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GEOLOGY AND MINERALIZATION OF THE (Antelope) TONKIN SPRINGS MINING DISTRICT

Ronald A. Espell and Thomas B. Rich
Tonkin Springs Gold Mining Company
P.O. Box 671
Elko, Nevada 89316

(702) 468-0510
FAX (702) 468-0522

Abstract

Gold mineralization in the Tonkin Springs mining district is localized within tectono-stratigraphic slices that were stacked during thrusting associated with the late Paleozoic Antler Orogeny. The Vinini Formation has been subdivided within the district into three lithologically distinct members. Slices of the Devonian miogeoclinal limestone were incorporated into the tectono-stratigraphic sequence in the main Antler event. Additional tectonic slices of eastern facies rocks may exist at depth, invalidating the concept of a single thrust. Innumerable low angle structures, in addition to the intramember and intraformational thrusts, are present with deformation often about Ordivician (?) mafic intrusives and flows which have been subsequently altered to greenstones. An orthogonal high angle fault system is comprised of north-northwest and east-northeast trending constituents.

Three distinct styles of mineralization are recognized. TSP-1 style mineralization is hosted by a carbonate-dominant member of the Vinini Formation. Thrust zones, were the predominant structural control on this style, resulting in tabular, widespread mineralization. Rooster Ridge style mineralization occurs along an intrusive filled thrust separating Nevada Group Limestone from underlying Vinini siliceous sediments. Ore grade values are encountered within the intrusive as well as the hanging wall Devonian limestone. Another significant difference between the TSP-1 and Rooster Ridge styles of mineralization is that, in the later style, both grade and thickness of the mineralization peaks significantly along high angle feeder structures. Rooster Main style mineralization is strongly controlled by high angle structures with negligible horizontal influence. Unlike the two other styles, Rooster Main mineralization is not spatially associated with intrusive rocks. No genetic association between intrusive and the gold mineralization is invoked in the Tonkin Springs district.

Introduction

The purpose of this report is to describe the geology and mineralization of the Tonkin Springs mining district. Mineralization on the project has currently been defined over a strike length of five miles along a north, north-west trend coinciding with the Eureka-Battle Mountain mineral belt or Cortez Rift (Barrash and Venkatakrishnan, 1982; Stewart and others, 1975; and Zoback and Thompson, 1978).

The Tonkin Springs project is located in the Simpson Park Mountains (see Figure 1) in Townships 23, 23 1/2 and 24 North and ranges 48 and 49 East. Elevations range from 6400 to 8166, using a mean sea level datum. Terrain varies from low hills of moderate relief to steep rocky cliffs. Vegetation is dominantly sagebrush, with pinion pine and juniper covering lower hills, and mountain mahogany confined to limy soils. Climate is semi-arid with moderate to severe, long winters and mild to hot, short summers. Annual precipitation averages 15 inches.

Several mineralized localities, such as TSP-1 and Rooster, are repeatedly referenced within this text. Their relative locations are indicated on figure 2. Many concepts presented in this paper should be considered a cumulative summary based on work done by all who contributed to the project. Especially notable are contributions made by M. Mehrtens, Precambrian Exploration and T. Gesick, U.S. Gold. Figures in this text were produced by L.L. Coon. The management of U.S. Gold Corporation is acknowledged for providing the time and support needed to produce this report. Detailed pit maps and deposit insights were provided by Peggy Espell, Mine Geologist.

Project History

Exploration activity in the area of the Tonkin Springs claim block began in 1966 when a prospector claimed the large jasperoid reef and surrounding Devonian limestones on what is now called the Rooster Claims. Between 1966 and 1981, the claims were optioned by several companies who through additional staking, added substantially to the block. Mineral Ventures Inc., began a regional drainage sediment sampling program in 1979. As a result, the Simpson Park Mountains were found to contain anomalous gold concentrations, not only on the original block but for several miles to the south. The Rob group was claimed in 1980 and exploration began.

Precambrian Exploration teamed with Mineral Ventures, Inc. in 1982. A detailed mapping and geochemical soil sampling program was initiated over all exposed Paleozoics on the claimblock. Rock chip sampling over the strongest soil anomalies defined drill targets that eventually became TSP-1, 3 and 4.

Silver State Mining (now U.S. Gold) optioned the property in January of 1985 and put the property into production. The first gold was poured during October 1985. The Rooster claim block was

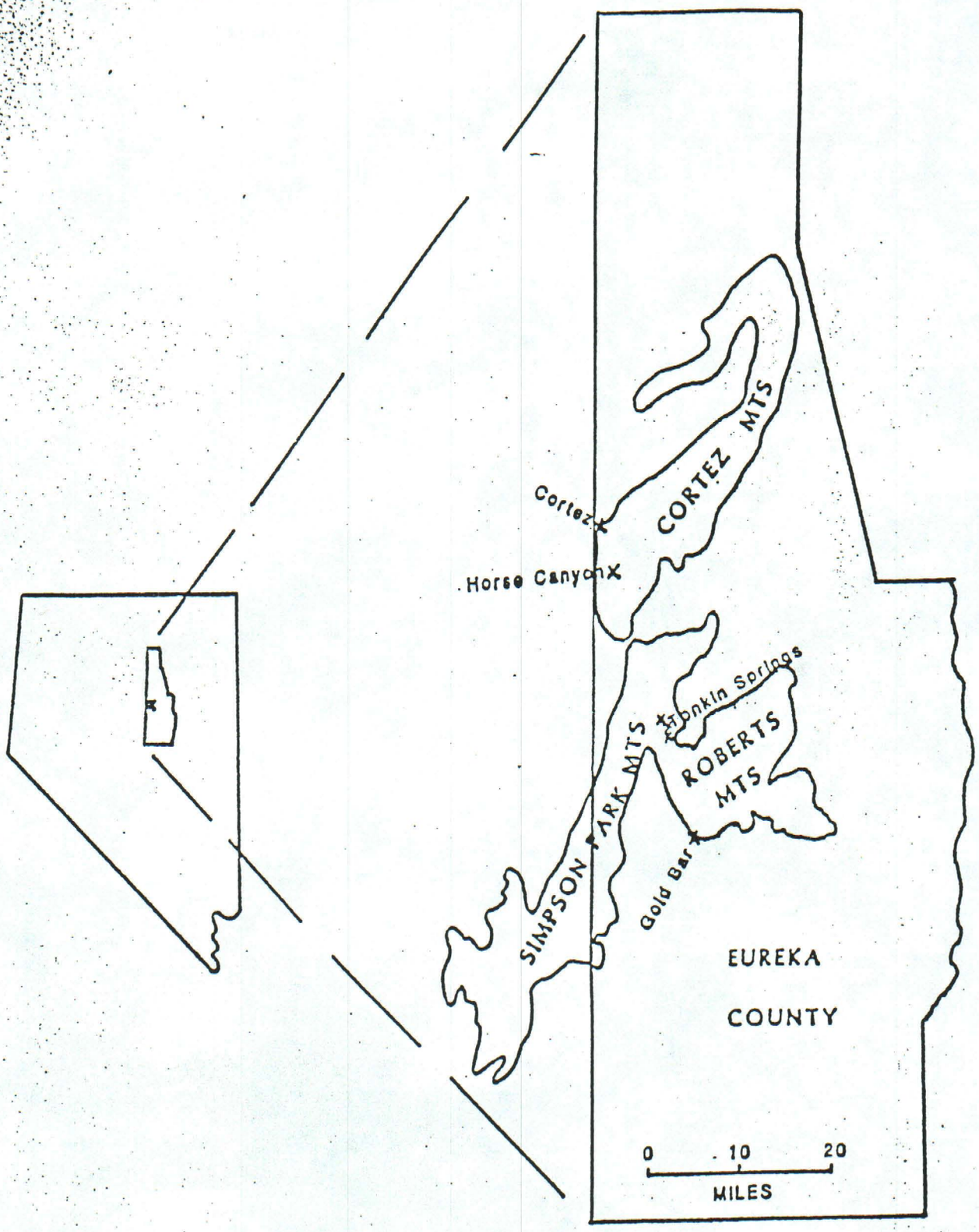
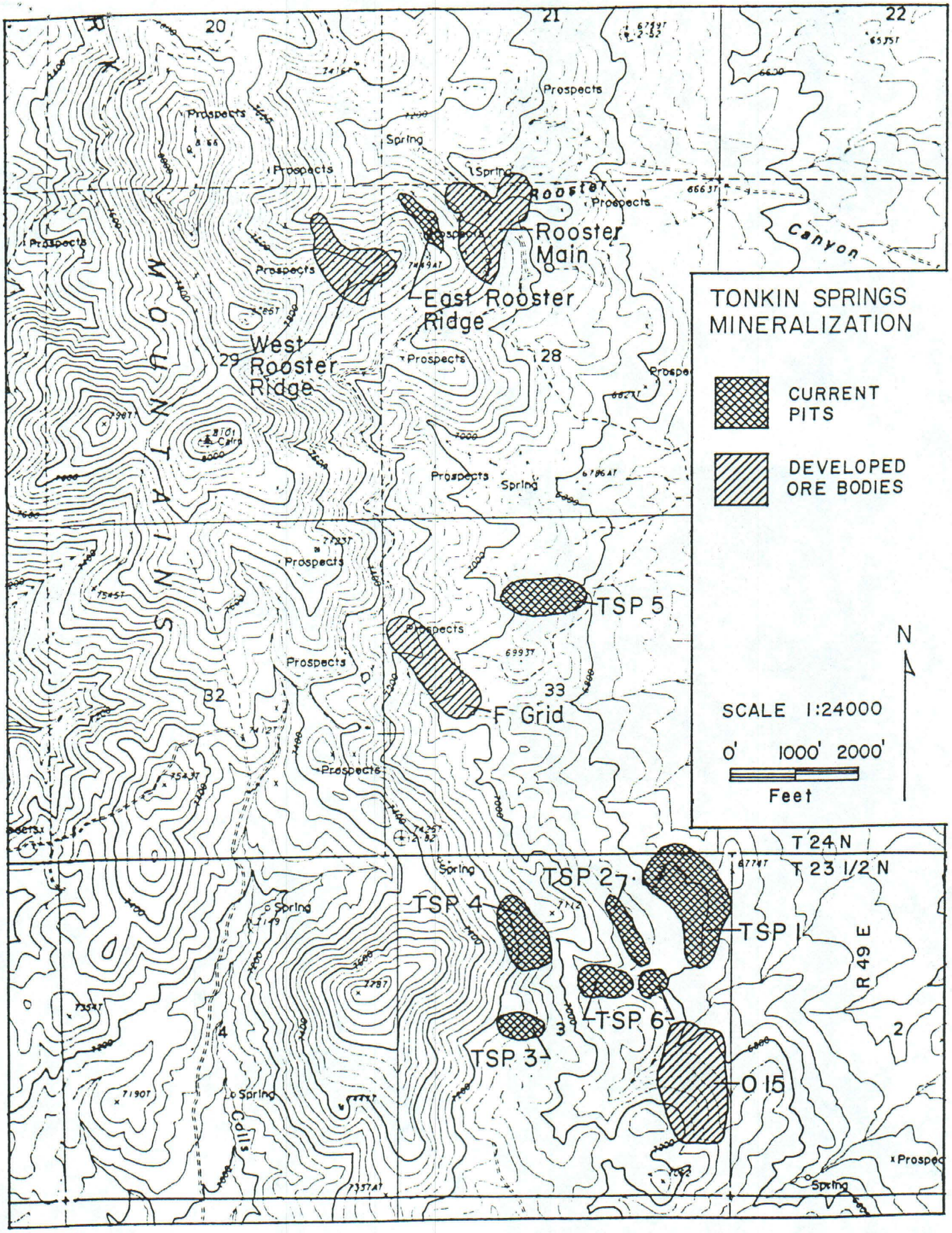


FIG. 1. Location of the Tonkin Springs Mining District.



Topographic base taken from USGS 7.5' Tonkin Summit, NV Quadrangle, 1986.

optioned by Silver State Mining in 1986. The Twin Peaks area was claimed by Silver State in 1987. To date, the claim block encompasses approximately 42 square miles along trend.

At the close of 1989, 2608 rotary holes had been drilled for a total of approximately 450,000 feet or an arithmetic average hole depth of about 173 feet. A global mineral resource of mineralized material has been calculated indicating approximately 30 million tons averaging .056 oz Au/ton using a cutoff grade of .030 oz Au/ton.

Regional Geologic Setting

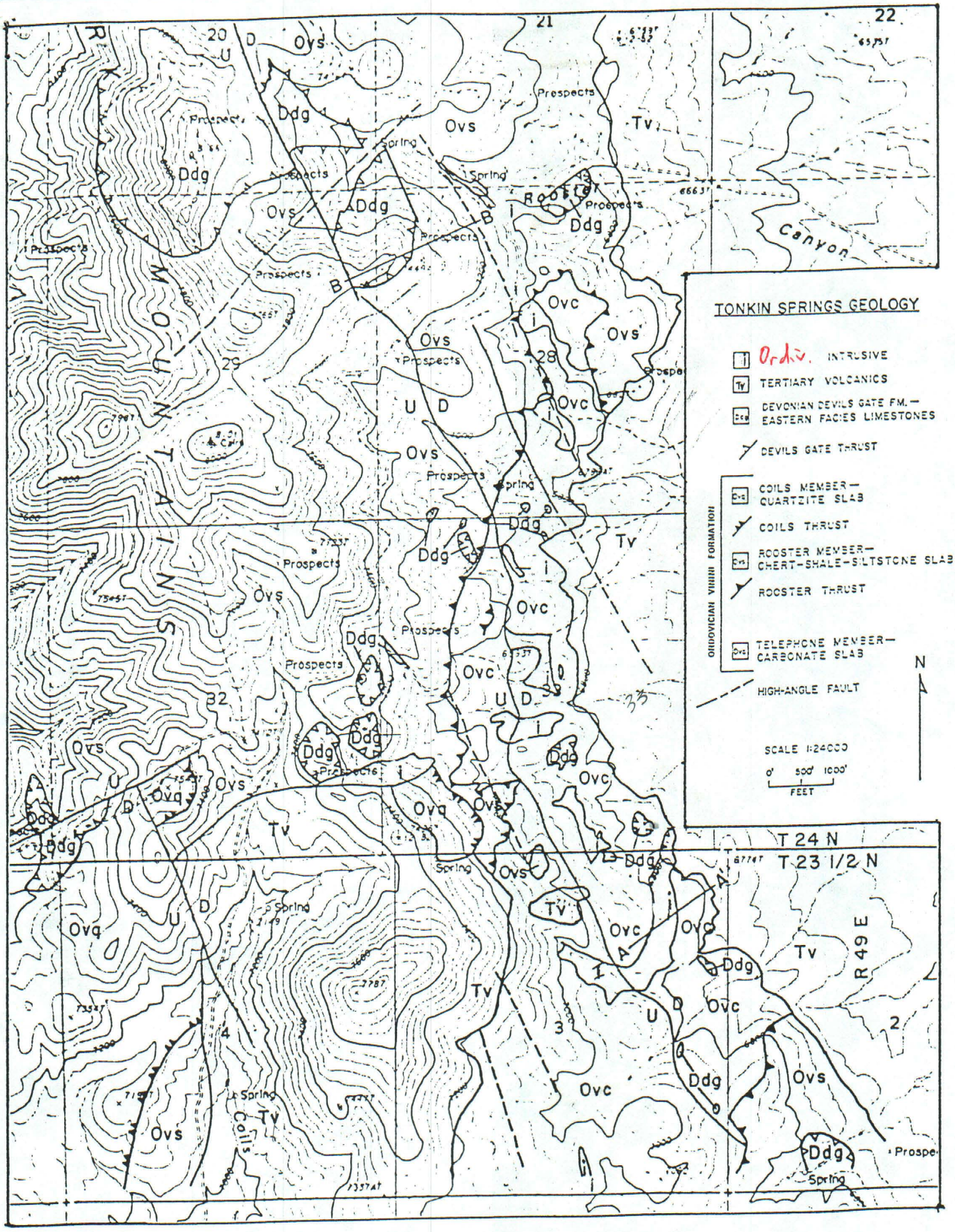
The Tonkin Springs mining district is situated in the Basin and Range Physiographic Province of the western United States. This region is defined by north-south trending mountain ranges separated by wide basins. This configuration was developed by block faulting related to extensional tectonism. The mine area is underlain mostly by allocthonous rocks that comprise the upper plate of the Roberts Mountains Thrust terrane. A belt of these allocthonous rocks trends roughly north-south through central Nevada.

The Tonkin Springs mining district is one of several mineralized areas lying along the Cortez Trend (also referred to as the Eureka-Battle Mountain mineral belt). A linear regional magnetic anomaly also defines this northwest trending feature (Mabey, 1964 and Zeitz et al., 1977). Silver and base metal production (such as from the Eureka district) prevailed historically whereas gold is the focus of contemporary interest and economic development. Other gold producers along this belt are Gold Bar, Cortez, Buckhorn, and Marigold.

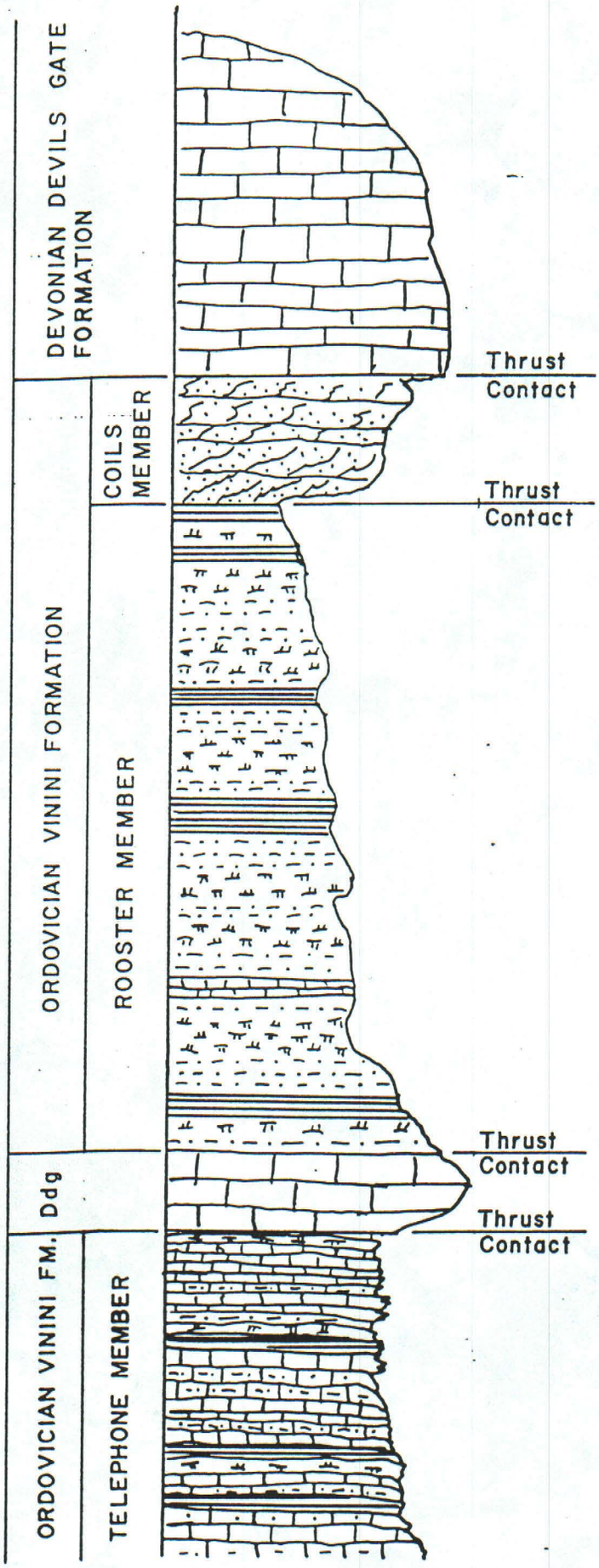
Stratigraphy

The allochthon in the Tonkin Springs area is comprised mostly of the Ordovician Vinini Formation (see figures 3 and 4). Three discrete tectono-stratigraphic packages are recognized. The Telephone Member is at the lowest level in the sequence exposed in the area. It is composed of lithologies that indicate deposition in a shelf to shelf-basin transitional environment. The relative abundance of carbonate-rich intervals within this unit distinguishes it from the overlying Rooster and Coils Members of the Vinini. Individual beds within the Telephone Member range from micrite, sandy dolomite, relatively pure limestone, silty limestone, calcarenite, calcareous carbon shale, cherty mudstone, chert and greenstone. There is a general decrease in carbonate content upsection. Where chert is present, such as in TSP-5, it generally occurs as lenses to thin beds intercalated between thin beds of limestone. Telephone Canyon, located about 3/4 mile north of TSP-1, is the type area for this member.

Overlying the Telephone Member in low-angle fault contact is the Rooster Member. The type-area for this unit is immediately south of Rooster Canyon. It is comprised of siliceous siltstone,



Topographic base taken from USGS 7.5' Tonkin Summit, NV Quadrangle, 1986.



TONKIN SPRINGS TECTONO-STRATIGRAPHIC COLUMN

Ddg— DEVONIAN DEVILS GATE FORMATION— EASTERN FACIES LIMESTONES

Ovq— COILS MEMBER— QUARTZITE SLAB

Ovs— ROOSTER MEMBER— CHERT—SHALE—SHALE—SILTSTONE SLAB

Ovc— TELEPHONE MEMBER— CARBONATE SLAB

SCALE 1" = 200'

chert, carbonaceous shale, and infrequent silty limestone. The highly siliceous nature of these sediments are typical of the western facies of the Roberts Mountains allochthon.

The uppermost of the tectonic slices that comprise the Vinini Formation is the Coils Member. This unit is chiefly comprised of orthoquartzite, indicating deposition in a nearshore environment. The base of the erosion resistant Coils is traced by a topographic break along the contact with the underlying, slope forming Rooster Member. Brecciation along this basal zone also reveals the structural nature of this contact. The Coils is about 200 feet thick where it is most prominent along the range crest to the west of TSP-1. The type area for the Coils Member is at the head of Coils Creek.

The Nevada Group is composed of medium-bedded muddy limestones and is well represented in and near the Rooster Reserve area. Exposures of Devonian limestone forming massive, dome-shaped topographic features have been reassigned to the Devils Gate Formation. These outcrops have previously been interpreted as belonging to the Nevada Group. Occurrences of Devils Gate along the range crest of the Simpson Park Mountains are generally gray to blue-gray, thick bedded to massive and, as such, are exactly as described for the Devils Gate by Roberts, Montgomery, and Lehner,(1967). Furthermore, the topographic expression and lithology of these limestones are virtually identical to that of the Devils Gate in the Roberts Mountains.

To the south of the Tonkin mine area are small, scattered outcrops of bituminous limestone. These occurrences are thought to represent correlative facies of Devils Gate Limestone exposed at the type-section of this formation, eight miles northwest of the town of Eureka, Nevada. Brachiopods, corals, and crinoids are present in the Devils Gate but no systematic biostratigraphic investigations have been undertaken. The regional overlap assemblage is represented in the northern Simpson Park Mountains but does not appear in the immediate mine vicinity.

Thicknesses of up to 100 feet of Ordivician greenstone occur as sill like bodies in low angle structural zones. This material is compositionally intermediate and has a medium to finely crystalline texture. It is generally heavily argillized where spatially associated with mineralization, such as in the TSP-1 subdistrict, but at Rooster Ridge it appears to have developed a gritty secondary texture. Coarse, primary pyrite is often ubiquitous within unoxidized intrusive. The presence of multiple layers of these sills separated by sections of Paleozoics is well documented. Evidence for discordant intrusive bodies is less distinct, but high angle feeders, nonetheless, may exist.

Two Tertiary extrusive units are recognized in the Tonkin Springs area. The oldest of these two units, a crystal-lithic rhyolite tuff, is exposed immediately east of, as well as within, the TSP-1 pit. An Eocene to Oligocene (37.5 m.y.) age for this tuff unit has been indicated by radiometric dating (Hardisty, 1983). A red-brown to purple, Oligocene (33.4 m.y.) andesite porphyry occurs as an inverted valley fill flow at the crest of the range.

District Structure

Movement within the Roberts Mountains Thrust zone (the principle source of Mississippian Antler deformation in the district) juxtaposed lithologically discrete tectonic slices (Roberts and Lehner, 1955). This stacking was achieved by active tectonic thrusting, passive gravity sliding (Ketner, 1989), or by some combination of these two mechanisms. Intercalated slices of both eastern and western facies are represented within the allochthon, suggesting possible back thrusting mechanisms as well. It is entirely possible that additional wedges of eastern facies carbonate rock are present at depth, invalidating the concept of a single thrust. Long axes of individual slices generally strike north-northwest, normal to Antler compression. These tectonic slices are miles long, thousands of feet wide, and hundreds of feet thick (Gesick, 1987). On a smaller scale, each slice consists of smaller, lithologically similar, "subslices" that are in intramember thrust contact with one another. Brecciation and recumbent folding are often well developed within the tectonically disturbed zone between slices. Low angle imbrication, often subparallel to bedding, commonly occurs and can be observed at scales down to hand sample size. High angle folding at various scales about the long axes of tectonic slices is assumed to have resulted from Antler compression.

Late Permian to Triassic Sonoma Orogenic activity resulted in a series of west-northwest striking, broad open folds. Although this trend is topographically subordinate in the mine area, it is well expressed as a regional direction of elongation of intrusive bodies (Gesick, 1987). It is also the dominant orientation of long axes of ore deposits. This west-northwest trend is also expressed in airborne geophysics where west-northwest anomalies exactly coincide with known mineralization.

Tertiary structural development is expressed locally by two distinct sets of high angle normal faults. The conjugation of these two trends results in an orthogonal fault pattern. Miocene extension and concurrent release of compressive load along axial planes of folds induced normal faulting parallel to the axis of the Cortez Rift (Gesick (1987). The resulting north-northwest striking, east dipping faults dominate the structural fabric of the area. These en echelon structures are clearly defined topographically and can be traced for long distances.

East-northeast striking, near vertical, normal faults are subordinate in magnitude to the north-northwest set. These structures influence drainage patterns and influenced the localization of silicification, as exemplified on Rooster Ridge. The origin of the east-northeast structures can possibly be traced to the development, in Antler times, of east-northeast trending tear faults that compensated differential compression.

A third structural trend runs north-south to north-northeast. It is a relatively minor feature but can be recognized topographically and on high altitude photography.

Mineralization

Structural control is recognized as being far more influential to the emplacement of the mineralization than lithology. Among the tectono-stratigraphic units in the area, only the Coils Member does not host any mineralization. All four high angle structural sets as well as the low angle zones were involved in the plumbing of the hydrothermal system. The influence of the structural trends on mineralization ranges from subtle to obvious and is expressed on different scales. The most noticeable mineralized strike direction on the property is north-northwest, parallel to and collinear with the axis of the Cortez Trend. This trend is defined by the overall alignment of mineralized areas within the Tonkin District. Relatively high-grade pods within the mineralized areas usually follow this azimuth. The north-northwest trend is best characterized as a structural zone rather than a single fault.

The structural trend bearing about N60E is second in prominence only to the north-northwest direction. Overall mineralization within the subdistricts at Tonkin Springs trend along this bearing. In fact, the subdistricts are defined by these structures. The developed pits in the TSP-1 subdistrict form a distinctive east-northeast trend in plan as does the overall subsurface mineralization in the Rooster area. A subparallel trend considered to be of the same generation is defined in the F grid subdistrict by anomalous soil geochemistry and jasperoid development.

A north-south gold-in-soils anomaly runs from the Rooster development area to the F-grid. This anomaly may represent the trace of intersecting north-northwest and east-northeast faults. In the 015 area, a north-south trace of mineralization is defined by multiple north-northwest and east-northeast structural intersections. Another north-south trend has been identified in subsurface gold mineralization in the Rooster Main area.

The presence of significant west-northwest trends has recently been brought into full recognition. There is a distinct west-northwest envelope of drill indicated mineralization surrounding ore grade material in TSP-1 and strong subparallel to parallel orientations in the Rooster mineralization. The west-northwest alignment of Rooster Canyon is probably reflective of this control as well. West-northwest bearing geophysical defined lineaments pass directly through subsurface mineralization that follows the same trend.

The spatial association of the intrusive sills and the mineralization is usually close, if not intimate. With regard to this relationship, there is considerable interdeposit variance. It is doubtful that the igneous and epithermal events are genetically interwoven, however. The intrusive is offset by high angle, north-northwest and east-northeast trending structures along which the highest grade and thickest mineralization occurs. Furthermore, there is no thickening of the intrusive along these faults. Thus, the intrusive appears to predate gold mineralization. In addition, there is virtually no development of hornfels or skarn

along intrusive-sediment contacts. Contact metamorphism is not invoked as the mechanism for emplacement of the gold mineralization.

Two mechanisms are suggested for ground preparation along low angle structures. Deformation of thinly bedded sediments is often more intense adjacent to the intrusives. This could suggest that the better developed low angle fault zones were a result of a differential response to the shear stress between the sediments and the igneous sills. Alternatively, reactivation of low angle structures possibly during tertiary basin and range deveopment may have created, or simply enhanced the low angle fracturing along which mineralization was localized. Other factors that may have been influential in the development of permeability are primary intergranular porosity in clastic sediments, secondary intergranular porosity induced by decalcification of carbonates, and brecciation along high angle fault zones during Tertiary extension. In the TSP-1 subdistrict , pre-ore argillization of the intrusive provided an impermeable barrier for mineralizing fluid, resulting in the localization of gold in sediments adjacent to the intrusive. In the Rooster Ridge deposit, the intrusive was not argillized (and was mineralized) and the mineralization is much more localized along high angle structures.

Microprobe analyses performed on material from the TSP-1 unoxidized mineralization indicated that about 75% of the gold occurs in pyrite and arsenopyrite and is micron sized. The remaining 25% was thought by Hardisty (1983) to occur as free gold in silica veinlets (although no silica encapsulation problem has ever been documented). In the siliceous ores at the Rooster Main area gold is recoverable by cyanidation below the redox boundary. indicating that gold was localized on fractures. In mineralization hosted by the carbonate-rich Telephone Member, a converse relationship has been noted. Gold occurring above the redox boundary is occasionally only partially cyanide soluble. Dark coloration in material previously thought to be highly carbonaceous has been shown to be due to abundant, finely disseminated sulfide (P. Espell, oral communication, 1990). The amount of carbonaceous ore probably has been overestimated in the past.

From thin section studies, Hardisty (1983) surmised the following paragenesis: decalcification --> silicification --> silica veinlet development --> calcification --> cinnabar and barite mineralization --> microfracturing --> carbonization. Thus gold mineralization transpired relatively early in the sequence of paragenetic events. Sulfide minerals identified by examination of polished sections are pyrite, arsenopyrite, marcasite, realgar, orpiment, sphalerite, and stibnite. Realgar/orpiment, in particular, is closely associated with the mineralization. Common secondary minerals at Tonkin Springs are goethite, jarosite, scorodite, and variscite. Barite is widespread throughout the Tonkin Springs area and does not seem to be in strict spatial association with the gold mineralization.

Extensive silicification is evident in the district, as exemplified by the massive jasperoid "reef" on Rooster Ridge. Elsewhere, the differentiation between chert and jasperoid can be most challenging, particularily in rotary drill cuttings.

Consequently, geologic inferences and correlations are often tentative. Ore grade gold mineralization is often found in decalcified and sanded limestones. Argillization of siliceous sedimentary and igneous rocks is widespread but is generally unmineralized with respect to gold.

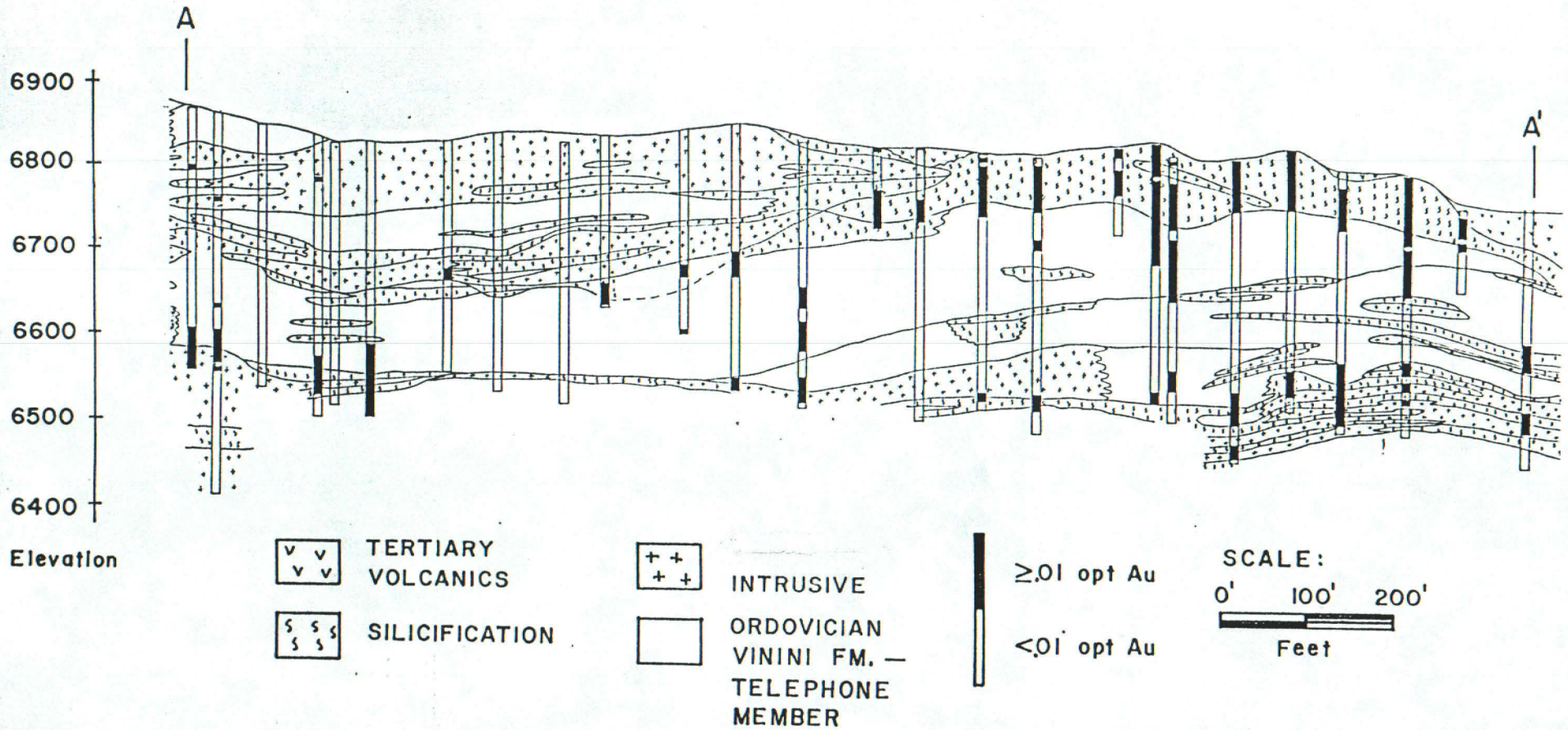
Three distinct styles of mineralization have been identified in the Tonkin Springs district. One of these occurs on the Rob claimblock, around TSP-1 (see figure 5). TSP-1 style mineralization, as it is referenced, displays elements of both structural and lithologic control. Other deposits found in the TSP-1 sub-district, which exhibit solely structural control, are more likely up-dip leakage deposits from a deeper TSP-1 style zone.

The TSP-1 mineralization forms a stacked series of nearly flat lying, wide spread deposits. The mineralization and associated alteration (primarily silicification) generally follows the footwall of a similarly stacked series of highly brecciated, low angle thrust zones. These thrust zones have been folded into a series of broad, open folds, trending west-northwest. Both the intrusive as well as the later hydrothermal fluids followed these now gently folded conduits. The folding event was instrumental in the development of the deposit as indicated by a closed antiform at TSP-1. Resultant ponding of mineralization occurred within this closure, at the base of the argillically altered, impermeable intrusive. Mineralization does not extend into the intrusive. The long axis of TSP-1 mineralization also exhibits a west-northwest trend, coincident with the axial plane of this fold. Both north-northwest and east-northeast trending high angle structures seem to have little effect on grade distribution within TSP-1, except to provide post-mineral offset. TSP-1 mineralization appears to be truncated both to the north and south by east-northeast structures.

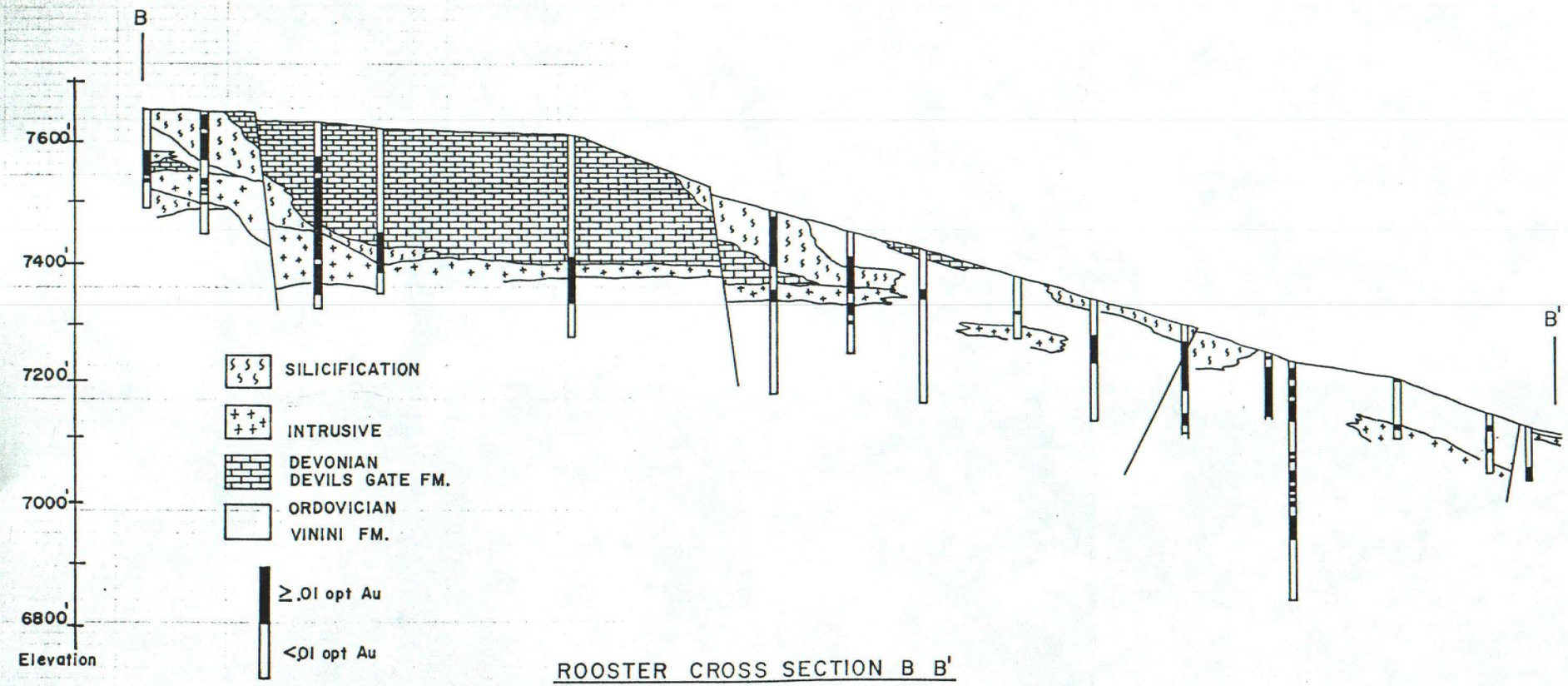
Although the dominant controls are the low angle thrust zones, subordinate lithologic control appears to exist. This is evidenced by mineralization and silicification extending well beyond the disturbed zone of the thrust. Other features indicating lithologic control include, the stratiform nature of mineralization, dissolution features along bedding planes of silicified carbonates and pervasive alteration of host lithologies.

Primary structural control created by intersecting north-northwest faults, east-northeast faults, and low angle intrusive filled thrusts can be invoked when modeling the surrounding satellite deposits in the TSP-1 subdistrict. Mineralization is generally confined within a common wedge of structurally prepared rocks in the common hanging walls of NNW and ENE high angle normal faults. Further structural preparation and lateral permeability were provided along intersecting low angle disturbed zones. Intrusive along these zones formed impermeable seals to further up-dip migration of the hydrothermal fluids. Mineralization rarely extends into the intrusive within these satellite deposits.

Anomalous gold values are widespread throughout Rooster Member sediments (see figure 6). However, ore grade mineralization in the Rooster Main area is confined to zones of strong structural preparation within these silicious sediments. This Rooster Main



TSP I CROSS SECTION A–A'



ROOSTER CROSS SECTION B B'

style mineralization exhibits the least spatial association with intrusive of the three mineralization styles identified in the Tonkin Springs district. The dominant controlling structural influence on the mineralization varies among the mineralized zones that comprise this area. North-south, east-northeast, and northwest structures have all been influential. Mineralization is relatively spotty and is predominantly fracture controlled. The redox boundary in the Rooster Main area tends to parallel topography about thirty feet below ground surface.

Rooster Ridge style mineralization exhibits characteristics of both the TSP-1 and Rooster Main styles. Gold values are localized along an intrusive filled thrust zone that separates Devonian Limestone from underlying Rooster Member sediments. The grade and thickness of the mineralization peaks where this low angle zone spatially coincides with intersections of high angle feeder faults. The strength of the mineralization also correlates positively with the thickness of the intrusive, indicating that igneous intrusion and epithermal mineralization occurred along same plumbing system. Inflation of the section during the intrusive event may have constituted, in part, ground preparation for subsequent mineralization. Sanded limestone, silicified limestone, intrusive, and carbon shale all host the Rooster Ridge style mineralization. The gold in the latter two lithologies is seldom cyanide soluble. Surficial oxidation is commonly well developed in the mineralized limestone.

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