Structural controls of precious metal mineralization at the Denton-Rawhide Mine, Rawhide, Nevada

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ABSTRACT

Epithermal precious metal occurrences at Rawhide are profoundly controlled by complex structural deformation related to the northeast margin of the Walker Lane. Miocene faulting has localized depositional volcanic and lacustrine environments, igneous intrusive and extrusive rocks, folding and tilting of stratigraphic units, and emplacement of economic precious metal mineralization. North-south-oriented right-lateral strike-slip displacements and northeast-oriented extensional dip-slip displacements of the Tertiary section are related to deep seated northwest-oriented right lateral strike-slip deformation of the pre-Tertiary basement. This pattern is repeated in an en echelon fashion and in a north-west direction throughout the district (i.e. the Crazy Hill and Murray Hill open pits). Significant early (21 Ma+) vertical components of offset of the pre-Tertiary basement are evidenced by a radical transition from the known minimum thickness (610 meters) of older lithic tuffs (Tlt) in the pit area to shallow depths of the top of the basement just east of the pit. This transition occurs extremely rapidly within the district in a south-west to north-east direction across the north-east boundary of the Walker Lane. Northwest-oriented faults in the Tertiary section are present, but are evident only as sinusoidal tears relative to the pronounced north-south strike-slip offsets. Though they appear subordinate to the north-south faulting, these structures have locally accommodated dramatic offsets.

Mapping of key structural relationships and recognition of stratigraphic sequences identifies a significant marker horizon that can be correlated throughout the district. The horizon represents a change from deposition of dominantly intermediate composition lithic tuffs (Tlt) to deposition of interbedded lacustrine sediments and locally derived silicic pyroclastic rocks (Tst). A depositional hiatus is probable at this horizon but is undocumented in Rawhide stratigraphy. Eruption of andesitic flows and flow breccias also mark this change and suggest the events are related to the pre-Basin and Range extensional events of 19 to 21 Ma. Geologic relationships in the Crazy Hill Pit provide clear evidence that northeast-striking faults were active prior to the deposition of the stratified tuffs and tuffaceous sediments (Tst). The development of the north-south near-vertical right-lateral strike-slip faults in the Tertiary section reflect northwest strike-slip activity of the pre-Tertiary basement and involved renewed motion of the northeast oriented faults. The inception of the northwest sinusoidal tears is inferred to have occurred with these events, however, the possibility that they are rejuvenated older faults cannot be ruled out. The close spatial and temporal relationship of Tst to the intrusion of mineralized rhyolites (Trp), the tilting of Tertiary units, the orientations of vent breccia (Tvbx) textures, the mineralization, renewed motion of the northeast structures, and the deformation of all these listed features, are related to this strike-slip faulting episode. Previous dating of hydrothermal adularia in mineralization controlled by one of the larger north-east structures yields a K-Ar age of 15.7 ± 0.6 Ma.

Intersections of the major fault structures coincide well with bulk-minable bodies of mineralization. Deep drilling (800 to 2000 feet) and interpretive modeling indicate these major structures do not flatten within these depths. The steep to vertical character of the faults and their influence on igneous and hydrothermal events attest to their importance as major plumbing conduits in the evolution of the district. The significance of this control is also evident in the variography of both exploration and production geostatistics. Anisotropic continuity of gold and silver distribution is reflected in the orientation of the major axis of ellipsoidal search parameters used to calculate ore reserve estimates. The major axis coincides with the north-south right lateral displacement direction. The control is evident on the scale of close-spaced blasthole patterns to district-wide structural patterns. Structure is the key to mineralization at Rawhide.

Recognition of the importance of structural control and implementation of such in exploration drilling strategies have been successful in adding reserves to the mine life. Mining of precious metals by Kennecott Rawhide Mining Co. began at the Denton-Rawhide Mine in 1990. Reserves at inception of mining were 31,181,000 tons of ore at a 0.020 oz/ton cutoff and 16,807,000 tons of lean ore at a 0.010 oz/ton cutoff. Production rates have increased from 2.5 million tons per year at start-up to 5 million tons per year in late 1993. 12,797,000 tons of ore and 5,356,800 tons of lean ore have been mined in total. Reserves at the end of 1993 are 23,100,000 tons of ore at a 0.020 oz/ton cutoff and 21,212,800 tons of lean ore at a 0.010 oz/ton cutoff.

INTRODUCTION

The Denton-Rawhide Mine is a large tonnage, bulk-minable open pit operated by Kennecott Rawhide Mining Company (KRMC). KRMC is a joint venture with Kennecott holding 51% and Kinross Gold Corporation and Kiewit

Mining companies each holding 24.5%. Gold and silver mineralization occurs in Miocene volcanic rocks associated with the Rawhide volcanic field and Walker Lane fault structures. Ore is mined at a rate of five million tons a year and is processed as crushed heap leachable material. Mining began in early 1990 and is scheduled to continue through 2002 with current mining rates and process technology. Exploration is ongoing and has good potential for gaining additional reserves.

REGIONAL SETTING

Rawhide is located in west-central Nevada within the central Walker Lane structural belt (Fig. 1). The deposits are part of the Regent Mining District and are on the northeast margin of the large through-going right-lateral strike-slip faults that characterize the Walker Lane in west-central Nevada. The deposits at Rawhide are on the northeast edge of the roughly circular Rawhide volcanic field located immediately to the southwest.

LOCAL SETTING

The low pass between the Koegel Hills and the Sand Springs Range in which Rawhide is located constitutes a divide between drainages reaching the Gabbs Valley playa to the east and drainages flowing northwestwards towards US highway 95. The northeast margin of the Walker Lane is located in this low divide. The northwest oriented fabric of the Walker Lane is evident in the orientation of the topography and of the major washes in the low pass. Figure 2 shows the topography prior to mining Crazy Hill and Murray Hill as open pits. Crazy Hill was a small hill of ore partly covered and surrounded by Quaternary alluvium filling the channels of Rawhide Wash. Murray Hill and Balloon Hill were knobs separated by a low saddle. These areas are now currently being mined away. Grutt Hill to the northwest is another hill of ore. These hills are erosion-resistant reflections of the widespread silicification associated with the mineralization. The north end of Balloon Hill and Hooligan Hill to the west are erosion-resistant rhyolite and rhyodacite flow domes respectively.

Figure 3 shows the topography of the mine area as of November, 1993. The Crazy Hill Pit is complete and is being back-filled. Development of the rim and highwall of the southern end of the Murray Hill Pit is well underway. It can be seen that the two pits are separate and distinct. The Murray Hill Pit, as it will be referred to in this paper, will include the Murray Hill, Balloon Hill, Grutt Hill, and Hooligan Hill areas as one pit.

DISTRICT STRATIGRAPHY

Introduction

Figure 4 is a generalized stratigraphic column for the main Rawhide district. The simplicity of the defined units belie the actual complexity of identifiable subunits, the variety of textures, and the rapid and intricate interbedding typical of many volcanic complexes. A presentation of the general geology and stratigraphy is in the paper titled Geology and Mineralization at the Rawhide Au-Ag Deposit, Mineral County, Nevada (Black, Mancuso, and Gant, 1990). This effort will present new understanding of the stratigraphy and structural evolution of the district based on additional drilling and production mapping. New concepts and observations will be presented for each of the Rawhide stratigraphic units from oldest to youngest.

Mesozoic Rocks

Pre-Tertiary rocks are well exposed only a few hundred meters east of the Crazy Hill Pit. Limestones, shales and dolomites that probably are correlative with the Triassic Luning Formation constitute the basement in the mine area. Extensive exposures of these and other Mesozoic rocks occur in the Sand Springs Range north and east of Rawhide. Drilling conducted immediately east of the deposits, in areas now underneath the waste dumps, has encountered these basement rocks at shallow depths (43 to 275 meters) below Tertiary rocks. Underneath the deposit areas the basement has not been encountered within the current maximum depths (610 meters) of drilling.

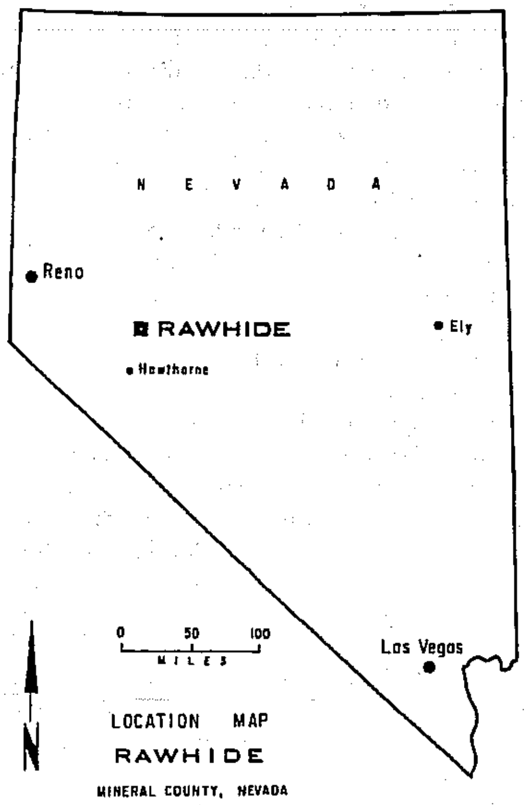


Figure 1—Map showing the location of the Denton-Rawhide Mine.

Tat

It is not clear which unit actually represents the oldest Tertiary rocks at Rawhide. Welded crystal-rich, rhyolitic/felsic ash-flow tuffs(Tat) are well exposed immediately to the north and east of the mine. The actual source of these tuffs is unknown. They are undoubtedly correlative with more regional ash-flow tuffs but do not represent (Hardyman, pers. comm., 1994) the Tuff of Toiyabe mapped in the Murphys Well and Pilot Cone quadrangles(Ekren and Byers, 1986) immediately south of Rawhide. The Tuff of Copper Mountain as mapped by Ekren and others (1980) in those quadrangles has since been renamed the Tuff of Toiyabe (John, 1992). Tat is encountered rarely within the mineralized deposits. Deep drilling below Rawhide Wash encountered thicknesses (up to 30 meters) of similar crystal-rich tuffs within the thick Tlt section at depths of 457 meters (1500 feet). These intercepts may not represent actual ash-flow tuff cooling units in place in the stratigraphy as they are equally well interpreted as large gravity slide blocks. These blocks may have collapsed into the actively down-dropping basin responsible for the thick and local accumulation of volcaniclastic and pyroclastic rocks collectively labeled lithic tuffs (Tlt). The only other clear stratigraphic relationship between Tat and the main district package is a gravity slide block that emplaced Tat on top of the youngest unit (Tst) in the district. If an age similar to other welded ash-flow tuffs in western Nevada is assumed, then Tat is probably not younger than early Miocene.

Tlt

The thick accumulation of volcaniclastic and pyroclastic rocks collectively termed lithic tuffs (Tlt) is at least 610 meters (2000 feet) thick. Vertical drilling below Rawhide Wash collared in Tlt below a thin alluvial channel and did not reach a clear lower contact. Bedding textures, where present, indicate shallow to near horizontal stratigraphic units. Hence, the actual depth of the drillhole is probably close to a realistic minimum thickness for this varied and complex unit. The lithic tuff unit can be broken into several subunits based on textural and compositional criteria. Rapid and complex interbedding, a decrease in drilling density, and structural displacements make correlation of these subunits increasingly more difficult with depth. However, higher in the section, recognition of key stratigraphic relationships has become valuable in correlating horizons throughout the district. The upper part of the lithic tuff (Tlt) unit consists of a sequence of well bedded, medium and coarse grained volcaniclastic rocks of overall andesitic composition that contain matrix supported, rounded clasts of heterogeneous composition. This well bedded upper part of the lithic tuff unit is capped by a distinctive marker horizon of white, well bedded to massive, fine-grained rhyolitic ash tuff (Tltw) and a Tat-rich volcaniclastic conglomerate (Tltq). The white rhyolitic tuff probably represents a distinct air fall event that marks the end of Tlt deposition. The volcaniclastic conglomerate (Tltq) is not everywhere present and has been mapped both immediately underlying and overlying the white rhyolitic tuff. These thin conglomerates, which have a maximum thickness of 6 to 7.6 meters (20 to 25 feet), contain abundant rounded, pebble-to-boulder sized clasts of welded, crystal-rich ash-flow tuff (Tat) in a clastic matrix containing abundant reworked quartz crystal phenocrysts that are also derived from the crystal-rich ash-flow tuff unit (Tat). This package of Tlt-Tltw-Tltq is an important assemblage in recognizing the top of the Tlt sequence and, as will be related in this paper, is extremely valuable in unraveling stratigraphic and structural problems in the district.

Ta

A series of andesite (Ta) flow breccias and flows locally overlie the Tlt unit. Thicknesses of this andesite unit range from 0 to over 122 meters (0 to over 400 feet) within the deposits. Primary textures exhibited in these rocks include pillows, flow breccias, flow foliations, carapace breccias, columnar jointing, and massive flows. Tectonic and hydrothermal breccia textures locally are superimposed on primary textures. Associated tuffs and pyroclastic rocks are locally intercalated with the Ta flows.

Tlat

The lapilli ash tuff (Tlat) is an enigmatic unit for which the stratigraphic position remains unclear. It is typified by the section exposed in the east highwall of the Murray Hill pit. Here it is a massive sequence at least 46 meters (150 feet) thick of weakly to strongly argillized pumice lapilli in an ash matrix. There is no evidence of any bedding or compositional changes, and textural variations are scant. Here it is stratigraphically overlying Tlt and in sheared contact with the intrusive Balloon Hill rhyolite. The highly argillized and sheared contacts with the rhyolite are usually faults that both controlled the intrusion of the rhyolite and exhibit post-intrusive movement. Tlat has been constructed in reserve models in other localities within the Crazy, Murray, Balloon, and Grutt areas based on its stratigraphic position and argillized character. Two important sections exposed by mining are no longer believed to be correlative with the type section in the east wall of the Murray Hill Pit. The section initially modeled as Tlat in the Crazy Hill Pit is now correlated with Tst. Bedding was clearly evident and some units were actually traceable across alteration contacts into silicified sections of Tst. This section was also discovered to overlie andesite in the north highwall of the pit, thereby supporting a correlation with Tst. A dipping section of argillized tuffs in the west temporary highwall of the Murray Hill Pit appears to overlie the Tst-Tlt contact. It also exhibits a well bedded character unlike the east Murray Tlat section. It is believed this section is correlative with volcaniclastic units in the Tstcl section.

Trench exposures demonstrate that Tlat extends along the east and north flanks of Balloon Hill. In this area, and in Stingaree Gulch the relationships of argillized sections of Tst,

Figure 2—Map showing the pre-mining topography at Rawhide.

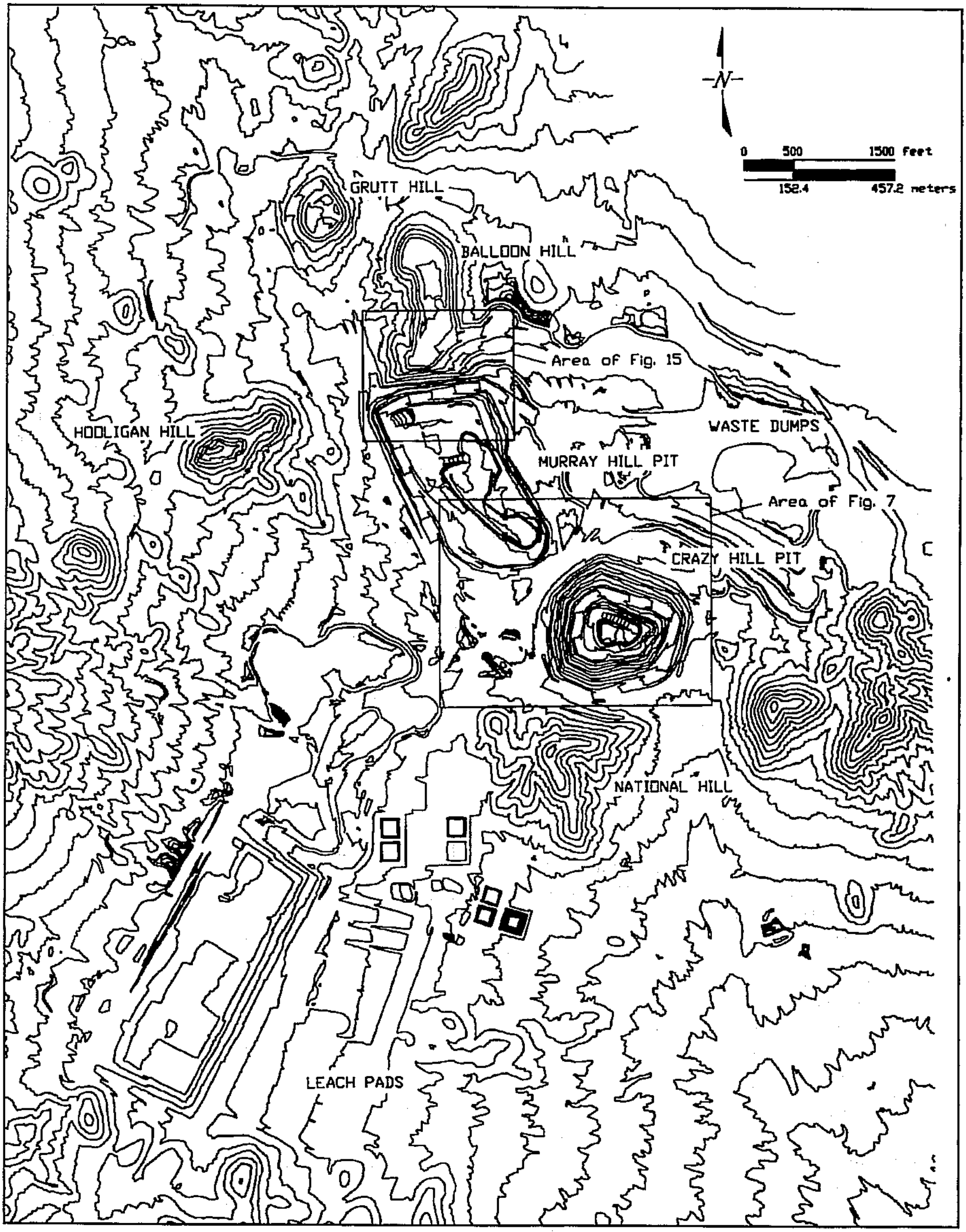


Figure 3—Map showing topography at Rawhide as of November, 1993.

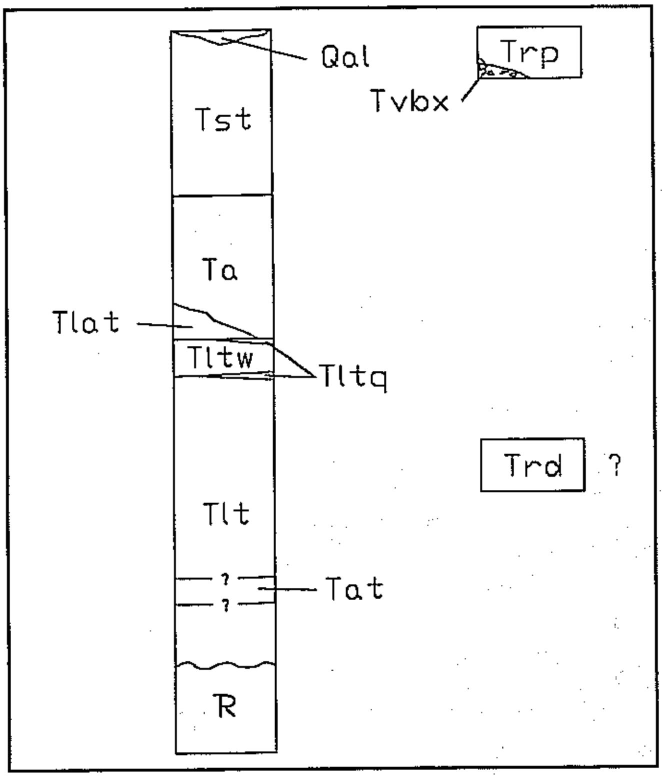


Figure 4—Generalized stratigraphic column of Rawhide units.

Tlat, and Tlt are very difficult to unravel with reverse circulation chips. It is hoped that future mining planned in this area will help unravel the problematic stratigraphic and spatial relationship of Tlat to Tst, Tlt, and Ta.

Tst

The stratified tuffs and tuffaceous sediments collectively known as Tst are nearly mined out at this time, and are relatively well understood. John Black in 1989 (Black, et.al., 1990) proposed a thicker section of Tst in the Crazy Hill deposit than had been previously thought. He subdivided Tst into a Tstc1 and a Tstc2. Tstc1 is a familiar sequence of interbedded silicic pyroclastic breccias, pyritic siltstones (commonly referred to as black sediments), and siltstones correlative with rocks in Murray and Balloon Hills. Tstc2 is a section of well bedded siltstones, pyroclastic rocks, and reworked volcaniclastic rocks that can be difficult to distinguish from bedded volcaniclastic rocks of the Tlt unit. This posed a problem in the Crazy Hill Pit where, except for only a few exposures in the north areas of the pit, Ta is absent from the section. The unit can be recognized by textures, notably the lack of quartz grains in contrast to their abundance in Tlt. This is a reliable criteria for the distinction between Tstc2 pyroclastic and volcaniclastic rocks and Tlt pyroclastic and volcaniclastic rocks. In addition, the underlying Tlt-Tltw-Tltq stratigraphic package helps define the Tstc2-Tlt or Tstc1-Tlt contact.

Tvc

Tvc is a volcaniclastic conglomerate recognized and defined as a new unit in the Crazy Hill Pit. Although local in nature this unit is instrumental in demonstrating early motion on northeast striking faults. Tvc is a heterolithologic collection of rounded, reworked clasts of volcanic rocks. The clast sizes range from grains of only millimeters in dimension to large boulders. Compositions of clasts are also highly variable and appear exotic in origin. Most notable are boulders, up to several meters in diameter, of an andesite whose closest known proximity is several kilometers distant.

Trd

The name of this unit has been simplified to rhyodacite (Trd) for ease of use and is the hornblende biotite rhyodacite as described in Black, et.al. (1990). This rock type is becoming more important as an ore host at Rawhide as Hooligan Hill and areas north of Hooligan Hill are being explored for additional reserves. The geologic relationships of Trd as a rooted flow dome in Hooligan Hill are more clearly understood because of this additional exploration activity. Future activity will focus on

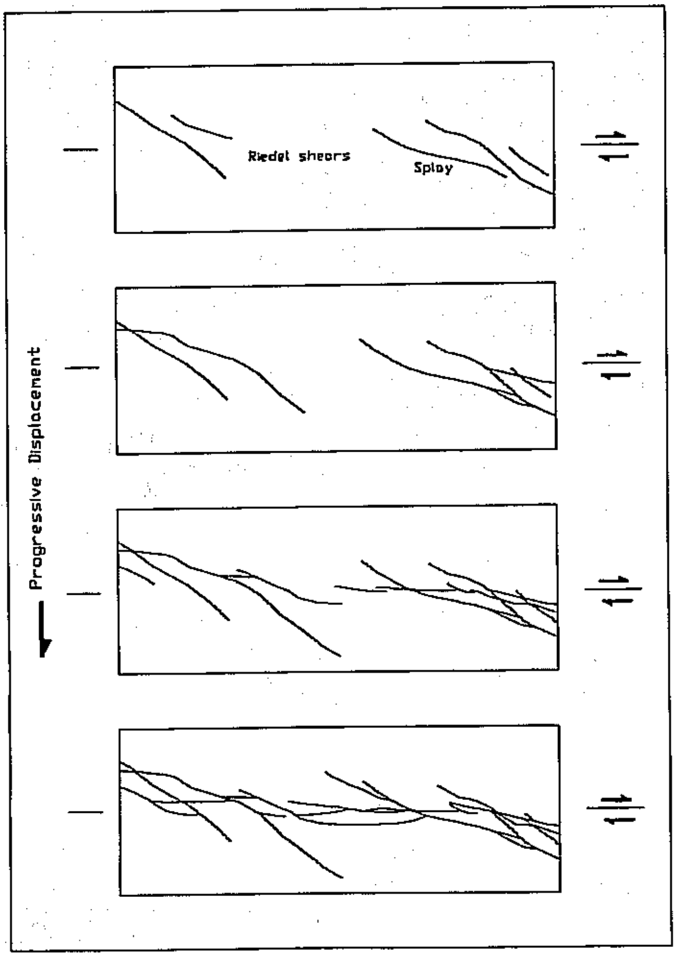


Figure 5—Generalized diagram of the development of Riedel shears and splay faults in strike-slip faulting of an underlying basement (modified from Naylor, 1986, Fig. 13a).

Trd north of Hooligan Hill and it is hoped that the relationship of Trd to the geologic development of Rawhide will become clearer. Trd has been encountered as intrusive bodies below Murray Hill, Crazy Hill, and Rawhide Wash. It is also clearly an intrusive flow dome at Hooligan Hill but appears to be extrusive in nature north and northwest of Hooligan Hill and Grutt Hill where it blankets sizeable areas.

Trp

The Balloon Hill rhyolite (Trp) includes fine-grained flow foliated intrusive and extrusive rocks in the Murray Hill Pit and in Balloon Hill. The rhyolite is typically a bleached white color exhibiting widespread alteration. Alteration types include weak silicification and/or argillization. Biotite has been observed, but is quite rare and was probably destroyed by the widespread alteration. Quartz phenocrysts are common. Local mineralization is strongly associated with silica veining and brecciation.

GENERALIZED DISTRICT STRUCTURE

Rawhide is located on the northeastern margin of the generalized north-west oriented Walker Lane trend where it passes through the low pass separating the Rawhide volcanic field from the Sand Springs Range. The margin is defined by the configuration of Triassic rocks underneath and adjacent to the main district. These basement rocks are encountered in outcrop and at depths of 40 meters (130 feet) to 253 meters (830 feet) below extrusive rhyolitic flows and crystal rich ash-flow tuffs in the waste dump areas immediately east of the mine. Deep drilling with both core and reverse circulation up to 610 meters (2000 feet) below the main pit areas did not encounter the basement. The basement of Triassic rocks drops off to an unknown depth below Rawhide. The control on the actual geometry of this structural boundary is very general but it is clear that it has an overall northwest strike and is a reflection of a large through-going Walker Lane structure.

The Tertiary section composed of a complex volcanic stratigraphic sequence and intrusive rocks is deformed in styles associated with strike-slip offsets of an underlying basement. This style of faulting has been well described in theory and with actual examples by Naylor, et.al. (1986) and Sylvester (1988) and this report will attempt to place observed phenomena at Rawhide into these contexts where possible. Figure 5 is a representation of the relationship typical of Riedel shears and splay faults with progressive deformation in this structural regime.

DETAILED DISTRICT STRUCTURE

Introduction

Throughout the life of the mine to date, pit mapping has been emphasized to optimize the economic viability of the precious metal mining venture. It was recognized in the early stages of mining that the extreme complexities of the deposit required measures to achieve the desired optimization. Although a detailed geologic block model is constructed prior to the actual mining of the deposit, the resolution available from the development drilling is not adequate to address the day-to-day mining issues. The intricate faulting, the complex distribution of alteration patterns, and rapidly diverse host rocks have a dramatic impact on ore control. All blast patterns are mapped for these features. All highwalls, temporary and permanent, have been mapped for slope stability. The production mapping has produced a sizeable database useful in modeling of future reserves, future pit designs, and in exploration for additional reserves. A considerable portion of the following discussions are derived from the knowledge gained from pit mapping.

Crazy Hill Pit

Mining began in the Crazy Hill Pit in January of 1990. Reserves were mined out in 1992 and the pit is currently being back-filled with waste. Two north-south oriented, steeply dipping faults were recognized in the modeling stages as important controls on mineralization. These faults, the West Crazy Fault (Black, 1990) and the Dead Zone Fault (Fig. 6), are two of many en echelon Riedel shears in the district that are conjugate to the Walker Lane wrench fault in the underlying basement. The West Crazy Fault is an important ore/waste contact in the western side of the pit. The Dead Zone Fault is similar in orientation and is in the center of the orebody. It is an important ore/waste contact along much of its extent and exhibits post-mineral right lateral offset. In addition, several northeast oriented structures were interpreted in the model as minor dip-slip offsets of the stratigraphy.

As expected, the reality encountered during mining was more complex than a model could provide and several key relationships were discovered as mining proceeded. A large northwest striking steeply dipping fault, subsequently named the Tvc fault was discovered in the south-east corner of the pit. This structure was clearly observed to change strike and merge into the north-south Dead Zone Fault. Recognition of the Tvc Fault was important to the understanding of the nature of the northwest oriented splay faults or "P" shears in Rawhide faulting styles and their relationship to the north-south strike-slip Riedel faults.

Sharp ore/waste contacts were encountered on a significant northeast oriented fault zone extending from the southwest to the northeast corners of the pit (Fig. 6). The contacts are most notable in the southwest area of the pit where silicification is a guide to the distribution of mineralization. Demonstrable right lateral offset of this fault occurs across the Dead Zone Fault. This northeast fault is also significant in that it controls the spatial distribution of the Tvc stratigraphic unit (see below).

An additional northeast striking fault (labeled the North Crazy Fault) encountered in the north area of the pit is probably related to the disappearance of the Dead Zone Fault. The Dead Zone Fault cannot be traced north of this fault.

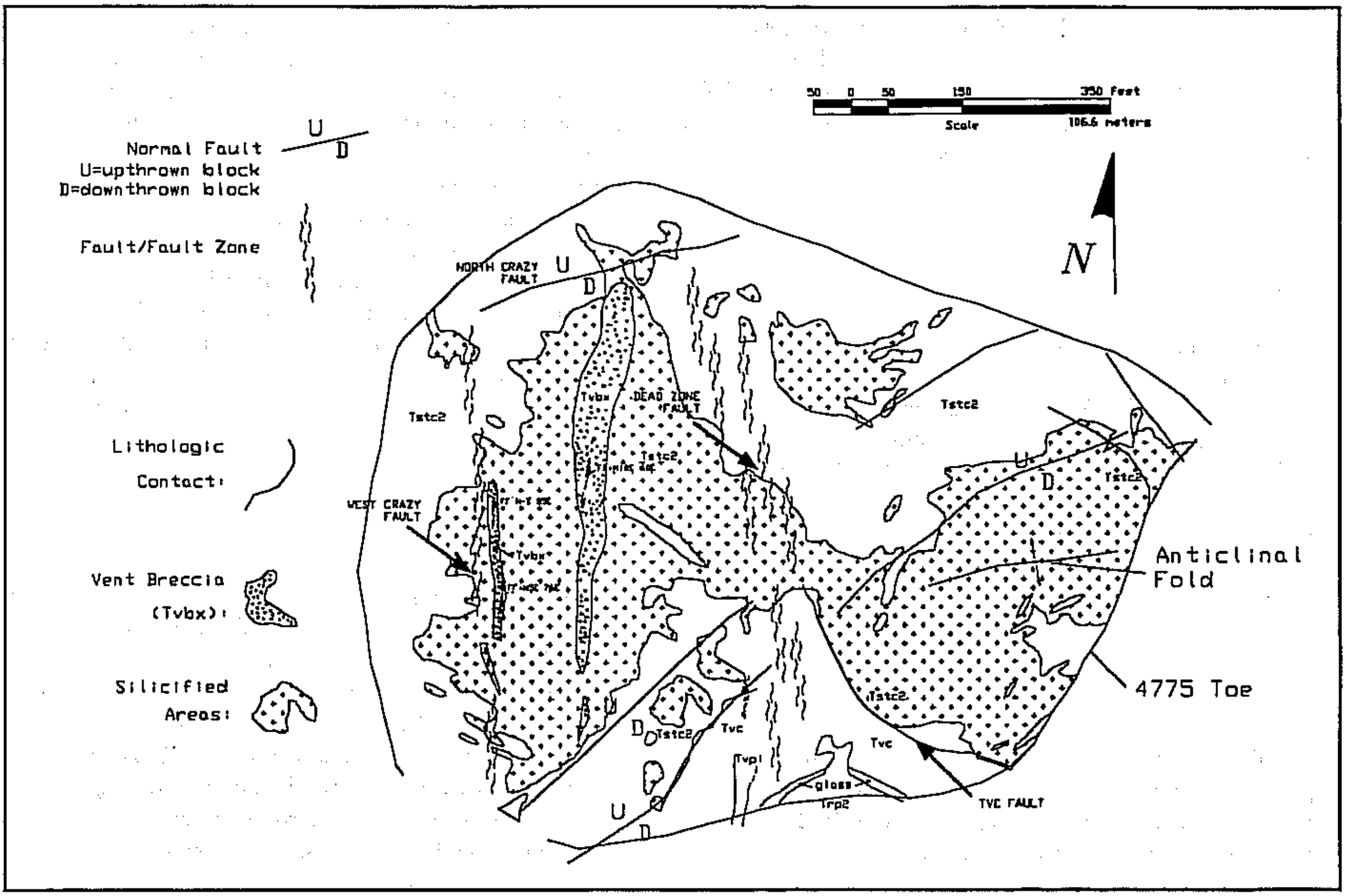


Figure 6—Geologic map of the 4775 level in the Crazy Hill Pit.

Although it is not an important structure impacting ore control, the North Crazy Fault is extremely important in understanding relationships between the Crazy Hill and Murray Hill Pits. Immediately north of this fault and exposed beneath the alluvium on the uppermost benches of the highwall is an andesite sequence at least seventeen meters (50 feet) thick (Fig. 7). The North Crazy Fault down-drops the andesite at least 38 meters (125 feet) to the main haul road on the 4775 bench. The andesite on the haul road is the closest exposure of the andesite to the main orebody of Crazy Hill where it is notably absent. Horizontal component of offset on the North Crazy Fault is unknown but may be significant and be the explanation for why the Dead Zone Fault cannot be traced north of this structure. The dip-slip displacement on this fault is directly related to the greater thickness of Tst in the Crazy Hill Pit. As mentioned previously, a thicker section of Tst was recognized in the Crazy Hill deposit and has been supported by the production mapping. This thicker section is attributed to the presence of Tstc2. However, Tstc2 was not recognized during the modeling stages of the adjacent Murray Hill Pit and posed interesting continuity problems between the two pits. Mining and the related mapping activity in the Murray Hill Pit (particularly the south end) and the correlation of east-northeast striking faults with the northerly portions of the Crazy Hill Pit is corroborating this difference in the thickness of Tstc2 between the two pits, as well as the reason for why this difference occurs (Fig. 7). Broad arching of the stratigraphic units in the south end of the Murray Hill Pit, with the south limb dipping southerly towards the Crazy Hill Pit, as well as down-dropping of the sections on the south or hanging wall side of east-northeast striking faults between the two pits is responsible for preserving the marker horizon (Tlt-Tltw-Tltq-Tstc2) deeper in the Crazy Hill Pit. Early down-dropping along the northeast striking faults during deposition is probably also responsible for the thicker section of Tst in the Crazy Hill deposit. Evidence for early down-dropping along northeast striking faults does indeed exist in the Crazy Hill Pit and will be discussed below.

The marker horizon of Tlt-Tltw-Tltq-Tstc2 was first encountered in the west wall of the Crazy Hill Pit at approximately the 4775 level (Fig. 7). The stratigraphic contact is near horizontal and is west of the West Crazy Fault. Minor vertical offset of the horizon is evident across the West Crazy Fault where the contact was encountered on the 4750 bench during production. The Tvc unit (see stratigraphy) is sandwiched between Tstc2 above and Tlt below and is 0 to 3 meters (0 to 10 feet) thick in this structural block. Tvc is absent in the west wall of the pit. Early vertical offsets on a northeast striking fault in the southwest area of the pit is indicated by the rapid thickening of the Tvc unit immediately southeast and adjacent to this fault (Fig. 6). The Tvc unit here is now several benches thick (@35 meters or @75 feet). The Tvc unit is a local fanglomeratic collection of exotic debris deposited adjacent to a fault scarp. This is clear evidence that a vertical component of offset was developing on a northeast striking fault prior to deposition of Tst. To the east and southeast into the Dead Zone Fault and adjacent to the Tvc fault, the clear relationships of Tst-Tvc-Tlt contacts are lost in the shearing and extreme argillic alteration associated with the Dead Zone and Tvc faults.

Additional evidence of vertical components of offset on the northeast striking faults is a progressive deepening of the level of the Tstc2-Tlt horizon. In the bottom and east side of the pit the horizon was not encountered until the 4600 bench. This is approximately 50 meters (150 feet) deeper than the level that exposes the sandwiched Tvc unit in the southwest area of the pit. The stratigraphic package is displaced deeper into the pit by dip-slip motion along the northeast striking fault east of the Dead Zone Fault (Fig. 6).

The stratigraphy in the eastern part of the Crazy Hill Pit is arched in a broad anticlinal flexure whose axis is approximately east-west and orthogonal to the north-south strike slip faults (Fig. 6). The orientation of this flexure is consistent with folds observed in other strike-slip regimes (Sylvester, 1988). Lower hemispheric stereonet plots of pole to plane bedding orientations of both Tlt and Tst show the overall flat lying character of the units. Figure 8 shows the stereonet plot for Tst. A plot of Tlt data looks almost identical. The split of the data into two clusters reflects the north and south limbs of the major flexure in the east part of the pit. The north limb dips gently to the north where it is truncated against the northeast striking fault and is in apparent reverse drag configuration. This suggests multiple periods of movement on this northeast striking fault. Compression resulted in arching of the beds and possible reverse motion along the northeast striking fault during a period or periods of strike-slip movement of the north-south faults. This motion was followed by dip-slip displacement of the same units along the same northeast striking fault.

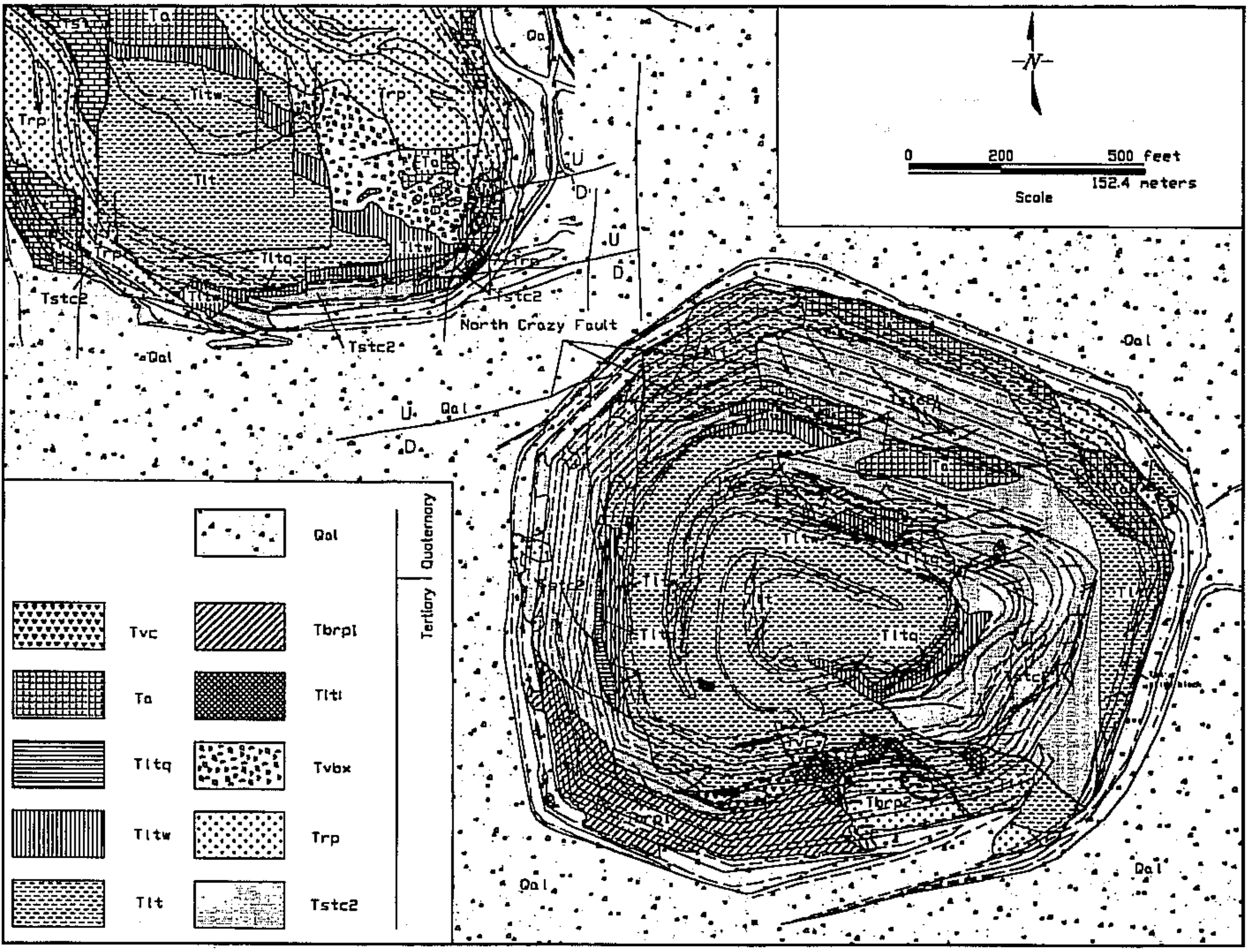


Figure 7—Geologic map of the Crazy Hill pit and the southern Murray Hill pit.

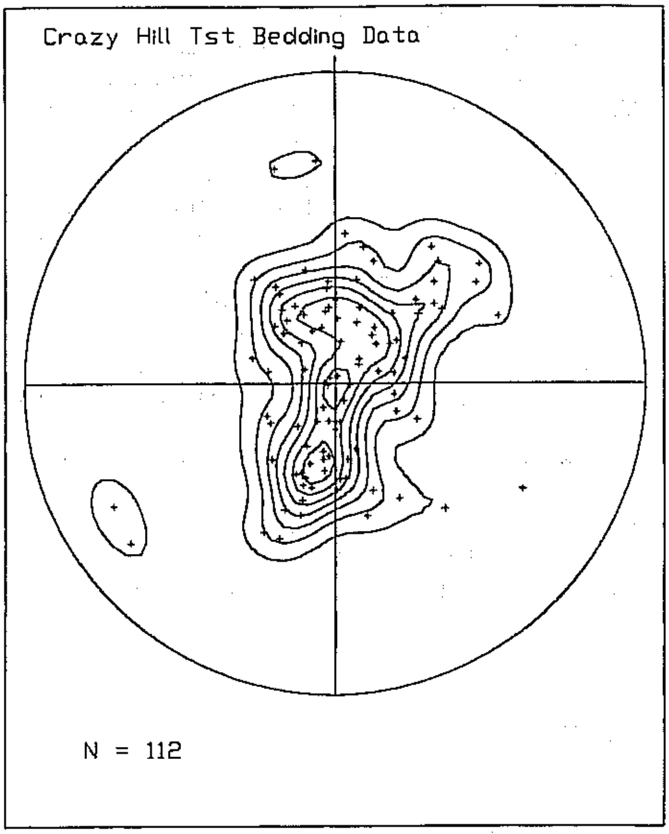


Figure 8—Lower hemisphere stereonet plot of pole-to-plane bedding data of Tst in the Crazy Hill pit.

The Tvc Fault is a prominent northwest striking fault that curves progressively northward along its northwestward extent and is lost into the main north-south striking Dead Zone Fault. In the upper two-thirds of the pit this structure was a major ore-waste contact and very likely accommodated some post-mineralization movement. The large body of ore in the anticlinal flexure in the east area of the pit is bounded on the south by this structure and is primarily hosted in Tstcl and Tstc2. The mass of sheared clay to the south of the structure is a confusing series of altered Tvc and Tlt, hence the name of the fault. The Tvc Fault within the limits of drilling and mining maintains a very steep dip and can deviate from a northeasterly dip to a southwesterly dip. Low to moderate angle slickenlines on this fault suggest rotation around a steeply inclined axis of the block of ore to the north. This may be related to the anticlinal folding of the Tlt and Tst sequence.

The Tvc fault is similar to other northwest oriented sinusoidal faults in the district in that it appears to have accommodated significant stresses with deformation and/or displacement. This is evidenced by the fact that a large block of silicified, mineralized rock to the north-northeast side of the fault is in contact with a strongly sheared mass of clay altered rocks to the south-southwest. The fault contact is abrupt and very commonly exhibits low angle slickenlines. However, in contrast to similar faults in Murray, Balloon, and Grutt Hills, the structural block to the northeast of the Tvc fault is not appreciably tilted (see discussion below).

The database created from highwall mapping in the Crazy Hill Pit was organized by rock type. Figure 9 is a lower hemispheric stereonet plot of unfiltered pole to plane fault and joint data from the Tst unit. The clustering of data representing the north-south striking and steeply west dipping fabric is clear. Note that the north-south group of structures is slightly west of north. These clusters are interpreted to represent the en echelon conjugate Riedel shear fabric commonly displayed in strike-slip fault systems (Naylor, et al.,1986; Sylvester, 1988). The cluster of data representing the northeast striking and southeast dipping fabric is also quite prominent. Note the moderate to steep south-east dip typical of this group of structures. The cluster representing the northwest striking and southwest dipping splay or "P" structures is present but not as prominent as the other orientations. Figure 10 is a lower hemispheric stereonet plot of linear slickenline data in Tst. Although somewhat scattered in character, some interesting trends are present. Much of the data is distributed around the periphery of the diagram and reflects the low-angle strike-slip nature of the offsets in the Crazy Hill deposit. There is a cluster of low-angle slickenlines just west of due north and corresponds well with the Riedel shears about N15W in Figure 9. Of importance to

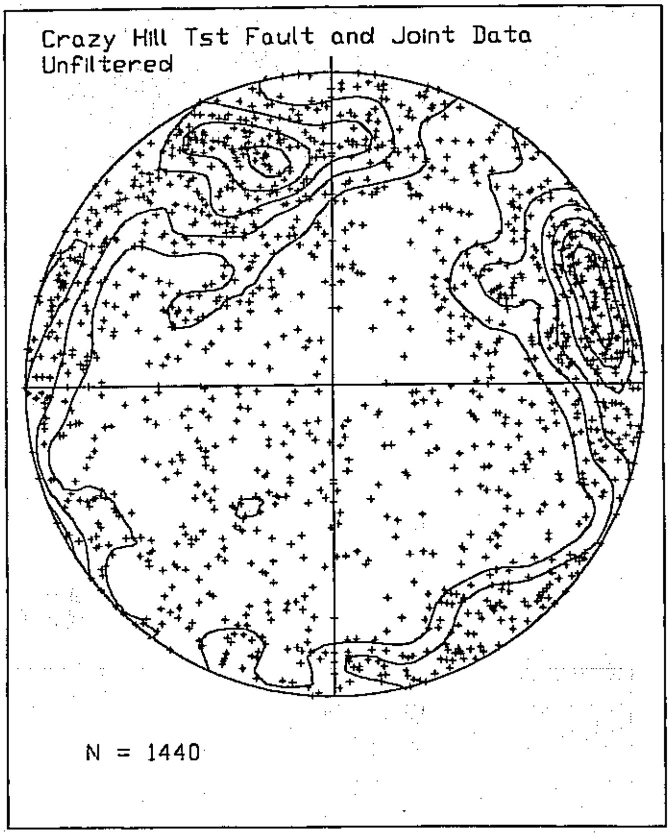


Figure 9—Lower hemisphere stereonet plot of unfiltered pole-to-plane fault and joint data of Tst in the Crazy Hill pit.

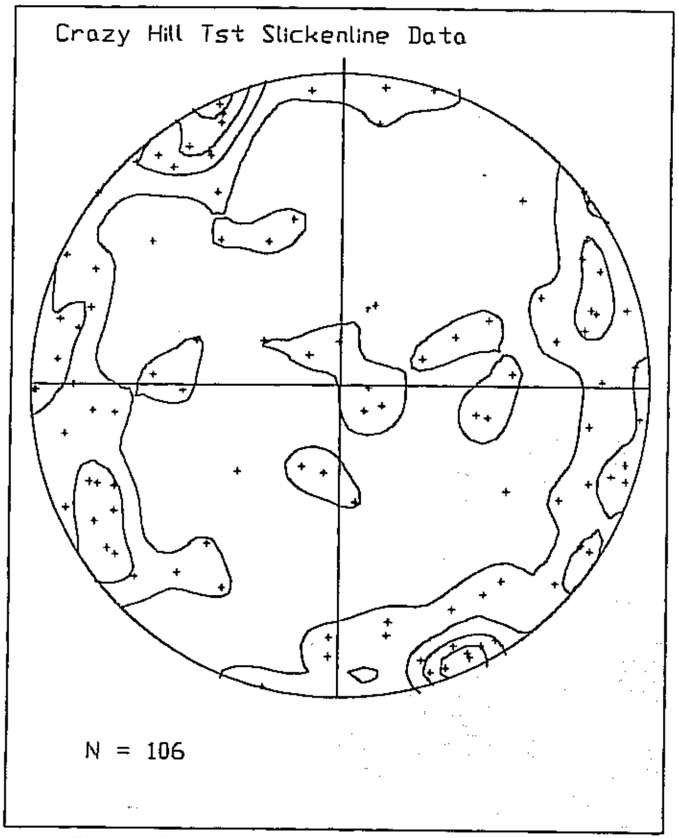


Figure 10—Lower hemisphere stereonet plot of linear element slickenline data in Tst in the Crazy Hill Pit.

the interpretations of dip-slip motion on the north-east set of faults is the cluster of high to moderate angle slickenlines oriented in a northeast swath across Figure 10. These data points reflect the significant component of dip-slip character of the northeast striking and southeast dipping faults.

An interesting structural control on the orientations of crosscutting hydrothermal breccias (Tvbx) was discovered during production mapping. Figure 6 is the level geologic map of the 4775 bench produced by the mapping techniques developed for geologic ore control. An extensive and linear north-south oriented crosscutting breccia is evident in the west portion of the pit. This feature was traced through successive benches in a similar orientation in the Tst section. Figure 11 is a similar level geologic map of the 4700 bench. Note that the orientation of the crosscutting Tvbx is northeast striking and that it is now crosscutting Tlt. When mining progressed downwards through the Tstc2 into Tlt this marked change in strike was encountered. This shift in strike is interpreted as an effect of the fact that the northeast striking faults were already active in units prior to deposition of Tst and were important in controlling later events related to the mineralization.

A significant textural feature mapped in numerous exposures of Tvbx is a measurable planar element defined by a noticeable elongation of locally derived breccia clasts. The elongated breccia clasts typically, but not consistently, reflect the wall rock type. The texture is often striking, and is invariably parallel, with the fault orientation controlling the

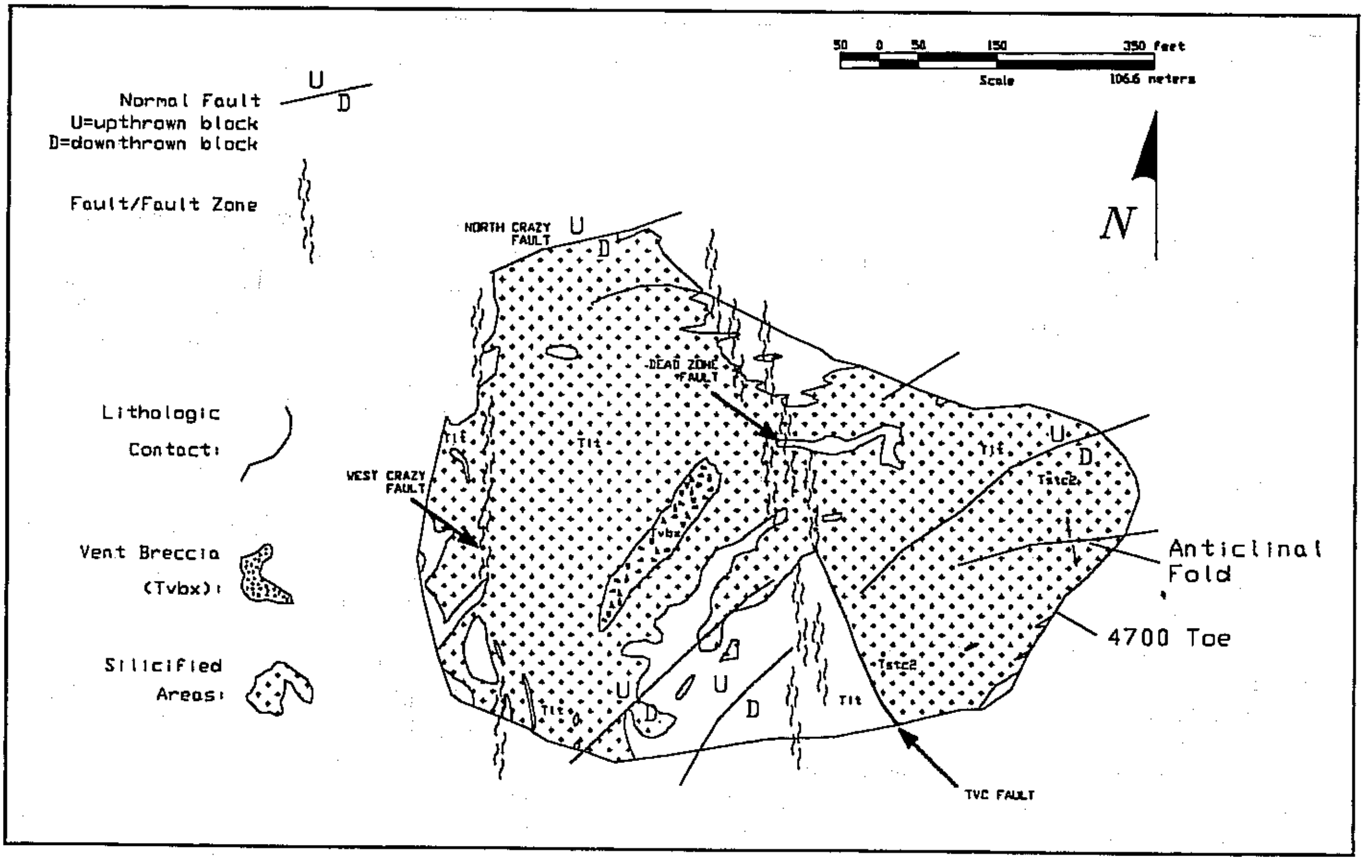


Figure 11—Geologic map of the 4700 level in the Crazy Hill pit.

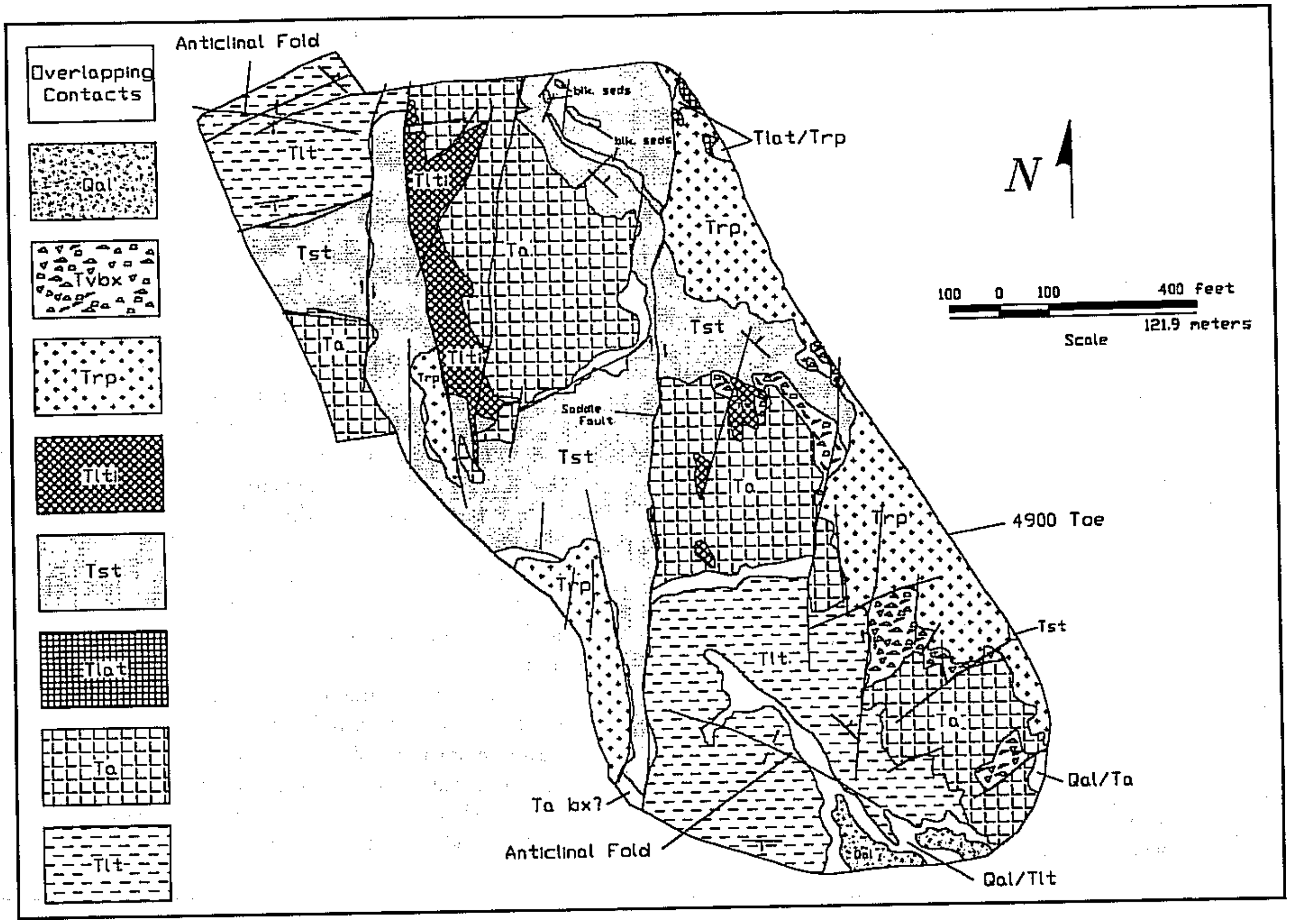


Figure 12—Geologic map of the 4900 level map in the Murray Hill pit showing lithology.

location of the crosscutting breccias. This texture is interpreted as a fluid flow or gaseous streaming texture associated with migration of hydrothermal fluids and attests to the importance of the role played by the controlling faults during mineralization.

Murray Hill Pit

Mining commenced in the Murray Hill Pit in 1991 and has been the focus of activities since 1992. It was recognized in the modeling stages that the heart of Murray Hill and the south end of Balloon Hill are the most complicated and difficult areas of the Rawhide district to unravel, both structurally and stratigraphically. The fine work done by Kennecott exploration (notably Gant and Black) was expanded upon by mine personnel (Gray and Mancuso). The structural models developed by experience in the Crazy Hill Pit were incorporated into the geologic model for the Murray Hill Pit. As this goes to writing, over 10 million tons of ore have been extracted from these areas and the structural models have been tested and further refined.

Figure 12 is a geologic map of the 4900 bench of the Phase I initiation of the Murray Hill Pit. It represents actual mined geology mapped by the techniques developed for geologic ore control. Tlt units are not differentiated. The en echelon and repeated pattern of north-south oriented right-lateral strike-slip faults is quite evident. Equally evident is the northwest striking, northeast dipping sequences of Tst. The Tst-Ta contacts are commonly depositional, making a similar rotation of the Ta blocks a safe assumption. Also evident are northeast striking faults creating offsets in Trp-Tst, Ta-Tlt, Trp-Tlat, and other contacts throughout the pit. The Saddle Fault, a prominent north-south striking fault in the central part of the pit shows right lateral offset and the offset is quite demonstrable as being at least in part post-mineral. Large pods of ore in well silicified host rocks are in sharp contact across this fault with extensively sheared and argillized sections of Tst tuffs that are waste. Figure 13 is from the same bench and shows the familiar right lateral offset patterns that have displaced silicification associated with the mineralization. The Saddle Fault is one of several faults exposed in the pit that exhibit a repeated en echelon pattern of right lateral displacement of the tilted stratigraphic units and the intrusive rhyolitic contacts.

Tilting and folding of stratigraphic units show substantially different patterns in the Murray Hill Pit than in the Crazy Hill Pit. Figure 14 is a lower stereonet plot of bedding orientations taken from highwall and bench level mapping. The prominent tilting around a northwest striking axis producing a northeast dip was not encountered in the Crazy Hill Pit. The repeated pattern of northwest striking and northeast dipping Tst beds in contact with the Balloon Hill rhyolite (as illustrated in Figure 12) define the northerly limbs of several open asymmetrical anticlinal arches where the northerly limbs are much steeper than the southerly limbs. Disruption of these asymmetrical arches by faulting is common along north-south, north-east, and northwest oriented faults. It is likely that the very similar sections displaced in a right lateral fashion by the Saddle Fault are parts of the same arch that have been distended and separated after rotation and after mineralization. Northwest oriented splay or "P" faults have a similar strike to that of the major tilted blocks where these faults are not curving into the major north-south strike-slip faults. These splay or "P" faults have undoubtedly accommodated much of the tilting of these northeast dipping limbs. The nature of the structure that accommodates the tilting of these limbs to the northeast is obscured by the Balloon Hill rhyolite intrusions. The east contacts of Trp and Tlat are commonly north-south oriented faults and the westerly contacts of Trp with the Tlt-Ta-Tst-Tvbx package are typically northwest striking and southwest dipping in orientation.

It is interesting to speculate on the relationship of the tilting of fault blocks accommodated by the northwest striking splay or "P" faults, strike-slip activity on the north-south Riedel faults, structural conduits of an ascending Trp magma, orientations of the Trp contacts, and related volume problems associated with these events. In the Crazy Hill deposit, where faulting, folding, and hydrothermal activity are not in immediate proximity to a rhyolitic flow dome, the fold structures are relatively simple. In the Murray Hill and Balloon Hill deposits, where faulting, folding, and hydrothermal activity are in contact with a rhyolite flow dome, this kind of complex deformation is well developed. Is there a relationship between the tilting of structural blocks around a northwest axis and undermining related to an ascending body of magma in this kind of strike-slip environment? Relationships in the Crazy Hill deposit suggest that more horizontal rotation around a vertical axis occurs in a structural block when a body of magma is absent. Currently, the Grutt Hill and North Forty deposits are modeled with northwest

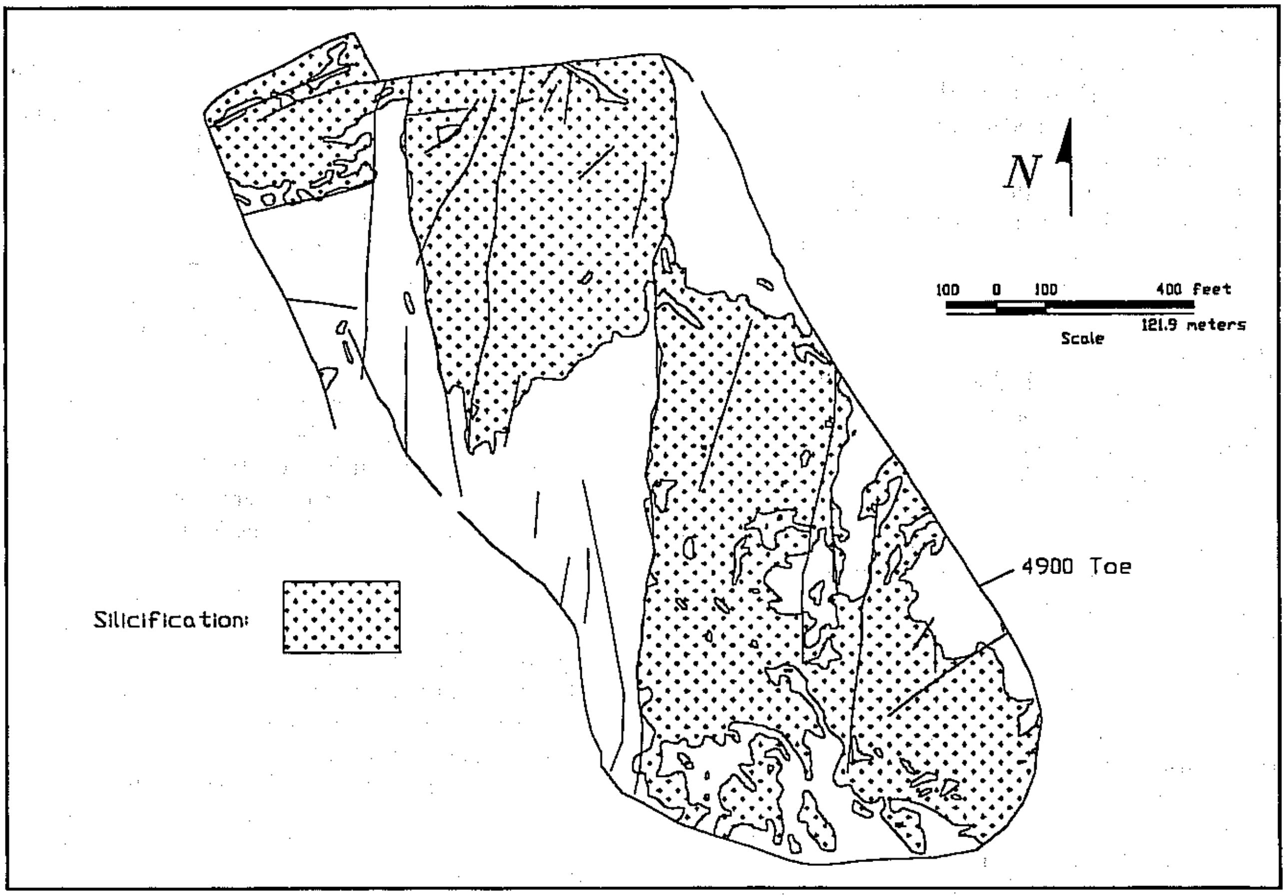
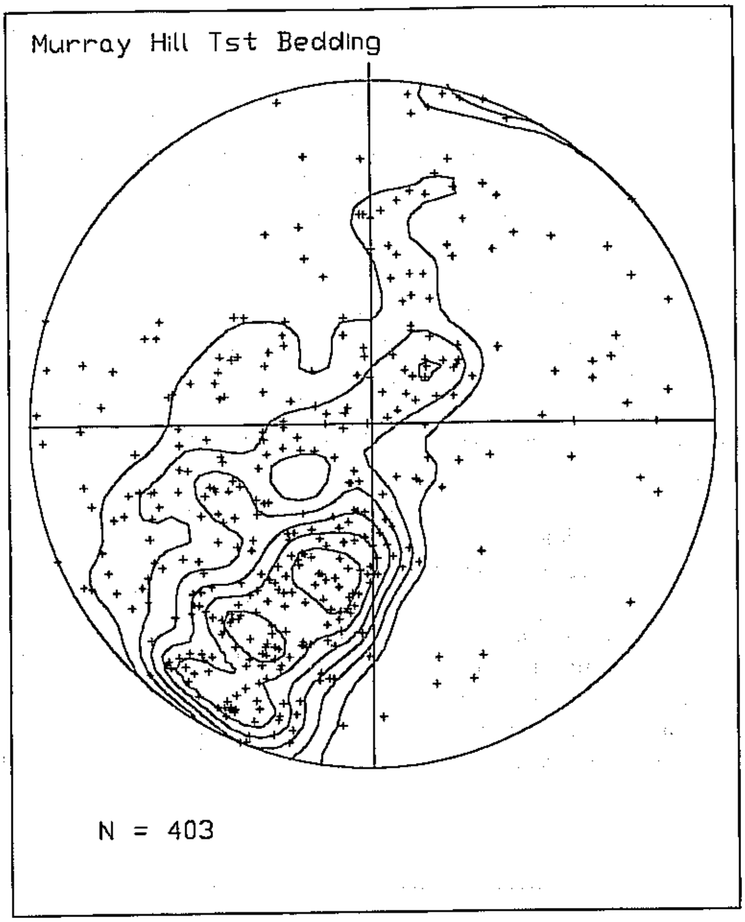


Figure 13—Geologic map of the 4900 level map in the Murray Hill pit showing extent of silicified rock.

Figure 14—Lower hemisphere stereonet plot of pole-to-plane bedding data of Tst in the Murray Hill pit.



striking, northeast dipping structural blocks accommodated by northwest striking sinusoidal splay or "P" faults without a rhyolitic flow dome being in close proximity. Hopefully, mining these areas will provide answers to these questions.

In the Murray Hill Pit the stratigraphic section is relatively easy to recognize as the Ta unit is typically present. The Tst overlies Ta and Tlt is stratigraphically below. The Tlt-Tltw-Tltq assemblage of units is present immediately below Ta. The classic assemblage of Tstc1 including coarse breccias interbedded with siltstones and pyritic siltstones is above Ta.

There are exceptions to this simplicity. As previously mentioned, there was a continuity problem with correlating units south to the Crazy Hill Pit. The Murray Hill Pit was modeled as being entirely Tlt around the southern highwall. This pit wall is approximately 100 meters (325 feet) to the northwest of the Crazy Hill Pit (Fig 7). Ta and Tst were absent from the section in the Murray Hill geologic model. Highwall mapping during production from the Murray Hill Pit revealed that a thin remnant section of Tst was preserved directly below the alluvial channel and in depositional contact on Tlt. The contact was recognized by the familiar sequence of Tlt-Tltw-Tstc2. Tltq was absent in the highwall but the criteria of the lack of quartz crystal grains helped identify Tstc2 in the pit wall. The horizon is then progressively warped from a more gentle southerly dip in the highwall to a moderate northeasterly dip in the deposit itself and then is truncated by a fault contact with the first Ta block in Murray Hill. In this northeasterly dipping limb Tltq was present immediately overlying Tltw and below coarse Tst pyroclastics.

An interesting and initially problematic relationship of Tst and Ta became evident during mining in the south central and southern portions of the Murray Hill Pit. A thick section of andesite (Ta) had dominated the ore types adjacent to the intrusive rhyolite (Trp) for several benches below the initial bedrock exposures. Crosscutting explosive vent breccias (Tvbx) typically characterized the contact between the intrusive rhyolite and the andesite flows and flow breccias. The vent breccias vary from narrow elongate zones along discrete faults to wider more pipe-like shapes that are the throats of vents that reached the surface as explosive (and probably maar-like) features. As mining progressed through the andesite it became evident that coarse silicified breccias modeled as crosscutting vent breccias below the Ta block were actually interbedded with black pyritic siliceous siltstones and appeared conformable in character. This stratigraphic positioning of a layer of black sediments below andesite has been noted and observed in several areas of the deposit. This suggests that an early "Tstc1-like" environment may have existed locally just prior to eruption of andesitic flows and flow breccias. However, including these early "Tstc1-like" sediments in Tstc1 may be problematic in correlating units and making assumptions as to the advent of deposition of Tstc1 and the events leading to the mineralizing episode(s). Although early "Tstc1-like" rocks do exist that predate andesite, a different interpretation is favored for this sequence in the south end of the Murray Hill Pit. Cross-cutting and faulted relationships in the south-central and southern Murray Hill Pit suggest that at least some of the major blocks of andesite are allochthonous chunks that have collapsed and/or slid into the undermining explosive vent breccias. The vent breccias and the interbedded black sediments do not predate andesite and represent units that are part of and correlative with Tstc1.

Evidence for large allochthonous blocks exist elsewhere in the pit. Located in the east highwall of Balloon Hill is a fault bounded section of Tstc1 approximately 23 meters (75 feet) thick. Overlying the Tstc1 section is a large block of mineralized Tat at least 23 meters (75 feet) thick. This is a minimum thickness as the top of the section was in outcrop and has been subject to some amount of erosion. The lower contact of the Tat block sits immediately on a layer of the black sediments. The lower contact of the block is highly brecciated with the black sediment remobilized as a matrix throughout the breccia. This is interpreted as a rubble zone at the bottom of a large gravity slide of Tat into a basin. The black sediments were actively being deposited in this basin and were unconsolidated at the time of the slide. This is evidence that there was a variable (and probably over-steepened) topography to the local terrain at the time of Tst deposition and that there was very likely significant seismic activity capable of triggering such a slide. Other blocks of Tat much smaller in size were mapped in the throats of vent breccias, both in the Murray Hill Pit and on Balloon Hill.

Development drilling encountered Trd below the Murray Hill Pit. Within the limits of the drilling the size of the Trd intrusive body increases with depth. It appears to be the top of a cupola of a larger and deeper intrusive body of rhyodacite. Moreover, interpretive modeling indicates some substantial right lateral offset of this intrusive body along north-south faults below the east highwall of the Murray Hill Pit. The timing and role of the rhyodacite with the development of the district is important as well as problematic.

Balloon Hill

The extent of mining at Balloon Hill as of this writing includes what was Murray Hill itself, the Phase 1 initiation of the Murray Hill Pit, and the south end of Balloon Hill. A temporary highwall currently creates an exposure with an approximate east-west trend through the south end of Balloon Hill. Figure 15 illustrates the geology of this temporary highwall. Almost every important unit at Rawhide is exposed in this cut. Traversing from west to east the stratigraphy is crossed from oldest to youngest. The northwestern corner of the pit shows a section of lithic tuffs (Tlt) that is almost in the center of a broad open anticlinal fold below Rawhide Wash (Fig. 12 and 15). A remnant section of Tst is exposed on both limbs of the fold. The contact is recognized by the familiar sequence of Tlt-Tltw-Tltq-Tstcl. Note that although a thick sequence of andesite (Ta) is present in fault contact with the southerly limb of the fold, Ta is absent from the sequence that underlies this part of Rawhide Wash and the southwestern flank of Balloon Hill itself.

The lithic tuff (Tlt) sequence in the northerly limb of this anticlinal fold is in dramatic fault contact with a silicified andesite (Ta) block that is well exposed in the temporary highwall. The orientation of this fault has a northwest strike and a steep northeast dip. Sandwiched between a converging north-south fault and this northwest fault is a block of extrusives exhibiting well developed pillow textures. The igneous textures in the individual pillows, although difficult to recognize due to the extreme alteration, does not appear to be similar to the andesite (Ta). It is suspected that this block is a coherent fault sliver derived from the lithic tuff (Tlt) section.

To the east of the Ta block is a sequence of silicified Tstcl. The contact of Tstcl on Ta in the upper benches of the temporary highwall is clearly depositional. In the lower benches, the contact changed to a fault offset that truncated easily recognizable beds in the Tstcl. Within this well exposed section of Tstcl are two major horizons of black sediments that can be traced down the highwall. The lowermost is approximately 3 to 4.6 meters (10 to 15 feet) thick and is approximately 3.6 meters (12 feet) above the depositional contact on Ta. This traceable bed is very coherent and has been tilted more than seventy degrees to its present northwest strike and northeast dip. Higher in the Tstcl section and closer to the contact with the Balloon Hill Trp is another black sediment horizon. This does not have the coherency of the lower horizon. Although it is a traceable horizon, it can only be followed as a zone of highly fragmented and distorted pieces of black sediment in a matrix of coarse pyroclastic debris. It has a very shredded appearance. There are several mechanisms to explain the difference in character of these two otherwise similar horizons:

1.) The proximity to the Trp contact and a closely parallel Tvbx unit distorted the black sediment horizon prior to silicification.
2.) The upper beds of Tstcl were still unlithified and unsilicified when tilting of the unit began. Distortion of the bedding is a soft sediment deformation.
3.) Overlying and intermingled coarse pyroclastic ejecta disrupted normal smooth beds during a period of explosive venting.

The answer may be all of the above, however the lower layer is also interbedded with coarse pyroclastic fragments and is coherent. The last mechanism is probably the least important as a probable cause for the above relationships.

The entire sequence is tilted and at least in the upper benches of the temporary highwall is conformable on the Ta. The Ta block must also be rotated in a similar fashion. The exposures of Tlt to the west of the Ta and in fault contact with Ta by the northwest oriented structure are not significantly tilted. The northerly limb of the anticlinal fold in the Tlt is dipping gently northeastward. The fault bounding the two units has accommodated a significant amount of the deformation associated with the rotation of the Ta-Tst block.

To the east of the Tst sequence is the intrusive contact with the Balloon Hill rhyolite (Trp). A crosscutting Tvbx unit is associated with this contact. This zone of brecciation is a complex contact. Shearing textures of a rhyolite intruding into incompetent and unlithified sequences of tuffs are obscured by explosive brecciation following the contact. Well silicified fragments of Tst, Ta, Tvbx, and Trp are distributed in an argillized matrix. The mappable unit wavers between coarse pyroclastic debris that is a part of Tstcl proper, and well brecciated and exploded zones composed primarily of Trp. The unit consistently follows the margin of the Trp contact along most of its' western contact in Balloon Hill.

The rhyolite is in fault contact to the east with another section of Tst-Tat. This is the unusual occurrence of the Tat gravity slide block previously mentioned. This silicified and mineralized block is entirely fault bounded and is

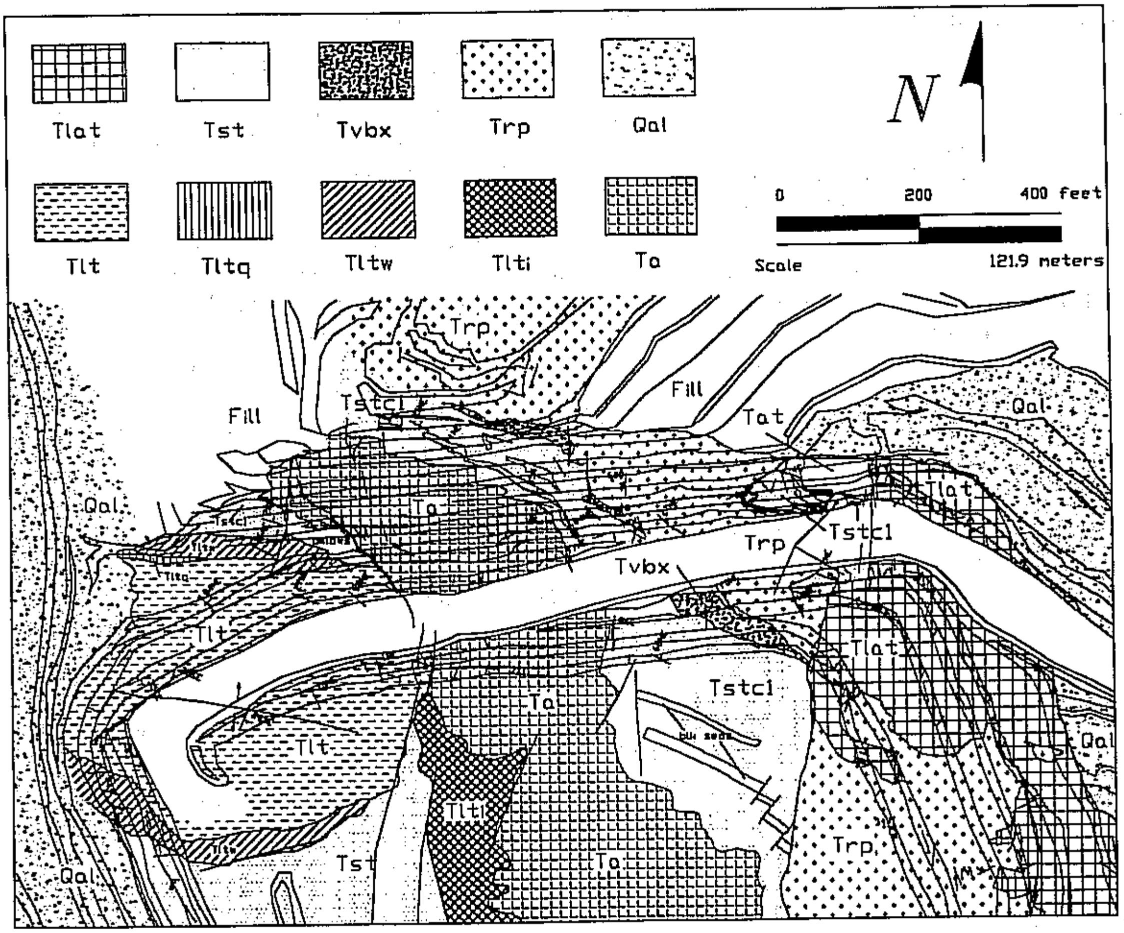


Figure 15—Geologic map of the temporary Phase I highwall of the Murray Hill pit showing lithology.

approximately 37 meters (122 feet) wide. The west contact is fault-controlled with the rhyolite and the east contact is in turn in fault contact with the argillized and unmineralized section of Tlat. This eastern fault contact is a segment of the large through-going Saddle Fault. This silicified, mineralized, and fault bounded block is interpreted as a preserved slice of what was probably a more coherent orebody now bounded by post mineral movement on the Saddle Fault. To the east of the Saddle Fault, in the Tlat and outside of the pit, drilling widens in density and knowledge of the geology becomes more sketchy.

BALLOON, GRUTT, AND HOOLIGAN HILLS

Combined surface mapping, development drilling, and modeling of future reserves in the Balloon, Grutt, and Hooligan Hill areas is recognizing similar ore controls and faulting patterns as mapped in the current and previous pits. The faulting patterns are important influences on intrusive and extrusive relationships of Trp and Trd, similar tilting of familiar stratigraphic units, and of mineralization. The complex geology of these areas continue to reinforce the importance of the observed patterns described in this paper. However, a detailed description of the geology in the unmined areas of Rawhide is beyond this scope.

REFLECTION OF STRUCTURAL CONTROLS IN GEOSTATISTICS

The importance of structural control on precious metal mineralization is reinforced by patterns of anisotropy in the variography of both exploration and blasthole geostatistics. This is data representing production of over 9 million tons of ore from the Murray Hill Pit to date and over 213,361 meters (700,000 feet) of development drilling. This degree of correlation between the preferential directions of anisotropy in precious metal variography and structural patterns observed in the lower hemispheric stereonet plots allowed decisions to be made in confidence as to the nature of the geostatistics to be used in the modeling of future reserves. The anisotropic search ellipsoid used in the kriging interpolations shows a preferential direction of continuity that is just west of north with an azimuth of 345 degrees (N15W). The plunge of the major axis of continuity is zero. This reflects the strike-slip character of the major set of faults controlling the deposit. The minor axis is perpendicular and is extremely steep at minus 85 degrees off of a horizontal azimuth of 255 degrees (S75W). This puts the intermediate axis at an azimuth of 75 degrees (N75E) with a shallow plunge of minus fifteen degrees. This reflects the steep westerly dip of the major north-south strike-slip faults. The ratios of the axes are

2.7:1:0.5 with the intermediate axis being assigned the value of one. An implication of this shape of a search ellipsoid is a relative lack of vertical continuity to the mineralization in the orebody. The deposit in rough overall geometry does indeed have vertical continuity but not for purposes of grade estimation.

Figure 16 is an isovariance contour map of horizontal variograms at fifteen degree intervals for production blastholes from the 4975 bench of the Murray Hill Pit. This representation of the variography helps to visualize the anisotropy. Note the strong degree of continuity in the north-south direction. The circle represents the search distances that have any actual meaning, beyond those distances the data is little more than noise.

AN INTERPRETATION OF THE CHRONOLOGY OF STRUCTURAL AND STRATIGRAPHIC EVENTS OF THE RAWHIDE DISTRICT

The spatial distribution of the Tlt sequence of rocks appears to be limited to the Rawhide volcanic field. Mapping by Gant (1986) identified Tlt at several localities within the field including the Regent area and south of Rawhide. These occurrences are widely scattered surface outcroppings of this unit where, for the most part, the widespread distribution of andesitic and latitic extrusive volcanics cover the field. Outside of the Rawhide volcanic field the unit is unknown or at least a clear correlation with work in other adjacent areas is not recognized. Within the main deposit areas however, it is clear that a significant site of accumulation of Tlt is profoundly controlled by the north-east margin of the Walker Lane structural regime. Deposition of interbedded pyroclastic and volcaniclastic rocks produced an effective minimum thickness of 610 meters (2000 feet). Within 457 meters (1500 feet) distance to the east the unit is absent. This dramatic difference coincides with the rapid increase to an unknown depth of the pre-Tertiary basement below Rawhide. Clearly, the site of deposition of Tlt is associated with earlier Miocene faulting at Rawhide. The nature and orientation of the control for the depositional site during this early period is poorly understood. It is known that the current configuration is a north-west oriented Walker Lane structure. Whether this same control was in effect during deposition of Tlt is speculative. Much of the derivation of locally thick pyroclastic debris is probably local in origin, suggesting a strong relationship of faulting with explosive volcanic activity in the area. Interbedded volcaniclastic rocks derived from surrounding terrains indicate subsidence of a site of deposition. The sections of Tat in Tlt, as mentioned earlier in this paper, perhaps attest to dramatic local gradients if the interpretation of these occurrences as gravity slide blocks is correct.

Answers to the question of the relationship between Tat and Tlt would shed light on when deposition of Tlt began and, as a corollary, when some of the structural events associated with its deposition began. Correlation of the Tat ash flow tuff regionally would also help answer this question. These are topics warranting study.

The assemblage of units marking the top of the Tlt section includes the sequence of Tlt-Tltw-Tltq and represents events leading to a significant change in depositional environments in the district. Tltw is a fine grained white ash fall tuff. Moderately developed bedding indicates some re-working of materials to a tuffaceous sediment. Scattered quartz grains suggest it may be rhyolitic in composition although these crystal fragments may be foreign and related to the associated Tltq unit. Tltq is a quartz crystal rich volcaniclastic rock composed of eroded Tat material and represents the last influx of Tat detritus into the site of deposition at Rawhide. The marker horizon defined by this assemblage of units can be correlated from the Crazy Hill Pit, through the Murray Hill Pit, and to the south-west flank of Balloon Hill. Despite the structural complexity in the Murray Hill Pit, the units can be traced and actually help unravel the faulting that has occurred. In Grutt Hill the horizon is interpreted to be present underneath the thick section of Ta.

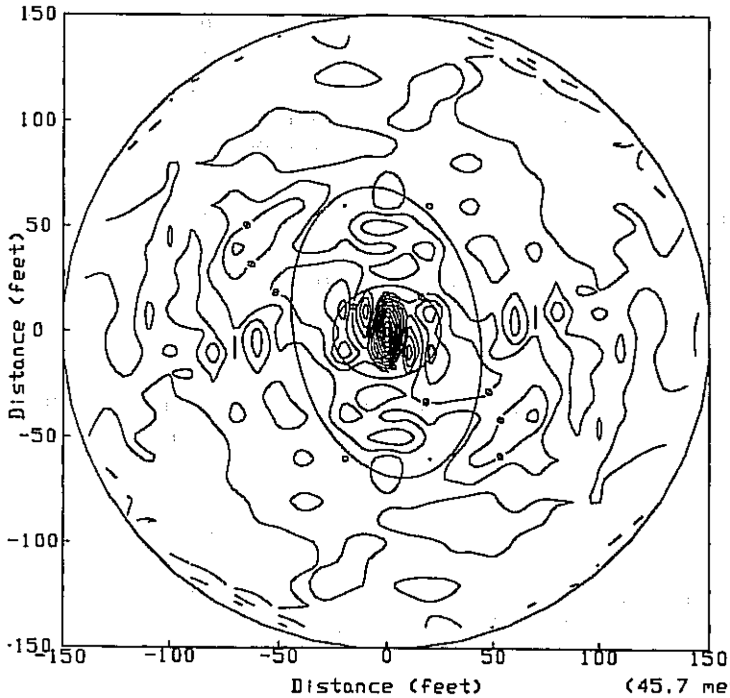


Figure 16—Isovariance contour map of the horizontal variography of the 4975 level production blastholes in the Murray Hill pit.

Overlying the marker horizon are a variety of units including the types of Tst, Tlat, and Ta. In the Crazy Hill Pit the Ta is absent and Tstc2 directly overlies the marker horizon. In a fault bounded block on the west flank of Balloon Hill the horizon is overlain by Tstc1, again with Ta missing from the section. In the Murray Hill, Hooligan Hill, and Grutt Hill areas the horizon is overlain by Ta of highly variable thickness. The relationship of Tlat to the marker horizon is less clear, but is interpreted to overly the horizon in the east flanks of Murray and Balloon Hills. The complexity of the overlying stratigraphy suggests a variable topography that reflects volcanic activity, faulting episodes, and erratic renewal of sedimentation represented by Tstc1 and Tstc2. The highly variable thickness of Ta is probably due to both the variations in thickness of the flows and a degree of erosion on the resultant topography. The presence of Tvc preserved between Tlt and Tst in the Crazy Hill Pit as a scarp controlled fanglomeratic deposit demonstrates that some of the topography was due to faulting.

As reported in Black, et.al., (1990) the andesite (Ta), where not extensively hydrothermally altered, is a plagioclase-hornblende andesite where phenocrysts are present. This would provide a tentative correlation with numerous hornblende andesites dated from 19 to 21 M.a. in Western Nevada. These andesites are associated with the pre-Basin and Range Extensional events (Zoback,et.al., 1981). In the Crazy Hill Pit the transition from rocks of the marker horizons at the top of Tlt to Tstc2 rocks represents a distinct change in depositional environments at Rawhide. The Tvc unit is evidence that faulting with at least a northeast strike was active at this time. This is interpreted to be related to structural and igneous events associated with the pre-Basin and Range Extensional events. The nature of the styles of deformation can only be speculated upon due to later intense faulting activity, but there is clear evidence in the Crazy Hill Pit that northeast oriented faults with at least a component of dip-slip activity were active at this time. In the Hooligan andesite block, a strong north-south steeply dipping fabric as well as some north-south oriented flow foliation textures points to the possibility of the north-south faults having some influence at the time of eruption. The possibility that eruptive sources of Ta may be rooted in the immediate vicinity of the district also exists. However, clear cross-cutting relationships have not been found either in exposures derived with mining or are suggested with interpretive modeling from the development drilling. It is probable that intense faulting and tilting of the units that postdates the eruption of Ta may be obscuring such relationships.

It is unknown if there is a significant hiatus in depositional events during and after the episode of pre-Basin and Range extensional activity. Tstc2 and lower Tstc1 are predominantly volcaniclastic in nature. Sedimentary textures in the fine grained reworked siltstones such as ripple marks and mud cracks suggest a lacustrine environment, if only ephemeral at best.

The coarsening upwards character of Tstc1 to the intricately interbedded pyroclastic rocks and siliceous pyritic sediments reflect increasing local explosive venting activity. Soft sediment deformational textures are common in beds that are in proximity to the throats of explosive vents. Many of these beds are physically sagging and tilting into the vents. Soft sediment flame structures in other fine grained Tstc1 beds may have been caused by seismic activity shaking unconsolidated and saturated sediments. Gravity slide blocks are known to be have been emplaced on or into pools of siliceous pyritic sediments. This implies the existence of variable topography, some perhaps over-steepened, in the older rocks. This is probably due to active faulting. Many of the explosion vents are related to rising bodies of rhyolitic magma that extruded as the flow dome complex of Balloon Hill. The rhyolite (Trp) probably intruded into and now obscures the geometry of earlier sites of cross-cutting and explosive vent brecciation. There is a general correlation of sites of vent breccias with precious metal mineralization. This would indicate that the tectonic and volcanic activity leading to this period of mineralization are closely linked spatially and temporally. The correlation is very good in the Crazy Hill, Murray Hill, and Grutt Hill deposits, but less so in Balloon Hill. Well silicified vent breccias are weakly mineralized in southern Balloon Hill and others are argillized waste in northern Balloon Hill. In Hooligan Hill if there was any surface expression of vent brecciation and associated pyroclastic rocks, it has since been removed. The Balloon Hill rhyolite (Trp) itself is mineralized where it has undergone structural preparation. The implication of this is that much of the explosive brecciation associated with the rise and extrusion of the rhyolite (Trp) and the emplacement of the dome itself precedes, however narrowly, the precious metal mineralization.

The mineralizing event(s) have been dated to 15.7 M.a. (plus or minus 0.6) by K-Ar dating of adularia associated with the mineralization (Black, et.al, 1990). The hydrothermal system leading to the deposition of precious metals, the explosive and eruptive volcanic activity closely linked with this mineralization, and the intense structural deformation controlling this relationship represent a period of significant strike-slip activity of the Walker Lane structural regime at this time.

It is clear that there has been renewed motion on some of the major faults after the 15.7 M.a. mineralizing event(s). The Saddle Fault in the Murray Hill Pit and the Dead Zone Fault in the Crazy Hill Pit are the better examples of post-mineral faults. The relative motion on these faults is in a right-lateral strike-slip sense. It is unknown when this faulting occurred, however offsets have been observed with low angle slickenlines involving the alluvial channel. The alluvial channel is assumed to be Quaternary in age. The conclusion that can be drawn is that strike-slip faulting has continued at Rawhide since the mineralization and is probably still active.

SUMMARY

Precious metal mineralization at Rawhide is profoundly controlled by structural events associated with Miocene tectonics of the Walker Lane. Development of sites of volcanism and of deposition of related pyroclastic and volcaniclastic rocks has been episodic within the district. The styles of structural deformation, including faulting and folding of the volcanic units, are related to northwest oriented right lateral strike-slip faulting of the pre-Tertiary basement. The strike-slip deformation of the basement is manifested as repeated en echelon north-south striking right-lateral strike-slip faults in rocks of the overlying Tertiary section. These faults have controlled sites of rhyodacite and rhyolite intrusions and extrusive flow domes. Major zones of intersection of these faults with northeast oriented faults correlate well with the major bodies of mineralization. Differential rates of displacement of major blocks led to the development of sinusoidal north-west oriented splay faults that can accommodate locally significant offsets. Northeast oriented faults that predate the episode of strike-slip activity associated with the mineralization have been reactivated during faulting and hydrothermal activity and are locally important controls on normal and higher grade mineralization. Repeated post-mineral deformation is evident from offsets of mineralized orebodies and of an offset veneer of alluvium.

The fault control on the distribution of mineralization is evident on all scales. Major orebodies are located at intersections of faults, bounded by faults, and show zones of preferential mineralization within the orebodies corresponding to the major sets of fault orientations. In addition, the controls are present on a pervasive scale and are manifest in the geostatistics of precious metal distribution. Preferential directions of continuity are determined by an anisotropic search ellipsoid and correspond well with lower hemispheric stereonet plots of thousands of fault and joint fabric data collected in the pits.

ACKNOWLEDGEMENTS

This paper is the product of an immense amount of work conducted by the author and of the geologists that are at or have been at Rawhide. The work has been conducted as a recognition of the extreme complexity of the geology of Rawhide and its impact on the development of and the day to day mining of such a deposit. The fine work in the pre-production era is attributable to Jon Gant and John Black. The paper could not be possible without the products of the sometimes grueling and tedious work of production and development geology. For this, we are grateful to the author, Jeff Dean, Kevin Crawford, and Dave Garbrecht. Other geologists whose association with the mine are greatly appreciated include Kelly Downing and Mike Kotraba. Appreciation of efforts of non-geologists in the Geology Department go to Steve Zayac and Neil Oberlander, the drilling and dozer specialists. Special acknowledgements go to Toby Mancuso for being our "buffer" while encouraging all possible activities in the geologic arena, and to Jerry Gubka, our computer guru. Appreciation goes to Kennecott Rawhide Mining Company for making this opportunity possible.

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