STATE OF ALASKA

DEPARTMENT OF NATURAL RESOURCES

DIVISION OF GEOLOGICAL AND GEOPHYSICAL SURVEYS

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September 1988

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Report of Investigations 88-13

THE USE OF GEOCHEMICAL STREAM-DRAINAGE SAMPLES FOR DETECTING BULK-MINABLE GOLD DEPOSITS IN ALASKA

by
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STATE OF ALASKA
Department of Natural Resources
DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEYS

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INTRODUCTION

Increasing investment in precious-metal-related mining ventures, particularly those which focus on gold, has produced new mines and new concepts for locating gold. Although exploration geochemists have long been an integral part of the search for gold deposits, much of their work relating to gold exploration is only recently being published. Berger and Bethke (1985) and Saheurs (1987) have summarized gold deposit characteristics into geologic models. Advances in geochemical gold exploration have also been made in sampling techniques, sample preparation, analysis, and data interpretation, and a concomitant expanded understanding of sources of variance among geochemical samples, especially those containing gold, has resulted.

This paper reviews recent insights that can be applied to geochemical drainage surveys for gold deposits. These methods can be modified to optimize their effectiveness for a given type of gold deposit and geographic setting. Not all procedures reported here have been thoroughly tested; the decantation procedures need further work to document their efficiency and effectiveness. However, preliminary laboratory trials indicate that fine-grained (-230 mesh ASTM) free gold can be captured by following the methods outlined.

TARGET

Types of Gold Deposits

Geologic gold-deposit models have been developed at an astounding rate in the past 10 yr. Some of the most useful summaries of these models are found in the compilations of Bagby and Berger (1985), Silberman and Berger (1985), Heald and others (1986), Panteleyev (1986), Hattori (1987), and Saheurs (1987). These references mention at least 40 different models based on actual deposits. The new models place many sound observations of older geologic literature into a conceptual framework. Modeling identifies specific and unique combinations of geologic and geochemical parameters on which to focus field observations and thus is useful in geochemical survey design.

Bulk-minable gold deposits contribute significantly to gold production in North America today. The term 'bulk-minable' covers a host of gold-deposit types and disregards all genetic and geochemical characteristics except the presence of free metallic gold that can be mined by low-cost (usually open-pit) methods. Bulk-minable gold deposits are an outgrowth of modern technology. Cheap and efficient cyanide leach processing and the ability to consistently and economically analyze for gold to 5 parts per billion (ppb) are the two main advances that have allowed development of new types of low-grade deposits. A high percentage of gold in these deposits is present in very fine (-230 mesh) particles.

Now that it is possible to analyze for gold at very low levels, it has become apparent that gold is more widespread than previously thought, and this is reflected in the recent proliferation of producing, bulk-minable gold deposits.

Size and Grade of Gold Deposits

Many North American gold deposits now being put into production contain between 2 and 25 million tons of ore with grades from 0.15 to 0.3 oz/ton. Cutoff grades range from 0.02 to 0.05 oz/ton. (For comparison, 0.03 oz/ton is about 1 ppm.) Deposits of 5 to 10 million tons with an average mining grade of 0.1 oz/ton and a cutoff grade of 0.05 oz/ton are common. A few mines--for example, Sleeper, Nevada, and McLaughlin, California--have higher-grade core zones. Figure 1 (modified from Babcock, 1984) displays a comparison of grade and tonnage ranges of several genetic gold deposit types. Cox and Singer (1986) have also compiled useful grade and tonnage data as cumulative-frequency diagrams for several gold-deposit types.

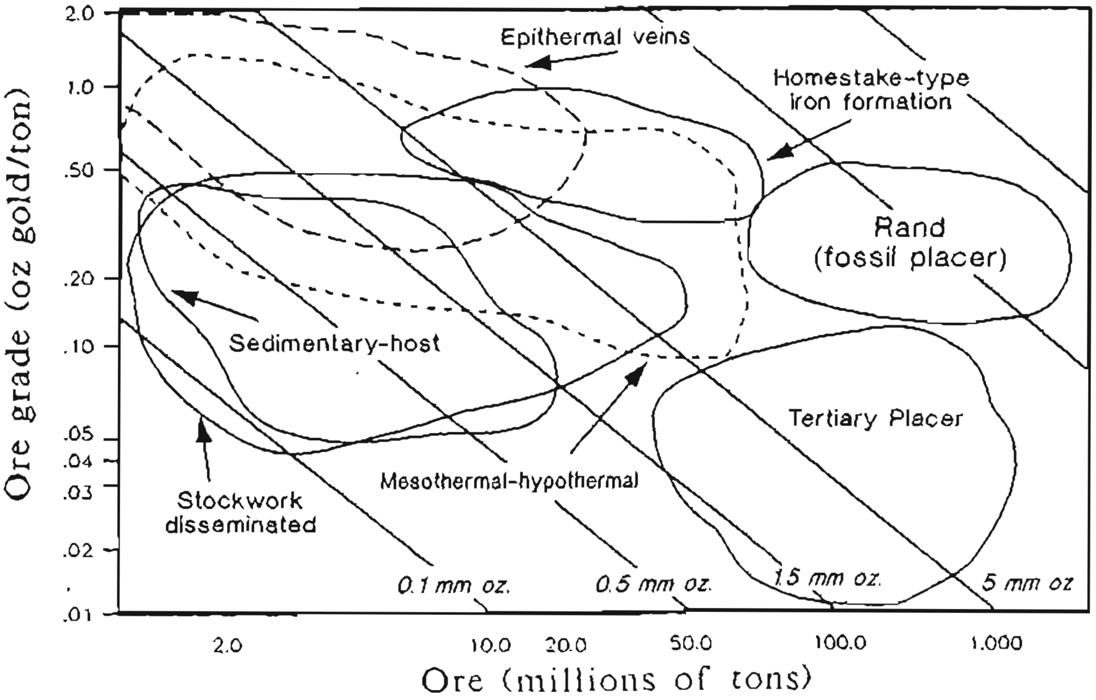

Figure 1. Approximate grade and tonnage limits of genetic gold deposit types. Diagonal lines indicate total contained gold in millions of metric ounces (mm oz) for a specific range of grades and tonnages. Modified from Babcock (1984); field of sedimentary-hosted gold deposits approximated from Bagby and Berger (1985).

For geochemical exploration purposes, the total size of a deposit is not as important as the size of its surface exposure, or near-surface area. The Sleeper gold deposit had only a few hundred square feet of anomalous outcrop exposed at the time of its discovery. Surface area becomes increasingly important during the geochemical soil and rock sampling of anomalous areas identified by drainage surveys. Some bulk-minable ore bodies are very large; for example, the pit at Gold Quarry, Nevada will reach dimensions of 1830 x 1220 x 300 m. Smaller (yet economically viable) bulk minable deposits now being mined usually cover a maximum surface area of about 1000 m x 300 m.

Geochemical Signature

Gold is often its own best 'pathfinder.' There are, however, several elements commonly associated with gold and these 'pathfinder' elements provide geochemical signals that indicate a gold deposit in the vicinity. The diversity in geochemical detail precludes generalizations concerning correlation of trace-element suites and specific gold-deposit types--even for gold deposits that are grouped into one genetic classification. Silver, copper, lead, zinc, barium, arsenic, antimony, and mercury are associated with gold in many environments. Other elements not as commonly associated with gold, but important in some geologic settings, are fluorine, manganese, molybdenum, tellurium, thallium, tungsten, and uranium.

Pathfinder elements may form a 'halo' around gold mineralization that is significantly larger than the actual deposit. When this occurs, the larger geochemical target is much more likely to be detected. In addition, determining pathfinder metal ratios (for example arsenic:mercury) can aid in determining direction and relative distance to a mineralized center. Explorationists who have pursued epithermal gold deposits, however, have learned the fallacy of believing that a strong anomaly in a pathfinder element indicates nearby gold. Often it does not.

It is common practice to analyze geochemical samples for gold and for a suite of associated elements thought to be characteristic of the deposit type being sought. In nature, such a diversity of gold-deposit types exists, and there is such an overlap in their trace-element content, that choosing an arbitrary subset of elements for a regional exploration target is often both misleading and fruitless. Because modern multielement analytical techniques allow rapid determination of many elements simultaneously and relatively cheaply, the explorationist does not have to omit those elements which may prove useful if an unexpected gold-deposit type is encountered.

Gold grain size in drainage-survey samples is a parameter in gold exploration geochemistry that has not been widely discussed in the literature until recently. This parameter is still being tested, but several bulk-minable gold deposits have been discovered from gold data that were interpreted on the basis of grain-size parameters. Unlike placer and lode-vein deposits, many deposits now being put into production are characterized by disseminated ultrafine-grained gold. Gold occurs in these deposits as discrete grains that range from 1 to 30 microns (less than ASTM 400 mesh), as compared to free milling gold of +400 mesh (usually +200 mesh). Historical experience has shown that highly anomalous values from coarse-grained samples usually lead to small gold-bearing veins or placer deposits. Conventional methods of obtaining heavy-mineral concentrate samples produce results strongly biased toward coarse-grained gold, and although conventional heavy-mineral-concentrate samples are effective indicators of placers and lode veins, they are not always useful for detecting low-grade bulk-minable deposits. An effective drainage survey must be able to detect geochemical signals from both coarse- and fine-grained gold mineralization.

There are an increasing number of documented finds of ultrafine-grained disseminated gold deposits close to known mining districts. These new deposits are being found through intensive rock geochemical sampling (lithogeochemistry). Lithogeochemistry is a labor-intensive analytical technique, and each sample documents only a small area of influence. The exploration strategy is straightforward: collect many bulk samples from an old mining district or from an anomalous area delineated by drainage geochemical surveys (-80 mesh stream sediments, pan concentrates, or table concentrates). These exploration strategies can be made more effective by improving initial drainage survey methods in the following ways:

(1) ensure that both ultrafine- and coarse-grained gold are retained in the sample
(2) decrease the random variance (geochemical noise) of drainage geochemical samples
(3) increase the geochemical signal-to-background ratio for both coarse- and fine-grained gold anomalies
(4) discriminate coarse-grained lode, placer, and random nugget signals from lower level ultra-fine-grained gold signals.

SAMPLING

Conventional Sample Types

The two primary sample types in drainage surveys are stream sediment (-80 mesh) and heavy-mineral concentrate. Stream sediment samples provide a good sample medium for those elements which occur in rapid-weathering minerals and are released into solution as free ions or inorganic metal complexes. These ions precipitate as insoluble metal compounds on sediment grains in response to changes in Eh and pH conditions in the stream or at the groundwater-slope interface; the sediment provides a substrate on which the insoluble metal compounds are deposited. A stream-sediment sample may contain primary-ore mineral grains, but they are incidental to sampling for hydromorphic pathfinder elements. The standard -80 mesh stream-sediment sample may indicate the presence of anomalous precipitates of copper, lead, zinc, molybdenum, iron, manganese, arsenic, antimony, mercury, and silver.

Heavy-mineral-concentrate samples are best suited to providing information on primary-ore minerals that have not been destroyed by weathering, elements that occur in resistate minerals, gold and platinum-group metals, and some gem minerals. Ore minerals, resistate minerals, precious metals, and gems tend to higher specific gravity than many common rock-forming minerals and can be separated from lighter rock-forming minerals by gravity separation techniques. A common way of doing this is by panning. Other separation methods include the use of Wifley tables, jigs, miniature suction dredges, and heavy liquids. Of these methods, panning and suction dredging are probably the least reliable.

Historically, heavy-mineral-concentrate samples have been used for regional gold exploration. Recent work by Fletcher and others (1987) and Shelp and Nichol (1987) has pointed out serious flaws in methods using conventional heavy-mineral-concentrate samples. These include excessive random variance between samples and loss of gold from the sample. Shelp and Nichol (1987) demonstrated serious problems with tabling samples for gold separation because both fine-grained free gold and occluded gold is lost to tailings (fig. 2). They also reported that gold losses occur in heavy liquid separations with material less than 200 mesh, because very fine-grained gold tends to float on the surface of the heavy liquid or becomes trapped in the light mineral cake floating on top of the heavy liquid.

Dummett and Fipke (1986), Fipke (1986), Mehrtens (1986), and Smith (1986) cited several examples of mineral deposits which were found only after the quality of heavy-mineral sampling was improved. The work reported by these geologists and others indicates that even if great care is taken in panning or tabling samples and in recording initial weights and those of analytical aliquots, the inherent variability of both conventional heavy-mineral sample and sample-concentration techniques seriously limits their use for locating ultrafine-grained gold deposits. Results from conventional heavy-mineral samples can be misleading. Because gold deposits may contain either coarse- or ultrafine-grained gold, sample collection and analysis must identify signals from both sources. To emphasize this, it is helpful to think in terms of a gold geochemical drainage sample rather than in terms of heavy-mineral-concentrate or stream-sediment samples. A single gold geochemical drainage sample should include the most effective elements of both a heavy-mineral-concentrate and a stream-sediment sample and also allow for discrimination of fine-grained gold anomalies.

Geochemical Drainage Samples

There are several sources of significant variance in a gold geochemical drainage sample which can create noise and influence the signal generated by mineralization:

- Site-to-site hydraulic variance
- On-site sample-collection inconsistency
- Initial variation in sample size
- Variance in heavy-mineral concentration efficiency
- Variable loss of fine fractions in the field
- Variable loss of fine fractions in the laboratory
- Analytical variance.

The signal can be masked by multiple sources of noise, which would effectively shield an anomaly from detection. A proper choice of analytical procedures for routine geochemical analysis can limit data variation from laboratory sources to less than 10 percent. This is far less than the total variance common to most geochemical samples. Thus, improvements in noise reduction must be made before analysis. Over the years, many sampling variations and normalizing schemes have been tried in an attempt to reduce the effects of nonanalytical sources of random noise while increasing the signal from heavy-mineral-concentrate samples, but none have succeeded until recently. Refinements of methods that have produced improvement are largely based on an increased understanding of the sample environment as it relates to the particulate nature of gold and an increased understanding of variance contributed by particle-sparsity effects that relate to sample size.

Beginning with the first source of noise noted above, it is desirable to reduce site-to-site hydraulic variability. Day and Fletcher (1986), Saxby and Fletcher (1986; in prep.), Smith (1986), and Fletcher and others (1987), have studied this problem in detail. Fletcher and others (1987) have shown that, for fine-grained heavy minerals, the effects of variable hydraulic gradients at different sites can be normalized. Their method involves analyzing the total metal content of a specific size range of heavy minerals and determining the ratio of that metal content to the weight of light minerals in a hydraulically equivalent size fraction of the same sample. This normalizing procedure is not as effective for coarse-grained heavy-mineral size fractions. Fletcher and others (1987) also found that for cassiterite at grain sizes of less than 200 mesh, there was no marked difference in the heavy-mineral concentrating effects of different hydraulic regimes (fig. 3).

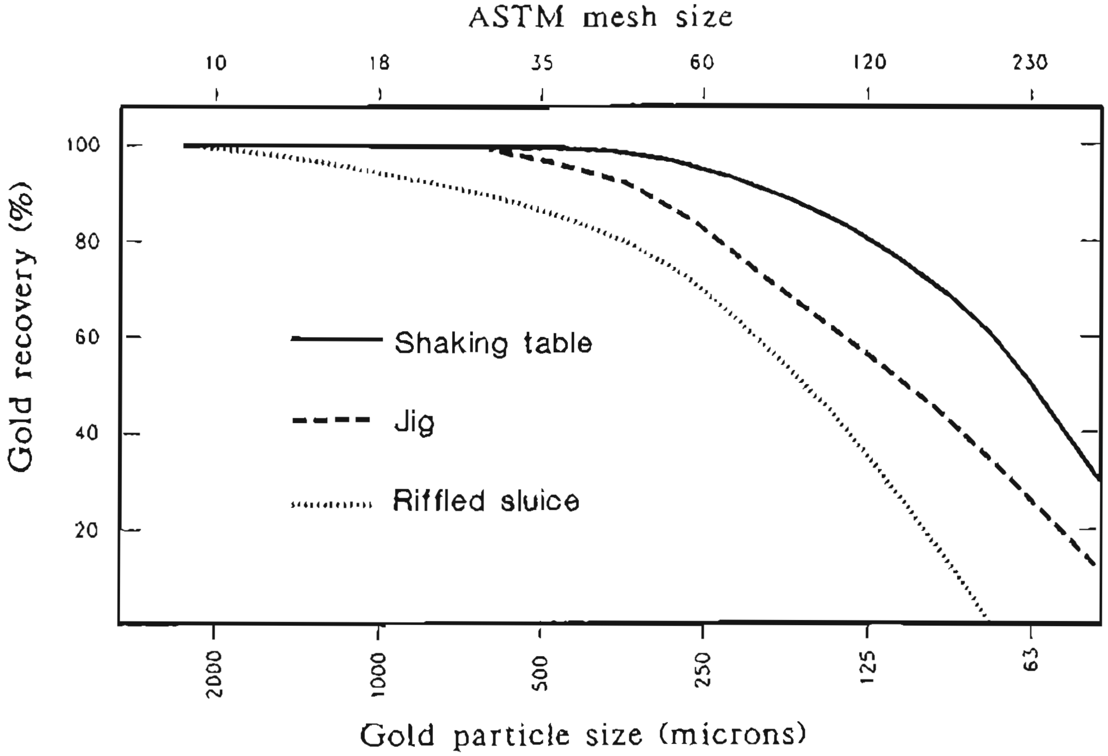

Figure 2. Percentage of gold recovered from till samples by sluice, jig, and shaking-table methods for heavy-mineral concentration. Modified from Shelp and Nichol (1987).

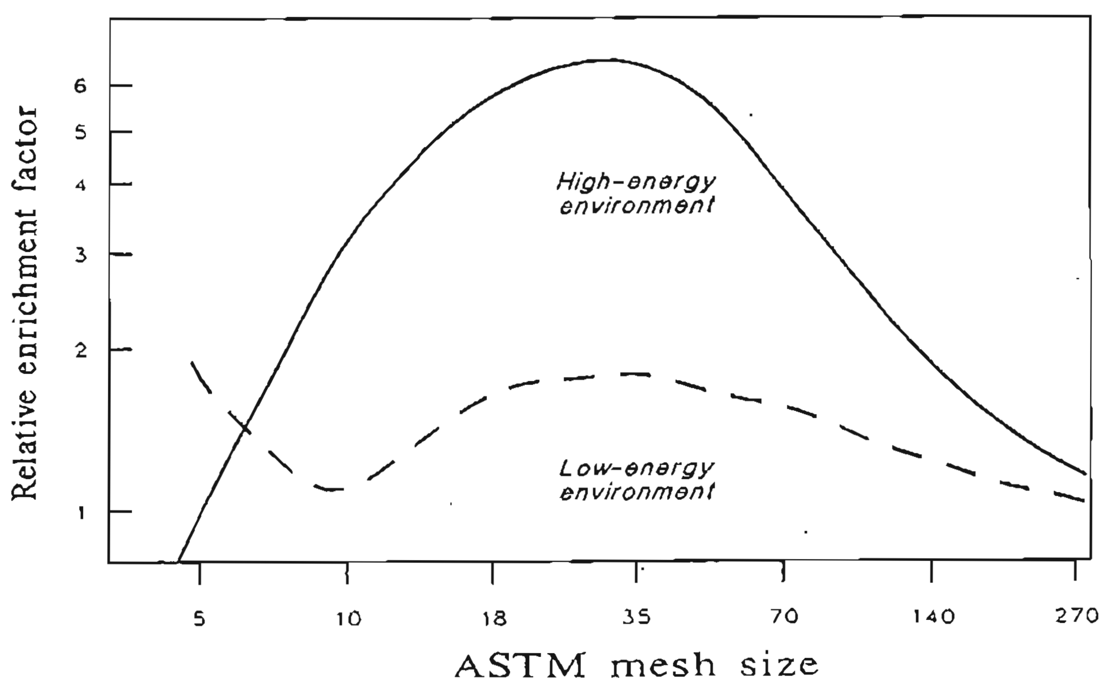

Figure 3. Relative enrichment of heavy minerals in stream sediments occupying low-energy (dashed line) and high-energy (solid line) hydraulic environments over a range of particle sizes. Modified from Fletcher (1988).

The grain size of the material on the streambed at the sample site provides guidelines for at least reducing, if not eliminating, site-to-site hydraulic variance. A range of sand, pebble, or cobble sizes can be systematically adhered to for sampling at each site. For example, samples can be consistently taken from material containing pebbles from 0.5 to 2.5 cm in diam. Such a site would be considered a moderate- to high-energy site and would provide a consistent environment for enrichment of heavy minerals, especially in grain sizes of less than 10 mesh. For comparison, a 1/4-in. (6-mm) pebble is hydraulically equivalent to about a 0.5-mm (35 mesh) gold grain (Tourtelot, 1968; fig. 4). That is, the velocity of water needed to move a 6-mm pebble is about the same that is needed to move a 0.5-mm spherical grain of gold. Ten mesh quartz is hydraulically equivalent to 70 mesh gold, and 18 mesh quartz is hydraulically equivalent to about 100 mesh gold (fig. 4). In the natural environment, streambed roughness, variable water velocity, and variability in gold grain shapes will result in the deposition of a wider range of gold particle sizes in the bed load. For example, on a sandbar where quartz and feldspar grains range from 10 to 18 mesh, 65 to 100 mesh gold grains would be the most common size expected. However, because large pebbles and cobbles slow the water velocity near the streambed and shelter finer-grained material, even high-energy sites will contain fairly abundant very fine-grained sand and silt-sized heavy minerals.

Smith (1986) used hydraulic equivalent relationships to construct a drainage survey for California-type mother-lode gold deposits, which are characterized by predominantly 'coarse gold' (that is, greater than +230-mesh). He used a backpack suction dredge to selectively vacuum off the 10 to 18 mesh sand near the heads of sandbars and thus collect and concentrate heavy minerals for gold geochemical analysis. Using this method, he had very close control on random intersite hydraulic variability and was successful in locating the lode mineralization he was looking for. By taking and processing very large samples he also was able to overcome the particle sparsity problem of gold sampling, discussed below.

An additional step that can be taken to reduce random sample-to-sample variability is to composite several smaller samples taken from the vicinity of the station of record and treat the composite as a single sample. Thus, rather than locating a single spot on the stream and digging one hole into the stream bed to obtain the total amount of sample material needed, several 'subsites' (six is a number often chosen) that meet particle-size criteria can be used to obtain the sample.

A common error made in heavy-mineral-concentrate surveys that adds to random sample variability is to collect an initial sample that is too small. An initial sample usually consists of a standard 16-in.diam (40.6 cm) goldpan full of material. This material is first sized to -1/4 in. (6 mm), or perhaps even to -10 mesh (2 mm), before it is panned, either to a fixed volume or to black sand. A 40-cm gold pan will hold about 7.3 kg (16 lb) of -10 mesh material if it is filled right to the brim. In practice, if material is screened into the pan it is very difficult to completely fill it. The sloping sides of the pan result in large changes in pan weights for relatively small differences in fill heights, thus most pan-concentrate samples start with a variable initial sample size ranging from 4.5 to 5.5 kg (10 to 12 lb).

Clifton and others (1969) published diagrams relating the grade of clastic material and gold grain size to size of sample needed to ensure an assay value within ± 50 percent of the true gold content. If gold grains and the enclosing material are all equant and 35 mesh, their diagrams show that about 28 kg (62 lb) of 35 mesh sample are needed to ensure consistent results for material that assays 1 ppm gold. Today, geochemistry samples are routinely analyzed to the 0.005-ppm level (5 ppb), and in some areas anomalies are significant if they exceed 0.020 ppm (20 ppb). Clearly, a single goldpan full of 10 mesh material will consistently find only extremely anomalous samples, and many subtle but significant anomalies will go undetected. It is often impractical to overcome this statistical hurdle. Depending on gold concentrations, hundreds of pounds of stream gravels might have to be processed to achieve a reproducible analysis falling within the limits suggested by Clifton and others (1969).

In practice, a drainage geochemistry sample of 10 to 20 kg has become a de facto upper limit for manually collected material in routine surveys. Even this amount of material presents problems in handling and collection for surveys that are only partly helicopter-supported. For surveys conducted on foot, 10- to 20-kg

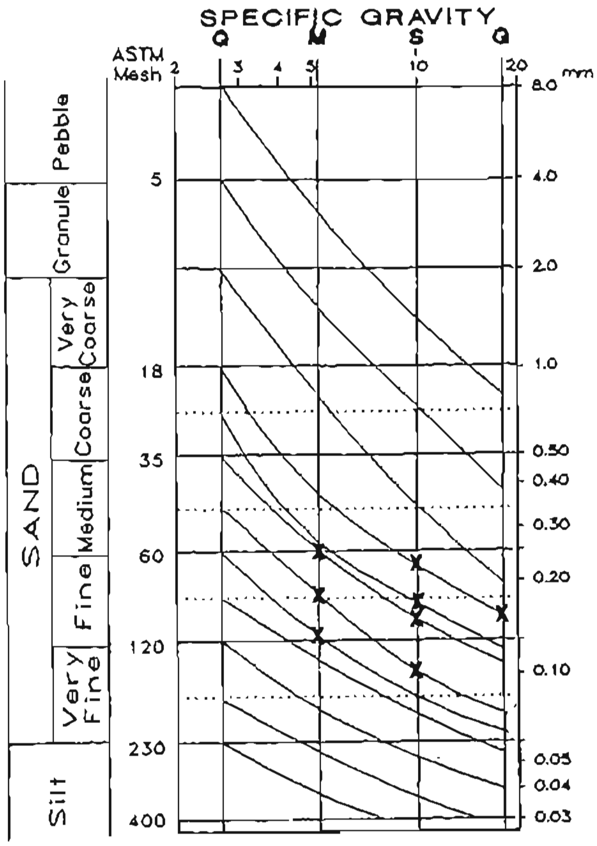

Figure 4. Hydraulic equivalent grain sizes for quartz (Q), magnetite (M), silver (S), and gold (G). X = average of values from both Stokes' law and the square-root law of particle settling. Modified from Tourtelot (1968).

samples must be further reduced at streamside so that the most effective size fractions can be packed out of the field.

If the sample consists of only -10 mesh material, there is a continuum of grain sizes much smaller than 10, 35, or even 100 mesh. The presence of these finer materials is variable, but if the gold in the sample is fine-grained, much less of the finer fractions is needed to achieve reliable assay results at low concentrations. The charts of Clifton and others (1969) show that only 50 g of spherical 230 mesh material would be needed to obtain consistent analytical results if that fine-grained material contained 1 ppm gold. If the gold particles have a flat shape, only about 8 g of 230 mesh material is needed, at 1 ppm concentration.

Fine-grained (-230 mesh) sample material can yield significant gold concentrations and deposit information. Day and Fletcher (1986) have reported up to 23 ppm gold in fine-grained heavy-mineral separates (this concentration would be much lower in unconcentrated -230 mesh sample material). An additional indication of the importance and desirability of retaining these fine fractions in the sample is provided by Stanley (1986, personal commun.), who reports that a biplot of gold assays made of the fine-grained fraction versus the coarse-grained heavy-mineral fraction in samples can be divided into fields that effectively distinguish probable fine-grained, disseminated gold deposits from vein or placer deposits (fig. 5). Mehrtens (1986, oral presentation) relied on the -200 mesh fine fraction of drainage sediments to focus his successful search for disseminated gold deposits in Nevada.

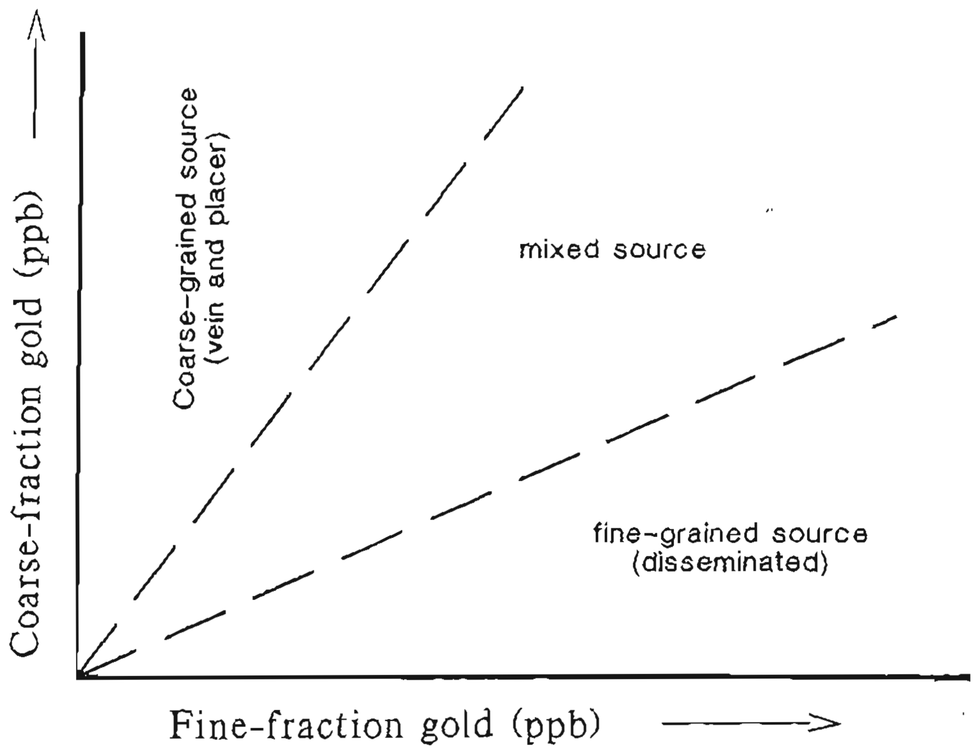

Figure 5. Conceptual biplot useful for discriminating fine-grained from coarse-grained gold deposits. Data plotted consist of gold assays obtained from coarse- and fine-grained fractions of a single gold geochemical drainage sample. Data points within the fine-grained source field suggest the presence of fine-grained disseminated gold deposits.

Shelp and Nichol (1987) conducted an extensive study of gold particle size distributions in large undisturbed initial samples, versus size distributions in samples concentrated by conventional means. Although much of this work was based on till samples, the survey results are pertinent because they show that (1) for many deposits there is a significant gold signal in the -200 mesh size fraction and, (2) common heavy-mineral sample reduction methods routinely lose up to 85 percent of the sample's total gold content (fig. 6). One example cited was Hemlo, Ontario, where fine-grained gold, characteristic of the deposit, was preferentially concentrated in the -63 micron (-230 mesh) size range of the till. This fine-grained gold would be lost in a conventional heavy-mineral-concentrate sample. In today's exploration strategies, such losses are unacceptable because many bulk-minable deposits will be overlooked. Therefore, in addition to reducing intersite variability and obtaining large initial samples, retaining the sample's fine-grained size fractions is fundamental to effective geochemical drainage surveys for bulk-minable gold deposits.

The amount of sample needed from a sample site to achieve the '± 50 percent of value reported' criteria of Clifton and others (1969) depends on the concentration and size distribution of gold at the sample site. This parameter is unknown, and it is not practical to determine it for each site. If time and program constraints permit, a series of orientation samples taken downstream from known gold occurrences in the region being explored can be studied to provide information applicable to the remaining unknown areas. Four important variables investigated in orientation surveys are gold grain-size distribution, distribution of gold among the sample's magnetic, paramagnetic, and nonmagnetic fractions, presence of gold-bearing minerals, and optimum sample spacing. Orientation studies are made either on relatively undisturbed initial material or on samples that have been collected, with care not to lose any size fractions smaller than 18 mesh. Ideally, an orientation survey would be made, prior to the main survey, on one or more streams which drain a known deposit with similar characteristics to the deposit being sought. The results of a well-done orientation survey would indicate (1) which sample size, grain-size fraction, and magnetic-susceptibility fraction provides the best geochemical signal, and (2) what sample spacing is needed to maintain a high probability of detecting a deposit.

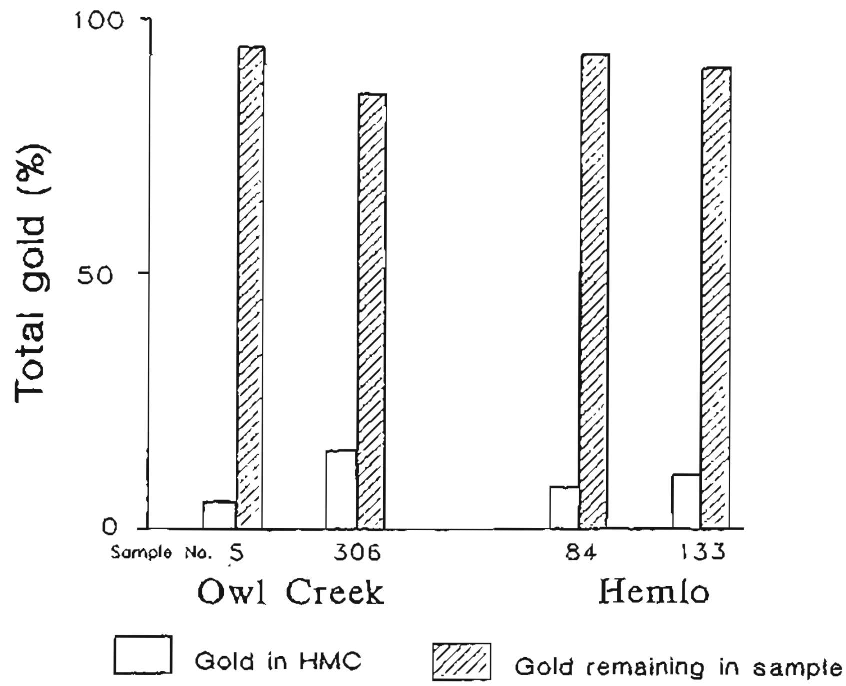

Figure 6. Percentage of total gold recovered from Owl Creek and Hemlo, Ontario, till samples by conventional heavy mineral concentrating techniques relative to gold remaining in the samples. Most of the gold in these samples is in the -120 mesh (ASTM) fraction. HMC = Heavy-mineral concentrate. Modified from Shelp and Nichol (1987).

Orientation surveys often are not practicable for Alaska geochemical programs. However, if the main survey samples are collected by using procedures designed to retain all sample material below an initial size-fraction cutoff limit, if the minimum sample size is kept to at least 10 kg of -18 mesh material (20 kg of -10 mesh material), and if at least one known gold deposit exists within the general area of the geochemical survey, some orientation work (an analytical orientation) still can be done. Samples collected downstream from a known deposit can be used to optimize sample preparation and analysis procedures prior to processing the remaining samples collected in the survey. Orientation samples collected during the main survey clearly will have no effect on optimizing sample spacing or size.

Regardless of the timing or outcome of the orientation survey, as a practical matter initial samples collected manually will probably not exceed 20 kg of -10 mesh material. Experienced personnel require from 20 min to 1 hr to gather this much sample, depending on the character of the sample site. About twice as much raw material must be processed to obtain 20 kg of -18 mesh material as that required for 20 kg of -10 mesh material. If the sample has to be carried out, it will need further reduction at streamside. In general, field time can be better used and sample processing better achieved by limiting streamside activities to collecting bulk samples, with subsequent sample processing carried out at a base camp or laboratory.

Sample reduction from initial stream-run material to final size can be effectively done by wet sieving. During the reduction process, care must be taken to collect washwater used in wet sieving so that no undersize material is lost. The time needed to collect larger samples while still retaining their fine-grained fractions is a major reason this method has not been more widely used in geochemical surveys. In the following discussion, a 10-kg sample of -18 mesh material is assumed to be the largest sample collected.

An improved geochemical-drainage-sampling procedure should incorporate methods based on the insights provided by the work of Fletcher (1986), Fletcher and others (1987), and Saxby and Fletcher (1987), who have shown that for a wide range of hydraulic conditions, there is little difference in the degree of preferential concentration of heavy minerals for particle sizes less than 200 mesh. The modeling work of Fletcher (1986) indicates that in high-energy conditions, heavy minerals (specific gravity greater than 3.3) ranging from -18 mesh to 140 mesh (~ 1 to 0.1 mm) will be enriched significantly, whereas those in the -200 mesh range will be enriched to a relatively minor degree. More recent work by Fletcher and Day (in press) shows that for samples collected in high-energy environments (bar-head gravels) on a known gold-bearing creek in British Columbia, the -150 to +270 mesh (ASTM) size fraction of heavy minerals provided the best geochemical signal. Shelp and Nichol (1987) have indicated that fine-grained free-gold particles are not reliably concentrated either by tabling or by heavy-liquid separation. Fine-grained free gold was apparently lost to the tails on their gravity concentration table and floated by heavy liquids. Experience has also shown that coarse-grained gold in geochemical samples (>0.5 mm = 35 mesh) is very rare but can be consistently concentrated and identified by a variety of manual methods. Clifton and others (1969) showed that, for an initial low-grade sample of 20 kg of -10 or -18 mesh material, it was not possible to achieve a high degree of statistical reliability for +35 mesh material. Trying to integrate these observations and to produce an improved gold geochemical drainage sample involves compromise.

The gold geochemical drainage sample will be improved if it is separated into three major size ranges and subsequently processed separately. Although a 20-kg sample is not large enough to provide a representative sample of gold at +35 mesh, except at very high concentrations, most explorationists would be reluctant to discard this material; hand panning of -10 mesh to +35 mesh material provides a quick streamside check for rare coarse-grained gold and for coarse grains of other heavy minerals that might be diagnostic of the sample environment. There are also a number of small laboratory-sized tables and jigs that can quickly process this coarse sample fraction.

A midsize sample fraction of -35 mesh to +230 mesh includes a part of the sample that has been efficiently enriched by the high-energy hydraulic environment and also has a much greater abundance of particles than does the coarse fraction. However, the -35 mesh to +230 mesh material from a 20-kg -10 mesh high-energy sample will rarely contain enough material to achieve the criteria of Clifton and others (1969) for a representative sample. The effect of this shortcoming will be a greater random variance in the analytical data. For geochemical-exploration surveys, this greater variance, although not desirable, may be an acceptable compromise for processing a smaller initial sample. Recent work by Smee and Stanley (written commun.) has shown that in geochemical surveys where large numbers of samples are analyzed and the results plotted on maps, the geographic-distribution patterns derived from 'small' samples of anomalous material delineate anomalies at effective gold particle abundances of much less than 20 gold grains per sample.

Heavy minerals can be efficiently removed from the midsize fraction by tabling, jigging, or heavy liquids. Heavy-liquid mineral concentration is the most thorough of the available methods. In addition to concentrating the heavy minerals in this fraction, magnetic minerals also are commonly removed prior to analysis. This would not be done if occluded gold was suspected in a magnetic mineral such as pyrrhotite.

The fine-grained (-230 mesh) size fraction of the sample is the part that may be of greatest interest for identifying the presence of a bulk-minable fine-grained, disseminated gold deposit. The geochemical signal from the -230 mesh fraction cannot be distinguished without first removing the masking effects of the sample's larger size fractions. The -230 mesh size fraction does not undergo marked enrichment in heavy minerals in either the low- or high-energy stream environment. Thus, site-to-site random hydraulic variance is minimized in this size fraction. Separation of heavies from this fine material without loss is very difficult. There is also a good likelihood that ultrafine particulate gold in these fines may still be locked in silicate minerals. Therefore, the -230 mesh size-fraction should not be subjected to routine heavy mineral concentration. At this size range, relatively less material (30-50 grams) is required to meet the criteria of Clifton and others (1969) for a representative sample with a concentration of 1 ppm. Several analytical techniques can effectively analyze low concentrations of gold in a sample aliquot this size. Orientation studies of fine-grained size fractions (-230 mesh) also may show them to be more effective than conventional stream sediment samples for common pathfinder trace-element analysis.

Experience has shown that while the variance of gold values derived from -230 mesh sample material is low, so is the absolute concentration of gold in this size fraction. In Alaska, the -230 mesh material also can be subject to dilution by glacially derived silt and loess, and such dilution would quickly suppress an anomalous geochemical signal. Thus, care must be taken to use analytical methods with low detection limits where loess or other glacial silts occur in the survey area. If loess is a problem, much of it can be removed from the sample by using techniques borrowed from sediment-size analysis procedures.

Two analytical fractions can be routinely derived from one gold geochemical drainage sample. The midsized and fine-sized fractions provide direct evidence for the presence or absence of gold mineralization and require chemical analyses. The coarse fraction is primarily of mineralogical interest.

Sample Processing

There are several ways to obtain the two required analytical-size fractions from the sample. The most thorough method involves prolonged wet sieving of the initial bulk sample in a closed container that retains all the fine-grained material. A less-stringent alternative for effecting the size separation required may be achieved by initially screening out the -18 mesh to +35 mesh material and then removing the -230 mesh material by a combined decantation wet-sieving operation. The decantation method can be used in a field laboratory (or even at streamside), or the bulk samples can be sent to a commercial laboratory for sizing, required concentrating, and analysis. Quantitative sizing of the sample usually cannot be done by decantation. However, it should be possible to obtain a representative -230 mesh sample fraction with limited loss of fine-grained gold or silicates and limited contamination of the mid-sized fraction with -230 mesh material.

The use of decantation to effect rapid particle-size separation of the gold drainage sample is based on the settling velocities of particulates in water and the ease with which a predominantly fine-grained slurry will pass through a 230 mesh sieve. Settling rates are a function of particle size, shape, specific gravity, and the viscosity of water. Wadell's modification of Stoke's law (Friedman and Johnson, 1982) estimates the settling velocities for fine silicate mineral particles (table 1). Recent work by Walsh (1986) provides data on the settling velocity of fine-grained gold in water (table 2). These data allow some generalizations to be made concerning decantation procedures for separating most of the -230 mesh sample material from the -35 to +230 mesh midsized sample fraction.

Table 1. Approximate settling velocities of nonspherical silicate particles based on Wadell's modification of Stoke's law. Velocities will vary with particle density and shape and water temperature.

Diameter (mm)	Mesh	Velocity (cm/sec)
0.063	230	0.223
0.031	<400	0.0558
0.016	----	0.0139

Table 2. Settling velocities of manufactured gold particles. Mesh sizes are ASTM; CSF = Corey shape factor, 1.0 = a perfect sphere; N = number of observations; confidence limits are at 95 percent.

Mesh	CSF	N	Velocity (cm/sec)
200	1.0	33	3.94 +/- 0.02
	0.7	33	3.25 +/- 0.02
	0.3	33	1.68 +/- 0.02
	0.1	33	0.71 +/- 0.01
270	1.0	33	2.29 +/- 0.03
	0.7	33	1.65 +/- 0.02
	0.3	33	1.19 +/- 0.03
	0.1	33	0.69 +/- 0.02

Walsh's (1986) data (table 2) indicate that between 200 and 270 mesh, the settling velocity of flat gold (CSF=0.1) is nearly constant at about 0.7 cm/sec, whereas the settling velocity of spherical gold (CSF=1.0) varies between 3.94 and 2.29 cm/sec, respectively. The data of Friedman and Johnson (1982) (table 1) indicate a light silicate mineral-settling rate of about 0.223 cm/sec within this same size range. These settling velocities indicate that fine-grained silicate minerals will be suspended in a column of water for a considerable period of time, whereas the suspension time for gold is much less (especially for spherical gold grains). If the initial sample has been wet-screened into a closed container so that the washwater and fine-grained fractions are all retained, the suspension times are adequate to allow suspended -230 mesh gold, heavy minerals, and light silicate minerals to be collected from the sample.

To separate the -230 mesh size- fraction, the initial -10 mesh or -18 mesh sample and washwater must be thoroughly stirred to create a uniform suspension of the finer grained materials. The fine-grained gold will begin to settle out of the suspension as soon as stirring ceases, and the suspension must be decanted immediately. The suspension will contain a wide range of grain sizes, including +230 mesh material, which is easily removed from the decanted suspension by pouring the decant slurry through a 230 mesh sieve into a collection container. Only a small amount of the suspension should be poured off before restirring the sample-washwater mixture to again uniformly distribute the fine-grained gold in the suspension. Oversize material caught on the 230 mesh sieve can be returned to the original sample-washwater container. This procedure is repeated until all the washwater has been decanted into the -230 mesh container.. After collection, the -230 mesh suspension can be settled by adding flocculant, which allows mostly clear water to be poured off the -230 mesh material after about 3 to 5 min. A more nearly quantitative separation of the -230 mesh size-fractions can be done by repeating this entire procedure when the -35 mesh fraction is wet sieved from the initial -10 or -18 mesh sample material. The -35 mesh to +230 mesh and -230 mesh size fractions are collected and submitted for analysis as separate colocated samples.

Although not as rapid as simply collecting 10 to 20 kg of untreated sample or 20 kg of -10 mesh sample, the sampling procedure outlined above can be conducted on site in about an hour, and the time spent collecting the initial sample will not exceed that needed to collect a 10- to 20-kg sample of -18 or -10 mesh material.

The positive features of this sampling method are that it incorporates several random-variance reduction and signal-enhancing practices and yet uses manageable samples that can be manually transported. Advantages are: (1) site-to-site hydraulic variance is controlled by adhering to a narrow bed-load size range; (2) sample volume is standardized and can be quantified at least to the precision and accuracy of a volume of -18 mesh material that approximates 10 kg; (3) panning variance is removed from the primary -35 to +230 mesh heavy mineral concentrate; and (4) a representative -230 mesh fine fraction is obtained for detecting ultrafine-grained gold that may indicate the presence of a bulk-minable disseminated gold deposit. In addition, virtually all the -35 mesh to +230 mesh material is conveniently extracted and washed, rendering it easily transportable and ready for any subsequent treatment in commercial laboratories. The fine fraction is essentially ready for analysis without further reduction. If any of the coarser (+35 mesh) fractions are desired for information pertaining to the coarse heavy minerals or rock types in the drainage basin, samples of that material also can be collected.

The disadvantages associated with the proposed gold geochemical drainage samples are: (1) they will either require more time at streamside to collect or they will involve transporting a minimum of 10 kg of material from the field site; (2) there is an extra cost involved in separating the -230 mesh fraction; and (3) collection may require the sampler to carry more field gear than normally used in a conventional pan-concentrate survey.

SUMMARY

Conventional pan-concentrate and stream-sediment geochemical surveys may not be effective in detecting ultrafine-grained bulk-minable gold deposits. Collecting minimum 10-kg samples of -18 mesh material from moderate- or high-energy stream sites and processing them to provide midsize heavy-mineral concentrate (-35 to +230 mesh) and fine-grained (-230 mesh) analytical fractions should furnish samples which can be used to detect ultrafine-grained gold deposits and discriminate between these and coarser-grained deposits. The necessary separation of sample-size fractions can be achieved by wet sieving or, with lesser precision, by a combination of wet sieving and decantation. Decantation can be done in the field, but at the cost of more field time or transport expense.

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