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FREDERICTON, NEW BRUNSWICK, CANADA

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NEW AND OLD DISCOVERIES: GEOCHEMICAL EXPLORATION CASE STUDIES

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Using regional geochemistry, geology, aeromagnetics, Landsat, and digital elevation models (DEM) to define favourable areas for porphyry-style mineralization in southwestern Alaska

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ABSTRACT: The Late Cretaceous (90 Ma) Pebble Cu-Au-Mo porphyry deposit is located within the southern Kahiltna terrane, which is comprised of the Chilikadrotna Greenstone and the Koksetna River sequence. Near the Pebble deposit, the Chilikadrotna Greenstone marks the northwest border of the southern Kahiltna terrane, and the Koksetna River flysch sequence is the host for mineralization at Pebble. Throughout the world, porphyry deposits are found in clusters associated with multiple intrusive events, typically, if not always, subduction-related, thereby suggesting the southern Kahiltna terrane is potentially favourable for other porphyry occurrences. Our integration of multiple geoscientific data layers has revealed that the world-class Pebble deposit may similarly be accompanied by additional porphyry-style mineralization elsewhere in the southern Kahiltna terrane. Delineation of watersheds, derived from processing of digital elevation data, provided an effective framework for predicting favourable areas for mineralization. Beyond analysis of individual data layers of geochemistry, geology, geophysics, and remote sensing, geographic information systems (GIS) applications facilitated an integrated approach that provided a more refined and detailed process to locate potential mineralization within those watersheds. Preliminary results suggest 23 watersheds contain favourable geochemical, geological, and geophysical signatures for Pebble-like porphyry-style mineralization.

KEYWORDS: *Pebble, Porphyry Cu-Au-Mo, Regional Targeting, Southwest Alaska, Kahiltna Terrane*

INTRODUCTION

Regional-scale spatial data are readily available from numerous United States Geological Survey (USGS) websites. The individual datasets can be processed and enhanced to help identify areas of particular geologic phenomena, in this case mineralization. Individually, these enhanced products provide clues to the underlying geology, but when integrated in a geographic information system (GIS), they allow a more detailed interpretation that can delineate favourable areas for porphyry-style mineralized rock.

The Pebble Cu-Au-Mo porphyry deposit (Fig. 1) contains one of the largest resources of copper and gold in the world (NDM 2009). Porphyry deposits typically occur in clusters within subduction-related magmatic belts, suggesting the possibility of multiple occurrences of porphyry-style mineralization near the Pebble deposit, within the southern Kahiltna terrane. In this study, we use USGS spatial data to locate additional highly favourable areas for porphyry-style mineralization around the Pebble deposit. Such datasets include, but are not limited to, geochemistry, geology, aeromagnetics, Landsat imagery, and Digital Elevation Models (DEM).

GEOLOGICAL SETTING

Regional Geology

The Late Cretaceous Pebble deposit is located within the southern part of the Late Jurassic to Early Cretaceous Kahiltna terrane, which is bounded to the southeast by the Peninsular terrane (Late Triassic to Late Jurassic) and to the northwest by flysch of the Kuskokwim Group (middle to Late Cretaceous) (Fig. 1). The southern Kahiltna terrane consists predominately of Jurassic to Cretaceous turbidite deposits and can be divided into two major lithologic units: the Koksetna River sequence and the Chilikadrotna Greenstone (Wallace *et al*. 1989). The

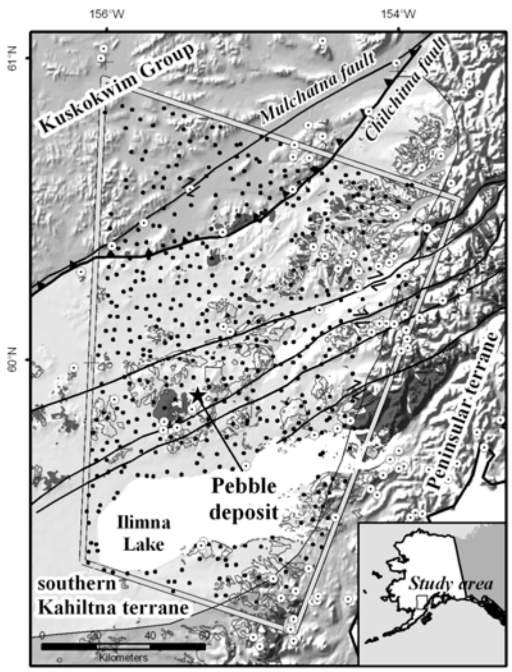

Fig. 1. Index map showing the location of the study area (double line). The southern Kahiltna terrane is located between the Kuskokwim Group and the Peninsular terrane. The localities of 485 regional geochemistry samples are shown as black dots. Generalized geologic structures are shown as black lines. Late Cretaceous-Tertiary intrusions shown in dark gray. Tertiary-specific rocks are outlined in gray. Reported mineral occurrences are shown as white circles.

deformed, interbedded volcaniclastic turbidites. The sediments of the Koksetna River sequence are mainly derived from the Peninsular terrane. These sedimentary rocks host the porphyry-style mineralization at Pebble. The Chilikodrotna Greenstone (Bundtzen *et al*. 1979) occurs near the northwestern boundary of the southern Kahiltna terrane and is comprised mainly of massive altered basalt. The contact between rocks of the Chilikodrotna Greenstone and the Kuskokwim Group is the steeply NW-dipping Chilchitna fault, which merges with the subparallel Mulchatna fault to the northwest (Wallace *et al*. 1989). The southern Kahiltna terrane is progressively covered towards the southeast by unconformably-overlying, mostly latest Cretaceous to Paleocene volcanic rocks of the Alaska Range (Wallace *et al*. 1989; Wallace & Engebretson 1984).

Local Geology

The Pebble district is comprised of gently folded rocks of the Koksetna River sequence that have been cut by diorite sills (Rebagliati & Lang 2008). Magmatism in the district includes a pre-hydrothermal ca. 96 Ma group of alkalic and subalkalic intrusions, and a ca. 90 Ma group of granodiorites which includes the Kaskanak batholith and plutons associated with the deposit. Hydrothermal mineralization at Pebble has a Re-Os date of ca. 90 Ma (Lang *et al*. 2008). Also in the district a later pulse of hydrothermal activity associated with an epithermal Au-Ag prospect occurred at ca. 46 Ma (Lang *et al*. 2008).

Hydrothermal alteration at Pebble consists of a central, strong K-silicate assemblage with sparse magnetite, and peripheral sericitic alteration that overprints the deposit, with propylitic and illite assemblages present locally (Rebagliati & Lang 2008).

METHODS

Multidisciplinary spatial datasets have been downloaded from USGS websites. Each dataset has been processed to enhance the signature of porphyry-style mineralization within and proximal to the southern Kahiltna terrane.

Geochemical data consist of analyses of 485 pond sediment samples collected as part of the 1970s National Uranium Resource Evaluation (NURE) program (http://tin.er.usgs.gov/geochem/).
Elements chosen from the limited NURE multi-element geochemical packages that may be pathfinders for porphyry-style deposits (Lefebure & Ray 1995) include Ba, Co, Cu, Mn, Pb, Ti, V, and Zn. Under the NURE program, two analytical techniques were used: energy dispersive x-ray fluorescence (Cu and Pb) and neutron activation (Ba, Co, Mn, Ti, V, and Zn). Single element plots and element association plots were generated. Geochemical data for pond sediments collected over the Pebble deposit in 2008

are pending and will be evaluated and used in the favourability modelling.

Geology of the studied area was derived from 1:250,000 scale geologic maps of the Lake Clark and Iliamna quadrangles (Wilson *et al*. 2006). These data contain attribute information that identifies lithologic units and their ages. Subsets were made of all igneous rock types from Late Cretaceous through Tertiary.

Regional aeromagnetic data (Connard *et al.* 1999) are useful for mapping the distribution of magnetic minerals, mainly magnetite. The analytic signal transformation (Nabighian 1972) was used to simplify the complexities associated with depth to source and remnant magnetization. The result is a map where high values suggest relatively high concentrations of magnetic minerals.

Landsat imagery was downloaded from the GloVis viewer (http://glovis.usgs.gov/). The data were atmospherically and geometrically corrected. Band ratios were used to map the presence of iron oxides, hydroxides, and hydrous minerals, possibly associated with porphyry-style hydrothermally altered and mineralized rocks.

Elevation (DEM) (http://agdc.usgs.gov/) and hydrologic data (http://nhd.usgs.gov/) were merged and processed to delineate individual watersheds for the 485 geochemistry samples. A watershed can be thought of as an area that would drain into a single point (geochemical sample location) as defined by the DEM. The watersheds tend to be 1 – 10 km2. Inaccuracies in location of the geochemistry samples were taken into account by creating proximity zones around each location using a 150 metre search radius. The resulting watersheds were used as a framework for interpretation of the multidisciplinary datasets.

RESULTS

Igneous activity that occurred between Late Cretaceous and Early Tertiary time shows a strong northeast-southwest trend, which is also evident in the regional aeromagnetic data. The aeromagnetic data define the boundary between rocks of the Kuskokwim Group and the southern Kahiltna terrane, thus marking the northwestern edge of favourable terrain for Pebble-age porphyry-style occurrences. Ninety watersheds show elevated (>95th percentile) values of one or more pathfinder elements and 63 of these are in areas characterized by a favourable geophysical signature. Of these 63 watersheds, 23 contain intrusive rocks of favourable age for Pebble-like porphyry-style mineralization. In general, relatively elevated copper concentrations (>47 ppm) are found in the more mountainous terrain north and east of Pebble. There is a spatial correlation between the elevated copper concentrations and Late Cretaceous and Early Tertiary igneous rocks. The Landsat data further refine the location of favourable watersheds by suggesting the presence of iron oxides, hydroxides, and hydrous minerals.

CONCLUSIONS

Preliminary results suggest that the integration of multidisciplinary data is crucial in locating favourable areas for porphyry-style mineralization. This contribution can be summarized as follows:

(1) Clipping the datasets using boundaries of watersheds reduced overall spatial coverage from 19,000 km^2 to 2,400 km^2 within the study area and allowed a more focused area for data interpretation, this is useful considering a porphyry target typically being less than 15 km^2. However, this may in turn, exclude areas where mineralized rock is present and detectable in datasets other than the regional geochemistry.

(2) NURE geochemical samples were not collected over the concealed Pebble deposit making it difficult to directly define the mineralization signature in the regional geochemical database. New pending pond sediment data will help rectify this.

(3) Patterns within the multidiscipline datasets can be queried against each other to further refine favourable areas.

(4) Proper watershed delineation provided an effective framework for interpretation and analysis of multidisciplinary data and relies on the quality of the original DEM. In the flat, vegetated lowlands, the resultant watersheds tend to be small, whereas in the alpine areas they are larger and more favourable to the detection of hydrothermal minerals by the Landsat imagery because of sparse vegetation.
(5) Without additional absolute dating of the intrusive bodies, or further geochemical analysis of the igneous rocks, differentiating between Pebble-aged igneous activity and later Alaska Range magmatic activity is problematic.

ACKNOWLEDGEMENTS

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Termitaria: its application as sample media to gold exploration-a case study in northern Ghana

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ABSTRACT: Extensive lateritization and widespread sheetwash and alluvial deposits characterized the savannah regions of northern Ghana. The presence of these materials affects geochemical gold response during surficial gold exploration. Anomaly detection thus becomes very difficult perhaps due to gold grain encrustation during lateritization and anomaly dilution by sheet wash deposits. The use of termite mounds sampling in areas of transported overburden and laterite cap has shown to be a successful way of locating buried anomalies. Termite mounds samples analyzed for Au using Fire Assay was able to define anomalous zones in northern Ghana. Size fractions consisting of -125µm, +125 µm, -500 µm and + 500 µm were analyzed for Au. The statistical analyzes between the results from -125 µm and +125 µm size fractions showed insignificant change in assay results but there were significant change when sub- samples were re-analyzed from the different size fractions. Au content repeatability was greater in -125 µm size fraction and decreases as the grain size become coarser, confirming the conclusion of the statistical analysis. The study showed that termite mound can be used as a geochemical sample media to support the conventional soil survey especially in areas under cover and that -125 µm size fraction is the most appropriate size fraction.

KEYWORDS: *Termite, mound, size fraction, northern Ghana. Geochemical field*

INTRODUCTION

Termite mounds are common in savannah regions of northern Ghana, though some are in southern Ghana. These mounds had significant uses in mineral exploration especially in areas under cover (Gleeson & Poulin 1989) but its application in Ghana became known when the studies by Affam & Arhin (2004) and Roquin *et al*. (1991), indicated that termites play an important role in the remobilization of the laterite weathering profiles. In reality, the termite mound building activity results in an upward transfer of clay, silts, fine Au grains, and sand particles to the ground surface; a process opposite to leaching. Also as a result of environmental stress and climate changes Termitaria collapse under different climatic condition and are subsequently eroded, transported and deposited in low-lying areas of the landscape influencing chemical element contents in the geochemical fields. This process of mechanical dispersion and formation of silty – clay soil cover is evident in most part of the study area, making conventional geochemical survey difficult to define anomalous targets.

The day to day geochemical surveys for gold often begin with soil surveys. But areas with in-situ soils and outcrops had all been explored; leaving behind an environment with complex regolith-generally masked by laterite caps and transported covers. Materials collected in these areas as samples generally do not bear relationship to the bedrock mineralization. Butt & Zeegers (1992) and Arhin & Nude (2008) found out that these materials on the landscape may be residual or transported in character. Their implication is the many False Au geochemical anomalies that are delineated in areas under cover. The research used termite mound as sample medium to support the conventional soil surveys. The results from termite mound samples gave gold results that were site specific and are considered as “Poor Man’s Drill hole”. The False anomalies were checked by results obtained from the termite mounds; reducing time and money on following non-existing anomalies.

GEOLOGICAL SETTING

The area is underlain by Birimian meta-volcanic and meta-sedimentary rocks that have been intruded by granites. The meta-volcanic rocks are of basaltic and gabbroic compositions and most have been altered to various schists. The metasedimentary rocks consist of sandstones, siltstones, tuffs, carbonaceous phyllites, tuffaceous phyllites, cherts and maganeferous rocks (Leube *et al.* 1990).

METHODS

Termitaria were sampled over an area of 10 km^2 with a regular density of 100 m x 50 m corresponding to soil sampling grid of a previous geochemical survey. The density of sampling was five (5) termite mounds over 1 km ^{2}. Composite samples were collected at areas with termite mound clusters i.e. about ten (10) termite mounds on a km^2 area. Total of 240 samples were taken from cluster of termite mounds from different anomalous areas which were in close proximity to known illicit mining area. The 240 samples collected comprised of 60 samples each from the four size fractions i.e. -125 µm, + 125 µm - 500 µm and +500 that were used as media for gold analyses. Five quality care (QA/QC) samples were inserted in each batch of size fractions that were sent to a commercial laboratory for gold analysis.

RESULTS

The gold contents (in ppb) in the various size fractions from the termite mounds are presented in Table 1 and the geochemical distribution of gold in the various size fractions were compared with the gold content in -125µm fractions as that appeared to be the size fractions used in gold exploration surveys especially in Ghana and West Africa.

For the purpose of comparison, gold content in -125µm was compared with +125µm, -500µm and +500µm respectively and the outcome summarised in figure 1. The results from the comparative studies show that the four size fractions appear to have similar gold distribution patterns defining the same anomalous zones. Conversely, –125µm size fraction from termite mound sample analysed registered relatively higher gold values than the other size fractions use in the study (Fig. 1). To add to that the gold content in –125µm size fraction appears reasonably consistent when sub-samples were re-analysed. The re-analyses of the other sub- samples collected from +125 µm, - 500 µm and + 500 µm lack precision (Table 1). It is probable that the assay values obtained in the coarser size fractions perhaps were due to some detrital Au grains that were picked up in the first or original analyses. The implication is that if coarser size fractions are selected as sample media, disregarding sample reproducibility, then critical assessment would be required as a single coarse gold grain in the sample could introduce nugget effect.

The two size fractions of -125 µm and +125 µm have similar gold geochemical patterns from the plots of the original assays but had different anomalous patterns when repeat samples were analysed. The variation in -125 µm sub samples was generally insignificant but the variations in +125 µm sub – samples were very significant. For example, a sample that originally registered gold value of 523 ppb returned assay of 200 ppb from the repeat analyses. Similarly 200 ppb sample from + 125 µm also returned assay value of 21 ppb in the repeat analyses. The lack of precision between the original analysed samples to the repeat samples make it impractical to use it as an appropriate size fraction for geochemical assay when nugget effect can lead to serious lost of time and money in exploration. The lack of precision escalates even more when coarser materials such as -500 µm and + 500 µm size fractions are analysed for gold. For instance 511 ppb Au obtained from analysing gold in - 500 µm size fraction from termite mound returned 56 ppb Au when sub-sample of the same sample was analyzed. The imprecision increases

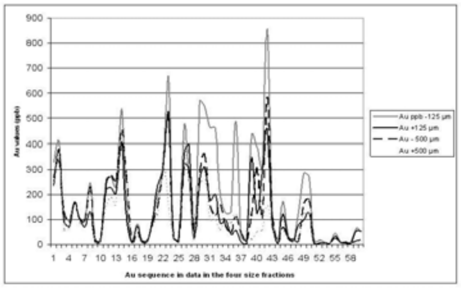

Fig. 1. Comparisons of Au in different size fractions.

as coarser samples are analysed.

Despite the lack of precision associated with the coarser size fractions, all the four size - fractions defined the same areas but confidence of finding potential mineralization appeared associated with the -125 µm size fraction. It is apparent that termite mound survey thus be used as a supplementary grassroots' exploration tool to enhance the conventional exploration methods especially in areas under cover.

CONCLUSIONS

The conventional soil surveys conducted in the study area often returned tricky results, with isolated high point anomalies that were not followed up with the anxiety that they were not real. The current study using termite mound as sample medium, however, isolated the real anomalies from the false anomalies. The sampled materials came from in-situ materials representing bedrock mineralization; making gold results from Termitaria more dependable than the surficial soils. It is concluded from the study that termite mound geochemical surveys provided cost effective method of defining prospective anomalous areas especially in areas covered by transported overburden and laterite caps. More so as termites can burrow beyond depths exceeding 10 m chasing the water table to get materials to build the mounds, sampled materials from them can be considered as 'Poor Man's Drill hole" during Greenfield exploration. Above all gold value precision in -125 µm size fraction was better in terms of grade and reproducibility during re-analyses than

Table 1. Comparisons of gold in different size fractions in termite mounds

Au ppb -125 µm	Au rpt -125µm	Au +125 µm	Au rpt-125 µm	Au - 500 µm	Au rpt -500 µm	Au +500 µm	Au rpt +500 µm
327	326	238	120	269	50	231	15
406		377		335		366	
114		97		134		59	
95		71		86		63	
172		167		169		162	
104		104		103		84	
99		71		93		102	
247	200	131	90	232	25	126	67
16		16		12		9	
15		16		12		10	
258		216		239		150	
271		227		276		187	
230		205		254		155	
539	534	408	512	455	390	437	12
184		104		277		252	
13		10		10		10	
82		74		49		32	
17		9		14		8	
15	13	12	10	17	12	12	5
100		109		91		74	
196		237		154		118	
302		302		312		318	
664	661	523	200	511	56	139	45
27		34		33		27	
18		12		14		32	
473		361		318		404	
281		391		296		233	
29		39		27		33	
570		260		294		221	
545		309		360		258	
464	451	178	50	154	12	100	5
460	450	200	21	114	15	98	9
195		85		159		58	
126		100		73		98	
130		40		47		85	
490		56		112		120	
30		10		44		44	
20		5		17		52	
435		349		114		19	
390		123		308		49	
310	300	290	59	106	13	58	23
855		456		588		154	
104		70		106		58	

the other size fractions used in the study, hence -125 µm size fraction could be used in all Greenfield exploration in savanna regions of Ghana as well as all areas under cover in West Africa.

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Exploration history and discovery of a new mineralization style, Freegold Mountain area, Dawson Range, Yukon Territory, Canada

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ABSTRACT: The Dawson Range Cu-Au-(Mo) Belt portion of the Tintina Au Province had been explored for decades through geological mapping, trenching, diamond and rotary drilling, and geochemical and geophysical surveys, all leading to the mining of a few claims, such as Laforma, Mt. Nansen and Minto. Gold-rich pyrrhotite veins (up to 113 g/t Au), Au-bearing sulphides in granitoids (up to 410 g/t Au), as well as Au-bearing pyroxene-actinolite-(biotite)–pyrite-pyrrhotite assemblage (1.15 g/t Au) have been newly discovered in the Nucleus zone of the Freegold Mountain Project of Northern Freegold Resources (NFR). Due to the presence of reduced minerals (pyrrhotite & pyroxene), and the abundance of Au relative to Cu, the Nucleus zone shares similarities with "reduced porphyry Cu-Au" and "intrusion-related pyrrhotite vein" systems.

KEYWORDS: *Dawson Range Cu-Au-(Mo) Belt, Tintina Gold province, reduced porphyry*

INTRODUCTION

The Dawson Range, in the Yukon Territory hosts several types of mineral occurrence that belong to the Dawson Cu-Au-(Mo) Belt portion of the the Tintina Au Province. The Tintina Au Province spans Alaska and Yukon and contains significant Au deposits, such as True North and Fort Knox in Alaska, and Dublin Gulch and Brewery Creek in Yukon (Fig. 1). The Dawson Range Cu-Au-(Mo) hosts minerals deposit of four main types: porphyries, epithermal veins, skarns, and transitional varieties associated with brecciation and porphyry dyke emplacement (Carlson 1987). Mineralization throughout the district has a spatial association with hypabyssal felsic porphyry stocks and dykes intruding Paleozoic Yukon Tanana metamorphic rocks and Mesozoic granitic rocks.

Mineralization in the Dawson Range is related either to the Middle Cretaceous Mount Nansen and Late Cretaceous Carmacks magmatic events (Mortensen *et al.* 2003) or only to the Late Cretaceous Carmacks magmatic event (Smuk *et al*. 1997; Selby & Creaser 2001).

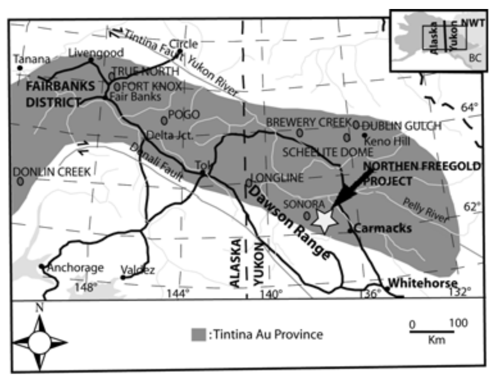

Fig.1. Location of the Dawson Range within the Tintina Au Province that extends from Alaska to Yukon and hosts significant gold deposits (after Tucker & Smith 2000).

Major mineral occurrences within the Dawson Range NW-SE trending Cu-Au belt as observed from the northwest to the southeast include: Casino, Cockfield, Sonora, Tad, Cash, Minto, Northern Freegold project mineral occurences, Laforma, Carmacks, and Mount Nansen (Fig. 2).

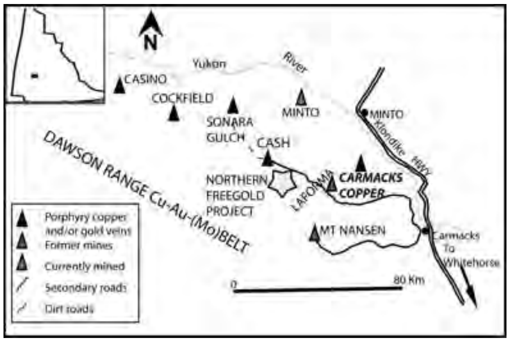

Fig. 2. Northern Freegold Project and other major mineral occurrences within the NW-SE trending Dawson Range Cu-Au-(Mo) Belt.

Mt. Nansen (Au-Ag) & Laforma (Au-bearing quartz vein systems) have been mined in the past and Minto (Cu-Au) is currently mined. This paper portrays the exploration history in the NFR Freegold Mountain project and highlights new discoveries recently made by NFR.

EXPLORATION HISTORY

The Freegold Mountain project of NFR extends 35 km along strike within the Dawson Range Cu-Au-(Mo) Belt. It covers 12000 hectares and comprises the following properties from northwest to southeast: Nitro, Big, Golden Revenue, Happy, Seymour, Glen, Rage, Goldstar, Goldy, and Tinta Hill (Fig. 3).

Nitro

The property first staked as Klazan in 1966 by Coranex Ltd. was later restaked as Nitro. Exploration on the property includes: geological reconnaissance, bulldozer trenching, grid soil sampling, magnetic survey, diamond drilling, and mapping. Nitro shows a strong gossan with anomalous Mo, Cu, Pb, Zn, Ag, and Au Cu-Mo-(Au-Ag) values.

Big: Au anomaly

This property consists of just one claim also referred to as Big. The Big property underwent only a few grid soil geochemistry studies.

Golden Revenue: Cu-Au

The Golden Revenue property is

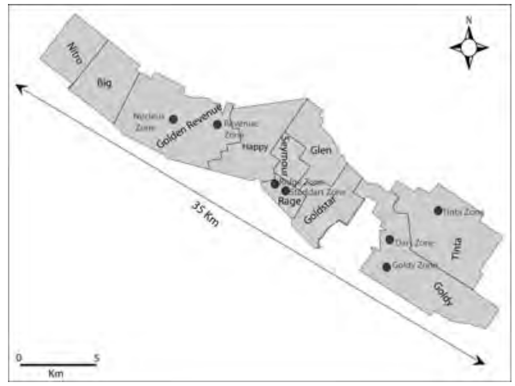

Fig. 3. Different properties and zones extending over 35 km at the Freegold Mountain NFR project.

composed of two zones: Revenue and Nucleus with each zone made up of several claims. The first claim in the Golden Revenue property was registered in 1950 by P.F. Guder as the Discovery zone and staked as Revenue. Exploration on the Golden Revenue property has involved EM, VLF-EM, resistivity, magnetic, and IP geophysical surveys, geochemical surveying, hand and bulldozer trenching, diamond (50296 m) and RAB (8582 m) drilling, grid soil sampling, reverse circulation or percussion drilling (3557 m), and geological mapping.

Happy

In 1954, P.F. Guder found gold-bearing quartz float and staked a claim on the Happy zone. The actual Happy property restaked as Happy by B. Harris in 2001 is made up of Guder's original Happy claims that have been tied to the east to the Luck claim (of Shawack Exploration) and to the north to the Angus claim of the Big Creek Joint Venture. So far, Happy underwent successively hand trenching, geological mapping, soil and rock sampling, minor blast trenching, line-cutting, grid work, magnetometer and VLF-EM surveying.

Seymour

The Seymour claims were staked in 1981. Nevertheless, exploration started much earlier in the area and the claims staked ceased thereafter. The Seymour showing consists of a weak potassic alteration? core surrounded by phyllic (with 5% pyrite and trace of chalcopyrite) and argillic zones. Exploration in the area involved mapping, grid soil and rock geochemistry, magnetic and VLF-electromagnetic surveys, hand and mechanized trenching.

Glen

The Glen property is centred on 2 showings: (1) the (Ag-Pb-Zn ± Au) quartz vein of the Red Fox showing first staked in 1931 by P.F. Guder and later restaked as Vindicator, and, (2) the Cu ± Ag Castle claims first staked as the Sun claim in 1969. Exploration in the area has involved mapping, rock and soil geochemistry, magnetic survey, hand and bulldozer trenching, and diamond drilling (317.6 m).

Rage

The Rage property contains 2 main zones: Ridge and Stoddart**.** The area was first staked as Low in 1969 by R. McKamey and afterwards restaked as Ag, Au, Seymour, May, and Rag. The property underwent hand and bulldozer trenching, geological mapping, rock and grid soil geochemistry, diamond drilling (4763 m), and magnetic and IP geophysical surveys.

Goldstar

The original discovery in the Freegold Mountain area was made on this property in 1930 by P.F Guder who staked the first claim (Augusta). The discovery consisted of a gold-bearing magnetite vein in which free gold was found in the oxidized magnetite. Guder subsequently acquired a property that included the Liberty, Augusta, Margarete, Peerless, and Gold Star claims. The actual Goldstar property includes the original Guder's claims and the Pauline claims. The Goldstar property had been explored by hand and bulldozer trenching, pitting, grid geochemical survey, VLF-EM and magnetometer geophysical surveys, and diamond (1058.6m) and rotary (304.8m) drilling.

Goldy

The Goldy property is made up of 2 main zones: Dart and Goldy. Dart is represented by quartz-barite-Sb-Au vein occurrences at Emmon Hill, discovered in the early 1930's by T. Bee and W. Renworth. Before being restaked as Dart, it had been staked as Ant, Bill, Darb, Free, Joe, and Moon. The Goldy zone comprises the Whale claim (blue-gray quartz vein containing very fine-grained sulphides and gold) staked in 1933 by J.H Carpenter and W. Forbes and the Forbes Creek showing. The property had been explored by hand and bulldozer trenching, geological mapping, geochemical rock, soil and stream sediment studies, line cutting, EM and IP surveying, diamond drilling (3920 m) and 12 reverse circulation drill holes (468 m).

Tinta Hill

In 1930, the original Tinta Hill showing made up of a quartz rich vein with galena, sphalerite, and, minor tetrahedrite and chalcopyrite was discovered, and a claim was subsequently staked in 1931 by George McDade and partners. Since 1931 the claim has been restaked as Tinta, May, June, and Sno. Exploration of Tinta Hill since 1930 has involved bulldozer trenching, underground development (939 m), diamond drilling (10493 m), rock and soil geochemistry, and VLF-EM surveying.

NEW DISCOVERIES

The 2007 & 2008 NFR diamond drilling campaign highlighted new mineralization styles at the Nucleus and Stoddart zones.

New discoveries at Nucleus were made following up Au-As-Bi soil anomaly zone, and they consist of (1) massive pyrrhotite veins with minor chalcopyrite, (2) calc-silicate (grossular-pyroxene-actinolite)–pyrite-pyrrhotite lenses or skarn and (3) massive sulphide replacement in granitoid. Interestingly, these new mineralized bodies are highly enriched in Au. For instance, some massive pyrrhotite veins grade up to 113 g/t Au, while sulphide-rich granitoids samples range up to 410 g/t Au, but the hydrogrossular-pyroxene-actinolite- pyrite-pyrrhotite assemblages grade, 1.15 g/t. Because of the predominance of reduced minerals (pyrrhotite & pyroxene), as well as the importance of Au relative to Cu, the Golden Revenue property shares similarities with intrusion-related pyrrhotite vein and reduced porphyry Cu-Au systems described by Rowins (2000), such as the Rossland and 17 Mile Hill deposits in British Columbia and Western Australia respectively. Field observations show that dykes, as well as granite of the Dawson Range Batholith, crosscut the mineralized calc-silicate. This suggests that mineralization may be older than the Dawson Rage Batholith (Early Cretaceous) and that may extend the age of mineralization in the Dawson Range to even earlier than the Cretaceous as suggested by Bineli & Lentz (2009).

In Stoddart zone, 2 holes have been drilled to test the historical Au, Mo, & Cu soil anomaly, coincident with airborne magnetic survey anomaly. The drill holes revealed for the first time the occurrence of porphyry-style Cu-Mo mineralization in the Freegold Mountain area. Mineralization occurs as either quartz-chalcopyrite-molybdenite veins and microstockworks, or chalcopyrite & molybdenite disseminations.

CONCLUSIONS

This study shows that:

(1) The Dawson Range and especially the Freegold Mountain area have been extensively explored for about 80 years, but only a few discoveries have been mined;

(2) New discoveries at the Golden Revenue property of NFR testify not only to the great wealth in Au in the Freegold Mountain area, but provide new evidence that suggests that the Golden Revenue is a reduced-porphyry system that does not display features typical of the classical oxidized porphyry Cu deposits.

ACKNOWLEDGEMENTS

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Evidence of 25-m of Vertical Metal Migration Over the High-Grade Perseverance Zinc Ore Body, Matagami, Quebec

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ABSTRACT: The CAMIRO 3D Geochem project (2002-2004) conducted a detailed geochemical survey over the high-grade zinc Perseverance Main Lens (14% zinc) that subcrops with a footprint of high grade sphalerite (approximately 25% zinc) over approximately 25 m. The sulphide lens subcrops beneath 25m of transported Quaternary sediments composed of glacial till, outwash gravel and varved lacustrine clay. Samples were collected at 80 sites, generally at 25 to 50 m spacings, and over 100 variables were measured including MMI, Enzyme Leach^{TM}, aqua regia digest-ICPMS, pH, conductivity, etc. Very closely-spaced sampling (5 m spacings) was undertaken overlying the subcropping area of the massive sulphides (25 by 40 meters). Low pH and strong conductivity readings directly over subcropping mineralization, combined with subtle aqua regia-ICPMS ("AR-ICPMS") responses, are compelling evidence of vertical metal migration. A supplementary verification sampling program was undertaken by C. Beaudry in 2006 to confirm the results of the CAMIRO study and, in particular to extend sampling further into the background area to the south. A total of 34 samples were collected The elements Zn, Cu, Co, Ti, V, Mn and Fe show significant responses over the deposit. Even with many other elements which do not show significant anomalous values over the deposit the results often show much higher variance in the target area compared to the graben or background samples.

KEYWORDS: *soil geochemistry, partial extraction, selective extraction, Matagami, Perseverance zinc deposit.*

INTRODUCTION

The high grade Perseverance Deposit, located in the historic Matagami mining district in northern Quebec, is composed of high grade massive sulphides that subcrop beneath about 25 m of transported Quaternary sediments composed of glacial till, outwash gravel and varved lacustrine clay. As such it is an excellent candidate test case for the study of non-conventional geochemical analyses since the transported cover sediments and in particular the lacustrine clays precludes the use of conventional soil sampling.

This study covers the results of deposit-scale sampling by Bloom in 2004 for CAMIRO Project 01-02-002 and supplementary soil sampling by Beaudry in 2006.

PERSEVERANCE ZINC DEPOSIT

The Perseverance property is located approximately 10km west of the town of Matagami, Quebec. The Perseverance deposit has been drilled off at close spacing but the actual surface expression of the deposit remains relatively undisturbed except for previous logging activities. The terrain is mixed coniferous and deciduous forest in a relatively flat topography with generally poor drainage.

The Perseverance deposit is comprised of three small volcanogenic massive sulphide (VMS) deposits, namely the Perseverance, Perseverance West and the Equinox deposits that, together are estimated to contain 5.1 M Tonnes (measured and indicated) grading 14.2% Zn, 1.1% Cu, 30 gpt Ag and 0.4 gpt Au. The Perseverance deposit itself is composed of the Main Zone with 1.12 M Tonnes at 17.07% Zn, 1.20% Cu, 26 gpt Ag and 0.3gpt Au and the smaller, 200,000 Tonnes Lens 2 Zone grading 13.74% Zn, 1.94% Cu, 24 gpt Ag and 0.4 gpt Au.

The Perseverance Main Zone deposit forms a compact mass of high grade massive sulphides approximately 175 m long, 24 m thick and 120 m down dip. The lenses have been at least partly eroded and outcrop beneath the overburden on their eastern limit. They plunge towards the west beneath the hanging wall Dumagami rhyolite and end at a depth of approximately 130 m.

The three Perseverance deposits are located in a graben structure bounded by two major NW-SE trending faults. The Perseverance block was down dropped to its current, near horizontal, position. Although there is clear evidence of late orogenic movement along these faults the similarities with other VMS environments in the Matagami district support the interpretation that these were originally syn-volcanic faults that focused hydrothermal fluid flow into the graben structure.

The Perseverance deposits are only weakly conductive because of the high sphalerite content of the massive sulphides and the general paucity of sulfides in the underlying pipe alteration zones. The Perseverance Main Zone was originally detected by a ground TEM survey in the early 80's but a drill hole failed to intersect the deposit (missed the east end by a few meters). It was the combination of the recently developed airborne MEGATEM system along with three-component borehole TEM technology that lead to the discovery of the Perseverance Zone in 2000 and shortly afterwards to the other deposits at Perseverance.

GLACIAL HISTORY

The Matagami area was covered by the Labrador ice sheet during the last ice age which deposited several till layers and fluvioglacial sediments. During the final deglaciation the Labrador ice sheet was split into two distinct entities separated by the Harricanna Moraine located approximately 50km west of Matagami. Glaciofluvial, glaciolacustrine, and, intertill organic deposits underlie the uppermost Cochrane till, and these are in turn underlain by older tills that were deposited by at least three distinct ice flows. The Cochrane advance deposited sandy, carbonate-rich till within the evolving glacial lake Barlow-Ojibway. As the lake slowly receded in response to isostatic rebound, poor drainage and cold weather resulted in the region being covered by forest and peat bogs, depositing up to several meters of organic material.

CAMIRO 2004 3D GEOCHEM PROJECT

The objective of the 2002 – 2004 CAMIRO 3D Geochem project was to study the dispersion of elements in overburden overlying known mineralization. The Perseverance project sampling focused primarily on measuring the geochemical response over the Perseverance Main Lens that subcrops with a footprint of high grade sphalerite over approximately 25 m. Samples were collected at 80 sites, generally at 25 to 50 m spacings, and over 100 variables were measured. Very closely-spaced sampling (5 m spacings between 15040 to 15100N and along several short east-west cross lines) was undertaken overlying the subcropping area of the massive sulphides (25 by 40 meters).

Low pH and strong conductivity readings directly over subcropping mineralization, combined with subtle aqua regia-ICPMS ("AR-ICPMS") elemental responses, are compelling evidence of vertical metal migration. Commercially available partial extractions, including targets in all cases; however, the threshold was manually selected to maximize the number of anomalous samples over the target and minimize the total number of anomalous samples. The following elements show significant responses over the deposit: Zn, Cu, Co, Ti, V, Mn and Fe. Even with many other elements that do not show significant anomalous values over the deposit, the results often display much higher variance in the target area compared to the graben or background samples.

2006 SUPPLEMENTARY SAMPLING

A supplementary verification sampling program was undertaken by C. Beaudry in June 2006 to confirm the results of the CAMIRO study and, in particular to extend sampling further into the background area to the south. A total of 34 samples were collected including 6 field duplicates. A series of samples were sent to Actlabs in Ancaster, Ontario for Enzyme Leach™ analysis and another to SDP in Australia for Soil Desorption Analysis (SDP). Only results for Enzyme Leach™ are reported here.

Samples were classified by location; over the deposit, within the Perseverance Graben or in background areas. Except for the effects of the deposit there does not appear to be any difference between samples over the graben and those in the background. Samples were also classified for underlying lithology namely Watson Lake Rhyolite (footwall) or Dumagami Rhyolite; in this case the differences were important, at least for some elements and in particular Ca and Mg.

The surface trace of the Perseverance Main and its small satellite deposit is identified over approximately 200 m along the sampling line by elevated values for a number of elements, some of which were expected, but others were surprising. All the profiled responses were tested using the hypergeometric function hypothesis tests using an alpha risk of 0.05. The same sample locations were presumed targets in all cases; however, the threshold was manually selected to maximize the number of anomalous samples over the target and minimize the total number of anomalous samples. The following elements show significant responses over the deposit: Zn, Cu, Co, Ti, V, Mn and Fe. Even with many other elements that do not show significant anomalous values over the deposit, the results often display much higher variance in the target area compared to the graben or background samples.

CONCLUSIONS

The CAMIRO and Beaudry surveys at Perseverance demonstrate that a geochemical signature can be measured where mineralization is buried under 30 m of complicated and stratified overburden. The low conductivity of the sphalerite-rich ore appears to have still been sufficient to generate electrochemical processes capable of generating surface geochemical responses, including changes in pH, conductivity and some AR-ICPMS variables. The interpretation of partial leach anomalies requires a systematic approach to classifying anomalous values and evaluating data for both single peak and “rabbit ear” anomalies.

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Exploration stream sediment geochemistry of the Otago region, New Zealand

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ABSTRACT: New Zealand open file mining company exploration stream sediment geochemical survey data are compiled in the REGCHEM (Regional Exploration Geochemistry) database managed by GNS Science (http://maps.gns.cri.nz/website/minmap). Data for the Otago region include more than 2000 stream sediment samples from 19 surveys, more than 800 BLEG (bulk leach extractible gold) samples from 14 surveys and a few pan concentrate samples. The stream sediment samples were typically analysed for Au and As, and in many cases for other elements including Cu, Pb, Zn, Sb, W and Mo. The BLEG samples were analysed for Au and occasionally for As. The main exploration target was orogenic Au±W±Sb deposits in the Otago Schist, although Au deposits associated with the Dunedin volcanic complex and W deposits in the schist were also targeted. Geochemically, the orogenic Au deposits are characterised by anomalous As and Au, with some also characterised by anomalous W and/or Sb. These four elements are the best pathfinders in stream sediment geochemical surveys and the anomalous values identified were associated with known deposits. Lower Au detection limits in the more recent stream sediment, and in the BLEG surveys, enables the use of this element as the primary pathfinder for orogenic gold deposits.

KEYWORDS: *stream sediment, BLEG, geochemistry, orogenic gold deposits, Otago*

INTRODUCTION

Mining companies have carried out stream sediment sampling as part of their exploration of mineralised provinces in New Zealand. These mining company data are the only stream sediment data with any significant geographic coverage in New Zealand. There have been no systematic geochemical surveys by Government agencies and the only research data are for localised areas. Results of the mining company surveys are reported to government (Crown Minerals, Ministry of Economic Development) as a condition of the prospecting and exploration permits. Much of the archived data has been compiled in digital form in the REGCHEM (Regional Geochemistry) database (Warnes & Christie 1995) and is publicly accessible via the MinMap interface at http://maps.gns.cri.nz/website/minmap/.
This study describes the REGCHEM data for the Otago region (Fig. 1), an area highly prospective for orogenic gold deposits (Crown Minerals 1982).

REGIONAL GEOLOGY AND MINERAL DEPOSITS

A large part of the Otago region is characterised by basin and range topography, with ranges of Mesozoic schist (Haast Schist Group) and basins of Cenozoic sedimentary rocks. Greyschist (sandstone and mudstone) is the predominant form of schist, although there are local areas of greenschist (volcanics).

The schist belt formed between the early Jurassic and mid Cretaceous during terrane collision beneath a fore-arc region. It hosts orogenic Au±W±Sb deposits (Fig. 1), typically lensoidal quartz veins localised along single or multiple parallel shear zones. Disseminated Au mineralisation is also present in several shear zones, including the 25 km-long Hyde-Macraes Shear Zone that hosts the Macraes deposit, currently mined by open

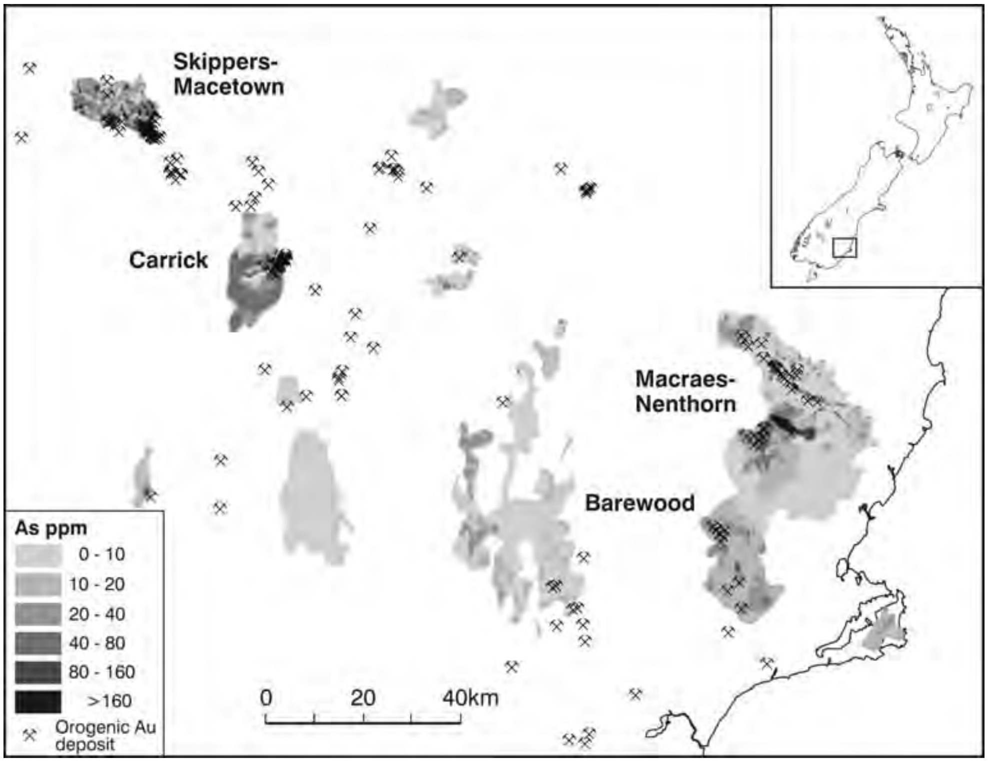

Fig. 1. As in stream sediments, and orogenic gold deposits in the Otago region.

pit and underground methods and producing 5000 kg (160,000 oz) Au annually.

The sedimentary basins contain schist and greywacke gravels eroded from the ranges, and some coal measures. Many of the alluvial gravel units and the modern river channels host placer gold deposits that have produced approximately 8 Moz Au.

Cenozoic volcanism produced the Dunedin volcanic complex, and several isolated cones of basalt are now preserved capping hills in eastern Otago.

STREAM SEDIMENT GEOCHEMISTRY

Mineral exploration stream sediment geochemical survey data for the Otago region includes more than 2000 standard stream sediment samples from 19 surveys, more than 800 BLEG (bulk leach extractible gold) samples from 14 surveys and a few pan concentrate samples (MR reports). The stream sediment samples were typically analysed for Au and As, and in many cases for other elements including Ag, Cu, Pb, Zn, Sb, W and Mo. The BLEG samples were analysed for Au and in some cases also for As. The main exploration target was orogenic gold deposits in the Otago Schist, although one survey of the Otago Peninsula targeted potential gold deposits associated with the Dunedin volcanic complex, and several surveys sought tungsten deposits, in addition to gold.

Samples with high detection limits (e.g. 10 and 50 ppb Au) have been discarded in the following analysis. Figures 1-3 show contour maps for As, Au and W, and Table 1 lists summary statistics for some elements.

Background values between different surveys have been assessed in relation to the geology, and sample groups with elevated background values have been levelled.

Anomalous values identified for Au and As are all associated with known orogenic gold deposits (Figs 1 and 2). Arsenic has

Table 1. Percentile statistics for stream sediment samples.

El ppm	As	Cu	Pb	Sb	W	Zn
N	2226	1907	1283	572	1524	1731
Mean	23.8	22.6	19.3	15.5	25.0	63.6
P10	<10	6.0	8.0	0.4	<1	38.0
P50	10.0	15.5	13.0	1.0	2.0	59.0
P90	50.0	34.0	18.0	3.1	7.0	79.0
P97.5	130	47.0	21.0	8.0	30.0	89.0
Con	13.0	3.0	1.6	8.0	15.0	1.5

been used in some exploration surveys at the prospect scale to help define extensions of known shear zones. The orogenic gold deposits at Skippers-Macetown, Macraes and in the Waipouri-Lammerlaw Range area exhibit anomalous W values (Fig. 3). Additionally, strong W anomalies, probably related to quartz vein and stratiform W deposits, are present in the Kakanui-Waitaki area and in the Pomahaka River area west of Roxburgh. Anomalous values of Sb are present in the Waipouri area, where stibnite has been reported associated with the orogenic Au-bearing quartz veins. Copper anomalies are present only in the Waipouri-Lammerlaw Range area, although some elevated values are present at Skippers-Macetown and Ophir. There are no Pb anomalies exhibited in the stream sediment data.

CONCLUSIONS

Geochemically, the orogenic gold deposits in Otago are delineated by anomalous Au and As, with some also characterised by anomalous W and Sb, and these four elements are the best pathfinders in stream sediment geochemical surveys. Lower Au detection limits in the more recent stream sediment surveys (e.g. 0.05 ppb Au for BLEG) enables the use of this element as the primary pathfinder for orogenic gold deposits. The Otago stream sediment data also exhibit W anomalies that are associated with W vein deposits and stratiform W deposits.

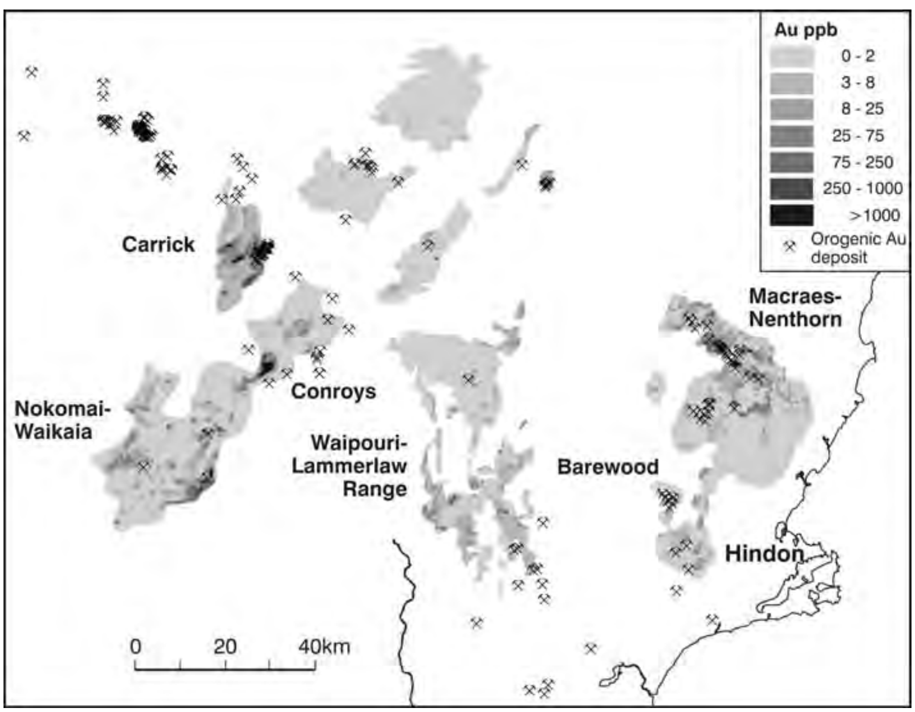

Fig. 2. Au in stream sediments (including BLEG data), and orogenic gold deposits.

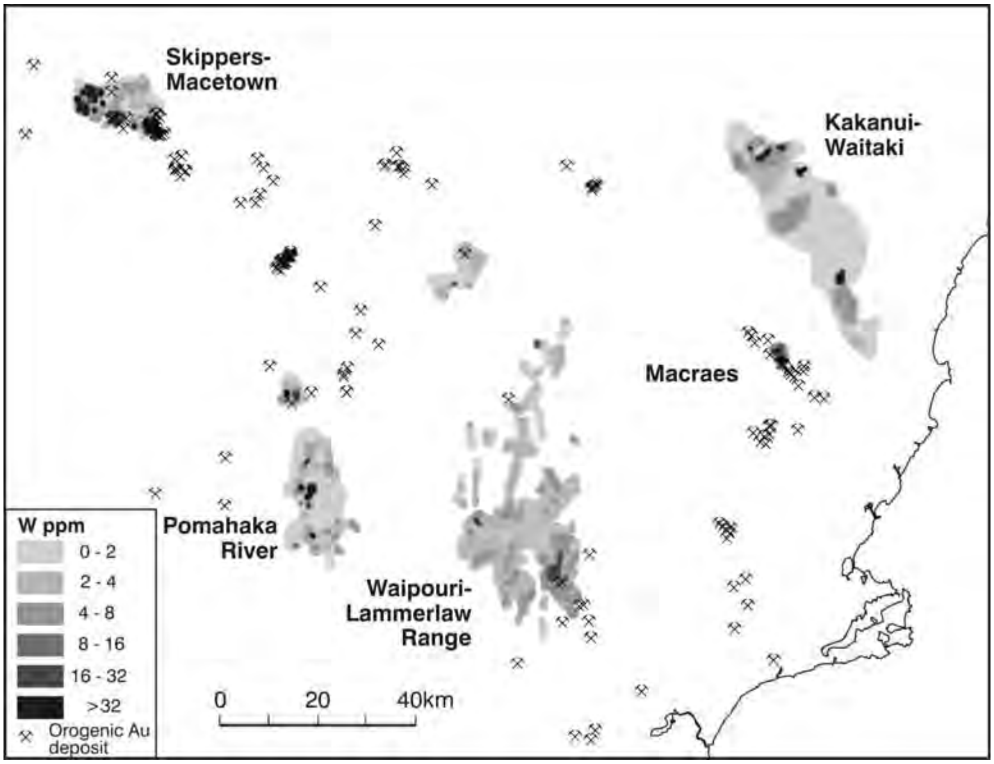

Fig. 3. W in stream sediments, and orogenic gold deposits.

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A Hydrogeochemical Exploration Study at the Pebble Deposit, Alaska

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ABSTRACT: A hydrogeochemical study using high resolution ICP-MS (HR-ICPMS) was undertaken at the giant Pebble porphyry Cu-Au-Mo deposit and we show that it is a powerful new tool in the search for concealed deposits.. Surface and ground water samples were collected from regional background and the deposit areas. Rigorous quality control confirms consistent results at low parts per trillion (ppt) levels. Overall, pH varies from 3.6 to 8.2, with values below 5.1 from ponds at Pebble West, where sulphide-bearing rubble crop is thinly covered. Anomalous SO_4^{2-} and F^- are present in waters from Pebble West. Silver distribution (maximum 61 ppt) reveals a cluster of anomalous spring and pond samples in a ~10 km^2 area centred on Pebble. Nearly the entire upper quartiles of both Ag and Mo data fall within this area. The widespread areal extent of Mo, Ag, and several other elements in ponds and their presence in springs and boreholes are evidence that the elements are present in shallow and deep groundwater systems. Anomalous elements around Pebble West (thin cover) include Cu, Ni, Re, the REE, and Tl. Anomalous elements over both Pebble West and Pebble East (thick cover) include Ag, Mo, Sb, Th, U, V, W, and Zn.

KEYWORDS: *porphyry Cu, exploration, hydrochemistry, high resolution ICP-MS, Alaska*

INTRODUCTION

The U.S. Geological Survey (USGS) began exploration-oriented geochemical and geophysical studies in 2007 at the giant Pebble porphyry Cu-Au-Mo deposit, 320 km west of Anchorage, Alaska. The research is still underway. Presented here are initial findings from hydrogeochemical studies in and around Pebble.

Cations were determined by high-resolution inductively coupled plasma-mass spectrometry (HR-ICPMS), relatively new analytical instrumentation with a large dynamic range and detection limits (DLs) in the low (1-50) parts per trillion (ppt) for most elements. The exceedingly low DLs allow for recognition of elemental variations that are not possible with traditional analytical methods for water.

In 2007, regional water samples were collected along with local waters where present, along an east-west soil transect across the deposit (46 samples). In 2008, these were augmented with 83 more water samples, mostly from ponds over and around the deposit area, for a combined total of 129 water samples (Fig 1). Pond sediments were collected as well and geochemical analysis is underway.

GEOLOGICAL SETTING

As summarized by Lang *et al.* (2007), regionally, upright Jura-Cretaceous argillite, siltstone, and wacke of the Kahiltna terrane are cut by a diverse suite of intrusions that occupy a northeast-trending structural corridor, likely related to the crustal-scale Lake Clark translational fault. At Pebble, subalkalic granodiorite bodies (91-89 Ma; satellites to the Kaskanak Batholith) appear to be genetically related to mineralization.

Unconsolidated cover at Pebble consists of 0-50 m of a variety of glacial deposits over Pebble West, where the deposit is partially exposed. At Pebble East, the deposit was partially eroded and is unconformably overlain by an eastward thickening wedge of post-mineralization Late Cretaceous to Eocene volcano-sedimentary rocks, up to 600 m in thickness, which in turn are overlain by the glacial deposits.

Mineralization is present mostly in strong K-silicate altered rocks dominated by K-feldspar, and in multi-generational stock works of quartz-carbonate-sulphide veins. Laterally extensive sericite-altered rocks are peripheral to and overprint the

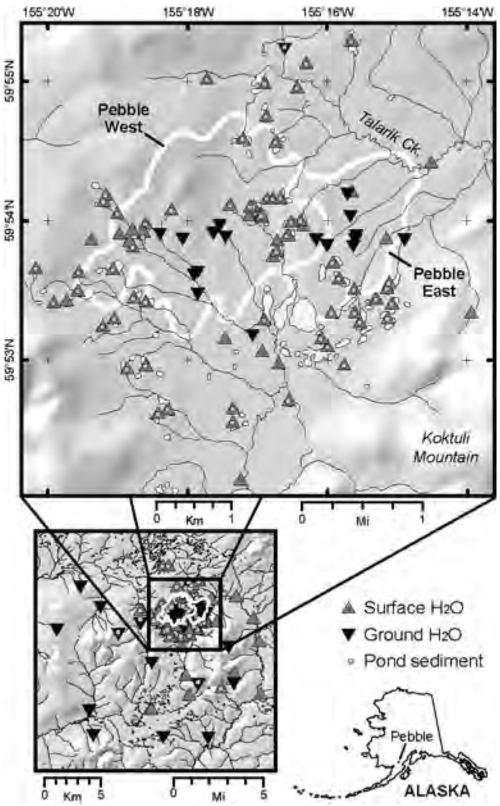

Fig. 1. Location and sample site map.

margins of the deposit; propylitic and illite assemblages are locally developed. Dominant ore minerals are chalcopyrite, molybdenite, and native gold, the latter mostly within chalcopyrite. High-grade, bornite-bearing mineralization was discovered at Pebble East in 2006.

The Pebble Cu-Au-Mo porphyry deposit contains one of the largest resources of Cu and Au in the world. The deposit consists of two zones: Pebble West, discovered by Cominco America in 1989, and Pebble East, discovered in 2005 by Northern Dynasty Minerals Inc. (NDM), who began exploring the area in 2001. In 2007, NDM and Anglo American formed the Pebble Limited Partnership. The West and East zones contain a combined resource of 72 billion pounds of Cu, 94 million ounces of Au, and 4.8 billion pounds of Mo (NDM 2009).

METHODS

Water samples were collected from ponds (78), springs (24), streams (18), and from rare deposit area borehole seeps (9), from numerous sites in a 20-km^2 area around Pebble, and from background sites in a 300-km^2 surrounding region (Fig. 1). A thorough description of collection, analysis, and quality control (QC) procedures, and a listing of the 2007 data is presented in Fey *et al.* (2008); a similar report for 2008 analytical data will be completed in 2009.

Water samples were collected in mid-summer, precipitation-free periods, following protocols of Ficklin & Mosier (1999). On-site measurements include pH, specific conductance, alkalinity, acidity, dissolved oxygen, turbidity, and water temperature. Samples were collected in 1-litre polypropylene bottles and filtered on-site (0.45 µm) with disposable filters. Sub-samples for cation analysis were placed in acid-rinsed polypropylene bottles and acidified with ultra-pure HNO_3. Filtered, unacidified sub-samples for anion analysis were refrigerated until analyzed. In 2007, samples for Hg analysis were collected; no Hg was detected at detection limits of 0.02 µg/L, precluding collection in 2008.

Determination of 63 cations by HR-ICPMS was done on filtered/acidified samples by Activation Laboratories Ltd., using a Finnegan Mat ELEMENT 2 instrument. Anions were determined by ion chromatography and Fe^{2+} and dissolved organic carbon (DOC) by spectrophotometry in USGS labs.

A QC assessment was done for all samples. De-ionized water field blanks were collected on seven different days to evaluate process contamination. Site duplicates were taken at eight sites to evaluate repeatability and site variation. Instrumental precision was constrained by analysis of laboratory duplicate solutions, and is typically less than 5%. Finally, standard reference material (SRM) water standards were analyzed with sample batches, to assess instrumental accuracy.

All aspects of the QC assessment yielded impressive results. There was no contamination by sample processing. In blanks, very low concentrations (<5 ppb) of some major elements were detected and most trace elements were not detected at low ppt levels. Comparison of site duplicate pairs showed agreement within 20% for most, and within 10% for some elements, even at low ppt levels. Comparison of the SRMs with accepted values showed that almost all elements were analyzed with an accuracy of ±10%.

RESULTS

Median, minimum, maximum, and upper quartile values are given in Table 1. The 7 sites with pH values below 5.1 are all from ponds in the Pebble West area, concentrated where sulphide-bearing rubble crop is exposed or under thin cover. All but two of the 32 sites with pH values below 5.88 (lower quartile) are from surface and ground water samples in and adjacent to the Pebble deposit. Borehole seeps are all circum-neutral.

Many surface waters are extremely dilute (low tens of µS/cm). The lowest specific conductance values are from ponds peripheral to or outside the deposit area. Samples with specific conductance above 89 µS/cm (upper quartile) are from ponds and ground waters within or close to the deposit area. The highest values are from borehole seeps that probably reflect a deeper ground water source.

For the major anions, the waters range from HCO_3^- to SO_4^{2-} dominant; the SO_4^{2-} dominant waters are from low-pH ponds in the Pebble West area (Fig. 2). The major cations are Ca dominant, with a few ponds that have stronger Na + K components. Not surprisingly, springs and borehole seeps have the highest major ion concentrations. The highest SO_4^{2-} and F^- concentrations occur in ground waters and lower pH ponds at Pebble West. The ratio of Fe^{2+}/Fe^{3+} (median, 4.1) indicates that most waters are reduced; the more reduced waters are highest in dissolved organic carbon.

Table 1. Statistics for selected variables***.***

Variable	***Min***	***Max***	***Median***	***Qrt[1]***	***unit***
pH	3.6	8.2	6.4	5.88	
Sp Con[2]	4	390	48	89	µS/cm
Ag	<2	60.5	<2	2.55	ppt
Cu	0.081	661	0.659	2.22	ppb
F^-	<0.08	2.6	<0.08	0.1	mg/L
Mo	7	18300	202	436	ppt
Ni	<0.05	19	0.138	0.379	ppb
Re	<0.1	158	0.93	5.49	ppt
∑REE	15.8	1820	139	219	ppt
Sb	6/67	281	18.9	29.1	ppt
SO_4^{2-}	<0.08	84.8	3.9	11.8	mg/L
Th	0.02	21.5	0.678	1.33	ppt
Tl	0.147	122	2.3	3.73	ppt
U	0.428	967	3.1	6.63	ppt
V	5.82	3420	167	269	ppt
W	<1	18600	1.97	7.04	ppt
Zn	0.709	93	3.11	5.63	ppt

[1] Qrt is the upper quartile value for all variables except pH, where it is the lower quartile value
[2] Sp Con, specific conductance

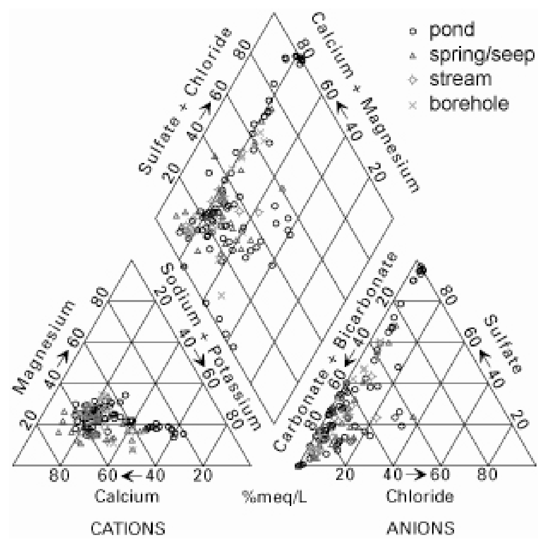

Fig. 2. Piper diagram showing major ion composition (Piper, 1944). Values for ions are in percent milli-equivalents per litre.

The HR-ICPMS cation analytical results are a robust dataset that is remarkably free of data qualifiers for 32 of the 63 cations analyzed; an additional 14 cations have <20% censored data. Further, the low-level data have consistent map distribution patterns that make sense geologically. Described below are patterns for several possible porphyry-related elements.

Gold was not detected at the 7 ppt DL. About 59% of the samples have censored values for Ag (DL = 2 ppt) and the maximum Ag concentration is 61 ppt. Nevertheless, the distribution pattern for Ag reveals a cluster of anomalous spring and pond samples in a ~10-km^2 area that is centred on the Pebble deposit. The area of anomalous Ag overlaps with that for Mo. Nearly the entire upper quartile of both Ag and Mo data falls within this area. Anomalous Ag and Mo in borehole seeps indicate that they are likely present in the deeper ground water system. However, the widespread areal extent of Mo and Ag in ponds and their presence in springs are evidence that they are also present in the shallow groundwater system, a pattern repeated for other elements.

Copper, Ni, Re, the rare earth elements (REE), and Tl exhibit similar distributions with the upper quartile of data from samples centred about Pebble West. These elements occur in ponds, springs, and borehole seeps, but are highest in the low-pH ponds. Curiously, elevated values of Cu and REE are not present in borehole seeps (circum-neutral pH).

Elements anomalous in waters over both Pebble West (thin cover) and Pebble East (thick cover) include Ag, Mo, Sb, Th, U, V, W, and Zn, occurring in all sample types. Anomalous W concentrations are confined to the deposit area, with highest concentrations in springs and boreholes.

CONCLUSIONS

(1) The low-level HR-ICPMS data exhibit good QC at ppt levels and consistent map patterns that appear to relate to mineralization.

(2) For pond and spring waters, nearly the entire upper quartiles of both Ag and Mo data fall within a ~10-km^2 area centred on the Pebble deposit.

(3) Anomalous elements around Pebble West (thin cover) include Cu, Ni, Re, the rare earth elements (REE), and Tl.

(4) Anomalous elements over both Pebble West and Pebble East (thick cover) include Ag, Mo, Sb, Th, U, V, W, and Zn.

(5) Hydrogeochemical exploration using HR-ICPMS delineates the variably concealed Pebble deposit and is a powerful new tool in the search for concealed deposits.

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Spectral, geochemical, and petrographic spatial analysis of the Maze Lake orogenic gold exploration project, Nunavut

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ABSTRACT: The Maze Lake orogenic gold exploration project is located in the Tavani Segment of the Central Hearne Supracrustal Belt, Hearne Province. The area is underlain primarily by massive mafic volcanic and volcaniclastic rocks, with subordinate felsic volcanic flows and siliciclastic units, and intruded by synvolcanic gabbroic dykes and sills, granitoid plutons, quartz-feldspar porphyry dykes, syenites, and lamprophyre dykes and sills. Three main exploration targets were identified on the basis of till and water geochemistry and airborne magnetic surveys. Haputilik-Dogleg, the northernmost target has the most advanced exploration database, including infrared spectra and multi-element geochemical analyses of eight drill holes. A careful re-examination of the geochemical and infrared spectroscopic data from Haputilik-Dogleg, aided by transmitted light petrographic analyses allowed for re-interpretations of lithology, structure, and hydrothermal alteration. Gold mineralization in the Haputilik-Dogleg zone is associated with iron sulfides in quartz-carbonate veins, with strongly anomalous silver, tungsten, molybdenum, copper, and tellurium. Mineralization envelopes have illite with high degree of crystallinity, low water content, and high Al-OH absorption feature wavelengths, and chlorite with high Mg-OH absorption feature wavelengths. The geochemical and spectral parameters that best correlate with gold were used to identify areas of high exploration potential beyond the drilled zone.

KEYWORDS*:* *infrared spectroscopy, transmitted light petrography, illite crystallinity index, 4-acid digestion ICP-MS, orogenic gold*

INTRODUCTION

A careful re-examination of the Maze Lake data set, including 1,357 infrared spectral feature extraction data points, 82 samples described in detail through transmitted light petrography and infrared spectroscopic analyses, and 2,200 gold fire assay plus 48-element ICP-MS analyses obtained using 4-acid digestion for nearly complete extraction of most elements allowed for an educated re-interpretation of lithological units, structure, hydrothermal alteration, and mineralization, and highlighted prospective, undrilled targets.

GEOLOGICAL SETTING

Regional Geology

The Maze Lake orogenic gold exploration project is located in the Tavani Segment of the Central Hearne Supracrustal Belt, Hearne Province (Park & Ralser 1992; Martel *et al.* 2007). The area is underlain by Archean supracrustal rocks comprising two volcanic assemblages that are unconformably overlain by Timiskaming-type sediments, and intruded by three igneous suites. The rocks underwent deformation and greenschist facies metamorphism towards the end of each depositional sequence. The second deformation event appears to be associated with the emplacement of gold mineralization. The Archean rocks are unconformably overlain by Paleoproterozoic Hurwitz Group siliciclastic and lesser carbonate rocks, which are currently distributed as erosional remnants of regional scale synforms.

Local Geology

Park & Ralser (1992) and Tella *et al.* (2005) mapped the southern half of the Maze Lake area as part of the Geological Survey of Canada's Tavani 1:100,000

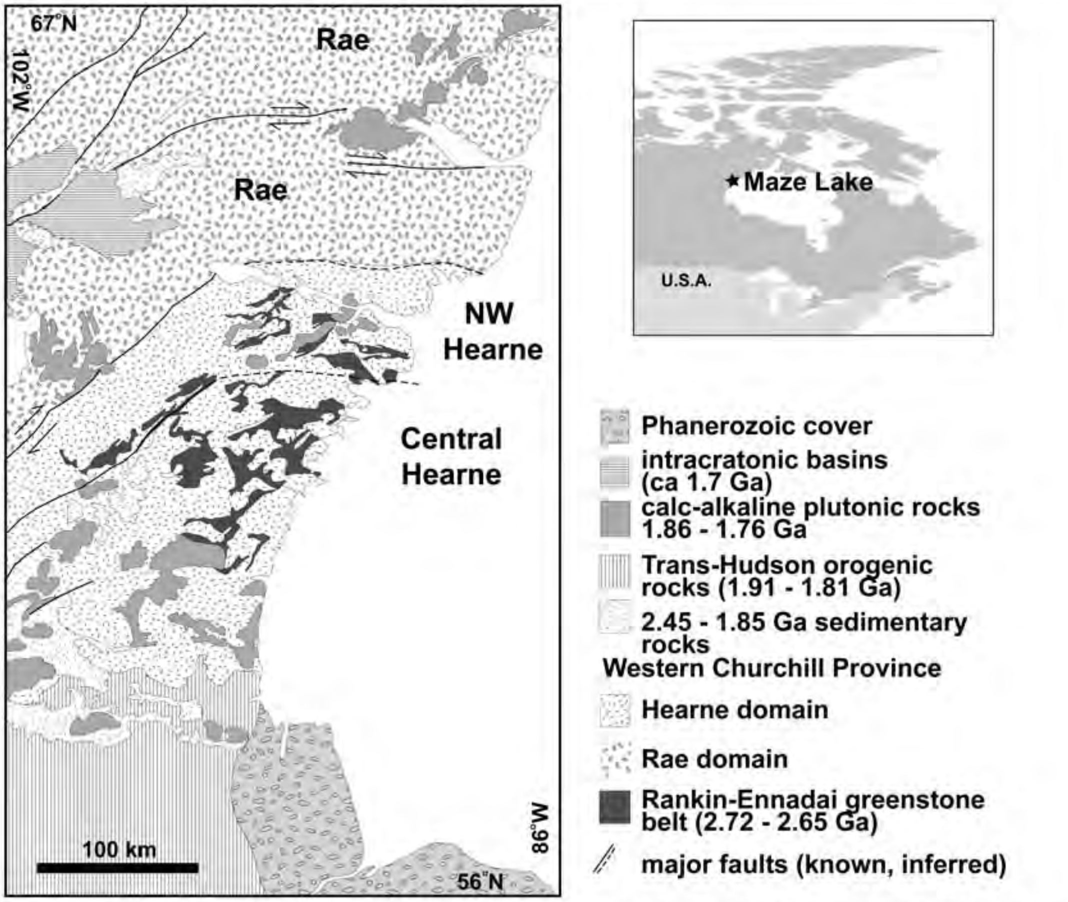

Figure 1. Location of the Maze Lake orogenic gold exploration project, and regional geology (after Sandeman *et al.*, 2003)

scale mapping project. They defined the stratigraphy as belonging to Kasigialik Group, which is divided into two main Archean volcanic formation (Atungag and Akliqnaktuk) and an Archean sedimentary formation (Evitruktuk). Kasigialik Group is unconformably overlain by the Archean dominantly sedimentary Taiulik formation, which is in turn unconformably overlain by Paleoproterozoic Hurwitz Group's Kinga and Tavani formations. Sikaman Resources and Placer Dome Inc. conducted geological mapping of the Maze Lake area in the 1980s and in 2003-2004, respectively.

The Maze Lake area is underlain primarily by massive mafic volcanic flows and lesser pillowed, and amygdaloidal flows and tuffaceous rocks in the southern and central portions of the property, and along the extreme northern edge. Minor felsic to intermediate volcanic flows and siliciclastic units occur in the northern and southern ends of the property, and banded iron formations are inferred from aeromagnetic data. The volcano-sedimentary sequence is intruded by synvolcanic gabbroic dykes and sills, granitoid plutons, quartz-feldspar porphyry dykes, diorite, syenite, and lamprophyric dykes. The main exploration targets are Haputilik-Dogleg in the north, Anomaly 1 in the south, and Anomaly 2 in the centre of the property. Haputilik-Dogleg and Anomaly 1 were drilled by Placer Dome Inc. and by Laurentian Resources Ltd.

ALTERATION & MINERALIZATION

Variably texture-destructive carbonate alteration is ubiquitous throughout the Maze Lake property, and often precludes conclusive lithological identification in hand specimen and in petrographic samples. The alteration hosting mineralized veins is dominantly potassic, though carbonate alteration is present as an early pervasive phase and as late veinlets in mineralized areas. Proximal potassic alteration consists of mosaic orthoclase replacing primary feldspar phenoclasts and fine-grained feldspars in the groundmass, very fine-grained biotite-carbonate replacing mafic phenoclasts and lithic clasts, and trace clusters of very fine-grained leucoxene. Elevated magnetic susceptibility associated with mineralized areas suggests that magnetite forms part of the potassic alteration assemblage.

Throughout the Maze Lake property, gold shows moderate positive correlation with illite crystallinity indices and with higher wavelengths for the Al-OH absorption features extracted from infrared spectroscopic analyses of drill core. Illite crystallinity index is defined as the ratio between the depth of the Al-OH spectral absorption feature centered around 2200 nm and the depth of the water feature centered around 1905 nm (Fig. 2). Gold has a weaker positive correlation with increasing Al-OH band wavelength, and a modest negative correlation with the depth of the white mica water absorption features. The spectral feature analysis suggests that gold mineralization is associated with white micas containing low structural water content and high degree of crystallinity, and with the Fe-rich chloritic end-member. Automated mineral identifications using The Spectral Geologist software is biased towards the most abundant phyllosilicates that define tectonic foliations, namely chlorite and muscovite, and therefore has limited use in characterizing alteration zones and defining new targets in the Maze Lake property. However, automated mineral identifications proved useful in the re-interpretation of lithological units. Manual mineral identifications of limited available infrared spectra indicates the presence of phengite adjacent to mineralized intervals, whereas the automated mineral identifications show a negative correlation between gold and presence of phengite.

Gold mineralization in the Haputilik-Dogleg zone is often emplaced near the contacts of lamprophyre and shonkonite intrusions, and hosted dominantly by volcaniclastic rocks, and less commonly by gabbro and quartz-feldspar porphyry dykes. Lamprophyric and shonkonitic dykes are characterized by high magnetic susceptibility, elevated HFSE and variably elevated LILE, P, and Li, and are inferred from geochemical striplogs in cases where they were not logged. Limited petrographic analyses suggest that some of what is logged as gabbroic rocks hosting mineralized veins likely consist of mafic syenite (shonkonite). Elevated sodium geochemistry coincident with intense

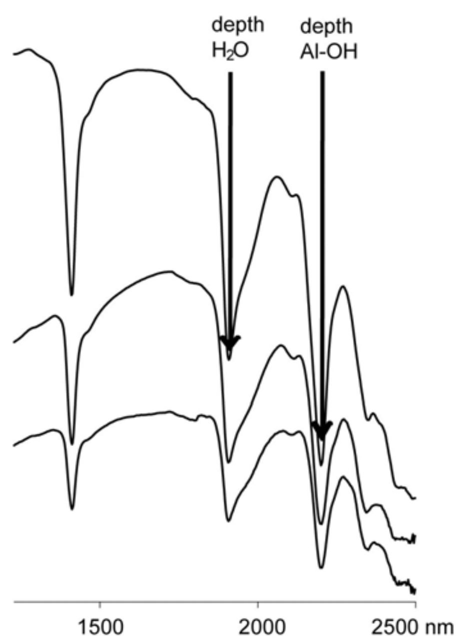

Figure 2. Illite crystallinity index. Illite crystallinity is defined as the ratio of the depth of the water feature to the depth of the Al-OH feature.

chloritic alteration interpreted from infrared spectroscopic automated mineral identifications of bleached drill core units logged as aplite are interpreted as propylitic alteration in a volcanic and volcaniclastic host. This interpretation allows for a simpler structural and lithological model for Haputilik-Dogleg zone.

Mineralized intervals in drill holes of the Haputilik-Dogleg zone show correlations between gold and Ag, W, Mo, Cu, and Te. A spatial analysis using geochemical analyses for those elements and K and spectral features highlights undrilled anomalous target areas at the far east, northwest, and southwest Haputilik zone, as well as anomalous areas in Anomaly 1 zone.

CONCLUSIONS

An integrated analysis of automated spectral mineral identifications and spectral feature extractions using The Spectral Geologist software combined with multi-element ICP-MS geochemistry using 4-acid digestion, and assisted by transmitted light petrography provides an efficient and affordable means to interpret the geology and characterize the alteration of orogenic gold style deposits.

Automated feature extraction using The Spectral Geologist provides a fast means to obtain abundant and valuable data pertaining to mineral alteration. However, the automated spectral mineral identifications of foliated rocks proved strongly biased towards the phyllosylicates that define tectonic foliations, and were not sufficient to model hydrothermal mineral alteration zoning.

In spite of limitations in the dissolution of certain immobile and mobile elements, 4-acid digestion ICP-MS analyses combined with petrographic observations provides an affordable means to track and model major oxide mobility in the Maze Lake orogenic gold property.

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Porphyry Copper Indicator Minerals (PCIMs) in glacial till samples from the giant Pebble porphyry Cu-Au-Mo deposit: exploration significance

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ABSTRACT: Porphyry Cu indicator minerals (PCIMs) are mineral species in clastic sediments that indicate the presence of mineralization and hydrothermal alteration associated with porphyry Cu deposits. PCIMs from glacial till samples near the giant Pebble Cu-Au-Mo deposit in southwest Alaska include visible gold and jarosite. All samples including those up-ice from the deposit, contain some gold. However, tills immediately west and down-ice of Pebble contain more abundant gold, and the overall number of grains decreases fairly systematically in the down-ice direction. Furthermore, all samples in the immediate vicinity of Pebble contain more than 30% pristine grains compared to mostly re-shaped grains in distal samples. Most gold in the deposit is contained in chalcopyrite; therefore, the pristine nature of the grains likely reflects liberation during *in situ* weathering of transported chalcopyrite grains. Jarosite is also abundant (up to 25%) in samples adjacent to and up to 7 km down-ice from the deposit. Most jarosite grains have a detrital morphology (variably worn) suggesting the jarosite formed prior to glaciation. Overall, the results indicate that PCIMs in till samples may be useful for exploration of porphyry deposits in southwest Alaska.

KEYWORDS: *porphyry Cu, indicator minerals, glacial till, exploration, Alaska*

INTRODUCTION

Indicator mineralogy has been developed as an exploration tool for a variety of base metal sulfide deposits (Averill 2001, 2007). Grain abundance and morphology are among the characteristics that may be diagnostic. Indicator minerals are heavy (>2.8 S.G.) and thus concentratable, readily identifiable, and chemically stable in weathered surficial sediments. The suite of porphyry Cu indicator minerals (PCIMs) were initially determined for deposits in arid regions but have more recently been applied to those in humid areas (Averill 2007). PCIMs typically produce strong anomalies in surficial sediments due to the large size of mineralized porphyry systems (Averill 2001). PCIMs that have been used successfully include diaspore, tourmaline, FeCaMn garnet, alunite, rutile, and jarosite (Averill 2007). As part of an orientation study, the PCIM method was applied to the Pebble porphyry Cu-Au-Mo deposit, located ~320 km southwest of Anchorage, Alaska (Fig. 1). Twenty six glacial till samples were collected up- and down-ice from the deposit. Several minerals were identified that target the deposit, suggesting that PCIMs may be useful in exploration for concealed porphyry deposits in southwest Alaska.

REGIONAL AND LOCAL GEOLOGY

The Pebble porphyry deposit contains one of the largest resources of copper and gold in the world. The deposit consists of the Pebble West and Pebble East Zones,

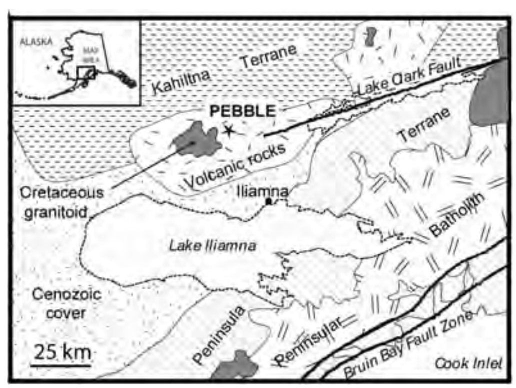

Fig. 1. Location of Pebble with major geologic and tectonic features (from Wallace *et al.* 1989).

containing a combined resource of 72 billion pounds of copper, 94 million ounces of gold, and 4.8 billion pounds of molybdenum (NDM 2009).

The Pebble deposit is located in the Kahiltna terrane, near the boundary between two lithologic packages: Jurassic and older magmatic-metamorphic rocks to the southeast, and an assemblage of Mesozoic volcaniclastic and sedimentary rocks overlain by Tertiary volcanic rocks, to the northwest. The Lake Clark fault trends northeast and is coincident with the change in lithologic packages (Haeussler & Saltus 2004; Fig. 1).

The Pebble district comprises Jura-Cretaceous andesitic argillite, siltstone and wacke, cut by diorite sills (Bouley *et al.* 1995). Diverse intrusions occupy a northeast-trending structural corridor. Subalkalic granodiorite intrusions (91-89 Ma) include the Kaskanak Batholith and smaller satellite bodies that are genetically related to Cu-Au-Mo mineralization (Lang *et al.* 2007).

The Pebble West Zone extends from surface to ~500 m depth. The East Zone, which extends to at least 1700 m depth, was partially eroded and is concealed by an eastwardly thickening wedge of Late Cretaceous to Eocene volcanic and sedimentary rocks (Bouley *et al.* 1995; Lang *et al.* 2007). Mineralization occurs in strong K-silicate alteration zones, and in multi-generational stockworks of quartz-carbonate-sulfide veins. Ore minerals include chalcopyrite, molybdenite, and native gold found mostly within chalcopyrite. High-grade, bornite-bearing mineralization occurs in the core of the East Zone (Lang *et al*. 2007).

Quaternary Geology

The Pebble area was affected by Pleistocene-age glaciers from two sources: one flowed southwestward down the Lake Clark structural trough, and the other overflowed westward from Cook Inlet. At various times, these glaciers blocked each of the three major drainages in the Pebble project area – Upper Talarik Creek and the North and South Forks of the Koktuli River. The resulting ice-dammed lakes filled lowlands in headward parts of each drainage (Fig. 2).

The glacial till deposits consist of poorly sorted to unsorted, nonstratified till ranging from muddy gravel to sandy coarse gravel. Pebbles and small cobbles are dominant. Surface morphology commonly includes morainal ridges, dry and water-filled kettle depressions, and meltwater channels (Hamilton 2007).

RESULTS AND DISCUSSION

Till samples (about 8 kg of material) were collected up- and down-ice from the deposit, over a total distance of about 20 km (Fig. 2). The samples were put through a shaking table (<2 mm) and gold grain counts were reported. Sieving and heavy liquid (S.G. 2.8-3.2 and >3.2) separation followed. The PCIMs were identified in the 0.25-0.5 mm fraction.

The most effective indicator minerals for targeting the Pebble deposit are gold and jarosite. Sulfide minerals (pyrite or chalcopyrite) are rare in the tills, in spite of their abundance in the deposit. Possible explanations for this are explored in the following discussion.

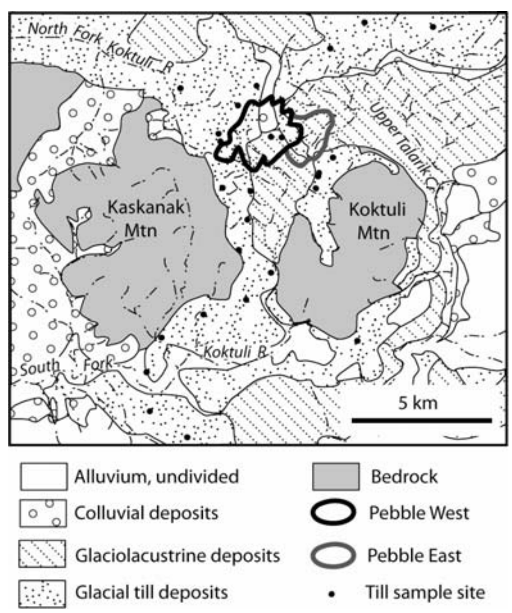

Fig. 2. Quaternary geology of the Pebble area showing sample locations (modified from Hamilton 2007).

Gold Morphology and Distribution

Gold grain abundance and shape show interesting patterns (Fig. 3). All samples contain some gold (avg. size 75 µm); even samples 8 km up-ice contain 5-10 grains. There are many possible sources of gold in the region, including porphyry, skarn, and epithermal deposits in the Lake Clark quadrangle northeast of Pebble (Bickerstaff 1998) and in the Pebble district (Hawley 2004). However, tills immediately adjacent to Pebble West contain 12 times the number of gold grains in samples up- or down-ice, and the overall number of grains decreases in the down-ice direction (Fig. 3).

Also important is the morphology (degree of rounding, polishing, bending and flatness) of the gold grains which may provide information about the transport mechanism (Averill 1988; McClenaghan 2005). All samples in the immediate vicinity of Pebble West contain 30% or more pristine grains whereas those at greater distance down-ice or up-ice contain almost exclusively re-shaped grains. The transport history of pristine grains may be interpreted in two ways: (1) gold grains were eroded from a bedrock source nearby and transported to the site with little or no surface modification (short transport distance), and (2) gold grains were liberated from rock fragments during *in situ* weathering of transported sulfide grains containing gold (Coker & Shilts 1991; McClenaghan 2005). Because most gold in the Pebble deposit is contained in chalcopyrite (Lang *et al.* 2007), the second option is the most likely, and it implies that post-glacial oxidation of the till was nearly completely sulfide destructive.

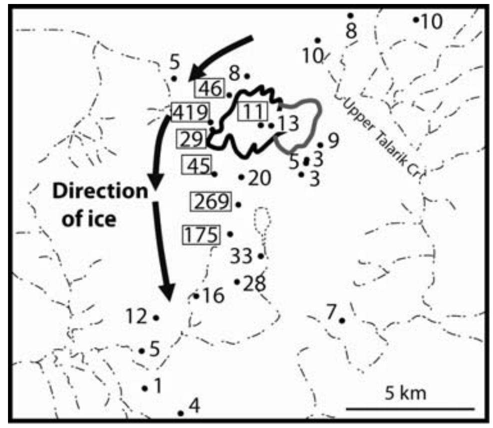

Fig. 3. Distribution of gold in till samples. The number refers to number of grains. Boxes around numbers signify >30% of gold grains are pristine.

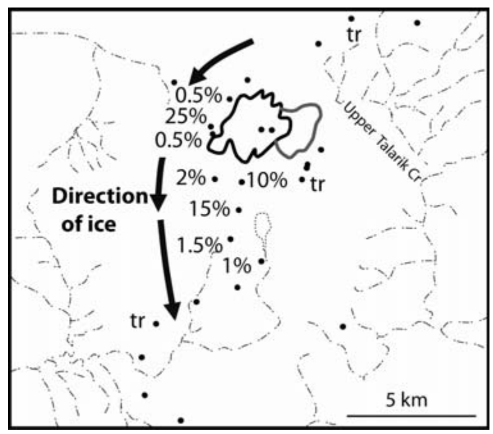

Fig. 4. Distribution of jarosite in till samples. The number refers to percent abundance.

Jarosite

The distribution of jarosite in till samples is even more compelling than that for gold. Except for three samples with trace amounts, the most abundant jarosite (from 1 to 25% of the grains in the heavy mineral fraction) occurs in samples adjacent to and within 7 km down-ice from the deposit (Fig. 4). Most jarosite grains have a detrital morphology (variably worn), suggesting the jarosite formed prior to glaciation. Jarosite occurs in porphyry systems that have extensive supergene enrichment zones, having formed from acidic weathering of pyrite in fluctuating arid/semi-arid conditions (intermittent periods of wetness in an arid climate) (Hartley & Rice 2005). The upper portion of the Pebble West Zone is oxidized, and much of it is underlain by supergene mineralization. The Pebble East Zone lacks such supergene development. Either it was not developed there or it has been completely eroded away; in many glaciated areas (i.e., areas with till), the level of bedrock erosion is below the level of the main oxide cap development (Averill

2001). Further studies are planned to date the jarosite and identify when it formed.

CONCLUSIONS

The primary PCIMs in till samples from the Pebble deposit are visible gold and jarosite. Summary points include:

(1) The abundance of visible gold in samples is highest adjacent to and immediately down-ice from the deposit

(2) Within the deposit, gold occurs mostly within chalcopyrite. The pristine nature of gold in the tills suggests that it was liberated during *in situ* weathering of transported chalcopyrite grains

(3) The presence of jarosite in tills is a good vector to mineralization.

ACKNOWLEDGEMENTS

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Geochemical and mineralogical exploration of sandstones in the Lublin Carboniferous Basin, SE Poland

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ABSTRACT: Geochemical and mineralogical studies were performed on sandstones drilled in the Lublin Coal Basin to characterize minerals and cements. The sandstones studied are mostly arenites and subarkose and quartz wackes (rare sublithic, sporadical lithic and arkose). Quartz is the main component with subordinate feldspars, micas (muscovite and biotite) and chlorites. The diagenetic processes observed in the sandstones are: dissolution, alteration, replacement and mechanical compaction. Different types of cements are present such as clay, quartz and carbonate cements. Kaolinite (vermicular and blocky), illite and dickite are the main components of clay cements. Quartz and carbonate cements (siderite, Fe-dolomite, ankerite and Fe-calcite) are significant. The carbonates display different isotopic and fluid inclusion characteristics. The $\delta^{13}C$ data suggest that siderite and ankerite formed in the zone of microbiological methane genesis. The organic matter of the Carboniferous deposits mainly represents the humus type and R_o indices point to a maximum palaeotemperature of about 120ºC. The K/Ar dating suggests that the crystallization age of diagenetic illite is from 286.5±3.4 Ma to 278±3.4 Ma.

KEYWORDS: *geochemistry, mineralogy, Carboniferous, sandstones, diagenesis*

INTRODUCTION

Rocks from 27 boreholes from the Lublin Carboniferous Basin (LCB) were analysed to characterize their mineralogy and diagenetic history (Fig. 1).

The top of the Carboniferous deposits occurs there at the depth of 2528 m in the Potycz 1 borehole and decreases towards SE in the Terebin 1 borehole.

The analysed sandstones with accompanying mudstones, claystones and subordinate conglomerates are of fluvial origin and interlayered with marine and deltaic deposits (Waksmundzka 2008).

GEOLOGICAL SETTING

The Lublin Coal Basin is the Carboniferous basin situated in SE Poland. It is located in the south-eastern part of the Polish Lowlands, close to the Teisseyre -Tornquist zone, which divides the whole territory of Poland to the Palaeozoic - Mesozoic and Precambrian platforms. The Lublin graben is an elongated NW-SE structural unit. The base of the Carboniferous in the basin is of Namurian age. The thickness of the Carboniferous deposits increases towards the SE from about 370 m to over 1600 m.

ANALYTICAL METHODS

Standard microscopic analysis was performed on thin sections. Quantitative mineralogical and porosity data were derived by point counting. Samples were stained with Evamy's solution (calcite became purple, ankerite – blue, dolomite

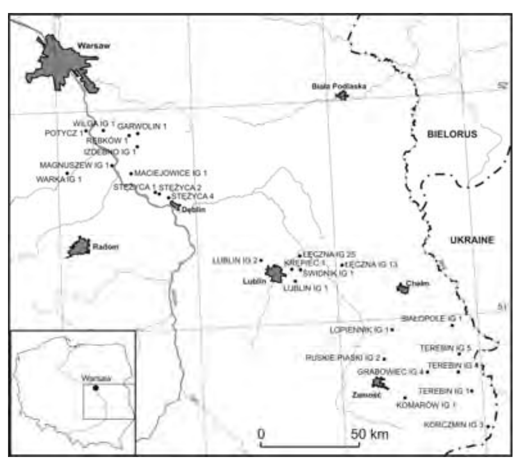

Fig. 1. Boreholes locations in the Lublin Carboniferous Basin (LCB).

and siderite – remain unstained), and analyzed using cathodoluminescence (CL) and energy dispersive x-rays (EDS). Clay minerals were determinated by XRD. Fluid inclusions were analysed in the different cement types. Homogenisation temperatures of two phase inclusions (T_h) were measured on quartz, calcite and ankerite (Fig. 2), and freezing experiments performed as well. Oxygen and carbon isotopic analyses were conducted on carbonates. The fibrous illite was dated by the K/Ar method.

RESULTS AND DISCUSSION

Petrological Characteristics

Microlithofacial classification of the sandstones is based on Dott's classification modified by Pettijohn *et al*. (1972). They are mostly arenites and subarkose and quartz wackes (rare sublithic, sporadically lithic and arkosic). Quartz is the main component of the sandstones (about 60-70 vol. percent). Feldspars (6 vol. percent) are mostly represented by potassium feldspars with plagioclases in lesser amounts. Some micas (muscovite and biotite) and chlorites are observed. Mica content of arenites reaches 3 vol. %, but is higher in the wackes. Heavy minerals present include zircon, sphene, rutile and apatite. Magmatic rocks (volcanic more than plutonic) are predominant among lithoclasts (about 2 vol. %), but some metamorphic and sedimentary clasts being present too.

The detrital material is most frequently semi rounded and well sorted. It is rather loosely arranged in the arenites - the indicator of grain contacts in the sediment may be estimated at about 2.0. Point contacts are few, or absent in the wackes.

The diagenetic processes observed in the sandstones are: dissolution, alteration, replacement and mechanical compaction.

Main Components of Cements

The sandstones studied contain different types of cements, such as clay, quartz and carbonate cements. Clay cements are often a mixture of allo- and authigenic minerals. Kaolinite is the main component

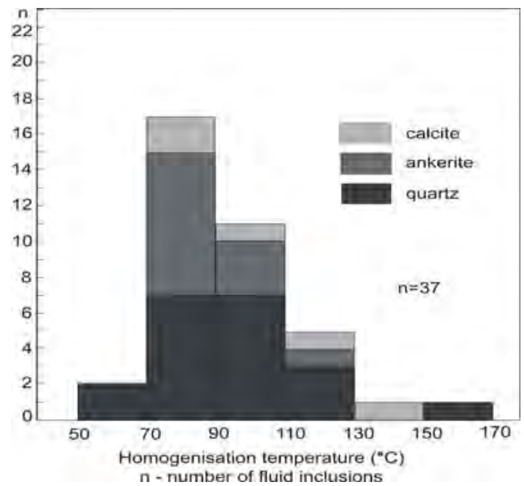

Fig. 2. Distribution of homogenisation temperatures in different cements

with a volume percentage from 4 to maximum of 19.3%. Two morphological types of kaolinite - vermicular and blocky kaolinites were observed in the Carboniferous sandstone profile. The higher amounts of the vermicular kaolinite occur in the upper parts of profiles. Dickite is present in the <2 μm and 2-10 μm fractions (XRD). Illite occurs in form of very fine plates. It coats detrital grains and fills intergranular space. K/Ar dating indicates that the crystallization age of diagenetic illite changes from 286.5±3.4 Ma in the Komarow IG 1 to 278±3.4 Ma in the Grabowiec IG 4 boreholes (Kozłowska 2006). Chlorite, mostly ferruginous, is developed as overgrowths and filling pore space. The presence of mixed-layered minerals illite/smectite, with over 90% illite, was indicated by XRD. Quartz, a significant component of the cements, occurs either as quartz dust mixed with clay minerals, or forms authigenic regeneration rims over the quartz grains. The percentage of quartz cement ranges from 1 to 10 vol.%, locally exceeding 20%. Fluid inclusion studies in the quartz cement revealed mostly one phase inclusions that may point to cement formation below 50ºC (Roedder 1984; Goldstein & Reynolds 1994). In two phase inclusions, the homogenization temperatures fall in the interval from 58ºC to 160ºC.

Carbonate cement content in the studied rocks varies from 0 to 45 vol. %, mostly forming the pore filling. The following carbonates were observed (Kozłowska 2004): siderite, Fe-dolomite, ankerite and Fe-calcite. The term “siderite” corresponds to minerals from the isomorphic group $FeCO_3$–$MgCO_3$ with 60–100 mol percent $FeCO_3$. Most siderites fall into the interval siderite – sideroplesite (Fig. 3).

Two siderite generations have been distinguished: early and late (Kozłowska 2004). Sideroplesite or siderite represent the early generation. The minerals mostly occur as finely crystalline grains or spherolites, rarely as massive forms. The $\delta^{18}O_{PDB}$ values for the siderite are in the interval from –18.37 to –4.30‰, while the $\delta^{13}C_{PDB}$ range from –8.52 to 3.63‰. The $\delta^{13}C$ data point to siderite formation in the zone of microbiological methane genesis (Morad 1998). The late siderite generation displays a higher $MgCO_3$ content, while the chemical composition corresponds to sideroplesite, and occasionally to pistomesite. These minerals often crystallize in form of rhombohedrons filling empty pore space or replacing the earlier siderite generation. Fe-dolomite and ankerite most frequently occur as isolated euhedral crystals or form massive spar cement. Two phase fluid inclusions homogenize in temperatures between 70ºC and 117ºC (Jarmolowicz-Szulc 1999). The $\delta^{18}O_{PDB}$ values for ankerite range from –15.11 to –7.47 ‰, while the $\delta^{13}C_{PDB}$ are in the interval from –8.77 to 3.74 ‰. The $\delta^{13}C$ data suggest ankerite formation in the zone of microbiological methane genesis (Morad 1998). Fe-calcite forms the pore cement, filling the inter- and intra-grain space. The fluid inclusions in calcite homogenized at temperatures from 84ºC to 138ºC. The $\delta^{18}O_{PDB}$ values for Fe-calcite lie in the interval from –19.35 to –3.48 ‰, while the $\delta^{13}C_{PDB}$ values vary between –19.45 and 1.39‰. The $\delta^{13}C$ data suggest Fe-calcite formation in the zone of microbiological methane genesis and of thermal decarboxilation of the organic matter (Morad 1998).

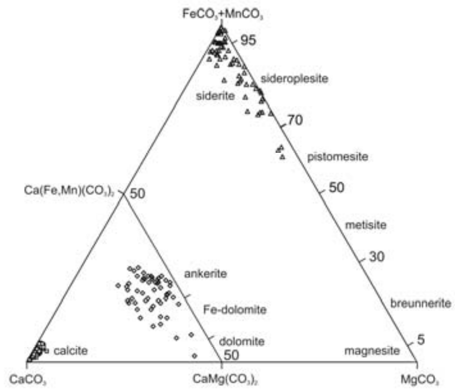

Fig. 3. Classification triangle for carbonates

Other types of cements include anhydrite, barite, pyrite, iron hydroxides haematite, albite and apatite and are subordinate.

The whole diagenetic sequence of the rocks drilled in the boreholes in LCB may be shown diagrammatically as in Fig. 4.

Organic matter in the Carboniferous deposits mainly represents the humus type with vitrinite as a main component. The R_o index measured on the authigenic vitrinite increases towards the bottom of the deposits from 0.49 to 1.15% (Grotek 2005). These data point to a maximum palaeotemperature of about 120ºC.

The sandstone porosity in thin sections oscillates from below 1 to 22.3 vol. % of rock (average 8 % vol.) Primary porosity dominates over secondary porosity in the sandstones.

CONCLUSIONS

The following conclusions may be drawn from the present contribution:

(1) The Carboniferous sandstones in the boreholes in LCB are represented by arenites and wackes, mainly quartz, subarkose and sublithic;

(2) Space between the detrital grains is filled in, totally or partly, by matrix and/or different types of cement;

(3) Clay minerals, quartz and carbonates predominate among the cements;

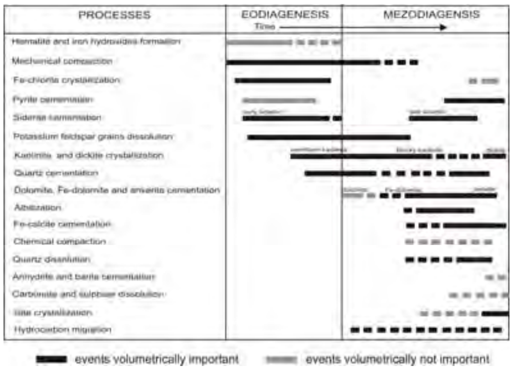

Fig. 4. Diagenetic sequence for studied rocks.

(4) The porosity (primary and secondary) of the sandstones ranges from below 1% to 22.3 vol. %.

(5) During their diagenesis, the Carboniferous deposits were subjected to temperatures up to a maximum of 120°C.

(6) The Carboniferous deposits reached their maximum temperatures at the end of the Carboniferous, while the diagenetic processes carried on until the Early Permian.

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Target delineation by Fuzzy Logic approach at East-Kahang Porphyry Cu-Mo deposit, Central Iran

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ABSTRACT: Mineral potential mapping in a GIS environment is becoming a common practice at different exploration scales. In this study information synthesis, by using a knowledge-based Fuzzy Logic method, has been examined on four multiclass maps extracted from detailed exploration data from the East-Kahang porphyry Cu-Mo deposit. Integration of geochemical data, mapped lithological/alteration units and structural controls, that could be associated with porphyry copper mineralization, are used to rate high potential areas for further drilling. This is achieved by validating the data integration model against elevated values of copper from previously drilled holes.

KEYWORDS: *Information Synthesis, Fuzzy Logic, Data Integration, Porphyry Copper, Iran*

INTRODUCTION

Data integration methods, within a Geographic Information System (GIS), are largely used to delineate mineral exploration targets on a regional scale (Asadi & Hale 2000; de Quadros *et al.* 2006). In this study, a Fuzzy Logic method is employed to integrate surface exploration data over the 1 Km^2 East-Kahang porphyry Cu-Mo deposit in order to predict potential hidden mineralized zones on a local scale.

The Kahang deposit is in the central part of the Urumieh Dokhtar belt, the main volcanic arc of Iran (Fig. 1). Kahang was discovered in 2002 by mapping hydrothermal alteration using Landsat-TM satellite imagery data. In the Kahang area, there are three separate mineralized zones (East, Central and West) within a 16 km^2 porphyry type alteration system. The exploration activities, completed in the East-Kahang, include detailed geological mapping and systematic geochemical and geophysical surveying, which have led to deep drilling. Three out of five bore holes, drilled at East-Kahang, intersected a number of relatively deep Cu-Mo mineralized zones. In order to design the best borehole locations for the next phase of drilling, an integrated analysis of the surface exploration data is employed using a Fuzzy Logic technique.

GEOLOGY OF THE AREA

The major rock units in the East-Kahang are made up of andesite, volcanic breccia, dacite, quartz-diorite, diorite and locally mineralized hydrothermal breccia (Fig. 2). Eocene andesite and volcanic breccias showing propylitic alteration are the oldest units in the area. They have been intruded by dacite, mostly showing phyllic alteration associated with weak copper mineralization. Quartz-diorite and dioritic

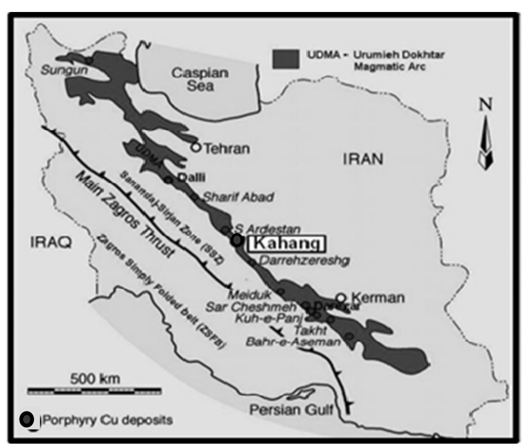

Fig. 1. The location of Kahang deposit in the Urmieh Dokhtart Volcanic Arc.

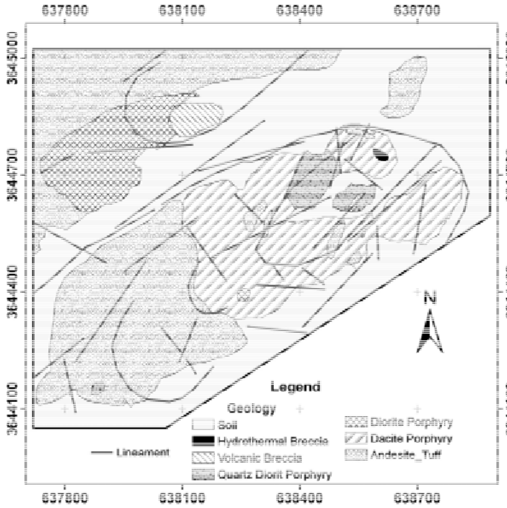

Fig. 2. Input lithological units and structures in the Fuzzy Logic model.

stocks with phyllic and propylitic alterations have intruded into dacite and andesites, causing alteration of older units and Cu-Mo mineralization (Fig. 3). The structural controls consist of linear and semi-circular features, some of which associated with Cu-Mo mineralization.

PRINCIPALS OF FUZZY DATA FUSION

Fuzzy Logic is a knowledge driven technique that works in mineral exploration on the basis of assigned weights to the different memberships/input layers, possibly associated with certain mineralization. Fuzzy membership values need to be determined by expert knowledge. The assigned weights for the memberships are then integrated, using different Fuzzy operators, for production of the final mineral prospectivity map. The Fuzzy operators applied in this study are as follows:

Fuzzy OR:

$$W_{\text{Combination}} = MAX(W_A, W_B, W_C, ...) \qquad (1)$$

Where W_A, W_B and W_C are weights of different memberships, associated with Cu-Mo mineralization.

Fuzzy PRODUCT:

$$W_{\text{Combination}} = \prod_{i=1}^{n} W_i \qquad (2)$$

Where n is the number of memberships and W_i is the given weight for each certain membership.

Fuzzy SUM:

$$W_{\text{Combination}} = 1 - \left(\prod_{i=1}^{n} (1 - W_i)\right) \qquad (3)$$

and,

Fuzzy GAMMA:

$$\mu_{Combination} = (Fuzzy \text{ Algabric } Sum)^{\gamma} * (Fuzzy \text{ Algabric Product})^{1-\gamma} \qquad (4)$$

Based on the importance of Fuzzy Product or Fuzzy Sum, Gamma values could be changed between 0 to 1.

INPUT LAYERS

Input map layers into Fuzzy Logic Operators include lithologies and hydrothermal alteration plus their ranges of influence (buffer zone), lineament density maps and multiplicative geochemical maps. Input map layers are explained in the following sections.

Lithology and Alteration

The lithological and hydrothermal alteration units from the geological map of the area (1:1000 scale) are converted to an appropriate format for information synthesis. By considering the conceptual models for porphyry copper deposits and

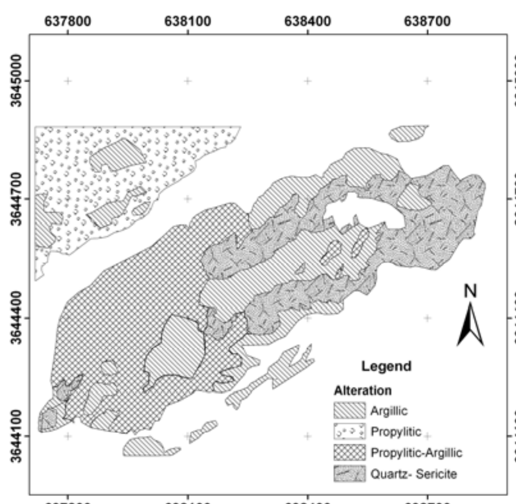

Fig. 3. Input hydrothermal alteration units in the Fuzzy Logic model.

characteristics of the mineralisation at East-Kahang, and based on expert knowledge, weights between 0.3 – 0.9 are assigned to appropriate lithological units and hydrothermal alteration (Tables 1 & 2).

Lineaments

The structural layer input is prepared by mapping linear and semi-circular structures from high resolution multi spectral Quick Bird satellite images as well as by digitizing them from the 1:1000 geological map of the area. These structures could control the migration of hydrothermal fluids and formation of porphyry copper mineralization. Using all lineaments and semi-circular structures, a lineament density map is prepared and weights are accordingly given to each structural density unit. The lineament density map is prepared by computing the magnitude per unit cell from linear/circular features in a given radius (30 m). The allocated weights are shown in Table 3.

GEOCHEMISTRY

Seventy soil samples were systematically collected over the East-Kahang area in a 150 by 150 m grid. The samples were analysed for 44 elements by ICP-MS at Amdel Limited lab in Australia. Using statistical techniques, it was decided to produce a multiplicative Cu*Mo map, as better defined anomalies can be achieved by multiplicative haloes (Beus & Grigorian 1977). The Cu*Mo map is then classified into four classes for final data integration (Fig. 4). Multiplicative Cu*Mo geochemical classes and their assigned weights are shown in Table 4.

FUZZY INTEGRATION MODEL

In order to prepare the final multi-class predictor map, the input weighted layers are fused using various Fuzzy operators (Fig. 5). Figure 6 is a reclassified final Fuzzy map, predicting the high potential areas for further drilling at East-Kahang. To validate the accuracy of the Fuzzy model, the projected Cu values of the completed drill holes are overlain on the final predictive map. The results show

Table 1. Fuzzy weights assigned to lithological units and their 20 m buffered zones.

Lithology Layer		Weight
Rock Type	Hydrothermal Breccia	0.9
	Dacite Porphyry	0.8
	Quartz-Diorite-Porphyry	0.8
	Volcanic Breccia	0.7
	Diorite Porphyry	0.5
	Andesite - Tuff	0.5
	Soil	0.5
Rock Buffer	Hydrothermal Breccia	0.9
	Dacite Porphyry	0.8
	Quartz-Diorite-Porphyry	0.8
	Volcanic Breccia	0.6

Table 2. Fuzzy weights assigned to alteration units and their 20 m buffered zones.

Alteration Layer		Weight
Alteration	Quartz-Sericite	0.9
	Argillic	0.7
	Propylitic-Argillic	0.4
	Propylitic	0.3
Buffer	Quartz-Sericite	0.8

Table 3. Lineament density classes and their Fuzzy weights.

Class		Weight
Lineament Density	>45	0.9
	45	0.6
	35	0.3
	<15	0

Table 4. Multiplicative geochemical classes and their weights.

Class		Weight
Geochemistry (Cu*Mo) ppm^2	>3500	0.9
	1000-3500	0.7
	500-1000	0.5
	<500	0.1

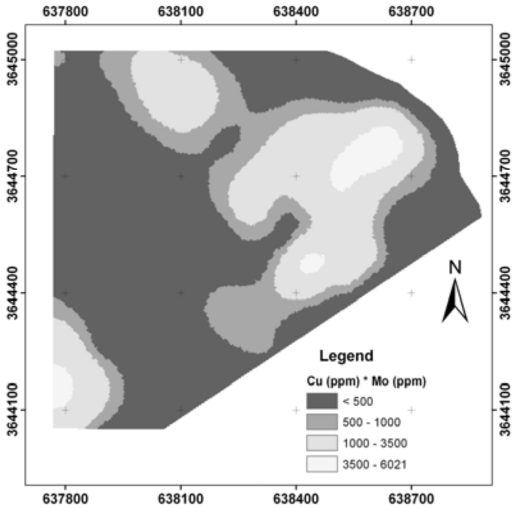

Fig. 4. Input Cu*Mo geochemical map in the Fuzzy Logic Model.

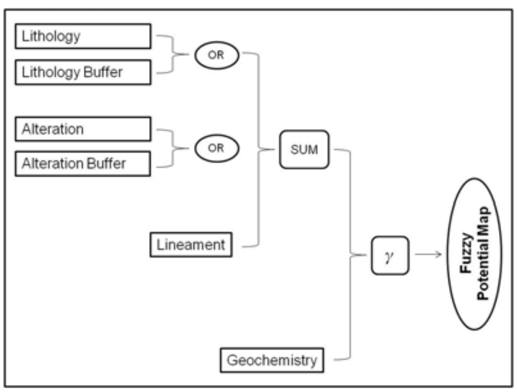

Fig. 5. Flow chart of the input data integration method in Fuzzy potential mapping.

relatively significant correlation between the high and moderate potential areas with the elevated Cu values in the boreholes.

CONCLUSION AND RECOMMENDATIONS

Although, methods of data integration for target detection are mostly used on a regional scale, in this study the Fuzzy approach is successfully employed on a local scale in the East-Kahang Cu-Mo deposit to map high potential areas, for further drilling.

It is recommended to use data fusion techniques such as the Fuzzy approach or other methods like the Neuro-Fuzzy on surface data to locate the most promising sites for drilling.

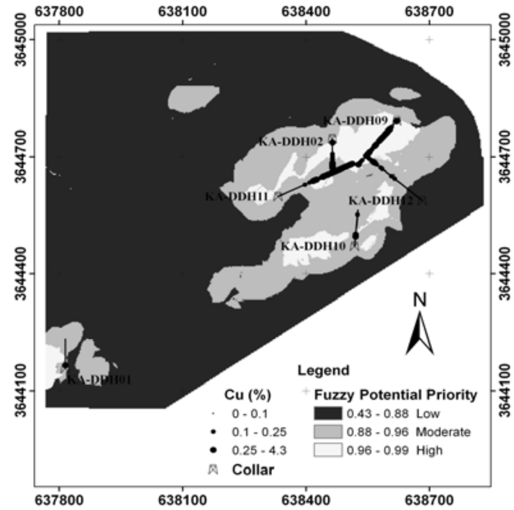

Fig. 6. Fuzzy potential priority map at East-Kahagn deposit.

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Carlin-type gold geochemical patterns delineated by different-density data

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ABSTRACT: The world's second largest Carlin-type gold province occurs in southwest China. The RGNR project covering the total area of the metallogenic province provides an excellent opportunity for insight into the multi-scale geochemical patterns using different data densities. The results show that local geochemical anomalies delineated by 1 datum/4km^2 can define individual ore deposits, regional anomalies delineated by 1 datum /16 km^2 reveal ore clusters, while geochemical provinces delineated by 1 datum/100 km^2 show the metallogenic province and the large deposit clusters.

KEYWORDS: *Carlin-type gold deposit, geochemical pattern, data density, ore cluster*

INTRODUCTION

Carlin-type gold deposits are currently being targeted and mined in Nevada, USA and in the southwest of China. The deposits are characterized by decarbonation, argillization, sulfidation, and silicification of typically calcareous sedimentary rocks (Hofstra & Cline 2000).

Many detailed studies have focused on local-scale geochemical anomalies for ore deposits. Limited attention has been paid to the regional geochemical patterns related to gold ore clusters or provinces. In this paper, we use different densities of data to display multi-scale geochemical patterns related to ore deposits, deposit clusters and metallogenic provinces of the Carlin-type gold deposits in the southwest of China.

GEOLOGICAL SETTING

The world's second largest Carlin-type gold province next to that in Nevada, USA is located in the boundary region of Guizhou, Yunnan and Guangxi provinces, with a total area of approximately 150,000km^2, and a central area of approximately 20,000 km^2 in Guizhou (Fig. 1).

Tectonically, it is situated in the western part of the South China Fold Belt adjacent to the north Yangtze Platform (Nie 1997). The outcropping rocks consist mainly of graywacke, siltstones, claystones, carbonates, argillites, carbonaceous slates, and siliceous rocks of Devonian, to Triassic age (Fig. 1). Gold mineralization occurs mainly in Devonian and Triassic strata as veins and as lenticular or layer-like bodies hosted by carbonaceous slate, siltstone, sandstone, argillite and carbonate (Nie 1997). Over 30 gold deposits have been discovered and 68 prospects have been identified, with total gold reserves of over 300 tons. The large deposits include Lannigou, Zimudang, Getang, Bangi, Jinya, etc. (Fig. 1).

METHODOLOGY FOR DELINEATION OF GEOCHEMICAL PATTERNS

A large Carlin-type gold deposit named Lannigou was found by a regional geochemical survey, as a part of the RGNR project (Xie 1997), in 1986 at a scale of 1: 200,000 in the Anlong map sheet of Guizhou (Wang & Xie 2000; Wang *et al.* 2007). Since then the RGNR project using -60 mesh fraction stream sediment samples has covered all of the Carlin-type gold province in the southwest of China. The project data provide an excellent opportunity for insight into the different-scale geochemical patterns using different data densities.

The database of the RGNR project consists of 1 datum per 4 km^2. In this paper three densities of data were used to delineate the different-scale geochemical patterns.

(1) An average value taken from a grid of 10 $\times$ 10 km, i.e. 1 datum per 100 km^2, is used to produce a 1:1,000,000 scale geochemical map.

(2) An average value taken from a grid of 4 $\times$ 4 km, i.e. 1 datum per 16 km^2, is used to produce a 1:500,000 scale geochemical map.

(3) One datum taken from a grid of 2 $\times$ 2 km, i.e. one per 4 km^2, is used to produce a 1:200,000 scale geochemical map.

Smoothed contour surface maps (contour maps where the areas between the isolines are filled with colours) were produced.

RESULTS

Figures 2, 3, and 4 show geochemical patterns delineated by densities of 1 datum/ 100km2, 1 datum/16km^2 and 1 datum/4km^2 respectively.

The results show that: (1) the general distribution area and direction of gold geochemical anomalies are very consistent for the three data densities, (2) geochemical anomalies delineated by the three density data coexist in the central area of the Carlin-type gold province containing large gold deposit clusters in Guizhou (Zimudang-Yanshang and Lanigou-Banqi clusters), (3) 1 datum per 100km^2 can only delineate large geochemical anomalies and miss small anomalies, for example a small gold cluster of the Dachang-Lamo is not delineated by this density (Fig. 2), (4) 1 datum per 16km^2 can delineate all the gold clusters (Fig. 3), (5) 1 datum per 4km^2 can not only delineate regional anomalies produced by deposit clusters but also delineate local anomalies produced by single deposits (Fig.4).

CONCLUSIONS AND DISCUSSION

Geochemical patterns are related to choice of map scale, which depends on densities of data. What map scale and data density used mainly depends on the size of the surveyed area and the purpose of the mapping study.

The preferred map scales and data densities for delineation of different scale geochemical patterns are as follows.

(1) Geochemical provinces related to Carlin-type metallogenic provinces can be delineated by the 1: 1,000,000 map at a density of one datum per 100 km^2.

(2) Regional geochemical anomalies related to Carlin-type deposit clusters can be delineated by the 1: 500,000 map at a density of one datum per 16 or 25 km^2.

(3) Local geochemical anomalies related to ore deposits can be delineated by the 1: 200,000 map at a density of one datum per 4 km^2 or by higher densities of data.

ACKNOWLEDGEMENTS

We would like to thank the Ministry of Science and Technology and the Ministry of Finance for financial support (projects: 2007CB411406 and Sinoprobe04).

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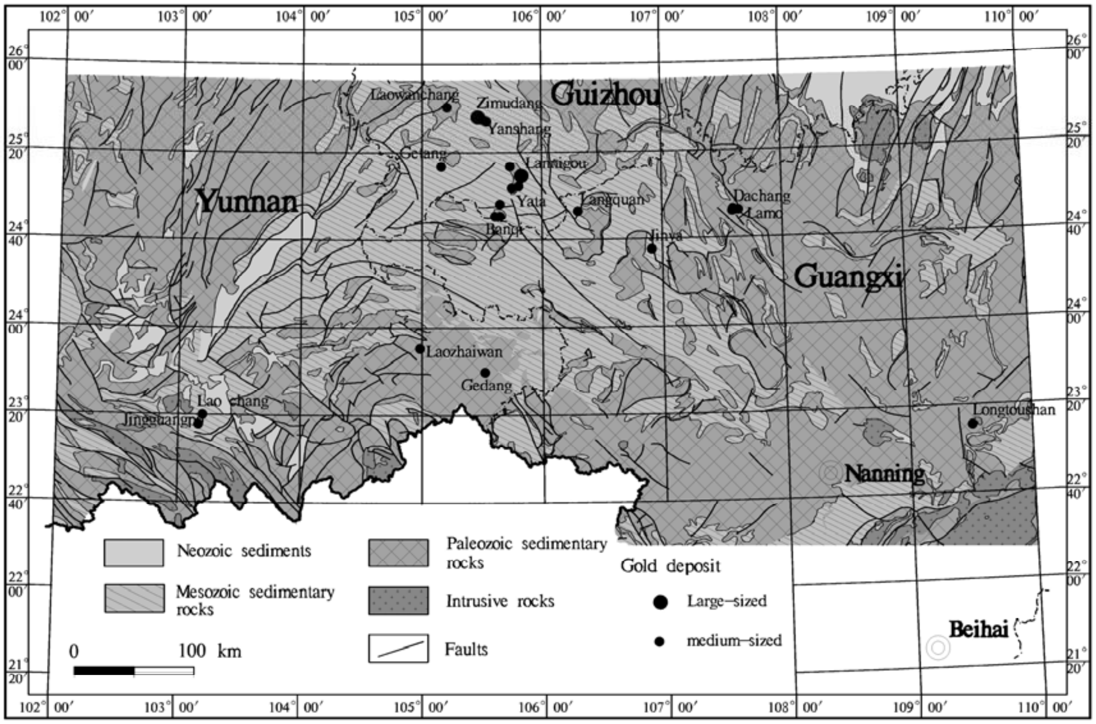

Fig. 1. Geological map with Carlin-type gold deposits in southwest China.

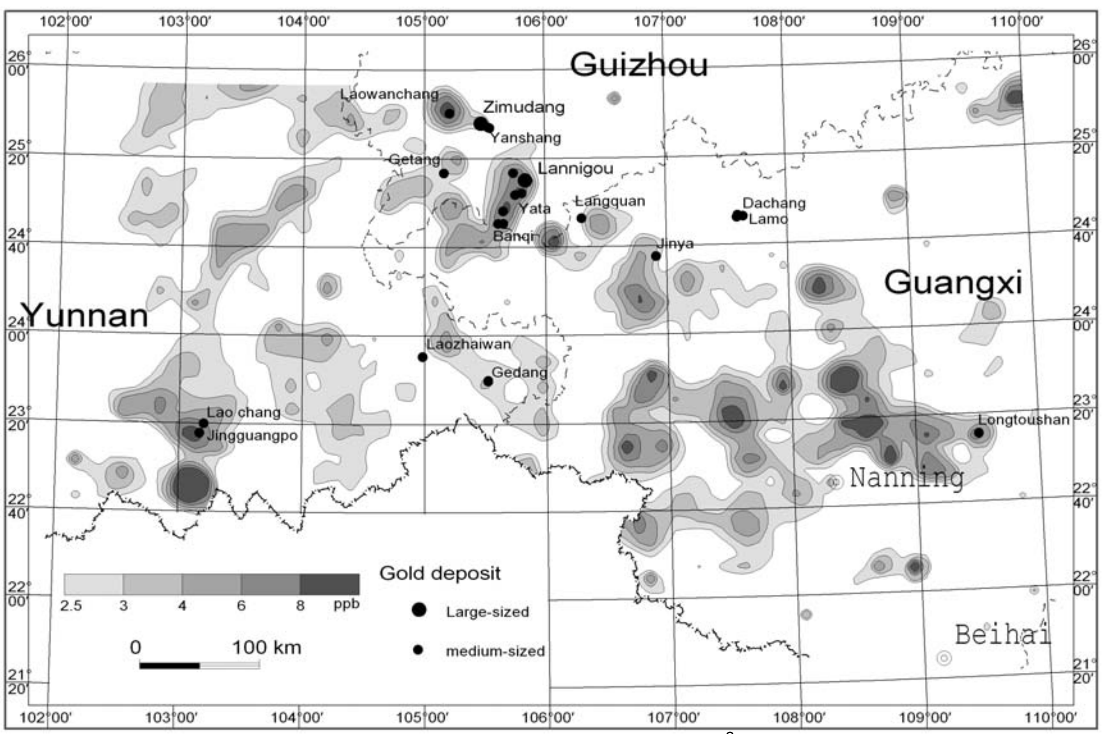

Fig. 2. Gold geochemical pattern delineated by 1 datum per 100 km^2.

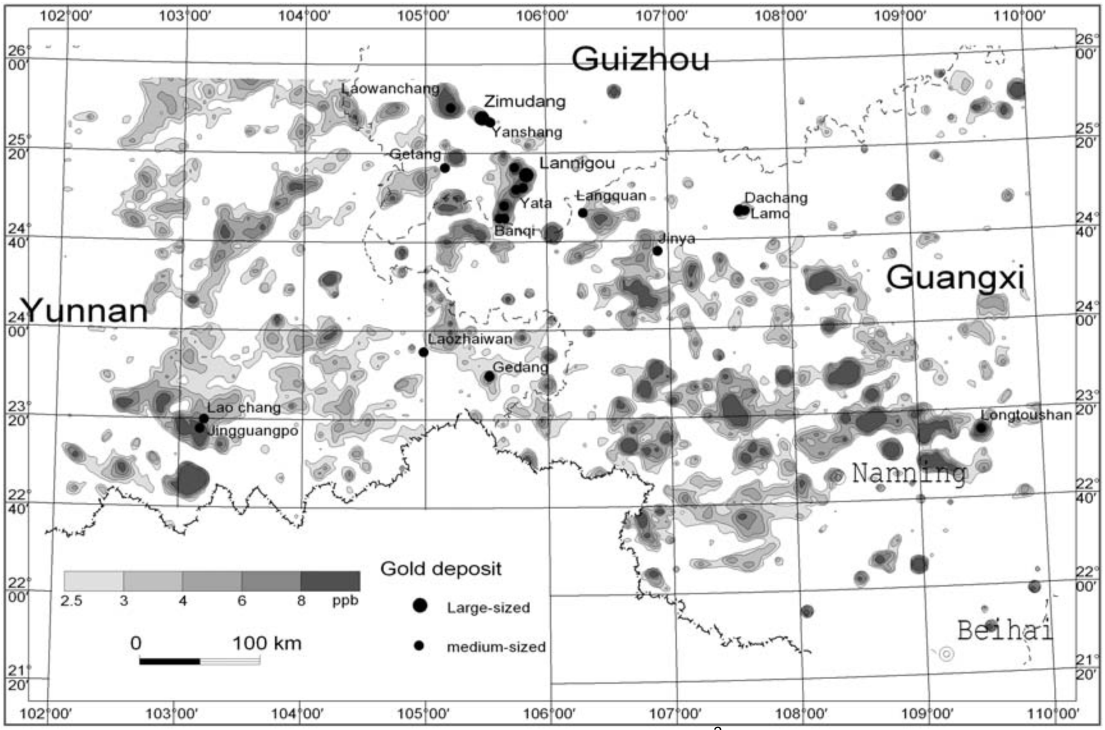

Fig. 3. Gold geochemical pattern delineated by 1 datum per 16 km^2.

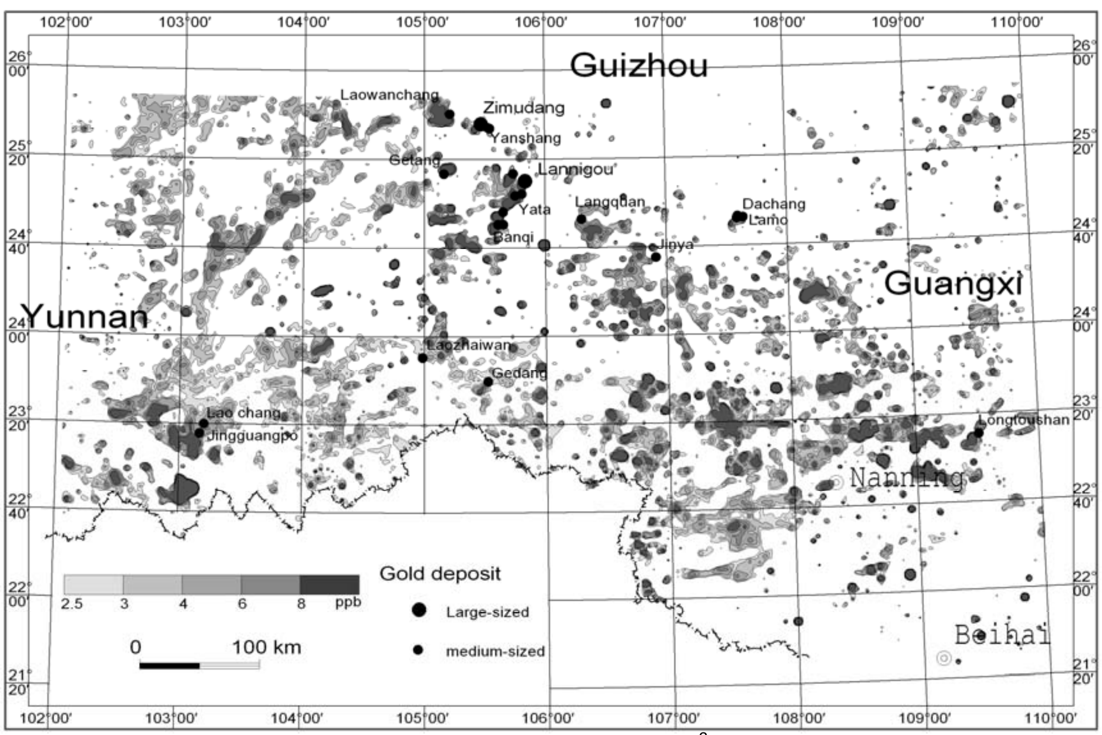

Fig. 4. Gold geochemical pattern delineated by 1 datum per 4 km^2.

Organic and inorganic surface expressions of the Lisbon and Lightning Draw Southeast oil and gas fields, Paradox Basin, Utah, USA

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ABSTRACT: Exploration for Mississippian Leadville Limestone-hosted oil and gas reservoirs in the Paradox Basin is high risk in terms of cost and documented low success rates (~10% based on drilling history). This study was therefore initiated to evaluate the effectiveness of low-cost, non-invasive, organic and inorganic surface geochemical methods for predicting the presence of underlying Leadville hydrocarbon reservoirs. Lisbon field was chosen for testing because it is the largest Leadville oil and gas producer in the Paradox Basin, and the recently discovered Lightning Draw Southeast field, with its almost original reservoir pressure, is also available for comparison. In comparison with Lisbon field, Lightning Draw Southeast field, San Juan County, Utah, is smaller, with more carbon dioxide, nitrogen and helium, and has productive intervals in the overlying Ismay zone of the Pennsylvanian Paradox Formation.

The main conclusion of this study is that hydrocarbon-based surface geochemical methods can discriminate between productive and non-productive oil and gas reservoir areas. Variables in surface soils that best distinguish productive from non-productive areas are ethane, *n*-butane and heavy (C_{24}+) aromatic hydrocarbons. Heavy metals (U, Mo, Cd, Hg, Pb) are possibly indirect indicators of hydrocarbon microseepage, but they are more difficult to link with the reservoirs.

KEYWORDS: *Lisbon field, hydrocarbons, microseeps, metals, exploration*

INTRODUCTION

Previous work has shown the potential of remote-sensing techniques for locating kaolinite-enriched, bleached redbed Triassic Wingate sandstones over productive parts of Lisbon field, San Juan County, Utah (Fig. 1) (Conel & Alley 1985; Segal *et al*. 1986). These studies used Landsat Thematic Mapper (TM) data to identify kaolinite as well as reduced iron (i.e., bleached redbed sandstones). Other than this work, there are no published surface geochemical studies in the Lisbon field area. The Utah Geological Survey (UGS), therefore, initiated this study to test the effectiveness of several conventional and unconventional surface geochemical methods in the Lisbon area. The main objective for testing these techniques is to find effective geochemical exploration methods to pre-screen large areas of the Paradox Basin, for follow-up geophysical surveys and lease acquisitions targeting the Leadville Limestone oil and gas reservoirs.

The premise behind surface geochemical exploration for petroleum is that light volatile hydrocarbons (i.e., C_1-C_5) from a pressured reservoir, ascend rapidly to the surface along water-filled fractures, joints, and bedding planes, as buoyant colloidal-size “microbubbles” (Klusman 1993; Saunders *et al*. 1999). In some cases, liquid C5+ hydrocarbons also ascend to surface along faults, to produce oil seeps at surface. Partial aerobic and anaerobic bacterial consumption of the ascending hydrocarbons produces carbon dioxide and hydrogen sulfide that can significantly alter the chemical and mineralogical composition of overlying sediments and soils (Schumacher 1996). Changes include decreased iron and potassium concentration and increased silica, carbonate, magnetic minerals and uranium.

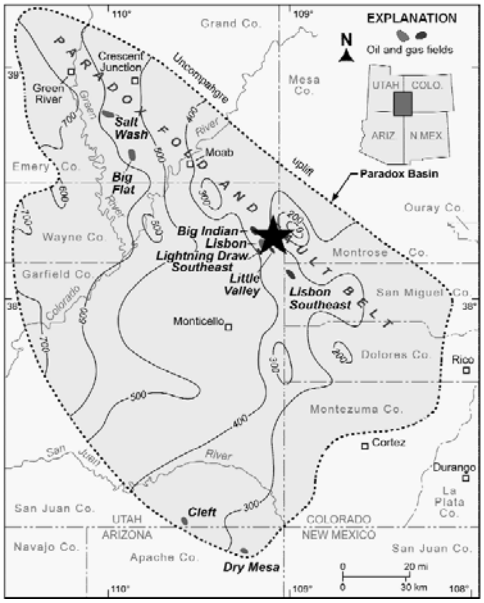


Fig. 1. Location of the Lisbon and Lightning Draw Southeast fields in the Paradox Basin of eastern Utah.

Both direct and indirect methods were tested in the Lisbon area. Direct methods include the assessment of hydrocarbon compositional signatures in surface soils, outcrop fracture-fill soils and mosses, and 6-ft (2 m) deep free-gas samples. Indirect methods use the major and trace element chemistry of soils to look for alteration effects resulting from hydrocarbon microseepage.

HYDROCARBON ANOMALIES IN SOILS

Soil samples were collected at 200 to 500 m intervals over the Lisbon and Lightning Draw fields and analyzed for thermally desorbed C_1 to C_{12} alkanes by Flame Ionization Detection Gas Chromatography (GC-FID) and solvent-extractable C_6 to C_{36} aromatics by UV-fluorescence spectrophotometry.

Aromatic hydrocarbon anomalies are evident in soils over both fields (Fig. 2). The anomalous 4-, 5-, and 6-ring aromatic hydrocarbons, which correspond with the 395 nm, 431 nm and 470 nm fluorescence peaks suggest the presence of heavy oil seeps at surface. Light alkanes (ethane and *n*-butane) are the most important variables for discriminating between the productive fields and down-dip water-legs.

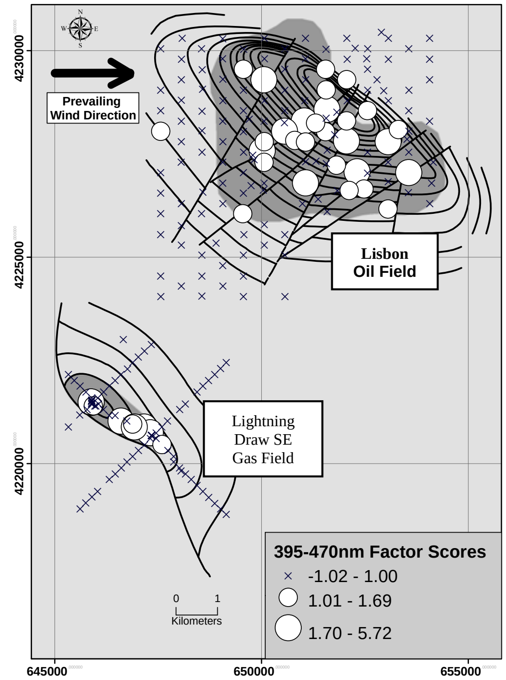


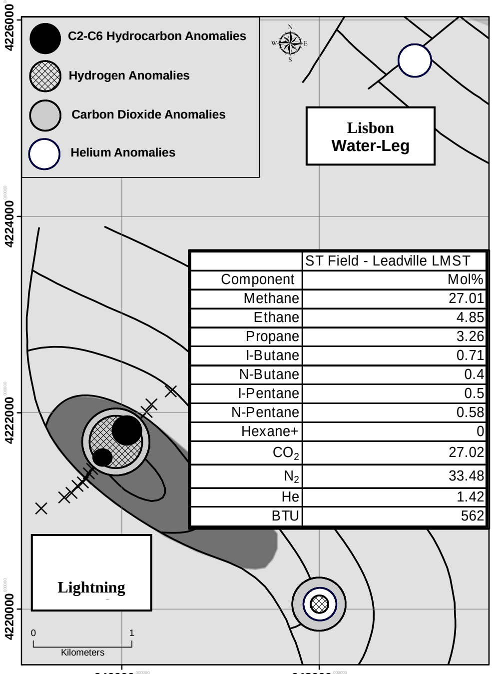
Fig. 2. Distribution of 395 to 470 nm factor scores in soils over the Lisbon and Lightning Draw Southeast fields, which correspond to high correlation with 4- to 6-ring aromatic hydrocarbons.

FREE GAS ANOMALIES

Free gas samples were collected at a 2 m depth with a GeoProbe drill, at 50 m intervals over Lightning Draw Southeast. The samples were analyzed for C_1 to C_6 hydrocarbons by GC-FID and fixed gases (He, H_2, CO_2, CO, O_2, N_2, Ne, and Ar) by Thermal Conductivity Detection Gas Chromatography (GC-TCD). The gas produced from the Leadville Formation is particularly rich in CO_2 and He, and thus these are key variables for identifying microseepages (Fig. 3). Light alkanes (C_2-C_6), H_2 and CO_2 are anomalous over the Lightning Draw field, but He is only anomalous off-structure to the southeast and over the water-leg of Lisbon (Fig. 3).

HEAVY METAL ANOMALIES IN SOILS

Soil samples were analyzed for 53 aqua regia extractable elements by Inductively Coupled Plasma Mass Spectrometry and



	ST Field - Leadville LMST
Component	Mol%
Methane	27.01
Ethane	4.85
Propane	3.26
I-Butane	0.71
N-Butane	0.4
I-Pentane	0.5
N-Pentane	0.58
Hexane+	0
CO_2	27.02
N_2	33.48
He	1.42
BTU	562

Fig. 3. Distribution of alkanes, H_2, CO_2 and He anomalies in 2 m deep free gas over the Lightning Draw Southeast field.

Emission Spectroscopy (ICP-MS-ES). Cadmium, uranium and molybdenum are anomalous over part of the Lisbon field and most of the Lightning Draw Southeast field (Fig. 4). Mercury, lead and organic carbon are also anomalous over both fields.

DISCUSSION

Light alkane and heavy aromatic anomalies over the Lisbon and Lightning Draw Southeast fields suggest that both volatile and liquid hydrocarbons are ascending to surface from the Leadville Limestone reservoir. The free gas C_2 to C_6, CO_2 and H_2 anomalies over the crest of the Lightning Draw Southeast field also provide evidence for the ascent of volatiles from the reservoir. In the case of Lightning Draw Southeast, however, there is also historic oil production from the stratigraphically higher Ismay Zone, and some of the hydrocarbon microseepage may be therefore partially or entirely from this reservoir. The higher CO_2 in free gas over the field suggests that there is leakage also from the lower CO_2-rich

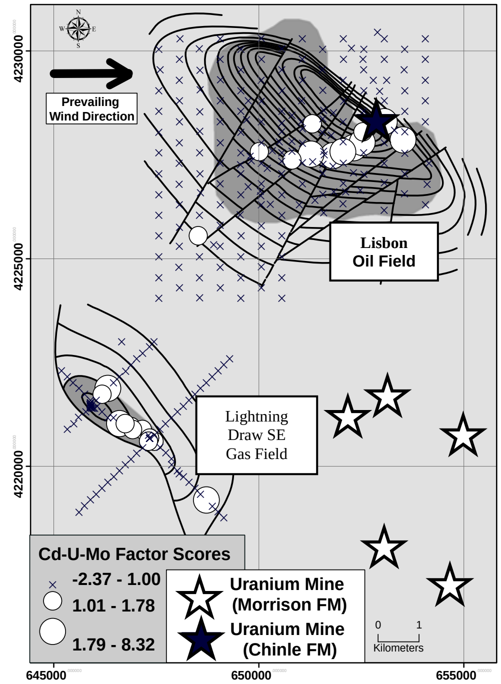


Fig. 4. Distribution of aqua regia extractable Cd-U-Mo factor scores in soils over the Lisbon and Lightning Draw Southeast fields.

The heavy metal anomalies over both fields are interesting, but more difficult to explain in terms of leakage from the reservoir. The Cd-U-Mo anomalies over Lisbon can be explained by outcropping uranium mineralization in the Chinle Formation (Fig. 4), but there are no outcrops of Chinle exposed at Lightning Draw Southeast. An alternative explanation could be that uranium mineralization eroded from Morrison Formation deposits to the southeast (Fig. 4) is being “fixed” by the hydrocarbon microseepage at Lightning Draw Southeast. The anomalies would, therefore, be an indirect indication of hydrocarbon microseepage. The mercury and lead anomalies observed over both fields may be derived from the oil seeping to surface.

CONCLUSIONS

The main conclusion from this study is that hydrocarbon- and fixed gas-based geochemical exploration methods in the Paradox Basin are cost-effective tools for pre-screening large areas for subsequent lease acquisition and seismic surveys for oil and gas exploration. Heavy metal anomalies are more difficult to link to the reservoir.

ACKNOWLEDGEMENTS

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An orientation soil survey at the Pebble Cu-Au-Mo porphyry deposit, Alaska

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ABSTRACT: Soil samples were collected in 2007 and 2008 along three traverses across the giant Pebble Cu-Au-Mo porphyry deposit. Within each soil pit, four subsamples were collected following recommended protocols for each of ten commonly-used and proprietary leach/digestion techniques. The significance of geochemical patterns generated by these techniques was classified by visual inspection of plots showing individual element concentration by each analytical method along the 2007 traverse. A simple matrix by element versus method, populated with a value based on the significance classification, provides a method for ranking the utility of methods and elements at this deposit. The interpretation of a complex multi-element dataset derived from multiple analytical techniques is challenging. An example of vanadium results from a single leach technique is used to illustrate the several possible interpretations of the data.

KEYWORDS: *porphyry Cu, soil, analytical methods, exploration, Alaska*

INTRODUCTION

Soil sampling surveys are routinely used to explore for concealed mineral deposits. The giant Pebble Cu-Au-Mo porphyry deposit, located 320 km southwest of Anchorage, Alaska, provides an opportunity to test various sampling and analytical methods commonly used by the exploration community.

As part of an orientation study, the U.S. Geological Survey (USGS) collected soils along traverses across the Pebble deposit area. In 2007, soil samples were collected from 78 sites along a 7.8-km east-west traverse over the Pebble East and Pebble West zones (Fig. 1). Eight additional soil sites were collected outside of the deposit area to determine background concentrations. A north-south traverse (4.5 km, 44 sites) across the Pebble East zone and a short east-west traverse within the Pebble West zone (1.4 km, 12 sites) were sampled in 2008. The soil samples were submitted to USGS and five cooperating laboratories for analysis by ten leach/digestion methods.

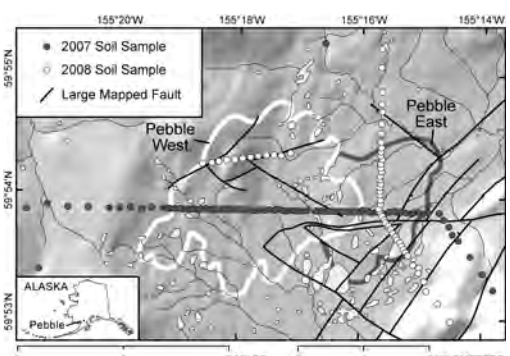

Fig. 1. Study location and soil sample map showing the 2007 and 2008 traverses.

GEOLOGIC SETTING

The Pebble deposit is located in the Kahiltna terrane, near the boundary between two lithologic packages: Jurassic and older magmatic-metamorphic rocks to the southeast, and an assemblage of Mesozoic volcaniclastic and sedimentary rocks overlain by Tertiary volcanic rocks, to the northwest. An extended discussion of the regional geology is given in Kelley *et al.* (this volume).

Above the bedrock are tundra-covered unconsolidated deposits from two episodes of Pleistocene glaciation. These glacial deposits consist of poorly sorted to unsorted, non-stratified compact till ranging from muddy gravel to sandy coarse gravel. Small cobbles and pebbles dominate. Surface morphology commonly includes morainal ridges, dry and water-filled kettle depressions and meltwater channels (Hamilton 2007).

The Pebble Cu-Au-Mo porphyry deposit contains one of the largest resources of copper and gold in the world. The Pebble West Zone, partially covered by glacial deposits up to 50 m thick, extends from the surface to ~500 m depth (Lang *et al.* 2007). The East Zone, which extends to at least 1700 m depth, was partially eroded and is concealed by an eastwardly thickening wedge (300-600 m thick) of Late Cretaceous to Eocene volcanic and sedimentary rocks (Bouley *et al.* 1995; Lang *et al.* 2007).

METHODOLOGY

Soil samples were collected along three traverses crossing different extents of the Pebble deposit. At each site, a pit about 0.5 m wide and 0.7 m deep was dug through the tundra. Four different soil subsamples were collected following recommended protocols of the commercial laboratories for the respective methods as described in Fey *et al.* (2008).

The subsamples were split and sent to different laboratories to be subjected to ten commonly-used and proprietary leach/digestion techniques: (a) aqua regia partial digestion method at Acme Analytical Laboratories; (b) sodium pyrophosphate and cold hydroxylamine leaches at ALS Chemex; (c) enzyme and TerraSol leach methods at Skyline Labs; (d) Bioleach and soil gas hydrocarbon analyses at Activation Laboratories; (e) Mobile metal ion (MMI) extraction at SGS Minerals; (f) 4-acid near-total and sodium peroxide sinter total digestions (under the USGS contract) at SGS Minerals; and (g) de-ionized water leach at the USGS laboratories.

For most of the laboratories, additional quality control (QC) samples were inserted within each batch of samples sent. These included sample site duplicates, sample splits for analytical duplicates, a suite of USGS-prepared standard reference materials (SRMs), and two Pebble project soil standards, created in USGS labs specifically for this project by compositing and homogenizing excess minus-80 mesh material derived from processing all of the soil samples from the 2007 field season.

The analytical data for soil, water, and vegetation samples from the 2007 field season plus an evaluation of QC samples are found in Fey *et al.* (2008). A similar publication for 2008 data will be completed in 2009.

DISCUSSION

Evaluation of Multiple Methods

The ten leach/digestion procedures range in intensity from a very weak, simple de-ionized water leach to complete digestions. Applying extractions of varying strengths targets the release of pathfinder elements from different phases within the soil: ion-exchangeable phases, carbonates, sulfides, or even biogenically derived phases. The purpose of applying less-than-total extractions is to determine whether geochemical anomalies (and therefore patterns) are better indicated by the weakly-bound ions than data from total digestions.

A subjective technique was used to evaluate the performance of the ten analytical procedures. Single element traverse plots were created for every element by every method, plotting them over the known spatial limits of the ore zone. Then each plot was visually evaluated to determine whether the geochemical response pattern could be related to background or the underlying deposit. Patterns for each element/method combination were classified as “significant”, “possibly significant”, or “no apparent relationship.” A simple matrix of analytical methods and elements was created from this information. By assigning values to each classification and then summing the values by row and by column, the matrix could be sorted to give an indication of the relative performance of analytical methods and to list elements that were classified as significant by the most methods. The most significant elements for the 2007 soil traverse were

Ag, As, Au, Cu, Mo, Re, Sb, Tl, U, and V. The highest ranking analytical methods were enzyme leach, cold hydroxylamine hydrochloride leach, and MMI. It should be noted that this matrix method did not take into account the added value of creating ratios (such as to total Fe or organic carbon) between related elements. The use of ratios may change the rank of evaluated analytical methods. Also, the soil gas hydrocarbons technique was treated separately, since the analyses are for organic compounds, rather than for the inorganic elements of the other methods.

Based on the results of this matrix evaluation, cold hydroxylamine leach and enzyme leach methods were chosen for use in subsequent field seasons.

Preliminary Interpretations

Some analytical results are still pending and interpretation of the large volume of analytical results is only partially completed. Thus, data for just two elements, determined by enzyme leach, are discussed here.

The Pebble Limited Partnership has provided drill core geology and rock chemistry, which were used to create a geologic and geochemical cross sections along the line of the 2007 soil traverse – a valuable third dimension to this orientation study. Figure 2 displays vanadium data from the drill core rock analyses and illustrates possible corresponding V concentrations in soils from the 2007 traverse. High V is noted in the soils over the near-surface Pebble West zone, but there is also an indication of high V over the deeply buried Pebble East zone. These anomalies appear to correspond with dense fracture networks and major faults that cut the overlying volcanic cover. This same general pattern is noted along the 2007 traverse line for As, Cl, Cr, K, Mo, Pb, Re, S, Sb, Sc, & U. High values of Ag, Au, & Cu only seem to be primarily associated with the shallow Pebble West zone.

Based in part on the above results, soils in 2008 were collected along a north-south traverse over the Pebble East zone to confirm the influence of large faults on surface geochemistry in the deeper portions of the deposit. The early results from the 2008 N-S traverse show a broad zone of high values. Figure 3 shows the distribution of molybdenum in a plan view from the combined 2007 and 2008 data. Enzyme leach values for Ag, As, Br, Ca, Cl, Mg, Re, S, Sb, Se, Tl, V, & W show similar distribution patterns in the N-S

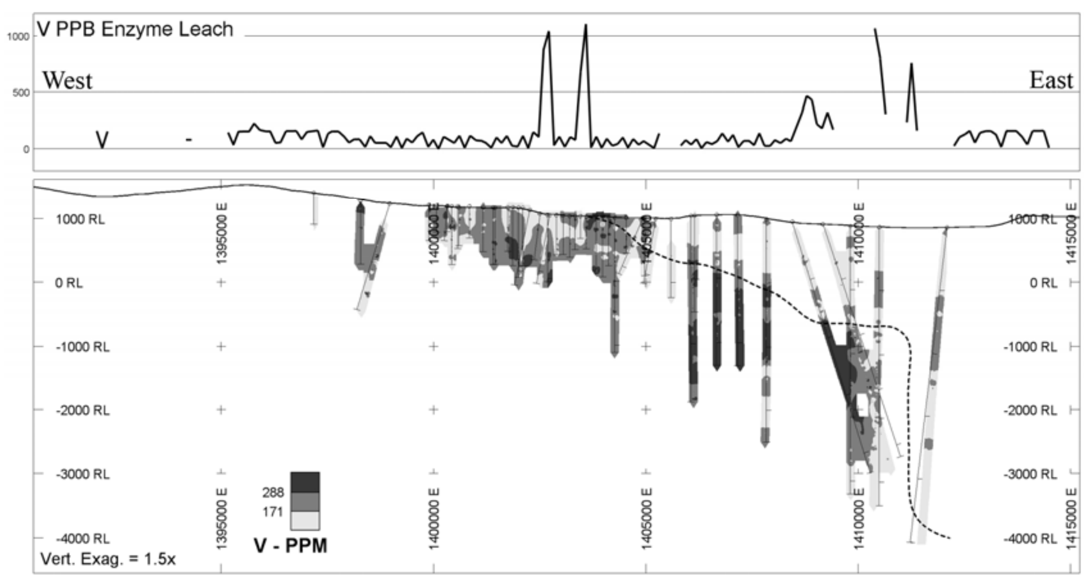

Fig. 2. West to east plot of vanadium by enzyme leach in soils on top of a cross section showing vanadium in drill core. Dashed line shows the subcrop of Cretaceous, granitic rock of Pebble East beneath the Palaeozoic/Eocene volcanic and sedimentary rock cover.

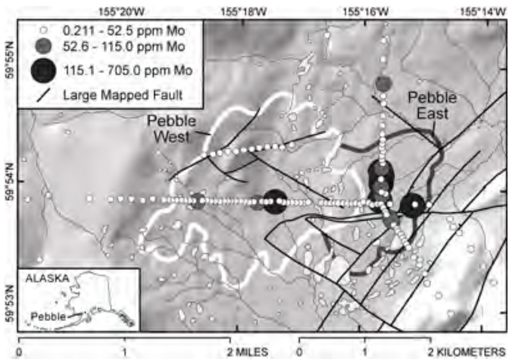

Fig. 3. Distribution of Mo in soil samples analyzed by the enzyme leach method.

traverse.

Because the underlying geology for the 2008 soil traverses is not yet available, hypotheses relating higher concentrations of specific elements to fault structures cannot be confirmed.

Hydrogeochemical anomalies for some elements reported by Eppinger *et al.* (this volume) show coincident anomalies with soils over the shallow Pebble West zone. A general lack of surface and spring water along the soil traverses over the deeper Pebble East zone make it difficult to see similarities.

CONCLUSIONS

(1) All ten of the analytical methods used show element patterns in soils over the Pebble West and Pebble East zones.

(2) The most significant patterns were seen for Ag, As, Au, Cu, Mo, Re, Sb, Tl, U, & V for the 2007 soil traverse.

(3) Early interpretations suggest that soil anomalies above the deeper Pebble East may be related to faulting. Incorporation of drill core geology for this traverse is underway to confirm this hypothesis.

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Ore deposit simulation and reserve estimation in Masjeddaghi epithermal gold mineralization – Azerbayjan - Iran

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ABSTRACT: Ore deposit simulation and reserve estimation is the most important part of an exploration project. This part is a good guide to evaluate all done work and shows the certification level of data. MASJED DAGHI, the area that was studied is well known for gold mineralization and some evidence of porphyry copper was reported in a limited area. Several exploration activities have been done on this area but most of them focused on a quartz vein. Ore deposit Simulation would provide a suitable atmosphere for work and shows the shape and extension of the ore body. To recognize the behaviour of the elements that are associated with gold mineralization, statistical processing was done. These studies revealed three different types of elements' parageneses whereas one of them had not been found before. The last processing on this study was GEOSTATISTIC studies. These studies lasted to block kriging estimation, which shows the amount of gold in each block as well as the variance of estimation. To recap, this study ends to show the amount of gold is much less than what was previously suppose to be in this quartz vein. However, this vein could be enough for a small local economic activity but switching the exploration activity from gold to porphyry copper, has been suggested.

KEYWORDS: *Epithermal Gold, Porphyry Copper, Geostatistic, Enrichment Blanket, Reserve Estimation*

INTRODUCTION

MASJEDDAGHI area is located in northwest of Iran and in the north of East Azerbaijan province adjacent to the boundary between Iran and Azerbaijan. The area's latitude is between 38° 52' 03" and 38° 53' 22" and its longitude is in the range of 45° 56' 05" and 45° 58' 29". Its total area is about 8 Km^2. The access road is JOLFA – SIAH RUD asphalted road. The highest elevation is 950 m from sea level. Weather in this region is hot in the summer and cold in the winter.

GEOLOGICAL SETTING

The geological history of this area seems started by sedimentary units of Mesozoic – Cenozoic age which contains Fylisch and Limestone. These units were influenced by intrusion of volcanic and sub volcanic rocks in Miocene – Oligocene age. These igneous rocks mainly contain dacite, trachyandesite and andesite. These young volcanic units exposed in KIAMACCI Mountain vastly and their outcrop continues to QAREDAGH Mountain in south and southwest of studied area. Metallic mineralization in whole of this area seems to be associated with QAREDAGH plutonic unit, which influenced a vast area and has made a couple of porphyry mines in Azerbaijan Country. Volcanic units in this area show a hilly morphology and the highest one is 950 meter above sea level. Different and varied types of volcanic rocks in studied area, show evidences of strato volcano of old composite volcano. Based on detail geology map of this area, geological units are pyroclastics, subareal tuff, flows, dykes and small outcrops of shallow intrusive rocks. Pyroclastic and tuff units are mostly found in high lands and intrusive units are located near the river.

Different types of alterations were reported in this area. Silicification is the most usual alteration whole over the area. Argillitic alteration was obsereved in two types, indogenic, which has extended around mineralization zone and exogenic,

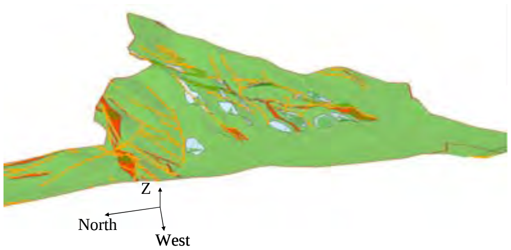

Fig. 1. 3D view of quartz veins and intrusive outcrops in Masjed daghi Area.

that was reported around sulfide (pyrite) zones. Two small exposed location of potassic alteration around river were reported. Phyllic alteration was reported around potassic alteration and sometimes destroyed it.

Mineralization is a little complex on this area and can be divided into two main types. The first one, which led explorers to this area, is Low Sulfide Quartz Gold vein. This vein has more than 700m length and its average width is 5 m. It can be classified to epithermal category. Another mineralization, which has just two small limited outcrops on the surface, is a porphyry copper – gold mineralization, which has identified with potassic zone. These two mineralizations have a significant difference in age and epithermal veins are much younger than the porphyry system and have ascended through the faults.

To recap, the argillic alteration, which has a vast extension on the surface, mainly was produced by epithermal system and over print on the other alterations, those associated with porphyry systems. The host rock is a Trachyandesite, whereas a porphyry Diorite had intruded in it and made a Copper – Gold mineralization in it as a porphyry system. Then after long time and maybe because of another intrusion system in depth (much deeper than the present porphyry mineralization) huge amount of silica came up trough the faults and brought gold in itself from an unknown source (present porphyry system or another source) and made an extension alteration that over printed on existing alteration. Nowadays, we see some quartz veins, include gold, that cross a copper porphyry system.

ORE BODY SIMULATION

Simulation of ore shape is the first step for 3d studies and provide a base for not only reserve estimatin but also for study on geochemical distribution of elements. For this porpose, all available data have been used that contain geological and topography map, results of 12 trenches with the volume of 200 m^2, 10 boreholes with about 2000 m accumulate lenght and all the samples that have beeb taken from trenched and boreholes. Simulation of MASJED DAGHI quartz gold vein shows the reasonable volume of porphyry copper system, rather than quartz vein (Fig.3). In addition, by study on the trend of oxidized zone it has revealed the boreholes logs and descriptions need a review. That's not a regular shape (Fig. 2) and though the sulfide zone for these sort of small resources, is not economic to mine, this boundary has a critical role in defining the resource.

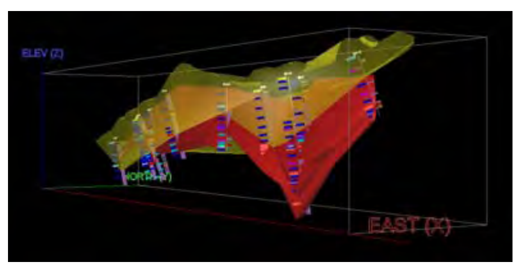

Fig. 2. 3D view of quartz veins (Red) and oxidized atmosphere around it (Yellow).

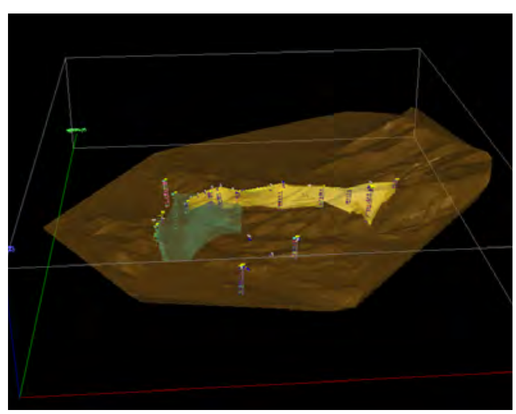

Fig. 3. 3D view of quartz veins (yellow) and porphyry body (Cyan).

GEOSTATISTICAL PROCESSING

Geostatistical processing is one of the most useful and practical methods for evaluation and estimation of a resource. Its BLUE (Best Liner Unbiased Estimator) Kriging not only can indicate the distribution and amount of ore in a resource, but also, based on variance and error of Kriging can identify some parts of ore body, that have lack of data and need more exploration. For a routine Geostatistical processing some issues should be considered:

(1) Kind of Mineralization and its basics and principals in ore forming and associated structure.
(2) Primary statistics processing
(3) Statistics parameters
(4) Correlations and trends of elements
(5) Outlier values and samples
(6) Specifics of populations
(7) Defining the estimation space for ore body
(8) Variograms
- o Effective structures in ore forming
- o Composite
- o Non directional Variograms
- o Directional Variograms
- o Spatial structure of elements' distribution
- o Anisotropic ellipsoid
- o Cross validation

(9) Estimation
- o Defining the type of the estimation based on essence of mineralization and available data.
- o Determining size of blocks, based on type of mineralization and its specifics.
- o Creating block model for ore body
- o Kriging Estimation and its associated errors
- o Ore reserve estimation and its Grade – Tonnage diagram

(10) Variograms: Variograms are powerful tools to determine the structure and pattern of distribution of ore, based on analytical results. Actually, Variograms are basics of Geostatistic methods and all other calculations would be done base on introduced model in Variograms. Although Variograms can work easily in disseminated and mass form mineralization, they could also work in vein type ore bodies if they consider the specifications and conditions of mineralization. In the MASJED DAGHI quartz vein gold resource, because of several types of mineralization, recognizing the suitable Variograms to use is a little complicated. A rich zone of gold and copper in host rock, which is very similar to an "Enrichment Blanket" could have a negative effect in Variograms (Fig. 4). On the other hand, because of the essence of mineralization, the directions of anisotropic ellipsoid's axes are approximately known but variograms can help us to find out the range of influence of elements inside the vein.

(11) After finding any structure in non directional variogram, the next step is looking for azimuth and dip of structure or structures of ore body. For this purpose, it is necessary to make directional variograms. All data of MASJED DAGHI were used to make these variograms. Variograms for all horizontal directions, from zero to 180 degrees, all vertical sections from zero to 90 degrees, and different Lag distances were made and studied. The three best of them were chosen for deducing the structure of gold distribution in the vein. Table 3, shows the quality and specifications of some of the variograms, and examples are shown in figure 5.

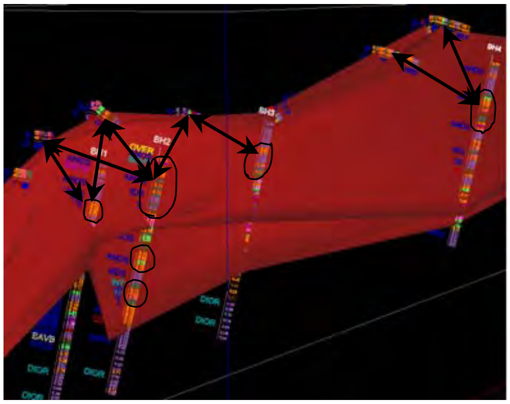

Fig. 4. Negative **e**ffect of Enrichment Blanket on Variograms.

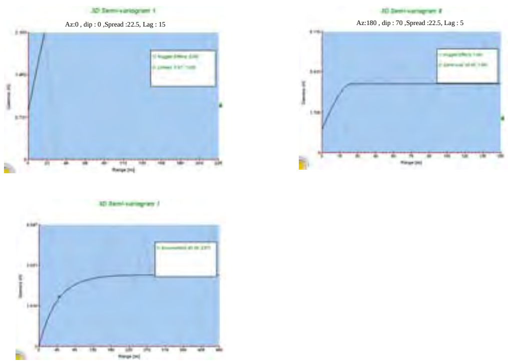

Fig. 5. Geostatistical Model for Estimation in Quartz Vein

(12) Model Fitting: When experimental variograms reveal the structure and distribution pattern in an ore body then for any further estimation, it is necessary to fit a mathematical model to experimental variograms, which are called theoretical variograms. These mathematical models will be used in Kriging estimation. Several predefined models (Linear, Spherical, Gaussian, etc.).

Three parameters are necessary for each model; Sill, Range and Nugget Effect. Each one has a specific meaning and has important effect on a Theoretical variograms for used data are as follow:

(1) For the present data, after replacing outlier values with 4 (ppm, equal to the value of 97% of Au population in data) the relationship between estimated data and reported ones is about 0.6, which make sense, though the amount of data is not enough at all.

(2) Space for estimation: Estimation is a mathematical process whereas the main constraint on the orebody is the geological condition. Therefore, it is necessary to introduce the spatial limits of mineralization. For this project mineralization is not only limited by the vein but also it will be limited by the oxidized zone so that, the estimated space is that part of vein, which is located in oxidized atmosphere (Figure 6).

Block Estimation Kriging: Kriging is an unbiased estimator and due to the conditions of mineralization, it has several different methods. On this project, "Simple Kriging" is used. The sizes of blocks are 1x1x1 m and if half a block contains mineralization, it will be involved in estimation. The results of Kriging will show the distribution of Au throughout the vein and Error of estimation as well. Therefore, not only the amount and volume of gold is ready for any further decision, but also it will be clear which parts of vein need more information and where the existing data is not useful for estimating those parts. The shape of estimated blocks, which have more than one gram per ton gold are shown in Figure 7.

To recap, after estimation, that was obtained total amount of gold in vein 3 is about 450 kg, that's not interesting for any mining sector. The tonnage – grade diagram has shown in Figure 8.

CONCLUSIONS

This project had targeted gold, but the results show there is little hope of obtaining much gold in this area. The thickness of the oxidized zone, the size of

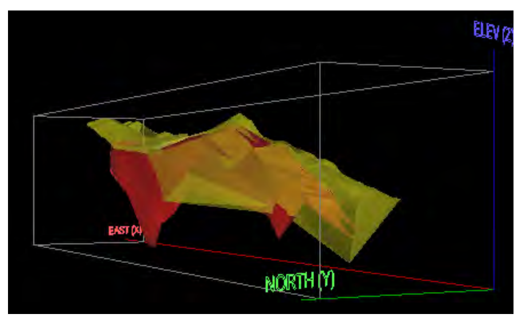

Fig. 6. State of Quartz Vein (Red) inside of Oxidized Zone (Yellow).

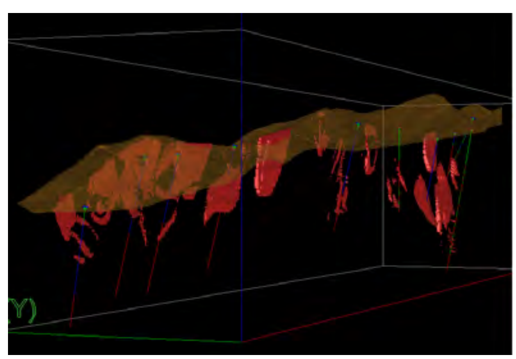

Fig. 7. Parts of Quartz Vein with grade more than one gram per tone gold.

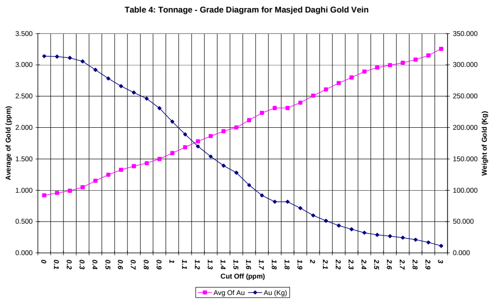

Fig. 8: Tonnage – Grade diagram of Gold in Quartz Vein.

vein and grades of gold could not justify defining this vein as a small gold resource. Therefore, my suggestion was to change the aim of exploration activities from epithermal gold to porphyry copper, which is laid down beneath the river as identified by some borehole results.

Of course, based on government policy for increasing employment in this part of the country and avoiding emigration from these parts to big cities, and as there are several veins like the studied one available in this area, country people can be guided to exploit veins like this and sell the ore to a central gold extraction refinery.

Some important issues for any other exploration for gold in this area are as follows:

(1) Due to fluctuation of gold assay, the distance between surface channel sampling, should be less than 25 m.

(2) All the samples should be analyzed for 40 elements (by ICP-MS) as well as gold (Fire assay) and the results should be cross checked by several methods.

(3) The thickness of the oxidized zone is not very great in this area, so it is necessary to establish a plant for extracting gold from sulfide zone.

(4) Drilling should be designed to cross the vein at a depth less than 30 meter because of oxidized zone thickness.

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The application of lithogeochemistry for VMS exploration in the Sherridon Complex, northern Manitoba

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ABSTRACT: The Sherridon complex in northwestern Manitoba is part of the Flin Flon – Snow Lake metavolcanic belt and hosts several economic Cu-Zn sulfide deposits. Deformation and metamorphism to upper amphibolite facies has erased primary igneous textures, obscured stratigraphic relationships and metamorphosed VMS-related alteration to higher grade assemblages. Lithogeochemistry has been employed to resolve these issues and improve exploration targeting. Analysis of immobile trace element patterns has been used to identify major lithologies and establish the relationships between them. As a consequence, the Sherridon complex has been shown to be a felsic-dominated bimodal arc suite. High-resolution geochemical sampling has been used on key sequences to identify stratigraphic units and aid structural models. This has helped reveal a previously obscured F_1 doubling of stratigraphy and the prospective ore horizon. Interpretation of major elements has lead to the identification, characterization and quantification of VMS-related metasomatism, factors vital in targeting new deposits.

KEYWORDS: *chemostratigraphy, alteration indices, VMS exploration, Sherridon complex, Manitoba*

INTRODUCTION

Terranes that have been subjected to high-grade metamorphism or high strain pose significant challenges for volcanogenic massive sulfide (VMS) exploration. Volcanic textures that are used in less deformed VMS settings may be obscured or obliterated by transposition and recrystallization. These processes can make stratigraphy more difficult to interpret, especially if early generations of deformation are overprinted by later ones. Likewise, alteration assemblages that are typical of VMS deposits are metamorphosed to higher grade assemblages and may be overlooked or misinterpreted.

The Sherridon complex in northwest Manitoba is host to the Sherritt Gordon Cu-Zn mines that collectively produced some 8 million tonnes grading approximately 2% Cu and 5% Zn, as well as six other smaller unexploited Cu-Zn sulfide deposits. Correlation between the Sherridon complex and the Flin Flon – Snow Lake metavolcanic belt (Zwanzig 1999) make it a good prospect for VMS exploration. The Sherridon complex has experienced upper amphibolite grade metamorphism and deformation resulting in elongation of 10:1 or more. Primary igneous textures are not preserved, early structures are obscured by subsequent deformation, and alteration minerals such as chlorite, sericite are present solely as retrograde phases.

Lithogeochemical analysis has been employed in the Sherridon complex in an attempt to better understand the geological setting and to target mineralization. The complex has been shown to be a felsic-dominated bimodal arc suite, lacking either sedimentary protoliths or igneous protoliths of intermediate composition. Orthogneiss with apparent intermediate composition has been shown to be either derived from metasomatized felsic volcanic rocks or are unrelated to the primary arc magmatism. Alteration indices have been established in an attempt to penetrate the effects of upper amphibolite facies metamorphism and vector toward mineralization.

GEOLOGICAL SETTING

Regional Geology

The Sherridon complex is one of several arc terranes that form the south flank of the Kisseynew Domain (Fig. 1), a metasedimentary terrane that is part of the Paleoproterozoic Trans-Hudson Orogen. The Kisseynew Domain is dominated by Burntwood Group metasedimentary rocks and flanked by arc terranes, notably the Lynn Lake Belt to the north and the Flin Flon Belt on the southern flank (Fig. 1).

The Flin Flon Belt is composed of the metavolcanic Amisk Group and the metasedimentary Missi Group. Recent work (Zwanzig 1999) has shown that the metavolcanic rocks of the Sherridon Complex correlate well with the Amisk Group metavolcanics and the surrounding Nokomis Group metasedimentary rocks are correlated with the Missi Group.

Local Geology

The Sherridon complex was initially interpreted as a sedimentary basin. This was due primarily to the abundance of metapelites and to the exceptional strike length of the deposits (>4 km). More recently, the complex has been reinterpreted as an antiform dominated by metavolcanic lithologies (Zwanzig 1999). The Sherridon complex is dominated by leucocratic quartz - feldspar - biotite gneiss derived from felsic volcanic rocks (Fig. 2). Amphibolites are also present, but less common, accounting for ~10% of sampled lithologies. Aluminous biotite – quartz – feldspar – garnet ± hornblende ± sillimanite ± cordierite gneiss is also common. All of these lithologies may have reacted with various amounts of carbonate to form calc-silicates and in a few instances marble and dolomite are observed. All lithologies are cut by a variety of different pegmatites.

Structural studies by Zwanzig (1999) identified five episodes of deformation in the south flank of the Kisseynew Domain, four of which are evident in the Sherridon Complex. An episode of F_1 isoclinal folding has been recently hypothesized based on the repetition of stratigraphy in the Sherridon Complex, but is largely obscured by subsequent deformation. The F_2 event deformed the complex into a large sheath fold with a shallow plunge to the east. This was followed by F_3 isoclinal folding that bent the complex into its distinctive hooked shape (Fig. 2). Lastly, the F_4 episode of brittle faulting cut across the center of the complex.

CHEMOSTRATIGRAPHY

Lithogeochemistry was initially applied to the rocks from the Sherridon complex in an attempt to help clarify the stratigraphy of the volcanic sequence. To date, the major- and trace-element compositions of 1964 samples of drill core and 751 outcrop samples have been analysed by

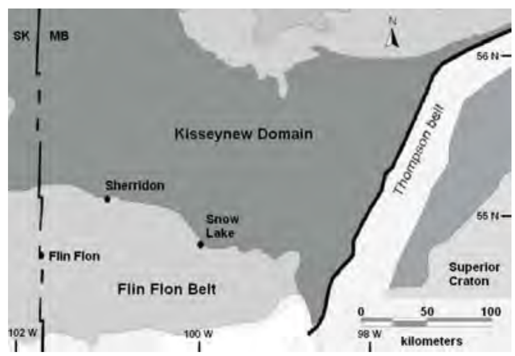

Fig. 4. Regional setting of the Sherridon complex within the Flin Flon Belt (Zwanzig 1990).

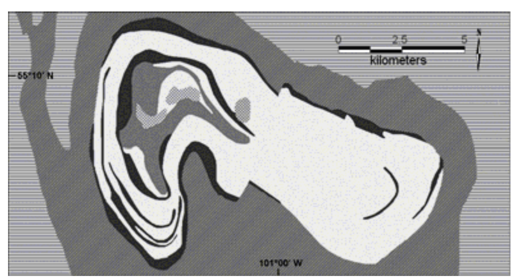

Fig. 5. Geological map of the Sherridon Complex (after Froese & Goetz, 1981). Felsic gneisses are in light grey, intermediate gneisses in medium grey and amphibolites in dark grey. The complex is surrounded by the Missi Group metasedimentary rocks (medium grey with diagonal lines) and Burntwood Group metasedimentary rocks (light grey with horizontal lines) and intruded by gabbro and pyroxenite (cross-hatched).

lithium metaborate fusion followed by ICP-MS. Drill core is typically sampled every ten meters. Outcrop sampling is limited by exposure, but is typically between 25 and 50 meters where exposure is good.

Protoliths have been inferred using the patterns of the immobile trace elements Th, Nb, P, Zr, Ti, Y, Lu and the rare earth elements. This met with limited success with respect to improving the stratigraphy due to the similarity of the trace element patterns of the protoliths and the extreme attenuation of the strata resulting from deformation. However, several key lithologies were identified and their affinities determined. The majority of the samples (63%) are felsic orthogneiss derived from a juvenile arc and are interpreted to be the felsic component of the VMS system. Two types of amphibolites have been identified. The first has a trace element pattern consistent with a mafic protolith derived from a juvenile arc and has been interpreted to be the mafic component of the VMS system. The second variety of amphibolite has an enriched mid-ocean ridge basalt (E-MORB) affinity and is considered to have been emplaced as younger dykes and sills. A large unit of intermediate gneiss has trace element patterns indicative of a more mature arc setting and is unrelated to the VMS system. Highly aluminous lithologies previously identified as metapelites have proven to have trace element patterns that are identical to the felsic orthogneiss and are interpreted to have been metasomatized prior to metamorphism. None of the lithogeochemical samples collected showed evidence of sedimentary protolith.

Higher resolution chemostratigraphic sampling of drill core has been used to recognize structurally induced repeats of stratigraphy. This effort has successfully demonstrated repetition of the stratigraphy in the immediate vicinity of the F_1 fold hinge.

ALTERATION

The metasomatic alteration that is characteristic of most VMS systems has been all but unrecognized in the Sherridon complex as the typical hydrothermal alteration minerals, i.e. chlorite and sericite, occur solely as minor retrograde phases. In the last decade it was realised that anthophyllite-cordierite pods at Sherridon represented zones of intense alteration (Froese & Goetz 1981); however, these pods are widely scattered and have not as yet provided an obvious vector to new deposits.

With the recognition that rocks with aluminous intermediate chemistry originated as altered felsic volcanic rocks it is now possible to use these more broadly distributed rocks to target new deposits.

CONCLUSIONS

Lithogeochemistry has proven to be a vital tool for VMS exploration in high grade metamorphic terranes. Analysis of immobile trace element patterns has allowed the identification of several major lithologies despite metasomatism and subsequent upper amphibolite facies metamorphism. Identification of key stratigraphic units by their trace element patterns has aided the creation and testing of structural models. Analysis of major elements has led to the identification of zones of metasomatism and reveals the nature and degree of alteration, factors vital in targeting new deposits.

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Orientation survey results at the Tameapa property in Sinaloa, Mexico

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ABSTRACT: In late 2008, soil and stream sediment orientation surveys were carried out to provide optimized field and analytical procedures for use in property and regional-scale exploration programs on MinCore's Tameapa property in Sinaloa Mexico. The property is host to two advanced mineral prospects named Pico Prieto (copper-molybdenum porphyry) and Venado (molybdenum-copper structurally controlled porphyry) that were first explored in detail by Las Cuevas during the 1970s and early 1980s.

A total of 80 soil samples and 30 stream sediment samples were collected in the vicinity of known mineralization and analyzed for 36 elements in four size fractions. Orientation results indicate that soil samples should be collected from the near-surface soil horizon on a 100 by 200 m grid pattern, and sieved to the coarse, -8+35 mesh fraction prior to analysis. Stream sediment samples should be collected at a sample density of approximately 1 sample per 1 km^2 and sieved to the fine, -150 mesh fraction. As expected, copper and molybdenum show the strongest response to copper-molybdenum mineralization at both Pico Prieto and Venado; in addition, the following elements are also associated with mineralization at Tameapa: Au, Ag, Pb, Zn, V, W, Ni, As, Sb, Bi, Se, Sr, and Ba.

KEYWORDS: *geochemical exploration, copper, molybdenum, porphyry, Mexico*

INTRODUCTION

MinCore Inc., a private mineral exploration company based in Toronto, Canada, is currently exploring the Tameapa property in Sinaloa Mexico, that contains two advanced mineral prospects separated by 2.5 km, named Pico Prieto (copper-molybdenum porphyry) and Venado (structurally-controlled porphyry molybdenum-copper). MinCore is focused on advancing these two prospects to a scoping level, and exploring the property for additional mineralization.

In October 2008, MinCore commissioned AMEC, a global engineering services company, to conduct soil and stream sediment geochemical orientation surveys at Tameapa. The primary purpose of these surveys was to define the optimal field and assay parameters for the regional soil and stream sediment surveys, planned for 2009. The results of these surveys are the subject of this paper.

GEOLOGICAL SETTING AND HISTORY

Copper and molybdenum mineralization at Tameapa are spatially associated with a Laramide-age batholith that intrudes a sequence of coeval interbedded volcanic and sedimentary rocks. Mineralized zones typically occur near the contacts of the batholith and are often associated with late stage, Tertiary-age, felsic porphyritic intrusive bodies. Pico Prieto is interpreted as a classic, porphyry copper-molybdenum system consisting of a leached cap, and underlying supergene copper, and hypogene copper (±molybdenum) mineralization. Oxide copper mineralization is mostly absent at Pico Prieto. Venado is a structurally controlled zone of molybdenum-copper mineralization along the eastern contact of a lower grade molybdenum mineralized quartz-feldspar porphyry body. Mineralization occurs within several rock types, including hydrothermal and contact breccia zones, that contain volcanic and intrusive fragments, and are cemented by molybdenum-rich quartz veins, quartz feldspar porphyry, and hornfels (Cargill 2007).

Detailed exploration of the 5,000 ha

Tameapa property has been confined to the 12 km^2 area surrounding the Pico Prieto and Venado prospect areas. Exploration by MinCore and previous operators has included geologic mapping, geochemical and geophysical surveys, and 43,000 m of drilling in 144 diamond drill holes. MinCore plans to systematically explore the entire property area during the 2009 and 2010 field seasons.

SOIL ORIENTATION SURVEY

Design and Collection

The soil orientation survey consisted of three east-west traverses across the known areas of mineralization on the property at Pico Prieto and Venado; and three soil profiles in the Venado area. The primary purpose of the soil traverses was to determine the spacing required to find a deposit of similar dimensions and style of mineralization, and to determine the optimum soil size fraction and pathfinder elements for these styles of mineralization. The purpose of the soil profile samples was to determine whether metal concentrations vary with soil horizon and depth.

A total of 72 samples were collected from the three soil orientation traverses, including three field duplicate samples. Samples were collected every 50 m along each traverse. A single pit was dug at each site to between 50 and 60 cm in depth. Soil was collected from the bottom of the hole, and sieved to 100% passing 8 mesh on site.

Eight samples were also collected from three vertical soil profiles. At each profile site, the soil exposed in a road-cut was first cleaned to remove possible contamination, and samples were collected from two distinct soil horizons between the surface and 1.2 m in depth.

All soil samples were sieved into four size fractions and analyzed for 36 elements by aqua regia digestion/ICP-MS finish. The size fractions included a coarse size (-8+35 mesh), a medium size (-35+80 mesh), a fine size (-80+150 mesh), and a very fine size (-150 mesh). The coarse and medium size fractions were pulverized to 70% passing 150 mesh prior to analysis, and the fine and very fine size fractions were analyzed as is.

Results

Evaluation of the soil profile results indicates that there is a strong partitioning of copper and molybdenum into the near-surface soil horizon. Copper and molybdenum concentrations are significantly greater in the near-surface (0 to 30 cm) B horizon soils than in the deeper C horizon soils (Fig. 1). More work is required to determine the reason for the preferential partitioning of metals into the B horizon.

Overall, copper and molybdenum show the best anomaly-to-background contrast in the coarse, -8+35 mesh, size fraction. Copper response is strongest in the coarse (-8+35 mesh) and very fine (-150 mesh) size fractions. Molybdenum response is generally strongest in the coarse size fractions, though in some places, the very fine, -150 mesh, fraction yields the highest values. Where molybdenum response is subdued, the coarse fraction often returns the lowest values, thus providing the best anomaly-to-background contrast ratios.

Anomalous patterns of copper and molybdenum suggest a maximum sample spacing of 100 m and line spacing of 200 m is required to adequately delineate areas of interest. This spacing is primarily aimed at adequately defining the

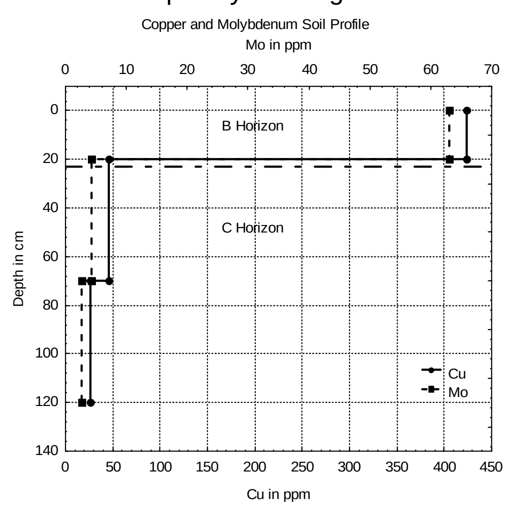

Fig. 1. Partitioning of Copper Near-surface B Soil Horizon (-8+35# fraction shown).

structurally controlled molybdenum mineralization at Venado. The Pico Prieto porphyry-style target would support a much wider sample spacing, say 200 to 250 m, without increasing the risk of missing significant mineralization.

The following elements are associated with copper-molybdenum mineralization in soils at Tameapa: Cu, Mo, Au, Ag, Pb, Zn, V, W, Ni, As, Sb, Bi, and Se. As expected, copper and molybdenum show the strongest response to copper-molybdenum mineralization at both Pico Prieto and Venado.

STREAM SEDIMENT ORIENTATION SURVEY

Design and Collection

The Tameapa stream sediment orientation survey consisted of 30 sample sites situated down-stream from the Pico Prieto and Venado prospect areas. The primary purpose of the stream sediment orientation survey was to determine optimum sampling and assaying parameters for use in the regional stream sediment survey.

A total of 31 stream sediment samples were collected from dry and flowing drainages, including one field duplicate sample. Sediment was collected from 2 to 4 sites along 30 to 100 m of drainage length, and sieved in the field to 100% passing 12 mesh. Stream sediment samples were processed in the same way as soil samples. Each sample was sieved into four size fractions (-8+35, -35+80, -80+150, and -150) and analyzed for 36 elements by aqua regia digestion of a 15 gram sub-sample with ICP-MS finish. The coarse and medium size fractions were pulverized to 70% passing 150 mesh prior to analysis, and the fine and very fine size fractions were analyzed as is.

Results

Analysis of down-stream single element profile maps indicates the very fine, -150 mesh, size fraction provides the best response to Tameapa copper-molybdenum mineralization and thus is the optimal size fraction for use in the regional stream sediment survey. This fraction provides the best anomaly-to-background contrast for both copper and molybdenum.

Copper and molybdenum concentrations are anomalous for nearly 18 km downstream from mineralization, though there are several sources of mineralization along the drainage (Fig. 2). The anomalous response is diluted sharply when the main stream reaches a confluence with other significant streams that are not draining mineralization. Anomaly to background contrast for both copper and molybdenum is about 3:1.

The following elements are associated with copper-molybdenum mineralization in stream sediments at Tameapa: Cu, Mo, Au, Sr, Sb, and Ba. Copper and molybdenum are clearly the most useful pathfinder elements for copper-molybdenum mineralization at Tameapa, but other elements may prove useful in delineating anomalous areas during the regional survey where copper and molybdenum concentrations are not anomalous.

CONCLUSIONS AND RECOMMENDATIONS

The results of the orientation surveys indicate that both soil and stream sediment geochemical methods are effective for the exploration of copper-molybdenum mineralization on the Tameapa property.

Results from the soil orientation survey suggest that soil samples should be

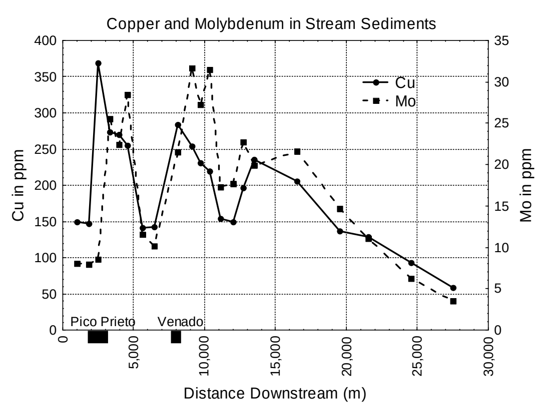

Fig. 2. Copper and Molybdenum Response in Stream Sediment Samples.

collected on 100 m spaced stations on lines spaced 200 m apart. This spacing is the maximum grid spacing recommended to allow discovery of Tameapa-style copper-molybdenum mineralization in the regional soil survey. Further, between 0.5 and 1.0 kg of -12 mesh soil should be collected from the near-surface B horizon (0-30 cm) at each soil site. The soil samples collected from vertical profiles show that the B horizon response is strongest and will provide greater anomaly contrast than the C horizon. At the assay laboratory, all soil samples should be sieved to the -8+35 mesh, coarse size fraction and analyzed by aqua regia digestion/ICP-MS finish. The coarse size fraction was shown to provide the best anomaly-to-background contrast for copper and molybdenum in soil samples.

Results from the stream sediment orientation survey indicate that stream sediment samples should be collected at a sample density of approximately 1 sample per 1 km^2. This is the optimal sample spacing determined from the downstream dispersion patterns in the orientation survey. About 1.5 kg of -8 mesh, sediment from the current stream channel should be collected from three or more locations along 20 to 100 m of drainage at each sample site. Samples should be sieved to the very fine, -150 mesh size fraction, and analyzed by aqua regia digestion/ICP-MS finish. The very fine size fraction was shown to provide the best anomaly-to-background contrast for copper and molybdenum in stream sediment samples.

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Gold dispersion under pediplanation in desert terrains

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ABSTRACT: Some desert terrains in northern and northwestern China are peneplains formed by a long period of erosion. A concealed gold deposit was selected for study of gold dispersions in the process of pediplanation by using overburden drilling sampling. The results show that (1) gold tends to concentrated in the top and bottom of the vertical profile over the ore body, (2) gold is enriched in the fine-grained fractions of soils with clay-rich horizons at surface or near surface and the largest gold anomalies occur in fine-grained samples (-100 mesh) over the ore body, (3) gold distribution in different size fractions of soils at the bottom of the weathering regolith display no obvious difference but tend to be anomalously enriched in bedrock troughs. This indicates that gold was concentrated in the lowest places by erosion and transportation during the process of pediplanation. Vertical migration to the soil surface and entrapment by clays and amorphous Fe-Mn oxides leads to the formation of geochemical anomalies directly over the ore body.

KEYWORDS: *desert terrains, gold deposit, ARC drilling, pediplanation, dispersion*

INTRODUCTION

A large, contiguous desert terrain, totalling c. 2× $10^6 km^2$, covers most of northern and northwestern China (Wang *et al*. 2007). Much of this region has not been explored or under-explored by effective geochemical methods due to peneplains formed during a long period of erosional and depositional cycles, and weathering regolith concealing mineral deposits. To search for mineral deposits using geochemical methods, it is critical to have an understanding of geochemical dispersion during pediplanation. Many researchers have been trying to understand the process of geochemical dispersion in the desert peneplain since the 1990s (Wang *et al.* 2003; Ye 2004; Wang 2005; Wang *et al*. 2007). In this paper, the authors will describe gold dispersion in the process of pediplanation based on sampling by Air Reverse Circulation (ARC) drilling.

GEOLOGICAL SETTING

The study area, Jinwozi gold field, is located at the boundary of Xinjiang and Gansu provinces in northwestern China and is a typical peneplain. There are two NE-trending mineralized belts (Fig. 1).

In the northern belt, ore bodies are associated with quartz veins, occurring at

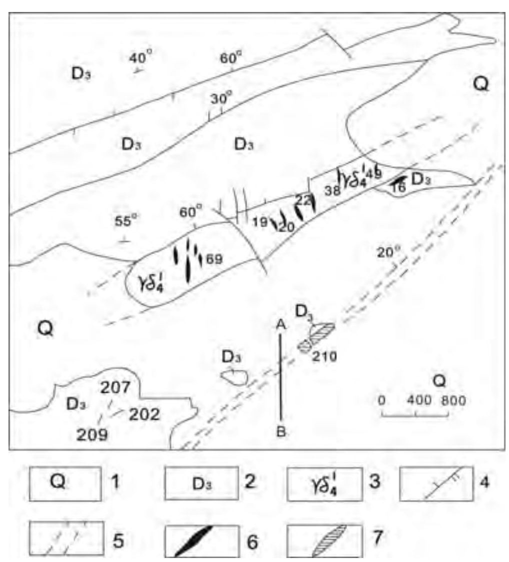

Fig. 1. Geological outline of Jinwozi gold deposit with drilling profile A-B 1 Quaternary; 2 Clasolite and volcanoclastic rocks of upper Devonion; 3 Biotite granodiorite; 4 Fault; 5 Ductile alteration zone; 6 Auriferous quartz vein; 7 Auriferous altered rocks.

the contact between granodiorite and Devonian sequences. The average Au grade is 7g/t. In the southern belt, the ore bodies occur in a ductile alteration fault within a Devonian sequence, which is composed of metamorphic tuff, carbonaceous tuff, sandstone and volcanoclastic rocks intruded by Carboniferous granodiorite or biotite adamellite granite (Zhao 2004). The average Au grade is 4 g/t.

The northern belt is situated in an outcropping area of relatively high relief. The southern belt is located in an area covered by regolith composed of windblown sand, alluvium and residuum. The depth of cover varies from 4 to 20m.

SAMPLING AND ANALYSIS

Sampling

An ARC drilling program was conducted alone Profile A-B across the southern concealed gold belt (Fig. 1). 23 bore holes were drilled at a spacing of 50-100 m. Samples were collected every metre from the surface to bedrock. They were split into three fractions: +40, 40-100, and -100 mesh by sieving in the field. Sample types (transported materials, weathered rock, and bedrock) can be recognized based on changes in sample colour, granularity and mineral composition.

Analysis

All the samples were ground to -200 mesh (75μm) for analysis. A 10.0 g sample was digested in aqua regia and analysed for Au and Ag by graphite furnace atomic absorption spectrometry (GF-AAS). A 0.5 g sample was used for As and Hg analysis by hydride generation atomic fluorescence spectrometry (HG-AFS) after an aqua regia digest. A 0.25 g sample was digested in a mixture of HF+HNO_3+$HClO_4$ and aqua regia. ICP-MS was used for the determination of Ba, Cu, La, Pb, Sb, Sr, Th, U and Zn, and ICP-OES was employed for the determination of P_2O_5, Li, MnO, TiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O, and K_2O. Standard reference samples of the GSS series (Xie *et al.* 1985) were used to monitor analytical quality.

RESULTS

Figure 2 shows the variations of gold and mercury contents in the fine fraction (-100 mesh) in drill hole (JWZZK8W) over the gold ore body (Fig. 3). Gold in the fine-grained fraction tends to concentrate in the top and in the bottom of the vertical profile over the ore body. This fact implies that fine-grained gold and similarly mercury could penetrate through the Tertiary and Quaternary sequences and be transported up to the surface.

Figure 3 shows gold distribution in different fractions (+40, 40-100, -100 mesh) along A-B profile. The top part of the figure is drawn by using results from the top sample in each drill hole and the bottom part of the figure from the interface samples between regolith and bedrock. Gold is enriched in the fine-grained fractions of soils with clay-rich horizons at surface or near surface and the greatest gold anomaly contrasts occur in fine-grained samples (-100 mesh) over the ore body. The gold distribution in different grain size fractions of soils at the bottom of the weathering regolith display no obvious difference but anomalies tend to be enlarged in the lowest places at the bedrock interface

DISCUSSION OF GOLD DISPERSION

From the Devonian to the Quaternary period, the study area experienced a complicated geological and weathering history (Fig. 4). Granodiorite or biotite adamellite granite intruded Devonian tuff

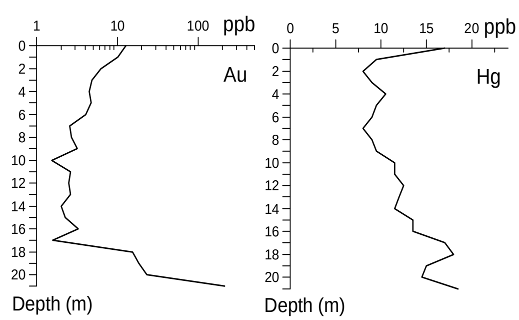

Fig. 2. Variations of Au and Hg from top to bottom in the vertical profile over the ore body.

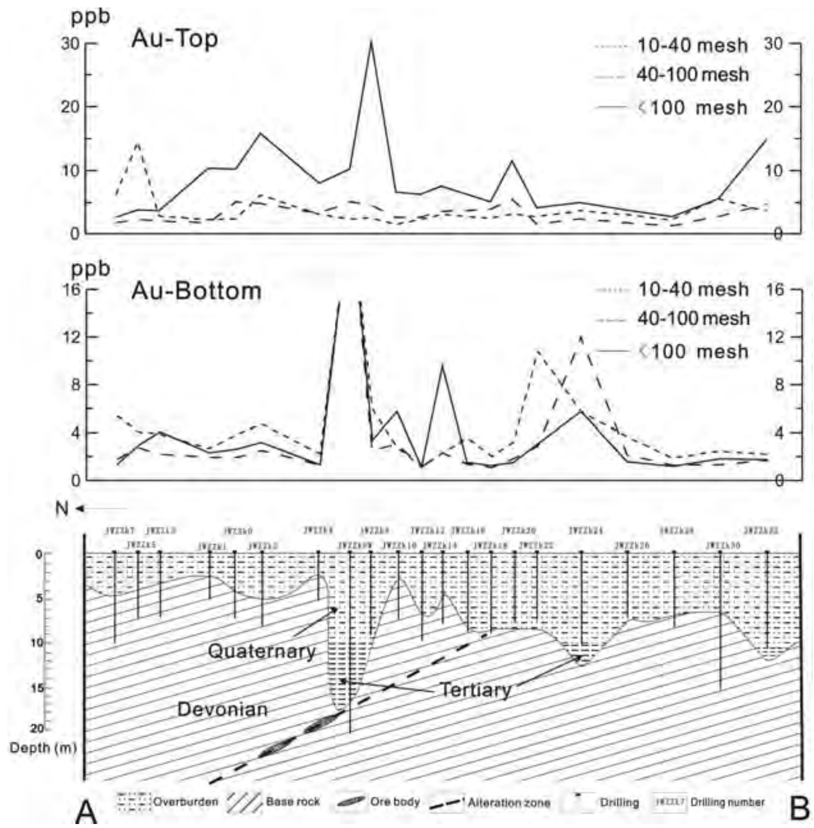

Fig. 3. Gold variations in different fractions at the top and bottom of the profile.

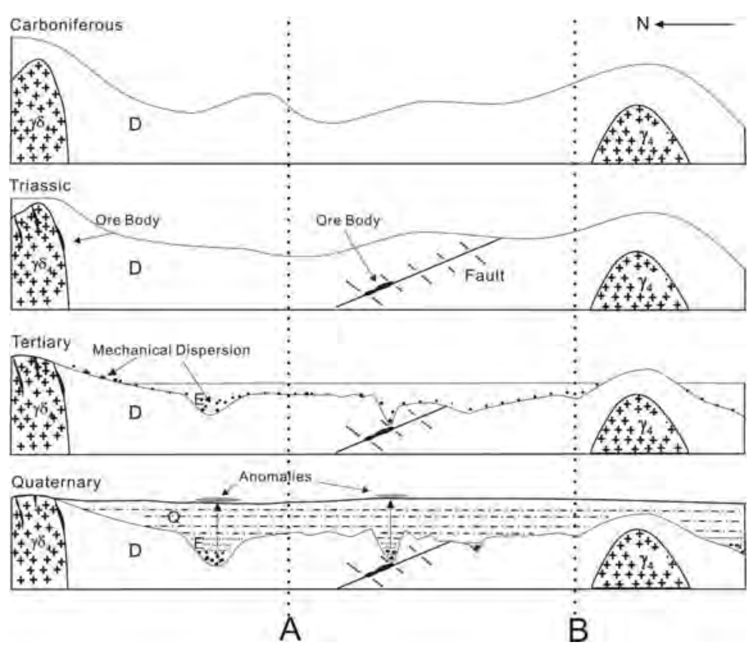

Fig.4. Model showing formation of Au anomalies during pediplanation.

and volcaniclastic sequences in the Carboniferous. Gold deposits were formed in the Triassic (Zhao 2004). The rocks have been under continuous pediplanation since the Tertiary period (Fig. 4). The eroded gold mineralized rocks were mechanically transported and deposited in the Tertiary in topographic lows to form gold anomalies at Drill hole 8 and Drill hole 24 JWZZK8W and JWZZK24 (Fig. 4).

Coarse gold grains are stable in weathered rocks in or near the ore bodies, whereas fine and ultra-fine grains of gold are mobile, so they can be easily dispersed and migrate a long way vertically, penetrating through cover to the surface (Wang *et al*. 1995, 2007). Arriving at the surface, gold may be trapped on clay surfaces and by amorphous manganese and iron oxides.

ACKNOWLEDGEMENTS

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Structure and stratigraphy of the Key Anacon Main Zone and East Zone massive sulfide deposits, Bathurst Mining Camp, NB, Canada

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ABSTRACT: The Middle Ordovician stratigraphy of Key Anacon consist of graphitic shale and quartzose wacke of the Miramichi Group that occur at the base of the stratigraphic section, and are disconformably overlain by the Tetagouche Group volcanic, volcaniclastic, and sedimentary rocks that are composed of fine-grained tuffs, quartz crystal tuffs, and quartz-feldspar crystal tuffs belonging to the Nepisiguit Falls Formation. Rhyolite flows of the Flat Landing Brook Formation and basaltic and sedimentary rocks of the Little River Formation overlie the exhalative (sulfides and iron-formation) horizon.

The felsic rocks have negative Sr and Eu anomalies suggesting plagioclase fractionation. Zr/Al_2O_3 appears to be the best criteria for the discrimination of volcanic rocks and related volcaniclastic sedimentary rocks, because the rocks have been hydrothemally altered; Al_2O_3 is the most conserved. The mafic rocks are dominantly of transitional alkaline to calc-alkaline affinity with high Cr and Ni contents.

The Key Anacon Main Zone and East Zone massive sulfide deposits occur on the eastern limb of the large-scale Portage River Anticline, and are locally concentrated in the hinges of parasitic F_2 folds. Local variations in plunge of F_1 are due to generation of sheath-type fold structures during progressive D_1 deformation, or F_1/F_2 interference folding.

KEYWORDS: *Massive sulfide deposit, geochemistry, chemostratigraph, structural geology*

INTRODUCTION

The Key Anacon Main Zone has approximately 785000 t grading 0.34% Cu, 3.07% Pb, 7.65% Zn, and 120 g/t Ag. This deposit is located 20 km south of Bathurst and 11 km east-northeast of the Brunswick No. 6 deposit, with the smaller Key Anacon East Zone located approximately 1.5 km to the northeast of the Main Zone (Irrinki 1992, Fig. 1).

The Key Anacon deposits lie on the eastern limb of the Portage River Anticline and are hosted by an autochthonous sequence of Middle Ordovician felsic and mafic volcanics and related sedimentary rocks of the Tetagouche Group. The Tetagouche Group is underlain by sedimentary rocks of the Miramichi Group (van Staal & Williams 1984). The stratigraphy hosting the east Zone is unconformably overlain by Carboniferous sedimentary rocks.

This study was undertaken to document the geometry, stratigraphic position of sulfide mineralization, and lithogeochemistry of felsic and mafic volcanic rocks of the sequence hosting the Key Anacon deposits.

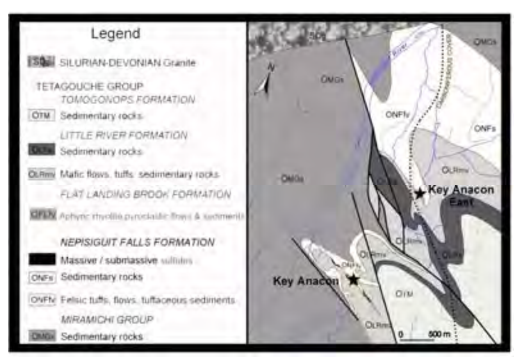

Fig. 1. Geological map of Key Anacon Main Zone and East Zone deposits, northeastern New Brunswick (Canada).

GEOLOGICAL SETTING

The rocks of the Bathurst Mining Camp are assigned to five groups, only two of which occur in the Key Anacon area, namely: the Cambro-Ordovician Miramichi Group and the Middle Ordovician Tetagouche Group (van Staal *et al.* 2003). The Miramichi Group is dominated by a mature quartzose sedimentary sequence, which becomes progressively finer grained and more graphitic towards its upper contact with the Tetagouche Group (van Staal & Williams 1984; Lentz 1996). Rice & van Staal (1992) interpreted the graphitic shale and quartzose wackes of the Miramichi Group as having been formed on an abyssal plain.

Conformably to locally disconformably overlying the Miramichi Group rocks are the bimodal volcanic and sedimentary rocks of the Tetagouche Group. The Tetagouche Group is divided into four all of which occur in the study area; in ascending stratigraphic order they are: Nepisiguit Falls (NF), Flat Landing Brook (FLB), Little River (LR), and Tomogonops formations.

The NF consists of the quartz- and quartz-feldspar-phyric felsic volcaniclastic and minor associated sedimentary rocks. This formation has been interpreted as a pyroclastic sequence dominated by crystal-rich ash flow tuffs, reworked tuffites, and related sedimentary (van Staal *et al.* 2003).

Aphyric to sparsely feldspar-phyric rhyolite flows, associated breccias and related hyalotuffaceous sedimentary rocks of the FLB Formation, and basaltic and related sedimentary rocks of the LR Formation immediately overlie the exhalitive (sulfides and iron-formation) horizon of the Key Anacon East and the Key Anacon Main Zones, respectively (van Staal *et al.* 2003).

A sequence of younger calcareous sedimentary rocks belonging to the Tomogonops Formation overlies the LR rocks at the Main Zone, and these are more calcareous than the LR sedimentary rocks.

LITHOGEOCHEMISTRY

Both Key Anacon deposits have large, well-developed footwall and hanging wall alteration halos. Therefore, major- and immobile trace-element data are used to help discriminate rock types.

The felsic rocks of NF are predominantly rhyodacite, whereas the FLB rocks are more evolved with compositions ranging from rhyopdacite to rhyolite. The LR mafic rocks have a dominantly alkali to subalkaline basalt signature. The basalts have low Zr/Al_2O_3 (<0.0025) suggesting that the parent magmas had relatively low Zr content. In contrast, Ti, V, Cr, and Ni are high in the basalts due to source characteristics and subsequent fractionation of olivine, pyroxene, Fe-Ti oxides, and glass prior to eruption (Fig. 2).

The positive correlation between TiO_2 and Zr is also characteristic of alkali basalts, and is interpreted to reflect mantle partial melting and fractionation of more mafic parent rocks, as Zr and Ti are both incompatible in primitive melts. Zr remains incompatible up to the felsic end-members (≥ 67 wt. % SiO_2), whereupon it becomes compatible and crystallizes as zircon. This explains the increase of Zr from rhyodacitic through to rhyolitic melts in the NF and FLB formations (Fig. 2). The Y/Al_2O_3-TiO_2/Al_2O_3 plots show two distinct populations of the LR mafic rocks, and the NF and FLB felsic rocks (Fig. 3). The Y/Al_2O_3-Zr/Al_2O_3 plot (Fig. 4) shows a scatter trend of the NF and FLB felsic volcanic rocks indicative of magma mixing with the crustal sequence during eruption. Zr/Al_2O_3 vs. Y/Al_2O_3 plots show a similar distinct genetic trend for the FLB rhyolite

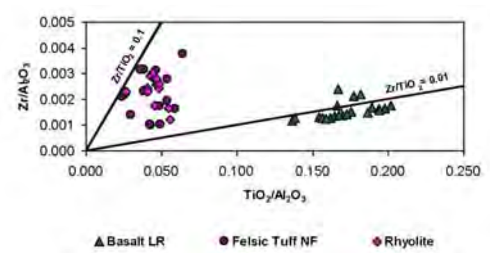

Fig. 2. TiO_2/Al_2O_3 vs. Zr/Al_2O_3 plot of mafic and felsic volcanic rocks of the Key Anacon area.

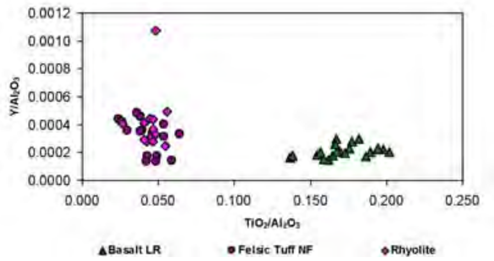

Fig. 3. TiO_2/Al_2O_3 vs. Y/Al_2O_3 plot of mafic and felsic volcanic rocks of the Key Anacon area.

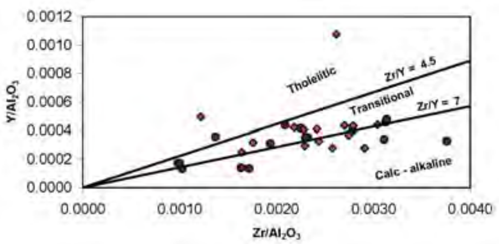

Fig. 4. Zr/Al_2O_3 vs. Y/Al_2O_3 scatter trend of felsic volcanic rocks of the Key Anacon area. Symbols as in Figure 3.

and NF tuffs, suggesting similar magma types as the source of the volcanic rocks. The Zr versus Al_2O_3 diagram is used to quantify the degree of alteration, with rocks having the same magmatic affinity falling on a straight line, whereas mass changes due to alteration show a deviation from the fractionation curve. The LR mafic rocks have moderate variation in Al_2O_3 content (12-16.4 wt %) which is compatible with the moderately altered samples from the hanging-wall, whereas footwall NF felsic rocks and the FLB hanging-wall rocks have variation in Al_2O_3 content (11.5-22.1 wt %) suggesting strong mass change during alteration.

The primitive mantle-normalized trace-element spider diagram of felsic rocks shows negative Sr and Eu anomalies that are indicative of either plagioclase restite or plagioclase fractionation resulting from a combination of the partial melting and fractional crystallization processes (Fig. 5), and later changed by hydrothermal alteration.

STRUCTURAL GEOLOGY

The structural history of the Key Anacon Main and the East Zones is the same as

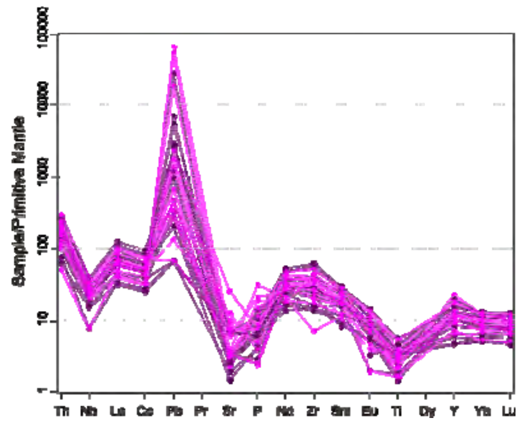

Fig. 5. Primitive Mantle-normalized spider diagram for the NF felsic tuffs and the FLB rhyolite of the Key Anacon area.

rest of the Bathurst Mining Camp, i.e. five phases of regionally developed penetrative deformation (D_1-D_5, van Staal & Williams 1984). Saif *et al*. (1978) and Irrinki (1992) recognised at least four deformational events (D_1-D_4) in the study area. During the course of this study mesoscopic and microstructural evidence of overprinting relations has identified 4 phases of penetrative deformation that are consistent with those of the previous authors.

The four phases are: D_1 thrust-related tight to isoclinal (F_1) folds and associated axial planar schistosity (S_1). D_2 tight-to-isoclinal folds (F_2), with S_2, are interpreted as high strain deformation with F_1/F_2 fold interference structure (Fig. 6) resulting in the development of $S1/S_2$ composite fabric elements. D_3 are recumbent and best developed in the west part of the BMC, and D_4 are represented as kink-folds.

The Key Anacon Main and East Zones are located along the east limb of the Key Anacon syncline, which is a very-tight steeply-plunging, F_2 fold with a well developed axial-planar (S_2) cleavage, and on the west limb of the adjacent moderately south-plunging F_2 anticline, respectively (Irrinki 1992). This interpretation is consistent with observations by van Staal & Williams (1984) who attributed the F_1/F_2 fold interference as having a significant role in the overall structure of the Mining Camp.

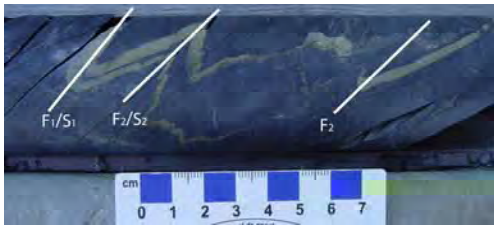

Fig. 6. Photograph of F_1/F_2 fold structures with axial planar S_1/S_2 fabric in shale (KA61-125 m).

Garnet and cordierite blastesis post-dating S_1/S_2 fabric contain inclusion trails of quartz, biotite and phengitic micas and indicate the influence of a late thermal overprint due to intrusion of the Pabineau Granite.

CONCLUSIONS

This contribution can be summarized in a number of points below:

(1) The F_1/F_2 folds are the dominant structure and control the distribution of rock-types with mineralization concentrated in the noses of the F_2 parasitic folds.

(2) Zr/Al_2O_3 ratio appears to be the best chemostrigraphic index for discrimination among felsic volcanic rocks in the Key Anacon area.

(3) Primitive mantle-normalized data show negative Eu and Sr in the felsic volcanic rocks. These negative anomalies are attributed to plagioclase fractionation and/or feldspar destructive hydrothermal alteration and removal of Eu during deposit formation.

(4) Low Nb and Ti in the felsic rocks are due to fractionation of Ti-bearing phases during calc-alkaline differentiation or during crustal partial melting.

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