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The Golden Triangle of Southeast China: Another Carlin Trend?

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Editor's note: This article is an expanded version of *The Golden Triangle of SE China: Potential for another Carlin trend,* which appeared in the inaugural *SGEG Newsletter* (July 2003, no. 1) published by the Special Group in Economic Geology at Monash University. Andy Wilde's paper provides an interesting complement to the current special issue (98-6) of *Economic Geology,* which focuses on gold deposits of the Carlin trend in northern Nevada.

INTRODUCTION

Numerous gold deposits and occurrences in southeast China are located in an area known as the "Golden Triangle," mainly in Guizhou province (Fig. 1). Comparisons have been made with sedimentary rock-hosted or "Carlin-type" deposits of northeast Nevada (e.g., Li and Peters, 1998), and at least one major multinational mining company has explored for Carlin-type deposits in this area. Such deposits represent attractive mineral exploration targets owing to the size of the contained resources, high grades, and amenability to open-pit mining operations. Furthermore, the deposits tend to occur as clusters (or "trends"). Discovery of a new mineralized cluster would represent a major coup. In this paper I provide a short summary of aspects of the geology of the southwest Chinese deposits and comment on their similarities and differences compared to the deposits of Nevada.

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CHARACTERISTICS OF CARLIN-TYPE DEPOSITS OF NEVADA

Gold deposits of the Carlin trend of Nevada are hosted by Ordovician to Devonian clastic and carbonate sedimentary rocks from the zone of transition between continental shelf and basin (Cook 1988; Armstrong et al., 1998). The presence of buried Precambrian crust beneath the continental shelf has been inferred from the radiogenic isotopic composition of Mesozoic and Cenozoic intrusive rocks that have significantly more crust-derived Nd and Sr in central and eastern Nevada (Farmer and De Paolo, 1983; Wooden et al., 1997). Progradation, transgression, and periods of nondeposition within the early Paleozoic sequence have been attributed by Cook (1988) to changes in sea level but may also reflect the movement along a bounding fault or faults at the edge of the Precambrian crustal platform. Emsbo et al. (1999) portray the presence of such faults in their reconstruction of the Carlin trend during the Middle Devonian. Furthermore, Teal and Jackson (1997, p. 13) have noted that "the north-northwest regional

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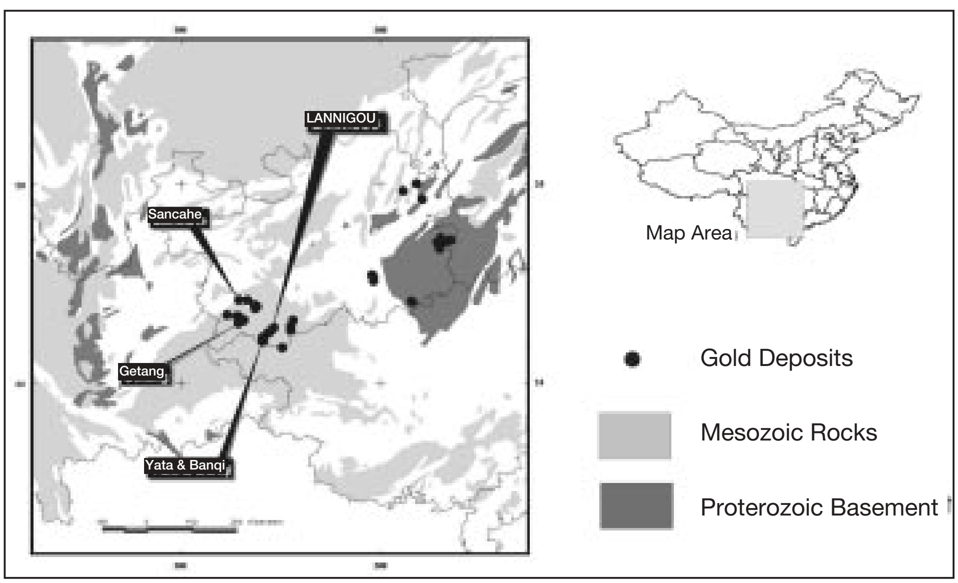

FIGURE 1. Geology of the Golden Triangle. The Golden Triangle is the triangular Mesozoic basin that straddles Guizhou, Yunnan, and Guangxi provinces. Gold deposits are shown for Guizhou province only.

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alignment of the Carlin trend reflects an apparent pre-existing zone of crustal weakness that transects the present-day north-south trending Basin and Range topography."

The bulk of gold in the Carlin trend is contained within the stratigraphic interval of the Silurian to Devonian Roberts Mountain and the Popovich Formations (Teal and Jackson, 1997; Peters et al., 1998). The environment of deposition of these formations ranges from inter- and supratidal to toe of slope and tidal shelf at the very top of the Popovich Formation (Armstrong et al., 1998). A large portion of the economic gold is restricted to a distinctive debris-flow breccia containing "megablocks" of over a meter in maximum dimension (Armstrong et al., 1998; Peters et al., 1998). The suitability of the Popovich Limestone as an ore host can be ascribed to diagenetic porosity resulting from early dolomitization of calcite (Armstrong et al., 1998) and probably intrinsic depositional porosity and permeability of the mega-block breccia.

Much of the gold is disseminated throughout the host rock, and is fine grained and typically encapsulated in arsenian pyrite, making the primary ore refractory. Gold ore is greatly enriched in As and also contains elevated Hg, Ag, Sb, Tl, and other elements, notably Pb and Zn. Primary hydrothermal alteration as manifested as deposition of quartz (commonly in fine-grained form as jasperoid, rather than in veins), as illite and kaolinite, and as dissolution of carbonate minerals. Ferroan carbonate dissolution may have been an important gold depositional mechanism (Stenger et al., 1998) and therefore the distribution of and controls on pre-ore—presumably diagenetic—ferroan carbonate is of some interest. Using an analogy with the Lennard Shelf of Australia, Wilde and Muhling (2000) have suggested that the distribution of ferroan dolomite may have been controlled by early basinal brine emission along major rift-bounding structures that also controlled development of subeconomic Au-Pb-Zn and barytes deposits (as documented by Emsbo et al., 1999).

The full extent and distribution of hydrothermal channelways related to gold transport and deposition is poorly understood. A combination of vertical faults and intrinsic and reaction-enhanced permeability permitted access by hydrothermal fluids. The presence of relatively impermeable siliciclastic basin rocks thrust over the host sequence (Roberts Mountain thrust) is thought to have been important in focussing fluid flow as upward-moving fluids would have been retarded at this interface and spread laterally (Hofstra and Cline, 2000).

The chemical processes of ore formation involved hot (probably in excess of 200°C), reduced, and sulfur-rich fluids. Thus gold would probably have been transported as a reduced sulfur complex and deposited by a combination of cooling and neutralization (Hofstra and Cline, 2000). According to Hofstra and Cline (2000, p. 24), the ideal host-rock "consists of permeable ferroan carbonate that is completely dissolved and its contained iron completely sulfidized such that all that remains is gold-bearing arsenian pyrite."

REGIONAL SETTING OF THE CHINESE DEPOSITS

The Golden Triangle is located at the southwestern margin of the Archean to Proterozoic Yangtze craton within the Phanerozoic Nanpanjiang basin (Fig. 1). Initiation of the Nanpanjiang basin was the result of Cambrian extension of the Yangtze Precambrian basement (e.g. Cooke, 1998). The sedimentary rocks of the Nanpanjiang basin range from Cambrian to Triassic in age, but the bulk of outcrop is of Permian and Triassic age. Triassic sedimentary rocks host most of the gold deposits in the region. Larger deposits lie at or close to the transition from carbonate platform facies (e.g., tidal flat and reef) to deeper-water siliciclastic basinal facies (Fig. 2). Buried rift-margin structures may have provided transient permeability and focussed fluid flow at various times (during reactivation) in addition to producing a major chemical contrast between basin sediments and platformal ones (Wilde and Muhling, 2000).

Major Carboniferous and Permian orogenic events are recognized in northeast Nevada, in which major thrust faults developed and basinal facies siliciclastic rocks were thrust eastward over platformal facies carbonate-rich rocks. Although thrust faults are interpreted in southwest China (e.g., at the Lannigou and Getang deposits) these appear to be related to Cretaceous compression and there is to page 10 · · ·

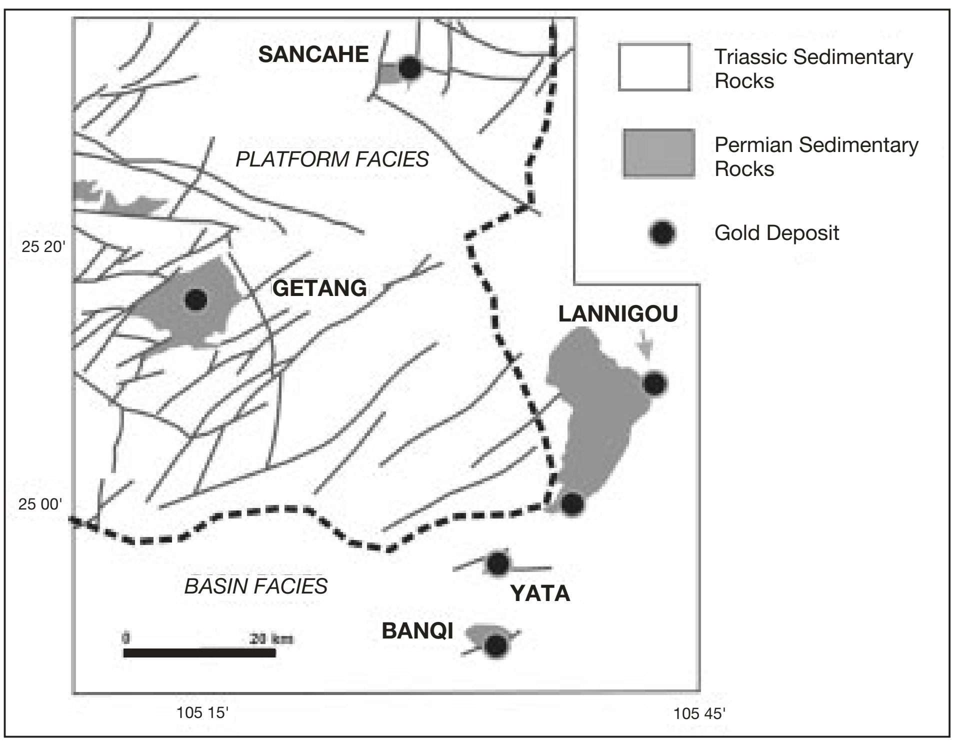

FIGURE 2. Geology of part of SW Guizhou province adapted from mapping by the Guizhou Bureau of Geology and Ashley et al. (1991).

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little evidence of major Carboniferous or Permian compressive tectonic events. On the contrary, a Permian extensional event (or events) has been inferred from the discordance between various Permian and Triassic units, and in places disconformable contact between Middle Triassic and Late Permian sedimentary rocks (Cooke, 1998). Support for an extensional event is provided by the alkalic basalt lavas and volcaniclastic rocks of the Emeishan Basalt, deposited at the early to late Permian transition. These basalts are associated with a few ultramafic pipes.

The major deformation event in the Nanpanjiang basin is the Late Cretaceous Yanshanian orogen (Li and Peters, 1998). This event produced small-scale folding and domal structures, with which gold deposits are commonly associated (Fig. 2). Apart from minor dikes, there is no associated magmatic activity (Li and Peters, 1998). Indeed, no large felsic intrusions of any age are known in western Guizhou province. This represents another major contrast with northeast Nevada where large volumes of felsic and mafic magma of various ages have been mapped.

Vitrinite reflectance measurements on organic material demonstrate a regional heating event in which temperature reached between 175° and 250°C (Ashley et al., 1991). The age of this heating remains in doubt, although Ashley et al. (1991) suggest that it predated gold emplacement. It seems likely that this heating event was the result of the Yanshanian compression.

GOLD DEPOSITS OF THE GOLDEN TRIANGLE

The largest gold deposit known in the Golden Triangle is at Lannigou (Fig. 2), which was originally discovered as a mercury prospect in 1986. Caution is required in specifying a gold resource for this deposit, owing to poor core recoveries and inability of the Chinese drill rigs of the day to drill other than vertical or steeply inclined holes. It is likely, however, that the Lannigou gold resource exceeds 1 Moz. Apart from a shallow oxidized zone that extends for a few meters only, the ore is considered to be refractory. This is one reason that the Chinese government permitted foreign access, as local technology for treating refractory ores is rudimentary.

Lannigou gold ore is found in cataclasite from near-vertical, northwest- to southeast-trending faults displacing Triassic clastic rocks, predominantly sandstone, siltstone, and argillite (Fig. 3). In primary (unweathered) ore, gold is fine grained and located within arsenian pyrite and arsenopyrite. Orpiment, realgar, cinnabar, and stibnite are also conspicuous and native mercury is being recovered by local tribes-people. Pervasive hydrothermal alteration and vein phases include quartz, chalcedony, illite, ankerite and calcite (Lou, 1998).

The main ore-hosting fault is interpreted as the result of compression although it has a complex history of reactivation (Lou, 1998). It is related to a domal feature attributed to the Cretaceous Yanshanian orogeny. A thrust fault has been identified to the west of the deposit, and has juxtaposed limestone with the top of the mineralized clastic rocks (Fig. 3). The limestone is not known to host significant gold. The thrust fault may, however, have influenced ore deposition by creating a permeability barrier above the mineralized Triassic rocks.

The Yata deposit (Fig. 2) is spatially restricted to vertical faults displacing open-folded Mid-Triassic Xinyuan Formation (Fig. 4; Ashley et al., 1991). The host rocks were originally carbonaceous ferroan-dolomite-rich shales and arkoses (Ashley et al., 1991). Of significance is the observation that ferroan dolomite and ankerite were partly removed during ore formation, supporting the idea that reactions involving the Fe in dolomite caused gold deposition (Stenger et al., 1998). Hydrothermal alteration and vein phases include quartz, illite, arsenian pyrite, and lesser arsenopyrite, stibnite, and sphalerite. Quartz ± calcite and realgar veins are

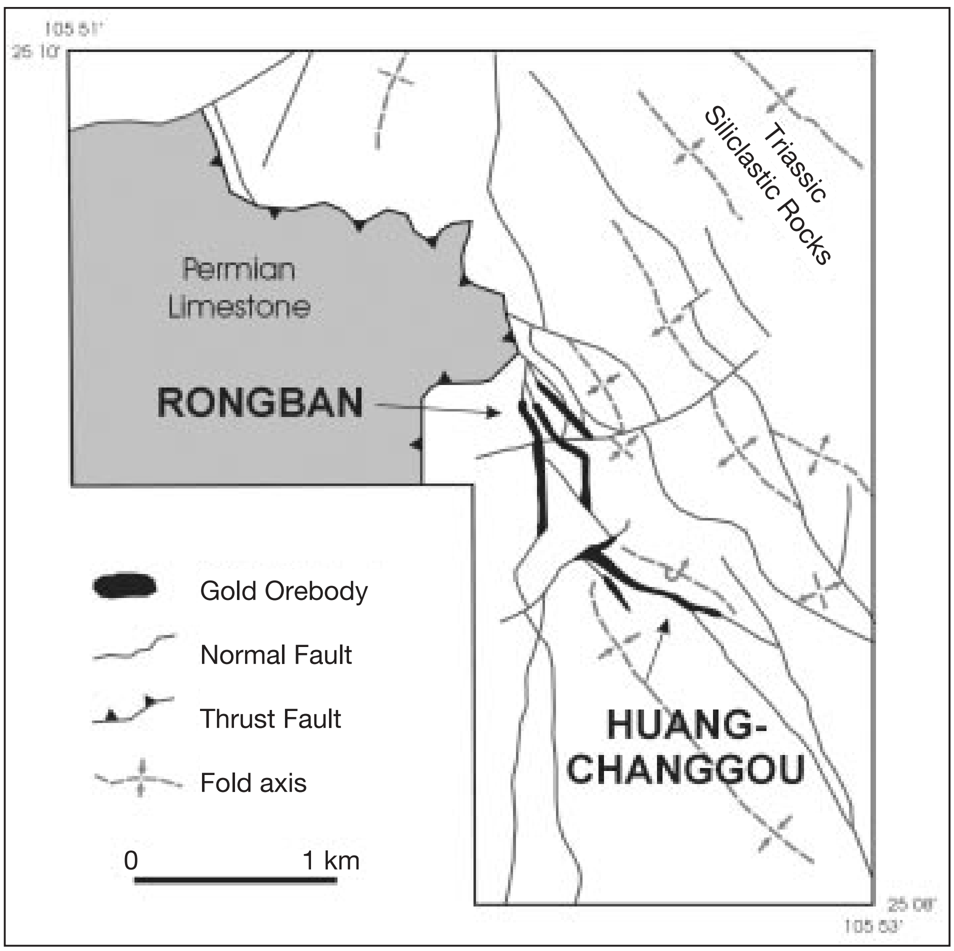

FIGURE 3. Geology of the Lannigou gold deposit, Guizhou Province. From Chinese mapping.

common but probably postdate gold deposition (Ashley et al., 1991). Bulk-rock samples clearly show enrichment in As, Sb, Hg, and Tl.

The Getang deposit (Fig. 2) is hosted by the Early Permian Maokou and Late Permian Longtan formations (Ashley et al., 1991). Coal beds are present in both units. Structural control is less significant in localizing gold ore, which occurs preferentially within a pervasively silicified breccia horizon. The origin of the breccia is disputed with interpretations including sedimentary, karstic collapse and tectonic. Hydrothermal alteration phases include quartz, kaolinite/dickite, and mixed-layer illite-montmorillonite. Anatase of uncertain origin is abundant as is organic matter. Quartz veins, uncommon in the Carlin-type deposits of Nevada, occur in abundance in high-grade ore from Getang, along with calcite, fluorite, pyrite, and traces of arsenopyrite, stibnite, and sphalerite (Ashley et al., 1991). Realgar and cinnabar are also present in high-grade gold ore.

At the Sanchahe deposit (Fig. 2) gold is spatially associated with a reverse fault. Host rocks range in age from Late Permian to Early Triassic and include shale, siltstone, coal, and limestone. The highest gold grades occur in pervasively silicified limestone. Alteration minerals include illite, kaolinite and arsenian pyrite. Unusually high levels of anatase are also a feature of the host rocks at this deposit. Realgar, cinnabar, marcasite, barite, fluorite, and stibnite have been described (Ashley et al., 1991). The deposit is also enriched in Tl.

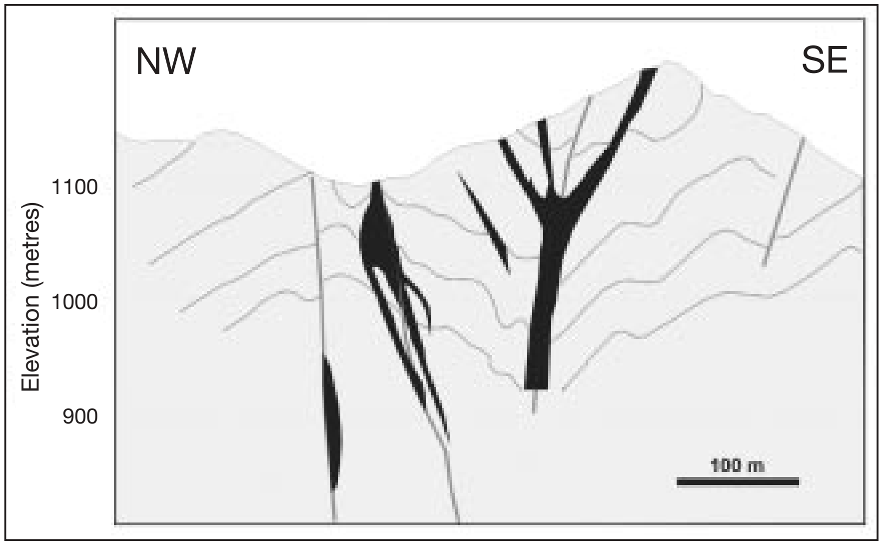

FIGURE 4. Cross section of the Yata gold deposit, illustrating the narrow and structurally controlled nature of the gold ore (from Ashley et al., 1991).

DISCUSSION

The host rocks to the Golden Triangle deposits and those of northeast Nevada are lithologically similar and share a similar evolution up until the Carboniferous. Gold deposits of both areas share a spatial association with a zone of transition between shallow water platformal sediments and deeper sediments with a stronger marine influence. This is believed to reflect the presence of profound and long-lived structures that focussed fluid flow from a large “catchment” area during ore formation (Hofstra and Cline, 2000; Wilde and Muhling, 2000). Secondly, the transitional zone represents a substantial chemical gradient between generally reduced and sulfur-rich marine sedimentary rocks likely to favour gold dissolution and transport as aqueous bisulfide complexes, and carbonate-rich sedimentary rocks that might cause gold deposition through promoting pH change in the ore-forming fluids (Hofstra and Cline, 2000; Wilde and Muhling, 2000).

During the Carboniferous basinal facies in Nevada were thrust back over the platformal sedimentary rocks to the east and began a quasi-continuous history of magmatic intrusion and extrusion that continued into the Quaternary. A consensus is emerging, based on a variety of dating techniques, that the Carlin-type gold deposits of northeast Nevada formed between 42 and 30 m.y. ago (see summary in Hofstra and Cline, 2000). It has been postulated that this is due to the arrival of a mantle plume during crustal extensional, while a direct link to felsic magmatism is yet to be proven (Hofstra and Cline, 2000)

In southwest China there is evidence for a mild Permo-Triassic extensional event as deduced by Cooke (1998) and the presence of the Emeishan basalts may be an indication of a coeval mantle plume event. The introduction of gold, however, appears to be a later event, although there are no high quality absolute age determinations to support this contention. Whatever the real age of gold emplacement, there is no doubt that the role of felsic magmatism is minor and there is a singular dearth of felsic magmatic bodies of any age. Clearly, felsic magmatism played no part in the genesis of the Chinese Carlin look-alike deposits.

At the deposit scale, similarities between deposits of the two regions extend to the refractory nature of the gold, its fine grain size and location in arsenian pyrite and arsenopyrite, and relatively high As and Hg content of the ore (as arsenian pyrite, arsenopyrite, cinnabar, native Hg, realgar, and orpiment), as well as enrichment in Sb and C. Significant differences at deposit scale include the tendency for the Chinese deposits to be restricted to vertical faults in siliciclastic rather than carbonate-rich rocks (although comparable deposits do exist in Nevada, for example the Alligator Ridge deposits) and for them to be significantly smaller.

Why then are there no significant deposits in the Permian limestone of southwest China? If we accept the depositional mechanisms proposed by Stenger et al. (1998) and Hofstra and Cline (2000) the Permian limestone is a less than ideal host rock as it tends not to show secondary dolomitization. Another factor is the apparent absence of an impermeable seal or aquitard above the limestone that would have promoted fluid flow within the limestone sequence.

CONCLUSIONS

It has long been recognized that the Carlin-type or sedimentary rock-hosted gold deposits of northeast Nevada and southwest China share many common characteristics at deposit scale. The similarity of

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alteration and ore assemblages is a clear indication that similar chemical processes occurred in both regions. However, there are also significant differences, particularly in their deformational and magmatic history. There is good evidence that the deposits of norhteastern Nevada were generated during the Tertiary, a period of high heat flow accompanying extension and, perhaps, a mantle plume event. Although there is a need for high-quality, absolute dating of the Chinese deposits, the available evidence points to their association with Cretaceous compression. This leads to the proposition that a specific regional fluid flow regime (be it topography, deformation or thermally driven) is less important than the chemical characteristics of the host sequence and the local physico-chemical controls on ore deposition.

Could the Golden Triangle host a cluster of deposits with similar gold endowment to the Carlin trend? There are three factors that suggest an answer to this question. First, the Golden Triangle lacks a large volume of the ideal host rocks (as defined by Hofstra and Cline, 2000). Secondly, the Gold Triangle presents an "inverse" hydrodynamic regime compared to the Carlin trend in that the aquitard or seal units (siliciclastics) are beneath rather than above the potential host limestone sequence. Thirdly, it is likely that the multiple deformation events and presence of intrusions as mechanical inhomogeneities in northeast Nevada have contributed to a greater overall porosity and permeability there, compared to the Golden Triangle. On the basis of these factors, it seems that the Golden Triangle is likely to be less well endowed with gold than Nevada.

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