THESIS

STRUCTURAL EVOLUTION OF THE GOLD QUARRY DEPOSIT AND IMPLICATIONS FOR DEVELOPMENT, EUREKA COUNTY, NEVADA

Submitted by

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In partial fulfillment for the requirements

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY DAVID MORRELL COLE ENTITLED STRUCTURAL EVOLUTION OF THE GOLD QUARRY DEPOSIT AND IMPLICATIONS FOR DEVELOPMENT, EUREKA COUNTY, NEVADA BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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Dedication

To Marjorie Cole Hansen, my elder sister, who I greatly enjoyed growing up with, hunting and camping with, whose support and friendship was unsubsiding, whose unfortunate death was felt by many.

ABSTRACT OF THESIS

STRUCTURAL EVOLUTION OF THE GOLD QUARRY DEPOSIT AND IMPLICATIONS FOR DEVELOPMENT, EUREKA COUNTY, NEVADA

The Gold Quarry deposit, located 7 miles north of Carlin, Nevada, is a bulk-minable sediment-hosted disseminated gold deposit situated along the Carlin Trend in Eureka County. A premier gold deposit in North America, Gold Quarry has total in-place reserves, and past production which exceed 15,000,000 oz gold.

Gold Quarry is hosted by lower Paleozoic eastern assemblage carbonate rocks, and lower Paleozoic siliciclastic and siliceous rocks of the transitional and western assemblage facies. The deposit is localized by a major structural intersection of the Gold Quarry and Good Hope fault systems at the southern end of the Carlin window. The Carlin window comprises an exposure of lower-plate eastern assemblage carbonate rocks through the upper-plate western assemblage siliceous rocks and the Tertiary Carlin Formation. The window is bounded by the Gold Quarry fault to the southeast and the Good Hope fault to the southwest.

The Gold Quarry deposit comprises four connected mineral zones, and several other small satellite deposits within one large mineral system. The four zones are: **Gold Quarry Main, Maggie Creek, Deep West, and Deep Sulfide Feeder.** These are believed to be genetically related, but differ from one another due to local stratigraphic and structural ore-controls.

Detailed pit mapping and drill-log interpretation, aided by palynologic dating techniques integrated with research conducted by other workers has yielded a coherent

tectono-stratigraphic sequence for the Gold Quarry area. Eastern-assemblage carbonate rocks, including the Ordovician Hanson Creek, Silurian Roberts Mountains Formation and a sequence of Devonian unnamed limestones, are in fault contact with upper Devonian siliciclastic rocks in the hanging wall of the Gold Quarry/Chukar Gulch fault. Locally termed the Quarry Member, this siliciclastic sequence includes laminated siltstone and lesser rhythmically bedded cherty-mudtstone and siltstone. The bulk of the siliciclastic sequence has been dated as Frasnian to Famennian (uppermost Devonian), however, the upper portions of the unit have yielded Kinderhookian (lowest Mississippian) dates. Highly folded and thrusted limestone of Devonian and Silurian ages are found in thrust contact above the siliciclastic sequence. This folded and thrusted package is locally referred to as the "allochthonous limestone wedge". The next tectono-stratographic higher package of rocks is the upper-plate to a major thrust fault locally referred to as the "Roberts Mountains Thrust"(RMT). The locally termed RMT is only one thrust plane within a sequence of thrusts which comprise the regionally recognized RMT zone. These upper-plate Caradocian (middle Ordovician) rocks include rhythmically bedded cherty mudstone and shale, laminated siltstone and lesser quartzite interbeds.

A structural model for Gold Quarry has been developed based on an integration of detailed mapping, structural and ore-control data from the Maggie Creek subdistrict. A structural paragenesis, based on cross-cutting relations of mapped faults and fault lineations, is proposed. Evidence for four main stages of faulting is noted at Gold Quarry:

1) **Compression-driven thrusting and related folding;**

2) **Wrench-driven strike-slip, reverse and dilational faulting;**

3) **Formation of collapse due to decarbonatization of**

host-rocks and associated normal faulting; and

4) Extensional tectonics resulting in normal faulting.

The oldest faulting and folding events at Gold Quarry are low-angle, generally east-dipping thrust faults and associated folds developed within the Devonian siliciclastic rocks and the overlying Ordovician siliceous rocks.

The next sequence of faulting is wrench-related, driven by a north-northeast principal compressive stress. This episode is interpreted to be responsible for forming the Carlin window, developing in response to a reverse-fault accomodation of movement along the Gold Quarry left-lateral shear. The Gold Quarry deposit is located at the "corner stone" or structural intersection of the Gold Hope reverse-fault and the Gold Quarry left-lateral shear. In addition, dominant ore-control directions are controlled by N10°W to N20°W (350° to 340°) right-lateral faults of lesser magnitude positioned in a conjugate manner to the Gold Quarry fault system.

An important structural event of the Gold Quarry main zone is volume-loss collapse of the system host rocks caused by extensive decarbonatization during hydrothermal alteration. Bakken (1990) documented 50% volume loss of the ore-host silty carbonate rocks at the Carlin deposit. A similar amount of volume-loss would be expected for decalcified and dedolomitized silty carbonate rocks in the footwall of the Gold Quarry Main zone. Volume-loss accomodation driven collapse and associated normal faulting, in addition to preexisting fracturing, rendered the otherwise poor host rocks of the siliciclastic sequence amenable to fracture-controlled ore-fluid penetration.

Significant extension-driven normal faulting and associated rotation of the deposit region occurred during the development of the Basin and Range. The extension reactivated many pre-existing structures as normal faults, most notably, the northeast-trending faults such as the Gold Quarry fault system. Dip-slip slickensides are common cross-cutting the low angle mullions and grooves on many of the northeast and north-

northwest-trending faults. The post-ore Tertiary Carlin Formation is offset, as well, by normal faults.

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Preface

The purpose of this study was to gain a more thorough understanding of the structural and stratigraphic parameters important in the development of the Gold Quarry deposit. Extensive in-house geologic data from Newmont Mining Corporation for the Maggie Creek subdistrict area have played an integral role in guiding and supplementing this thesis project. This study is intended to enhance the existing geologic database generated by current and previous geologists working in the Maggie Creek subdistrict.

The Gold Quarry mine workings, at the time of this study, exposed the Gold Quarry Main zone and portions of the Deep West zone, allowing detailed mapping and data collection. Mining of the Maggie Creek deposit was completed prior to this study; however, mine exposures within the pit were examined. The Deep Sulfide Feeder deposit, beneath the current Gold Quarry pit level, has not been examined in the field. Information about the Deep Sulfide Feeder deposit has been gathered from Rota et al. (1991) via interpretation of drill results.

Acknowledgements

It is with the utmost gratitude that I thank Newmont Exploration Limited (NEL) for the support they have provided me during the course of studying the Gold Quarry deposit. Many NEL geologists have been very helpful by sharing data and interpretations. The primary contributor to this study has been Joseph C. Rota, Senior Mine Geologist at Gold Quarry. Additionally, numerous geologists working in the Maggie Creek subdistrict have been very helpful, sharing ideas and discussing the developing new exposures along the production benches. I would specifically like to thank Brian Arkell, Dean Heitt and Ron Crouse for their keen interest and support. I would like to give a special thanks to Walt Smith and Mark Goings for drafting all the illustrations in this study. Critical edits of the manuscript by Lewis Teal have been of keen assistance.

The advice and guidance of academic professionals has been of great importance during this study. It is with much gratitude that I acknowledge Dr. Tommy B. Thompson of Colorado State University for his guidance. A very special thanks is due to Dr. Tom Westervelt of Fort Lewis College for invaluable time spent with him in the Gold Quarry pit observing the structural geology, and for his critical review of my interpretations. Dr. Sam Romberger of Colorado School of Mines has also played a helpful and supportive role.

Introduction

The Gold Quarry deposit, located 7 miles north of Carlin, Nevada, is a bulk-minable sediment-hosted, disseminated gold deposit situated in the Maggie Creek subdistrict along the Carlin Trend in Eureka County (Fig. 1). The Gold Quarry mine is one of the most productive gold mines in North America, producing an estimated 1,034,548 oz gold in 1991. Total in-place reserves are currently estimated at 179 million tons at 0.041 oz Au/ton. The mine operates at a capacity of 220,000 tons of ore and waste moved daily (Newmont Gold Company annual report, 1992). Gold production from 1980 to 1992 from the Gold Quarry and Maggie Creek mines totals 5,500,000 oz. (Rota, J. C., personal communication, 1993).

The Gold Quarry deposit lies within the Carlin Trend, a belt of disseminated gold deposits trending approximately N40°W (320°). The total resource plus production of the Carlin Trend is estimated to exceed 70 million ounces of gold, making it one of the premier gold districts in the world (Christensen et al., 1986). The alignment of gold deposits and associated alteration is coincident with windows of lower-plate carbonate rocks within the allochthonous siliceous assemblage of the Roberts Mountains thrust (Roberts, 1960). Sediment-hosted-disseminated gold deposits including (from north to south) Dee, Bootstrap, Post, Genesis, Carlin, Pete, Tusc, and Gold Quarry have been discovered along the margins of these structural windows (Fig. 1).

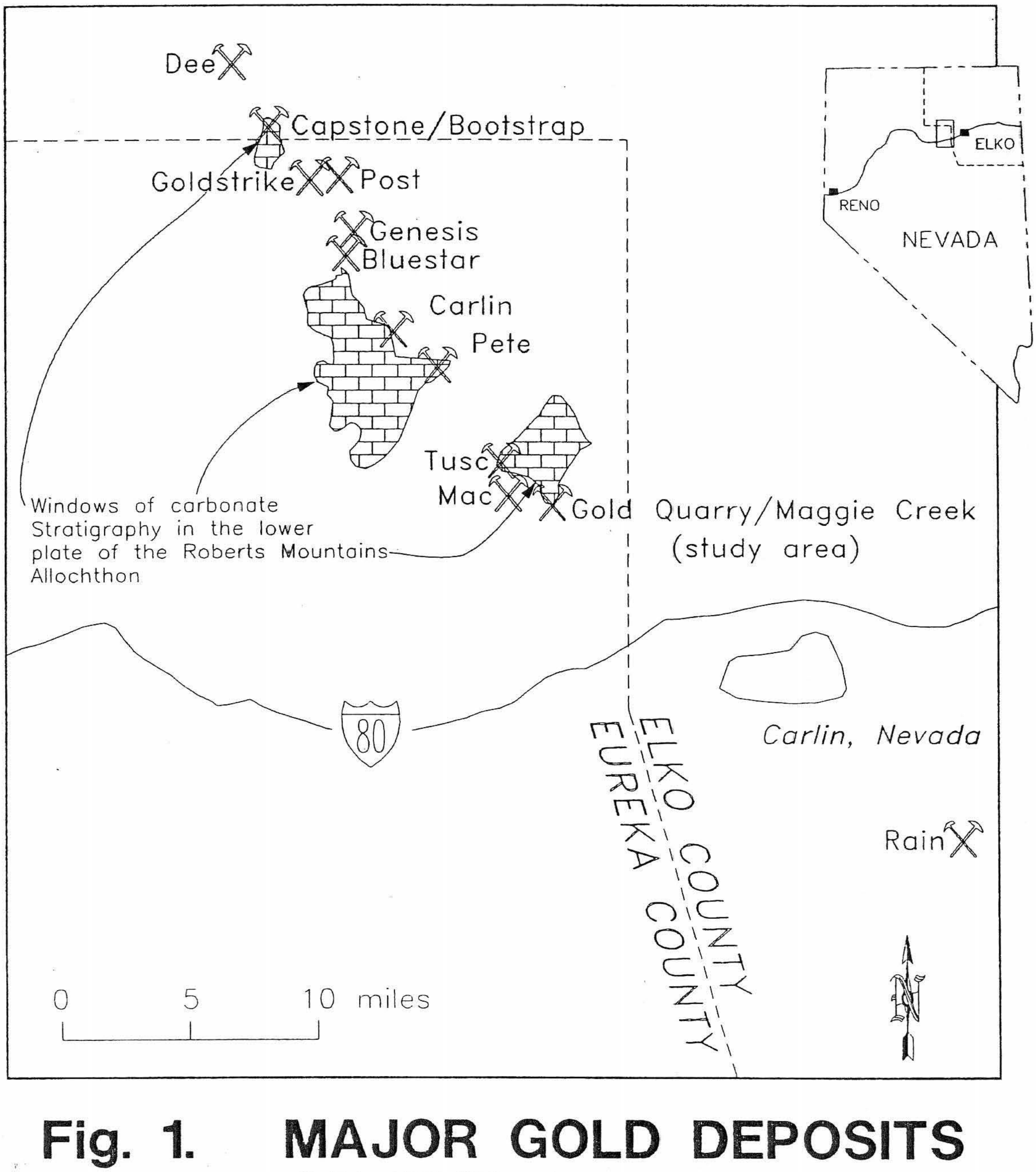

Fig. 1. MAJOR GOLD DEPOSITS OF THE CARLIN TREND

Regional Geology

The Gold Quarry deposit lies within the Basin and Range physiographic province of northeastern Nevada. The region has experienced major periods of sedimentation, igneous activity, orogenic deformation, strike-slip faulting and continental rifting.

Cambrian through upper Devonian carbonate and quartzite were deposited along the western margin of North America, in a continental shelf and slope setting. In this time period an estimated 30,000 ft. of sediments accumulated within the Cordilleran miogeocline (Stewart, 1980). Dominantly carbonate rich sediments accumulated along a regional north-south trending shallow shelf environment. These rocks have been referred to by Roberts et al. (1958) as the "eastern assemblage" and include the Ordovician Hanson Creek dolomite (Ohc); the Silurian Roberts Mountains Formation (Srm); and the Devonian limestone sequence (Dl). Concurrently, a thick wedge of outer slope and deep basinal shales, cherts, sands and interbedded pillow lavas were deposited in a depositional basin to the west. These rocks have been referred to as the "western assemblage" (Stevens, 1991; Stewart, 1980). Coeval siliciclastic rocks with variable carbonate component believed to be deposited at the base-of-slope to deep-water transition are locally referred to as the "transitional assemblage". These transitional rocks include portions of the Ordovician Vinini Formation (Ov) and the locally recognized "Devonian clastics" (Ds) (Dickerson, 1990) and Devonian Rodeo Creek unit (Drc) (Ettner, 1989).

During late Devonian to early Mississippian the Antler orogeny resulted in the emplacement of the Roberts Mountains allochthon. Regional compressive tectonism transported siliceous rocks of the western assemblage eastward as much as 90 miles (145 km) along generally shallow west-dipping thrust faults, thus juxtaposing western assemblage rocks over the eastern assemblage carbonate shelf and slope sediments, forming the Antler highland (Roberts et al., 1958).

During the late Paleozoic the Antler highland shed detrital sediments eastward into the foreland basin. These clastic rocks are referred to as the "overlap assemblage". Carbonate sedimentation continued along the shelf margin. During Pennsylvanian and Permian time a thin sequence of clastic marine sediments was deposited on the eroded Antler highland and the foreland basin area, (Stewart, 1980).

Emplacement of the Golconda allochthon occurred to the west and north during Late Permian and Early Triassic as the result of the Sonoma orogeny. Deep-water sediments from the west were thrust eastward (up to 60 mi (100 km)) onto the shallow water sediments previously deposited on the Antler highland (Stewart, 1980). Although the Golconda allochthon has not been mapped in the vicinity of the Carlin trend, effects of the compressional event may have extended that far east.

Regional emplacement of granodiorite to monzonite plutons occurred during the Jurassic and Cretaceous (Stewart, 1980). Beginning in the Eocene, faulting, volcanic and intrusive activity were wide spread. Beginning in the Miocene and continuing to present, Basin and Range tectonic extension and associated erosion and deposition have resulted in the present setting (Stewart, 1980).

Geologic Setting of the Gold Quarry Deposit and

Geology of the Maggie Creek Subdistrict

The Gold Quarry deposit is located in the Maggie Creek subdistrict of the Carlin Trend (Fig. 2). Gold Quarry is hosted by lower Paleozoic eastern assemblage carbonate rocks, and lower Paleozoic siliciclastic and siliceous rocks of the transitional and western assemblage facies juxtaposed along a series of thrust faults. Gold Quarry is localized within the complex intersection of the Gold Quarry and Good Hope fault systems at the southern end of the Carlin window. The Carlin window, an exposure of lower-plate eastern assemblage carbonate rocks is bound by the Gold Quarry fault to the southeast and the Good Hope fault to the southwest, forms a present day topographic high called Schroeder Mountain. The window is a fault bounded, doubly-plunging anticline or dome. Jasperoid is developed on both the Good Hope and Gold Quarry faults for over one mile along strike away from the deposit, demonstrating their role as mineralizing conduits. Other disseminated gold deposits found in the subdistrict are likewise located along the Carlin window margin.

The Gold Quarry deposit consists of four interconnected mineral zones, in addition to several other small satellite deposits, within one large system. The four zones, **Gold Quarry Main**, **Maggie Creek**, **Deep West**, and **Deep Sulfide Feeder** (Fig. 3), are believed to be genetically related but differ in their nature due to local stratigraphic and structural ore-controls. The Gold Quarry Main ore zone is hosted by siliciclastic rocks and chiefly controlled by high-angle faults and fractures. The Maggie Creek ore zone is hosted by carbonates within splays of the Gold Quarry fault system. Deep West is a strataform ore horizon hosted by siliciclastic and carbonate rocks at and above the

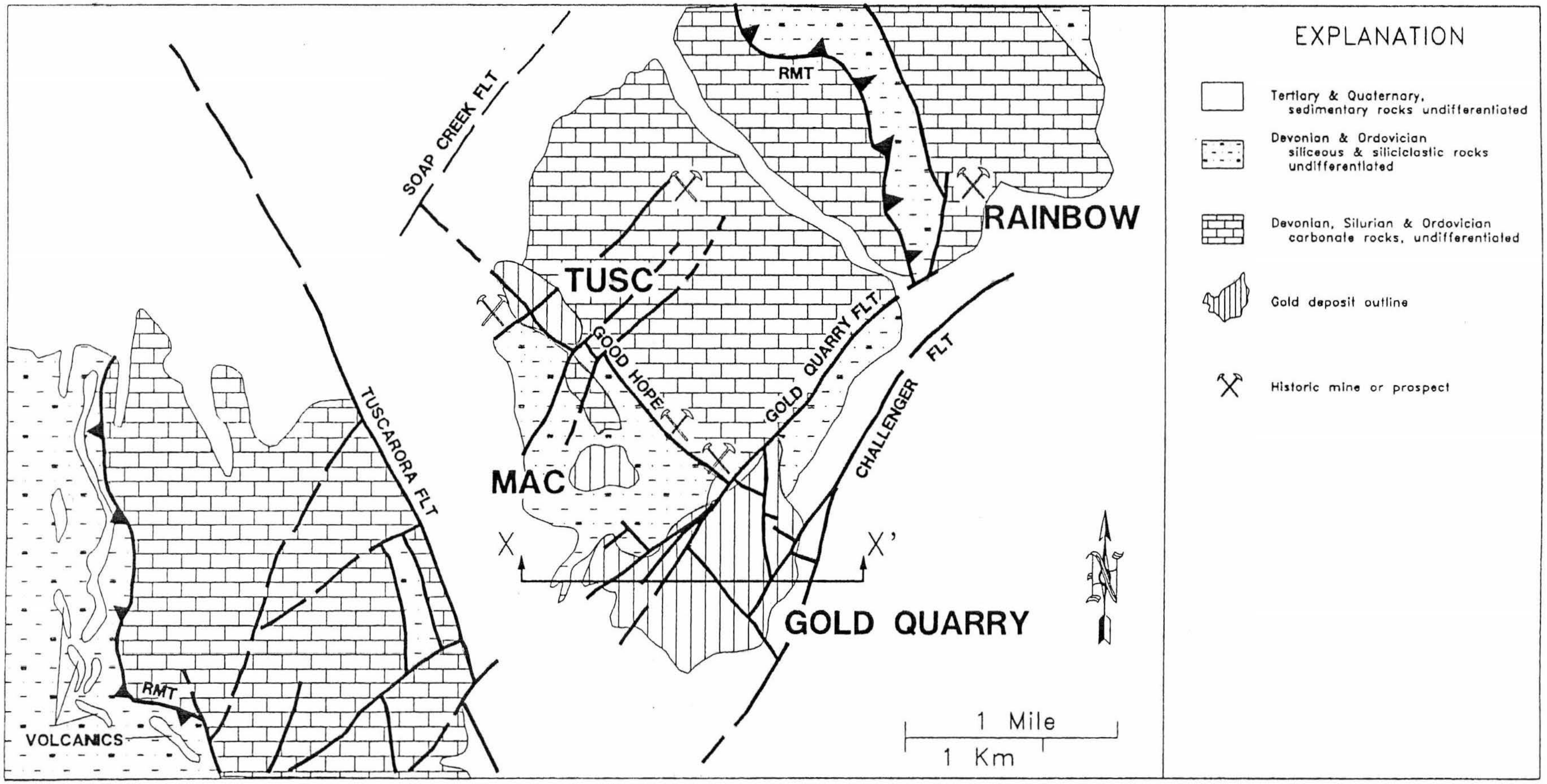

Fig. 2. MAGGIE CREEK SUBDISTRICT DEPOSITS AND GEOLOGY

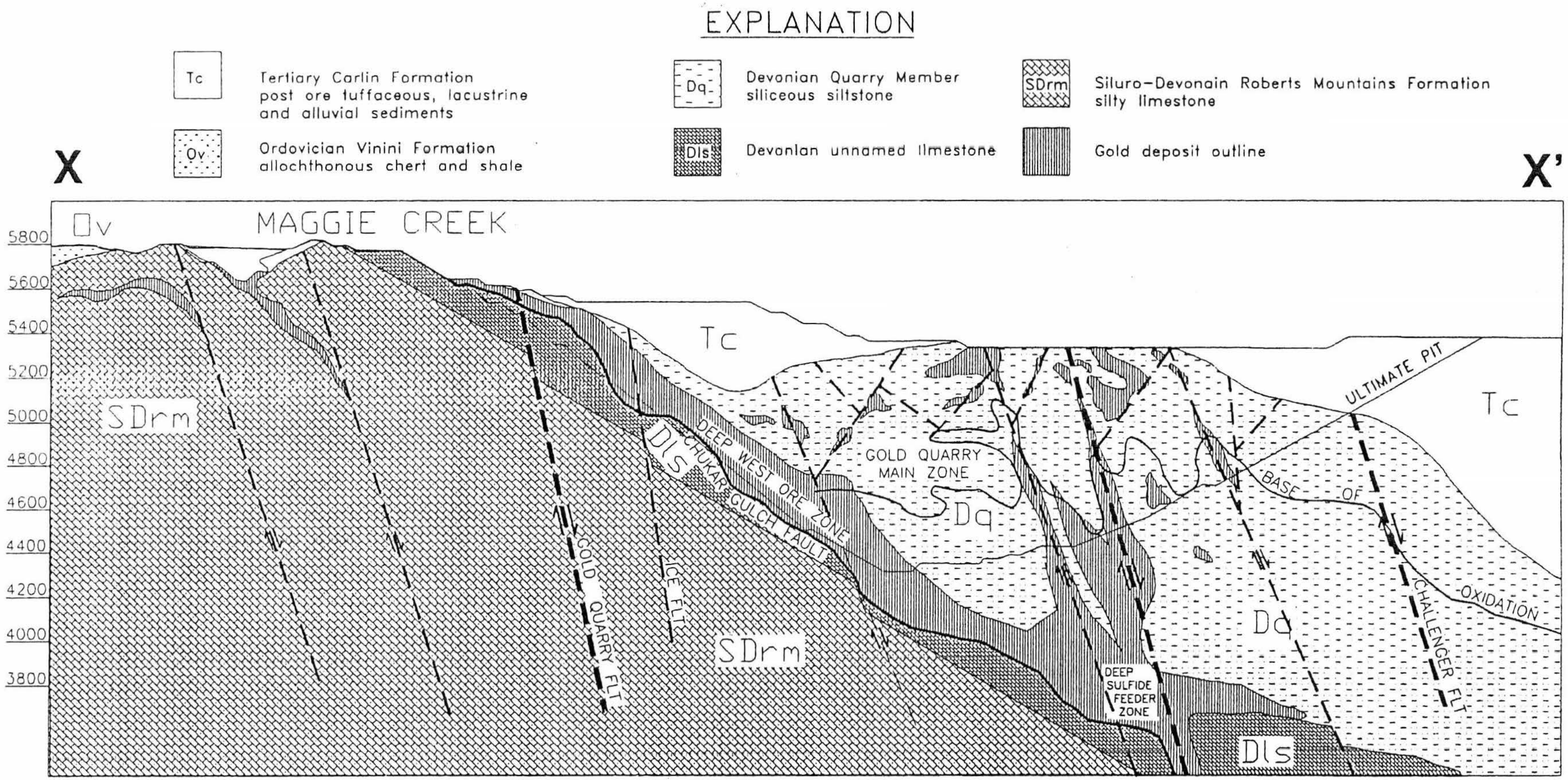

Fig. 3. GOLD QUARRY SECTION 17100 N. showing location of major gold deposits
(after Rota, 1993) (see Fig.3 for section location)

Chukar Gulch fault. The Deep Sulfide Feeder is a high-grade (+0.15 ounces per ton) cross-cutting mineralized zone hosted by both carbonate and siliciclastic rocks along the Deep Sulfide Feeder high-angle fault zone.

Stratigraphy

Introduction:

The Paleozoic stratigraphy of the Gold Quarry mine area consists of a lower section of autochthonous Ordovician to Devonian carbonate rocks and allochthonous siliciclastic rocks. This rock package has been offset by extensive high angle faults showing older strike-slip and younger normal-slip kinematic indicators, forming a complex array of juxtaposed rocks (Fig. 4). Interpretation of the stratigraphy is complicated by rocks of like lithologies but different ages, which in turn is critical to understanding and unraveling the structure. Detailed pit mapping aided by palynologic dating techniques (Plates 1, 2; Fig. 4; Appendix 1) and integration of research conducted by other workers in the Maggie Creek subdistrict along the Carlin Trend and throughout northeast Nevada have yielded a tectono-stratigraphic sequence for the Gold Quarry area (Fig. 5).

Discussion:

The tectono-stratigraphic interpretation presented in this thesis for Gold Quarry is generally consistent with the stratigraphic interpretations and column put forth by Dickerson (1990) for the Carlin Trend. Eastern-assemblage carbonate rocks including the Ordovician Hanson Creek (Ohc), Silurian Roberts Mountains Formation (Srm), and

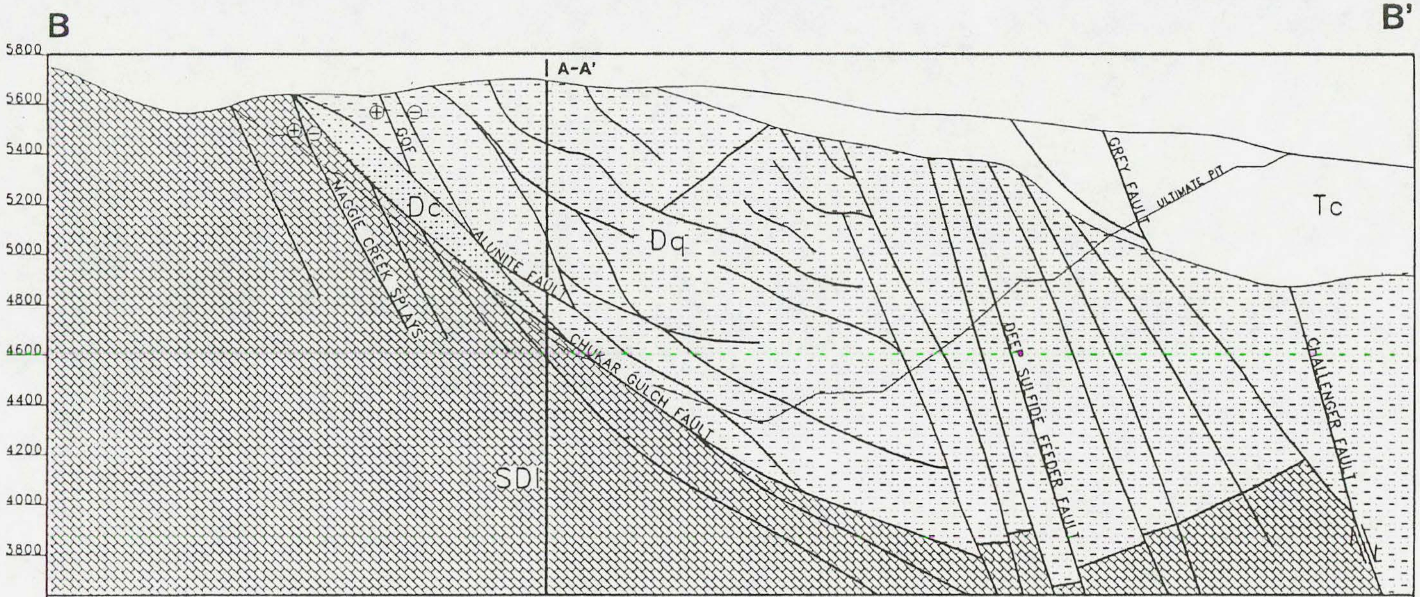

FIG. 4b. GOLD QUARRY SECTION 4000 NE.

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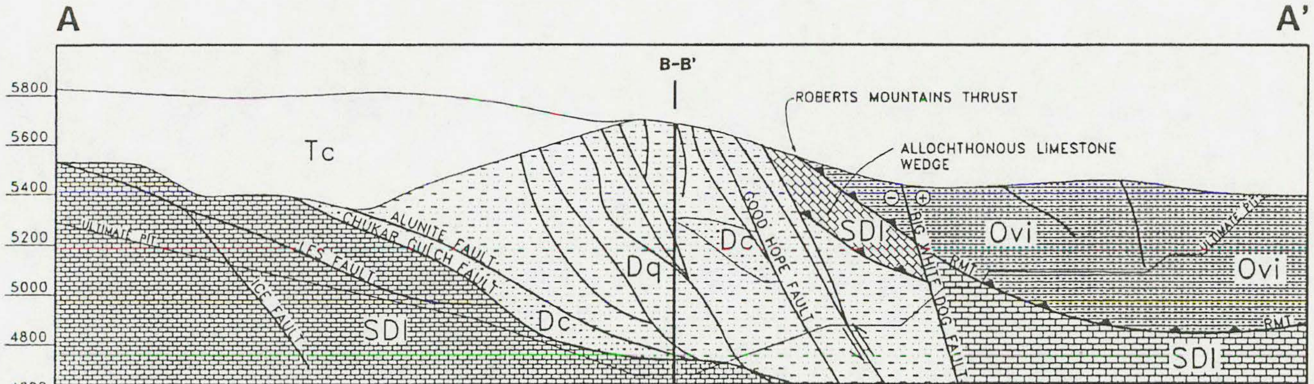

FIG. 4a. GOLD QUARRY SECTION 3400 NW.

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These lines of cross section are shown on Plate 1, Interpretive Geology

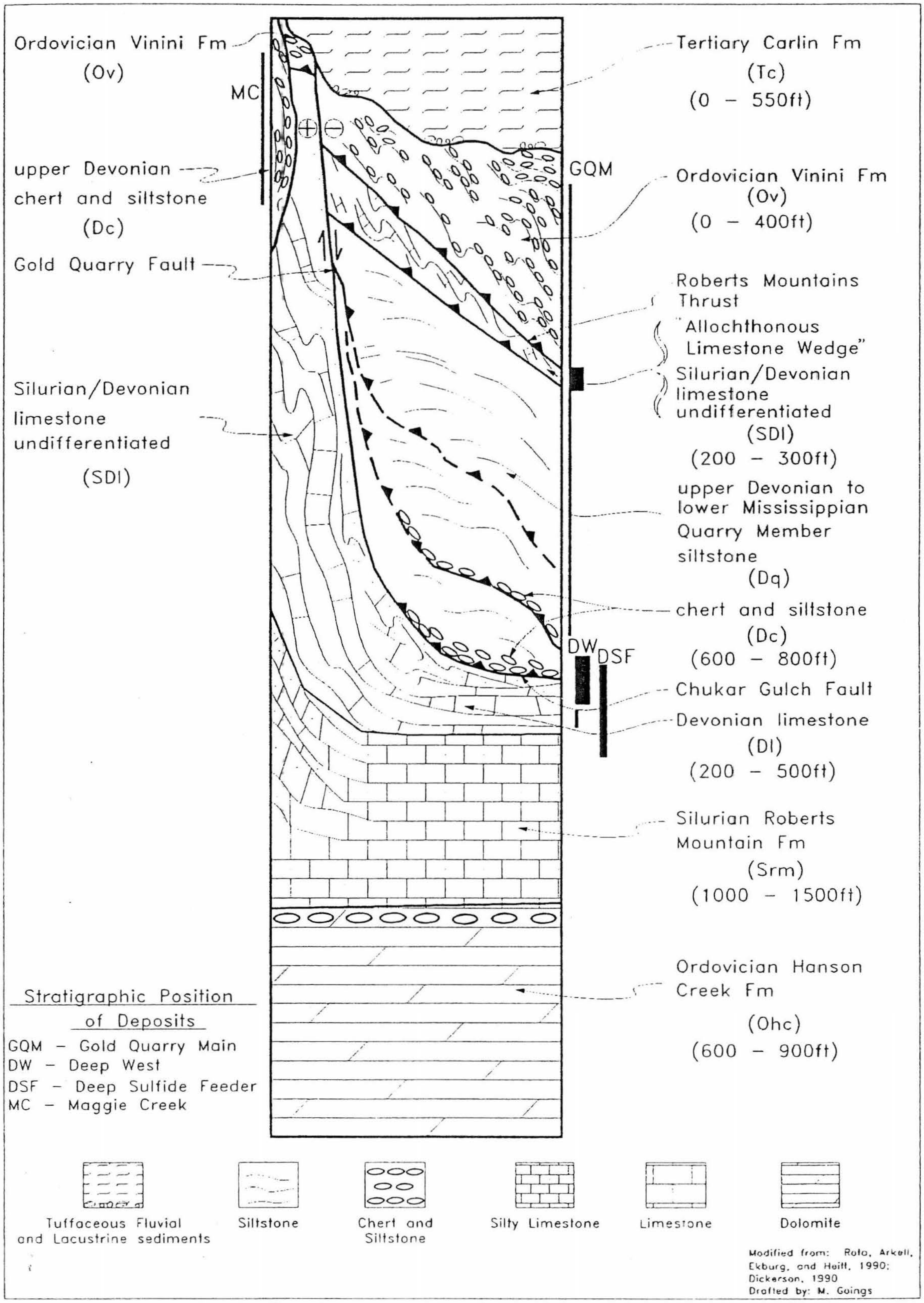


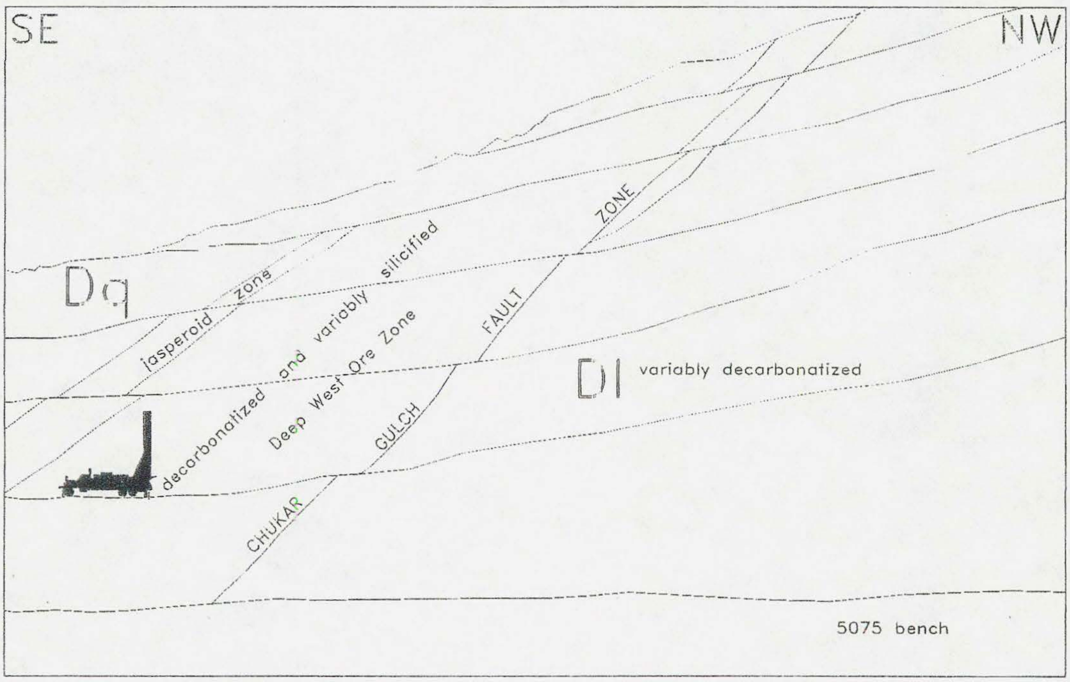
Fig. 5 GOLD QUARRY - DIAGRAMMATIC TECTONO-STRATIGRAPHIC COLUMN

a sequence of Devonian limestone (Dl) are in faulted contact with Devonian and Ordovician siliceous and siliciclastic rocks in the hanging wall of the Chukar Gulch Fault (Fig. 6). The locally-termed Chukar Gulch fault locally occupies the classic position of the Roberts Mountains Thrust (RMT), at the faulted contact between autochthonous carbonates (eastern assemblage) and siliceous and siliciclastic rocks (western and transitional assemblages). As Ettner (1989) concluded, the position of the thrust fault with older over younger relationships occurs locally above (stratigraphically) a Devonian sequence of siliceous siltstone and radiolarian chert and cherty mudstone which he termed the Rodeo Creek unit. These rocks compose the "transitional assemblage".

The Rodeo Creek unit is not ubiquitously accepted stratigraphic nomenclature, and the unit is typically difficult or impossible to distinguish from the Ordovician Vinini Formation in the allochthon of the RMT. Dickerson (1990) termed the Rodeo Creek unit the Devonian clastic rocks, in reference to the abundant siliciclastic and less common carbonate-clastic component to the rocks.

At Gold Quarry the Devonian clastic rocks or Rodeo Creek unit, is termed the Quarry Member. Here the Quarry Member has been further divided into either a chert dominant (Dc) or a siltstone dominant (Dq) package. The contact between the Quarry Member and the Devonian limestone at Gold Quarry, is commonly a low angle structural (thrusted?) contact. However, Ettner (1989), Dickerson (1990), and others have locally recognized the contact as depositional. The Quarry Member, is a siliciclastic sequence and includes laminated siltstone (Dq) and lesser rhythmically bedded siliceous (cherty) mudstone and siltstone (Dc). The Quarry Member is a thrusted package as shown in Figures 7 and 8. The majority of the Quarry Member siltstone and cherty packages have been palynologically dated as Devonian Frasnian to Famennian (Hutter,1990;

A.



B.

Fig. 6. A. Photograph looking along strike of the Chukar Gulch fault and the Deep West ore zone.

B. Sketch of the geology of the photograph.

A.

B.

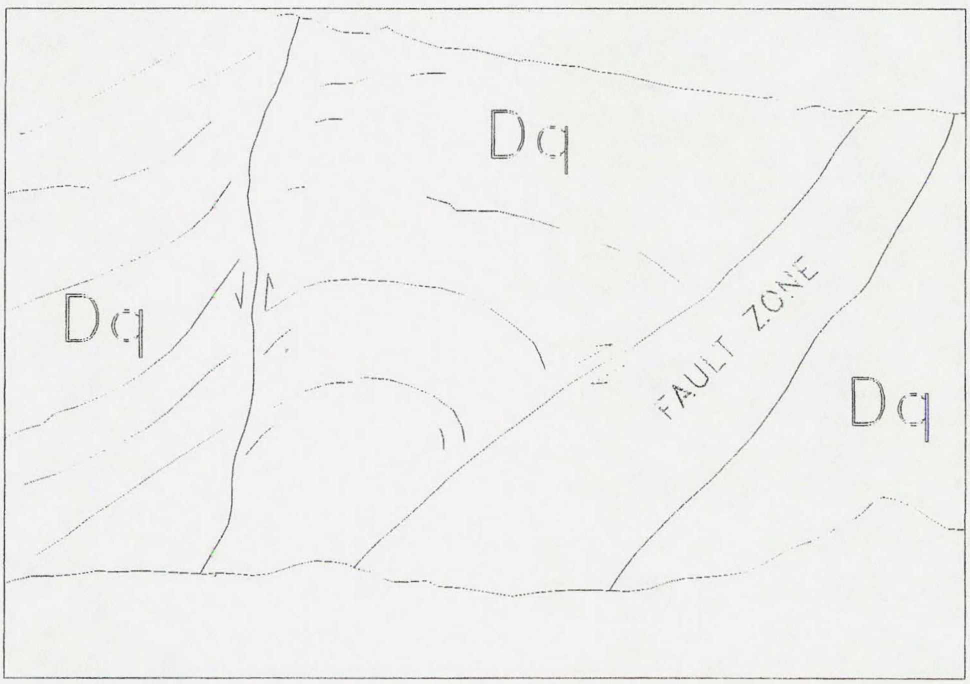
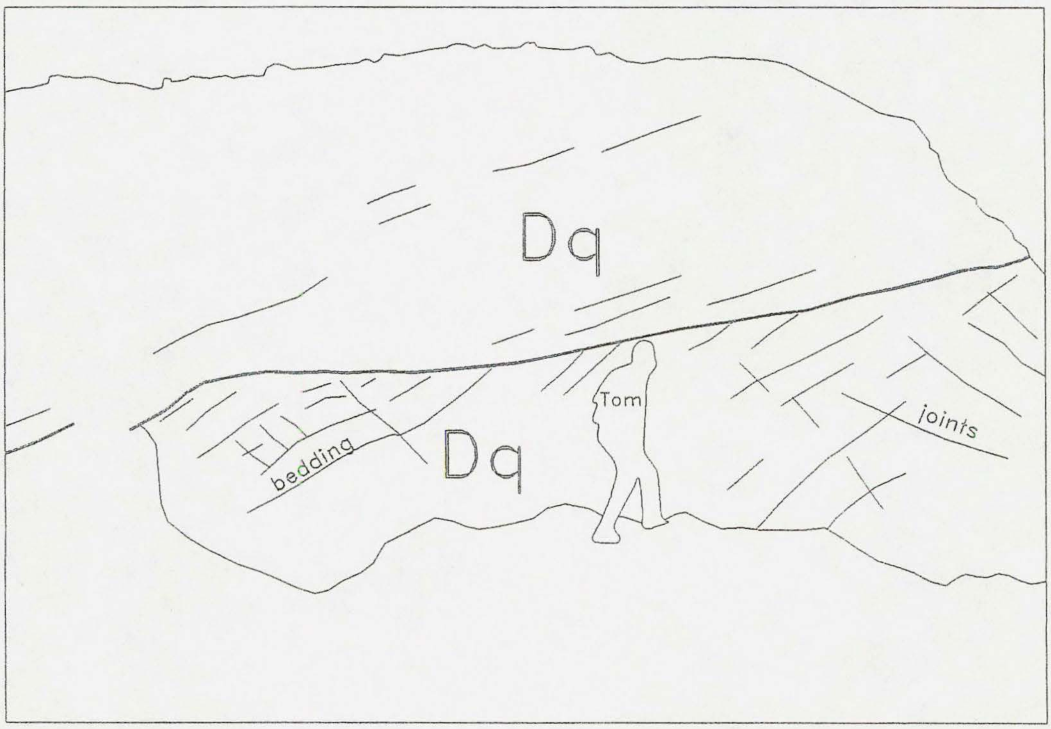


Fig. 7. A. Photograph of faulted Quarry Member siltstone on the 5300 bench.

B. Sketch of photograph illustrating drag folding suggesting normal and reverse fault movement for the two faults.

A.



B.

Fig. 8. A. Photograph of Quarry Member siltstone on 5300 bench.

B. Sketch of photograph showing low angle faulted contact (thrust). Note the well developed joint pattern in the massive siltstone.

Appendix 1; plate 2). This is generally in agreement with the Devonian radiolarian dates obtained by Ettner (1991) for the Rodeo Creek unit. However, the uppermost portions of the unit, consisting of laminated, coarse siltstones, have returned Mississippian Kinderhookian dates (Hutter, 1990; Appendix 1; Plate 1). Kinderhookian rocks occur along the south wall of the Gold Quarry pit just below the Tertiary contact and were chosen for age date analysis due to the recognized high level of stratigraphic exposure. The Kinderhookian siltstone rocks are clay altered, oxidized and highly fractured. Establishing an exact boundary between the upper Devonian and lower Mississippian rocks is considered a futile effort at this time due to alteration and structural complexity.

Highly folded and thrusted Devonian and Silurian limestone (SDl), are found in thrust contact above the siliciclastic sequence (Fig. 5). This package is locally referred to as the "allochthonous limestone wedge", shown in Plate 1 and 2 in plan view and Figure 4a in cross sectional view. Extensive jasperoid occurs in these rocks where they meet the Good Hope Fault (mined out). Recognition of the allochthonous limestone wedge resulted from detailed mapping along the north wall of the mine in an effort to better understand the complex juxtaposition of rock types in this area (Plates 1 and 2). Presence of the package was confirmed from drill results and subsequent mine mapping and modeling (Rota, J. C., personal communication, 1992).

The next higher package of rocks is above a major thrust fault referred to as the Roberts Mountains Thrust by mine geologists at Gold Quarry. This fault is not to be confused with the regional RMT, but is likely one in a sequence of thrust planes starting at the basal Chukar Gulch fault (a part of the regionally recognized RMT zone) (Fig. 5). Although effects of thrusting are noted down section to the Chukar Gulch fault, the lowest recognized thrust at Gold Quarry with older over younger relationships is actually the thrust at the base of the allochthonous limestone wedge (Fig. 9). The rocks above the RMT (local terminology) are ribbon chert and shale, laminated siltstone and lesser quartzite interbeds. Palynologically dated as Ordovician Cardocian (Hutter, 1990; Appendix 1; Plate 2), it is interpreted to belong to the Ordovician Vinini Formation (Ov). This agrees with Evans' (1972) interpretation.

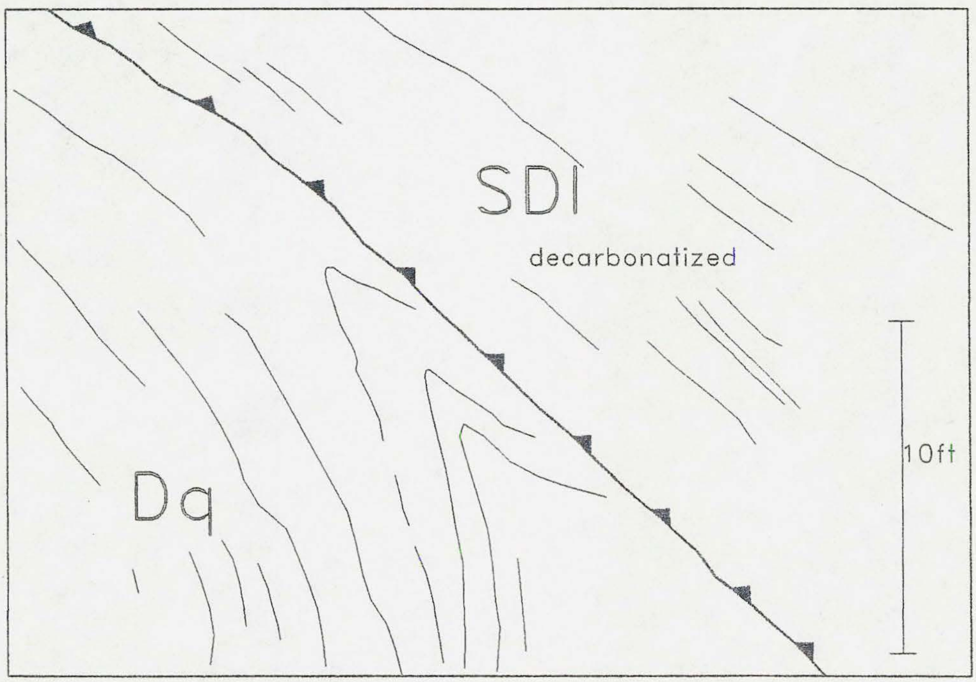
Locally, in the footwall of the Gold Quarry fault zone (e.g. 10000 N, 19500 E) (Plates 1 and 2), the RMT is mapped at the juxtaposed contact of Ordovician Vinini Formation (dated Ordovician Caradocian, by Hutter (1990) over the Devonian limestone rocks. Within the thrust zone the geometries can be very complex, as shown in Figure 10.

Amenability of Stratigraphic Units to Mineralization:

Discussion:

The variability of the stratigraphic units to host mineralization is an important ore-control in the Gold Quarry deposit. The most favorable host lithologies throughout the Carlin Trend are Devonian and Silurian silty carbonate rocks of the autochthon. At Gold Quarry (Deep West) this is the case; however, siliceous siltstone is a significant host rock as well (Gold Quarry Main). The "dirty" carbonate rocks make excellent host rocks due to greatly enhanced permeability following early decarbonatization (Bakken, 1990; Kuehn 1989). At Gold Quarry, the siliceous siltstone of the Quarry Member is also a favorable host rock due to extensive joint propagation characteristics. Thick bedded "cleaner" limestones of the (Dl) form less amenable horizons. Rhythmically bedded chert, siltstone, and shale rock packages form non-receptive hosts unless very well fractured. Relative strength of gold mineralization for the individual ore zones at Gold Quarry is

A.

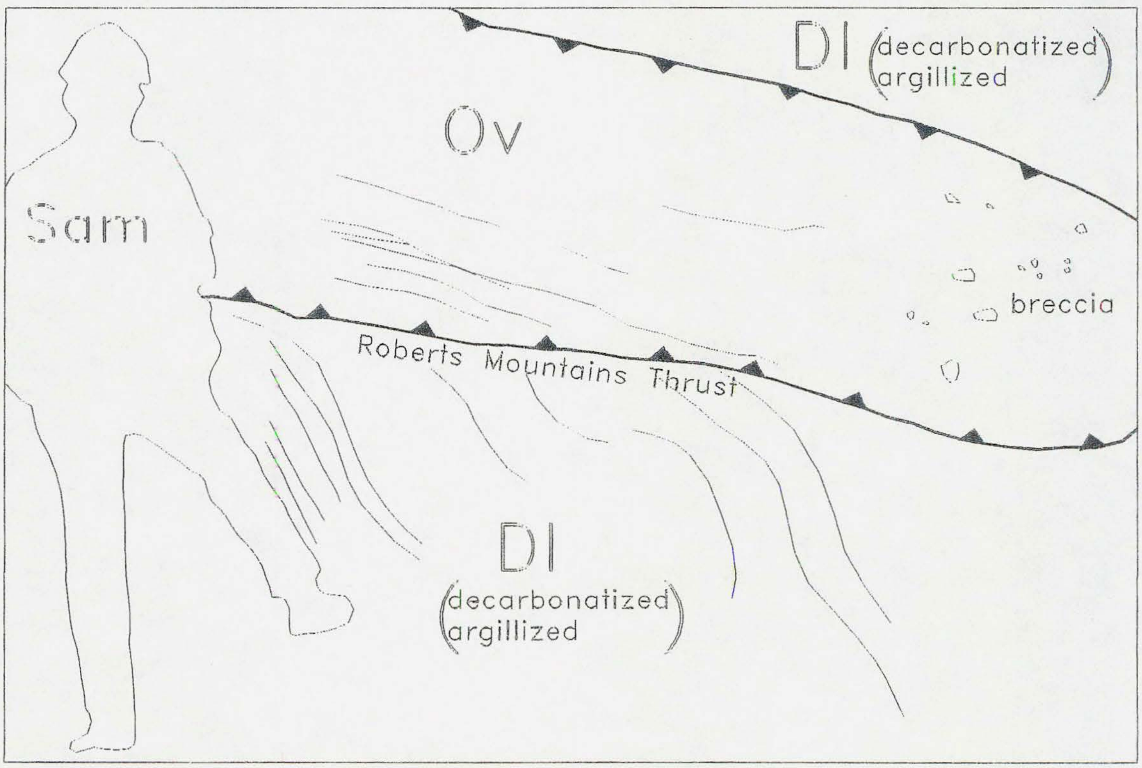


B.

Fig. 9. A. Photograph of the lower thrusted contact of the "allochthonous limestone wedge" on bench 5220.

B. Sketch of the photograph showing the folded chert and siltstone in the footwall of the thrust

A.



B. Fig.10. A. Photograph of Roberts Mountains Thrust zone exposed on 5600 bench.
B. Sketch of photograph showing recumbent folded thrust within the complex thrust zone.

diagramatically represented in Figure 5 as solid bars on the right and left sides of the tectono-stratigraphic column.

Western Assemblage Rocks:

The Ordovician Vinini Formation (Ov), consisting of ribbon chert, shale and quartzite, is a poor host due to the short joint propagation in the unit and the resulting poor paleo-hydrothermal transmissivity. Joints typically 1 to 2 inches in length cut chert beds, then lose continuity in the interbedded shale horizons. The Ov hosts small amounts of leach grade (0.040 to 0.006 opt) ore with only minor amounts of mill-grade ore (>0.04 opt) along faults.

Allochthonous Limestone:

The allochthonous limestone wedge (ALW) (SDl) is an excellent host rock when highly altered and hosted significant mill grade (> 0.04 opt) in the upper portions of the Gold Quarry Main deposit (mined out). These highly fractured, folded, and thrusted rocks were amenable to extensive decarbonatization, rendering them highly permeable and receptive to ore fluids.

Transitional Assemblage Rocks:

The Quarry Member siliceous siltstone and chert sequence (Dq) form an excellent fracture-controlled host lithology. The dominant host of the Gold Quarry Main deposit, the Quarry Member, fractures well with exceptional joint propagation. As observed in Figure 8, the massive siltstone is particularly amenable to fracturing, with single joints commonly traceable over 20 feet. It is interpreted that these joints acted as fluid conduits allowing penetration of ore solutions along fracture controlled zones of high transmissivity.

The Quarry Member ribbon chert and lesser siltstone lithology (Dc) form a locally good host rock due to a slightly calcareous component of siltstone interbeds, making it a chemically reactive and permeable (when decarbonatized) host. A high degree of fracturing is usually present in the ore grade material of this type. This unit hosts minor amounts of ore in the upper portions of the Deep West deposit and portions of the Gold Quarry Main deposit.

Eastern Assemblage Rocks:

The Devonian limestone package (Dl) is a variable host rock. Thin bedded, silty carbonate rocks high in the sequence provide excellent host lithologies and hosts a large portion of the Deep West and Maggie Creek deposits. This zone is extensively decarbonatized well into the footwall of the ore horizon (Romberger, 1992).

The lower portion of the Dl is a thicker bedded, cleaner limestone than the upper portion and is less amenable to widespread decarbonatization and thus hosts ore only along major faults. Mineralization along the Deep Sulfide Feeder fault zone within the Deep Sulfide Feeder deposit, and structurally controlled mineralization in the Maggie Creek deposit are hosted by lower D1.

The Silurian Roberts Mountains Formation (Srm), thinly laminated silty limestone, is considered to be one of the best host rocks on the Carlin Trend and is the host for the Carlin deposit. At Gold Quarry, the Srm only hosts (known) mineralization at depth, along the Deep Sulfide Feeder fault. This horizon may have potential for future exploration for deep resources in the Maggie Creek subdistrict but to date it has provided no ore grade intercepts.

The Ordovician Hanson Creek Formation, massive dolomite, is considered a nonreceptive host rock in the Maggie Creek Subdistrict. Although drill tested in the top six hundred feet, no significant gold values have been encountered in these rocks (Rota, J. C., written communication, 1993)

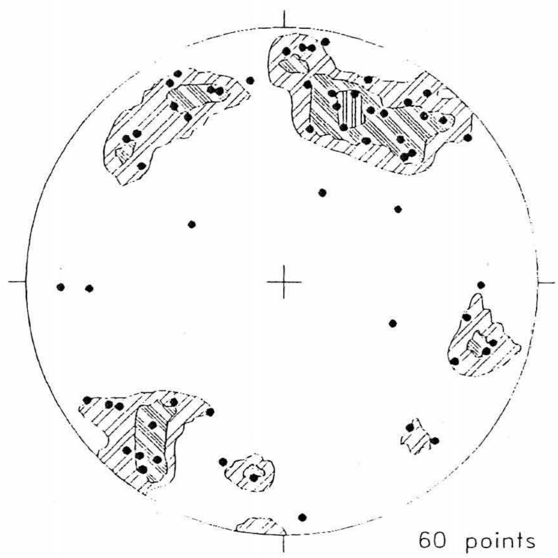
Structural Geology and Development of the Gold Quarry Deposit

Introduction:

The Gold Quarry deposit lies at the southern corner of the Carlin window, a structural dome or doubly-plunging anticline with fault-bounded margins. This broad fault-bounded fold warps the RMT, which is generally bedding plane parallel. Subsequent erosion of this structural high has resulted in exposure of autochthonous eastern assemblage carbonate rocks. Faults along the southeast and southwest margins of the window, the Gold Quarry and Good Hope, respectively, are major ore controlling features in the Maggie Creek subdistrict and the Gold Quarry deposit lies at the complex zone of intersection of these two faults.

Detailed mapping of bench-faces by the author and integration with an extensive database put together by Newmont geologists has been used to build a structural model for the deposit. The data collected by the author includes detailed mapping in selected areas within the pit (Plates 1 and 2). Stereographic plots of fold axis and fault and lineation data are shown in Figures 11 and 12. Contoured stereonet plots of the entire

Gold Quarry
Areas of Detailed Mapping
Fold Axes – Equal Area Net Projection



Contoured fold axes; equal area net;
using Schmidt (1925) contouring method; contour interval: 2% points per 1% area; data collected by by author, 1990 and 1991.

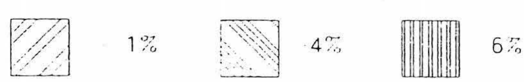


Figure 11 – Gold Quarry Fold Data

Gold Quarry
Areas of Detailed Mapping
Fault Lineation
Stereonet Projection

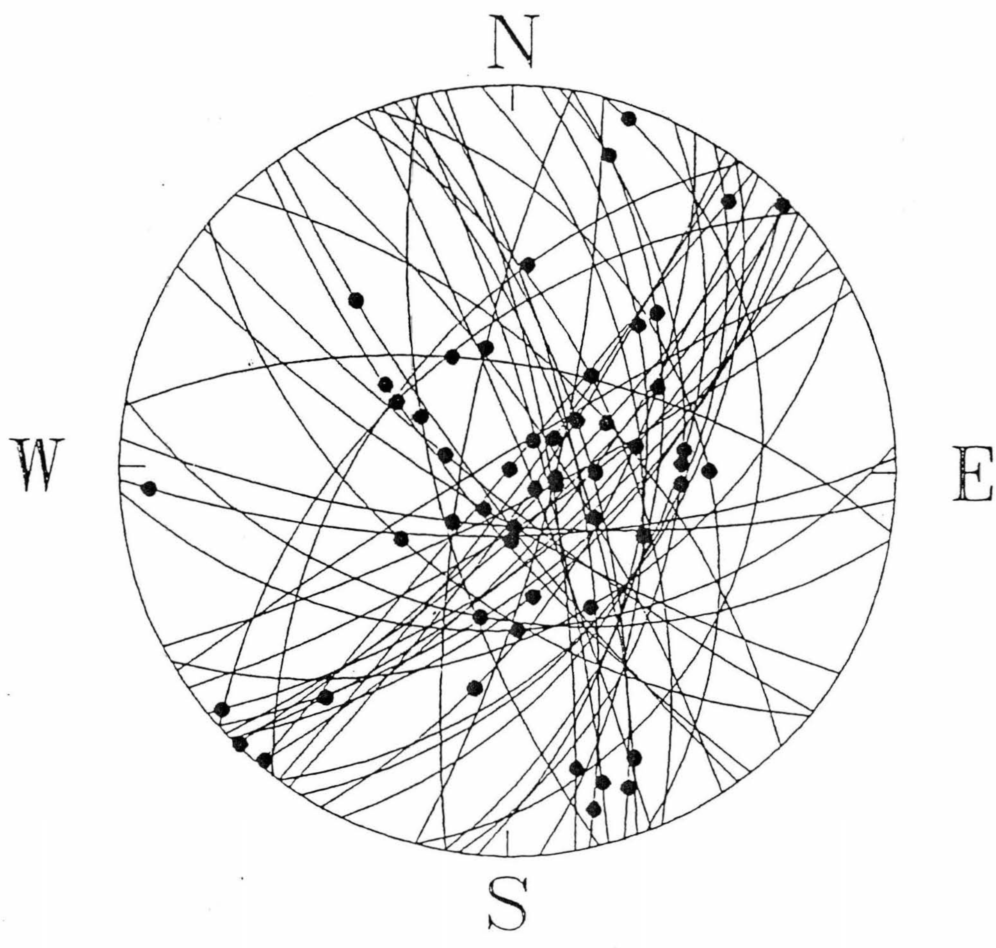


Figure 12. — Measured slip direction rakes on faults.

Gold Quarry structural database and of the area of detailed mapping, including bedding, fault and joint data, are presented in Figures 13.a. and 13.b.

Small Folds:

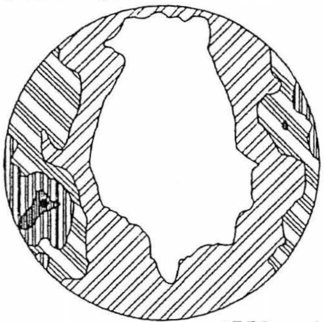
Fold axis data collected in the areas of detailed mapping presented in Figure 11 shows a nearly random scatter of shallow plunging axes. A dominant group of northeast and southwest trending, shallowly plunging small folds shown in Figure 11 as the area of greatest fold axis concentration in stereonet projection, were measured within the Gold Quarry fault zone and are subparallel to the Gold Quarry fault. No interpretation of this small data set is here presented; however, review of these data by S. G. Peters of the United States Geological Survey in Reno, Nevada indicates that similar fold plot patterns are present in the northern portion of the Carlin Trend.

Thrust Faulting:

The oldest faulting and folding events at Gold Quarry are low-angle, generally shallow east-dipping thrust faults and associated folds within Devonian siliciclastic rocks and overlying Ordovician siliceous rocks, including the "allochthonous limestone wedge" (ALW). These structures have associated folds which indicate transport from the east, possibly in a back-thrust fashion related to westward compressional regime recognized by many regional workers to be present from Devonian through possibly Eocene time. All other faults cross-cut these low-angle thrusts. Thrust faults have been discussed with respect to their tectono-stratigraphic position in "Stratigraphy".

Mapped thrust faults include the Chukar Gulch fault, located at the carbonate/siliceous rock (Dl/Dq-Dc) boundary. The Deep West deposit is located along the Chukar Gulch fault (Fig. 6). A structure contour map of this faulted contact is

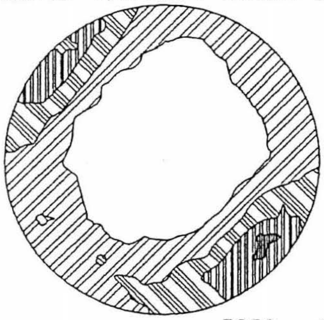
GOLD QUARRY MAIN: FAULT DATA



These data show a dominant fault trend of N18W,78E

4358 points

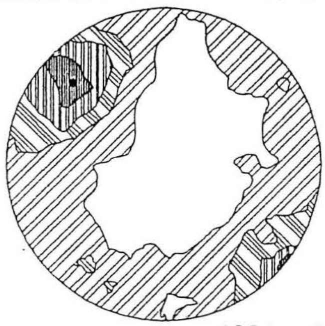
GOLD QUARRY MAIN: JOINT & SMALL FAULT DATA



These data show a wide distribution of high angle fractures and a distinct cluster of northeast striking high angle fractures

3256 points

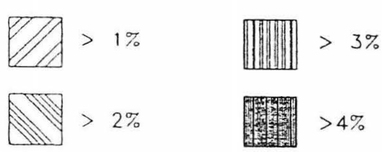
MAGGIE CREEK: FAULT DATA



These data show a dominant fault trend of N44E,73SE

1284 points

Contoured poles to planes; equal area net; using Schmidt (1925) contouring method; contour interval: 1% points per 1% area; data collected by local mine geologists over a period of eight years



modified from Rota & Hein (1990) and Rota (1990)

Fig. 13a. GOLD QUARRY STRUCTURAL DATA

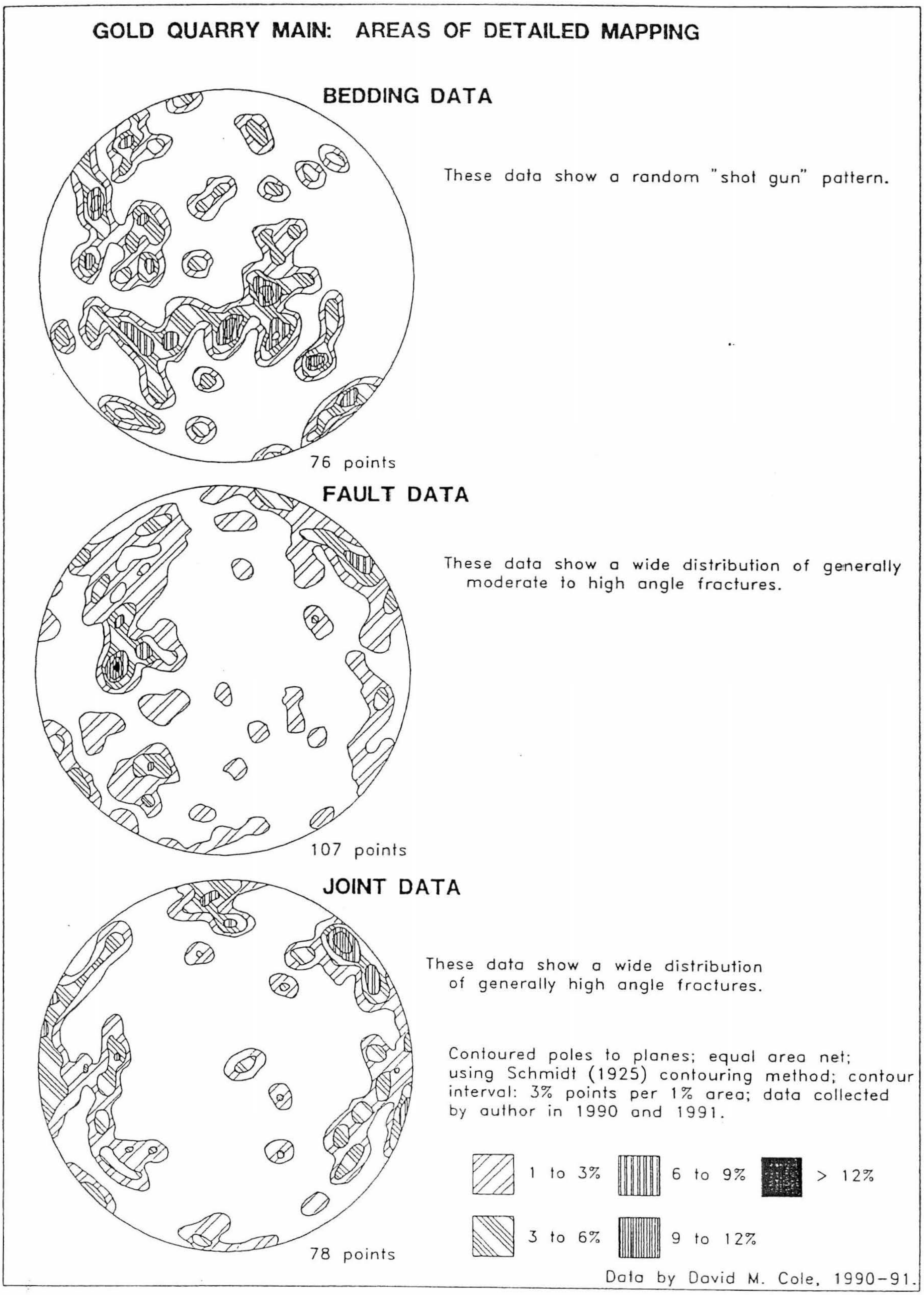


Fig. 13b. AREA OF DETAILED MAPPING STRUCTURAL DATA

illustrated in Figure 14. Although the thrust faults are interpreted as older than the high angle faults, based on cross-cutting relationships, the Gold Quarry fault (high angle) does not cross-cut and offset the Chukar Gulch fault in the central portion of the deposit. This is demonstrated by the lack-of offset shown in Figure 14 along the carbonate/siliceous rock contact, at the Gold Quarry/Chukar Gulch fault intersection. It is interpreted that movement along the Gold Quarry fault (see Wrench Faulting and Related Effects) is accommodated along the Chukar Gulch fault as the Gold Quarry fault system splays into the Chukar Gulch later in the structural development of the area. The Chukar Gulch fault is also interpreted to have been reactivated as a normal fault (see Extensional Faulting). Due to this complex history of reactivation, the term Chukar Gulch fault has been adopted as opposed to the term Chukar Gulch thrust which was previously the local terminology. Other low angle faults mapped within the Quarry Member sequence are interpreted to be thrust faults in origin. Figures 7 and 8 illustrate an interpreted thrust in the Quarry Member rocks. These thrusts have likely resulted in a thickening of the Quarry Member rocks in the Gold Quarry area. Figure 8 illustrates some of the open folding associated with these thrust features. However, tight, overturned folds are commonly noted in the chert sequences along the thrust planes (Fig. 9).

Thrusting at the base, within and along the top of the ALW has been mapped (Fig. 9; Plates 1 and 2). The thrust at the top of the ALW is locally termed the RMT and juxtaposes Ordovician Vinini rocks (hangingwall) against the ALW (footwall). The structure contour map shown in Figure 14 illustrates the top of the ALW (RMT); note that the ALW is only present in the hanging-wall of the Good Hope fault.

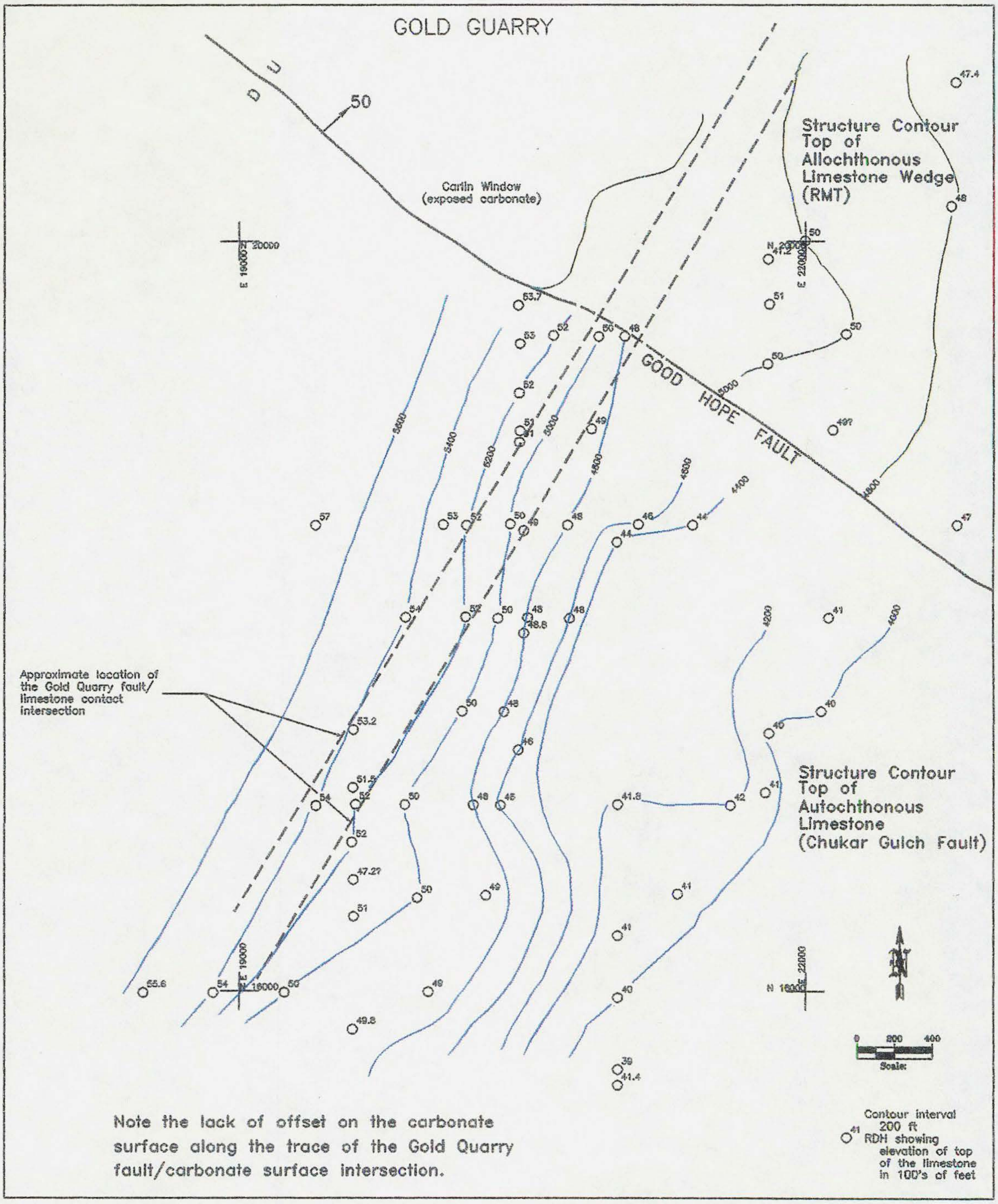


Fig. 14. STRUCTURE CONTOUR MAP OF TOP OF LIMESTONE

Wrench Faulting and Related Effects:

Evidence for Wrench Faulting:

The dominant ore-control direction in the Gold Quarry Main deposit is approximately N 10°W to N 20° W (350° to 340°) and the dominant ore-control direction at the Maggie Creek deposit is approximately N 40° E (040°) based on variogram studies of blast hole assay data compiled over the history of mining of the Gold Quarry Main and Maggie Creek deposits (Britt, A., personal and written communication, 1990; Rota and Heitt, 1990). Variogram studies are conducted using blast hole assay data variance in true space. The direction of least variance in blast hole assays is considered the dominant ore-control trend. The dominant fault trend based on contoured stereonet plots of fault data for the Gold Quarry Main and Maggie Creek zones (Rota, 1990; Rota and Heitt, 1990; Rota and Crouse, 1993), correlate precisely with the variogram data; indicating the strong control of fault orientation on gold grade continuity. Contoured stereonet data for 8898 data points collected over an eight year period show dominant fault planes of N 18° W (342°), 78° E and N 44° E (040°), 73° SE for Gold Quarry Main and Maggie Creek deposits, respectively (Fig. 13a). Interestingly, the small fault and joint stereonet plots for Gold Quarry Main show a wide distribution of high angle features but the dominant direction is coincident with the fault plot for Maggie Creek (Fig. 13a). Contoured stereonet data for the areas of detailed mapping (Plates 1 and 2) are shown in Figure 13b. The data presented in Figure 13b represents a small data set from local areas, along bench exposures during a short span of the mining. These data (Fig. 13b) are not representative of the Gold Quarry Main deposit as a whole.

It is clear from pit mapping, ore control, and blasthole variogram studies, that fault and fracture (small faults and joints) planes are the dominant control on gold mineralization in Gold Quarry Main and Maggie Creek deposits. Figure 15 illustrates the distribution of gold mineralization (>0.035 opt) from blast hole assay data, relative to mapped faults. Gold mineralization in the Gold Quarry main deposit extends well out into the walls of the major faults as shown in Figure 15 due to the extensive jointing and small fault fracturing of the ore host. Figures 16 and 17 show stereonet plots of the dominant fault directions for the Gold Quarry Main and Maggie Creek deposits corresponding to dominant ore control directions. Both structural orientations form an apparent conjugate set of exactly 60 degrees true angular separation (Fig. 18). This apparent conjugate relationship allows determination of the theoretical paleo-stress regime responsible for the development of the ore-controlling structures. Figure 19 illustrates the mean paleostress regime determined for the given fault population data using a simple application of the Anderson theory of fault dynamics (Anderson, 1942; Ragan, 1985). The paleo-stress regime indicated by the conjugate set is dominantly lateral with a near horizontal north-northeast directed maximum principal stress direction (σ_1); near vertical intermediate principal stress direction (σ_2); and shallow plunging west-northwest directed minimum principal stress direction (σ_3). Predicted slip direction for the conjugate pair is dominantly left-lateral for the Gold Quarry fault system and sympathetic structures and dominantly right-lateral for the north-northwest high angle fault set (e.g. Big White Dog, Hangfire, and Kristalle faults).

Kinematic data on the Gold Quarry and Kristalle conjugate fault set include an older, partially masked set of shallow-raking fault mullions or grooves and slickensides that are cross cut by younger, dominantly dip-slip slickensides (see extensional tectonics).

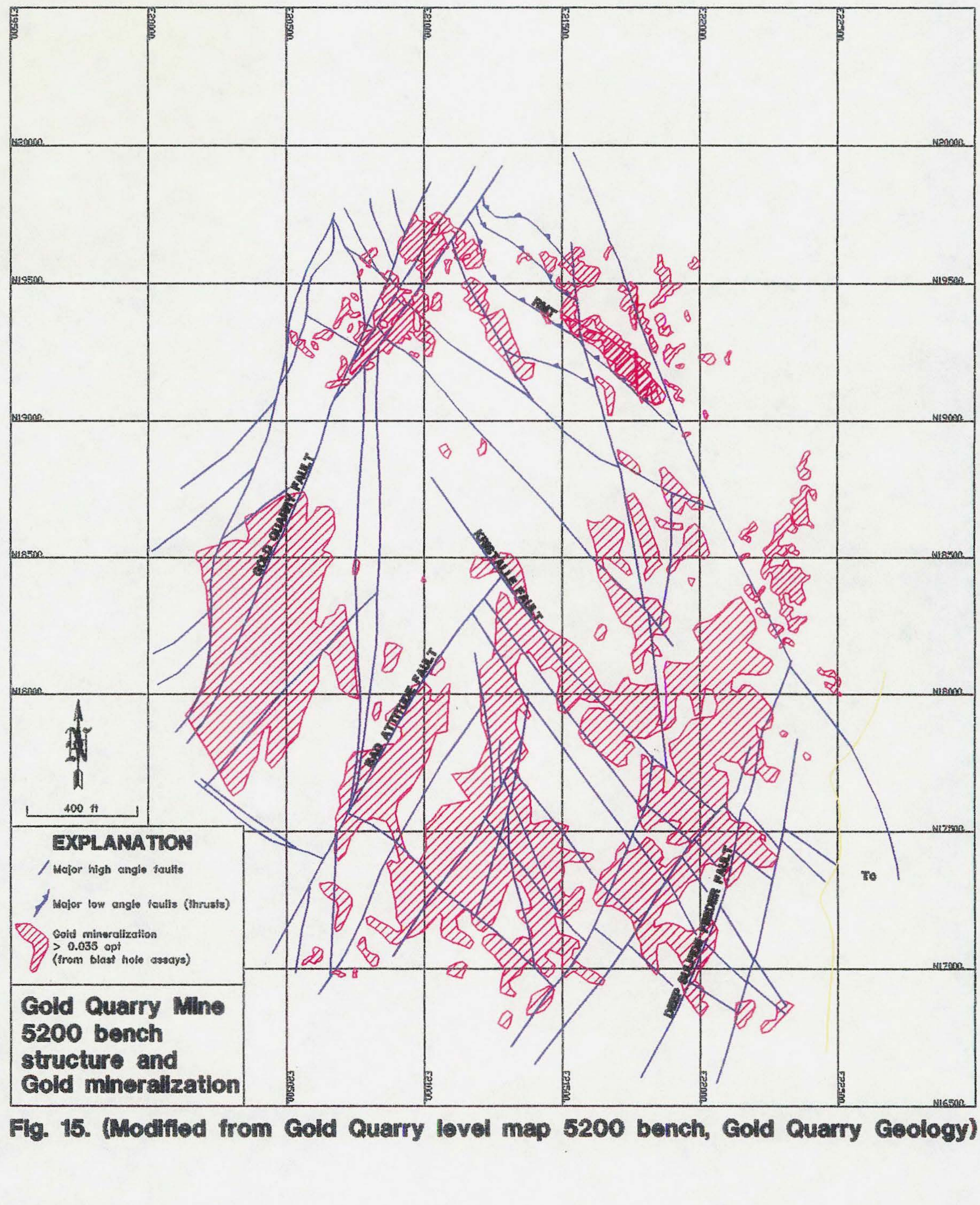


Fig. 15. (Modified from Gold Quarry level map 5200 bench, Gold Quarry Geology)

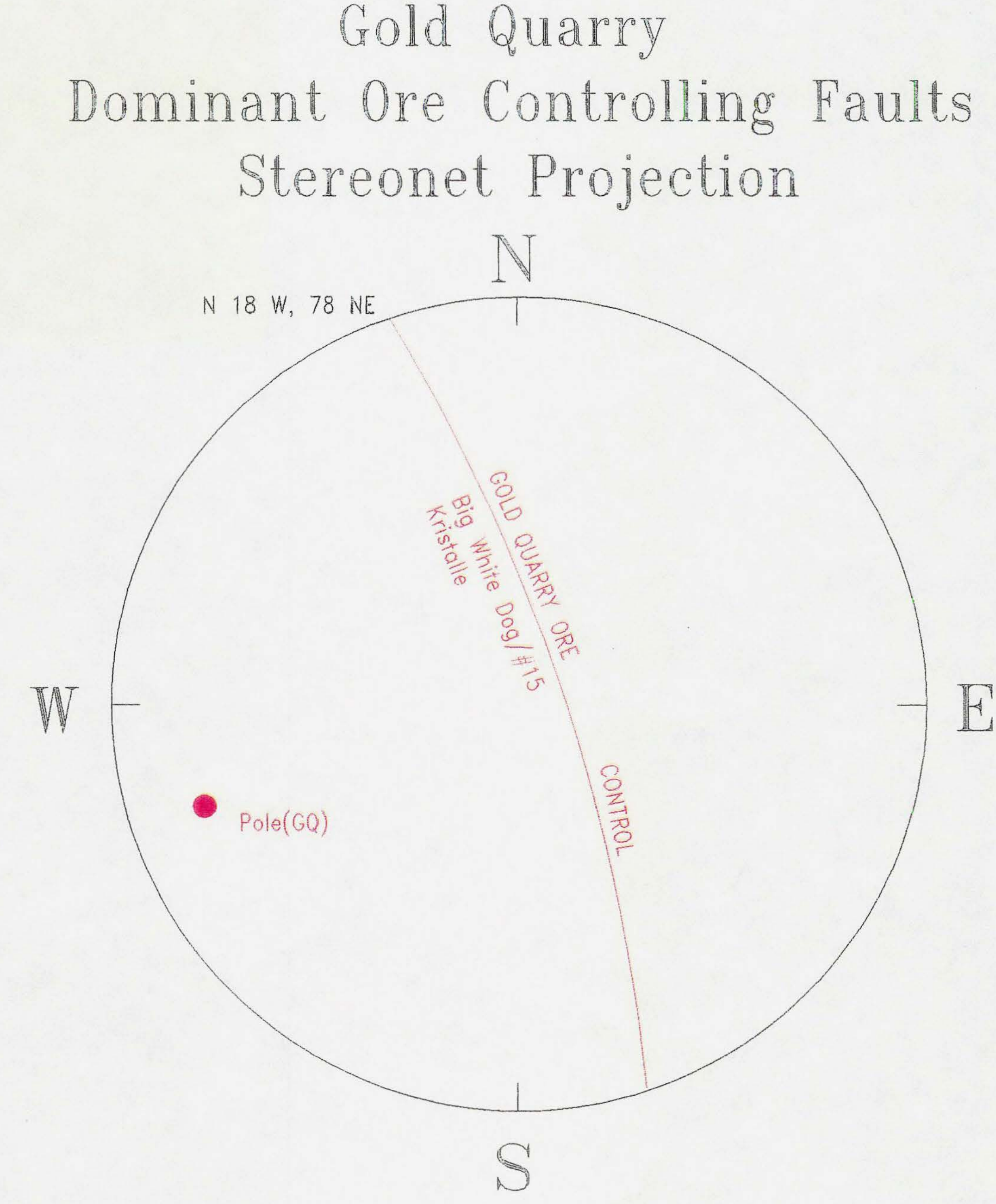


Figure 16. - Gold Quarry Main dominant fault direction based on contoured data shown in figure 13a.

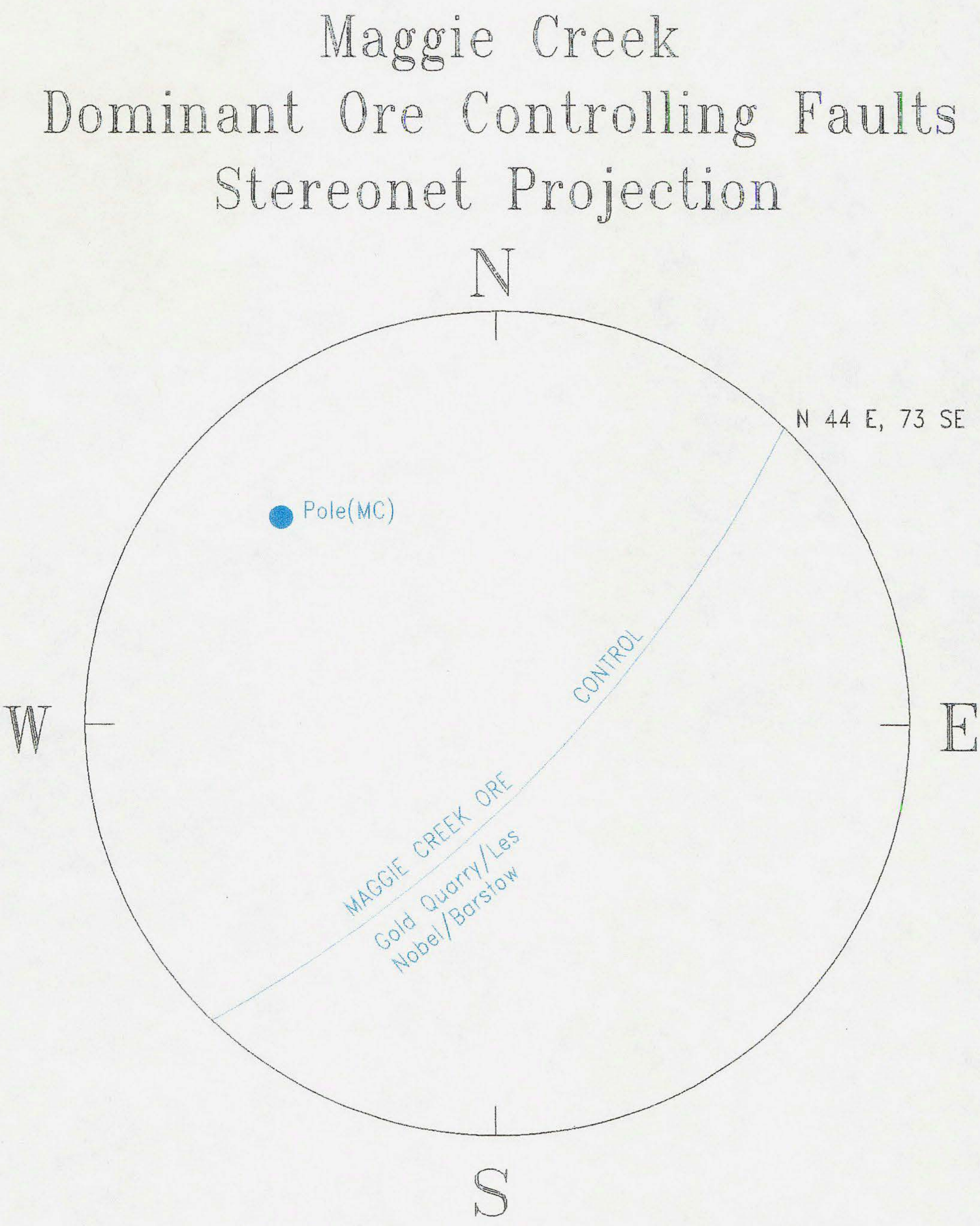


Figure 17. - Maggie Creek dominant fault direction based on contoured data shown in figure 13a.

Gold Quarry / Maggie Creek
Dominant Ore Controlling Faults
Stereonet Projection

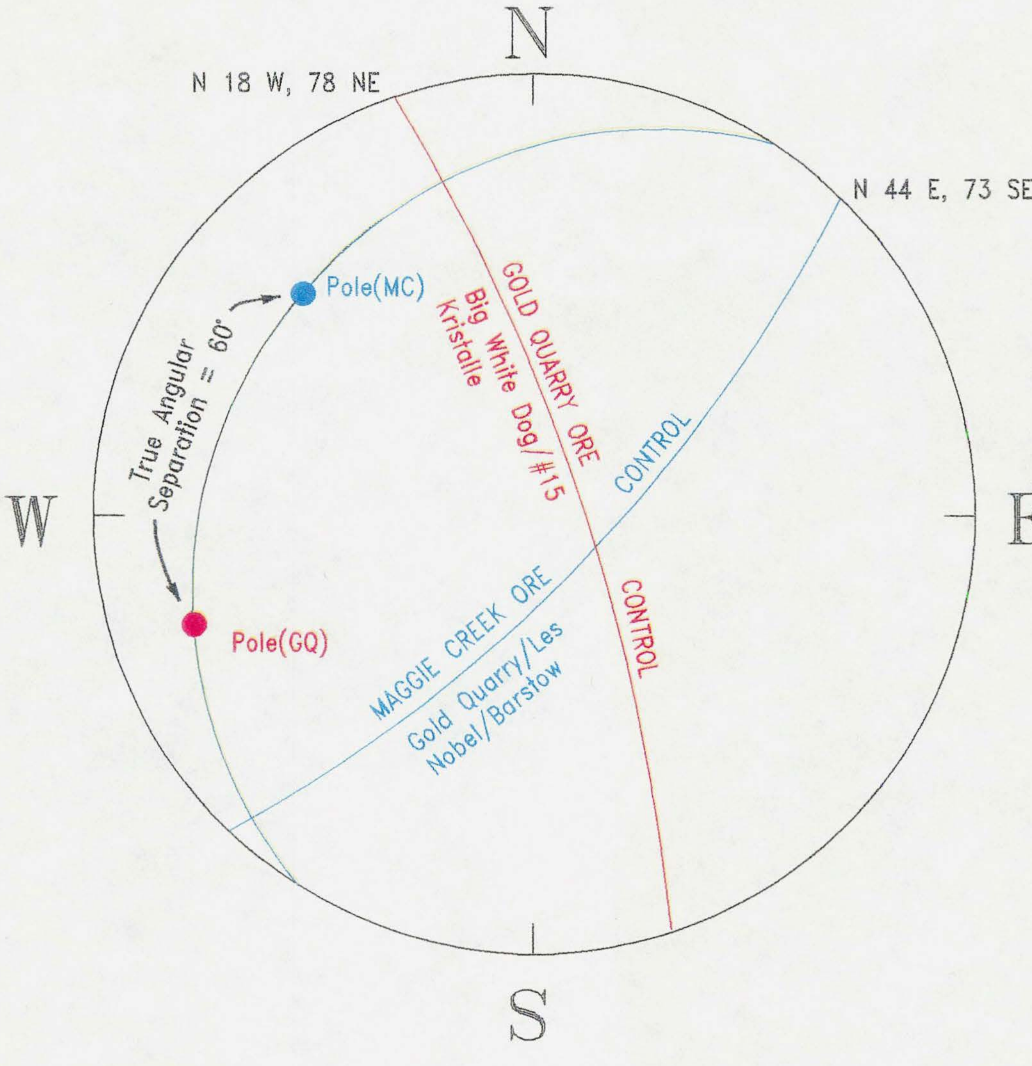


Figure 18. – Dominant fault directions for Gold Quarry Main and Maggie Creek showing true angular separation of 60 degrees.

Gold Quarry / Maggie Creek Dominant Ore Controlling Faults Stereonet Projection

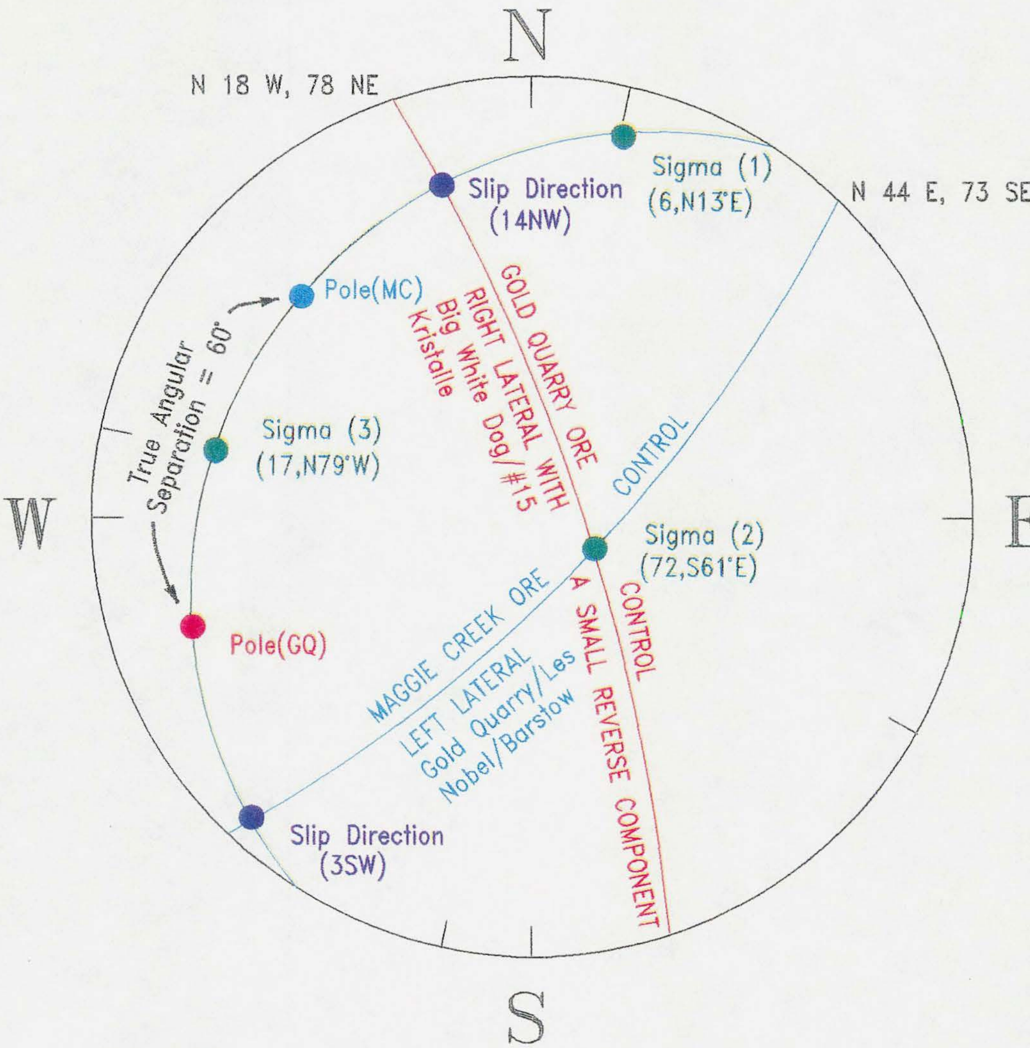
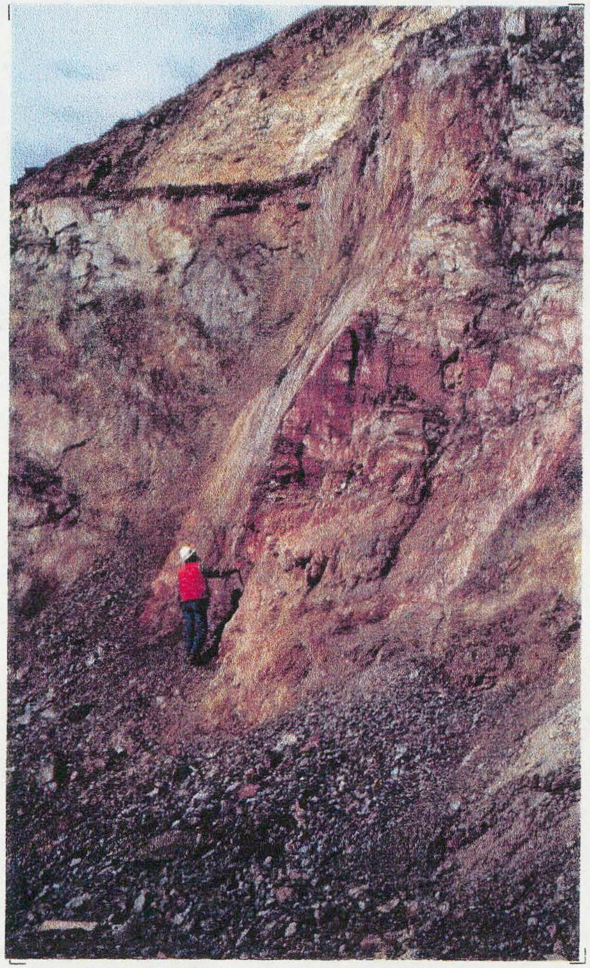


Figure 19. - Apparent conjugate fault set showing indicated paleo-stress-field and predicted slip directions. Note the shallow rake of the predicted slip directions.

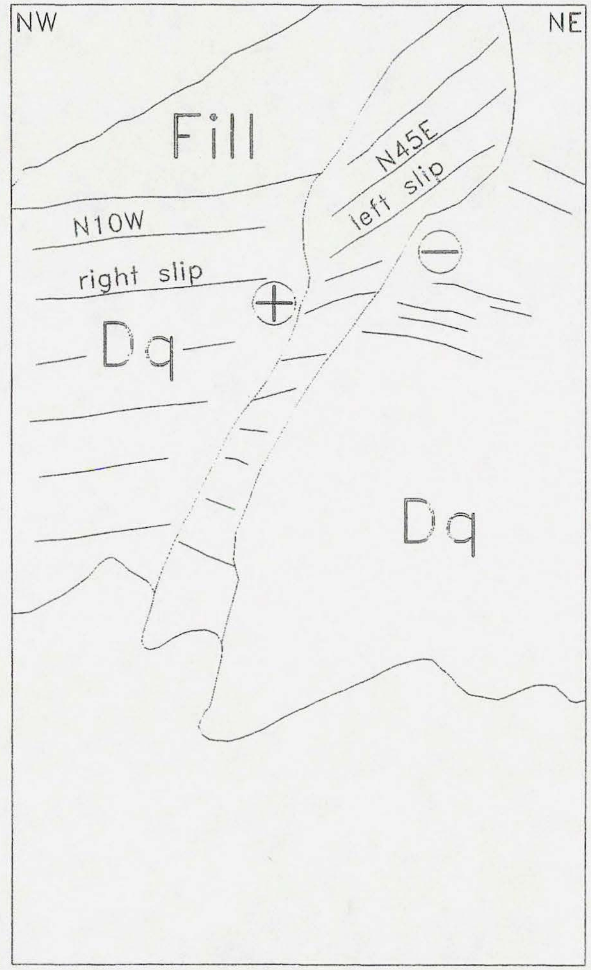
The term fault mullion here is in reference to fault lineations that are large grooves in the fault plane as described by Davis (1984). For clarification, Spencer (1977), in his discussion of mullions states:

"Terms such as slickensides grooves have been applied to "parallel striated and grooved prisms suggesting logs of wood", and the elongate forms seen on fault planes are well known. Such structures have almost certainly formed by movements parallel to the grooves."

Figures 20, 21 and 22 show the large fault mullions commonly seen raking horizontally on the Gold Quarry fault splays (e.g. Noble fault). The fault mullions are up to 30 feet in amplitude and have been traced for several 100's of feet across several mining faces in both the Maggie Creek and Gold Quarry pits (Rota, J. C. and Ekburg, C., personal communication, 1991). The most spectacular of those mullions, exposed during this study, was located on the 5125 bench on the Noble fault (Fig. 22). Horizontal slickensides, as shown in Figure 23, have been measured on the Kristalle fault system and other north-northwest high angle faults. Dip-roll-over fabric (Stone 1969), forming shallow raking fault mullions coincident and parallel to the measured horizontal slickensides have also been noted on north-northwest faults (Fig. 24 and 25). Dip-roll-over fabric and shallow raking mullions are typical of strike-slip faults (Sylvester 1988; Wilcox et al. 1973; Stone 1969). A preponderance of late stage, generally dip-slip slickensides, commonly cutting hypogene clays are ubiquitous throughout the Gold Quarry mine. Figure 12 illustrates in stereographic view, the measured faults with slickenside data collected. A predominance of steep rakes on presumed normal faults is recognized. However, a small population of older shallow raking lineations is also



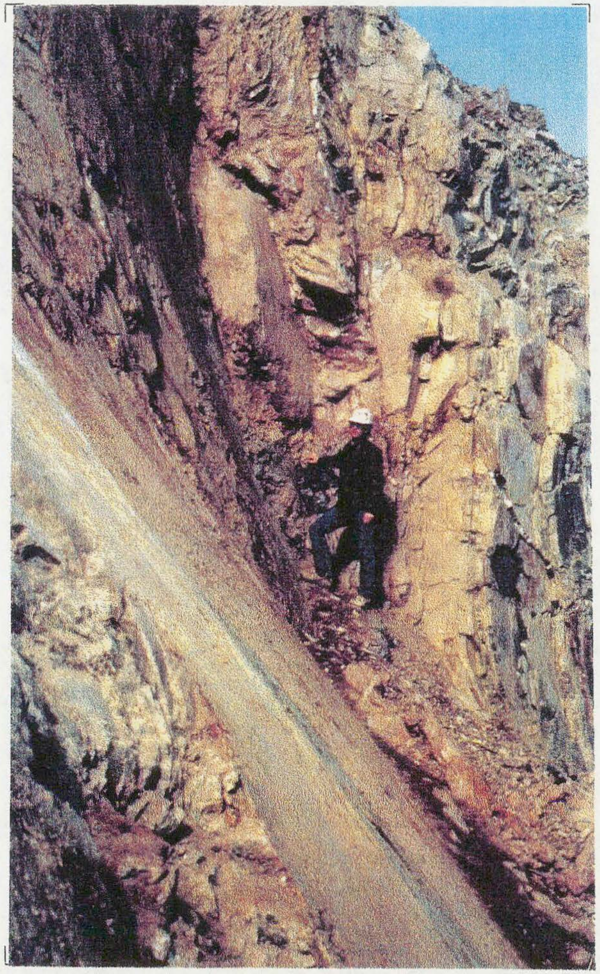
A.



B.

Fig. 20. A. Photograph of a triangluar failure on the 5125 bench formed at the intersection of two unnamed faults representative of the conjugate fault pattern recognized thoughout the deposit.

B. Sketch of the photograph illustrating the interpreted slip direction on the conjugate fault systems. Note the dip roll-over forming a shallow raking mullion on the N45E fault.

A.


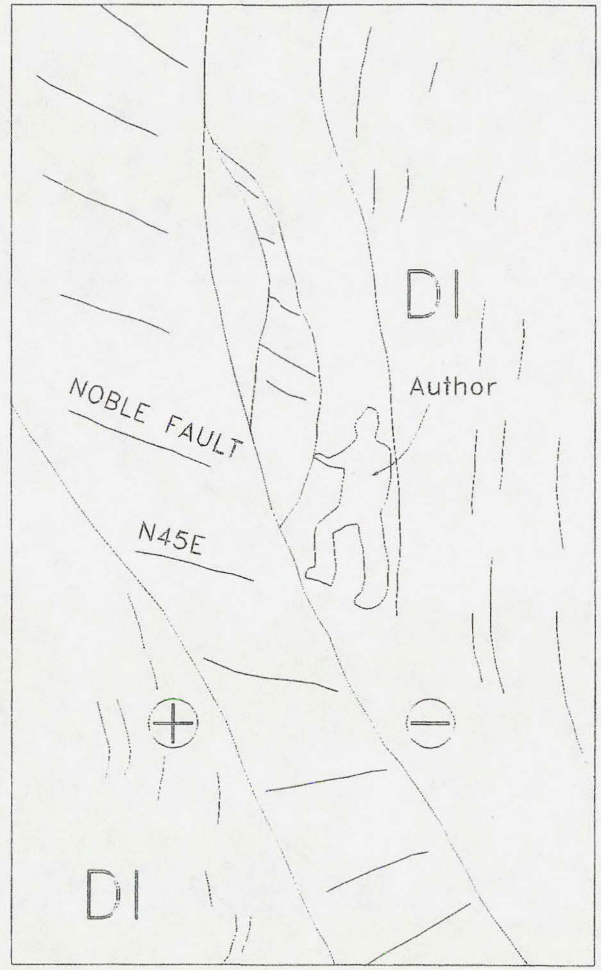
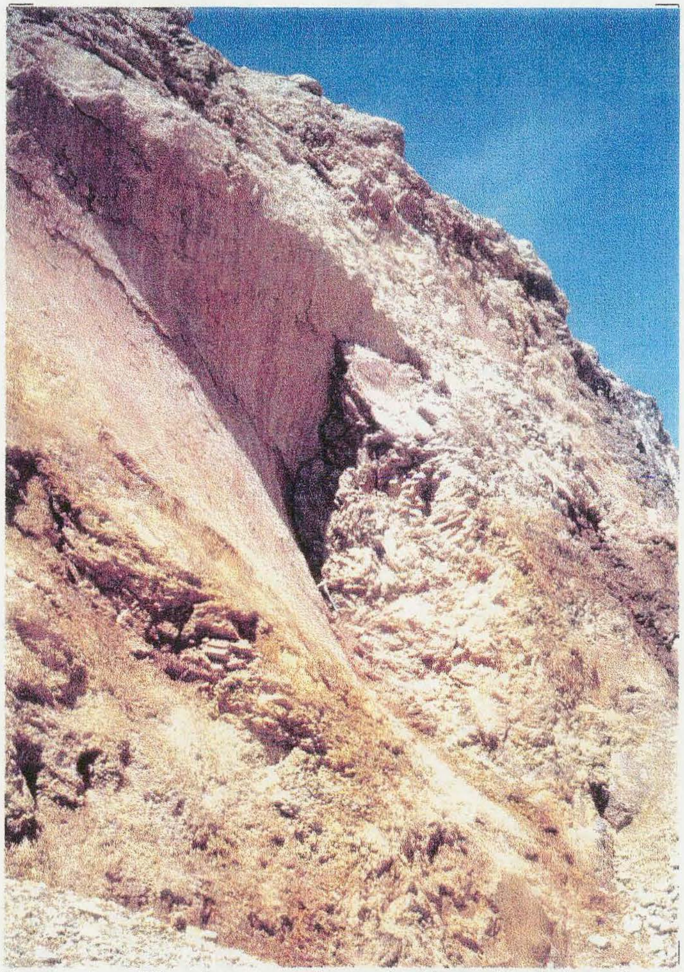
B.


Fig. 21. A. Photograph of the Noble fault on the 5500 bench.

B. Sketch of the photograph showing the Noble fault and the interpreted slip direction (left lateral).

A.


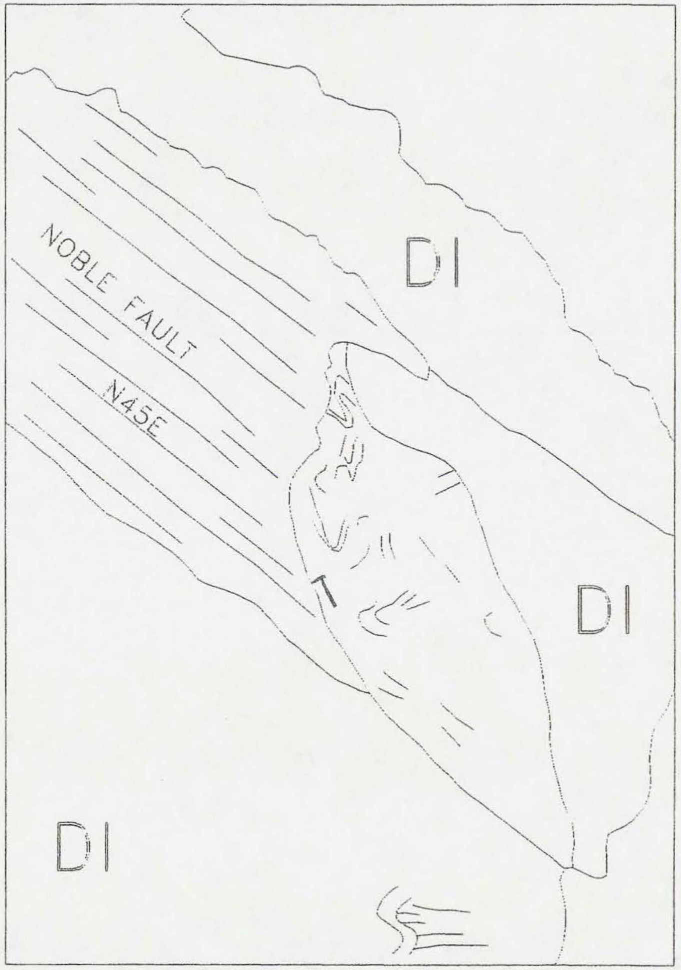
B.


Fig. 22. A. Photograph of the Noble fault on the 5125 bench cutting variably decarbonatized and argillized Devonian Limestone. Note the large fault mullion raking subhorizontally on the fault plane.
B. Sketch of photograph. Note intense folding of the limestone beds with subhorizontal axial plunges subparallel to the fault strike.

A.

B.

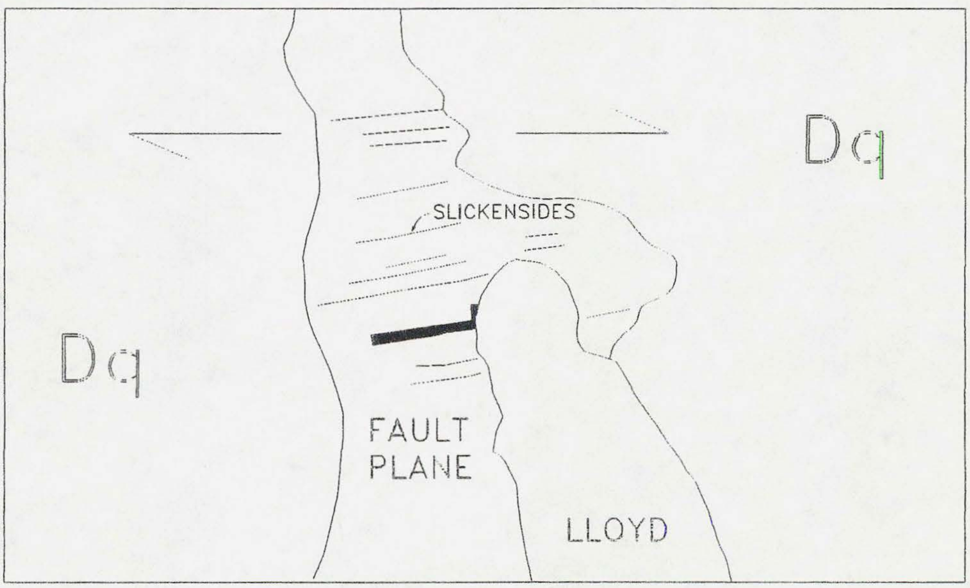
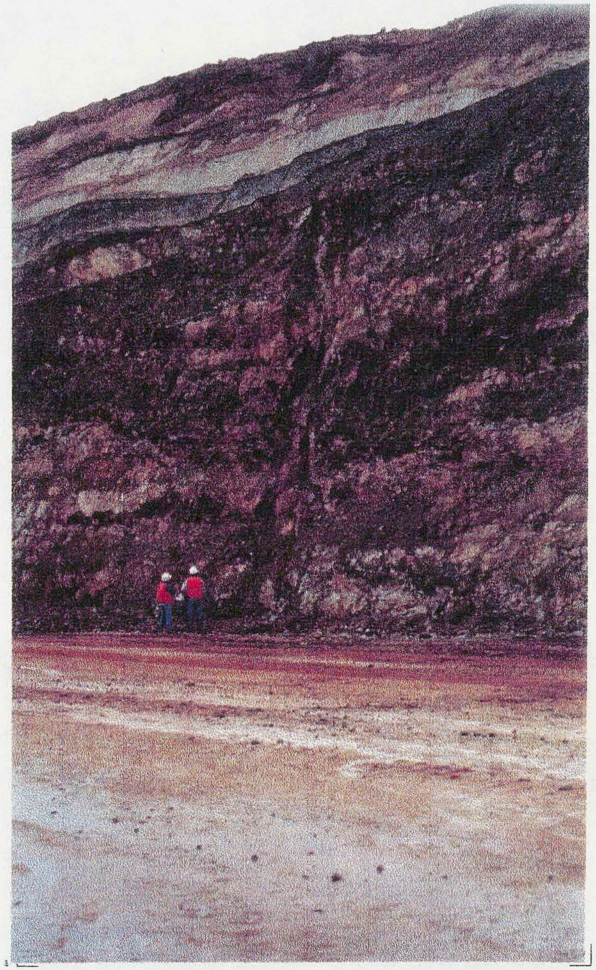


Fig. 23. A. Photograph of Kristalle fault exposure on the 5225 bench.

B. Sketch of photograph showing well preserved shallow raking slickensides and interpreted right lateral displacement.

A. 

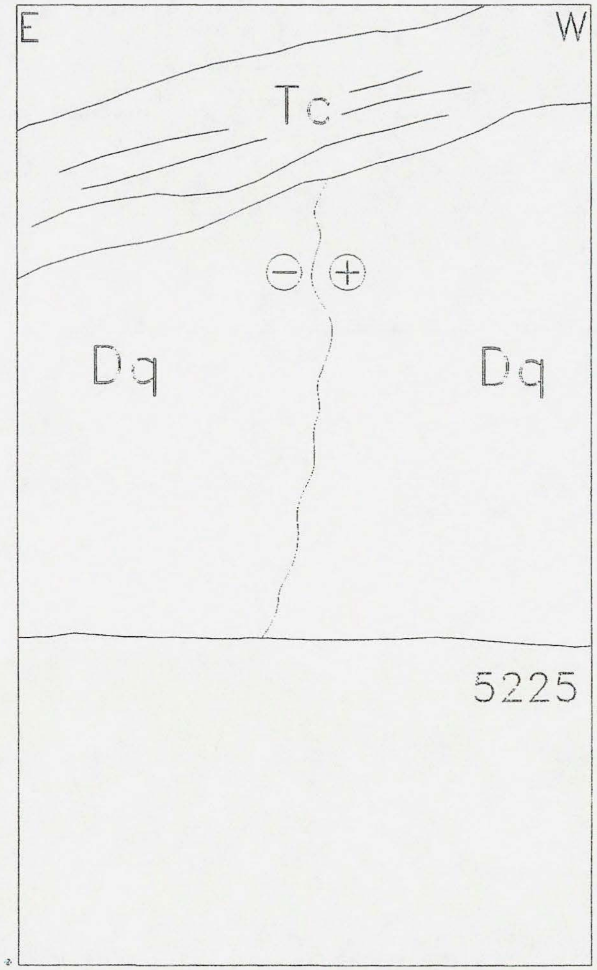
B. 

Fig. 24. A. Photograph of the Kristalle fault on the 5225 bench looking south. B. Sketch of photograph.
Note the down-dip anastomosing pattern of the fault created by dip-roll-over. The concave/convex pattern rakes shallowly on the fault and is interpreted as fault mullions. Right lateral motion is interpreted for this fault.

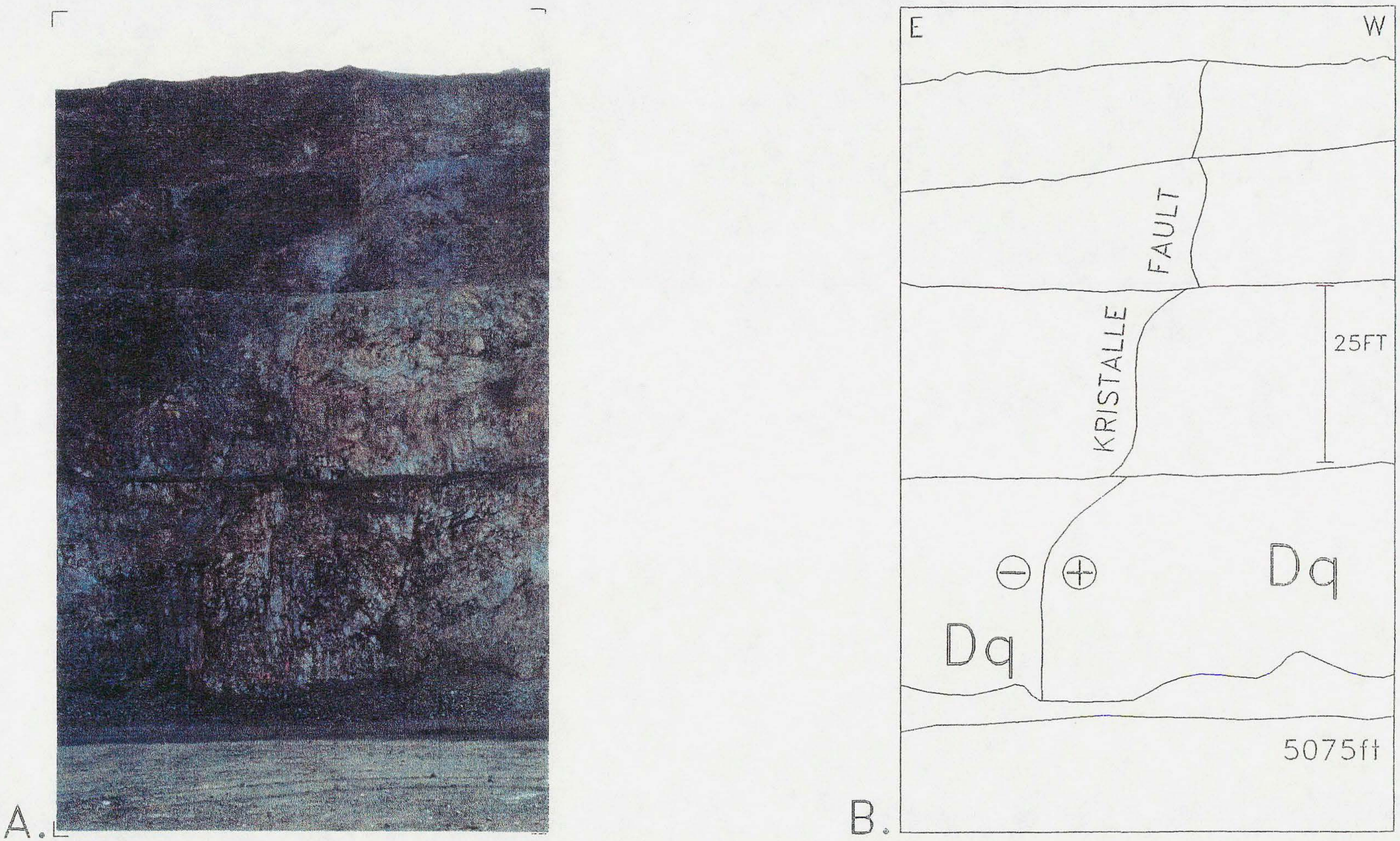


Fig. 25. A. Photograph of the Kristalle fault on the 5075 bench

B. Sketch of the photograph illustrating the dip-roll-over, and anastomosing down-dip fabric typical of the Kristalle fault and other N10 to 20W faults. Interpreted relative movement (right lateral) is shown.

present. The data set of older, shallow raking fault mullions and slickensides collected is presented in Figure 26.

In summary, shallow-raking fault mullions or grooves and slickensides measured along the N 0° to 20° W (360° to 340°) faults (Hangfire, Kristalle, Big White Dog) and the N 40° E (040°) Gold Quarry fault system are consistent with the predicted orientation for lateral-slip direction given conjugate formation (Fig. 27), strongly suggesting a wrench tectonic environment. Thus, it is proposed that the ore controlling Gold Quarry faults and the north-northwest faults are conjugate left and right lateral faults, respectively.

Carlin Window Trap Door Structural Model:

Recognition of the role of wrench faults as ore-controlling structures at Gold Quarry does not, by itself, explain the location of the deposit along the Good Hope fault. The Good Hope fault is recognized as one of the important mineral controlling structures on the Carlin Trend, and to date, the most important structure in the Maggie Creek subdistrict (Fig. 3). The Good Hope fault strikes N40° to 50°W (320° to 310°) and dips 40° to 50° NE into the Carlin Window and forms the southwest edge of the uplifted carbonate block (Fig. 28 and 29) (Arkell and Cole, 1992; Evans 1974). The Good Hope fault is thus, an apparent reverse fault with approximately 800 to 1500 feet of reverse-stratigraphic-separation represented northwest of the Gold Quarry deposit, along the southwest edge of the window. Lower portions of the Silurian Roberts Mountains Formation are exposed in the hanging-wall of the Good Hope fault, juxtaposed against the Ordovician and Devonian siliceous (ODs) rocks in the footwall (Fig. 28 and 29). Although segmented by later faulting, the Good Hope fault can be traced southeast across

Gold Quarry Summary Plot of
Low Angle Slickenside and
Mullion Data
Stereonet Projection

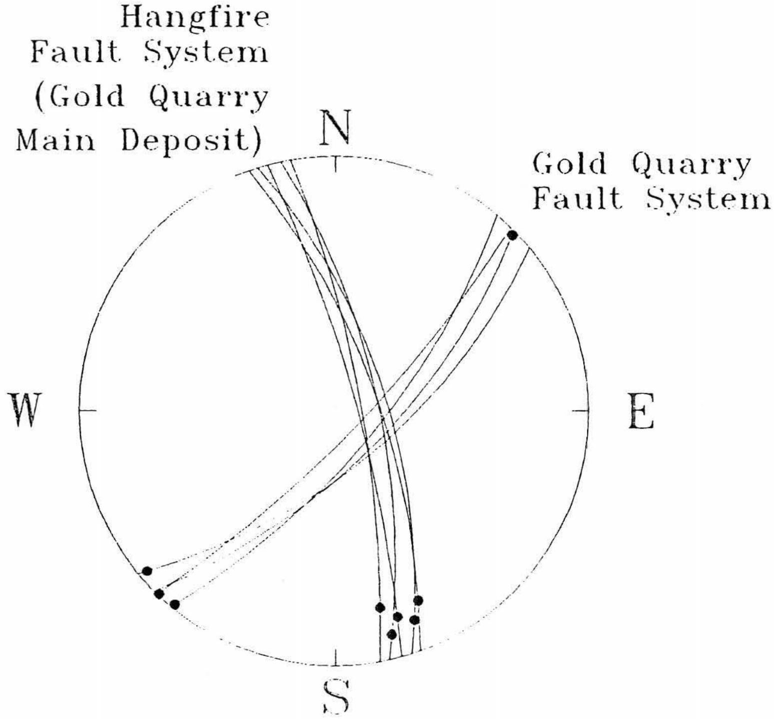


Figure 26. – Measured slip direction rakes on dominant ore-controlling faults.
Data collected by author in 1992.

Gold Quarry / Maggie Creek Dominant Ore Controlling Faults Stereonet Projection

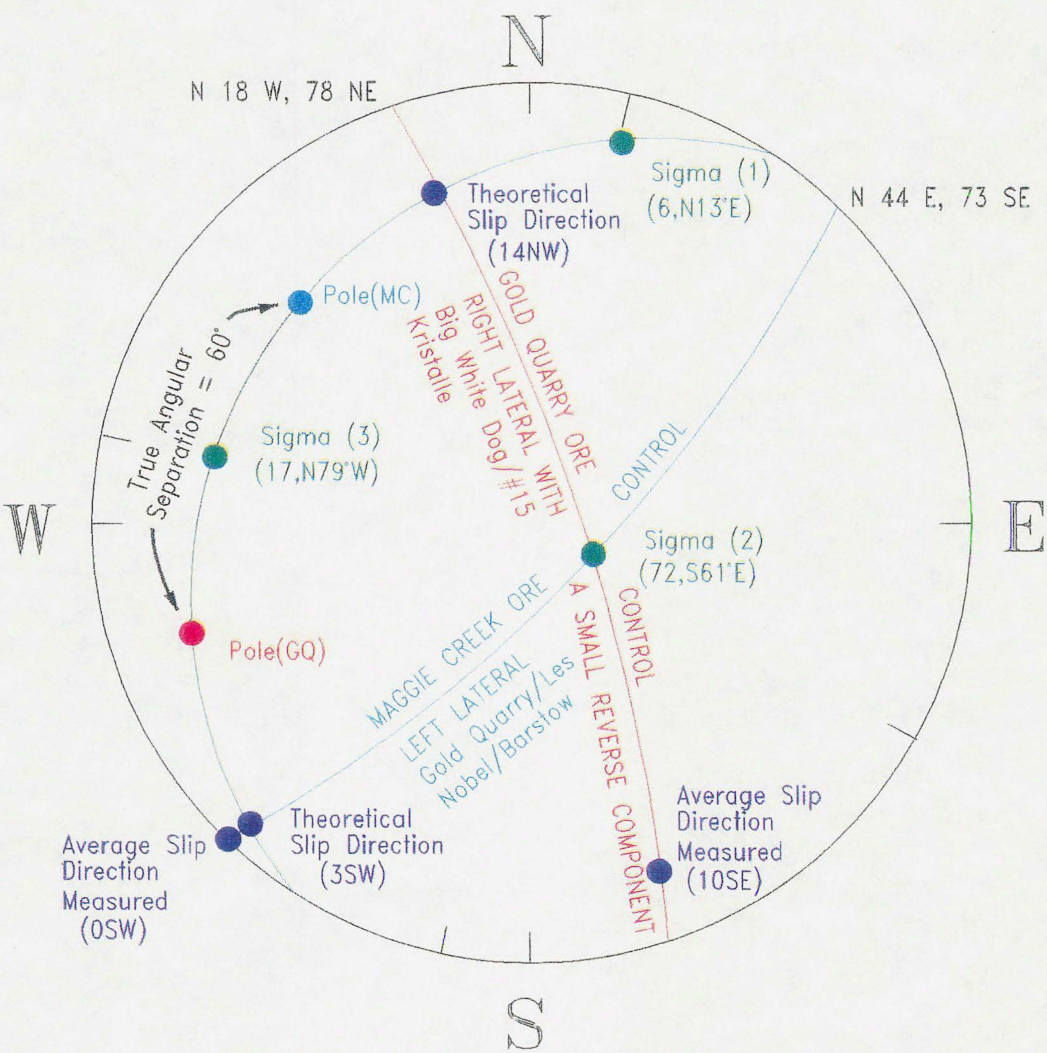


Figure 27. - Conjugate ore forming structures of Gold Quarry showing theoretical and actual measured slip direction rakes.

A.

B.

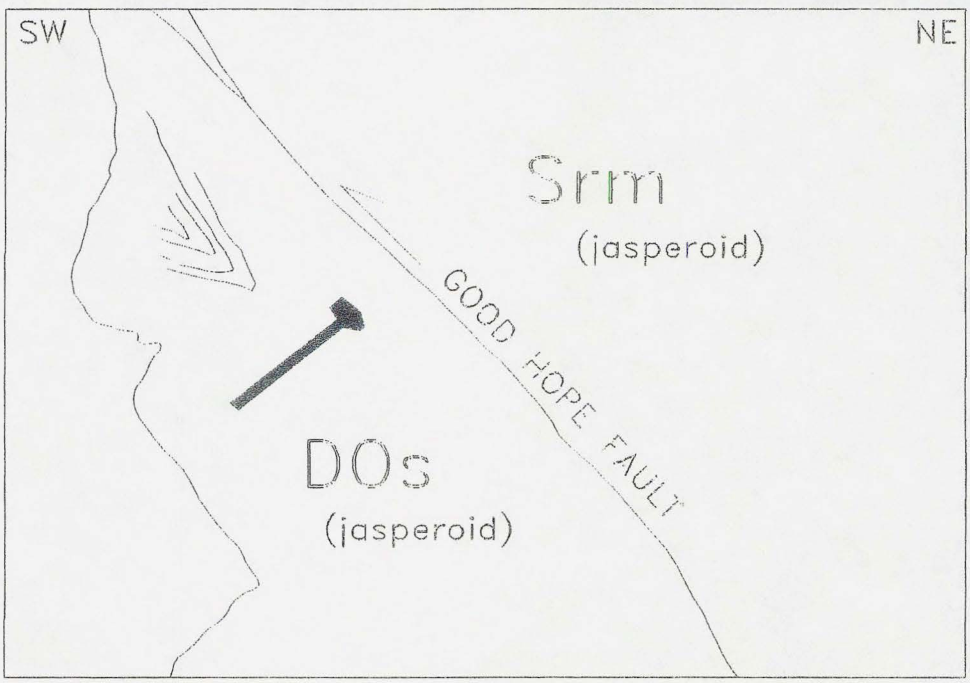
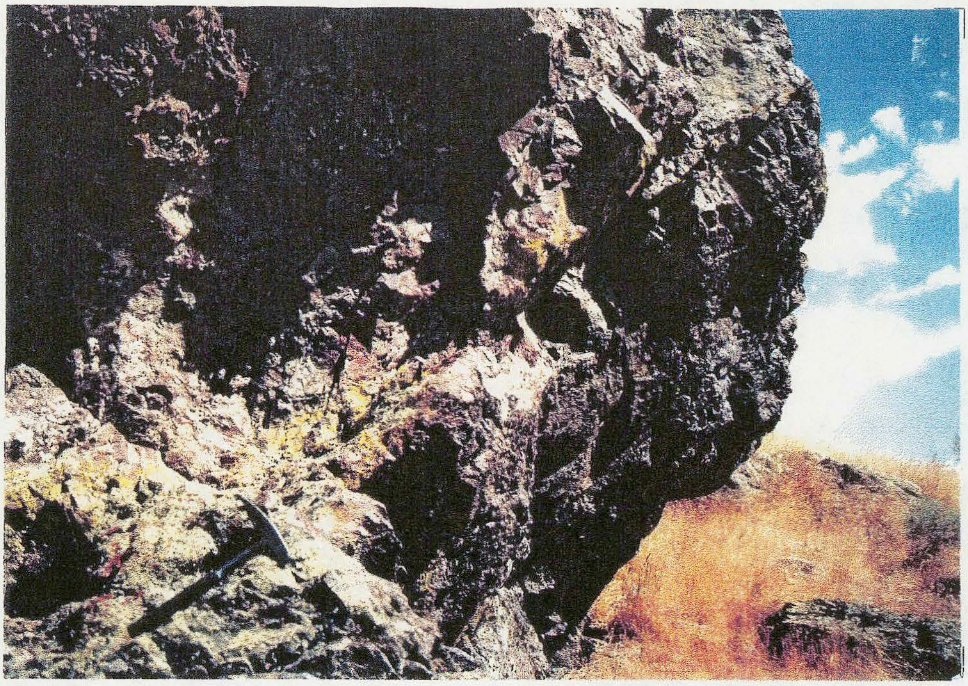


Fig. 28. A. Photograph of the Good Hope jasperoid outcrop approximately 2400 ft. northwest of the Gold Quarry pit. Drill road for the Tusc deposit is visible in the background along strike of the Good Hope fault.

B. Sketch of the Good Hope fault plane illustrating the protolithologies of the jasperoid and apparent reverse movement of the Good Hope fault. Note the tight fold in the footwall siliceous rocks.

A.



B.

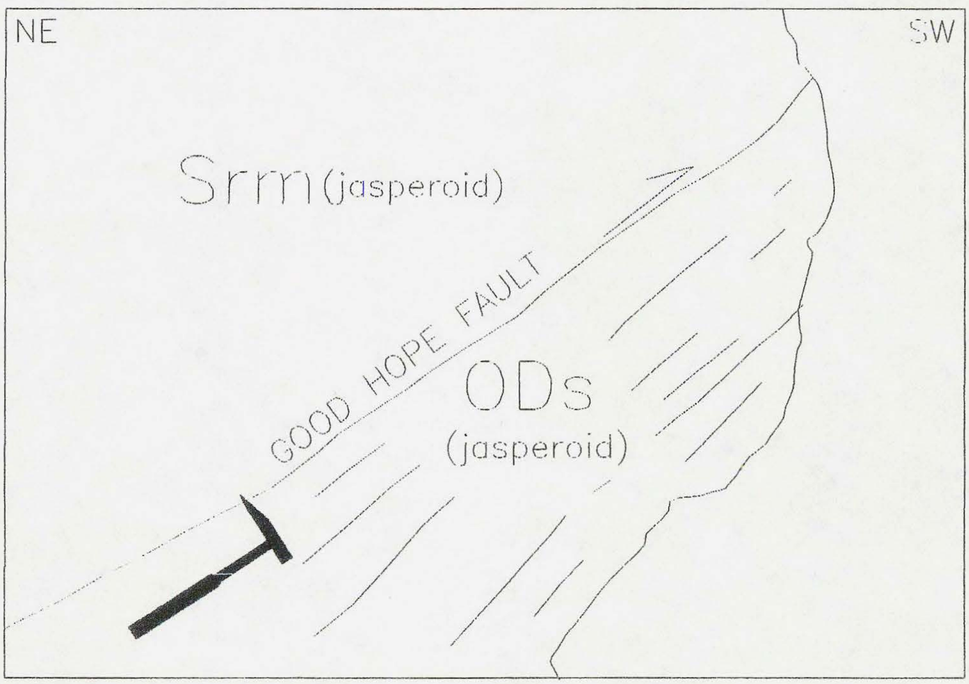


Fig. 29. A. Photograph of the Good Hope jasperoid outcrop approximately 2000 ft. northwest of the Gold Quarry pit.

B. Sketch of the Good Hope fault plane illustrating the protolithologies of the jasperoid and the apparent reverse movement of the Good Hope fault.

the Gold Quarry fault where the reverse-stratigraphic-separation determined from drilling, decreases to approximately, a nominal 100 feet (Rota, personal communication, 1992). Based on the observation that apparent size and throw on the Good Hope fault decrease significantly to the southeast across the Gold Quarry fault, and that the Gold Quarry and Good Hope faults both bound the uplifted carbonate block of the Carlin window, it is interpreted that left lateral movement along the Gold Quarry fault is partially accommodated by simultaneous reverse movement along the Good Hope fault and doming of the carbonate rocks, forming the Carlin window uplift. The Carlin Window model is adapted from a model presented by Stone (1969) termed a "trap door structure" (Fig. 30). Stone (1969) hypothesized that trap door structures are common in wrench fault terrains and form excellent oil reservoirs. It is proposed that the Carlin window uplift is a trap door structure formed as a result of a wrench tectonic environment with a north-northeast directed maximum principal stress direction (σ_1). The resultant fracturing at the southern "corner stone" of the Carlin window uplift (i.e. the intersection of the Gold Quarry and Good Hope faults) provided excellent fluid conduits for later ore solutions. Figure 31 illustrates a structural model for the Gold Quarry area showing the Gold Quarry left lateral shear, the Carlin Window anticline uplifted along the Good Hope reverse fault and the conjugate right lateral, north-northwest faults. Note that the Gold Quarry deposit was formed at the complex zone of intersection at the cornerstone of the Carlin window trap door structure.

Other hypotheses for formation of the Carlin window include the commonly held idea that the window is normal fault bounded and related to extensional tectonics. Recognition of the Good Hope fault dip direction (45° NE), dipping into the Carlin window (Arkell and Cole, 1992) and, therefore an apparent reverse fault, discards this

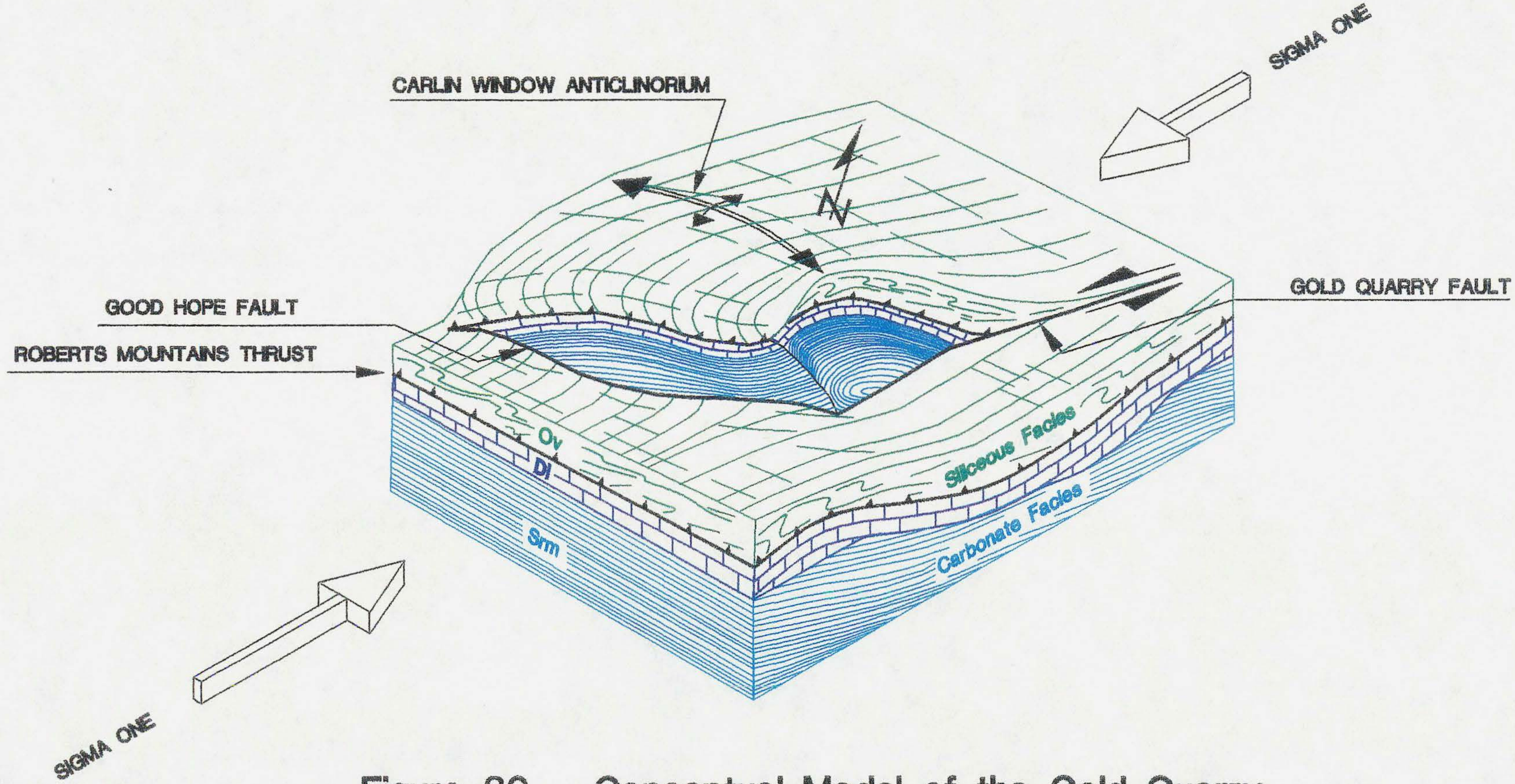


Figure 30. - Conceptual Model of the Gold Quarry "Trapdoor" Structure, after the "Trapdoor" model of Stone (1969).

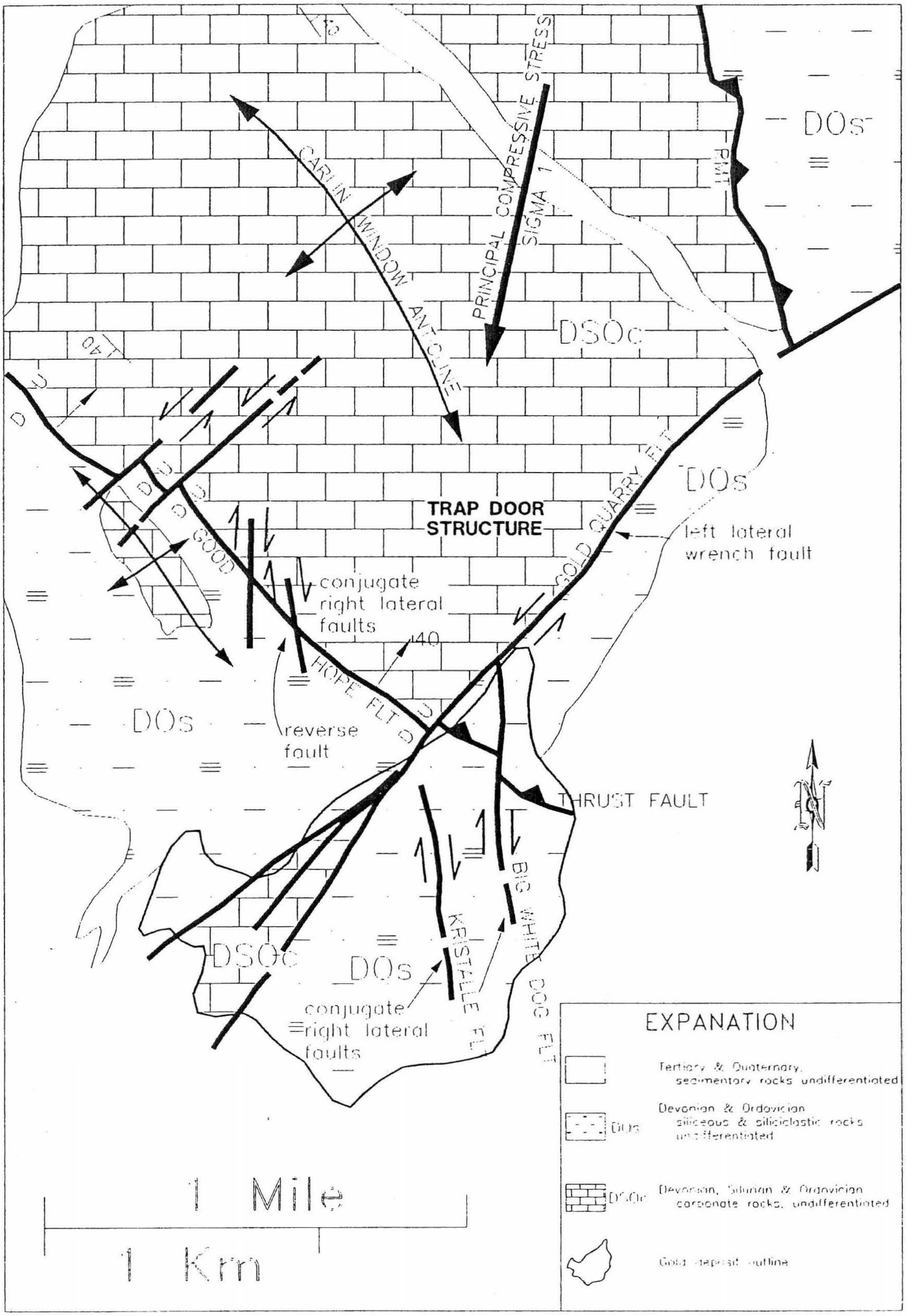


Fig. 31. INTERPRETED STRUCTURAL MODEL FOR GOLD QUARRY AREA

possibility. An additional idea put forth by Putnam and McFarlane (1990); Putnam (1986); and Wilson and Kufeld (1990) calls for the Good Hope fault to be a "positive flower structure" in response to dextral shear movement along the Carlin trend. It was suggested that the Good Hope fault steepened with depth in a classic flower structure pattern. This is not in agreement with the detailed drill data base compiled by Arkell and Cole (1992) which shows the fault to maintain a constant dip of approximately 45° NE for at least 2000 feet down dip. Additionally, no strike-slip kinematic indicators have been noted along the excellent fault exposure despite an extensive search for such features by the author. An alternate hypothesis for the origin of the Carlin window is a large anticlinorium in the Roberts Mountains autochthon created by the compressional tectonics during the Antler orogeny. This is similar to the hypothesis put forth by Roberts (1960). This hypothesis clearly has merit, however, the Good Hope fault cuts the pre-existing thrust faults thought to be associated with the Antler orogeny. A model where a pre-existing antiformal fold in the autochthon is enhanced and uplifted further by a wrench related trap door structure may be worthy of consideration.

Deep Sulfide Feeder - Dilational-Jog Model:

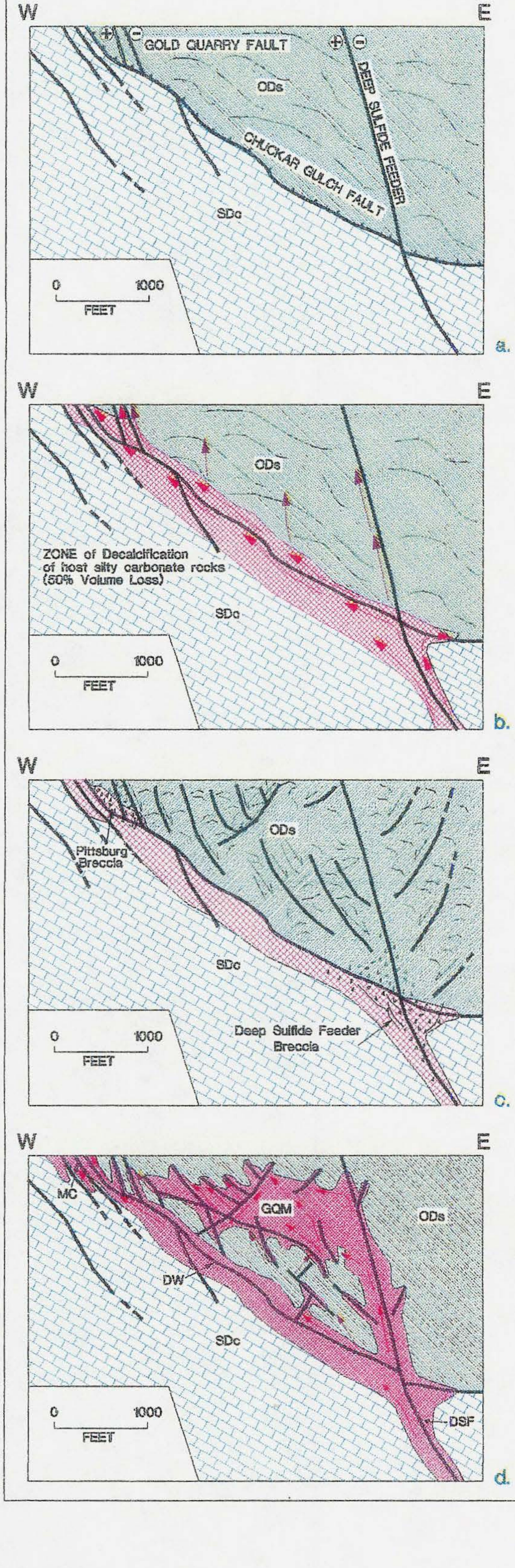
Drill data indicate the Deep Sulfide Feeder ore zone strikes north-northeast (Rota, J. C., written and personal communication, 1992), at an acute angle to the Gold Quarry fault. This orientation is coincident with extension indicated by stress directions hypothesized for development of the Gold Quarry left-lateral fault (parallel to the north-northeast directed maximum principal stress direction σ_1). Similar examples of extensional zones generated in wrench environments have been noted in other mineral systems (Sibson, 1987). It is proposed that the Deep Sulfide feeder structure was formed as a dilational jog, within a strike-slip fault environment. This trans-tensional setting may have created an excellent ore-fluid conduit for the Gold Quarry system.

Formational Collapse Due to Decarbonatization of Host Rocks:

An important structural event with respect to the development of the Gold Quarry Main zone is the volume loss and resultant collapse of the system caused by the extensive decarbonatization of lower host carbonate sediments during hydrothermal alteration. Romberger (1992), in his petrographic study of the alteration assemblages at Gold Quarry documented decalcification and dedolomitization, collectively referred to as decarbonatization, of silty-carbonate rocks in the footwall of the Chukar Gulch fault and decarbonatization of protolith calcareous siltstones in the hanging-wall of the Chukar Gulch fault within and peripheral to the Deep west ore zone. Rota (personal communication, 1990) indicates that the extent of completely decarbonatized limey rocks along the Deep West ore zone averages 200 feet in stratigraphic thickness. Bakken (1990) documented up to 60% volume loss of ore-host silty carbonate rocks at the Carlin deposit and concluded 50% volume loss for the decarbonatized silty limestones at the Carlin mine. A similar amount of volume loss would be expected for the decarbonatized silty carbonate rocks in the Deep West zone. Based on the thickness of the decarbonatized zone indicated at Deep West it is reasonable to interpret a minimum volume loss that would account for approximately 200 feet of stratigraphic thinning based on Bakken's (1990) conclusions. Volume loss accommodation is theorized to account for a large degree of fracturing and faulting noted in the Gold Quarry Main deposit. It is proposed that early decarbonatizing ore fluids rose along the Deep Sulfide Feeder and the Chukar Gulch faults causing significant volume loss. Volume loss is interpreted to have created an extensive normal faulting and fracturing event superimposed on the already structurally broken zone. Collapse driven by volume loss, in addition to the preexisting fracturing, rendered the otherwise poor host rocks of the siliciclastic sequence amenable to fracture controlled ore fluid penetration. Figure 32 illustrates the sequential effects of this process in the development of the Gold Quarry deposit.

Intense and pervasive fracturing in the Gold Quarry Main ore zone has been mapped by local mine geologists and during this study. Collapse features evident in the Gold Quarry pit are manifest as multiple block rotations, pervasive dip-slip oriented slickensides, listric fractures and discontinuous small scale faults. These faults are represented by the girdle of steep dips shown in Figure 13a and 13b. The general "shot gun" pattern of the bedding data and the wide distribution of generally high angle faults and fractures shown in Figure 13b and the wide distribution of high angle fault and fracture data shown in Figure 13a are interpreted to be representative of the effects related to dissolution and collapse of the rocks during decarbonatization. An example of volume loss causing formation collapse breccias is shown in figure 33, from the allochthonous limestone wedge in the upper portions of the Gold Quarry main deposit. Williams (1992) described this breccia occurrence as a fragment supported, monolithic collapse breccia with fragments composed of decarbonatized silty limestone.

Diagrammatic East-West Sequential Cross Sections of Gold Quarry Showing Effects of Decarbonatization and Associated Volume Loss Accomodation



Pre-Hydrothermal Development

ODs - Ordovician and Devonian siliceous and siliciclastic rocks undifferentiated

SDc - Silurian Devonian limestone undifferentiated

Decarbonatization and Incipient Volume Loss

Hydrothermal Solution Pathways

Decarbonatization of silty carbonate rocks along the deep sulfide feeder and Chukar Gulch faults.

Collapse Due to Volume Loss Accomodation

Normal fault formation and reactivation of preexisting faults, fractures and bedding planes. in response to approximately 200 feet of stratigraphic thinning.

Gold Deposition Along Permeable Fluid Conduits

Deposits:

GQM - Gold Quarry Main
MC - Maggie Creek
DW - Deep West
DSF - Deep Sulfide Feeder

Ore Solution pathways

Figure 32.

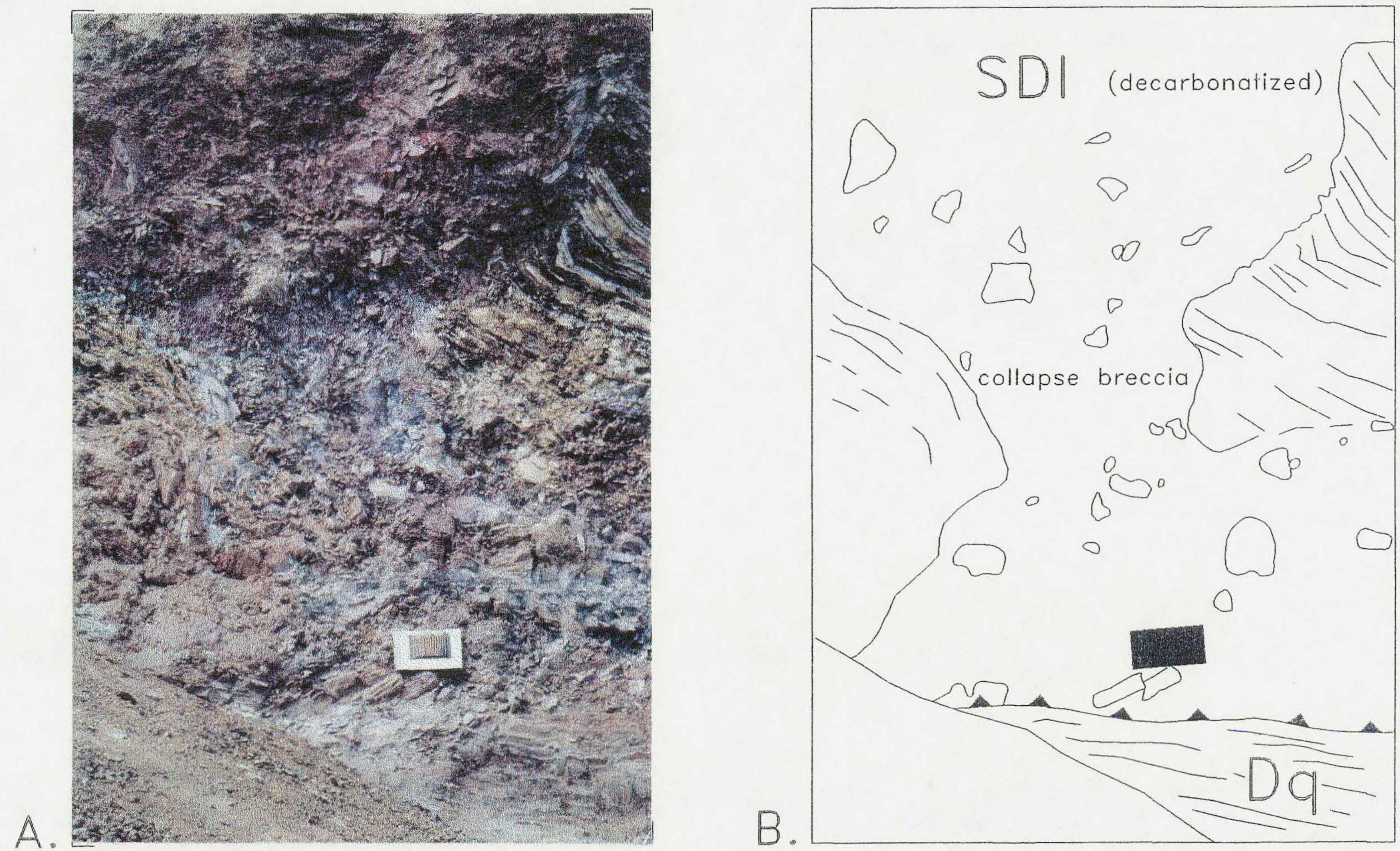


Fig. 33. A. Photograph of collape breccia on old road above 5175 bench within the "allochthonous limestone wedge"

B. Sketch of photograph illustrating the basal thrust contact of the "allochonous limestone wedge" and the collapse breccia within the decarbonatized hanging-wall limestone, interpreted to be decarbonatization volume loss collapse.

Extensional Tectonics:

Significant extensional-driven, normal faulting of the surrounding region occurred during development of the Basin and Range orogeny. Normal faulting is the youngest and most prevalent style of faulting evident in the region. Common north to northeast striking range-bounding normal faults, present throughout the Great Basin, were generated by an east-northeast/west-southwest extensional direction. Extensional tectonism resulted in the reactivation of pre-existing structures as normal faults. Northeast fault sets such as the Gold Quarry fault system are commonly noted as having recurrent normal movement. In addition, development of new normal faults (eg. Challenger and Grey faults) is noted.

Normal Fault Reactivation and Development:

Normal fault reactivation of pre-existing structures can be seen as steeply raking (dominantly dip-slip) slickensides superimposed on older shallow raking mullions and grooves. Cross-cutting kinematic indicators have been noted on structures of various attitudes at Gold Quarry, but are most prevalent along the northeast-striking Gold Quarry fault-system. As would be expected in a west-northwest/east-southeast extensional setting, pre-existing north to northeast striking, high angle faults would be easily reactivated as normal faults. In the case of Gold Quarry, the Gold Quarry fault system exhibits significant normal offset including post- jasperoid development normal movement, and post-Tertiary Carlin Formation (Tc) (post-ore sediments) normal movement.

The Chukar Gulch fault likewise has undergone normal fault reactivation, as would be expected given its northeast strike and moderate southeast dip orientation. The

Gold Quarry faults splay into and follow the Chukar Gulch fault; thus it can be assumed that normal movement along the Gold Quarry fault is accommodated along the Chukar Gulch fault.

Normal faults that cut the post-ore (Tc) are also noted. Figure 34 shows the Grey fault which cuts (Tc). Reverse drag, typical of listric normal faults, is recognized along the Grey fault.

Slumping:

Recent land slides and slumping have occurred in the (Tc). The poorly consolidated, tuffaceous sediments of the (Tc) are clay rich and prone to landslide failure, presenting continued problems in mining of the underlying Paleozoic rocks.

Summary and Paragenesis:

A structural model for Gold Quarry area has been developed based on an integration of detailed mapping conducted as a part of this study (Plates 1 and 2), and extensive internal Newmont Exploration Limited mine geology, and structural and ore-control data for the Maggie Creek subdistrict. A structural paragenesis, based on cross-curring relations of mapped faults, folds and kinematic indicators is proposed. The structural paragenetic sequence diagram is presented in Figure 35.

Four main stages of faulting are noted at Gold Quarry:

1) compressional-driven thrusting and related folding;

2) wrench driven strike-slip, reverse and dilational faulting;

A.

B.

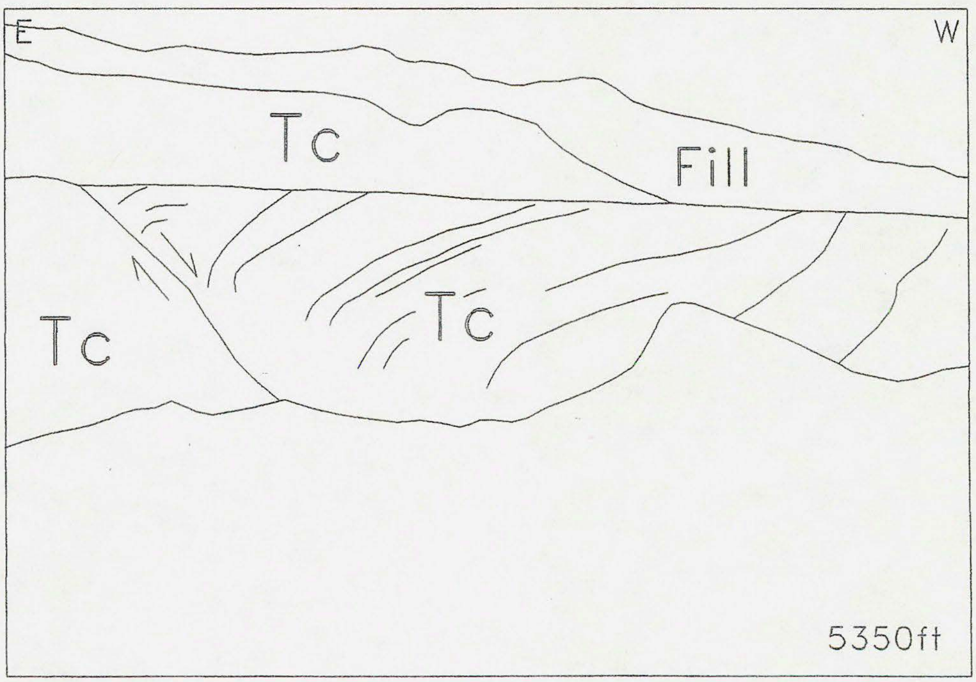
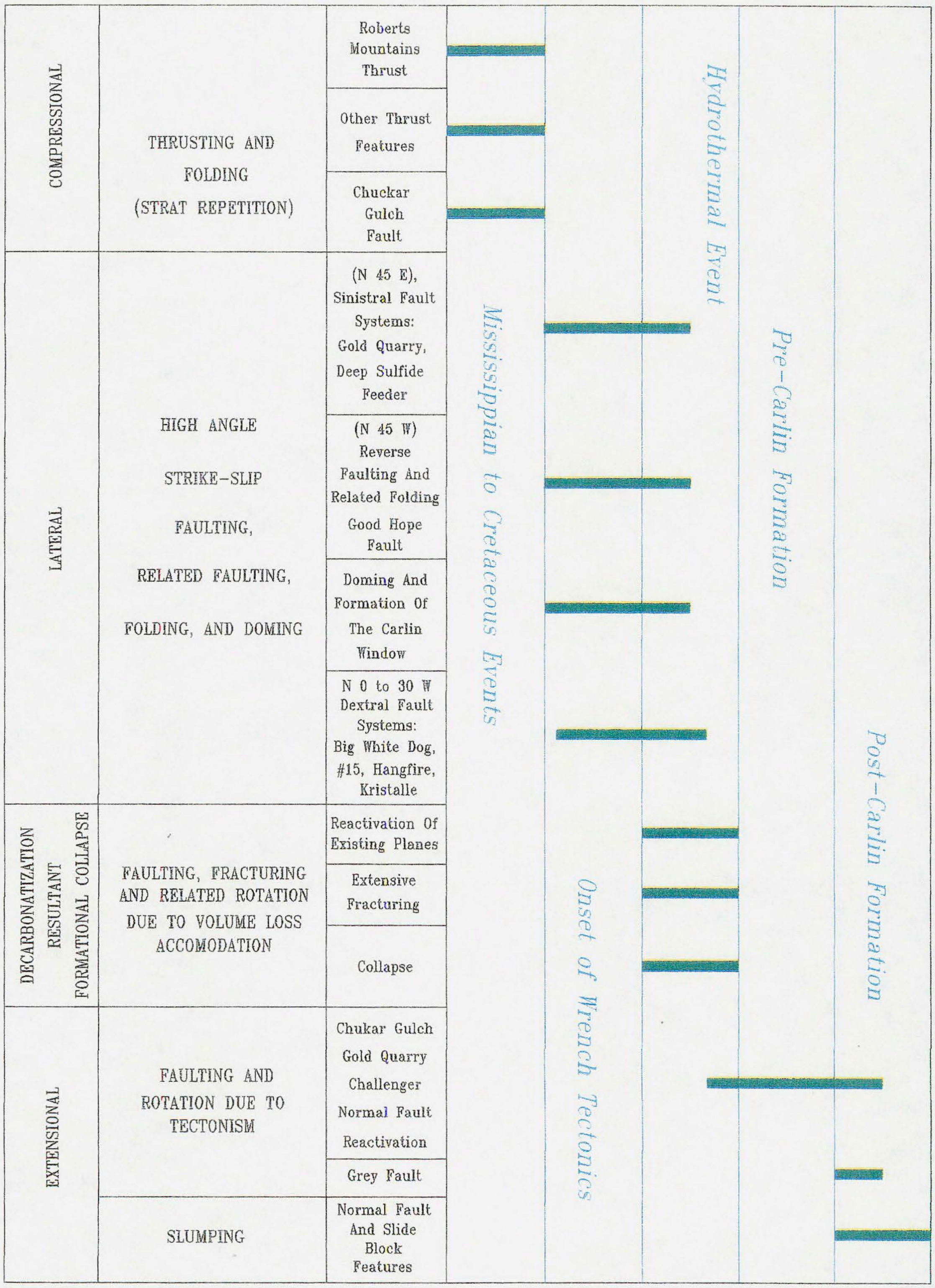


Fig. 34. A. Photograph of the Grey fault within the post-ore Tertiary Carlin Formation.

B. Sketch of photograph. Note the reverse drag on this late stage post-ore normal fault.

Figure 35.- GOLD QUARRY - STRUCTURAL PARAGENETIC SEQUENCE DIAGRAM



3) formational collapse due to decarbonatization of host-rocks and associated normal faulting; and

4) extensional tectonics resulting in normal faulting.

Thrust faulting and related folding is the oldest structural event noted in the Gold Quarry area. Thrusts are cut by high angle faults district wide. Clearly, the initial wrench tectonic event predated gold mineralization, as the wrench structures control gold distribution at the deposit and outcrop scale. At smaller scales, wrench or wrench-related structures, such as the Good Hope fault, and the Carlin window trap door structure, are interpreted to control location of deposits in the Maggie Creek subdistrict. Unfortunately, the age of mineralization at Gold Quarry and along the Carlin Trend is not certain. Generally, two groups of ages are most frequently referenced: Cretaceous (Arehart et al., 1993; Drews, 1993) and mid-Tertiary (Rota, 1991). Dating of the mineral event at Gold Quarry has been attempted by Heitt (1992). Determinations from alunite K/Ar dating yielded a range from 27.4 to 28.0 Ma (Heitt, 1992). Although the relationship of alunite to gold mineralization is not known, it is presumed to be younger (Heitt, 1992). Clearly the alunite is younger than the initial wrench faulting event, placing an upper date on the development of the wrench faulting. The lower age limit is constrained by the fact that wrench related structures cut or fold both thrust faults and the sedimentary rocks. The age of thrusting is not fully agreed upon either, and is only constrained on the lower end by the age of the sediments they cut, the youngest of which is Mississippian Kinderhookian (Plate 2, Appendix 1) (Hutter, 1990). Thrusting is recognized as lower Mississippian (Antler Orogeny) by many workers, but Mesozoic thrusting is recognized in the region. However, it is the interpretation of the author that the wrench event is early to mid Tertiary in age, related to the shift in the tectonic setting of western North America from a compressive subduction plate boundary to a transform plate boundary (Coney and Reynolds, 1977; Liviccari, 1979). As mineralization obviously post-dates wrenching, a mid-Tertiary age of deposit formation can be inferred. If, however, it was determined that wrenching in the region is older, perhaps Cretaceous, then this conclusion would be erroneous.

In summary, after thrust faulting, wrench faulting is interpreted as the next stage in the structural evolution of the Gold Quarry deposit. Wrench faults are interpreted to have formed by a north-northeast principal compressive stress direction. This wrench episode is interpreted to be responsible for development of the Carlin Window in response to a reverse fault termination of the Gold Quarry left-lateral shear. This model has been adapted from Stone's (1969) "trap door" structural model, with Gold Quarry located at the "corner stone" or structural intersection of the Good Hope reverse fault and the Gold Quarry left-lateral shear. In addition, N 10° W to N 20° W right-lateral faults of lesser magnitude formed in a conjugate manner to the Gold Quarry fault system.

Normal faulting is clearly post-ore in that it cuts (Tc) which is a post-ore rock. Normal fault movement was active during (Tc) deposition as evidenced by growth fault relationships of (Tc) stratigraphic units across splays of the Gold Quarry and Gray faults. Direct evidence for pre-ore (extensional-tectonics-driven) normal fault development is not known. However, the possibility of extensional faulting causing reactivation of the pre-existing wrench faults, aiding in ground preparation and thus fluid flow and hydrothermal system development is appealing.

REGIONAL IMPLICATIONS

Gold Quarry mine exposures have provided an opportunity to study the structurally complex history of the area. The structural model proposed is consistent with models proposed for other deposits along the Carlin Trend (Putnam, 1986; Rota, 1986; Cole, 1989; Putnam and McFarlane, 1990; Smith, 1989; Wilson and Kufeld, 1990; Putnam and Henriques, 1991) which call for a period of wrench faulting in development of the ore-control structures. The alignment of gold deposits known as the Carlin Trend (Fig. 1) is coincident with the predicted orientation of a dextral wrench fault given the conjugate wrench faults interpreted at Gold Quarry, where the N10° to 20°W (350° to 340°) faults are synthetic right lateral, strike-slip faults, and the N45°E (045°) faults are antithetic left lateral strike-slip faults. These data are generally supportive of the hypotheses presented by Putnam and McFarlane (1990), Putnam and Henriques (1991), and Adams and Putnam (1992), where wrench fault tectonics are proposed for development of the Carlin Trend and other sediment-hosted gold deposit trends within the region. However, the models proposed by Putnam and McFarlane (1990); Wilson and Kufeld (1990) and Putnam (1986), which call for the Good Hope fault to be a dextral wrench fault are not supported by the data here presented. Livaccari (1979) proposed a Cenozoic structural evolution model, where the Basin and Range province is hypothesized to be part of a large dextral shear zone extending eastward from the San Andreas transform fault. Evidence from the Ruby Mountain-East Humboldt range metamorphic core complex shows a ubiquitous stretching lineation within the Tertiary mylonitic rocks of west-northwest (Snoke and Miller, 1988), consistent with the σ_3 (extensional direction) indicated by the structures at Gold Quarry during the wrench faulting event. This relationship may be fortuitous but is worth noting. It would be expected that ductile strain indicators within these uplifted mid-crustal rocks be consistent with brittle strain indicators in the hanging wall of the low-angle detachment. Snoke and Miller (1988) clearly interpret an extensional setting for the formation of the stretching lineations, not a strike-slip tectonic environment. However, a model whereby the hanging wall of the low angle detachment is breaking into a series of wrench blocks driven by dextral shear during post-orogenic relaxation-driven extension should be considered. Kuehn (1989) suggests a low-grade metamorphic fluid source for the main-stage-gold-ore-solutions at the Carlin mine. Perhaps, deep-seated dextral wrench faults acted as fluid conduit for gold- bearing metamorphic fluids, resulting in the alignment of these deposits along dextral wrench fault systems.

SUMMARY

The Gold Quarry deposit was localized at a major structural intersection, flanking the uplifted "trap door" structural block of the Carlin Window. The structural evolution of the deposit conforms with the interpreted regional development of a dextral wrench zone along the Carlin Trend. Hypogene gold-bearing fluids migrating along the Deep Sulfide Feeder fault zone resulted in extensive decarbonatization and mineralization of ore-hosting, silty carbonate protoliths. Host rock volume loss accommodation (collapse induced normal faulting) caused further significant fracturing of the hanging-wall siliciclastic rocks, allowing enhanced ore fluid penetration and formation of the overlying Gold Quarry Main ore zone. The Maggie Creek ore-zone, an up-dip extension of the Deep West, formed as a structurally controlled deposit along splays of the Gold Quarry fault zone. Deep West, hosted by decarbonatized silty carbonate rocks and calcareous siliciclastic rocks, is strataform in geometry, localized along the bedding plane semi-conformable Chukar Gulch fault. The Deep Sulfide feeder zone is a high angle fault controlled, silty limestone-hosted ore zone, interpreted to have localized along a dilational-jog within the left-lateral Deep Sulfide Feeder Fault zone.

Clearly the role of structure in development of the Gold Quarry deposit is of primary importance. Faults and fractures have the greatest control in ore distribution for all deposit zones. Additionally, the overall stratigraphic position of the mineral system, with respect to the carbonate/siliciclastic contact can not be overlooked. The great majority of known gold deposits along the Carlin Trend are located within several hundred feet of this contact. The presence of amenable silty limestone lithologies of the upper portions of the Devonian and Silurian carbonate sequence would appear to be a major factor in the development of these deposits, even though significant ore is hosted by the hanging-wall siliciclastic rocks.

Reactive host rocks also play an important role at larger scales, due to primary and induced permeability characteristics. The amenability to decarbonatization, as seen at Deep West and the joint propagation and resultant fracture induced permeability of the Gold Quarry Main are examples of the interaction of receptive host rocks and structure in the overall genesis of the Gold Quarry deposit.

SUGGESTIONS FOR PROSPECTING

Sediment hosted disseminated gold deposits remain an attractive exploration target. An understanding of the structural and stratigraphic controls on mineralization is critically important in any exploration program, especially in development of conceptual deep and covered targets. The information presented in this study should be utilized by the explorationist to:

1. add to the geologic data base available for this deposit type;
2. extrapolate data and conclusions herein presented to aid in new exploration target development; and
3. extrapolate data and conclusions presented herein to existing (known) exploration target areas in order to develop greater insight as to their potential.

Specific suggestions for sediment hosted disseminated gold deposit prospecting, based on this study should include:

1. (System): Recognition of the effects of extensive volume-loss within the carbonate host lithologies during decarbonatization. These effects include extensive fracturing, faulting and collapse of hanging wall units and subsequent fluid migration, alteration and possible mineralization of these structurally prepared units above the carbonate hosts. Geochemical anomalies may be present and detectable in the hanging wall rocks due to the likely potential of anomalous fluids to circulate upward along the fractures and faults associated with collapse of the hanging wall rocks. Extensive fracturing and random orientations of bedding, joints and faults,

apart from regional and local orientations may be indicative of volume-loss-related collapse.

2. (Structure): An understanding of the types of structural settings that are favorable for ore formation is enhanced by recognition of the structural paragenesis and the role of the structures in ore formation.

It is not a new concept by any means but never-the-less, the importance of a major fault intersection in causing focused fluid flow can not be overstated. Major fault intersections, especially along the edges of uplifted blocks (e.g. tectonic windows), present attractive settings. Recognition of the role of wrench tectonics in the development of Gold Quarry may be of significant regional importance. The role of wrench tectonics in the development of the entire Carlin Trend may be likewise significant.

It is clear from this study that significant post-ore normal fault development has taken place at Gold Quarry. It is important to remain aware that reactivation is the rule, not the exception especially in areas of multiple deformational events. Potential ore-controlling structures may be expressed at the surface as reactivated faults cutting post ore rocks. In the Gold Quarry area and along the Carlin Trend, north to northeast striking faults would be expected to be more commonly reactivated as normal faults during the east-southeast/west-northwest directed extension.

3. (Host): Clearly the presence of amenable host lithologies is a critical factor in exploration targeting. The important conclusions presented here, worthy of consideration by the explorationist, are the recognition that the

siliceous host rocks of the Gold Quarry Main deposit would likely not have been a productive host if not for the fracturing induced permeability due to decarbonatization related volume-loss within silty carbonate rocks at depth. The vast majority of the known gold resources on the Carlin Trend have been located within several hundred feet of the carbonate/siliceous rock contact. This relationship exemplifies the importance of amenable stratigraphy in exploration targeting. Structure contouring of the carbonate/siliceous rock contact at regional and local scales has proved to be a powerful tool in exploration on the Carlin Trend.

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APPENDIX 1

GOLD QUARRY LITHOLOGIC AGE DATA

The following list of age data is a compilation of palynological data from the Gold Quarry/Maggie Creek mine areas. These data have been integrated with detailed geologic mapping to construct a representative tectono-stratigraphic section. All samples were collected by the author unless otherwise noted. All sample locations are expressed by bench (or elevation where bench number is not given in the sample number) and Gold Quarry mine coordinates. The abbreviation "ap" indicates that only an approximate sample coordinate location is known. A few samples collected by other workers, have unknown locations or geologic control and are not included in this data set. One sample collected by me on the south wall of the Gold Quarry pit is not included due to the fact that the GEO-POINT used to survey the sample location was mined away before the survey crew shot the point in.

All samples were analyzed by Terry Hutter of TH Geological Services utilizing palynological dating techniques. The age of the samples are expressed in decreasing order of certainty. For example: upper Devonian (Frasnian) ((upper Frasnian)) indicates the sample has been interpreted to be upper Devonian, probably Frasnian and possibly upper Frasnian.

GQ 5240-20

19492N 21788E — hanging wall of Chukar Gulch Thrust, highly folded ribbon chert and shale

upper Ordovician Caradoc (lower Angochittina capallata) ((Desmochitina lata))

GQ 5240-21

19522N 21635E siltstone — hanging wall of Chukar Gulch Thrust, interbedded quartzite and lesser chert

upper Ordovician Caradoc (lower Angochittina capallata) ((Desmochitina lata))

GQ 5175-23

19147N 21269E — ribbon chert and siltstone, immediate foot-wall of Good Hope Fault

upper Devonian (Famennian - Frasnian transition) ((basal Famennian))

GQ 5175-24

18970N 21187E — siltstone with minor black discontinuous chert lenses

upper Devonian Famennian (middle/upper Famennian, VU-GM spore zones) ((GM spore zone))

GQ 5125-25

17719N 22132E — laminated coarse siltstone

upper Devonian Famennian (middle/upper Famennian) ((GM#15 spore zone))

GQ 5325-26

16800N 21650E ap — thin bedded light gray siliceous silty-mudstone, 20ft below Tertiary contact

lower Mississippian (Kinderhook)

GQ 5280-27

19521N 21312E	footwall of Chukar Gulch Thrust, within the "allochthonous limestone wedge", thin bedded silty limestone, well folded
	middle Devonian (lower Givetian)

GQ 5125-31

19168N 21369E	black unoxidized ribbon chert, cherty siltstone and shale, well folded, immediate footwall of Good Hope Fault
	upper Devonian Famennian

GQ 5475-33

18991N 21369E parallel	micritic limestone with 1mm silty beds spaced 0.5cm with local sparitic beds (1mm), well folded into chevron folds trending to the Gold Quarry Fault system
	Devonian undifferentiated

GQ 5340-34

19105N 22225E	light gray planar laminated siliceous siltstone, hanging-wall of Chukar Gulch Thrust, 200 ft north of Tertiary contact, abundant visible graptolite siculae fragments noted along bedding planes
	(upper Ordovician Caradoc) ((Desmochitina lata sub-zone of the Angochitina capallata of the middle Caradoc))

GQ 5250-37

17660N 22400E	folded ribbon chert and shale in hanging wall of a low angle fault (thrust ?), see GQ 5250-38
	Devonian undifferentiated

GQ 5250-38

17660N 22400E	siltstone in footwall of low angle fault (thrust ?), see GQ 5250-37
	upper Devonian lower Famennian to upper Frasnian

GQ 5525-39

18030N 19230E — folded thin bedded silty limestone within Gold Quarry Fault system splays

middle to upper Devonian undifferentiated

GQ 5525-40

18100N 19240E — siliceous siltstone chert and cherty siltstone in thin beds, well folded, in hanging-wall of Noble Fault

upper Devonian (Famennian)

GQ 5300-50

16650N 21240E ap — siltstone, 20 ft below Tertiary contact

lower Mississippian Kinderhook (lower Kinderhook)

GQ 5300-51

16600N 21350E ap — siltstone, just below the Tertiary contact

lower Mississippian Kinderhook (lower Kinderhook)

GQ 5225-52

16700N 21360E — siltstone

lower Mississippian Kinderhook (lower Kinderhook)

GQ 5600-54

19200N 19650E ap — ribbon chert and variably calcareous siltstone

upper Devonian Frasnian (upper Frasnian)

GQ 5350-56

19250N 20420E — well folded ribbon chert exposed along Gold Quarry Fault zone juxtaposed against limestone (GQ 5350-57) in the footwall and siltstone (GQ 5350-58) in the hanging-wall

Devonian undifferentiated

GQ 5350-57

19250N 20320E — well folded limestone in the footwall of the Gold Quarry Fault, see GQ 5350-56

Devonian undifferentiated

GQ 5350-58

19250N 20580E — siliceous siltstone, hanging-wall of Gold Quarry Fault, see GQ 5350-56

upper Devonian Frasnian (upper Frasnian)

QRC-391 MC 1832ft elevation = 3620ft (Pat Dickerson)

16701N 21601E — Deep West

middle to lower Devonian (lower Devonian) ((upper section of the lower Devonian))

QRC-377 MC 1678ft elevation = 3542ft (Pat Dickerson)

17559N 22070E — silty limestone with calcite veins and fossil hash

Devonian (upper to middle Devonian) ((upper Devonian))

QRC-377 MC 1690ft elevation = 3530ft (Pat Dickerson)

17559N 22070E — Deep West, graphitic

Devonian undifferentiated

GQ-3 (DMC 4-90)	5600 bench (Pat Dickerson/Dave Cole)
19010N 19570E	well folded ribbon chert and shale, hanging-wall of the extensive low angle fault zone in the area (Chukar Gulch Thrust ?)
	Ordovician (upper Ordovician) ((middle Caradoc))
GQ-9	very approx elevation = 5600ft (Pat Dickerson)
20100N 20700E ap	upthrown side of Gold Quarry Fault, calcarenite of lower Roberts Mountains Formation
	Silurian (lower Silurian)
GQ-10	5280 bench (Pat Dickerson)
19500N 21350E ap Gulch	directly beneath the "Roberts Mountains Thrust" a.k.a. Chukar Thrust, within the allochthonous limestone wedge
	Silurian (lower Silurian Llandovery)
MC-2	very approx. elevation = 5360ft (Pat Dickerson)
21100N 22600E ap	Chukar Gulch, chert
	upper Ordovician (middle Caradoc)