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# Geology and Genesis of the Alligator Ridge Mine

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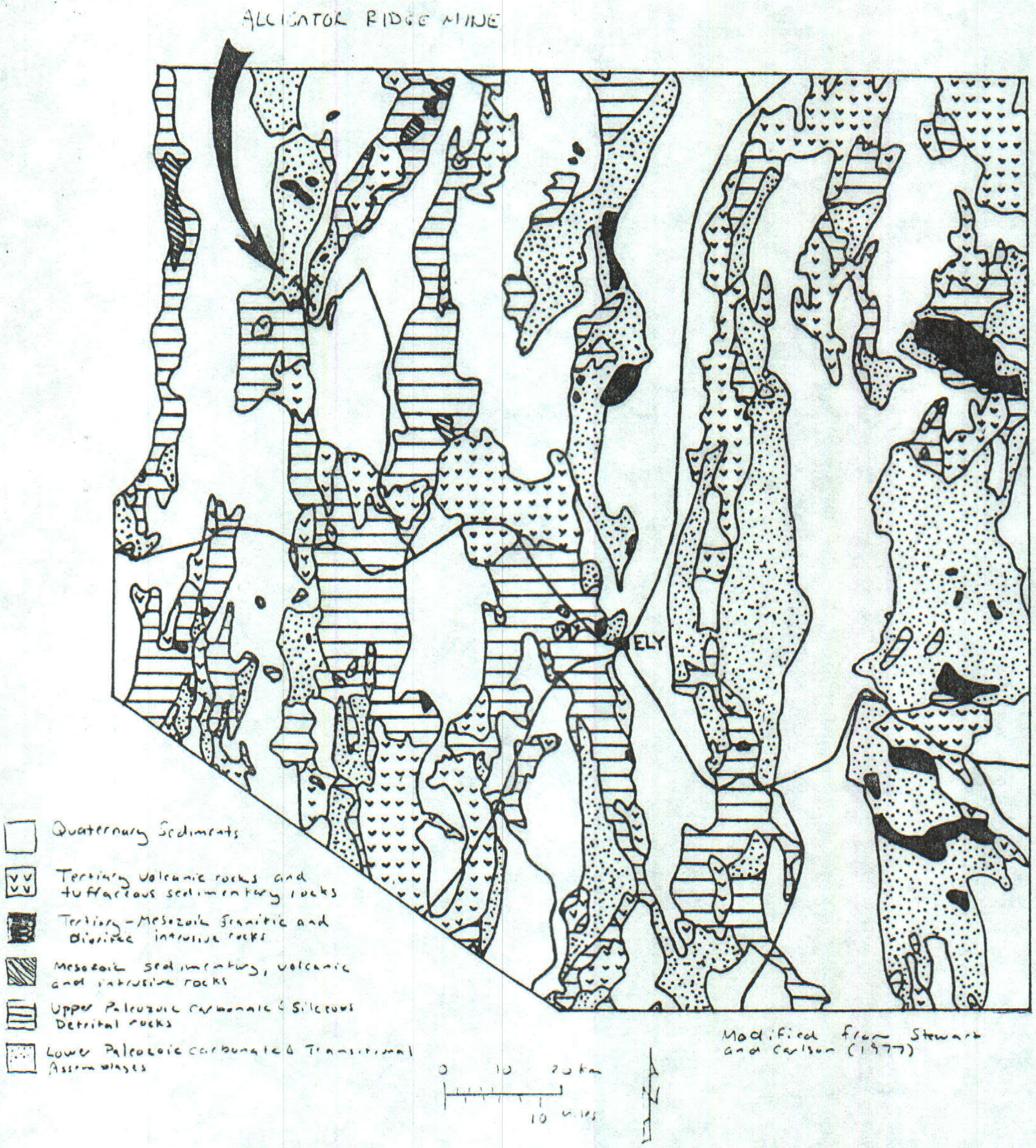
## Introduction

The Alligator Ridge mine is located in the northwest corner of White Pine County, Nevada, approximately 40 miles northwest of Ely, Nevada (Fig. 1). It is reached by 70 miles of paved highway. The mine is located in the Vantage Basin at the southern tip of the Maverick Springs Range and in the southern Ruby Mountains.

The disseminated gold deposits at Alligator Ridge are stratabound, being hosted in the lower Pilot shale, and localized by normal faults. The deposits in some ways resemble those at Carlin, but there are important differences. The Alligator Ridge deposits have a low Au-to-Ag ratio, have an alteration suite much more typical of hot-springs deposits, have a basal jasperoid zone underlying the productive mineral zone, and have abundant examples of hydrothermal breccias.

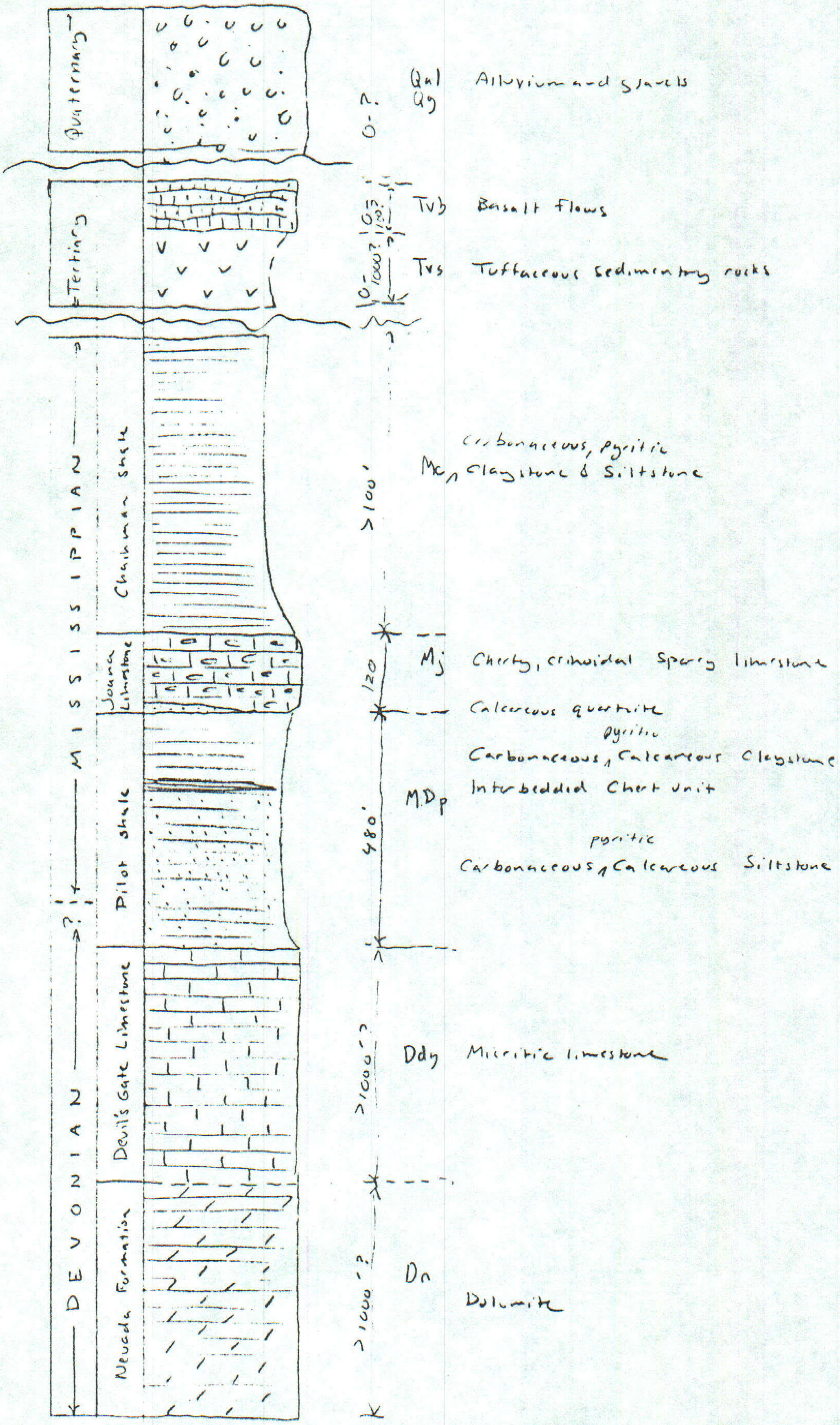
## Stratigraphy of the Vantage Basin

The stratigraphy of the Vantage Basin (Figure 2) played an important role in localizing alteration and mineralization. The main ore host is the Devonian-Mississippian Pilot shale. It typically is 480' thick in the Vantage Basin (Ilchik 1984) and, where unaltered, consists of a lower calcareous, carbonaceous siltstones totaling roughly 300' and grading upward into calcareous carbonaceous claystones totaling roughly 180': Other lithologies present include limestone lenses and a discontinuous zone of interbedded chert and limestone. The Pilot shale overlies a thick sequence of Devonian carbonates. The Devonian Nevada formation is exposed in Alligator Ridge to the east of Vantage Basin, but most exposures in the Vantage Basin are of the uppermost Devil's Gate limestone. Overlying the Pilot shale is the Joana limestone. A discontinuous calcareous quartzite may mark the contact between the Pilot shale and Joanna limestone. The Joana limestone is a sparry, crinoidal limestone with abundant chert nodules. The Joana limestone is overlain by the Chainman shale which is dominantly claystone and siltstone where exposed in the Vantage Basin. Unconformably overlying an erosional surface consisting of at least the Pilot shale, Joana limestone, and Chainman shale is at least 500' of Tertiary tuffaceous volcaniclastic sedimentary rocks. These, in turn, are overlain by Tertiary basalt flows.



Modified from Stewart and Carlson (1977)

Figure 1.


Quaternary
Tertiary
MISSISSIPPIAN
DEVONIAN
Chainman shale
Joana Limestone
Pilot shale
Devil's Gate Limestone
Nevada Formation
0-?
0-1000'?
0-50'?
>100'
120
480'
>1000'?
>1000'?
Qal Alluvium and gravels
Qg
Tvb Basalt flows
Tvs Tuffaceous sedimentary rocks
Mc Carbonaceous, pyritic Claystone & Siltstone
Mj Cherty, crinoidal Sparry limestone
Calcareous quartzite
Carbonaceous, pyritic Calcareous Claystone
Interbedded Chert unit
MDp
Carbonaceous, pyritic Calcareous Siltstone
Ddg Micritic limestone
Dn Dolomite

## Geology of the Vantage Basin

The geology of the Vantage Basin (Figure 3) is dominated by a large horst-block of Devonian Nevada and Devil's Gate limestone on the east side. The Basin itself forms from a gentle, south plunging anticline or antiform, which has been breached in the center to expose a core of Devil's Gate limestone, on the north side of the Vantage Basin, and Pilot shale. The Pilot shale dips under Joana limestone and Chainman shale on the west side of the Basin.

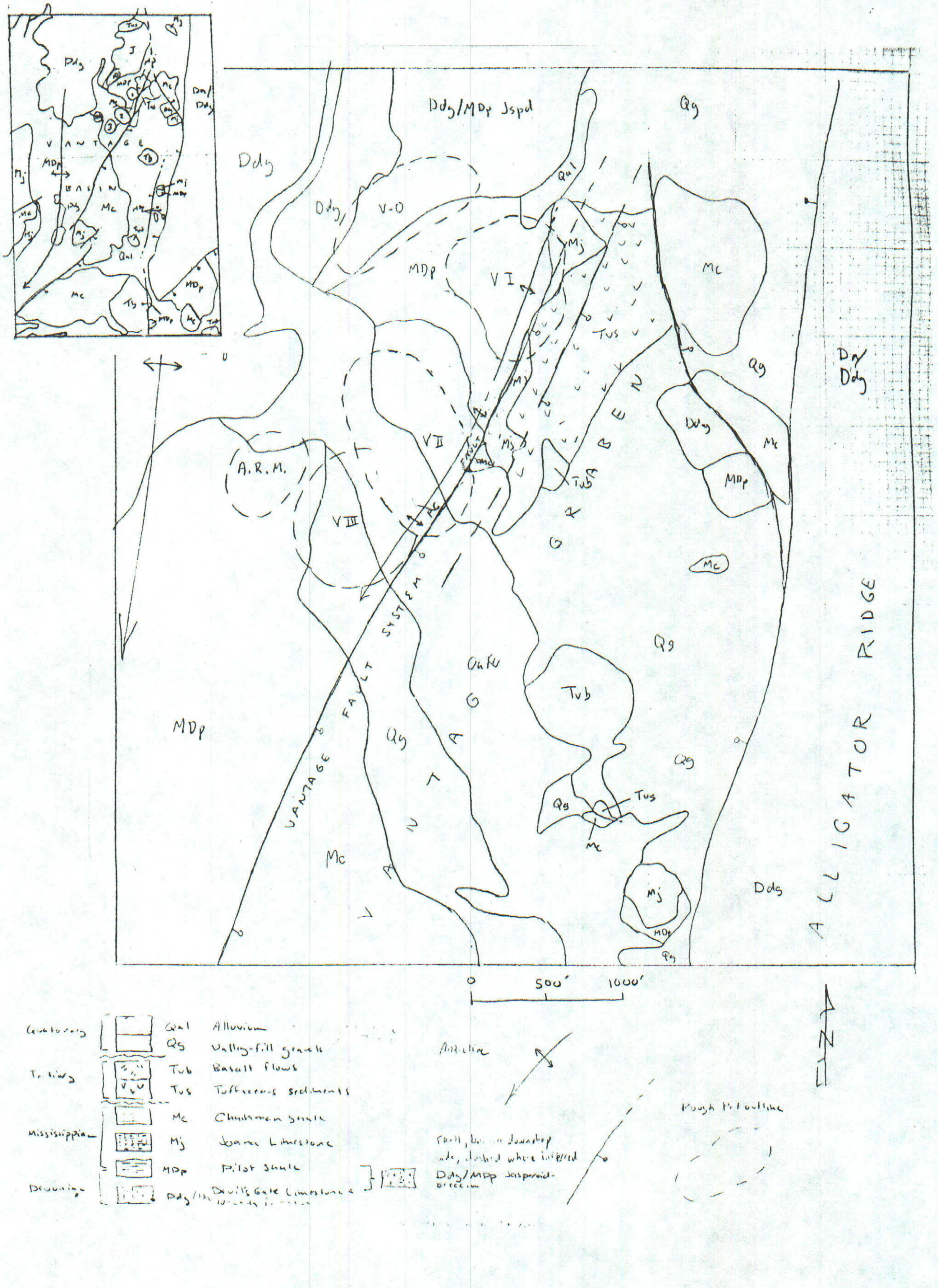
A large northeast trending graben, the "Vantage Graben", juxtaposes Chainman shale, on the downdropped side, against Pilot shale. The boundary fault system, "Vantage fault system", includes numerous strands and parallel faults, among which is the "PC" fault. The PC fault cuts through Vantage I and Vantage II (Fig. 4a). In Vantage I it moves upper Pilot shale against lower Pilot shale. In Vantage II it moves Chainman shale and Joana limestone against Pilot shale.

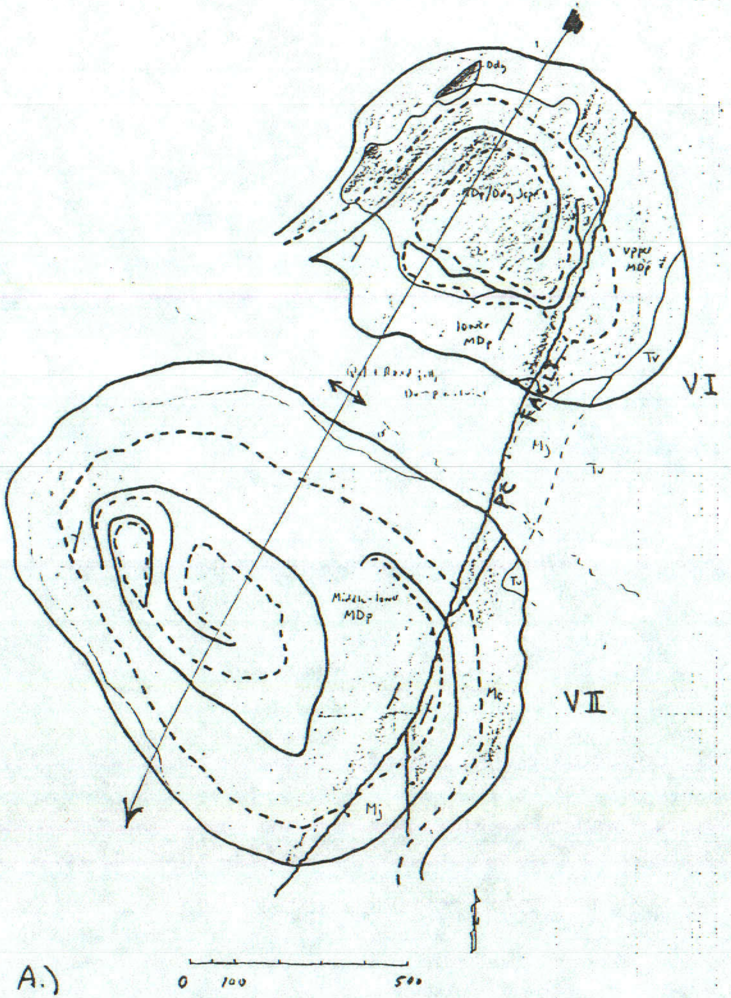
A small-scale anticline parallels the strike of the Vantage fault systems, and probably is related to drag along that fault zone. A syncline is formed in the hanging wall rocks (Mc or Mp). West-northwest trending normal faults are also present.

## Alteration

Alteration is strongly zoned within the Pilot shale and uppermost Devil's Gate limestone. The alteration zones form flat-lying horizons that are stacked vertically and grade laterally outward and upward into unaltered rock. The lowermost alteration zone is a jasperoid-breccia developed at the shale/limestone contact and derived mainly from the Devil's Gate limestone. It is variable in thickness and distribution. Typically the jasperoid-breccia is black to brownish-black in color and a matrix-supported breccia. These rocks are well-silicified and have a sucrasic texture. The jasperoid-breccia is characterized by closely spaced fractures and abundant veins and open-space coatings of kaolinite, barite, jarosite, quartz and calcite. Alunite may be present, as well as stibnite (usually oxidized to stibiconite).

In the areas of strongest alteration and mineralization, the jasperoid-breccia is overlain by a zone of strong hypogene oxidation and intense acid leaching ("strong oxide zone"). The Pilot shale is decalcified and argillized, punky, weakly to strongly silicified, and is bleached to a light grey color. Alteration minerals include jarosite, alunite, kaolinite, barite, and hematite. Hydraulic fracture textures and hydrothermal brecciation


Ddg/MDp Jspd
Qg
Ddg
Qal
Ddg
V-O
MDp
VI
Mj
Tus
Mc
Qg
Dn/
Ddg
Mj
Ddg
Mc
MDp
VII
Mj
Tub
A.R.M.
VIII
G R A B E N
Mc
VANTAGE FAULT SYSTEM
Qg
Qal
Tub
V A N T A G E
Qg
Qg
Qg
Tus
MDp
Mc
Mc
Mj
MDp
Qg
Dds
ALLIGATOR RIDGE
Ddg
J
Tus
Mj
MDp
Dn/
Ddg
VANTAGE
MDp
Mj
BASIN
Mc
Qal
Mc
Tb
MDp
Mc
0
500'
1000'
N
Quaternary
Qal Alluvium
Qg Valley-fill gravels
Tertiary
Tub Basalt flows
Tus Tuffaceous sediments
Mc Chainman shale
Mississippian
Mj Joana Limestone
MDp Pilot Shale
Devonian
Ddg/Dn Devil's Gate Limestone & Nevada formation
Ddg/MDp Jasperoid-breccia
Anticline
Fault, ball on downdrop side, dashed where inferred
Rough Pit outline



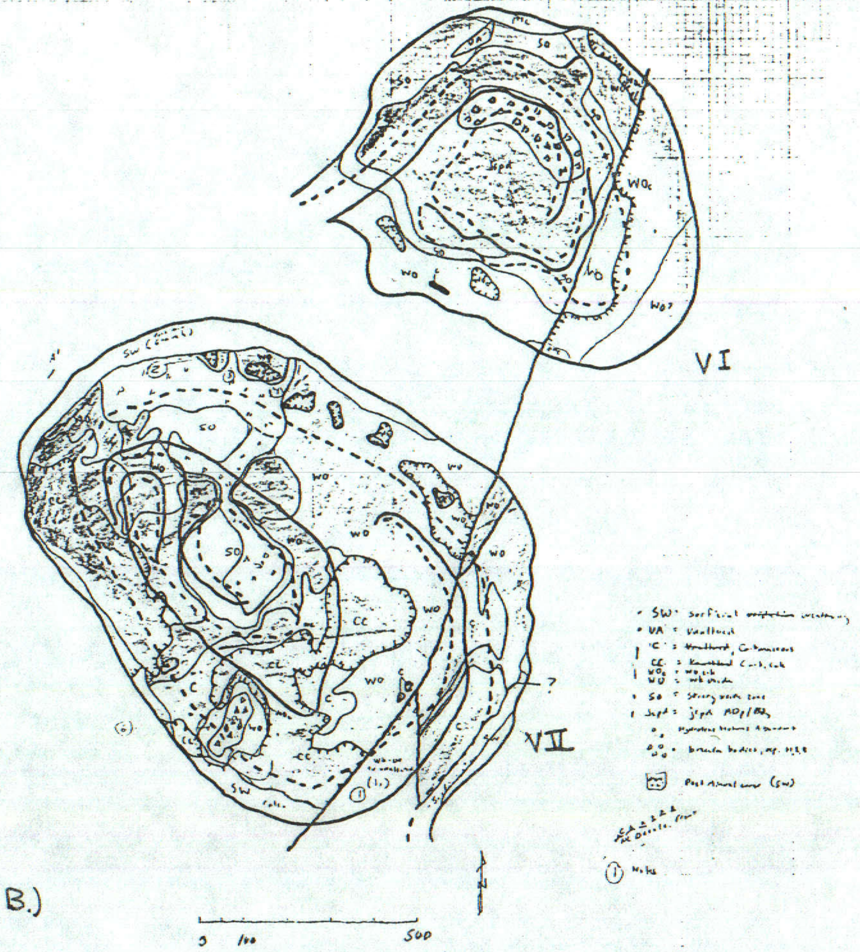


Fig. A. Geologic Map of the Vantage I and II Pits in Fall of 1983.

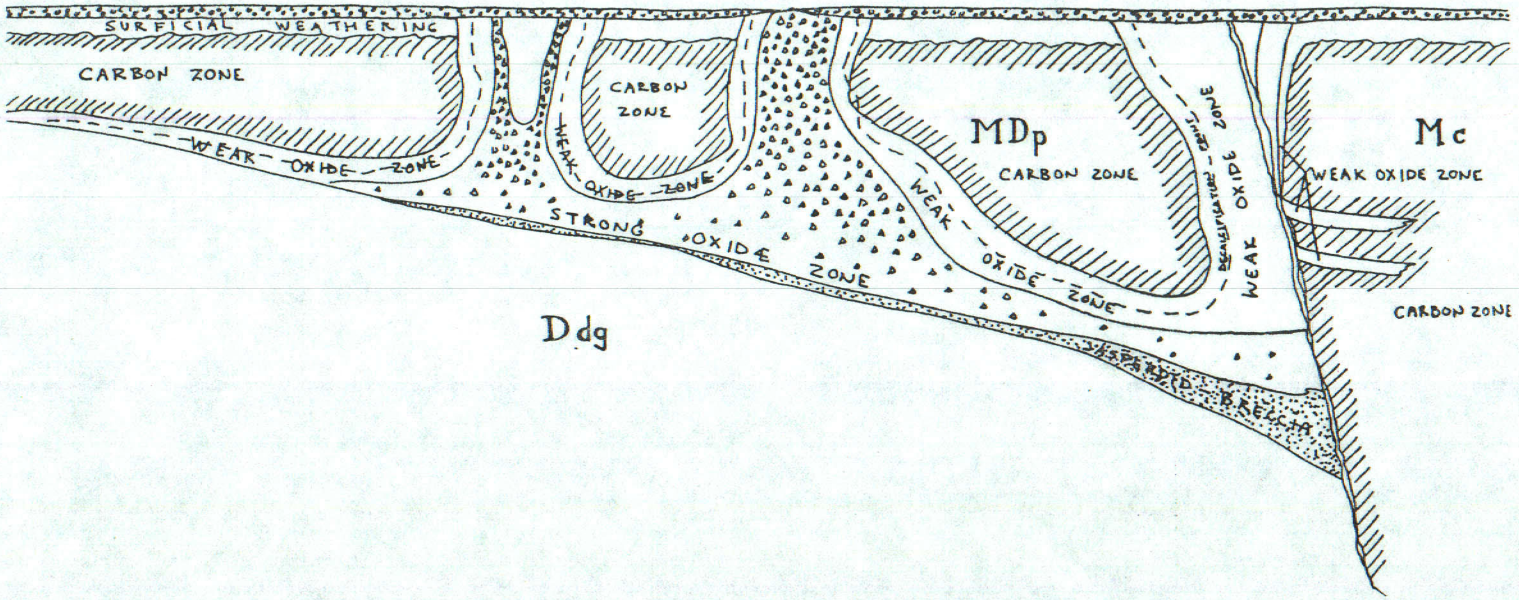
Fig. B. Alteration zonation of the Vantage I and 2 Pits in Fall of 1983.

(e.s. jig-saw puzzle and crackle breccing) is typical of rocks in the strong oxide zone. Hydrothermal explosion or eruption breccias form finger-like upward projections of the strong oxide zone. These breccias form dike-like bodies that cross-cut the overlying rocks and alteration zones. The hydrothermal explosion breccias are characterized by clast-supported and matrix-supported heterolithologic breccias. The strong oxide zone grades laterally and vertically into a transitional zone of weaker hypogene oxidation ("weak oxide zone"). Rocks of the weak oxide zone are characterized by pervasive jarosite and/or hematite stain, often with lisegang banding. A decalcification front is usually found within the weak oxide zone (oxidation and decalcification fronts rarely coincide). In Vantage II and III, where a more complete section of Pilot is preserved and not completely oxidized, the weak oxide zone grades into carbonaceous, calcareous Pilot shale (the "carbon zone"). Some of the carbonaceous Pilot shale is hydrothermally-altered (Ilchik, 1984) and apparently contains activated carbon. Alteration minerals typical of the carbon zone are relatively occurances of realgar-orpiment, typically in calcite veins, and stibnite.

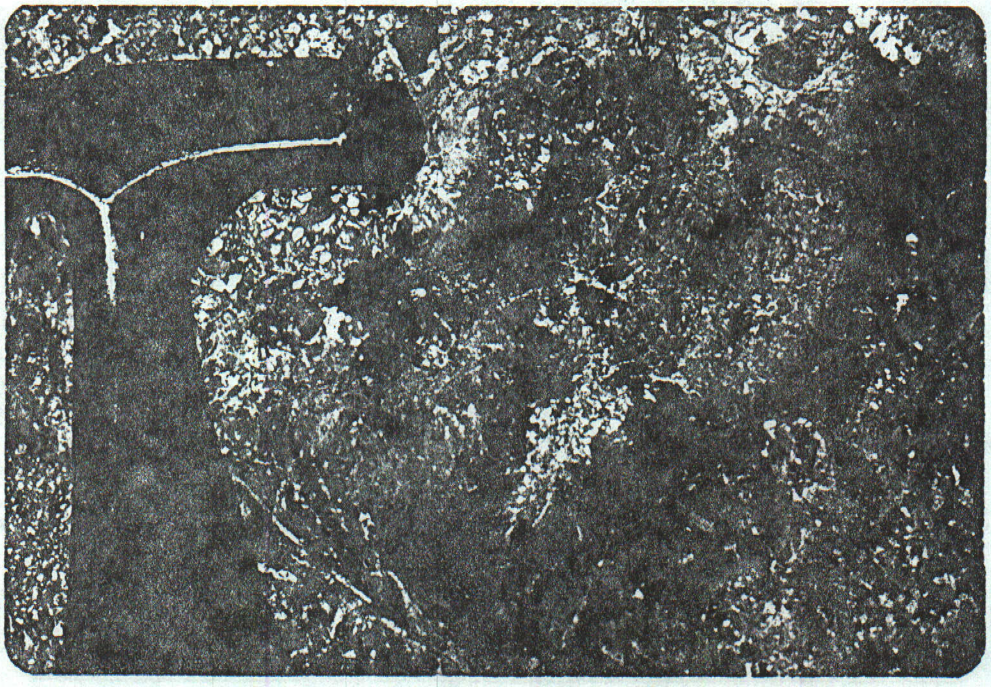
A schematic diagram illustrating the arrangement of the alteration zones is shown in figure 5. This diagram would correspond to the alteration zonation present in the Vantage II and III deposits.

## Hydrothermal Breccias

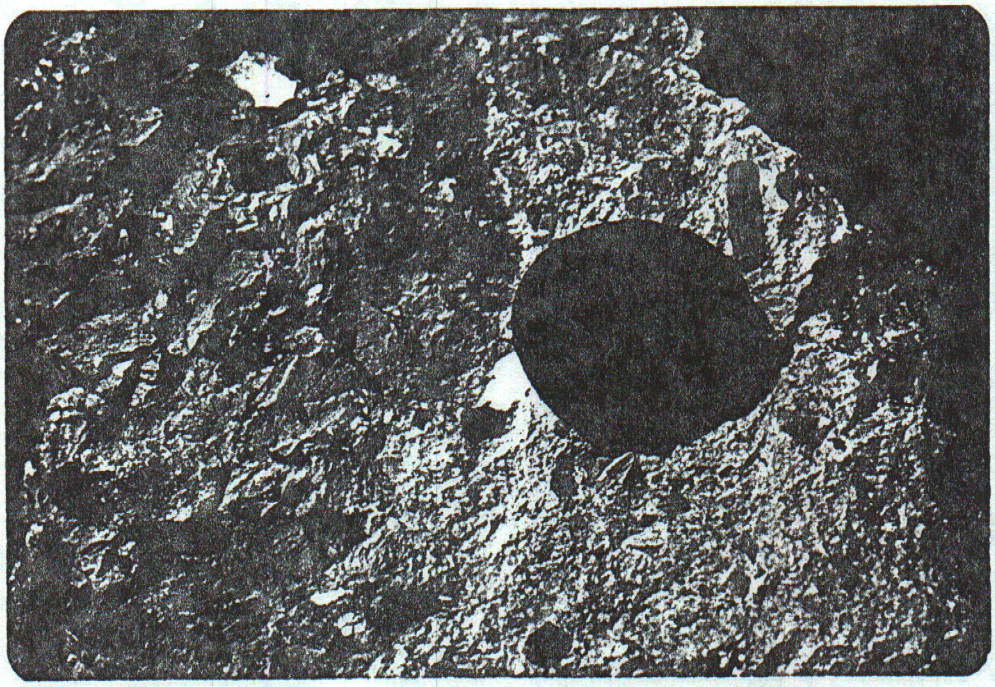
The hydrothermal explosion breccias are finger-like upward extensions of the strong oxide zone that cross-cut the overlying carbon zone. These breccia bodies are encased in a sheath of weak-oxide type oxidation that grades laterally into carbonaceous Pilot shale. The breccia bodies open downward into less disrupted rocks in the relatively stratabound part of the strong oxide zone (Figure x). Three main breccia types have been described: 1) clast supported, 2) matrix supported, and 3) jigsaw-puzzle and crackle breccias. Clast supported breccias (Figure A,B) typically consist of strongly oxidized and acid leached Pilot shale clasts and rounded clasts of the basal jasperoid breccia. The area between clasts typically is blown clean of rock flour and is partly filled by crystalline barite, ± drusy quartz, ± crystalline to earthy jarosite, ± alunite, ± kaolinite, ± hematite. Matrix supported breccias (Figures C,D) typically consist of oxidized, acid leached, silicified Pilot shale clasts and rounded clasts of the basal jasperoid-breccia "floating" in a matrix of silica and rock flour. Alteration minerals include barite, alunite, jarosite, and hematite. Another type of matrix supported breccia observed in Vantage I and termed a "rubble breccia" (Figure E), consists of a crumbly zone of uncemented rock flour and clasts of Pilot shale and jasperoid-breccia. Most


SURFICIAL WEATHERING
CARBON ZONE
WEAK OXIDE ZONE
CARBON ZONE
WEAK OXIDE ZONE
STRONG OXIDE ZONE
MDp
CARBON ZONE
WEAK OXIDE ZONE
DECALCIFICATION - FRONT
WEAK OXIDE ZONE
Mc
WEAK OXIDE ZONE
CARBON ZONE
Ddg
JASPEROID - BRECCIA

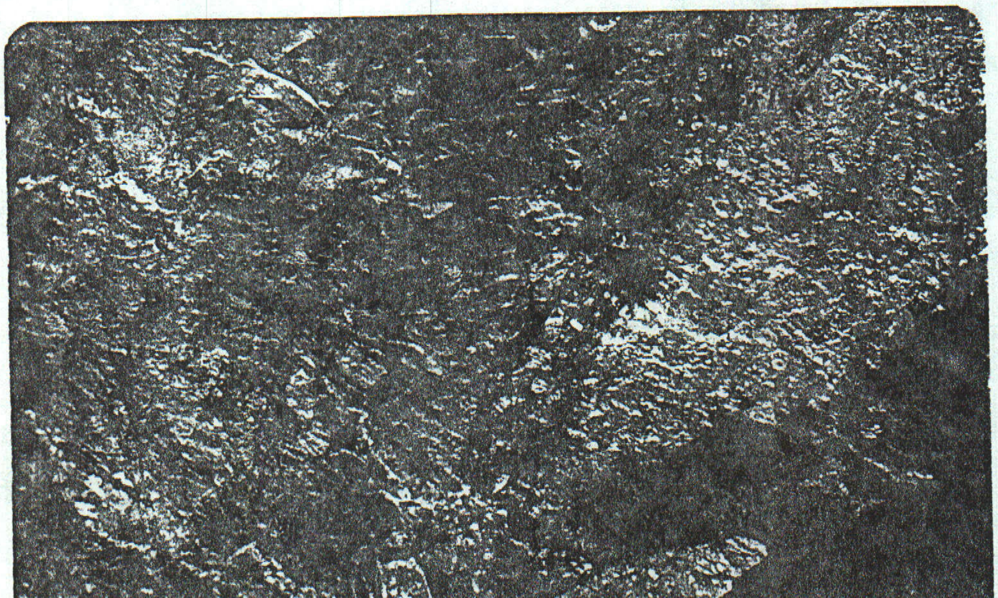
Matrix-supported breccia consisting of Pilot shale and jasperoid breccia clasts in silica and rock flour matrix. Jasperoid clasts are slightly rounded and transported 200' vertically.



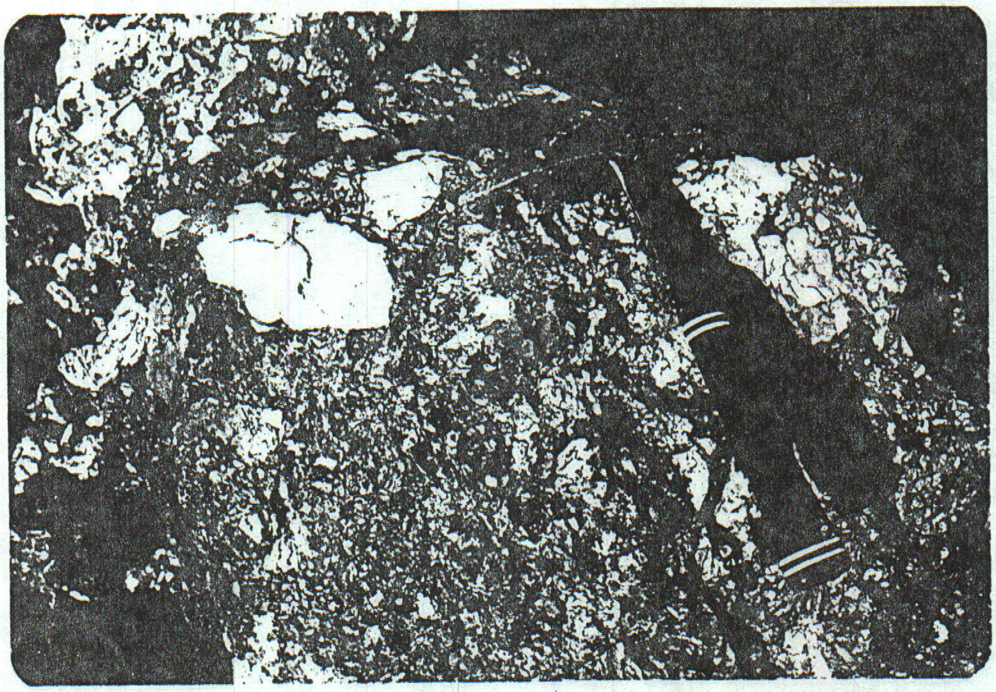
Rounded clast of jasperoid-breccia in heterolithologic explosion breccia comprised of jasperoid breccia, Pilot shale, and brecciated Pilot shale clasts.



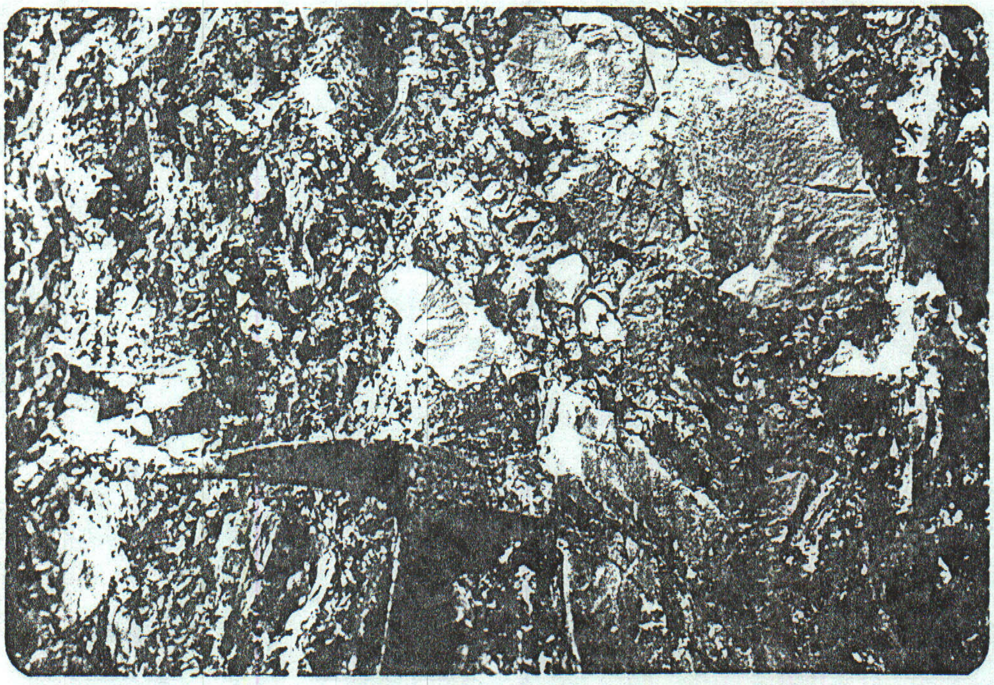
Matrix supported breccia



Matrix supported breccia veins, note rounded Pilot shale clasts



Clast-supported hetrolithologic explosion breccia



Clast supported, hetrolithologic breccia.

Rubble-breccia

Rounded jasperoid-breccia boulder, on left side of above photograph.

Breccia body in Vantage II.

clasts, including some up to boulder-sized, exhibit some transport rounding. All of the breccia types grade into jigsaw-puzzle and crackle breccias, and outward into undisrupted rock.

The distribution of breccia types within the bodies is related to the intensity of vapor streaming. Clast-supported breccias form in the narrow, upper part of the pipes where vapor streaming was most strongly focussed. The vapor stream transported jasperoid-breccia clasts vertically as much as 200' and removed the rock flour. The clast-supported zone grades downward into a broader zone dominated by matrix-supported breccias. The breccia bodies grade outward and downward into less-mobilized rocks.

## Mineralization

Economic mineralization is localized within the oxidized rocks in the lower part of the Pilot shale and in the basal-jasperoid breccias. The ore deposits are stratabound and localized by northeast and west-northwest trending Basin and Range faults. Mineralization in the Pilot shale tends to be more laterally consistent in grade, although spotty on a smaller scale, with sharp ore cutoffs, although some high-grade structurally-controlled ore occurred in the hanging wall of the PC fault. Ore in the jasperoid breccia tends to be lower grade, spotty and restricted to structural zones.

Uneconomic, but relatively high-grade mineralization is also contained in carbonaceous, "preg-robbing" (gold scavenging) rocks of the carbon zone in the Vantage II and III deposits. These mineralized rocks tend to be formed in the lowermost part of the Pilot shale, directly above the mineralized rocks in the weak and strong-oxide zones. The preg-robbing character of the rocks is generally attributed to activated carbon, presumably formed during hydrothermal maturation of organic material in the unoxidized Pilot shale.

Gold in the oxidized ore bodies is dominantly microscopic and disseminated, but some coarse gold is typical. Coarse gold typically occurs as dipyramids or needles that may be visible using low power optical microscopes (Klessig 1984). In rare occurances, samples with visible gold (often associated with stibnite/ stibiconite) have been discovered.

## Genetic Model

A general model for the Vantage deposits at Alligator Ridge must fit the following circumstances: 1) the presence of an apparently pre-mineral basal jasperoid 2) carbonaceous pilot shale overlying a zone of hydrothermal brecciation, hypogene oxidation and acid-leaching 3) hydrothermal eruption breccias and 4) the differences in texture and fineness of the gold in the carbonaceous and oxidized zones.

The premineral surficial rocks at Alligator Ridge are not definitely known and in most cases they presumably have been removed but likely were the tuffaceous sedimentary rocks exposed in the southeast wall of Vantage I. These rocks overlie an erosional surface composed of the Pilot shale, Joana Limestone and Chainman shale, and thus likely were deposited after initiation of Basin and Range faulting. A total thickness for these rocks is not known, but it may have been 500 - 1,000'. With the assumption that the tuffaceous sediments were pre-mineral and that the Pilot shale was likely totally carbonaceous, a schematic cross-section though a Vantage II type deposit may have looked like the drawing in figure xx. Depth of formation would be approximately 1,000' - 1,500' and age of formation less than 17 m.y.

Hydrothermal fluids ascended along conduits formed by the Basin and Range faults and initially deposited silica at the Pilot Shale/Devil's Gate limestone contact, to form the basal jasperoid, and in the lower Pilot shale as weak silicification of the calcareous rocks in the lower Pilot shale Ilchik (1984) reports that this early stage of silicification was accompanied by quartz-stibnite veins. Stibnite was also precipitated in the basal jasperoid.

In addition, the hydrothermal solutions initiated hyrothermal maturation of pre-existing organic material in the carbonaceous Pilot shale Ilchik (1984). This likely resulted in the formation of some activated carbon. Gold mineralization may have occurred at their early reducing stage of alteration by 1) adsorption of gold complexes onto activated carbon 2) reduction of gold-bearing solutions.

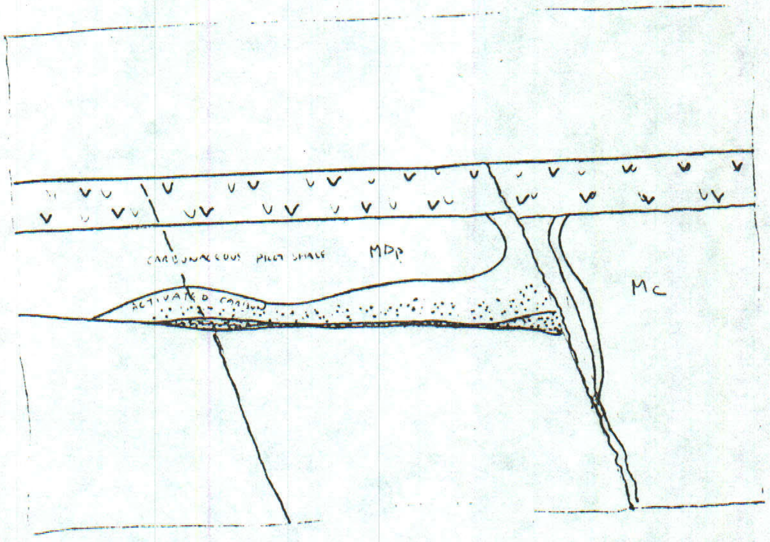
A later stage of alteration involved boiling of the hydrothermal solutions, perhaps due to an overall increase in the temperature of the solution (and/or change in ground water table). Boiling was localized along the lower Pilot shale contact as evidenced by the formation of hypogene oxidation and acid-leaching zones at the contact. Boiling could have been episodic due to the localized silica sealing in the jasperoid. Rupturing of the seal and flashing of solutions could have resulted in the formation of the observed jasperoid-breccia. In addition, gentle boiling above the jasperoid contact could have occurred. The oxidizing and acid leaching conditions are evidenced by the occurance of jarosite, alunite, barite, kaolinite, and hematite as alterations minerals and the partial to complete oxidation of pre-existing carbonaceous material and sulfides (e.s. stibnite to stibiconite) in the lower Pilot shale and the jasperoid.

A more explosive phase of boiling occurred that resulted in hydraulic fracturing of the lower Pilot shale and the formation of hydrothermal explosion or eruption breccia bodies. This explosive activity may have been the result of self-sealing of the system by the silica precipitation in the fault/conduits. The self-sealing may have been aided by the relative impermability of the upper Pilot shale claystones. Self-sealing would have allowed the lower, permeable Pilot shale to be flooded by solutions under lithostatic load. Pressure release, by rupturing of the seal, would have resulted in decompression of the fluid-saturated lower Pilot shale and flashing of the confined solutions to steam (as well as promoting effervesing of dissolved constituents such as CO2). The vapor then streamed out through the conduit zone, transporting clasts of lower Pilot shale and jasperoid breccia upward and emplacing them in the breccia bodies, sometimes hundreds of feet above their stratigraphic origin. Another possible mechanism for breccia pipe formation would be formation of a "gas cap" (Hedenquist and Henley, 1985). Since the concept of self-sealing is not universally accepted, Hedenquist and Henley proposed that in the hydrothermal system, once self-sealing closed off a conduit and the hydrothermal system diverted to another, vapor-steam and CO2 from boiling and effervescing - could collect under the sealed zone. With pressure build-up, local overpressurized conditions could occur. Tectonic rupturing of the seal, or pressure buildup to the point of exceeding lithostatic load + rock tensile strength would initiate a hydrothermal explosion or eruption followed by gentle boiling. Either mechanism would result in the observed features.

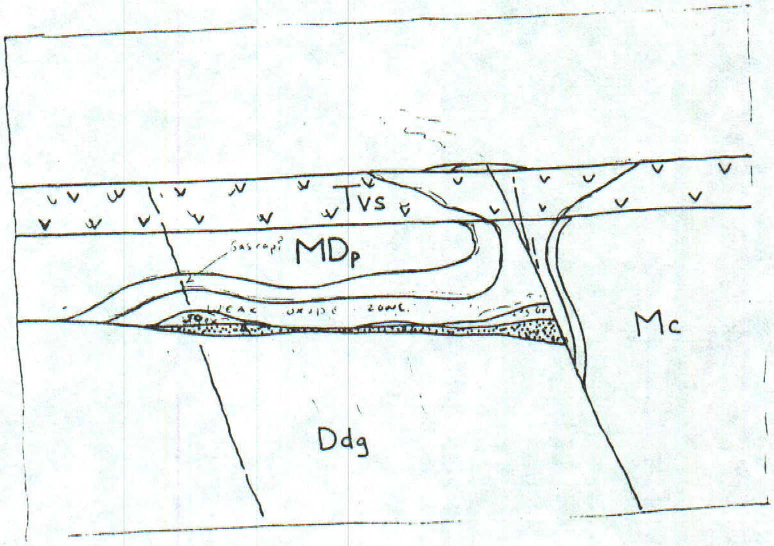
Gold precipitation may have occurred in response to changes in solubility of gold complexes during boiling, but there is no direct evidence of this. The coarser-grained, euhedral gold in the oxide zone could just as well result from oxidation and recrystallization of the sub-micron sized gold in the carbon zone during oxidation. Fining of the gold could also have occurred at the same time. Perhaps the only contribution of the boiling was to make the ore amenable to heap leaching and therefore economic.

## Summary & Conclusions

The Alligator Ridge deposits formed from a complex series of hydrothermal alteration stages. Mineralization was localized by normal fault zones (conduits) and strongly influenced by stratigraphic permeability differentials (throttles and caps). Alteration began by deposition of silica in the lower most Pilot shale and uppermost Devil's Gate limestone to form a jasperoid. Thermal maturation began in response to the elevated thermal gradient and presence of hydrothermal solutions. All or part of the gold



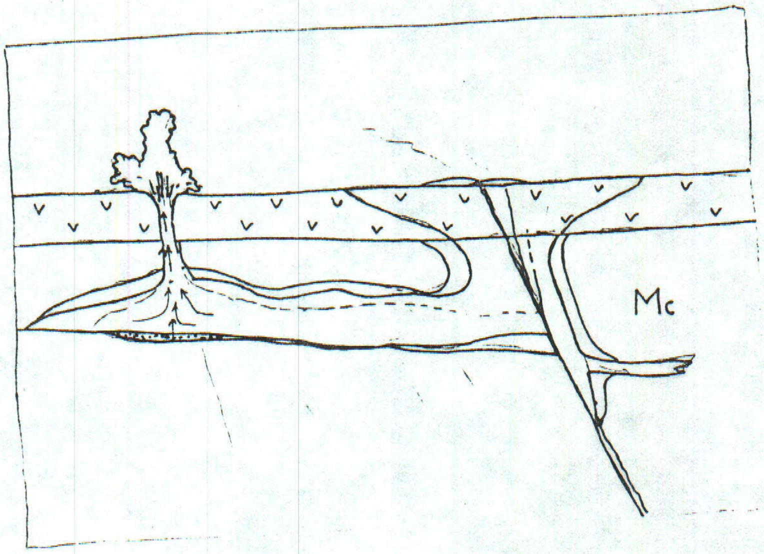
STAGE 1: THERMAL MATURATION OF OM, PPT. OF SILICA AT Ddg/MDp contact due to [illegible] partial, slight silic. of lower MDp. Qtz-stibnite veins, reducing cond., stibnite in jspd



STAGE 2: Boiling at contact, hypogene oxidation and acid leaching destroys carbon, decalc. MDp, enhancing permeability porosity. Oxidizes/frees gold, ppt? gold.

Pressure buildup at jspd could result in episodic bxn & sulfides silica ppt.

Development of seals along conduits (ref.) or gas cap (ref.)
- development of pressurized zone.



STAGE 3: Pressure release along structure, due to pressure exceeding lithostatic p + rock tensile strength, or tectonic activity etc. Immediate flashing of confined fluid in lower Pilot Shale, accompanied by boiling. Vapor streaming out through structure vertically transports clasts from lower Pilot section and jspd-brg zone,

deposition may have occurred in the latter part of this early stage, possibly due to the adsorption of complexed gold onto activated carbon. A second, later stage of alteration was characterized by boiling and explosive activity. Boiling occurred at the contact between the Devils' Gate limestone and Pilot shale, resulting in explosive brecciation of the jasperoid. Also, the lower Pilot shale was hydraulically fractured and brecciated due to explosive activity. Apparently the activity was the result of formation of an impermeable cap in the upper Pilot shale and either self-sealing or formation of a gas cap. Pressure build-up ensured and breaking of the seal resulted in explosive brecciation of the lower Pilot shale and the formation of heterolithologic eruption breccia bodies. This activity was probably followed by boiling. The hyprogene oxidation and acid leaching of boiling hydrothermal solutions. Some gold may have precipitated during boiling, but there is no direct evidence for it. The pre-existing carbonaceous gold-bearing material likely was oxidized to form the coarser-grained, euhedral, and "fined" gold seen in the oxidized ores.

In conclusion, the Alligator Ridge deposits are sediment hosted "semi-hot springs"-type deposits - probably the root-zones of a hot springs field - in which permeability of the units strongly influenced ore formation and alteration.

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# GEOLOGY AND GENESIS OF THE ALLIGATOR RIDGE MINE, WHITE PINE COUNTY, NEVADA

## INTRODUCTION

The purpose of this report is to describe the general geologic setting and some of the unique alteration and mineralization features of the Alligator Ridge disseminated gold mine. Although the Alligator Ridge deposits are similar to the other sedimentary rock-hosted or "Carlin-type" deposits in many ways, some of the unique features, such as the hydrothermal explosion breccias, suggest significant differences in genesis. A generalized genetic model will be presented to illustrate some of these differences and to describe how these deposits may have formed.

The Alligator Ridge gold mine is located approximately 40 miles northwest of Ely, Nevada, in the northwest corner of White Pine County. The mine can be reached from Ely by approximately 70 miles of paved highway. The mine is located in the Vantage Basin which lies between the southern Ruby Mountains to the West and Alligator Ridge, part of the Maverick Springs Range, to the East.

The disseminated gold ore deposits are hosted primarily in the Pilot shale, part of the lower Paleozoic carbonate-and-transitional assemblage (figure 1) of East-central Nevada. These rocks are continental-shelf carbonate deposits and clastic rocks shed eastward off of the Antler orogenic highland during the Devonian and Mississippian.

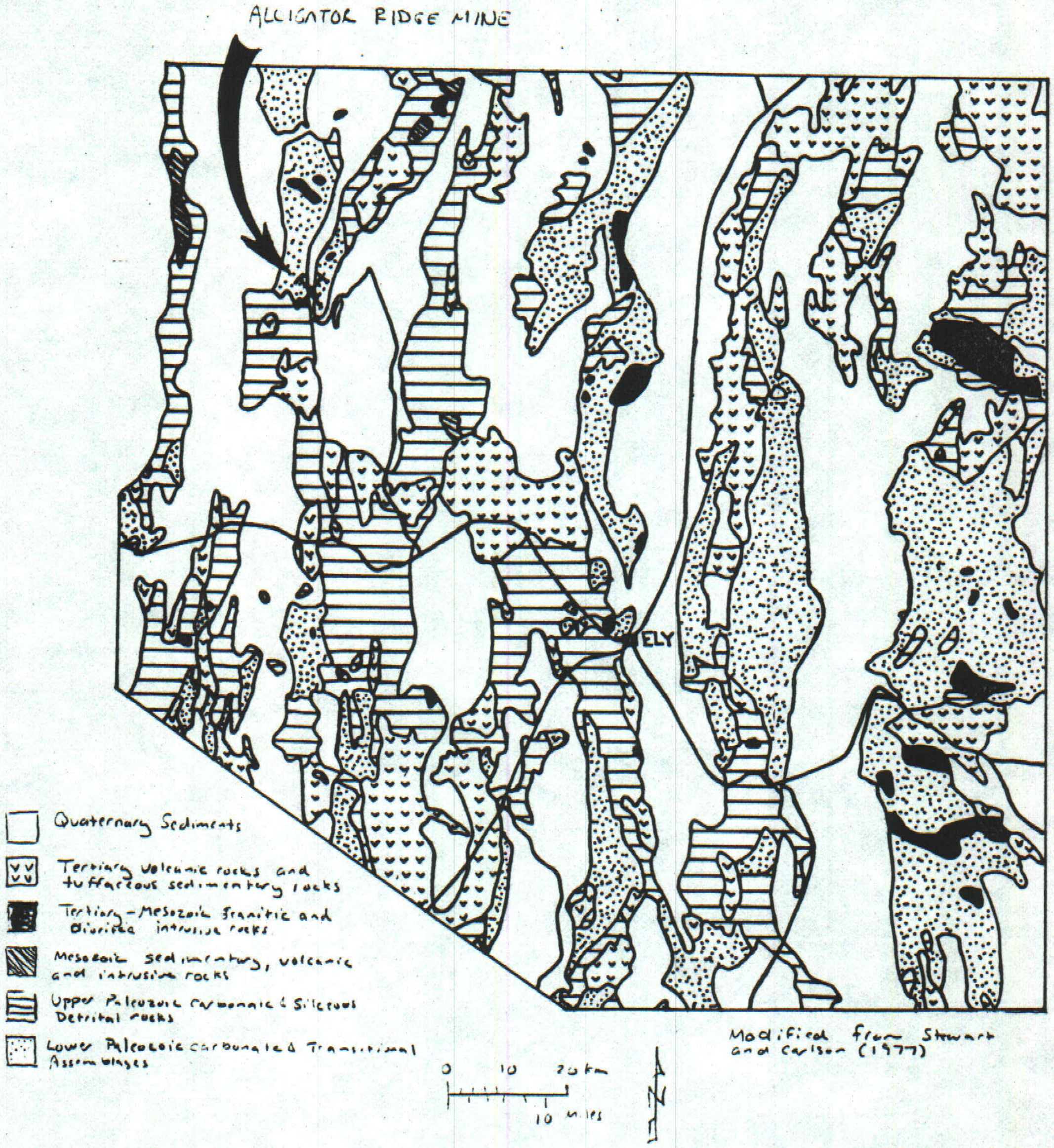
Previous, published work on the Alligator Ridge mine includes deposit overviews by P. J. Klessig (1984a and 1984b), a published abstract by J. Ainsworth (1983) covering some of the findings of his geochemical study of the Alligator Ridge deposits. An unpublished MSc. thesis by R. P. Ilchik (1984) documented some of the effects of hydrothermal maturation of organic material in the Pilot shale at the Alligator Ridge gold mine.

I would like to acknowledge Ed Flood and Jeff Pontius of NERCO minerals and Ron Parratt, Wayne Bruce, and Wade Hodges of Santa Fe Mining for their encouragement in the preparation of this report. Acknowledgement is also extended to Ed Bartels and Clynt Naumann of NERCO Minerals and Alan Glaser of Amselco Exploration.

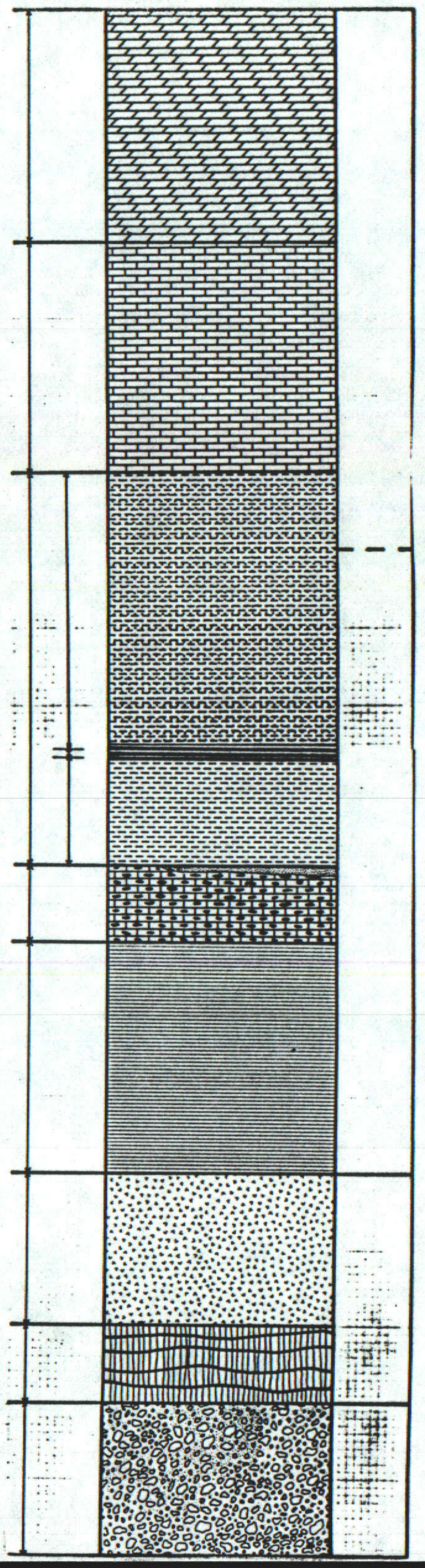
## GEOLOGY

### Stratigraphy of the Vantage Basin

The stratigraphy of the Vantage Basin (figure 2) played an important role in localizing alteration and gold mineralization in the Alligator Ridge deposits. The lowermost exposed units are the Devonian Nevada formation and Devils Gate limestone. The Nevada formation is exposed in Alligator Ridge, on the East side of Vantage Basin, but most exposures in the Vantage Basin are of the uppermost Devis Gate limestone. The Devils Gate limestone is overlain by the Devonian-Mississippian Pilot shale. It typically is 480 feet thick in the Vantage Basin (Ilchik, 1984) and, where unaltered, consists of a lower calcareous, carbonaceous, pyritic siltsone unit that is approximately 300 feet thick. This is overlain by an upper calcareous, carbonaceous, pyritic claystone that is roughly 280 feet thick. The



Modified from Stewart and Carlson (1977)



contact between the two units may be marked by discontinuous interbedded chert and claystone unit (Klessig, 1984). Limestone lenses are common in the lower Pilot shale. The Pilot shale is overlain by the Joana limestone which is approximately 120 feet thick (Ilchik, 1984) in the Vantage Basin. The Joana limestone is a sparry, crinoidal limestone typically abundant chert nodules. The Joana limestone is overlain by the Chainman shale, which is dominantly claystone and siltstone where expossed in the Vantage Basin.

Unconformably overlying an erosional surface that consists of at least the Pilot shale, Joana limestone, and Chainman shale are Tertiary tuffaceous volcaniclastic sedimentary rocks that are at least 500 feet thick (Klessig, 1984a). The tuffaceous rocks likely are part of the Miocene-Oligocene tuffaceous sedimentary rocks that occur in the area (Hose and Blake, 1976), although Paleocene-Eocene ash-flow tuffs occur in areas north of and south of the Vantage Basin. These rocks are unconformably overlain by basaltic-andesite flow rocks (Ilchik, 1984). The present surficial geology (figure 3) resulted from erosion of the Tertiary and older rocks and deposition of alluvial gravels and valley-fill of Quaternary age.

## Structure of the Vantage Basin

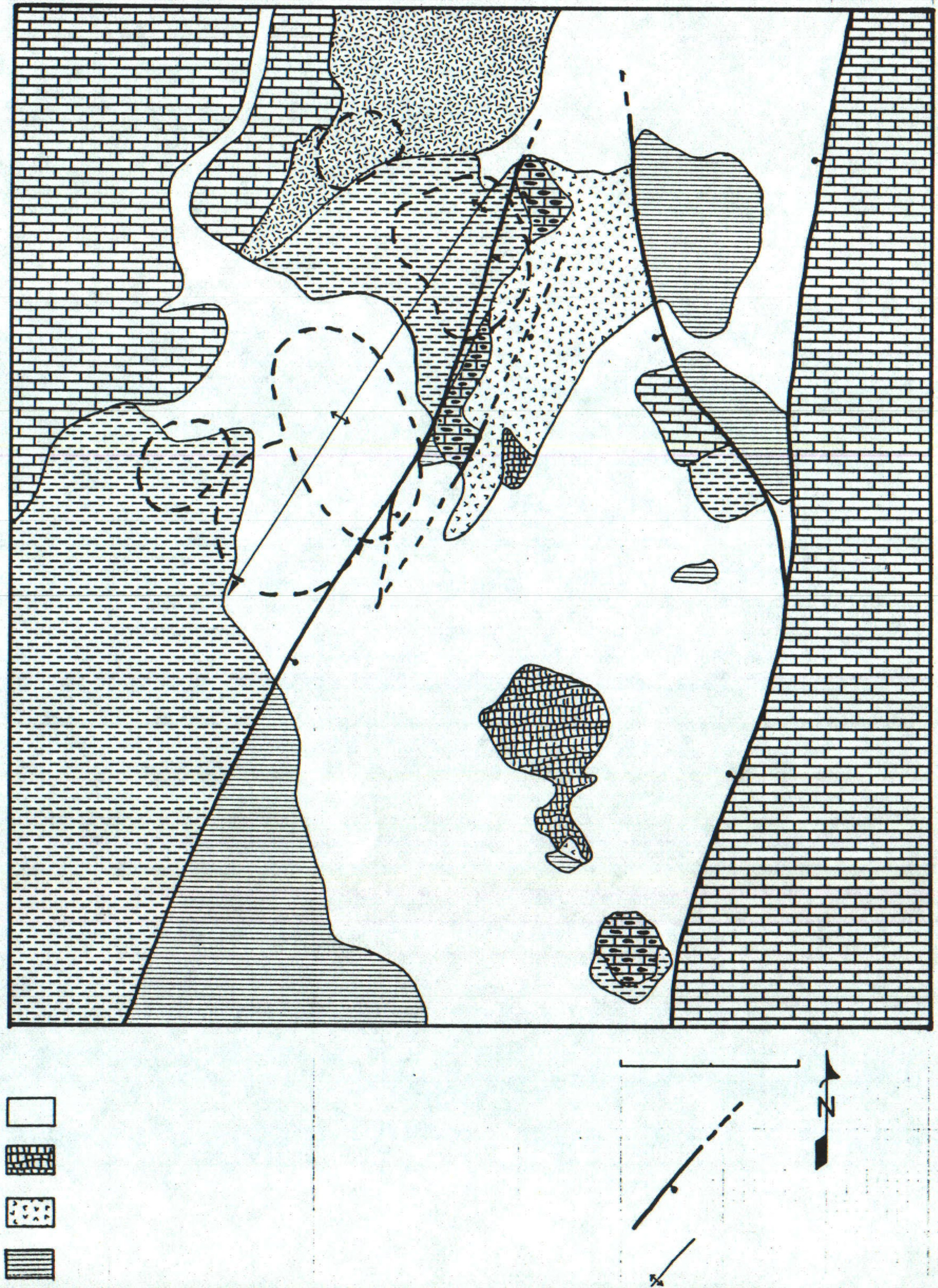
The Vantage Basin forms a gentle, south plunging anticline that is breached in the center to expose a core of Devils Gate limestone. The Pilot shale dips westwardunder the Joana limestone and Chainman shale on the West side of the basin. On the East side of the Vantage Basin, a large northeast trending graben, the "Vantage Graben", juxtaposes Chainman shale, on the downdropped side, and Pilot shale. The boundary fault system, the "Vantage fault system", includes numerous strands and parallel faults, among which is the "PC" fault. The PC fault cuts through the Vantage-1 and Vantage-2 workings, downdropping the upper Pilot shale against the lower Pilot shale in the former and moving the Chainman shale and Joana limestone against Pilot shale in the latter (figure 4.). The Vantage basin is truncated on the east side by a large horst-block of Devonian Nevada and Devils Gate limestone.

The ore deposits are localized along northeast-trending structures that are parallel to the Vantage fault system, including the PC fault, and at intersections between northeast-trending and west-northwest trending cross-faults. A small-scale anticline parallels the strike of the Vantage fault system, and probably was formed as a result of drag along those faults. The axis of the anticline crosses the Vantage-1, -2, and -3 ore bodies and may have been a control on gold mineralization.

## ALTERATION

Alteration in the Alligator Ridge deposits is strongly zoned within the Pilot shale and upppermost Devils Gate limestone. The alteration zones form flat-lying horizons that are stacked vertically and grade laterally outward and upward from strongly altered rock into unaltered rock. Within the Vantage Basin, there is some overlap between alteration around the Vantage-0, -1, -2, -3 deposits, the A.R.M. deposit, and smaller hydrothermal centers on the West side of the basin. Also, the amount of alteration decreases as the Pilot shale sectioin plunges southward.

The lowermost alteration zone is a jasperoid-breccia developed at the Devils Gate/Pilot shale contact and derived mainly from the Devils Gate limestone. It is variable in thickness and distribution. Typically the jasperoid-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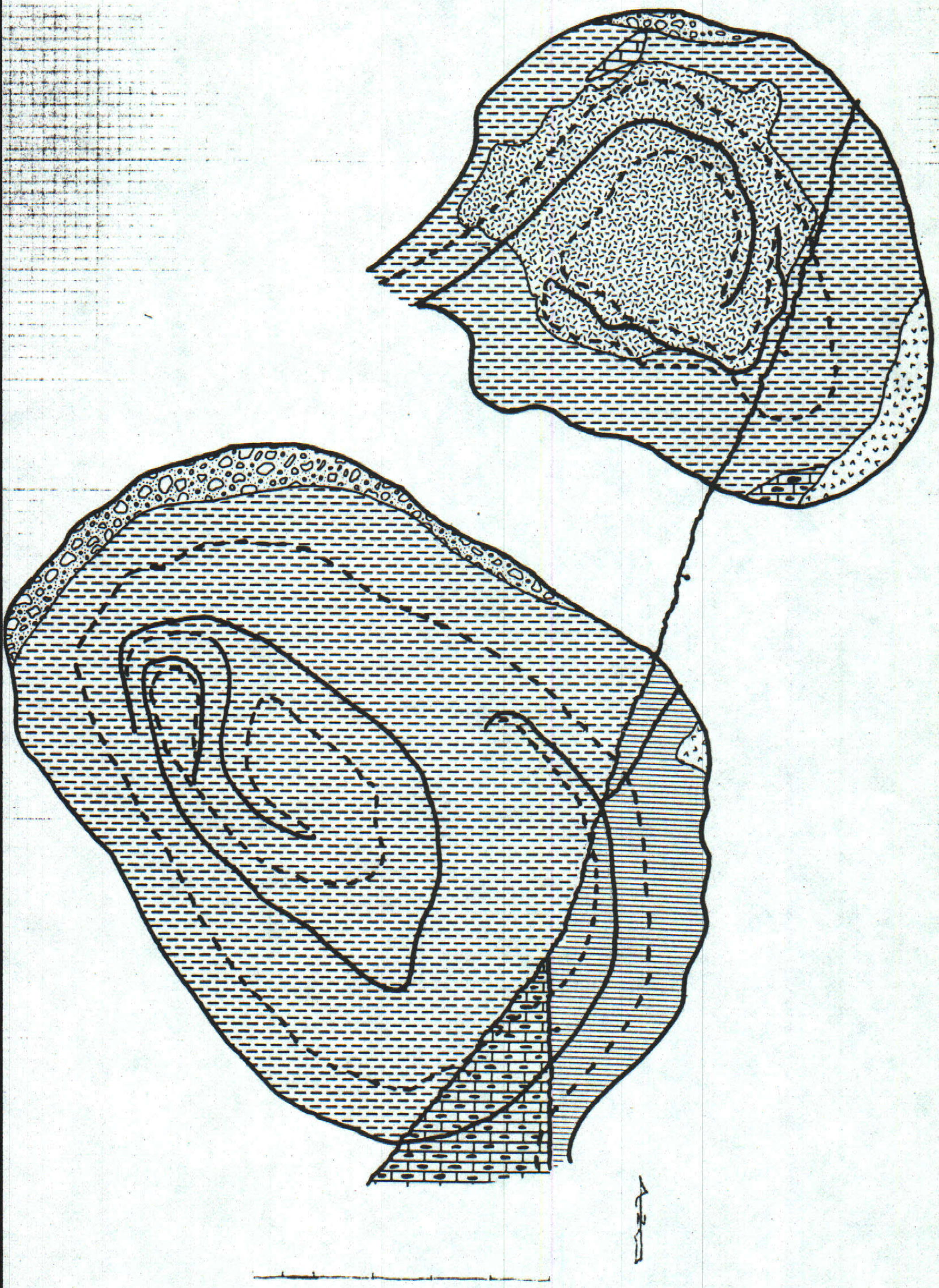


breccia is brownish-black to reddish-brown in color and a matrix supported breccia. These rocks are well-silicified and have a sucrosic texture. Stibnite, typically partially oxidized to stibiconite occurs in early-formed veins. The jasperoid-breccia contains closely spaced fractures and abundant later-formed veins and open-space coatings of kaolinite, barite, jarosite, quartz and calcite. Alunite may be present as veins, but is less common.

In the areas of srongest alteration, the jasperoid-breccia is capped by a zone of strong hypogene oxidation and strong acid-leaching ("strong hypogene oxide zone"). In this zone, the Pilot shale is decalcified and argillized, punky, weakly to strongly silicified, and is bleached to a light grey color. Alteration minerals include jarosite, kaolinite, barite, hematite, and less commonly, alunite. Hydraulic frcture textures and hydrothermal brecciation is typical of rocks in the strong hypogene oxide zone. Hydrothermal explosion breccias extend upward from the strong oxide zone and cross-cut the overlying, less altered rocks. The hydrothermal explosion breccias occur as dike-like bodies of clast-supported and/or matrix-supported heterolithologic breccias, typically consisting of clasts of Pilot shale and the basal jasperoid-breccia.

The strong hypogene oxide zone grades vertically and laterally into a transitional zone of weaker hypogene oxidation ("weak hypogene oxide zone"). Rocks of the weak hypogene oxide zone are characterized by pervasive hematite and/or jarosite stain, often in the form of lisegang banding. Rocks of the weak hypogene oxide zone are typically decalcified, although the decalcification and oxidation "fronts" rarely exacty coincide.

In the Vantage-2 and -3 deposits, where a more complete section of Pilot shale is preserved and not completely oxidized, the weak hypogene oxide zone grades into carbonaceous Pilot shale (the "carbon zone"). Some of the carbonaceous Pilot shale is hydrothermaly altered (Ilchik, 1984) and apparently contains activated carbon. The hydrothermally altered Pilot shale is typically also decalcified. Alteration minerals typical of the carbon zone are relatively rare occurrances of realgar-orpiment, typically in asssociation with stibnite, in calcite veins, and stibnite-calcite veins. Minor kaolinite may be present in hydrothermally altered carbonaceous rocks.

Along the southward, downdip extension of the Pilot shale, there is a decrease in the amount of jasperoid formed in the uppermost Devils Gate limestone. The amount of hypogene oxidation decreases, but even deep drilling (400 feet or more) south of the Vantage-2 pit encountered a small weak hypogene oxidation zone developed in the lowermost Pilot shale at the contact with the Devils Gate limestone.

Hydrothermally altered carbonaceous material is also present in the Devils Gate limestone. A hole drilled East of the Vantage-1 pit encountered 50 feet of "normal" Devils Gate limestone and entered carbon-enriched limestone that contained a large amount of "sooty", black carbonaceous material. This material resembled the hydrothermally altered carbon found in the Pilot shale. Deep drilling in the area south of the Vantage-2 pit in 1984 interesected a breccia zone, apparently a hydrothermal breccia body, in the upper Devils Gate limestone that contained clasts of limestone in a carbonaceous matrix that exhibited streaming textures. The carbonaceous material was apparently hydrothermally altered. The occurrance of this breccia is also unique because breccia-body formation below the contact between the Devils Gate limestone and the Pilot shale is not observed in the Vantage-1 or Vantage-2 pits, or on Jasperoid Hill.

Surficial weathering of unaltered carbonaceous, calcareous, pyritic Pilot shale resulted in formation of a 20 to 40 foot zone of very weak oxidation. The shale became brownish-black to orangish-brown in color and was not decalcified. It is evident that surficial weathering did not cause the brightly-colored (and commonly decalcified) rocks found in the mine workings.

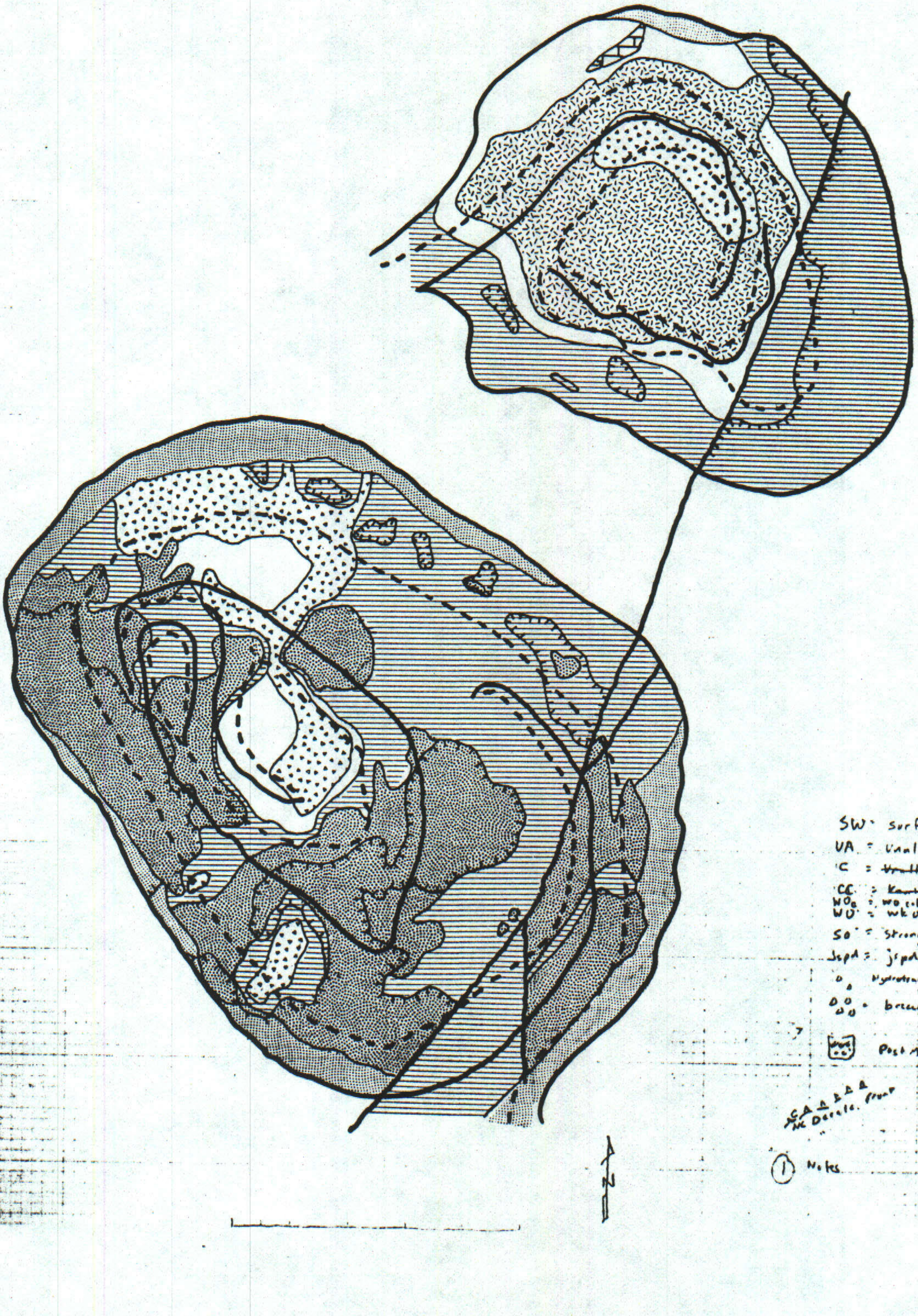
An alteration map based on the Fall 1983 pit configuration of the Vantage-1 and Vantage-2 pits is shown in figure 5. The altertion map shows the vertical zonation of the alteration (e.g. the small pit in the center of the Vantage-2 pit penetrated the carbon zone to expose the ore-bearing rocks of the strong oxide zone), the breccia bodies cross-cutting the carbon zone, the decalcification "front", and the lateral zonation of the weak oxide zone around the breccia bodies and the PC fault zone in the southeast corner of the pit. The altered Chainman siltstone unit illustrates the higher permeability of siltstone relative to claystone. The alteration/geology cross-sections (figures 6 and 7) illustrate the vertical zonation of the alteration in the Vantage-2 deposit.

## HYDROTHERMAL BRECCIAS

The presence of abundant examples of hydrothermal brecciation at the Alligator Ridge deposits distinguishes these deposits from those at, for example, Carlin or Jerritt Canyon. Hydrothermal brecciation and hydrofracture textures are ubiquitous in the rocks of the strong hypogene oxide zone. Relatively large breccia bodies are found in the Vantage-1 and -2 pits to be localized along relatively minor fault zones. The breccia bodies tend to be localized more along the anticlinal axis crossing the Vantage-1 and -2 orebodies. Very little tectonic brecciation is found at Alligator Ridge. That which is present is small scale and is found along the major normal fault that cuts the Vantage-1 and -2 deposits (the PC fault). The small amount of tectonic brecciation that does occur is along that fault consists of locally-derived clasts in a sheared matrix and are unlike the hydrothermal breccias.

The hydrothermal explosion breccias at the Alligator Ridge mine are dike-like bodies of heterolithologic breccia that open downward into less disrupted rocks in the relatively flat-lying strong hypogene oxide zone (see figure 6). The examples described below are from the Vantage-1 and Vantage-2 pits. The photograph in figure m shows one of the breccia pipes in the north wall of the Vantage-2 pit. The breccia bodies are typically strongly hypogene oxidized and acid-leached and the alteration forms a continuum with the relatively stratabound part of the strong hypogene oxide zone.

Three main breccia types have been observed: 1.) clast-supported, 2.) matrix-supported, 3.) jigsaw-puzzle- and crackle-breccias. Clast-supported breccias (figures 8 and 9) typically consist of strongly oxidized and acid-leached clasts of Pilot shale and rounded clasts of the basal jasperoid-breccia. The area between clasts typically is blown clean of rock flour and is partly filled by crystalline barite, +/- drusy quartz, +/- crystalline to earthy jarosite, +/- alunite, +/-kaolinite, +/- specular hematite. Matrix-supported breccias (figures 10 and 11) typically consist of oxidized, acid leached, silicified, angular to rounded Pilot shale clasts and rounded clasts of the basal jasperoid-breccia suspended in a matrix of silica and rock flour. Streaming textures are common in the silica + rock flour matrix. Alteration minerals, which may take the place of silica in the matrix, include barite, jarosite, and alunite. Some hematite or jarosite stain is common. Another type of matrix-supported breccia observed in the Vantage-1 pit and termed a "rubble-breccia" (figure 12) consists of a crumbly zone of uncemented rock flour and clasts of Pilot shale and jasperoid-breccia. Most clasts, including some up to boulder-sized,



SW = surficial

VA = Unaltered

C = ~~Unaltered~~, C

CC = ~~[illegible]~~ C

WO$_a$ = wo cib

WO = wk oxide

SO = Strong vein.

Jspd = jspd MDp/

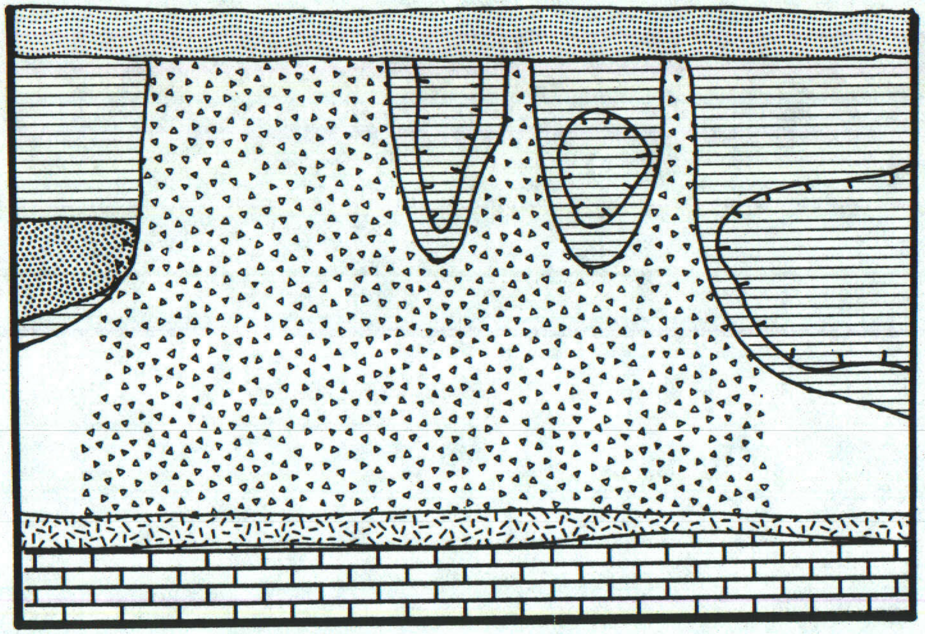
Hydrothermal [illegible]

breccia bodie

Post Mineral ca

[illegible] front

① Notes.



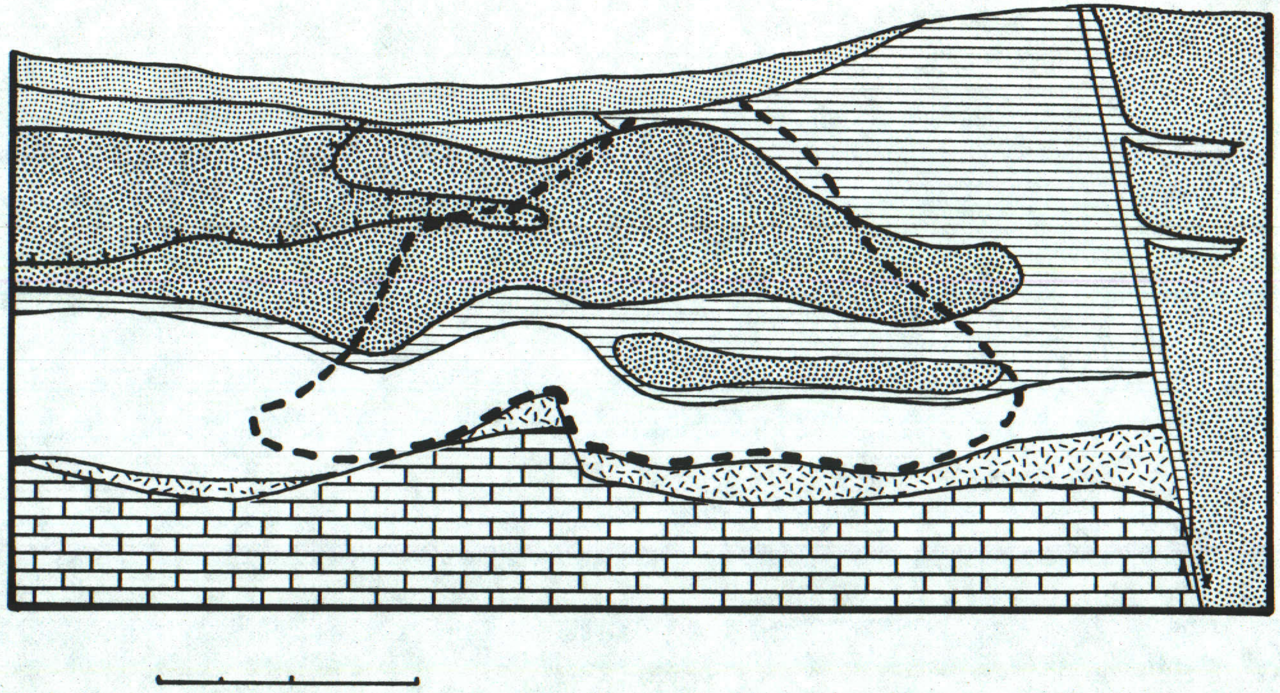


exhibit some rounding. The clast-supported and matrix-supported breccias grade into less mobilized breccia types, the jigsaw-puzzle- and crackle-breccias, and outward into undisrupted rock.

The distribution of breccia types within the bodies seems to be related to the intensity of vapor streaming. In the breccia bodies in the north wall of the Vantage-2 pit, clast-supported breccias form in the narrow, upper part of the bodies where vapor streaming was most strongly focussed. The vapor stream transported jasperoid-breccia clasts as much as 200 feet vertically, typically rounding them, and removed the cominuted material from the interstices between the clasts. The clast-supported zone grades downward into a broader zone dominated by matrix-supported breccias. Jigsaw-puzzle breccias and crackle breccias are found at the margins of the breccia bodies where the breccias grade into undisrupted rock.

The rubble breccia zone observed in the Vantage-1 pit was apparently formed by vigourous vapor streaming through a narrow structure near the contact between the jasperoid-breccia/strong hypogene oxide zone contact to form a chaotic, rubbly zone of rounded jasperoid-breccia and Pilot shale clasts suspended in rock flour. The rubble breccia locally graded into clast-supported breccias where the rock flour had been removed by the vapor stream.

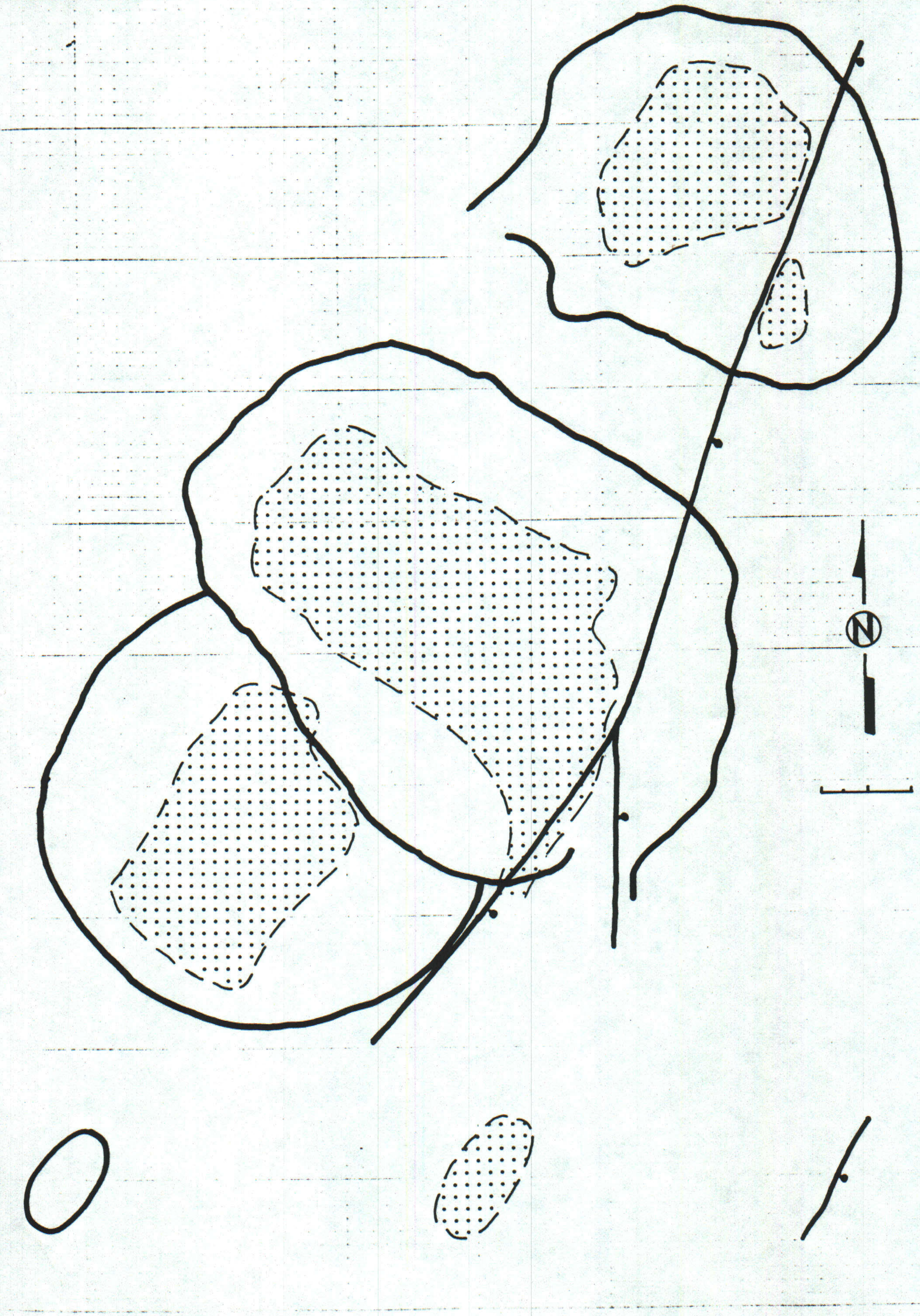
As mentioned earlier, some apparent hydrothermal breccias were discovered in the Devils Gate limestone. These breccias were discovered during deep drilling of a deep, carbonaceous, subeconomic gold deposit located south of the Vantage-2 pit. These breccias are of a type not observed in workings from Vantage-2 northward or in exposures of the Devils Gate limestone elsewhere in the Vantage Basin. The breccias contained limestone clasts in a carbonaceous silica + rock flour matrix. Unfortunately, little is known of this breccia type.

## MINERALIZATION

Economic gold mineralization at the Alligator Ridge Mine is localized within the oxidized rocks in the lower part of the Pilot shale and in the basal jasperoid-breccia. The ore deposits are strata-bound and localized by northeast- and west-northwest-trending normal faults. The northeast-trending faults are parallel to those in the Vantage Fault System, but with the exception of some hanging-wall ore in the southeast corner of the Vantage-1 pit, and deep, sub-economic gold mineralization south of the Vantage-2 pit (~~called the "Vantage-4" deposit~~), mineralization is not localized directly along the Vantage Fault system. The Vantage-1, -2, and -3 orebodies also fall on the trend of the axis of the south-plunging anticline described earlier. The anticline may have played an important role in channeling fluids flowing in the Pilot shale and thus acting as a control on mineralization.

The rough outlines of the Vantage -1, -2, and -3 ore shells and pits are shown in figure k. A cross-section through the orebody in the Vantage-2 deposit is shown in figure 7. The Vantage-0 orebody (see figure 3) is in low-grade mineralization within structurally prepared zones in the basal jasperoid-breccia that is exposed on Jasperoid Hill. The A.R.M. pit will reach a small satellite orebody formed in the lower Pilot shale.

Mineralization in the oxidized rocks is dominantly microscopic and disseminated, but some coarse gold is typical. Coarse gold occurs as dipyramids or needles that may be visible using low-power optical microscopes (Klessig, 1984a). Rare occurrances of gold visible in hand-specimen have occurred. Gold-mineralized carbonaceous rocks occur in the Vantage-2 and -3 pits. Gold in the carbonaceous rocks is submicron and its mode of occurance is unknown. The presence of activated carbon,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which can scavenge cyanide-complexed gold from the leach solutions, and abundant diagenitic pyrite cause the gold-mineralized carbonaceous material to be uneconomic.

Klessig (1984b) reports an overall 9:1 gold-to-silver ratio for the Vantage deposits. Ilchik (1984) notes that the gold-to-silver ratio in the carbonaceous rocks is 1:1 and in the oxidized ore is 5:1, showing that the oxidized ores contain less silver. This suggests that the gold was originally deposited as sub-micron gold in unoxidized, carbonaceous Pilot Shale and oxidized at a later time. The silver could have been leached out of the gold by the oxidizing solutions and the gold could have been coarsened at the same time.

## GENETIC MODEL

The genetic model was developed to explain the alteration zonation and distribution of gold mineralization using well-understood physical and geochemical processes. Unfortunately, since the original surficial rocks have been large removed by post-mineral erosion and insufficient geochemical data, particulaly in geothermometry and fluid composition, is available to constrain the model of the system, some important assumptions had to be made to allow construction of the interpretive diagrams in figures 13 to 16.

The first assumption is that the the mineralization followed basin and range faulting. This is supported by strong evidence that the mineralization used the normal faults as conduits, including the PC and other northeast trending faults in and parallel to the Vantage fault system. These faults cut tuffaceous sedimentary rocks that are likely of Miocene to Oligocene in age, although definative age dates are not available. The Tertiary tuffaceous rocks are shown as the pre-mineral surficial rocks, and although the actual surficial rocks have been removed, it is likely that the geologic section could have been close to the one represented in the diagrams.

The secound assumption is that the Tertiary tuffaceous rocks were approximately 500 feet thick, although the exact thickness of this unit cannot be determined. This implies a shallow depth of formation in the "roots" of a hot springs-type system, which is also suggested by the alteration mineral assemblages, presence of hydrothermal breccias, and abundant acid-leached rock.

The third assumption is that the solutions were alkaline to slightly acidic, at a temperature of 150 to 200 degrees celcius, and of low salinity. This approximates the data reported by Rye (1985) for the ore-stage fluids at the Carlin disseminated gold mine. The acid-leaching therefore could only be from formation of acidic solutions by condensation of vapor from boiling and effervescing solutions. It is thought that at these low temperatures gold is transported as a thiosulfate complex.

With the previous assumptions, a best-fit genetic model for the formation of a Vantage-2-type orebody at the Alligator Ridge mine consists of three stages: 1.) a premineral jasperoid-formation stage, 2.) the main ore stage, and 3.) the acid-leaching and hypogene oxidation stage. Idealized cross-sections through a Vantage-2-type ore body are shown in figures x, y, and z.

Stage 1, Pre-mineral jasperoid formation: jasperoid forms preferentially at the Devils Gate limestone-Pilot shale contact, dominantly replacing the limestone below the contact but also apparently replacing some of the lowermost Pilot shale (figure 13). Weak silicification of the lower Pilot shale also occurred in this early stage. No silica veining is present in the Devils Gate limestone below the jasperoid suggesting that physical and/or geochemical changes at the contact forced silica precipitation and enhanced carbonate soluability.

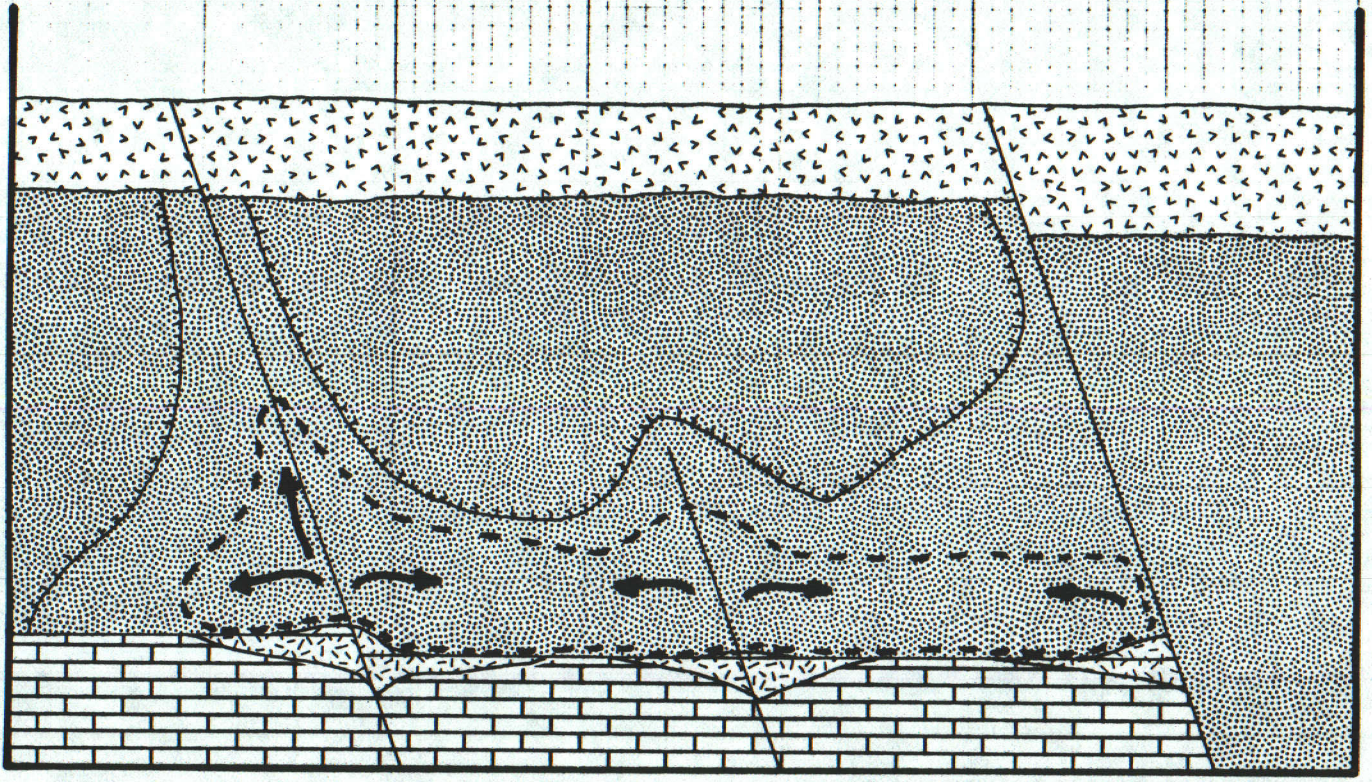
A possible process for this is pressure loss and cooling of solutions due to expansion of ascending solutions that were confined to narrow conduits in the Devils Gate limestone outward into the more permeable Pilot shale. This process, called "throttling", would have caused the precipitation of silica to occur at or above the contact, as observed.

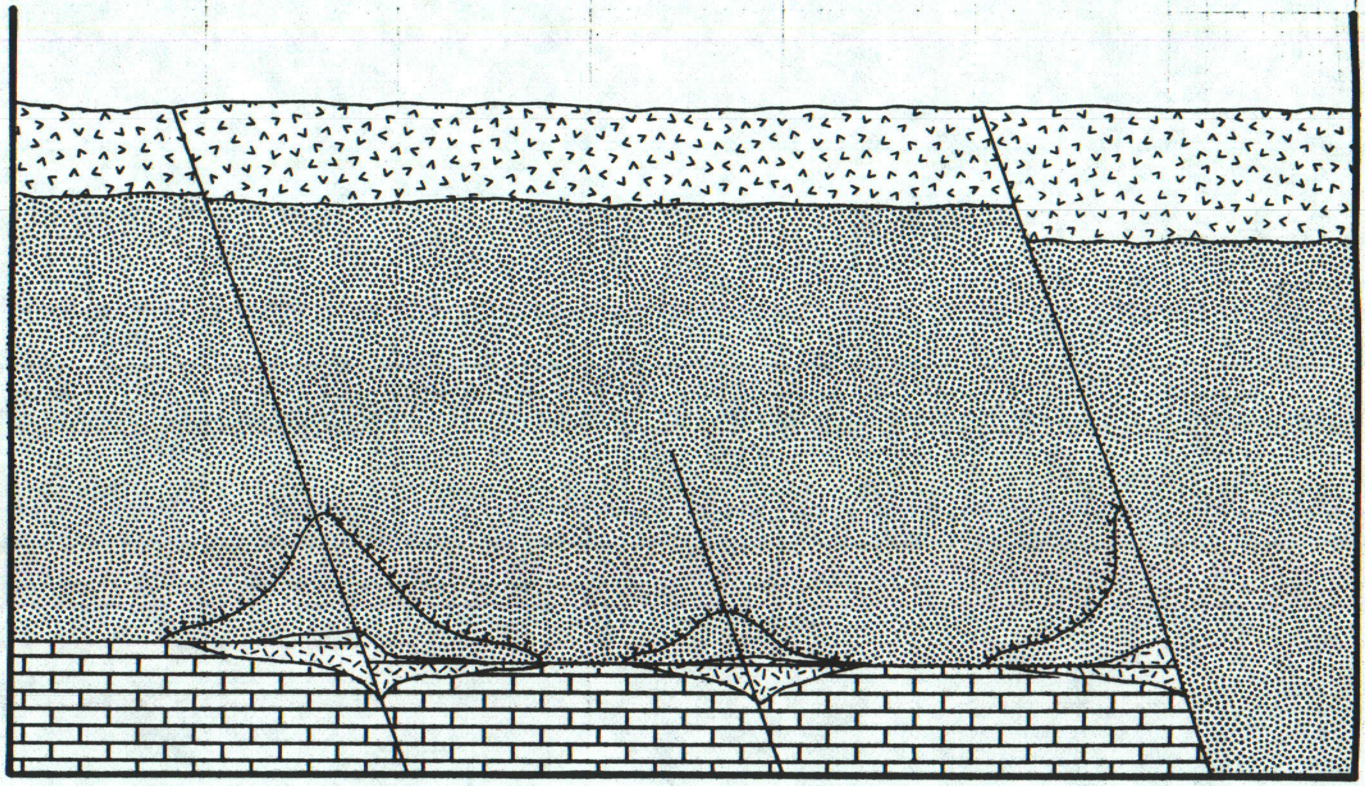
Stage 2, Main ore stage: The main gold mineralization event seems to have occurred prior to extensive hypogene oxidation and acid-leaching of the Pilot shale, but after formation of the jasperoid-breccia (figure 14). This is suggested by the occurrance of ore-grade mineralization that cross-cut the oxidized zones and extends into the carbon zone in Vantage-2 (figure 7), and Vantage-3. Mineralization in the jasperoid-breccia is lower in grade and tends to be restricted to fault zones, suggesting that the jasperoid-breccia was pre-ore and that it was impermeable except where structurally prepared. Extensive hydrothermal alteration of the organic material in the Pilot shale likely occurred at this time, forming activated carbon in the lower Pilot shale.

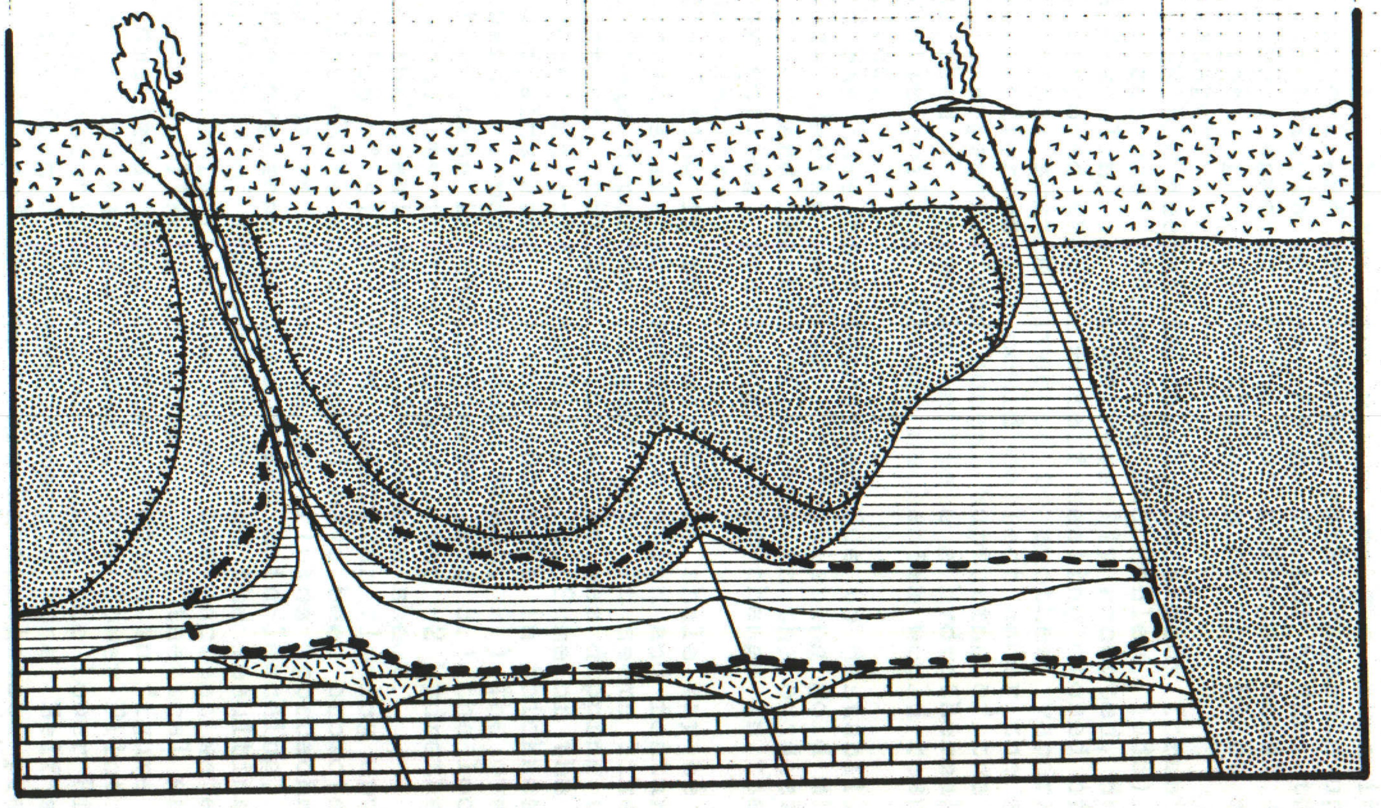
Gold deposition may have occurred due to 1.) reduction of the ascending solutions, 2.) by scavenging of the complexed gold from solution by activated carbon, and 3.) by boiling. Gold could be precipitated from a gold-thio complex by reduction of the solution by the carbonaceous material in the Pilot shale. The scavenging of gold from solution as a gold concentrating mechanism is suggested by the abilility of the activated carbon in the carbonaceous ore to remove cyanide-complexed gold from solution. Perhaps the thio-sulfate-complexed gold check was removed from solution by the same process. Boiling, perhaps in response to the pressure change at the Devils Gate limestone-Pilot shale contact, could have caused precipitation of gold from solution. The oxidizing effect of the boiling would have been off-set by the reducing environment created by the large amount of carbonaceous material in the Pilot shale. Also, if boiling occurred beneath the water table, low pH and strongly oxidizing conditions would be less likely to occur. No data is available at this time to indicate which process or processes directly caused gold mineralization.

Stage 3. Acid-leaching and hypogene oxidation: gentle boiling of solutions streaming into the lower Pilot shale from conduits in the Devils Gate limestone due to throttling (pressure loss) formed the bulk of the hypogene oxidation (figure 15). Condensation of the vapor-phase and effervesced gases resulted in precipitation of acid-leaching solutions. The strong oxidizing and acid-leaching environment likely occurred as a later stage simply due to the large amount of carbonaceous material present in the Pilot shale that had to be destroyed by oxidation and the abilility of the calcareous Pilot shale to buffer low-pH solutions. Once the carbon was destroyed and the Pilot shale decalcified, oxidation and acid-leaching could be carried to extremes. Another possible cause of later-stage hypogene oxidation and acid-leaching could be a drop in the paleo-water table. Boiling occuring above the water table would enhance the ability of the solutions to become strongly oxidizing and would promote the formation of extremely low pH solutions.

A more explosive phase of boiling resulted in extensive hydraulic fracturing of the lower Pilot shale anf the foramation of hydrothermal explosion breccias. This explosive activity may have been the result of self-sealing of the system by the precipitation of silica in the upper parts of the faults/conduits. Self-sealing of the conduits would have allowed the lower, permeable Pilot shale to be flooded by solutions under lithostatic load. The relatively impermeable upper Pilot shale claystones, presumably already folded into an anticline, could have aided in the ponding of solutions in the lower Pilot shale. Pressure release caused by rupturing of the seal by renewed fault







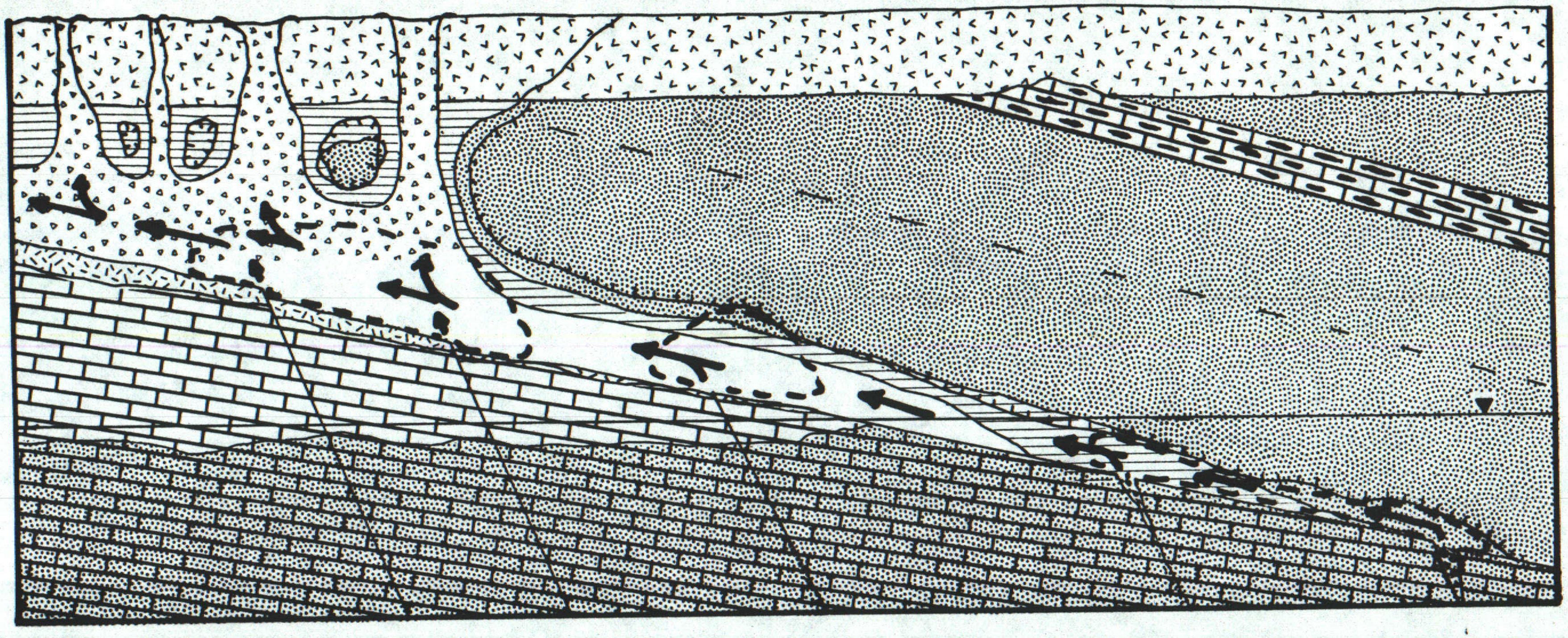
movement or by the pressure buildup exceeding the lithostatic load plus the rock tensile strength, would result in decompression of the fluid-saturated lower Pilot shale and flashing of the confined solutions to steam. Decompression would also promote the rapid effervescing of dissoved gases such as CO2. The pore-fluid in the lower Pilot shale, flashed to steam, hydraulically fractures the rock as it expands. Where a pathway exists to the surface, vapor and gas streaming could occur, brecciating the rock and transporting rock fragments upward to form the hydrothermal breccia bodies. At Alligator Ridge, the vapor streaming carried fragments of the early-formed basal jasperoid-breccia as much as 200 feet upward from the base of the Pilot shale and rounded them during transport.

Another possible mechanism for breccia-body formation would be formation of a "gas cap" (Hedenquist and Henley, 1985). Since the concept of self-sealing is not universally accepted, Hedenquist and Henley (1985) proposed that once self-sealing closed off the conduit and the hydrothermal system diverted to another, vapor/steam and CO2 from boiling and effervescing could collect under the sealed zone creating local overpressurized zones. Rupturing of the seal by the processes described above would initiate a hydrothermal explosion followed by gentle boiling. Either mechanism would result in the observed features.

Some gold may have been deposited due to destabilization of thiosulfate complexes during boiling . Pre-existing gold mineralization was coarsened and leached of silver in the oxidizing environment created by boiling, resulting in the change in the gold-to-silver ratio mentioned earlier.

Up-dip fluid flow in the lower Pilot shale may be responsible for some of the larger scale alteration zonation and features observed in the Alligator Ridge deposits (figure 16). It seems likely, based on alteration zonation, that the Pilot shale was dipping to the south during alteration and gold mineralization. Some of the features that this process explains are: 1.) the increase in thickness and continuity of the basal jasperoid-breccia sheet, 2.) The overall zonation of hypogene alteration in the deposits, and 3.) the localization of the explosive activity in the Vantage-1 and -2 hydrothermal explosion breccias above the basal jasperoid-breccia sheet.

Precipitation of silica from solutions flowing upward along the Devils Gate/Pilot shale contact would have been promoted by simple cooling and by pressure release as the fluids approached the surface. Boiling, and the hypogene oxidation and acid-leaching, may have been caused by updip flow of the solutions and the resulting change in pressure. It is also likely that the below the ancient water table reducing conditions were more likely to occur. A hypothetical water table is shown in the idealized cross-section section in figure 16. The explosive hydrothermal activity was localized in the lower Pilot shale because the updip-flowing solutions passed through the lower Pilot shale and above the earlier-formed jasperoid-breccia zone. Self-sealing or gas-cap formation, discussed above, would have released pressure on solutions mainly contained in the Pilot shale and uppermost part of the jasperoid-breccia zone, hence the apparent lack of Devils Gate limestone clasts and apparent "rootless" nature of the hydrothermal breccias. The carbonaceous hydrothermal breccias in the Devils Gate limestone are the result of boiling of solutions and solutions at and not above the Pilot shale-Devils Gate limestone contact. Because the boiling occurred below the water table, and because of the abundance of carbonaceous material and carbonate, the solutions were unable to become strongly oxidizing or of low pH, except locally. The presence of hydrothermally altered carbonaceous material in the Devils Gate limestone and the breccia bodies suggests that organic complexes could



have been important transport mechanisms for gold.

## SUMMARY AND CONCLUSIONS

The Alligator Ridge disseminated gold deposits are apparently relatively young and represent the root zones of a hot springs-type system. This is suggested by the alteration zonation, type of alteration (especially the hypogene oxidation and argillization), the alteration mineral suite (especially jarosite, alunite, and kaolinite), and the presence of hydrothermal explosion breccias.

Ore-body genesis can be divided into three phases: 1.) an initial barren phase of jasperoid-breccia formation, 2.) a phase of gold deposition within the carbonaceous Pilot shale, and 3.) a final phase of boiling, acid-leaching, strong hypogene oxidation, and explosive hydrothermal brecciation. During the final stage, some gold deposition may have occurred, but it is evident that much of the coarse gold in the oxidized ore is reworked submicron gold originally deposited in carbonaceous rock.

The genetic model developed for the Alligator Ridge deposits, although not definative, uses up-dip flow of the hydrothermal solutions through the Pilot shale to explain the large-scale overall alteration zonation. On a smaller scale, physical processes such as throttling and self-sealing or formation of a gas-cap controlled boiling and explosive brecciation.