic units into a fold model. Lack of marker horizons of adequate lateral extent hinders structural and stratigraphic analysis in the region.

In the vicinity of the deposits, there is an extremely varied package of volcanic and sedimentary rocks. (Figure 1) Metavolcanic units are complexly interlayered and indicate that rapid facies changes were characteristic of the protoliths, that potential growth structures existed to obscure the stratigraphic relations, and (or) that structural repetition has taken place.