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GEOLOGICAL SURVEY

Relationship between disseminated gold deposits and a regional paleothermal anomaly in Nevada

by

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ABSTRACT

Several regional features show spatial coincidence with many of the disseminated gold deposits in Nevada: the western edge of the Precambrian granitic crust, a major lower Paleozoic carbonate facies change, the eastern edge of the Roberts Mountains thrust system, some pronounced aeromagnetic and gravity anomalies, and the eastern edge of a regional paleothermal anomaly. A genetic model for the origin of the disseminated gold deposits embodying these features suggests that the deposits were formed in the upflowing limbs of large convection cells whose circulation was caused by regional heating of the crust. According to this model, the gold was scavenged from crustal rocks at depth and deposited near the tops of the upflowing limbs of the cells.

DISSEMINATED GOLD DEPOSITS

Many disseminated gold deposits in the Basin-Range Province of the western United States are large, low-grade deposits containing micron-sized gold with high gold to silver ratios. These currently comprise important bulk-minable sources of gold and are targets for intensive exploration efforts, particularly in Nevada. The host rocks for some of the deposits, such as those at Jerritt Canyon, Carlin, Pinson, Getchell, and Alligator Ridge, are dominantly interbedded calcareous and/or dolomitic shaly mudstones, siltstones, limestones, and dolomites. Many of these deposits do not have an obvious relationship to igneous rocks. Host rocks in other deposits, such as Round Mountain, Goldfield, and Buckhorn, are dominantly volcanic rocks. The sedimentary-rock hosted deposits are replacement deposits in which gold, pyrite, silica, and locally barite were introduced along with anomalous concentrations of Hg, As, Sb, and Tl. Organic material was commonly remobilized. Some recent significant studies of these deposits include those reported by Radtke and Bagby (1984), Rytuba (1985), Ilchik (1985) and the collections of papers in Tooker (1985) and Berger and Bethke (1985). Locations of the gold-producing districts in Nevada were shown by Bonham (1976) and are plotted on Figure 1. The data for this map are based on gold production as of 1976 and does not include the substantial production since that time, nor the reserves. It also includes gold production from deposits of all types, such as byproduct gold from copper deposits in Cretaceous plutons such as at Ely and replacement deposits such as at Eureka. Locations of the bulk-minable precious-metal deposits in eastern Nevada are shown on Figure 4.

Mineralization at volcanic-related disseminated precious metal deposits in central Nevada appears to have taken place in the middle to late Tertiary, and by analogy, many of the sedimentary rock-hosted deposits probably formed at about the same time. Published mid-Tertiary isotopic ages of mineralization include those on Cortez, Gold Acres, and Horse Canyon at approximately 32 Ma (Rytuba, 1985); Round Mountain 25 Ma (Silberman et. al., 1975; Tingley and Berger, 1985); Goldfield 20 Ma (Silberman and Ashley, 1970), and Buckhorn 15 Ma (Wells and Silberman, 1973). A compilation of ages was published by Silberman et. al., (1976).

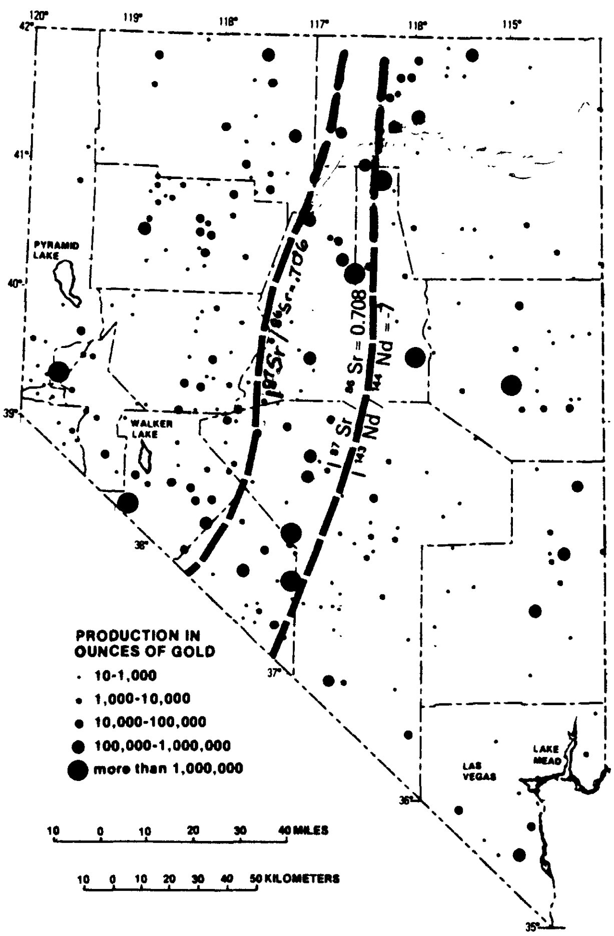


Figure 1.--Map showing spatial relationships between the gold-producing districts of Nevada (Bonham, 1976) and lines bounding the areas containing granitic plutons with initial $^{87}Sr/^{86}Sr$ of 0.708 and 0.706 and initial $^{143}Nd/^{144}Nd$ of -7 (Farmer and DePalo, 1983; Kistler and Peterman, 1973).

LOCATION OF THE PRECAMBRIAN CRUST

The location and composition of the Precambrian crystalline basement in western North America has been investigated using Sr, Nd, Pb, and O isotopes (Kistler and Peterman, 1973, 1978; Zartman, 1974; Kistler et. al., 1981; Farmer and DePalo, 1983; and Kistler, 1983). The position of the western edge of the granitic crust in Nevada has been inferred from the isotopic compositions of Precambrian crystalline rocks in the region. Lines depicting the position of granitic plutons with initial $^{87}Sr/^{86}Sr$ compositions of 0.708 (Farmer and DePalo, 1983) and 0.706 (Kistler, 1983), have each been interpreted to indicate the position of the western margin of the buried craton. The line showing the boundary between areas characterized by plutons having initial $^{87}Sr/^{86}Sr=0.708$, coincides with a similar line for initial $^{143}Nd/^{144}Nd=-7$. This line, together with a line showing the boundary between areas characterized by plutons having initial $^{87}Sr/^{86}Sr=0.706$, is based on data from Farmer and DePalo (1983), Kistler and Peterman (1973), and Kistler et. al., (1981) and is plotted on Figure 1. The narrow belt, about 40 to 100 km wide between these two lines, trends approximately north-northeast across central Nevada. As shown on Figure 1, the location of this belt is coincident with many of the major gold deposits in Nevada, including most of the deposits near Carlin, Cortez, Austin, Round Mountain, Manhattan, Tonopah, and Goldfield. Four major deposits (Bonham, 1976) outside the belt are Virginia City, Aurora, Eureka, and Ely and they appear to have formed in somewhat different geologic settings. The northern end of the initial $^{87}Sr/^{86}Sr=0.708$ line is not well constrained and may trend slightly more to the northeast, following the rest of the isotopic trend and the paleothermal anomaly (discussed further on) and including all of the deposits near Carlin and Jerritt Canyon.

LOWER PALEOZOIC FACIES CHANGES AND THE ROBERTS MOUNTAINS THRUST

Several distinctive assemblages of sedimentary rocks that reflect contrasting sedimentary environments, including water depth, submarine topography, sediment sources and amounts, and water chemistry, were deposited in different parts of Nevada during the lower Paleozoic. Figure 2 is a palinspastic map showing the generalized distribution of latest Silurian and earliest Devonian lithofacies based on studies by Poole et. al., (1977) and Matti and McKee (1977). They show that both limestone and dolomite were being deposited on the continental shelf while siliceous rocks were deposited off the continental shelf, to the west. The change from dolomite to limestone marks a change from shoal-water subtidal and supratidal conditions on the broad shelf above the craton, to deeper water conditions with submarine topography marked by broad basins and subdued ridges, along the continental slope (Matti and McKee, 1977; Poole et. al., 1977; Hurst et. al., 1985). The line corresponding to this change trends north-northeast across central Nevada (Fig. 2), is at approximately the same position as lithologic changes in other Paleozoic intervals, and has the same general trend and position as the major gold deposits and western margin of the buried Precambrian crust as delineated by isotopic studies.

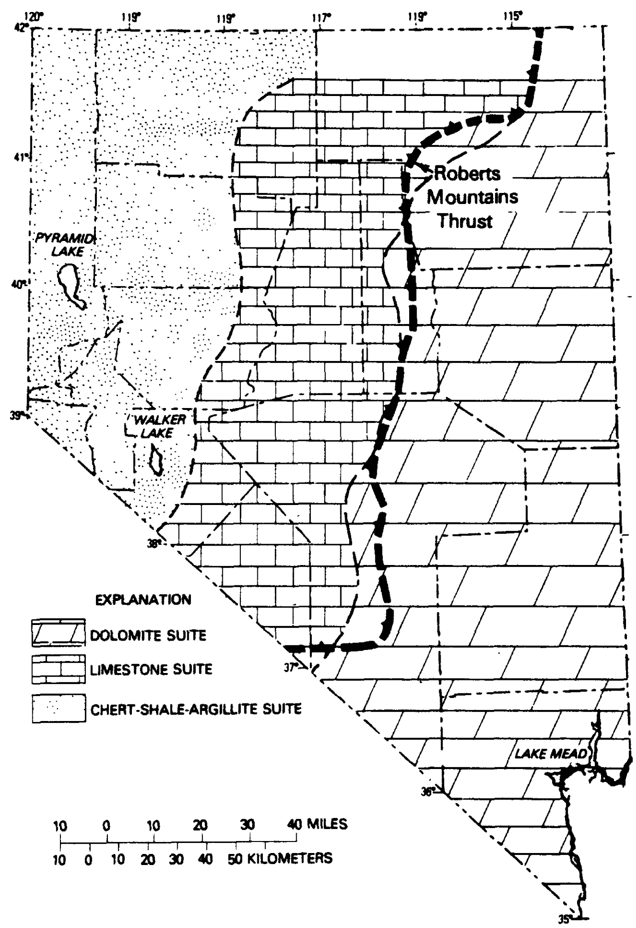


Figure 2. -- Palinspastic map showing generalized distribution of latest Silurian and earliest Devonian lithofacies and the approximate position of the Roberts Mountains thrust. Modified slightly from Poole et. al., (1977, 1983) and Matti and McKee (1977).

The Roberts Mountains thrust is a major regional overthrust that formed during the Late Devonian and Early Mississippian Antler orogeny. At that time, deep-water siliceous and volcanic assemblage rocks were thrust eastward as much as 145 km over the coeval but lithologically dissimilar shallow-water limestones and dolomites discussed above (Roberts et. al., 1958; Stewart, 1980; and many others). The present location of the eroded eastern edge of allochthouous siliceous rocks marks the leading edge of the Roberts Mountains thrust system. Erosion subsequent to thrusting has not changed its position very much on a state-wide scale. Outcrop distribution of the thrust has been summarized by many authors (for example, Stewart, 1980; Poole and others, 1983) and is shown on Figures 2 and 4. It also has the same general trend and position as the gold deposits, edge of the craton, and Paleozoic facies changes.

GEOPHYSICAL ANOMALIES

Geophysical anomalies provide additional information about the position and identity of crustal-mantle features. A distinct aeromagnetic anomaly in north-central Nevada (Mabey, 1966; Robinson, 1970) shown as a magnetic high on figure 3, corresponds to the mapped location of late Cenozoic igneous rocks and has been interpreted to represent a basalt-filled rift (McKee and Noble, 1985). The feature trends north-northwest, is approximately coincident with the northern half of the area between the initial $^{87}Sr/^{86}Sr$=.706 and .708 lines, and is located beneath the gold deposits in the vicinity of both Carlin and Cortez. The area south and east of the aeromagnetic high is characterized by low aeromagnetic intensities and has been interpreted to possibly reflect a crustal rift with elevated heat flow and shallow Curie isotherm (McKee and Noble, 1985). The most linear part of this aeromagnetic low, called the "quiet zone" (Stewart et. al., 1977), is a north-trending feature east of the area between the initial $^{87}Sr/^{86}Sr$=.708 and .706 lines and is bounded on either side by the gold deposits at Eureka and Ely. High heat is believed to have caused destruction of magnetization of the lower parts of igneous bodies (Stewart et. al., 1977). Mabey et. al., (1978) speculated that this may be a rift system formed at the inception of basin-range faulting.

Eaton et. al., (1978) have recognized a regional gravity configuration in Nevada that is characterized by bilateral symmetry of the Bouguer gravity field. The axis of this bilateral feature lies along the western edge of the magnetic "quiet zone", and the western lobe of the prominent gravity low is centered between the initial $^{87}Sr/^{86}Sr$=.708 and .706 lines (fig. 3). An upper crustal, low-velocity layer exists in eastern Nevada and western Utah (Smith 1978). This feature has been interpreted to be related to either granitic intrusions (Mueller and Landisman 1966) or to an increase in pore pressure accompanied by high temperatures (Smith et. al. 1975). The western margin of the crustal low-velocity layer also coincides with the edge of the craton and the disseminated gold deposits.

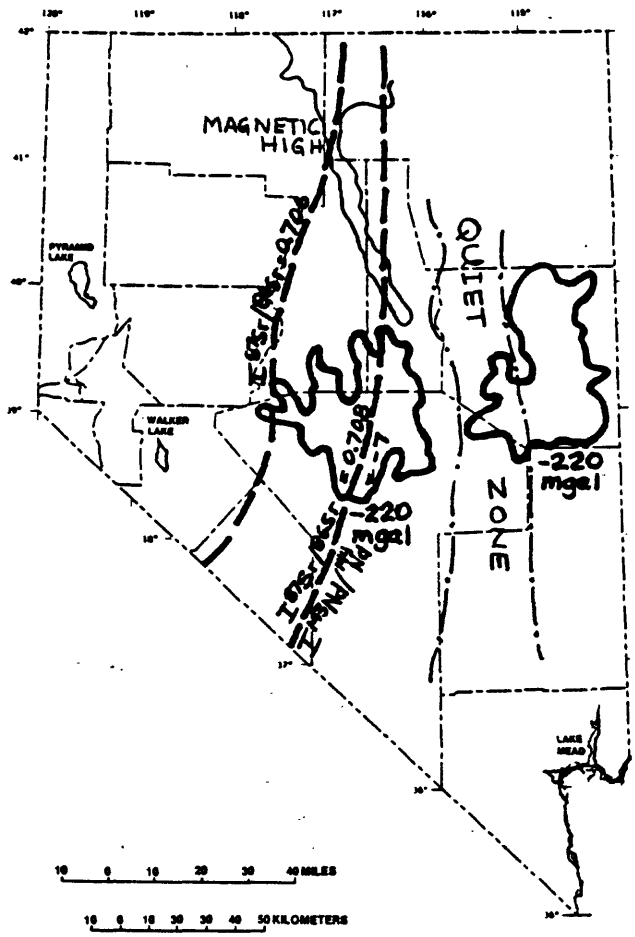


Figure 3. -- Geophysical features discussed in the text. Thick solid lines are the -220 mgal Bouguer gravity contour lines that encircle gravity lows (Eaton et. al., 1978). The thin solid line on the northern part of the map defines the area of a prominent, linear, magnetic high (Stewart et. al., 1977). The dash-dot lines define a north-trending magnetic "quiet-zone" (Stewart et. al., 1978; Mabey et. al., 1978).

PALEOTHERMAL ANOMALIES

A paleothermal anomaly is a region of the earth that once experienced an event that heated it relative to nearby regions. The thermal event has now disappeared, leaving a record in the mineralogy and textures of the rock which can be deciphered to interpret the former thermal event. Paleothermal anomalies provide unique insights into the thermal evolution of an area and its paleohydrology; they could constitute important exploration tools to investigate ore-forming processes and predict the location of hidden ore deposits. Subtle thermal aureoles resulting from circulating, heated fluids that were nearly in chemical equilibrium with their host rocks commonly extend far beyond the direct heat source (Fig. 4) and its associated metasomatically altered and possibly mineralized rocks. In places these anomalies may be the only indication at the ground surface of a former hydrothermal system (Cunningham and Barton, 1984).

Parameters useful in detecting paleothermal anomalies include reset or partially reset fission track ages of minerals; reset K-Ar ages; improved crystallinity of clays, feldspars, or other minerals; progressive changes in the maturation state of organic matter; increased vitrinite reflectance; coal rank; altered conodont and palynomorph colors; reoriented paleomagnetic directions; thermal and compositional variations in fluid inclusions; local discharge of thermoluminescence; and changes in the oxygen and hydrogen isotopic compositions of rocks. Patterns of the degree of responses of organic and inorganic materials to thermal events may provide vectors toward the source of heat.

Mineral deposits associated with a paleothermal anomaly need not be located in close proximity to the center of the anomaly. This is especially true if the heat source was not a source of the metals but served mainly to drive hydrothermal convection cells. Mineralization takes place where upwelling, metal-bearing fluids enter environments where physico-chemical changes cause precipitation.

REGIONAL PALEOTHERMAL ANOMALY IN NEVADA

The Paleozoic sedimentary rocks of central Nevada record the composite effects of multiple stages of heating and petroleum generation during both the Mesozoic and Cenozoic (Poole et. al., 1983). An early episode of heating took place in early Mesozoic time when lower Paleozoic rocks were deeply buried by a thick section of upper Paleozoic and lower Mesozoic rocks. Some rocks were again heated locally near Mesozoic plutons (Roberts et. al., 1971) and associated hydrothermal ore deposits. Regional heating in the middle and late Tertiary time took place in response to high regional heat flow and to local igneous activity during subduction- and extension-related processes (Stewart 1978; Eaton et. al. 1978; Blackwell 1978; McKee and Noble, 1985). Many organically submature and mature lower Paleozoic and younger rocks in central Nevada are presently being subjected to another episode of thermal degradation in Neogene basins where valley fills are thick enough for temperatures to increase significantly (Poole et. al., 1983).

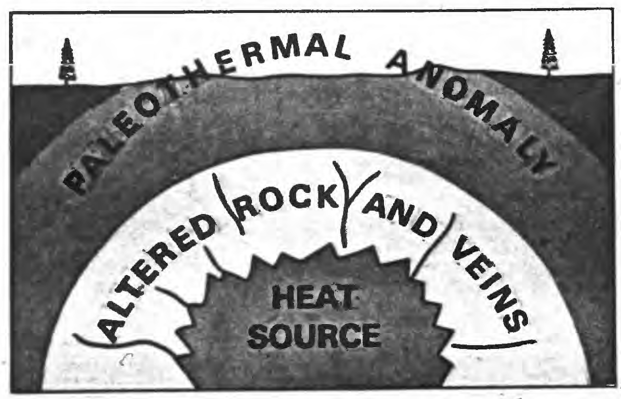


Figure 4.--Diagrammatic representation of the relationship between a paleothermal anomaly, visibly altered rocks and veins, and a heat source that may host an ore deposit.

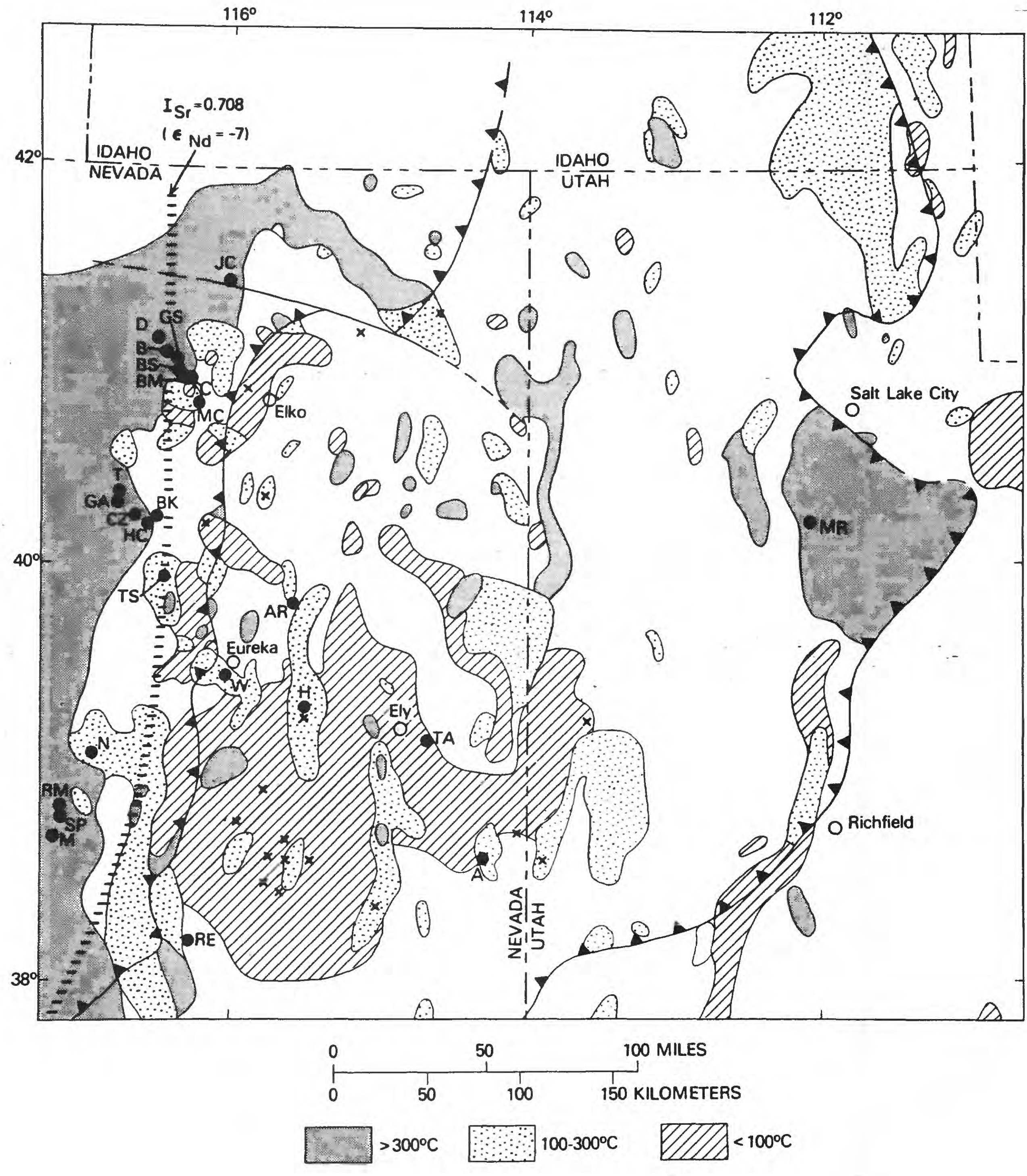
Petroleum geologists have been investigating kerogen type and thermal maturation of organic matter in sedimentary rocks on a regional scale to aid in identifying potential petroleum source beds (Connon, 1974; Waples, 1984). These studies of hydrocarbon potential have mostly been based on thermal changes of the organic material as indicated by conodont color alteration (Epstein et. al., 1977), pyrolysis such as measured by Rock-Eval techniques (Orr, 1981), vitrinite reflectance (Bostick, 1979), nuclear magnetic resonance (Dennis et. al., 1982), and gas chromatography. Organic maturation studies have recognized a regional paleothermal anomaly in central Nevada (figure 5) that is about 600 km long north-south and at least 100-200 km wide east-west. The minimum extent of the anomaly is shown on the conodont color alteration index maps of Harris et. al., (1980) by the paleoisotherm of the color alteration index (CAI) of 4.5 or greater (considerably higher than the thermal cutoff for most hydrocarbon production and preservation). The maps are generalized and patterned areas are extended between ranges to maintain cartographic continuity. The maps, however, are based on over 5000 samples representing about 1200 localities that could be plotted at a scale of 1:2,500,000, so the broad thermal patterns are believed reliable.

The eastern edge of the regional paleothermal anomaly has been studied in greatest detail because of petroleum exploration interest in eastern Nevada. The base map of Figure 5 is from Poole et. al., (1983) and is a detailed and comprehensive map of maximum temperatures indicated by samples of outcropping and subsurface Paleozoic strata along the eastern edge of the paleothermal anomaly. Several thousand organic maturation data points on Ordovician to Permian rocks have been integrated on the map, supplementing data from Harris, et. al., (1980). Extensive new analytical data, largely Rock-Eval pyrolysis determinations, used in the compilation have been published by Poole and Claypool (1984). Figure 5 shows areas of Paleozoic rocks that are submature to early mature (<100°C), mature to supermature (100°-300°C) and supermature (>300°C).

The eastern edge of the paleothermal anomaly is of particular interest to economic geologists because some of the largest disseminated gold deposits, including Carlin, Jerritt Canyon, and Round Mountain, are located near the boundary of the area containing dominantly supermature (>300°C) rocks. These deposits are located on the gradient of the paleothermal anomaly, where lower Paleozoic rocks to the west were heated to over 300°C and similar rocks to the east were heated to less than 100°C. The thermal gradient also is located close to the edge of the buried Precambrian craton, based on the isotopic studies.

The west side of the paleothermal anomaly is not well constrained; however, there is a consistent north-south pattern in the paleothermal anomaly as shown in the thermal maps of various Paleozoic rocks (Harris, et. al., 1980). The widest known extent of the paleothermal anomaly is shown on their map of color alteration index for Devonian rocks. This edge is in close proximity to major precious metal districts including Relief Canyon, Spring Valley, Rochester, Bell, Bruner, Candelaria, Imlay, and Lodi (Koschmann and Bergendahl, 1968; Elevatorski, 1982). Most of the precious metal deposits located east of the paleothermal gradient shown on figure 5 dominantly are silver (Reveille, Hamilton, Taylor) or silver/gold (Atlanta) deposits that may reflect the composition of the underlying crystalline basement and/or regional thermal or fluid zoning.

Figure 5.--Spatial relationship of the major precious-metal deposits in northeastern Nevada to the gradient of a regional paleothermal anomaly superimposed on Paleozoic rocks. The dashed line indicates the location of initial $^{87}Sr/^{86}Sr$=0.708 and $^{143}Nd/^{144}Nd$=-7 isotopic compositions in granites. The x indicates the location of wells and outcrops containing oil. The western thrust is the eastern outcrops of the siliceous assemblage of Paleozoic rocks marking the Roberts Mountains thrust system of Late Devonian and Early Mississippian age, and the eastern thrust is the trace of the Sevier thrust system of Cretaceous age. Figure 4 is modified from Poole et. al., (1983), Bonham (1981), and Farmer and DePaolo (1983). Deposits are: JC=Jerritt Canyon (Bell); B=Bootstrap; GS=Gold Strike; BS=Blue Star; BM=Bullion Monarch; C=Carlin; MC=Maggie Creek/Gold Quarry; R=Rain; T=Tenabo; GA=Gold Acres; CZ=Cortez; HC=Horse Canyon; BK=Buckhorn; TS=Tonkin Springs; AR=Alligator Ridge; W=Windfall; N=Northumberland; RM=Round Mountain; SP=Shale Pit; M=Manhattan; RE=Reveille; H=Hamilton; TA=Taylor; A=Alanta; and MR=Mercur.



116°
114°
112°
42°
40°
38°
I_{Sr}=0.708
(ϵ_{Nd}=-7)
IDAHO
NEVADA
IDAHO
UTAH
NEVADA
UTAH
JC
D
GS
B
BS
BM
C
MC
Elko
T
GA
BK
CZ
HC
TS
AR
Eureka
W
H
Ely
TA
N
RM
SP
M
A
RE
MR
Salt Lake City
Richfield
0 50 100 MILES
0 50 100 150 KILOMETERS
>300°C
100-300°C
<100°C

DISCUSSION

The close spatial correspondence between: 1) the position of many of the major disseminated gold deposits, 2) the buried western margin of the Precambrian craton, 3) a distinctive lower Paleozoic facies change, 4) the trace of the leading edge of the Roberts Mountains thrust system, 5) pronounced aeromagnetic and gravity anomalies, and 6) the eastern edge of the regional paleothermal anomaly, suggests that there is a genetic connection between all of these features. The approximate position of the buried boundary of the Precambrian cratonic basement is intrepreted to be depicted by the initial $^{87}Sr/^{86}Sr=.708$ and $^{143}Nd/^{144}Nd=-7$ values in plutons (Farmer and DePaolo, 1983). The precise position of this boundary probably has been obscured somewhat by sedimentary debris spread westward during the Precambrian, by rifted fragments of the crust detached by younger tectonism and by the accreation of anomalous terranes. The position of the edge of the craton appears to have had a profound effect on geologic processes since the Precambrian. During the lower Paleozoic, the edge of the craton appears to have controlled the distribution of environments in which the sedimentary rocks were deposited; shallow-water carbonate rocks were deposited on the continental shelf east of the boundary, whereas deeper water carbonate rocks and siliceous sediments dominated in oceanic basins west of the boundary marked by the continental slope (Matti and McKee 1977; Hurst et. al., 1985). During the early Mississippian Antler orogeny, the Roberts Mountains thrust was probably deflected upward by the buried Precambrian craton and moved western facies rocks up and over the shelf carbonates onto the higher-standing craton. The present position of the trace of the thrust reflects erosion of the structurally higher parts of the plate which has removed most of the supra-continental allochthonous rocks.

The origin of the composite regional paleothermal anomaly is constrained by its position, shape, maximum temperatures, and age. In order to heat an area as much as 100,000km^2 to the temperatures indicated, heat from the mantle is practically required. The eastward limit of heating against the craton suggests that radioactive heating from a K/U/Th-rich continental mass is not responsible for the thermal event. Patterns of early- to mid-Tertiary igneous activity, reflecting changes in basic tectonic and magma-producing activity, moved southward across the Western United States (Lipman et al, 1972; Christiansen and Lipman, 1972). Voluminous middle Tertiary andesitic and rhyolitic igneous activity in the Western United States took place in central and eastern Nevada 38-20 Ma (Armstrong et. al., 1969; McKee et. al, 1970; McKee, 1971; Lipman et. al., 1972; Noble, 1972; Shawe and Stewart, 1976; Stewart et. al., 1978; Stewart and Carlson, 1976, 1978) and must have been accompanied by regional heating. Basin-range extension began about 18 Ma, and was accompanied by regional uptilt, crustal thinning, and high heat flow, related to elevation of the mantle. Whether the ultimate cause of the extension was drag between the North American and Pacific plates (c.f. Atwater, 1970; Christiansen and McKee, 1978), back arc spreading (c.f. Thompson and Burke, 1973; Eaton, 1984), subduction of the East Pacific Rise (c.f. Menard, 1960; McKee, 1971), or the presence of mantle plumes (c.f. Matthews and Anderson 1973; Suppe et. al., 1975), the heat flow was increased over the region. The coincidence of the eastern edge of the paleothermal anomaly with the western margin of the continental crust indicates that the Paleozoic rocks underlain by the Precambrian crystalline basement received less heat flux than similar rocks immediately to the west. This would have been the case if the crust acted as a thermal shield, retarded the rise of basalt, and protected the Paleozoic rocks above it from being heated.

The regional paleothermal anomaly is a composite thermal feature and the younger thermal episodes are not well dated. Most probably these younger episodes took place in the mid-Tertiary, between approximately 37 and 14 Ma, when spatially associated volcanic rocks were erupted, volcanic-hosted disseminated gold deposits formed, and the basin-range tectonic setting began. Available data indicate that the volcanic-related disseminated gold deposits formed during subduction-related processes prior to the onset of basin-range extension. The sedimentary-rock hosted disseminated gold deposits not clearly related to volcanic processes (such as Jerritt Canyon and Carlin), are not well dated. The Carlin deposit is older than an overlying unmineralized 14 Ma rhyolite flow (McKee et. al., 1971), but geologic constraints on the older limit merely indicate a post-thrusting (post Antler Orogeny) and probable post altered-Cretaceous dike (Morton et. al., 1977) age. It is widely assumed that the sedimentary-rock hosted and volcanic-rock hosted gold deposits are of the same general age, which seems a likely although unproven possibility. If this is true, disseminated gold deposits and the most intense Tertiary heating of the rocks in the paleothermal anomaly may have been broadly coeval either during the southward sweep of volcanic activity 34-20 Ma, or near the onset of basin-range extension at 18-14 Ma. The present shape of the regional paleothermal anomaly (which by implication, places constraints on the age of the sedimentary-rock hosted disseminated gold deposits) could have been produced by either event, or a combination of events, since its north-south trend parallels the position of the buried edge of the craton as well as being approximately parallel to the long axes of ranges produced during basin-range faulting and the orientation of the magnetic "quiet zone."

The age of mineralization would place constraints on the depth of mineralization and the pressures that could exist during the process. Mid-Tertiary ash flow tuffs and lava flows from the various volcanic centers, and siliceous sinters from surface emanations of hydrothermal systems mark the position of the ground surface at that time. Pressures at the site of Tertiary mineralization would probably be mostly hydrostatic, occasionally up lithostatic, and only rarely overlithostatic as might occur during acid dissolution of a carbonate. Fluids present at an earlier time, such as during deep burial or thrusting, would probably be at significantly higher pressures than during mid-Tertiary mineralization. Furthermore, these earlier fluids might be marked by higher organic volatile content produced during these first major thermochemical changes in the sedimentary rocks.

A genetic model for the origin of the disseminated gold deposits suggests that they formed near the top of hydrothermal plumes localized along upwelling limbs of large convection cells. The cells would be driven by the heat that formed the paleothermal anomaly; some of the gold could have had a magmatic source but much could have been scavanged by deeply circulating fluids that traversed deep-water marine strata and lower crustal rocks of oceanic provenance west of the cratonic boundary. Such rocks have been shown to be favorable sources with recent experimental studies (Dickson et. al., 1979).

Not all disseminated gold deposits in northeastern Nevada are along the eastern marginal gradient of the paleothermal anomaly. A prime exception appears to be Alligator Ridge where recent studies of the organic matter (Ilchik 1985) indicate that the deposit is spatially related to a separate paleothermal anomaly marked by a pronounced lowering of the hydrogen index in the organic material of the host rocks. This suggests that individual deposits are related to separate hydrothermal plumes and that the deposition of gold may be related to a near-surface drop in temperature and/or boiling, rather than changes in Eh related to organic material. Alligator Ridge is located over the magnetic "quiet zone" (fig. 3). It may be related to this feature and be younger than many of the other sedimentary-rock hosted disseminated gold deposits.

This study provides some obvious implications for exploration strategies. The opportunity for discovering disseminated gold deposits appears to be enhanced by identifying the distribution of the gradient of the regional paleothermal anomaly and the location of the Precambrian craton. There appears to be a diffuse pattern of the spacing of known deposits along the north-south trend at about 80 km intervals that reflects information about the size, shape, number, and distribution of hydrothermal cells modified by local structural control and permeability. This might aid in predicting areas that have not been thoroughly tested, especially in areas overlain by young, thin, cover. Other areas in Nevada and Utah have been identified as having thermally mature sedimentary rocks (Harris et al, 1980; Poole et al, 1983; figure 5) and some of the thermal alteration may have been caused by local paleothermal anomalies. Some anomalies are related to known centers of igneous activity, such as the Pioche-Marysvale belt (Shawe and Stewart, 1976; Callaghan, 1973; Steven et. al., 1979) and the Oquirrh-Unita and Deep Creek-Tintic belts (Hilpert and Roberts, 1964; Stewart et. al., 1977). Several major gold deposits and gold producing areas are known to occur within these paleothermal anomalies, including Mercur, East Tintic, Gold Hill, and the Deep Creek Mountains, and the other anomalies should be carefully investigated.

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