BIOGEOCHEMISTRY

Discovery Using Metal Concentrations in Plants

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West Generator Deposit, Jerritt Canyon District

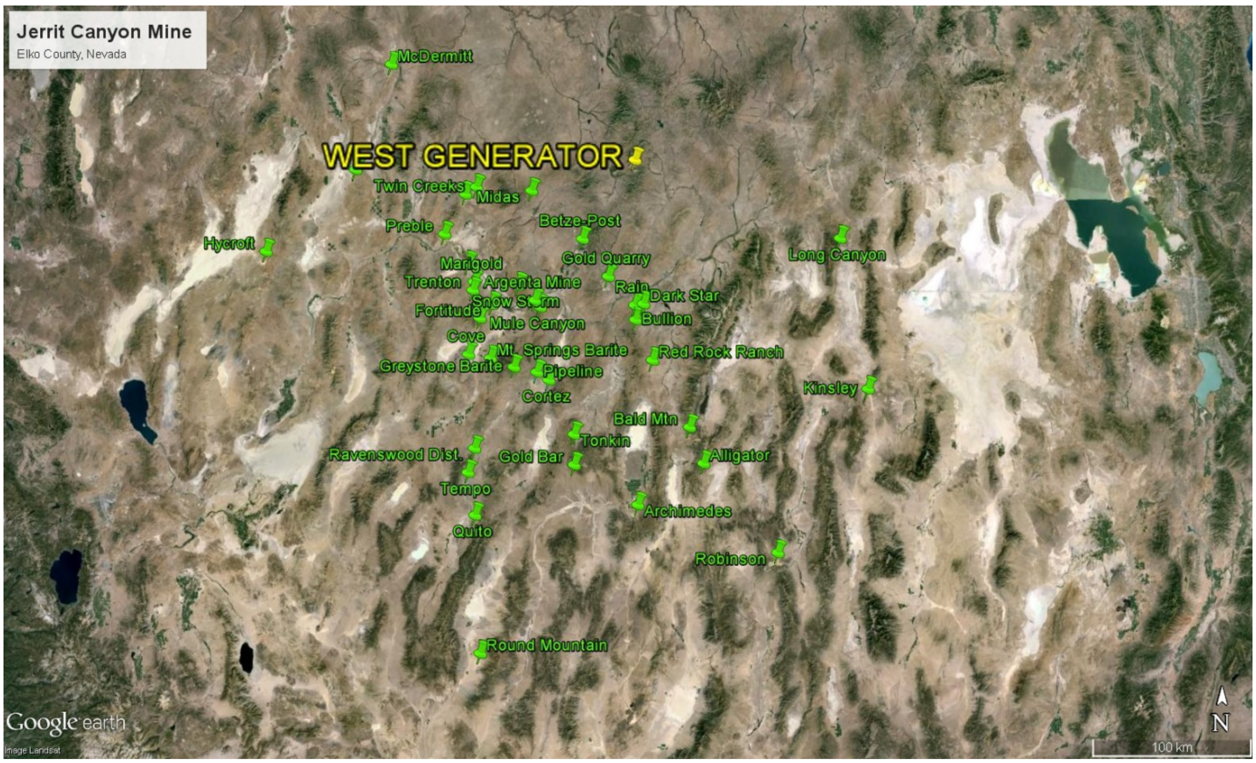
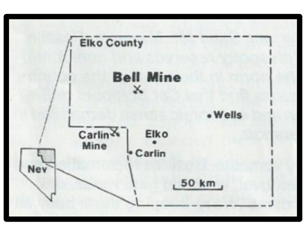


Fig 1. Location map of West Generator, Jerritt Canyon District, relative to other gold mines in Northern Nevada.

Introduction



Ore discovery in the Jerritt Canyon district was a 70/30 joint venture between Freeport Gold Company and FMC Gold Inc. In the early 1970's FMC began reconnaissance exploration in the district looking for antimony, guided in part by Nevada Bureau of Mines publications. Anomalous gold and pathfinder anomalies in soil were drilled in 1973 at the "Alchem" target on the North Fork of Jerritt Canyon (Figs 6 & 7). The hole encountered "interesting" grade yet uneconomic tonnage in lower portions of the Roberts Mountain Formation. After three more years of mapping and soil sampling, Freeport (now operator), discovered the Marlboro Canyon orebody, which began operations as the E.B. Bell Mine in the fall of 1976. However, it was not soil or sediment geochemistry that led to discovery, since the discovery hole was in an area that was geochemically barren. Rather, Freeport claims it was mapping and new structural interpretation that was key to their success. The first gold bar was poured in on July 4, 1981 (Hawkins, 1982).

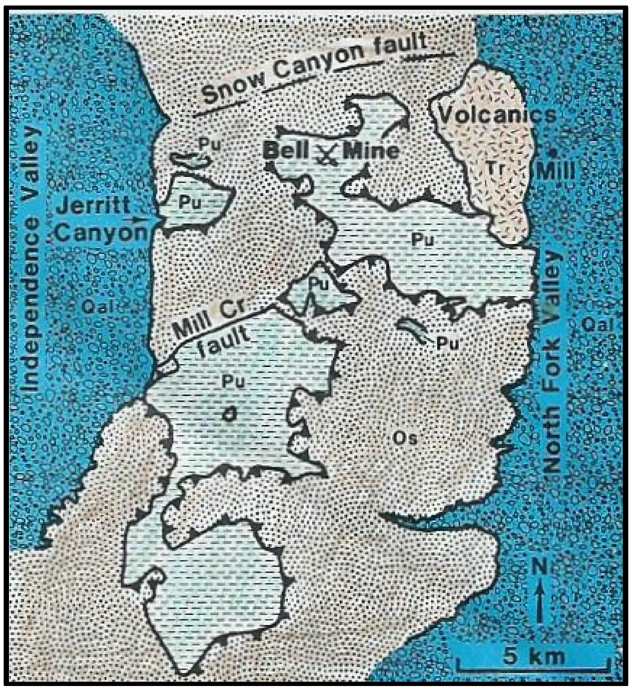
Fig 2. Location map of West Generator in the Jerritt Canyon Mine complex, Elko County, Nevada.

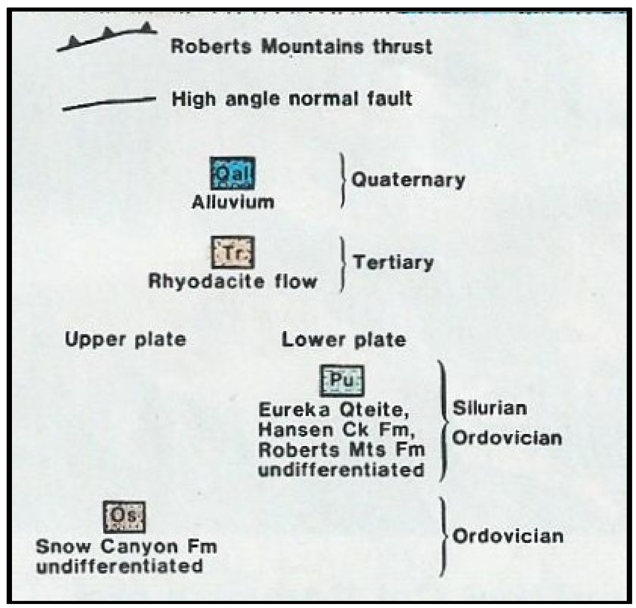
Fig 3. Location map of the pre-mining 1985 West Generator biogeochemical and mercury soil gas surveys, superimposed onto the current mine workings.

In the summer of 1985, Freeport initiated a biogeochemical survey over the newly discovered West Generator deposit. These were early tests, with the intent to determine which plant tissues and plant species were useful for the detection of blind mineralization. A mercury soil gas collector survey was also undertaken. The contents of this presentation report the results of these survey data. Hopefully the reader will appreciate that this work was done after discovery, but well before mining of the West Generator deposit, and how biogeochemistry and soil gas geochemistry can add to the efficiency of discovering the next Jerritt Canyon.

Geology

The Jerritt Canyon District is in the Independence Range of north-central Elko County, Nevada, and lies at a regional stuctural crossroads, the most important of which is the Midas Trough, home to the Twin Creeks Mine and the Midas Mine. The Bell Mine is located in the northern quarter of the Jerritt Canyon Window in Sections 33,34, and 35 of Township 41N, Range 53E. The geology of Jerritt Canyon is similar to that of the Lynn Window that hosts the Carlin Mine (Radtke, et al.). Siliceous rocks of the western facies were thrust over carbonate rocks of the eastern facies along the Roberts Mountains thrust fault in the late Devonian period as the Antler Orogeny culminated.

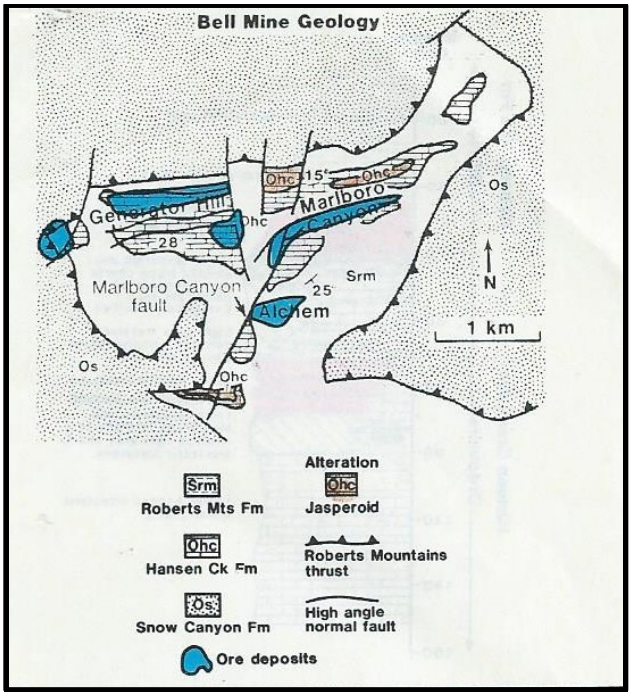


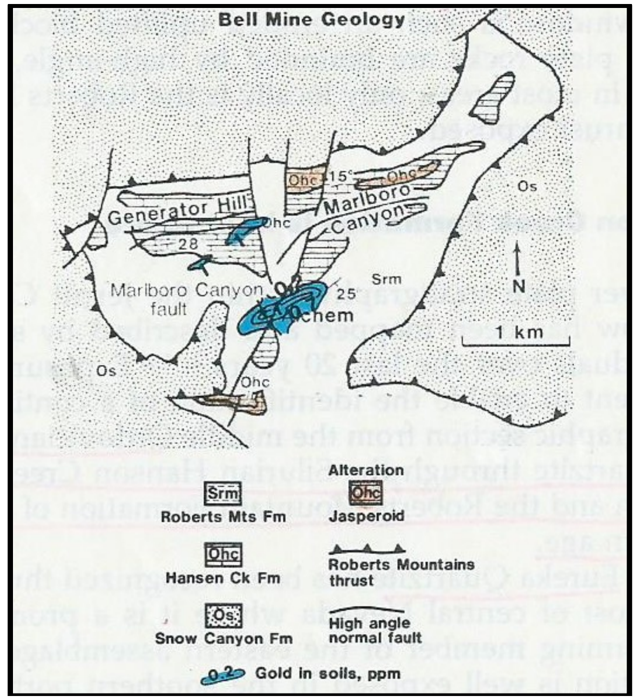


Hanson Creek Formation (Ohc) is the primary gold host in the Jerritt Canyon District. It is composed of reactive carbonates characterized as banded, interbedded carbonaceous and shaly limestones, to massive, cherty, bioclastic limestones and dolomites, to fine grained, banded, grey-black carbonaceous limestone. Bounding these productive units are massive limestone units that have been hydrothermally altered to jasperoid.

The basal 60 m of the Roberts Mountain Formation (Srm) is a relatively minor gold host at Jerritt Canyon. It is composed of reactive carbonaceous carbonates, calcareous siltstones, and dolomites. Carbonaceous matter is contains sygenetic and diagenetic pyrite, some of which is gold bearing. Exposures of Srm dominate all other ore-bearing host rocks at Jerritt.

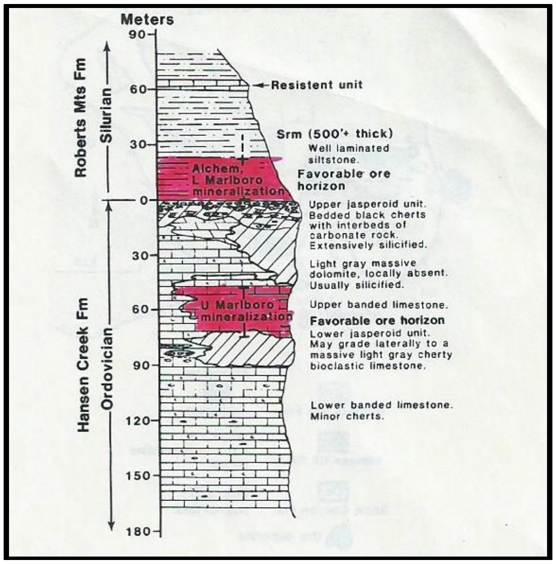
The Snow Canyon Formation (Os) is a western facies Upper Plate unit that has been thrust over Srm north of the Jerritt Canyon Window. Snow Canyon Fm. is correlative with Valmy Group rocks, and is composed of interbedded cherts, argillite, shale, and quartzite, with minor greenstones, limestones, and bedded barite.

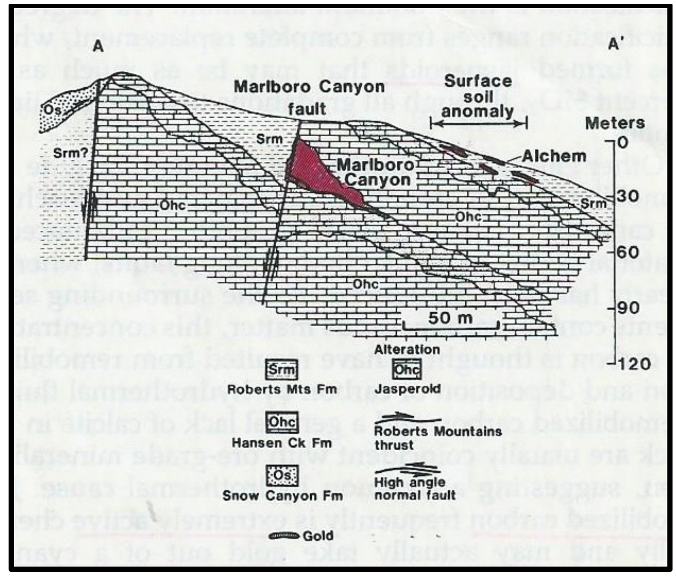




Figs 6 & 7. Geology of the Bell Mine, showing ore deposits (6) and soil geochemical anomalies.

High angle normal faults dissect the stratigraphy and include east-west sets (oldest), northeast sets (ore bearing), and northwest sets (post-mineral). High angle faults are associated with drag folds and breccia zones, which created favorable porosity and permeability for later hydrothermal gold mineralization. Thickest ore bearing zones are adjacent to these faults, which thin and decrease in grade away from the faults. At North Generator Hill (the location of biogeochemical sampling), higher grades and greater thicknesses are found in the deformed and fractured host rocks proximal to northeast trending faults.
Hydrothermal minerals that are associated with gold include realgar, orpiment, arsenopyrite, and cinnabar. Therefore, arsenic and mercury concentrations in plant tissue should be directly related to ore at West Generator. Stibnite (Sb), barite (Ba), and quartz occur with jasperoid alteration and are believed to have formed during the later stages of mineralization.





Figs 8 & 9. Generalized stratigraphy and north-south section through the Bell Mine, looking east.

Biogeochemical Survey

Two species of sagebrush were collected: Artemisia tridentata and A. arbruscula. Distribution was dependent on elevation and soil composition, where dwarf sage (arbruscula) dominate at higher elevations and in areas of more calcareous soils. Both leaves and twigs were collected and treated separately at MEG Labs (Carson City, NV). Sample spacing was 100 feet on two E-W lines that were approximately 600 feet apart. Splits of each tissue (leaf or twig) were washed and the washed and unwashed data were compared.

Geochemical analysis was reported by X-Ray Assay Laboratories, Toronto, Canada, (XRAL) on October 3, 1985. Analytical preparation involves pelletizing 8 grams of dry plant tissue. Instrumental neutron activation analysis (INAA) reports concentrations of As, Au, Ba, Br, Cr, Fe, Mo, Sb, U, W, and Zn, which are useful for mapping structures and defining zonation related to the gold system.

XRAL also reported Ag, Cu, Pb , and Zn concentrations after digesting 30 grams of ashed sample in aqua regia. Mercury was reported after wet digestion in aqua regia (without ashing). Analysis was done by either atomic absorption (AAS) or plasma spectrophotometry (DCP).

These biogeochemical data were later compared to results from the mercury soil gas collector survey.

Results

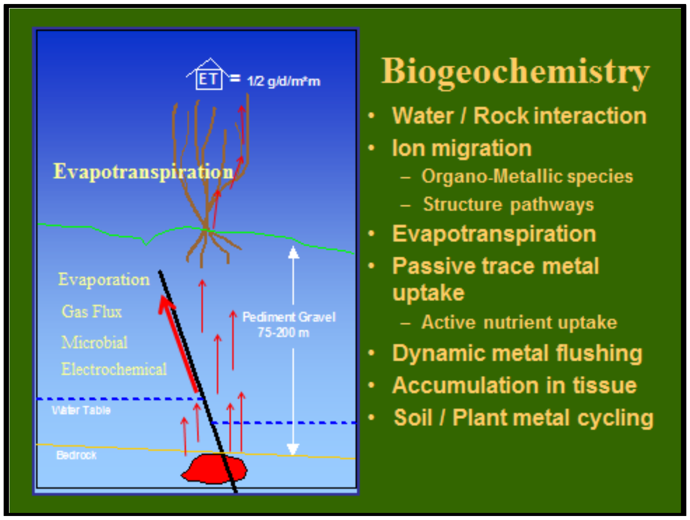
Washing proved to be important for the removal of mineralized dust. At the time of the survey, reverse circulation exploratory drilling was ongoing, and in 1985 RC drilling was done dry. Consequently, dust was a hygienic and environmental hazard, as well as a hazard for reliable geochemical survey work. Air-borne dust (inorganic and organic) in windy arid environments is still a problem. Drilling is now done with water circulation to sequester fugitive dust. Nevertheless, human sources (road traffic, excavation, industrial activity, mine activity, etc.) and natural sources (plant pollen, wind-borne dust, etc.) will always create an opportunity for contamination, so washing continues to be part of the sample preparation procedure.

This study shows that metal concentrations in leaves are generally higher than twigs for gold and pathfinder elements. However, field and analytical duplicates show leaf data to be more highly variable, and therefore less reliable. Since pattern rather than high concentration is a better guide to ore, the more stable washed twig data are preferred for interpretation when metal concentrations are sufficiently above analytical detection limits. In this survey, some metal concentrations in twigs tissue were at or below detection, consequently leaf data were used for interpretation.

Mercury soil gas anomalies were the most direct indicator of underlying mineralization (Fig 20). The highest mercury soil gas concentrations were over ore that was 200-300 feet deep. Curiously (at the time) higher concentrations were achieved over deeper ore. It is now appreciated that volatile mercury is released where oxidizing ground water and microbial activity interact with mineralization, releasing plumes of molecular mercury to the surface through structural pathways including low-angle and high-angle structures, and joints and fractures in the hanging wall. Depending on the depth to the interaction zone, survey data may show higher biogeochemical metal concentrations over deep ore, and lower concentrations over shallow ore.

Biogeochemical mercury in leaf tissue also provides reliable indication of ore. Unlike mercury soil gas, however, the anomalous pattern is shifted to the west as the result of up-dip migration along bedding and post-mineral structures.

Interpretation of the biogeochemical gold pattern (Figs 10 & 11) relied heavily on supporting pathfinder data. The best pathfinders were mercury (Figs 18 & 19) and bromine (Figs 16 & 17) in leaves, and arsenic (Figs 12 & 13) in twigs. Collectively, they indicated Lower Plate mineralization 100-300 feet deep. Biogeochemical data seemed to be extremely influenced by structure, which provides a major conduit for upwardly percolating ground water and sustenance for those fortunate sagebrush that effectively exploit this source of water. Bedding faults at West Generator have dips to the southeast of 25-30 degrees, which accounts for many anomalies with up-dip offsets of 100-300 feet from actual ore location.



Barium appears to be very reliable for mapping Lower Plate exposures and geochemically determining the Upper Plate / Lower Plate contact (Figs 14 & 15). At West Generator, Lower Plate rocks have a higher Clarke abundance of barium, resulting in Ba concentrations of 50-200 ppm. In contrast, Upper Plate rocks have significantly lower Ba concentrations resulting in sagebrush concentrations < 50 ppm. Studies in other areas have shown that biogeochemical data are useful as a bedrock lithogeochemical mapping tool through thick overburden.

Barite is also found in oxidized ore and jasperoids, and so in part, biogeochemical barium anomalies may be a reflection of oxidized ore in the Lower Plate exposures of the Roberts Mountain Formation.

High zinc concentrations appear to indicate sulfide ore at West Generator (Figs 33 & 34). Sphalerite is part of the sulfide mineral assemblage in sulfide / carbonaceous ore (also including pyrite, realgar, orpiment, cinnabar, arsenopyrite, and graphite). Lead and copper are not reliable pathfinders in the Jerrit system.

Jasperoids have a relatively restrictive mineralogy including stibnite, variscite, wavellite, apatite, (calcium and aluminum phosphates), and fluorite (Daly, et al.). Bromine and fluorine are mobile halogens and useful pathfinders to many if not most hydrothermal ore deposits. Bromine anomalies at West Generator (Figs 16 & 17) reside almost exclusively over the mine pit, and appear to indicate deep ore, presumably associated with jasperoid alteration.

Gold concentrations in sagebrush from West Generator reached highs of 3-10 ppb, with broad zones of 1-2 ppb (Figs 10 & 11). It was not appreciated at the time of this survey that these concentrations represent the upper 90^{th} percentile of all biogeochemical gold concentrations commonly encountered in the Great Basin. Biogeochemical gold tends to be anomalous near structures where plants uptake metal from upwardly percolating ground water. Offsets can occur when structures guide the metal plume up-dip. Pattern anomalies at somewhat lower concentrations can occur over mineralization in the hanging wall.

Conclusions

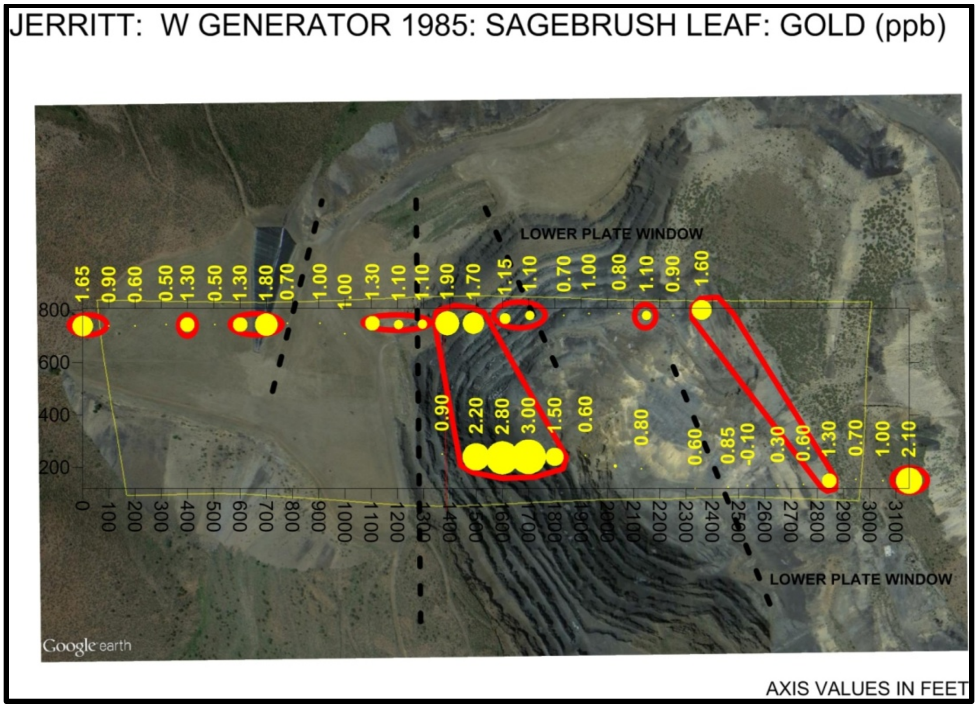
The challenge for biogeochemistry (and mercury soil gas geochemistry) at West Generator was to detect blind ore through over-thrust Upper Plate rocks. Ideally, anomalies would directly overlie gold ore that was known to be 200 – 300 feet deep.

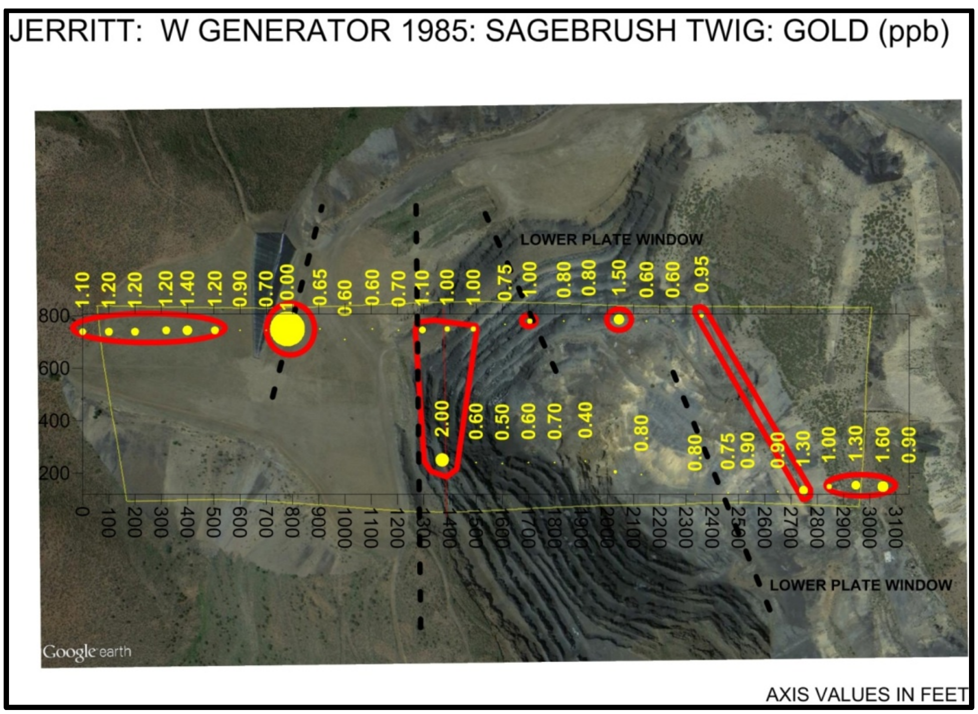
The gold pattern did not create a footprint as a direct reflection of deep ore. Instead, it indicated post mineral faults where mineralized ground water had migrated up-dip, creating offset gold anomalies from deep ore locations. Pathfinder metals, like arsenic, mercury and bromine, were better indicators of deep ore location perhaps because these more mobile metals found vertical pathways (joints, fractures, etc.) to the sagebrush rhizosphere. Other metals (cobalt, selenium, uranium) may have also been useful pathfinders, but analytical detection did not sufficiently provide background / anomaly contrast. Analytical methods have greatly improved since this survey was completed. Currently, 60 elements are now reported with detection limits to well below crustal abundances.

Mercury soil gas is a very reliable pathfinder to West Generator ore. The anomalous pattern is found almost exclusively over the mine pit. Equally reliable is mercury in leaf tissue, yet the pattern shows some offset to the west due to up-dip migration along bedding and post-mineral structures.

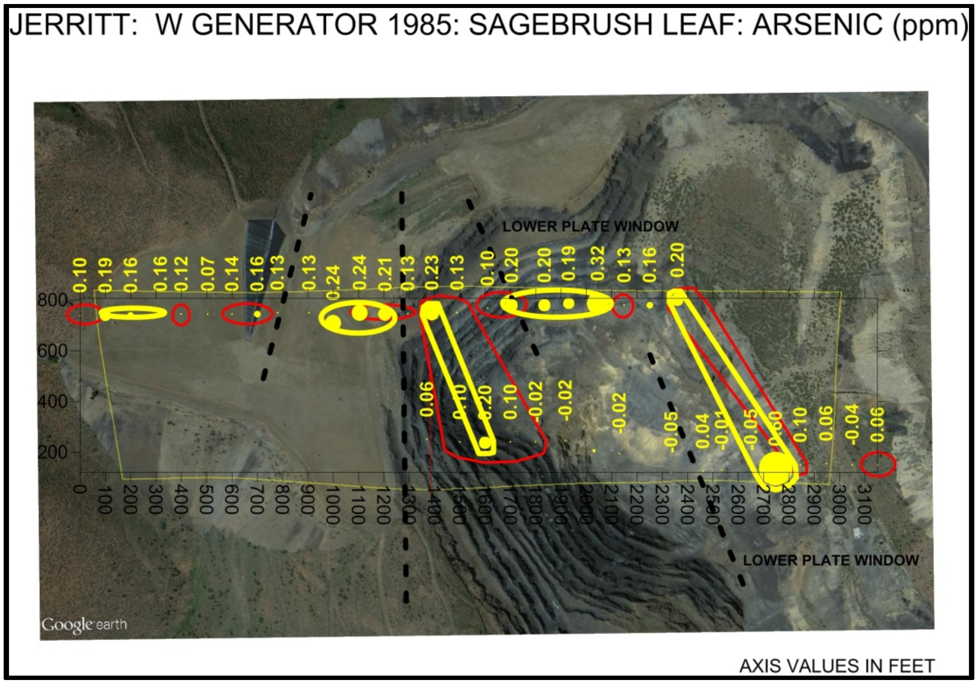
Barium appears to be a good lithogeochemical mapping tool for Lower Plate rocks. Barium in particular shows the contact between over-thrust Upper Plate and exposed Lower Plate rocks very clearly. Barium is also associated with oxidized ore and jasperoid alteration. The biogeochemical barium pattern over the mine pit might also be an indication of oxidized ore and mineralized jasperoid.

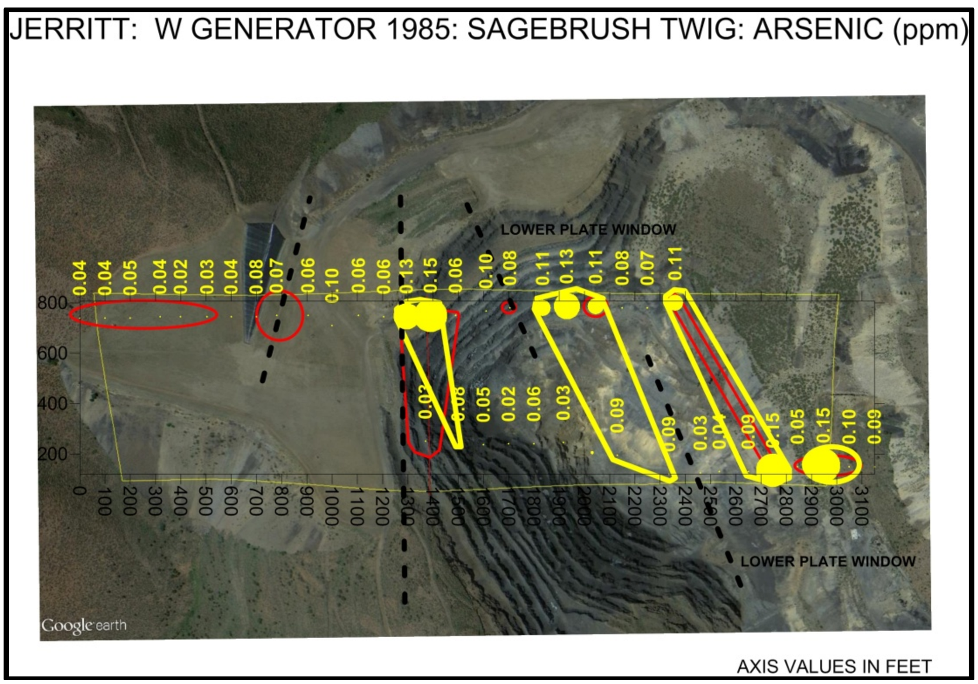
Zinc as sphalerite is part of the sulfide / carbonaceous ore mineralogy. Biogeochemically, it appears to be a good pathfinder to unoxidized ore.



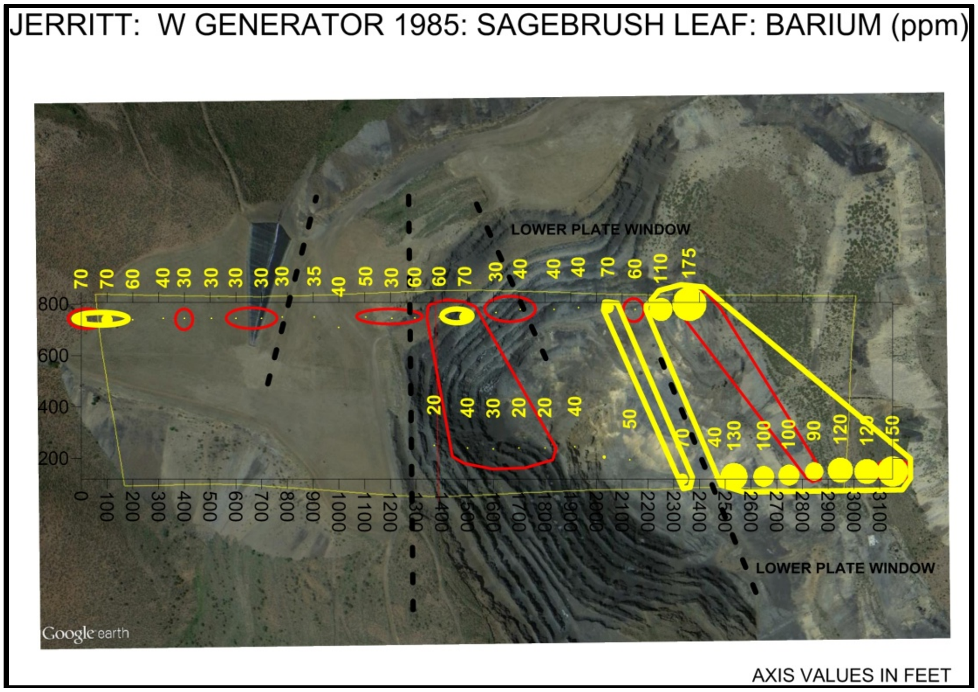


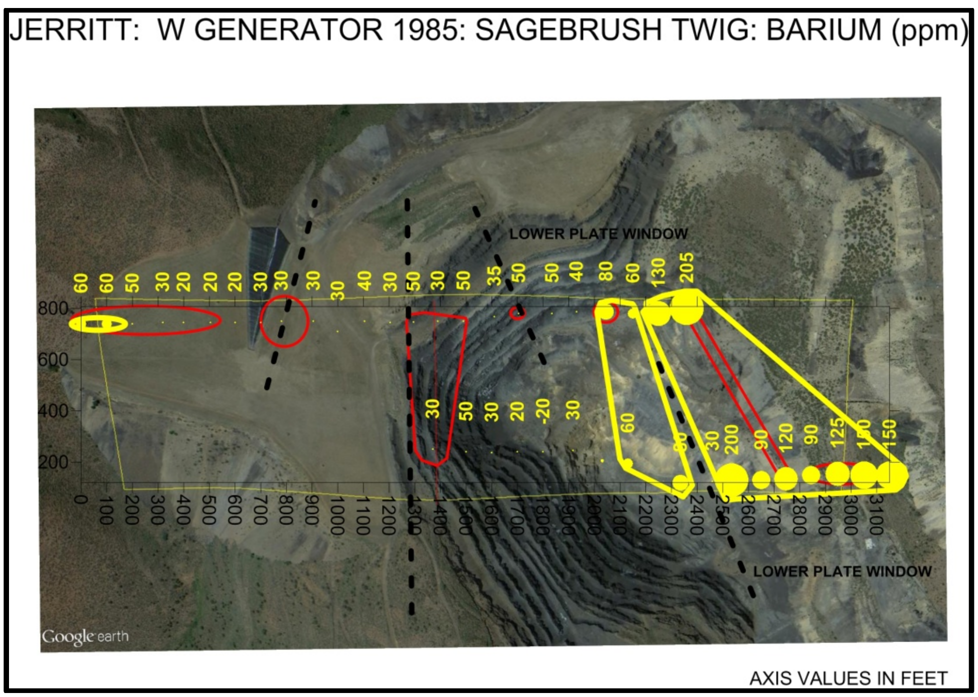
Figs 10 & 11. Gold concentrations are higher in leaves and biogeochemical anomalies are more extensive. Note the up-dip anomaly offset from deep ore (pit center). Also note that higher gold concentrations are found on the south line where oxidizing ground water / microbe / ore interaction was likely more active. Upper Plate rocks far west of the pit may be mineralized.



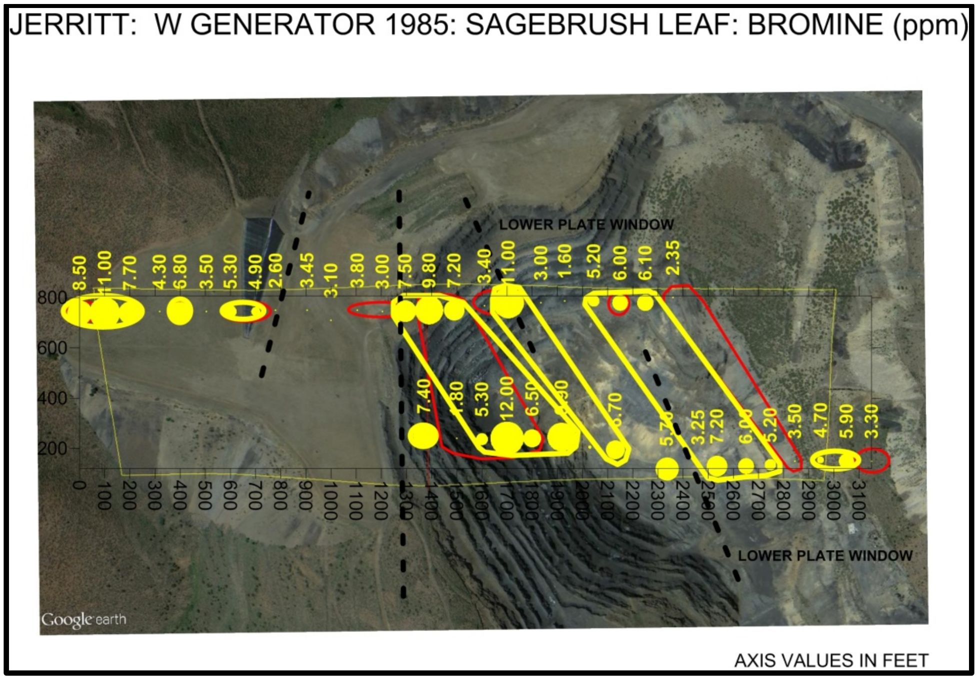


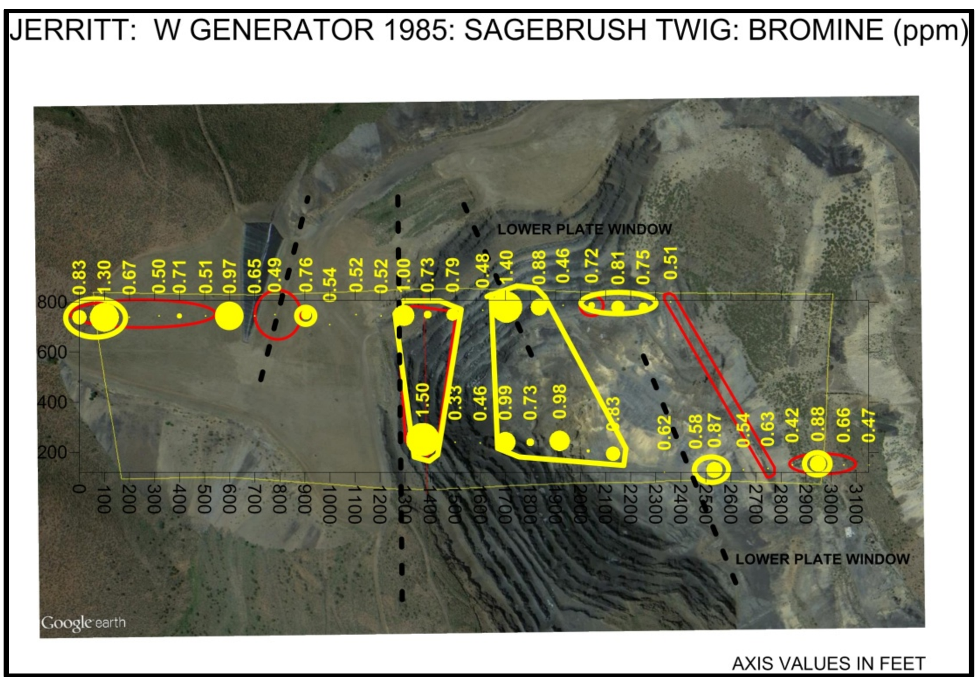
Figs 12 & 13. Arsenic is anomalous at the pit margins, suggesting that As is mobilized within bounding structures to sagebrush roots growing near those structures. Post-mineral faults and thrust margins preferentially mineralize the sagebrush, yet geological mapping indicates that it is northeast faults that are ore bearing.



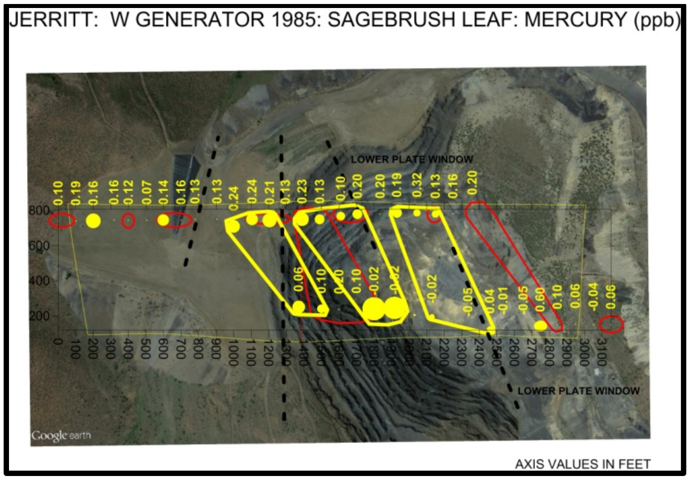


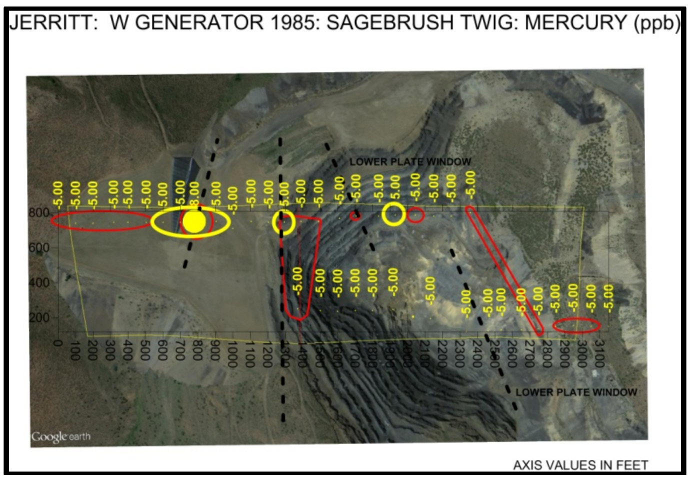
Figs 14 & 15. Barium in both leaves and twigs map the Lower Plate rocks and distinctly show the contact between Upper and Lower Plate assemblages. Barium is also associated with oxidized ore and jasperoid alteration. The barium pattern over the mine pit might be indication of oxidized ore and jasperoid. Note that Ba concentrations in twig tissue are generally higher than in leaf tissue, suggesting different biochemical compartmentalization than other metals.

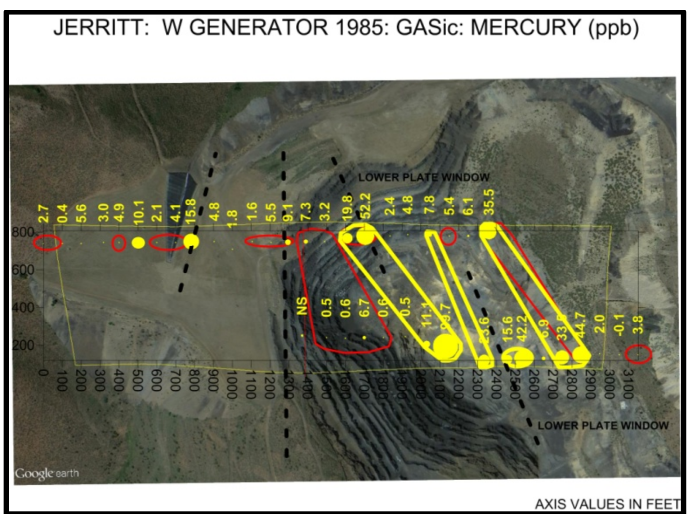




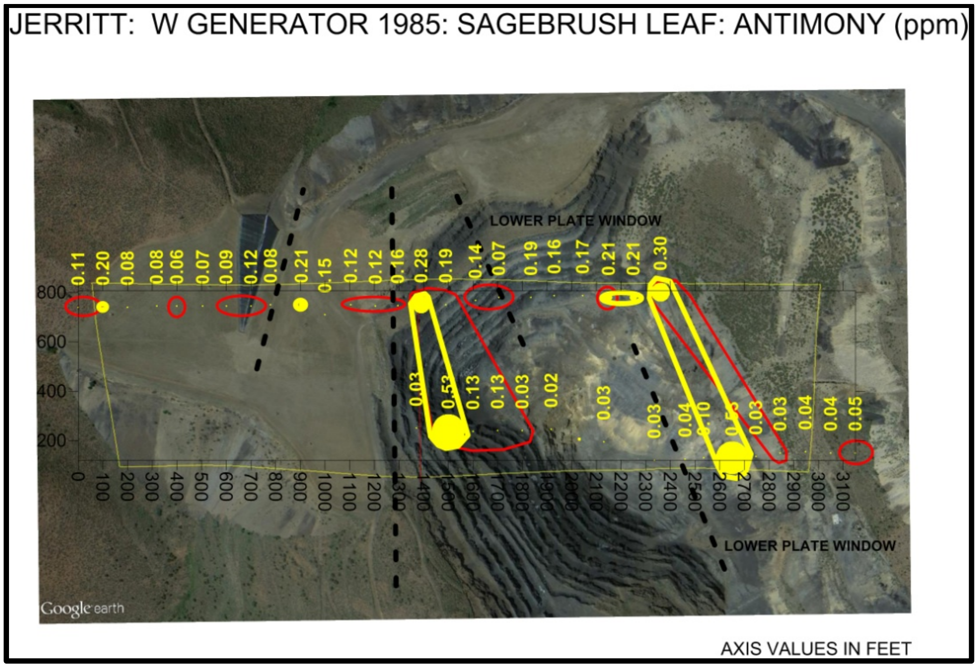
Figs 16 & 17. Bromine is highly mobile and a good pathfinder to deep ore. Most of the anomalous Br concentrations are found over ore. Some of these anomalies are related to Lower Plate ore that is biogeochemically detected through Upper Plate rocks.

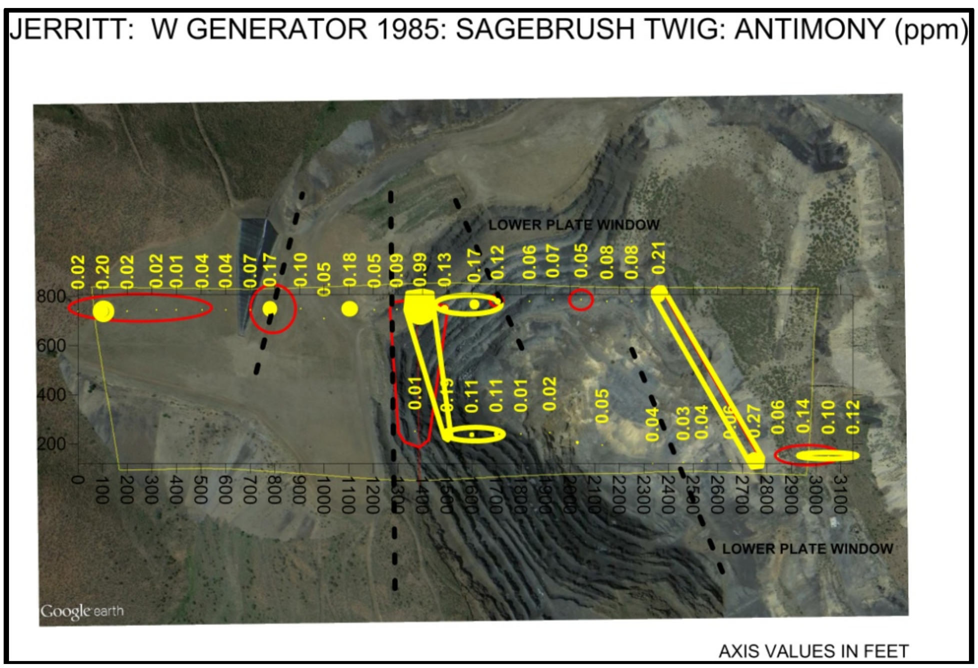




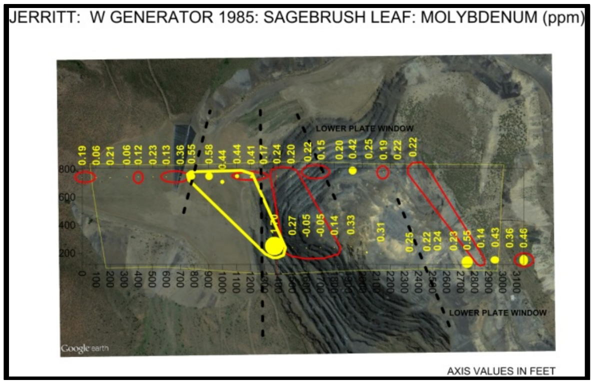


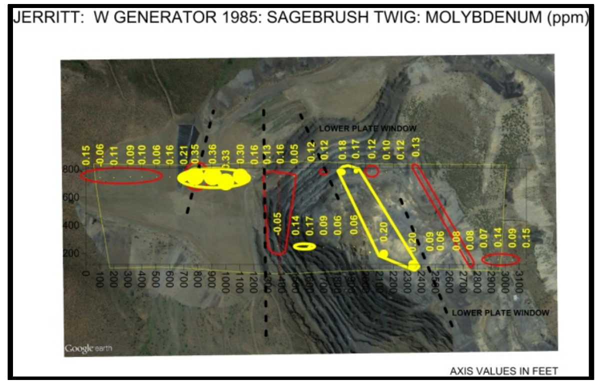
Figs 18 & 19 & 20. Mercury in leaves achieve anomalous concentrations over ore. However, the analytical method for twigs raised the limit of detection so that these data were not diagnostic. Mercury soil gas data (GASic) was very much like mercury in leaves, yet achieved much higher contrast. Note that higher mercury soil gas concentrations were obtained over the deepest ore.



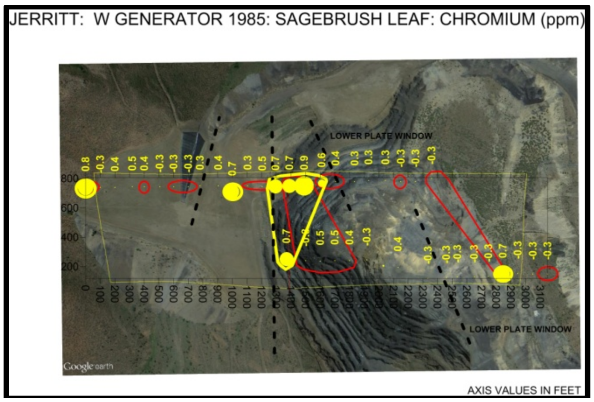


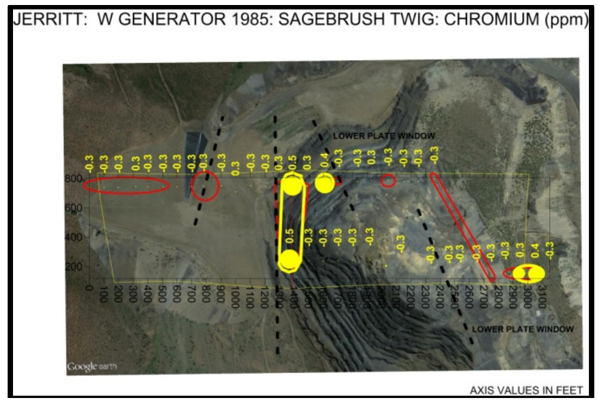
Figs 21 & 22. Though the Jerritt District is known for high antimony, sagebrush did not accumulate much from ore-grade mineralization. Much like arsenic, antimony anomalies highlight bounding structures. Antimony (stibnite) is also known to be restricted to jasperoid.





Figs 23 & 24. Molybdenum does not behave as a pathfinder to Jerritt gold mineralization.





Figs 25 & 26. Chromium does not behave as a pathfinder to Jerritt gold mineralization.

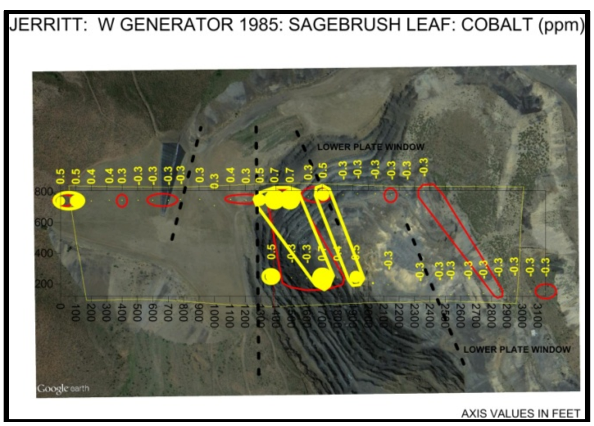
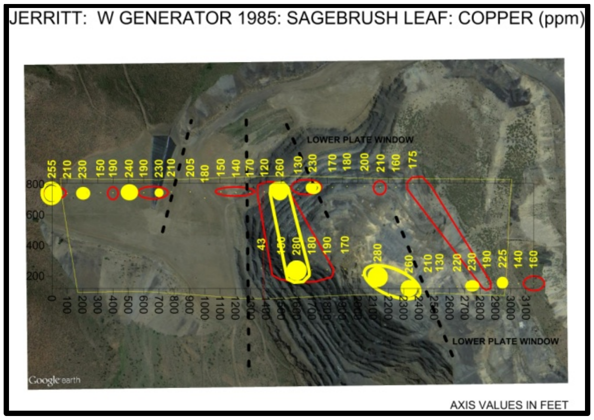
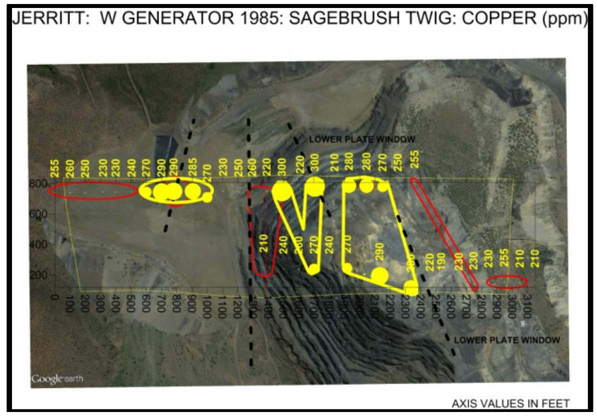
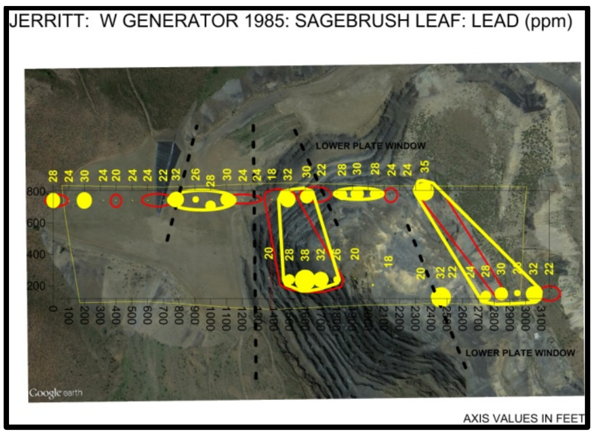


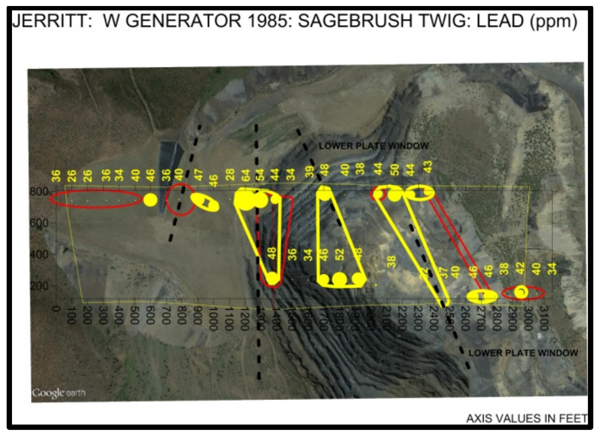
Fig 27. High detection limits for cobalt preclude it as a reliable pathfinder to gold mineralization.



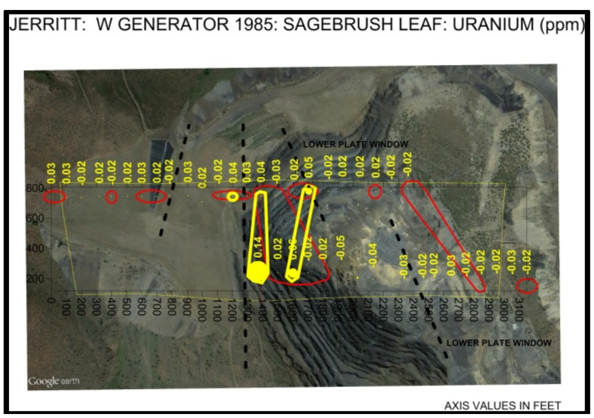


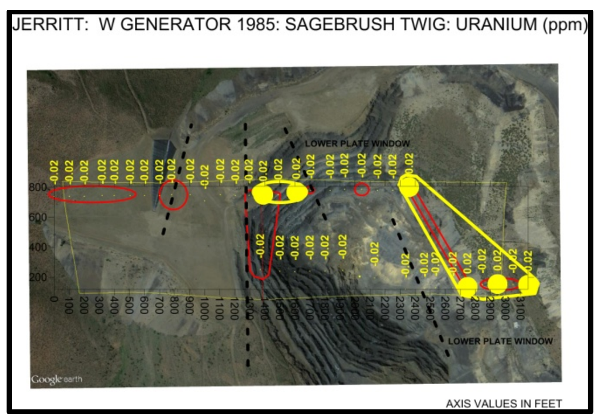
Figs 28 & 29. Copper in twig tissue may have some utility as a pathfinder to gold mineralization.



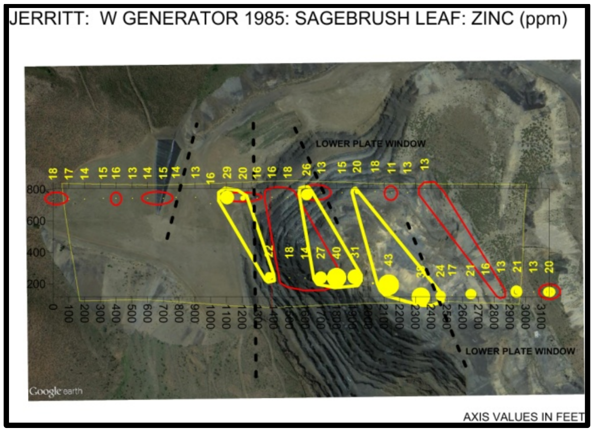


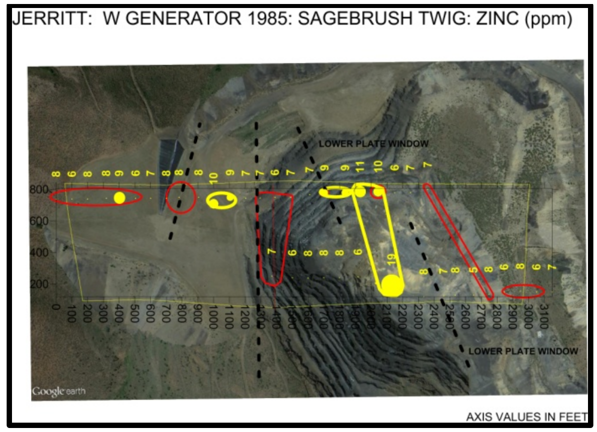
Figs 30 & 31. Lead may have some utility as a pathfinder to gold mineralization.





Figs 32 & 32. With lower detection limits, Uranium may have been a reliable pathfinder to oxidized Jerritt gold mineralization.





Figs 33 &34. Zinc is a pathfinder to sulfide / carbonaceous gold ore at Jerritt.

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