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APPLICATIONS OF THE HOT SPRINGS OR FUMAROLIC MODEL IN PROSPECTING FOR LODE GOLD DEPOSITS

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Introduction

Increases in the price of gold starting about five years ago, and rapid fluctuations since then, have caused a substantial popular interest in the noble metal. Gold prospecting had been at low ebb since the end of World War II in most of the United States except for a flurry of activity in Nevada occasioned by the Carlin and Cortez discoveries. The last five years, however, have seen a great awakening of interest in gold exploration as well as an opportunity for education for many explorationists in the geology and other vagueries of gold deposits.

The present writers have participated over the last few years in a search for gold deposits throughout the United States. This search was greatly influenced by the geologic studies of Dr. Wm. Spence at the Haile Gold Mine in South Carolina as reported in a companion paper. Spence's studies resulted in definition of a geologic model that has proven useful in a number of other geologic environments in the United States. These programs were all carried out under the auspices of Cyprus Mines Corporation and permission by Cyprus to present these results is gratefully acknowledged. The writers, however, reserve for themselves all responsibility for the results and conclusions.

The exploration program to be described began in the southeastern United States. Spence's studies provided a reasonable basis for interpreting and understanding the geology of the Haile deposit and also provided a means for predicting additional occurrences. This concept was then expanded to other gold occurrences in the Piedmont and became an effective tool for evaluating other prospects. Finally it became evident that the concept could be applied in some western gold districts. The following discussion will then include descriptions of other Piedmont examples and a few western districts that also appear to fit the pattern.

Lode Gold Deposits of the United States

Renewed interest in gold has let to a reexamination of gold mining districts throughout the United States. Gold mining districts are widely distributed throughout the United States. Koschmann and Bergendahl (1968) list 465 districts with significant production (over 10,000 oz.) occurring in 20 of the 48 conterminous states. Lode gold districts are somewhat more restricted in area, but generally occur in the same 20 states, mostly in the Appalachian and Rocky Mountain regions. Most exploration in the last five years has been focused on lode districts, with emphasis on locating large tonnage deposits that may be lower in grade than had heretofore been considered as profitably minable. Much of this effort has been described as seeking "Carlin type" targets, but the term "Carlin type" is a poor one for several reasons. The Carlin deposit itself is really not typical of the low grade deposits common in Nevada; Carlin is much larger and higher in grade than almost all the other known deposits. Secondly, the Carlin geologic model is not necessarily typical of all disseminated low grade gold deposits. Such deposits may occur in a wide variety of geologic environments having nothing at all to do with thrust faults or other details of Carlin geology. The parameters that are necessary to the formation of a large disseminated gold deposit are simple: an auriferous source, a permeable host, and a trap. These features may occur in a great many geologic environments. This paper will attempt to describe how one such environment was identified in one area and used in other areas where geologic similarities existed. Other sets of geologic conditions may exist, however, that permit disseminated gold deposits to form, and there is no intent here to imply that this type of deposit is any more than one of many.

Lode gold deposits, excluding placers and fossil placers, may be conveniently grouped into three broad catagories; magmatic, metamorphic, and volcanic. All are hydrothermal in the conventional sense that gold is deposited from an aqueous solution of elevated temperature. Almost all are also epigenetic in the sense that they are deposited in openings in preexisting rocks, although there may be a few circumstances where auriferous solutions are directly incorporated in an igneous rock. Some may be considered syngenetic in a time sense only, in that ores may be deposited very closely in time in openings in pre-existing rocks. We believe, however, the term "syngenetic" should be restricted to use where the formation of ore minerals and enclosing rocks are equivalent in both time and process.

Magmatic gold deposits include most veins and replacement lodes as well as porphyry deposits that contain recoverable gold. Such deposits have a recognizable affiliation with an igneous body which may also be, or may be related to, the auriferous source. Major porphyry copper districts such as Bingham, Butte or Bisbee that are also major gold districts are good examples of such porphyry deposits. Districts that contain auriferous veins and replacements might include such examples as the replacement lodes and veins at Bisbee, Leadville or Tintic.

Metamorphic gold deposits are those formed by remobilization by hydrothermal waters of metamorphic origin of pre-existing gold occurrences. The great Motherlode system of gold lodes is probably the best example of such deposits in the United States. These lodes occur in great shear zones cutting complex metamorphic strata and are far too uniform over too many miles of strike length to be ascribed to a conventional igneous source. Metamorphic waters, acting uniformly throughout the zone, could have remobilized gold from pre-existing deposits or even from weakly auriferous peridotites or mafic volcanics and deposited it in favorable structural loci along the Motherlode fault system.

Volcanic gold deposits are obviously those that are associated with vulcanism in some form. Many of the famous epithermal districts of the West are now considered to be associated with Tertiary volcanic vents or calderas. Districts such as Cripple Creek, Goldfield, Tonopah and many others are well known examples. In such districts, ores typically are epigenetic in character in volcanic host strata often of relatively restricted age. The mineralization is often considered to be related to a hydrothermal phase that is related to a single volcanic unit.

The hot springs or fumarolic class of gold deposits as typified by the Haile deposit in the accompanying paper could be considered a sub class of the Volcanic group. Such deposits are formed in hydrothermal systems that may be directly associated with vulcanism or may be more remote. They may occur in rocks of any age and may be identified by geometry and mineralogy. The ensueing discussion will attempt to describe several geologic environments in which deposits with similarities to Haile occur and will also elucidate how recognition of Haile type mineralization may be applied to exploration and evaluation of gold occurrences.

Exploration Applications

The Hot Springs or Fumarolic class of gold deposits has been described in detail in the accompanying paper by Spence, et al. This model was originally developed by Spence in his studies of pyrophyllite deposits in Moore County, North Carolina (Spence, 1975). In subsequent studies under the auspices of Cyprus Mines Corporation of the Haile Gold Mine in South Carolina, Spence and co-workers were able to define a geologic model that we now believe may have wider applications in gold prospecting. We believe that gold mineralization at Haile is consanguinous with its enclosing volcanic strata, a series of bedded felsic lithic tuffs of probable early Cambrian age (Bell and Popenoe, 1976), that are tightly folded and steeply dipping. The Haile mineralized system is visualized as one (or several) centers of intense hydrothermal activity that was expressed as a hot spring or fumarole at the time of, or very shortly following, deposition of the tuffs. Gold mineralization occurs in siliceous zones that are strata bound and similar to siliceous sinters deposited in present hot springs systems. Small massive pyrite bodies are also present but are distinct from gold mineralization. The large area of sericite alteration at Haile represents an alteration root that lies stratigraphically below the Haile gold deposit. This pattern of strata bound siliceous gold mineralization overlying a highly altered root of sericite, pyrophyllite, or other aluminous silicate was quickly seen to be a useful model for prospecting elsewhere in the slate belt of the southeast Piedmont and ultimately elsewhere in the United States.

Other Slate Belt Occurrences

Brewer Mine

A well known gold deposit in the Carolina volcanic slate belt is the Brewer Mine near Jefferson, Chesterfield County, South Carolina (Figure 1). The Brewer has a nearly 150 year history of intermittent exploration of its gold deposits, beginning with recovery of placer gold from superficial placer deposits. Later mining of lode deposits resulted in the development of the larger Brewer Pit and the smaller Hartman and Topaz Pits. All of the workings occur along the top of a prominent northwest trending ridge which is transverse to regional geologic trends. Total gold production of the Brewer Mine is estimated to be $450,000 (8).

The Brewer deposits occur within an area characterized by silica enhancement about 1.6 km in diameter (7). Country rocks in the mine vicinity are quartz-sericite (-pyrophyllite) schists presumably altered from felsic tuffs of the Carolina volcanic slate belt. An inlier of Atlantic Costal Plain sediments occur on the south flank of the ridge and contain the Tanyard Placer workings. In the Brewer and adjacent pits the gold lodes consist of dense, compact, cryptocrystalline, light to dark gray quartz rock. Adjacent to this massive silica rock are zones composed of white, very fine grained quartz that readily disintergrates into a fine silty sand. Bodies of this material are exposed in the Hartman Pit and the upper periphery of the Brewer Pit. Disseminated pyrite, enargite, and fine grained topaz also occur in quartz rock. In places, irregular bodies of topaz form masses several feet in diameter, especially in the Topaz Pit.

The massive silica rock has the texture of a breccia and in places contains kyanite pseudomorphs now completely silicified. Other minerals reported in very minor quantities are chalcopyrite, bornite, covellite, bismuthinite, and cassiterite. Pyrite reportedly carries most of the gold, but free gold is readily observed by panning of the white, sandy rock, especially in the Hartman Pit.

Origin of the Brewer copper and gold mineralization and related silicification and brecciation was believed by ourselves and other investigators at various times to be attributable to: 1), intrusion of the Pageland pluton exposed about 2 km north west of the Brewer Mine; 2), an older buried intrusion lying at depth under the prospect with Brewer mineralization representing leakage from a mushroom cap of mineralization; or 3), a mineralized volcanic plug or explosion vent. More recently our views concerning the genesis of Brewer mineralization have undergone change. New information and application of concepts developed at the Haile Mine suggests that Brewer mineralization is best explained as originating in a hot springs or fumarolic system that originated comtemporaneously with the enclosing strata and has now been folded and tilted into its present position.

The deposit is evisioned as originally accreting from a fumerolic system as a cap or apron over an altered stem or root. Subsequent folding and regional metamorphism has modified and somewhat distorted the silica cap by tilting it to the northwest and imparting a slight northeast plunge. Concurrently, the eastern segment of the silica cap was folded to the northwest. Subsequent erosion now exposes an arched siliceous zone of mineralization and a barren zone of sericite and pyrophyllite alteration essentially standing on edge as shown in Figure 2. Mineralization at Brewer is therefore considered to be similar in origin (although somewhat different mineralogically) to the strata bound metamorphosed and folded deposits at Haile.

Sawyer Prospect

The Sawyer gold prospect, near Asheboro, Randolph County, North Carolina, is another slate belt area in which gold mineralization may be attributed to action of a hot springs system. The Sawyer workings lie along a low topographic ridge trending northeast along regional strike (Figure 3). Felsic metavolcanic rocks assigned by us to the Uwharrie Formation underlie the ridge and dip moderately to the northwest. Gold values of .01 oz. per ton or more encompass most of the old workings with the highest values found in a mineralized metasiliceous sinter exposed in the southeast portion of the main pit. The sinter is gray, dense, cryptocrystalline and thinly banded. Enveloping the sinter is a sericitic, sparodically pyritic, felsic tuff that weathers white. Outcrops at the Sawyer are very limited and no subsurface exploration has been conducted, therefore the existence and precise location of intensive sericite - pyrophyllite alteration cannot be established at this time. However, intense sericitization has been observed in a creek bottom along the strike trend of mineralization northeast of the Sawyer workings. The presence of intense sericitization in the area, the presence of mineralized metasiliceous sinter, and the proximity both geographically and stratigraphically to known centers of vulcanism (Seiders and Wright, 1977) establishes the Sawyer gold prospect as a deposit of the Haile class.

Silver Peak Nevada

As part of a Cyprus Mines Corp. gold reconnaissance program conducted during the winter of 1975-76, the gold occurrences in Esmeralda County were examined. During this program, certain petrologic features were noted by the authors between the rocks in the vicinity of the old mine workings at Mineral Ridge and those of the Haile Mine, South Carolina, which suggested a possible hot spring origin for the gold deposits in the district. These brief field examinations prompted additional field work which was carried out by I. T. Kiff during August, 1976. Kiff's work suggested that a genetic relationship existed between the so called pegmatites, the quartz bodies and the ore minerals. This interpretation was based partly on the spacial relationships of the above and partly on new interpretations of the origins of the so called pegmatite bodies. A single district in the Mineral Ridge area (Silver Peak District) has recorded production of approximately two (2) million tons, grading .3 oz/ton gold, from stratabound lenticular quartz masses and gold bearing horizons within silicate hornfels and calc-silicate-carbonate rocks of the Wyman Formation. The gold bearing quartz bodies in the Wyman have been interpreted by various workers as originating from viscous magmatic solutions to quartz veins or hydrothermal re - placement quartz in selected horizons. The authors would like to suggest an alternate origin for the gold bearing quartz deposits in the Wyman Formation.

The Precambrian of Esmeralda County is composed primarily of intercalated phyllitic siltstones and silty claystones (Albers and Stewart, 1972) with minor limestone and silty limestone beds. The lower most formation is known as the Wyman formation and contains the gold deposits of interest in this study on Mineral Ridge. The Wyman Formation at Mineral Ridge was originally deposited as a sequence of thin-bedded siliceous, argillaceous, and lesser calcareous sediments. Metamorphism has converted the sediments into phyllites or schists and calcarenites. Interlayered with the metasediments are bands of a curious quartzofeldspathic rock variously described in the literature as an alaskite, white granite, pegmatite, or granite gneiss. The layers range from a few inches to several feet in thickness and in the Mary Mine area a large mass of unknown thickness constitutes the footwall of the gold mineralization (Spurr, 1906).

The structure of Mineral ridge as defined by the Wyman Formation is that of a broad, open, anticline plunging gently to the southeast. Superimposed on the larger structure are secondary folds with amplitudes of several hundred feet. In addition, abundant drag folds ranging from an inch to 20 feet in amplitude are present.

Observations of geology on Mineral strongly suggested to the writers that the gold mineralization is confined to a definitive stratigraphic zone no more than 100' thick within the Wyman Formation and further, that the gold had its origins in a hot springs system not too unlike that postulated for certain gold deposits in the southeast United States such as the Haile Gold Mine.

The stratigraphic control can be established by the fact that the position of the mineralized zone maintains a constant concordant relationship with foot wall and hanging wall lithologies over a great lateral extent. Because the overall slope of the ridge is about the same as the general dip of the strata, it is possible to observe the mineralized environment for several hundred feet along the dip direction (Figure 4). Everywhere observed, the brownish colored calc-silicate phyllites or schists in the hanging wall grade downward into a grayish siliceous zone associated with the gold mineralization. As the target zone is approached, there is a corresponding increase in the number and thickness of quartzofeldspathic layers in the Wyman schists. Below the siliceous zone the quartzofeldspathic rock forms the footwall.

The form of the mineralized bodies themselves are lenses which old stopes show were a minimum 5' to 10' in width to a maximum of 40' averaging about 20 feet. The lenses were up to a few hundred feet in length and approximately the same in depth. Disruptions of the lenses and the lenslike form itself are interpreted as resulting from the complex two-phase deformation and metamorphism which has been operative at Mineral Ridge. Ductility contrast between the more brittle mineralized zone and the more plastic behavior of Wyman metasediments account for the apparent splitting and en echelon form of the gold deposits within the target zone. The lens shape is to some extent caused by primary deposition in the hot spring enfironment, but is more likely a boundinage feature not unlike the small boudins noted on limbs of the small, reclined isoclinal folds in Wyman rocks.

Once stratigraphic control of the mineralization can be accepted attribution of the genesis of the gold deposits on Mineral Ridge to a hot springs event during Wyman time can be more easily postulated. Subtle geologic observations and an admitted synthesis of events are necessary in light of the radical alteration of original lithologies and geologic relationships caused by deformation and metamorphism. The key to interpretation lies within the siliceous portion of the target zone and the associated quartzofeldspathic rock.

Within the upper portion of the target zone thin-bedded Wyman rocks contain abundant layers of quartzofeldspathic rock. Crossing into the hanging wall siliceous zone, the quartzofeldspathic rock nearly disappears and the zone is composed of banded siliceous hornfels and perhaps some calcsilicate hornfels. This grades into a gray, banded porcellaneous quartz and often associated white vitreous quartz of the "vein". The footwall is composed of a thick mass of quartzofelds-pathic rock (Figure 4).

The gold-bearing siliceous hornfels and porcellaneous quartz are believed to be siliceous sinter deposited, along with gold, in a hot springs system. The system was active within a definite time interval during the Wyman deposition and over a large area that could be compared roughly, with our present knowledge, to the Haile area in size.

The quartzofeldspathic rock has been variously interpreted by past investigators as an alaskite, white granite, and pegmatite, all assuming or orthomagmatic origin of the rock. In areas where the conformable quartzofeldspathic layering prominently alternates with metasediments, the rock has been called a magnatite. The quartzofeldspathic rock was assumed to have been injected lit-par-lit.

In the present interpretation the quartzofeldspathic rock is believed to be a recrystallized metasomatite. Hydrothermal activity during the hot springs event altered the host rock into a metasomatite consisting of silica, clay, probably some sericite, possibly some pyrophyllite, and adsorbed volatiles. Such a rock would be very suscieptable to recrystallization under conditions of almadine-amphibolite metamorphism. A silica + sericite + clay assemblage would not be stable under moderately high pressures and temperatures above 500°C, and probably less because of hydrous phases and presence of volatiles. Therefore in the thermal region of andalusite-sillimanite transormation at about 550°C, or perhaps less, the metasomatite would recrystallize into a quartz + feldspar + muscovite rock. The massive quartzofeldspathic rock in the footwall and "migmatite" at Mineral Ridge are somewhat analogous to the massive sericite bodies at the Haile Mine and the altered sericite bands alternating with layers of host rock in Haile core.

Keating District, Oregon

Observations in a district located northeast of Keating, Baker County, Oregon, indicate the possibility that gold mineralization at a number of copper and gold prospects in Permo-Triassic volcanics may be referred to the hot springs model to account for their origin. Geology and mineralization in the district have been described by Gilluly (1931). At the Motherlode Mine, one of the more extensively developed mines, Gilluly noted that mineralization occurred in sheared and hydrothermally altered volcanics and that the highly silicified "mineralized masses" are roughly aligned parallel to strike of the formation although distribution of the metals is irregular. Pyrite and chalcopyrite occur in addition to gold, with gangue that is dominately quartz, with some sericite, ankerite, calcite, chalcedony, and barite.

Our observations in the district indicate that the country rocks consist of a suite of keratophyre, quartz keratophyre, spillites, and associated volcaniclastic rocks intruded by albite granite and containing scattered occurrences of copper minerals and gold. Subsequently folding, faulting, and metamorphism have greatly complicated geologic observations, but it is still evident that at many of the prospects generally conformable zones of silicification, and argillization occur and gold, when present, generally occurs in the silicic zones. This can be demonstrated, for example, at the above-mentioned Motherlode Mine, where, at the surface silicic and argillic zones can be seen to be crudely conformable to enclosing streta and the strongest gold mineralization occurs in silicic alteration in the Motherlode Glory hole (Figure 5).

Our application of the hot springs model to many of the prospects in the Keating District is based on the occurrence of gold in volcanic rocks containing similar type alteration noted in association with hot springs type gold deposits elsewhere.

Homestake, South Dakota

The Great Homestake lodes at Lead, South Dakota, have long been considered enigmatic in origin. No significant field work was conducted in these studies in the Lead District, but a review of the literature suggests that a hot springs or fumarolic origin, subsequently metamorphosed, might reasonably account for many of the present day geological aspects of the deposits. The present authors, of course, defer to the greater knowledge and experience with the Homestake deposits of the many geologists that have spent much more time there, and only mean to suggest by the following comments that the model proposed here might explain some of the enigmatic aspects of these important gold deposits.

The gold lodes at Homestake occur as disseminations of free gold, usually fine grained and only rarely visable, accompanied by varying amounts of assenopyrite, pyrrhotite, pyrite, quartz, and chloritic alteration in the Homestake formation. Vitually all significant gold concentrations occur within the Homestake formation, although only a small percentage of the Homestake is ore. Because of the extreme deformation of all of the Precambrian strata in the Black Hills the Homestake formation is variable in thickness ranging from attenuations to near zero to thicknesses in noses of folds of several hundred feet. The Homestake formation is now composed of sideroplesite or cummingtonite schist depending on metamorphic grade and must have originally been an iron- and magnesium rich carbonate mud bank (probably a carbonate exhalite) as originally deposited.

Past controversies about Homestake ores have been involved with whether the deposits were of Precambrian high temperature origin or Tertiary epithermal deposits related to the younger intrusives of the region. We suggest that the deposits were initially formed from a hot springs or fumarolic system that operated during Homestake time and that deposited sulfur arsenic, silica, gold and other minor constituents in the semi-consolidated carbonate muds. These deposits were then buried, folded, and metamorphosed to their present aspect. One of the greatest difficulties with any epigenetic origin for these widespread lodes is their near total affinity for Homestake strata. An origin considering time equivalence of host sediments and ore elements provides a simple explanation for this phenomenon. The district alteration patterns provide another bit of evidence. Noble (1950) describes extensive chloritization and disseminated pyrrhotite in the Poorman formation stratigraphically beneath the known lodes but a virtual absence of alteration and mineralization in the overlying Ellison formation. This is consistent with hot springs deposition in Homestake time and would account for alteration in underlying strata and none in overlying, younger strata. Additional evidence has been presented by Rye and co-workers (1974) that modern isotope studies suggest a hot springs origin for these deposits. It is gratifying that laboratory work reinforces a field hypothesis; but we believe, based on evidence available to a field geologist, that the conformable nature of the deposits and the lack of evidence for a conventional hydrothermal source suggest that a hot springs or fumarolic origin for the ore mineralization, subsequently modified by regional metamorphism, can adequately account for the present geologic aspect of the Homestake ore bodies.

Discussion and Summary

The purpose of the present discussions has been to demonstrate how the exploration concept developed at the Haile Gold Mine was extended first to nearby properties in similar geologic environments and then farther afield to less similar and more distant geologic terranes. The examples that have been cited here are not exactly similar, but they do possess common characteristics, particularly if metamorphic overprinting can be considered. We consider that the strata bound nature of all of the examples, their similar mineralogical zoning (sans metamorphism), and absence of other clear cut evidences of origin constitute a strong argument that the hot springs or fumarolic model applies at the above examples and may, in fact, be applied usefully elsewhere.

The application of the above concept in field exploration situations is very simple and can be quite useful. If a prospect can be recognized to probably conform to our model then the location of the potentially best mineralized zone can be predicted and other similar mineralization can be sought along strike. Thus, indentification of one segment of a mineralized zone, or its metamorphic equivalent, placed in its proper stratigraphic setting, would enable prediction of the remaining parts of the system, even if marked by younger geologic cover. In other words, gold mineralization should be sought in siliceous strata adjacent to and stratigraphically above a zone rich in sericite, pyrophyllite, kyanite, or similar material. Early recognition of a prospect as being similar to Haile could then aid considerably in its efficient exploration.

Comparison with Massive Sulfide Deposits

The Haile model for gold deposits possesses many similarities to be currently prevalent model for generation of massive sulfide deposits. Such sulfide deposits are considered by many geologists to be associated with marine eugeosynclinal volcanic and volcaniclastic strata and to originate from late volcanic exhalations usually from felsic pyroclastic explosive eruptions. A fumarolic stage as visualized in our model would probably occur either slightly later or more distant from such an explosive center, but the basic driving mechanism is the same volcanic process. Occasionally small sulfide bodies do occur close to Haile type gold deposits as at Haile itself, the Brewer mine, and possibly at the Motherlode prospect at Keating, Oregon. In general, however, we believe that these gold deposits can occur in a wider depositional environment than massive sulfides. They do not appear to be restricted to a sub-aqueous environment as are massive sulfides. They can probably also occur at varying distances from volcanic vents as hot springs are now found in the world today, but they do not appear to be as closely associated with explosive volcanic activity as sulfide deposits. They are therefore visualized as an equivalent phenomena in perhaps a slightly lower energy environment. This would probably fall into the class of Iron and Gold bearing Exhalites as proposed by Hutchinson, Ridler and Suffel (1971).

The Haile model appears to us to provide a valid explanation for many of the peculiarities of the Haile deposits themselves, is helpful in understanding quite a variety of other deposits, and has considerable predictive value in exploring for similar deposits.

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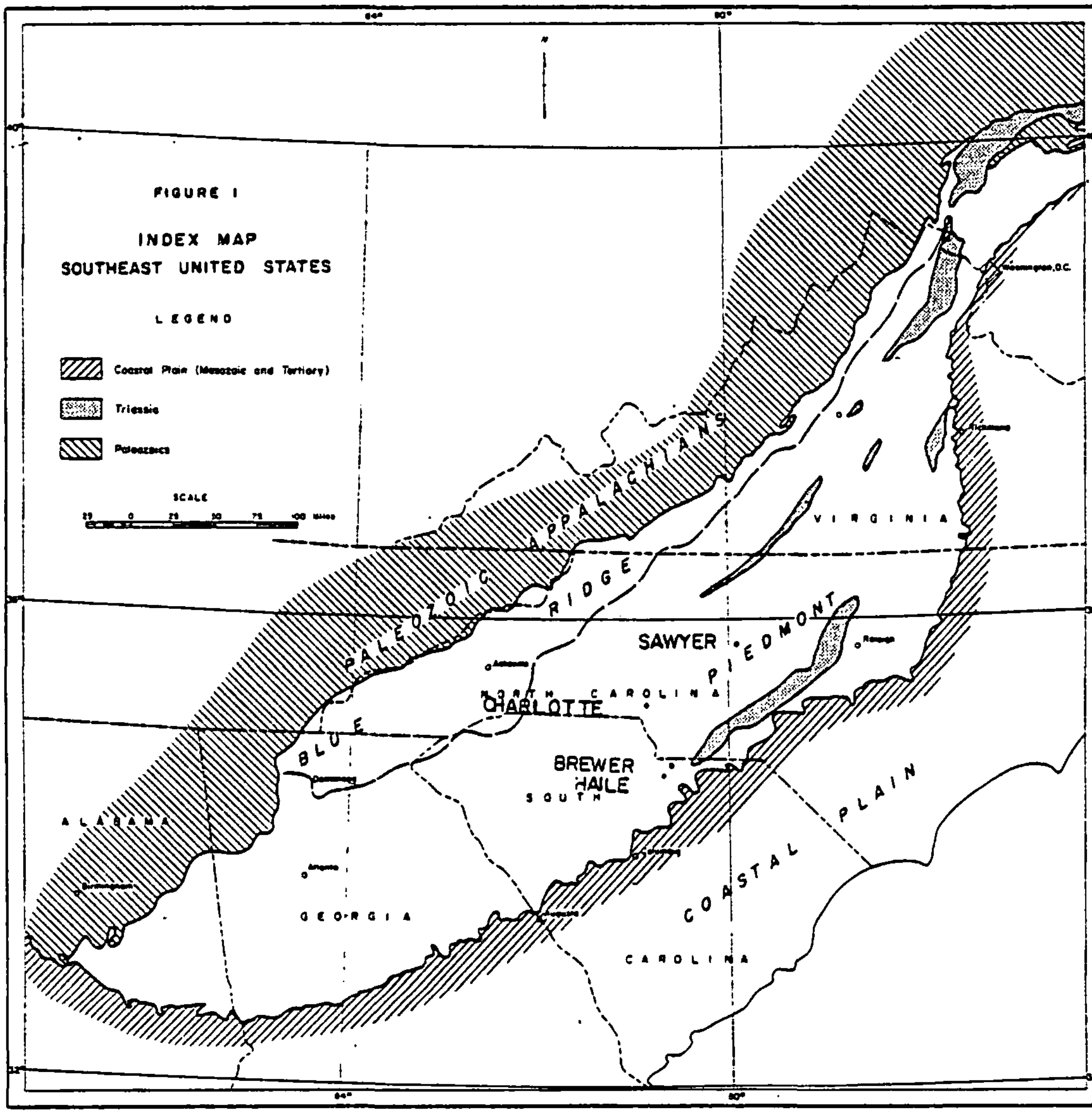


FIGURE I
INDEX MAP
SOUTHEAST UNITED STATES
LEGEND
Coastal Plain (Mesozoic and Tertiary)
Triassic
Paleozoics
SCALE
PALEOZOIC APPALACHIANS
BLUE RIDGE
PIEDMONT
COASTAL PLAIN
VIRGINIA
NORTH CAROLINA
SOUTH CAROLINA
GEORGIA
ALABAMA
SAWYER
CHARLOTTE
BREWER
HAILE

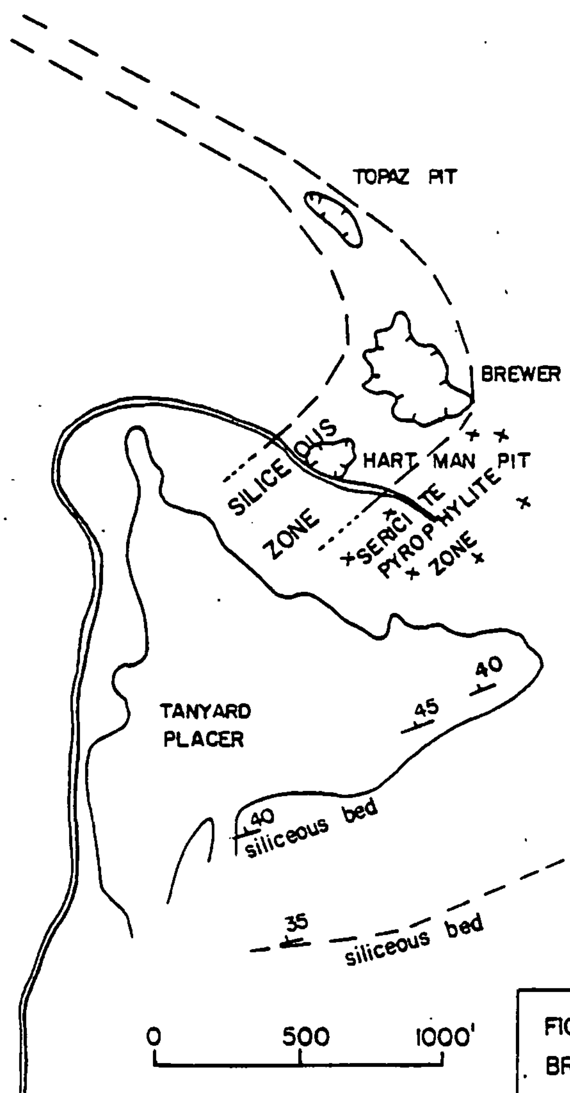


FIGURE 2
BREWER GOLD MINE
CHESTERFIELD COUNTY
SOUTH CAROLINA

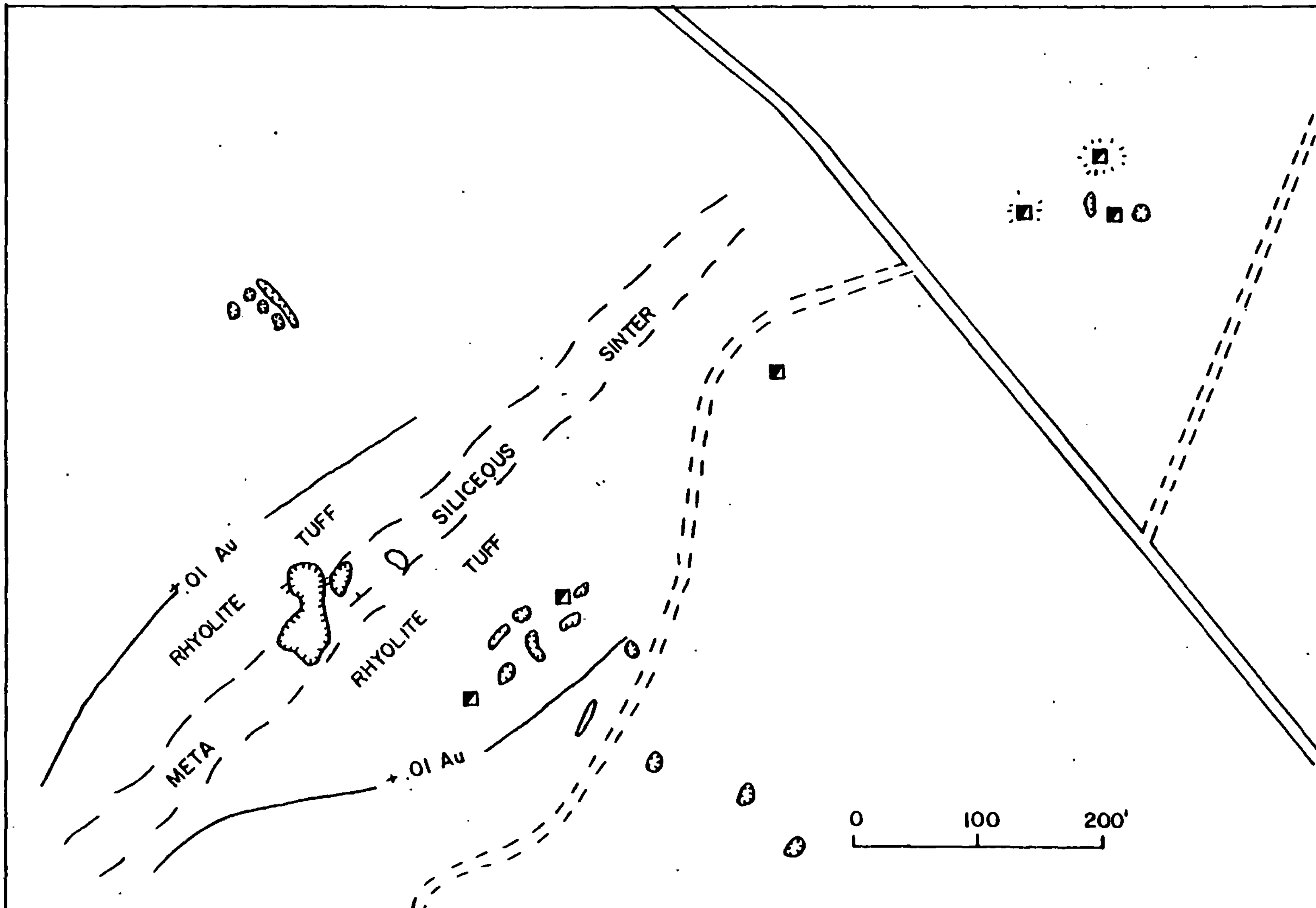
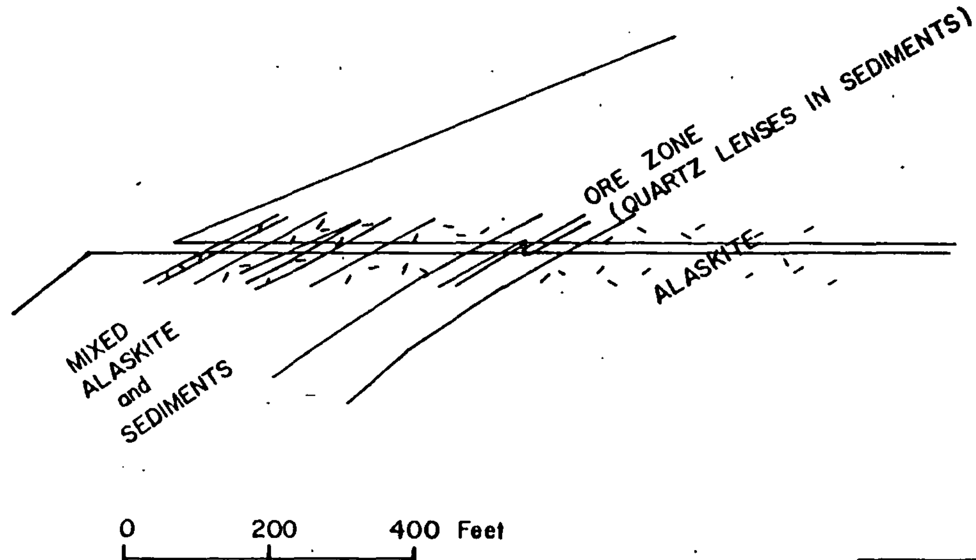


FIGURE 3

SAWYER GOLD MINE, RANDOLPH COUNTY, NORTH CAROLINA



(from Spurr., 1906, Figure 9)

FIGURE 4

CROSS SECTION

MARY MINE

SILVER PEAK DISTRICT

ESMERALDA COUNTY

NEVADA

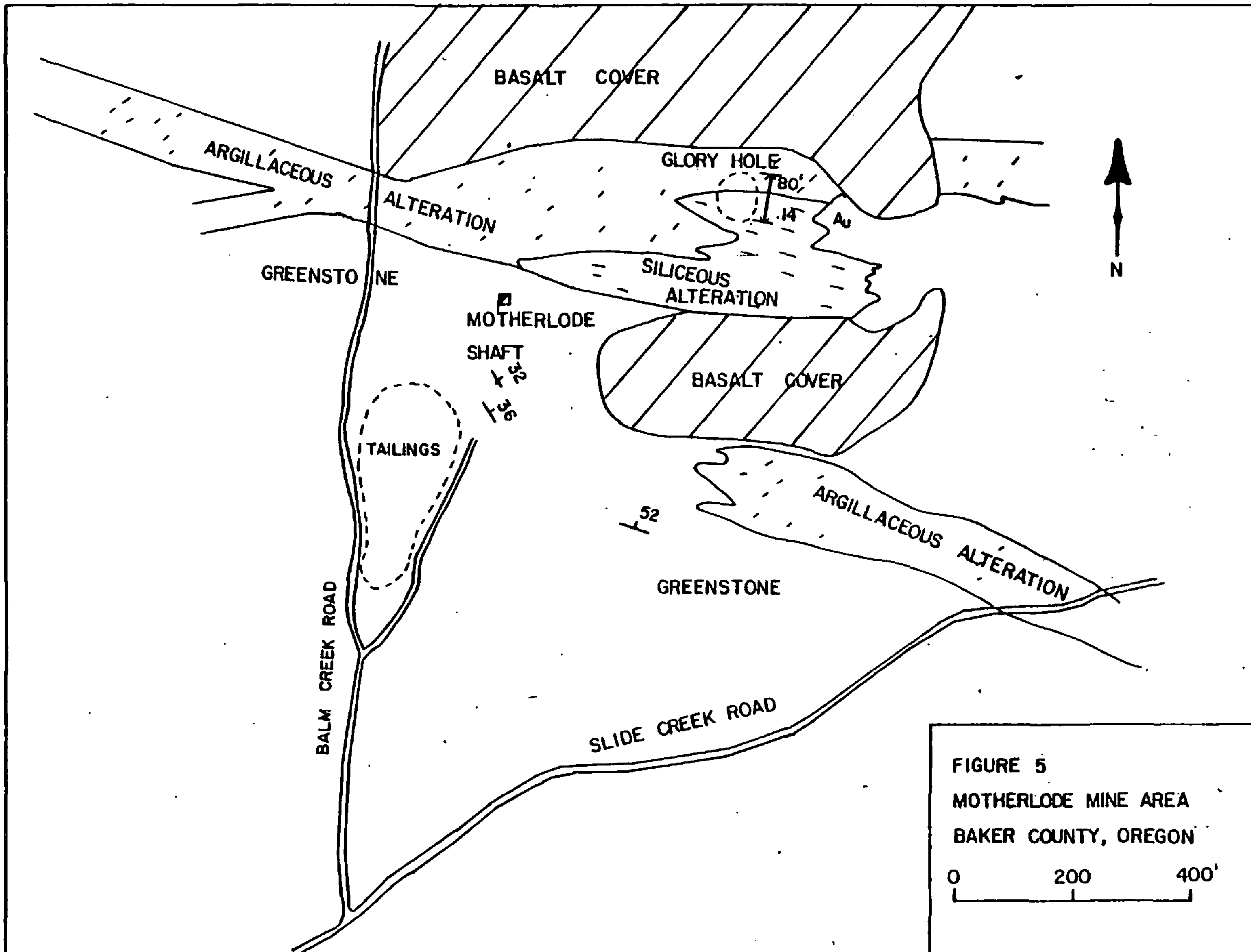


FIGURE 5
MOTHERLODE MINE AREA
BAKER COUNTY, OREGON