ON THE DISTRIBUTION AND ORIGIN OF THE GLACIAL GOLD PLACERS OF SOUTHERN QUEBEC, CANADA

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ABSTRACT Heavy mineral concentrates were systematically collected and analyzed for gold and about 30 other elements in the Estrie-Beauce region of southern Quebec, in an effort to map and interpret the distribution of alluvial gold in this historically important placer region of eastern Canada. The primary objective was to outline dispersal patterns that could help explorationists locate undiscovered primary- or placer-type gold mineralization.

Gold is widely scattered throughout the region and it is evident that glacial dispersal played a key role in shaping the present geochemical landscape. The paper describes the methods used to sample and analyse the heavy minerals, and presents a compilation of the gold data. Some examples on how to interpret the results are presented along with some cautionary notes regarding their significance. Morphological features of gold grains found in southern Quebec suggest that some gold particles may have formed in the glacial detritus from gold mobilized during weathering and soil profile development.

RÉSUMÉ Des concentrés de minéraux lourds ont été recueillis de façon systématique et analysés pour l'or et une trentaine d'autres éléments dans la région de l'Estrie-Beauce (sud du Québec), afin de cartographier et d'interpréter la répartition de l'or alluvionnaire dans cette région de placers historiquement importante de l'est du Canada. Le but principal du projet était de délimiter des traînées de dispersion pouvant servir à l'exploration pour de nouveaux gisements primaires d'or ou des placers.

L'or se retrouve dispersé largement à travers toute la région et il ne fait aucun doute que la glaciation a joué un rôle majeur dans le façonnement du paysage géochimique actuel. Le texte décrit les méthodes utilisées pour la cueillette et l'analyse des minéraux lourds, et présente une compilation des résultats d'or. On donne également quelques exemples de la façon d'interpréter les résultats ainsi que des mises en garde au sujet de leur signification. Un examen morphologique de paillettes d'or provenant du sud du Québec suggère que certaines ont pu s'être formées dans le détritus glaciaire à partir d'or mobilisé durant l'oxydation de ces dépôts et la formation du sol.

INTRODUCTION

The gold placers in the Estrie-Beauce region of southern Quebec have been known since the 1830's. Their discovery led to one of the first gold rushes on the North American continent, which lasted intermittently until the Klondike at the end of the century. The last placer operation in southern Quebec ended in 1964 and it is estimated that about 4 tonnes of placer gold were extracted from the region. Several award-winning nuggets were found in the last century, the record being one weighing 2.2 kg (71 oz).

There have been recent attempts to recommence alluvial mining in parts the area; current reserves for one of the earliest known and most promising prospects, on Gilbert River, are estimated at slightly over 1.5 tonnes of recoverable gold at about 1.1 g/m^3.

Over the years, the widespread occurrence of alluvial gold in southern Quebec attracted the interest of many geologists. Most reported on the small-scale mining operations that flourished until the 1920's, but no comprehensive study of the phenomenon was ever carried out. This lack of basic knowledge, combined with a growing interest in gold exploration in the 1980's, prompted an investigation by the Geological Survey of Canada (GSC).

One important aspect of this project was to produce a regional geochemical map that would show the distribution of gold in modern alluvium throughout southern Quebec. It was hoped that such a map would reveal dispersal patterns that could lead not only to exploration targets for concealed economic deposits, but also to a better understanding of the genesis of the alluvial gold in the region. With these specific objectives in mind, it was thought that heavy mineral concentrates (HMC) systematically extracted from large volumes of stream alluvium would constitute an ideal geochemical sample.

PLACER GOLD IN SOUTHERN QUEBEC

Figure 1, from Boyle (1979), is a compilation from historical records that shows the overall distribution of gold-bearing streams in a 15 000 km^2 area of southern Quebec. In most of the auriferous stream segments shown on the map, the gold occurs in the Quaternary and Recent stream gravels, and these were rarely worked at a profit.

Exceptionally, and this was the case in the Gilbert River and in a few other locations, rich auriferous Tertiary gravels were found underneath the Quaternary cover at the bottom of deeply incised valleys. These gravels are the remnant of a long period of weathering and alluvial processes. Their position at the bottom of the valleys protected them from erosion by the Pleistocene glaciations.

Figure 2, after Shilts and Smith (1988), is a typical cross section of a Tertiary placer in southern Quebec. The Tertiary gravels containing the pay streaks are overlain by a few tens of metres of heavy laminated clays which were deposited in proglacial lakes at the onset of glaciation. The lakes formed as a result of the northward drainage system being dammed by the advancing ice sheet coming from the north.

Glaciation eroded most of the unprotected saprolites that covered a large proportion of the terrane, and spread the debris down-ice depositing it as till. Because it contains a high proportion of oxidized saprolitic material, this till tends to be brown and darker than the overlying till, which is paler and grey (Shilts and Smith, 1986; 1988). The later grey till is made up of remobilized older

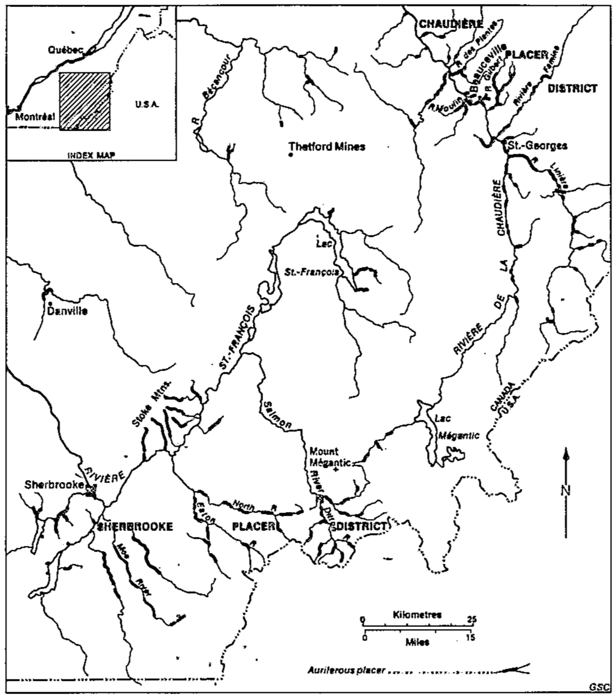

Fig. 1. Distribution of alluvial gold in southern Quebec from historical records (from Boyle, 1979)

till diluted by relatively fresh bedrock material and laminated lake sediments which were deposited in proglacial lakes during short glacial retreats and longer interstadial periods. Figure 2 is a simplified section and does not show all the complexity of the various glacial advances and retreats.

The present drainage flows on a recent alluvial floodplain but it has carved valleys into the underlying till sheets, mostly into the grey tills but also occasionally into the older darker tills. In places where the eroded saprolites were auriferous, the tills deposited down-ice tend to contain a certain amount of gold. The gold concentrations will, of course, be highest in the lower, darker tills but the younger tills also contain some gold.

MAPPING THE DISTRIBUTION OF ALLUVIAL GOLD

One of the main objectives of the GSC project consisted in mapping the gold dispersal at a regional scale across the entire region, to help mineral exploration. It was hoped that the dispersal patterns would point to areas where auriferous saprolite had been eroded. Then exploration companies could use this information to explore for uneroded gold-bearing saprolites or Tertiary placers, or primary gold mineralization, assuming that auriferous saprolite would have been eroded from the exposed portions of such deposits.

The GSC project in southern Quebec produced regional distribution maps for many elements other than gold, some of which are valuable pathfinders for gold mineralization, while others are useful to explore for other commodities. This paper, however, is concerned exclusively

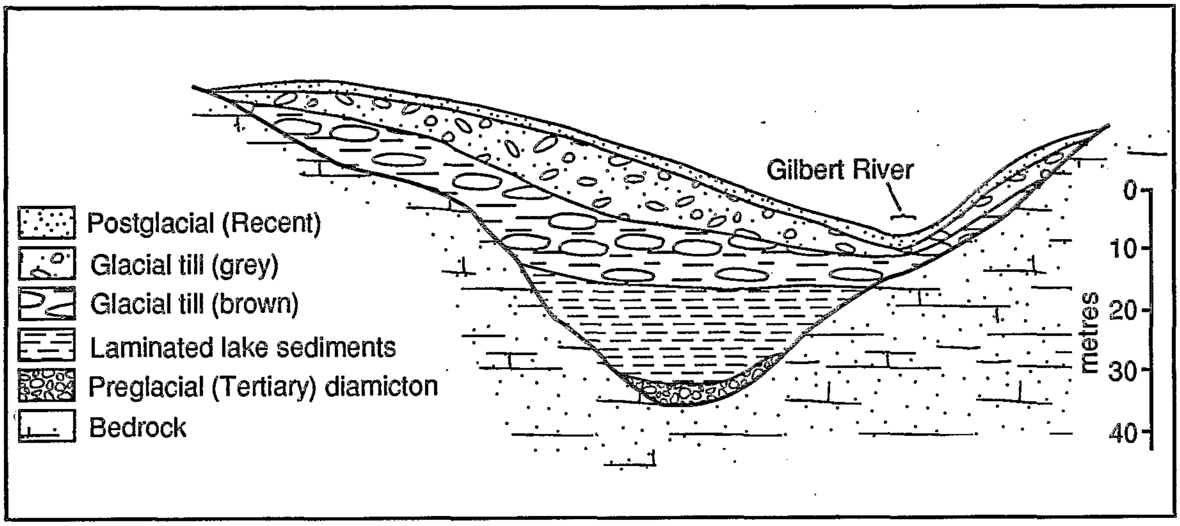

Fig. 2. Cross section of a typical Tertiary placer in southern Quebec (after Shilts and Smith, 1988)

with gold and, with one exception (Fig. 6), the other data are not presented here. These are available from the author.

SAMPLING TECHNIQUE

The methodology employed in sampling the heavy minerals was developed by Maurice and Mercier (1986) specifically for the purpose of mapping the regional distribution of alluvial gold in southern Quebec. Some of the important factors that had to be taken into consideration in designing the sampling program were: (1) the existence of a good road network providing easy access to nearly all sectors of the survey area; (2) the fact that much of the alluvial gold occurs as coarse native gold particles; and (3) relatively low gold concentrations in the surficial deposits as a result of dilution by glacial processes.

The coarseness and the relatively low frequency of gold particles necessitated extraction of the HMCs from large volumes of alluvium. An orientation study (Maurice, 1986) also showed that samples should be obtained from below the uppermost layer of active stream sediments, which tends not to retain native gold particles. The procedure finally adopted is carried out in two stages:

(1) a heavy mineral preconcentrate is obtained at the sample site using a portable suction dredge (Fig. 3);
(2) the final heavy mineral concentrate is produced in the laboratory with a rotary spiral concentrator (Fig. 4).

The dredging operation is time-controlled, lasting usually one half hour. The volume of alluvium treated during that period of time varies from site to site depending on local conditions, but averages about 200 litres. The suction enables sampling deeper into the sediment pile than would otherwise be possible, thereby increasing the likelihood of collecting particles of precious metals and of other high density minerals if they are present.

The rotary spiral concentrator was found to be the ideal instrument to extract the heavy

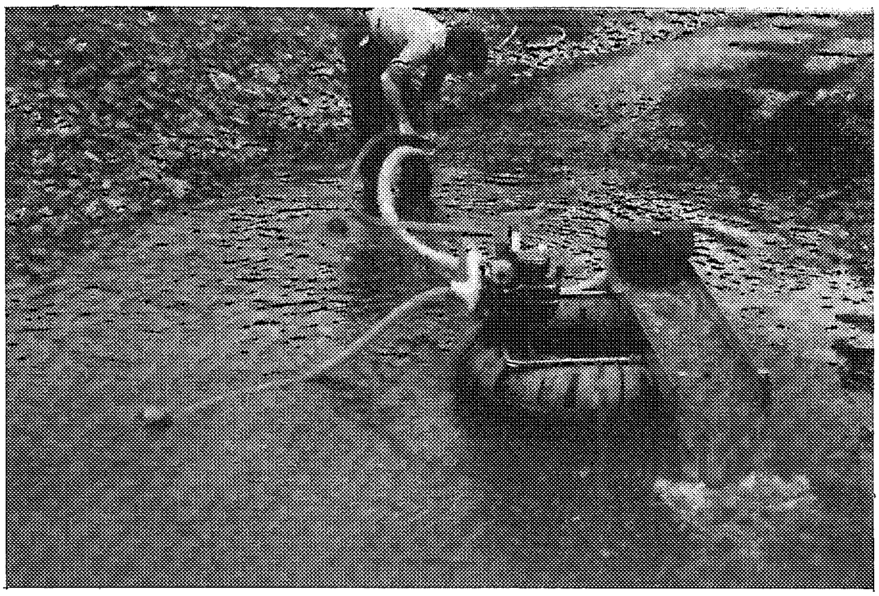

Fig. 3. Portable suction dredge used to collect a preconcentrate of heavy minerals in the field

Fig. 4. Rotary spiral concentrator used to produce pure heavy mineral concentrates in the laboratory

minerals from the 3 to 5 kg preconcentrates from the suction dredge. The separates produced with this apparatus consist mostly of sand size grains (>100 µm) of specific gravity ≥3.6 g/cm^3 and are practically free of light minerals, thus eliminating the need for further processing with heavy liquids. The procedure to obtain the final concentrates includes sieving the heavy mineral separates to minus 850 µm, removal of the magnetite with a hand magnet and splitting the non-magnetic portion with a microsplitter; one half of the HMC is sent to the laboratory for chemical analyses and the other is retained for mineralogical observations. In southern Quebec, 75% of the sample sites yielded between 10 g and 100 g of non-magnetic heavies (before splitting). About 5% produced over 200 g. A minimum of 5 g is required to perform all the chemical analyses.

CHEMICAL ANALYSES

To overcome the nugget effect and ensure that the gold analyses were representative of the original volume of alluvium treated with the suction dredge, it would have been desirable to analyse the entire non-magnetic heavy mineral fraction from each sample site. However, this was not done because of the necessity to perform other analyses on the samples, and the need to preserve some of the concentrate as reference material and for mineralogical examinations. As a compromise, one of the two splits was prepared following the procedure for the Metallics Sieve Analyses method of gold analysis, which provides representative results from samples containing coarse particulate gold without consuming the entire sample.

With this method, a ring and puck pulverizer is used to grind the entire sample split sent to the laboratory. Unlike the disc type, which can cut or smear the gold particles, the ring and puck pulverizer acts like a 'rolling pin' and flattens the gold grains thereby increasing their surface area. The pulverizing is controlled to minimize breakage of the gold grains. In practice, the sample is run through the mill until about 90% has been ground to a fine powder. The sample is then sized to ±100µm. The total coarse fraction, that contains the flattened gold grains, and a subsample of the fine fraction, usually between 5 and 20 g depending on the amount of sample pulp available, are analyzed for gold. In the present study, the coarse fraction was analyzed by fire assay lead collection and atomic absorption spectrophotometry, and direct irradiation neutron activation was used to analyse the fine fraction.

The gold content of the minus 100 µm subsample is assumed to be representative of the entire fine fraction because fine gold would be expected to be evenly distributed throughout that fraction. The final gold concentration is calculated by adding to the gold content of the fine fraction, the gold content of the coarse fraction mathematically redistributed over the original weight of the sample.

Besides gold, the samples are analyzed for Ti, Sn, Nb, Ta, Ba by X-ray fluorescence, base metals by atomic absorption, and As and S by colorimetry and gravimetry respectively. In addition, data for 33 elements are obtained along with gold, as part of the multielement neutron activation packages offered by commercial laboratories. Some of those elements, including W, Cr, Ir and the REE are very useful in the study of heavy minerals, but many are not (e.g. Na, Br, Rb, Cs, etc). Platinum and palladium are routinely analyzed by NiS fire assay/D.C. plasma emission spectroscopy on 5 g subsamples.

REGIONAL GOLD DISTRIBUTION MAP

Figure 5 is the principal product sought by the heavy mineral survey: a regional distribution

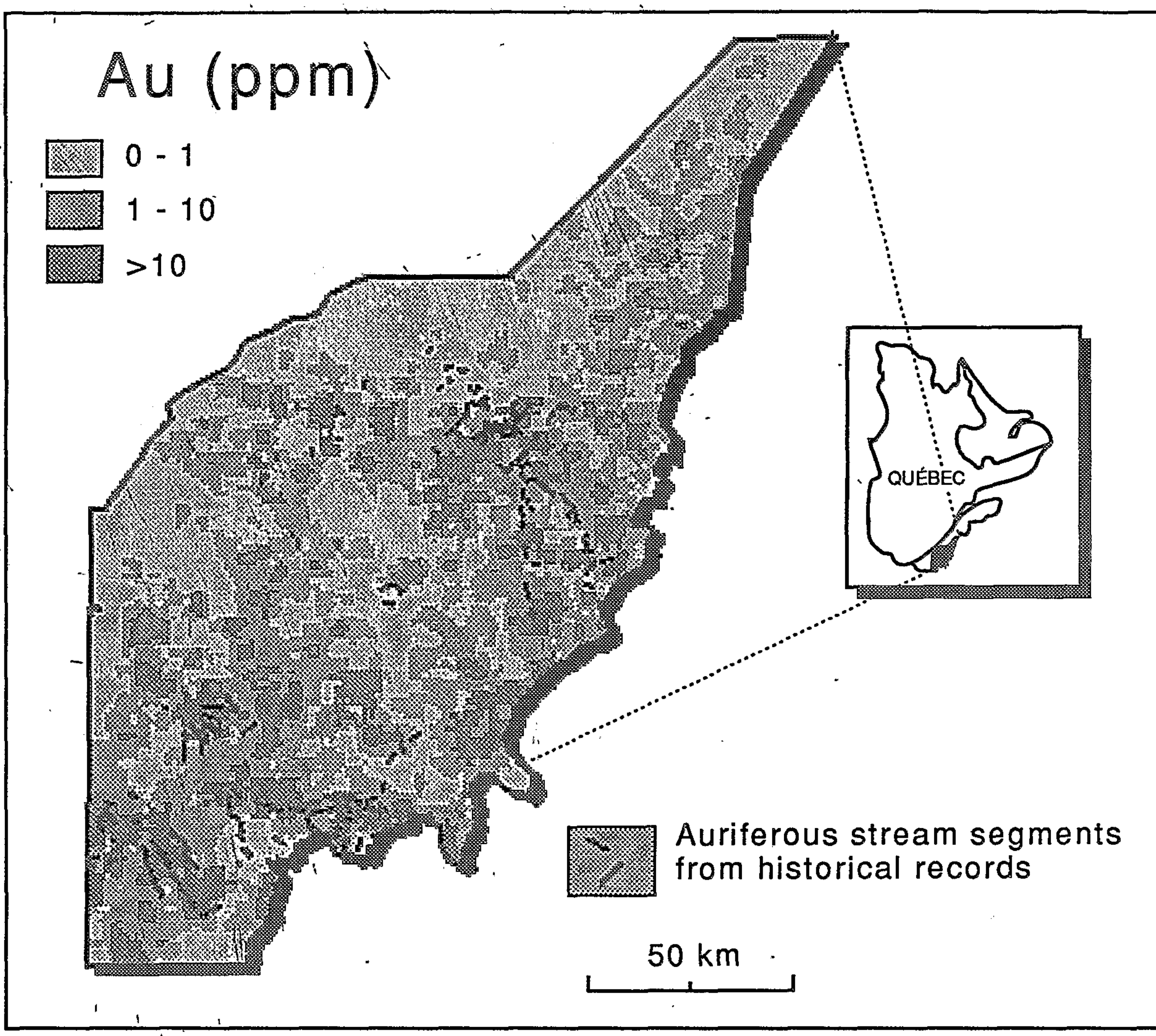

Fig. 5. Regional gold distribution in stream alluvium obtained from analyses of ≈1600 alluvial heavy mineral concentrates. Auriferous stream segments from Boyle (1979).

map of gold in stream alluvium. It was produced from approximately 1600 HMC gold analyses at a site density of one per 10 to 12 km^2. About 82% of the HMCs collected contained analytically detectable gold (Au >10 ppb) and about 40% had over 1 ppm. At many of the sites, native gold particles were seen in the concentrates during their preparation (i.e. with minimal searching). It can be assumed that in all samples containing more than 1 ppm Au, part of the gold occurs as particles of native metal. This is due to the fact that gold-carrier minerals (e.g. pyrite, other sulphides, arsenides, etc.) are never sufficiently abundant and/or never contain sufficient gold to account for more than 1 ppm in the HMC (Maurice, 1988).

There is generally a good correlation between the known (historical) alluvial gold occurrences and HMC gold anomalies (Fig. 5), although the gold anomalies tend to be more widespread than is shown by the historical documents. This supports the common belief among Quebec geologists and many area residents that "it is difficult to find a stream in the region that has no gold at all".

The gold distribution shown in Figure 5 reflects widely scattered sources throughout the area combined with a thorough redistribution of the metal by glaciation. Auriferous saprolites, formed as a result of deep weathering during the Tertiary, probably covered large areas of the pyritiferous sedimentary and volcanic rock units, which are plentiful in the region. Rich eluvial and alluvial placers probably occurred in many valleys adjacent to these formations prior to glaciation. When the Pleistocene ice sheets flowed across the region in a predominantly southeastward direction, they were very efficient in eroding this loose to semi-consolidated material. As shown by data for other elements not presented in this paper, the detectable distance of glacial transport reached 80 to 100 km and more in some cases.

Every anomaly on Figure 5 should be investigated for potential economic sources. This is a task intended for the exploration industry and several private companies and individuals have already began following-up some of the anomalies by a variety of means. In most instances, the source rocks are thought to have been simply sedimentary and volcanic rock units with abundant pyrite. On weathering, the gold was freed and was incorporated as native gold particles in the saprolitic material. Analyses of several pyrite concentrates from various parts of the region showed that they contain on average several hundred ppb Au, up to a few ppm (Maurice, 1988).

In some rarer cases, gold-bearing mineral deposits have been identified as the likely source of the alluvial gold. Figure 6 shows an example where gold anomalies occur down-ice from a group of auriferous sulphide deposits in the Sherbrooke-Coaticook area. Associated elements in the deposits, Ag (Fig. 6b) and Cu (Fig. 6c), also form dispersal trains that coincide with the gold anomalies (Figs. 6a). It is interesting to note that alluvial gold has long been known to occur in Moe River and adjacent valleys, but until this survey was carried out, those who had studied these occurrences believed the source to lie to the SE of the anomalies (up-drainage) rather than to the NW (up-ice) as the geochemical pattern suggests. One observation that strongly supports a glacial rather than alluvial origin for these anomalies is that not only are the main channels of the Moe, Coaticook and Ascot rivers enriched in gold, but also their tributaries, which points to a gold enrichment of the glacial till.

INTERPRETING ANALYTICAL RESULTS OF HEAVY MINERAL CONCENTRATES

The gold concentrations reported on Figure 5 are very precise and accurate results obtained by modern analytical techniques. The large volume of stream alluvium from which the HMCs are extracted reduces the "nugget effect" and ensures better data representativity and reproducibility. However, when interpreting the absolute concentrations of any element in HMCs, it is important to remember that the value is highly dependent on the abundance of heavy minerals in the original deposit sampled. The same amount of gold (or of any other metal) in the alluvium will generate different concentrations in HMCs depending on whether the surficial deposits and the bedrock from which they are derived are heavy mineral-rich or heavy mineral-poor. A consequence of this variable dilution factor is to produce what could be regarded as semi-quantitative data.

One way to overcome this problem is to convert the metal concentrations in the HMCs to concentrations in the original sediment. This, however, requires accurate measurements of the weight or at least the volume, of the material from which the HMCs are extracted, and of the total heavy minerals contained in this material. In practice, because of the large volumes involved and

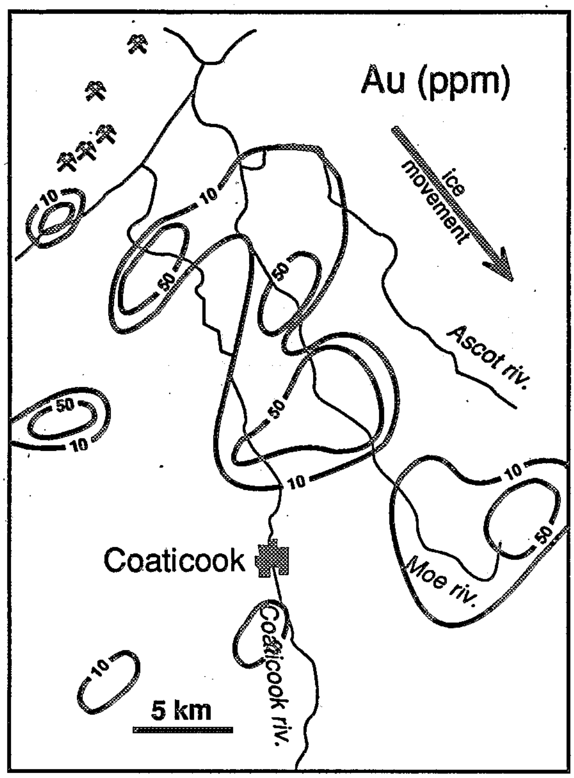

Fig. 6a Gold distribution in the Sherbrooke-Coaticook area (Estrie, Quebec) from the analyses of alluvial heavy mineral concentrates

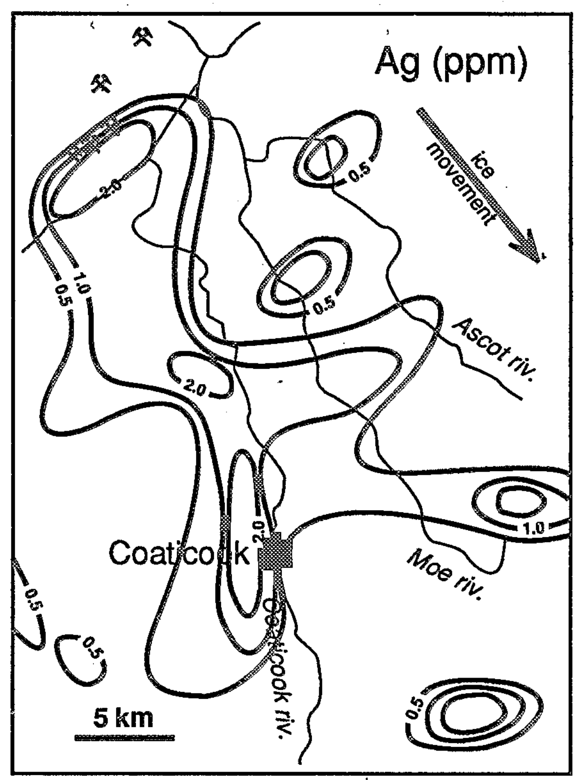

Fig. 6b Silver distribution in the Sherbrooke-Coaticook area (Estrie, Quebec) from the analyses of alluvial heavy mineral concentrates

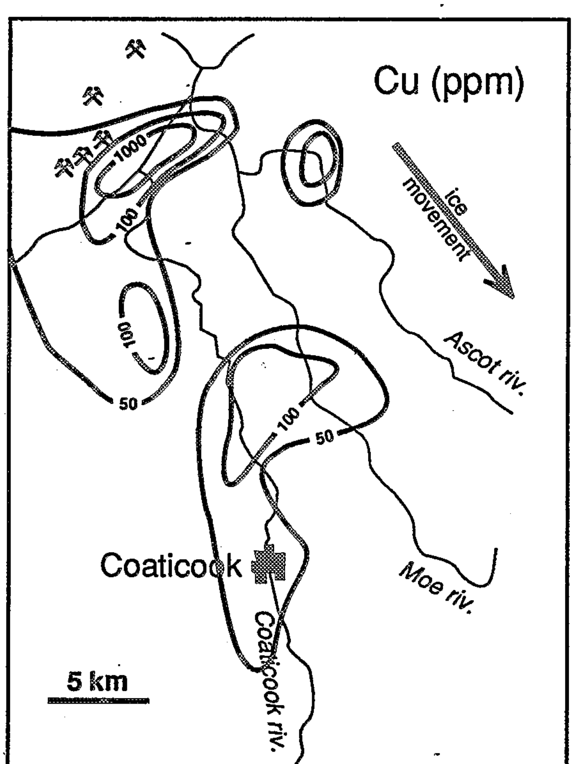

Fig. 6c Copper distribution in the Sherbrooke-Coaticook area (Estrie, Quebec) from the analyses of alluvial heavy mineral concentrates

the inevitable losses of heavy minerals during the dredging operation, these quantities could not be measured accurately and it was decided early in the project not to apply any conversion. Another technique would be to express the results in terms of the weight of gold contained in each sample rather than as a concentration, as proposed by Shelp and Nichol (1987). This option, however, requires that the amount of material passed through the dredge be constant from site to site, which was not case in the present survey. Furthermore, in non-uniform material, such as stream alluvium, the numbers generated by either of these procedures become dependent on hydraulic and sedimentation processes that affect heavy mineral accumulation on the streambed (although it can be argued that these are minimized when large volumes are involved).

Therefore, the results obtained in the present survey and shown on the various distribution maps reflect the composition of the heavy mineral suite at any given site; they are largely independent of the amount of original material processed or the proportion of heavy minerals lost during sampling or sample processing, but they are affected by the quantity of heavy minerals "diluting" the element being measured. Although it does not eliminate the uncertainty surrounding the HMC data, experience in southern Quebec has shown that the variations in the abundance of heavy minerals in stream alluvium are seldom extreme, and they are regional and somewhat predictable as they tend to follow variations in the composition of bedrock and/or glacial deposits. For this reason, patterns and anomalies within them, reflect real dispersal even if the absolute concentrations, especially between patterns, are affected by variations in heavy mineral abundances. The effect on pattern definition is minimized by using wide contour intervals as in Figure 5. As a rule, however, when dealing with anomalous concentrations of any metal in HMCs, it is prudent to pay less attention to the absolute values and focus more on what mineral species and metal associations are present, whether they correspond to the type of mineralization expected, what are the trends in the patterns, etc.

HEAVY MINERAL VERSUS STREAM SEDIMENT PATTERNS

Could stream sediments provide a less expensive and equally, or perhaps even more, useful alternative to concentrating heavy minerals for precious metal exploration? It is well recognized, for example, that heavy mineral concentration processes are not efficient at extracting heavies in the finer grain sizes, and this can result in the loss of fine gold and prevent the detection of significant anomalies.

To ascertain that the additional costs of using heavy minerals were justified in southern Quebec and to verify whether an important part of the gold signal was lost in the finer fractions (and whether stream sediment geochemistry could rectify that problem), stream sediments were collected in the southern third of the region, sieved to -100 μm and analyzed for gold. The samples were collected at the same sites as the heavy minerals.

Figure 7 compares the gold content of the stream sediments (Fig. 7a) with that of the HMCs (Fig. 7b). Note several easterly- and southeasterly-oriented dispersal trains in the heavy mineral map and a near absence of interpretable patterns in the stream sediment map. This is hardly surprising since about 88% of the stream sediment values are below the analytical detection limit of 10 ppb Au (compared with only 14% for the HMCs). On the other hand, some anomalies were detected in the stream sediments and, in some cases, without an equivalent HMC anomaly. This is the case of the large stream sediment anomaly in the northwestern part of Fig. 7a. This anomaly may be important because it involves four sample sites and could reflect the presence of fine gold,

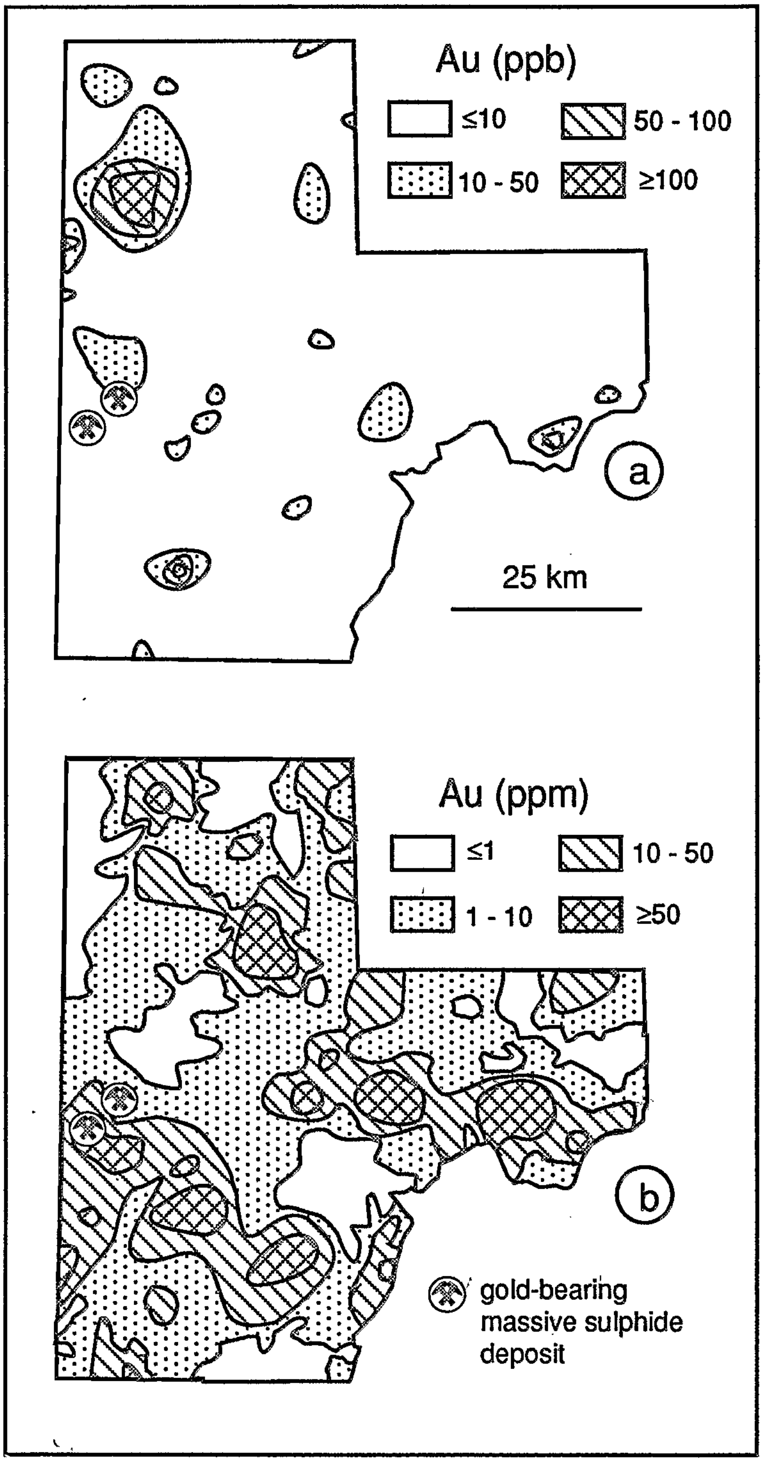

Fig. 7. Gold distribution from analyses of -100 μm stream sediments (a) compared with analyses of heavy mineral concentrates (b) in southern part of survey area

too fine for the HMC technique.

The much stronger signal in the HMCs is explained by the fact that sand-sized heavy minerals (>100 μm) in southern Quebec streams represent between 0.1% and 2.0% of the alluvium by weight. The concentration of gold and other heavy minerals is therefore enhanced in HMCs by a factor varying between 50 and 1000 times compared to their concentrations in unprocessed stream alluvium. Furthermore, the small amount of stream sediment sample material analyzed, in the order of 20 to 50 g maximum, is much less representative than the huge volume from which the heavy minerals are extracted and would be greatly affected by the "nugget effect".

GOLD PARTICLE MORPHOLOGY

Heavy minerals offer many opportunities to study anomalous samples using a variety of follow-up techniques based on mineralogy and mineral chemistry. X-ray diffraction, scanning electron microscopy and microprobe analyses can be used to study individual grains to help determine their provenance and mode of transport. Man-made contaminants that on occasion cause anomalies, can also be readily identified by these techniques.

Alluvial gold particle morphology and chemistry, including the mineralogy, structure and composition of solid inclusions, are often used to speculate on the origin of detrital gold. Figure 8A shows a gold grain in which a variety of mineral grains are embedded. The gold appears to be cementing the mineral grains, which are mostly quartz and feldspar with at least one grain of ilmenite.

Quartz and other mineral grains are often found embedded in gold particles. Generally, they are interpreted as grains that became trapped in leafy gold flakes as they folded during alluvial transport. Some are believed to represent remnants of the host rock of the primary mineralization, but unless there are diagnostic features about the grains that can positively link them to the host rock, it is seldom possible to be certain that this is what they represent.

The mineral grains embedded in the gold particle in Fig. 8A appear like distinct clastic sand grains, especially the large quartz which show typical signs of abrasion: subrounded outlines with conchoidal chipping along the edges (Fig. 8B). The embedded grains are quite numerous and yet the gold grain itself, although well rounded at the margins, does not appear heavily battered and is rather delicate, especially when seen under the binocular microscope (Fig. 8F). In small cavities, the gold appears to show crystalline growth structures (Fig. 8C). A small fracture in one of the quartz grains (lower left, Fig. 8A) appears to have been partially filled with gold and the protruding excess hammered against the quartz grain (Figs. 8D; 8E).

These features seem to suggest that the mineral grains were not acquired by tumbling and folding in the streambed but rather by chemical precipitation of gold around the grains. This would indicate that the gold is primary and that the mineral grains are fragments of the host rock. However, the mineral grains do appear to be detrital and if they are, the gold must be secondary. Perhaps this gold particle formed in a soil or in a till and was subsequently introduced into the stream not far from the spot where it was found as a result of bank erosion.

Although, admittedly, Fig. 8 does not provide nearly enough evidence, the mechanism alluded to above may be responsible for a significant amount of gold in the surficial environment in southern Quebec. The glacial deposits of southern Quebec are highly pyritiferous in places. Gold particles may have formed from gold released from the breakdown of this pyrite during soil profile development, followed by precipitation of the gold, occasionally trapping detrital grains,

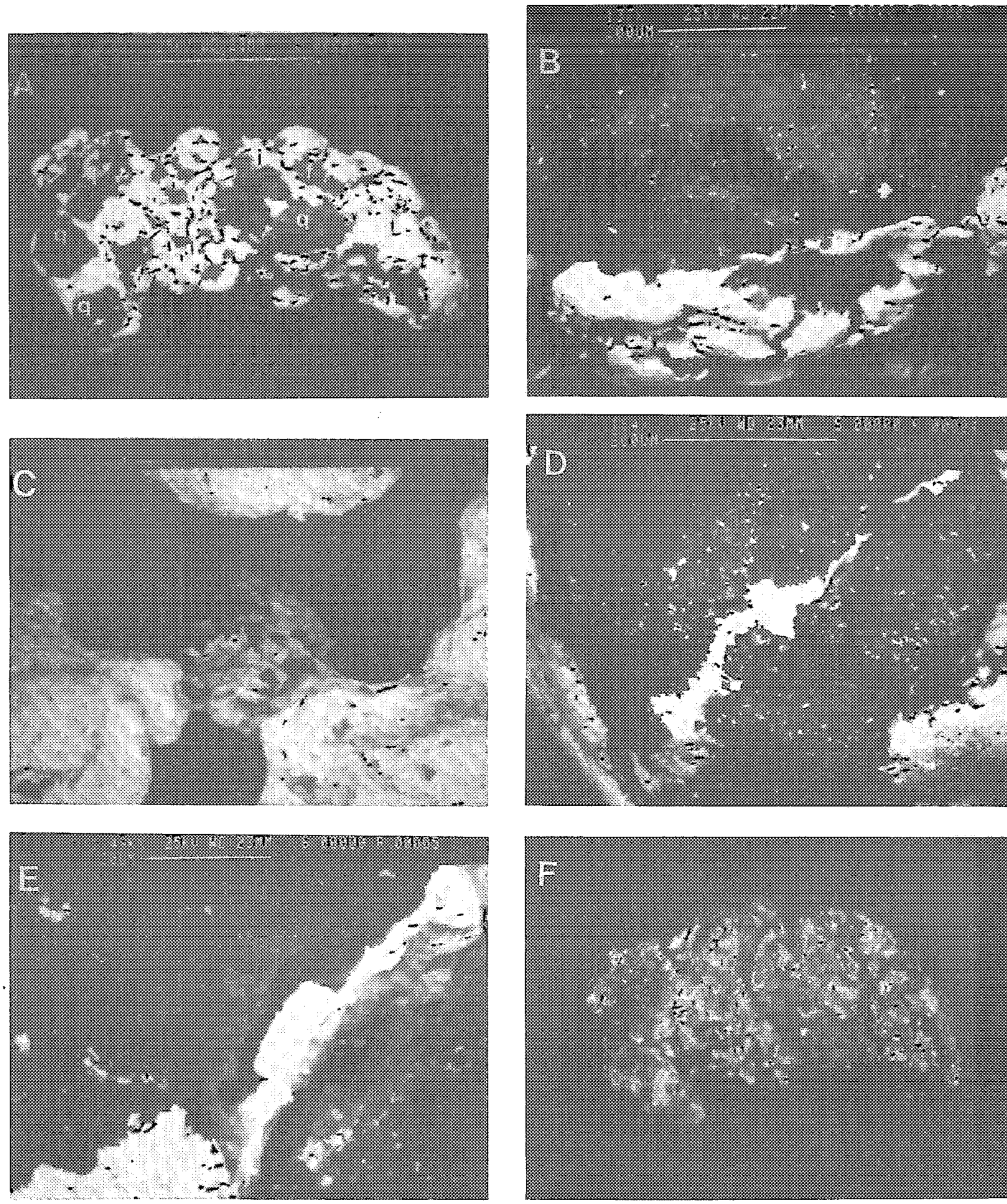

Fig. 8. SEM (except F) photomicrograph of gold grain; (A) entire grain showing embedded quartz (q), feldspar (f) and ilmenite (i); (B) detailed view showing conchoidal fracturing of quartz grain in contact with gold; (C) possible crystalline growth structure within small cavity in gold grain; (D) gold partly filling microfracture in quartz grain; note the protruding gold hammered against the quartz grain over part of the length of the fracture, a result of tumbling in the streambed; (E) detail view of (D); (F) gold grain in reflected light (binocular microscope)

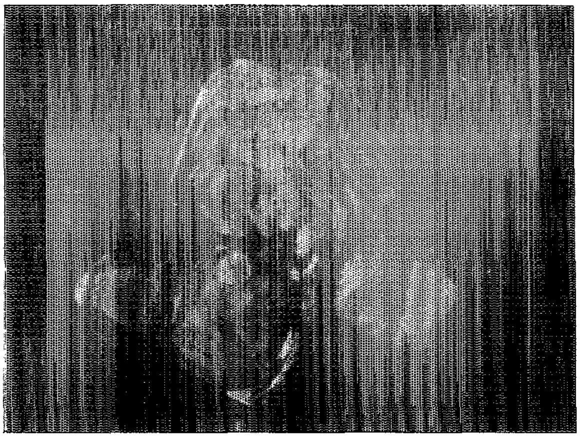

Fig. 9. SEM photomicrograph of distinctly crystalline alluvial gold grain

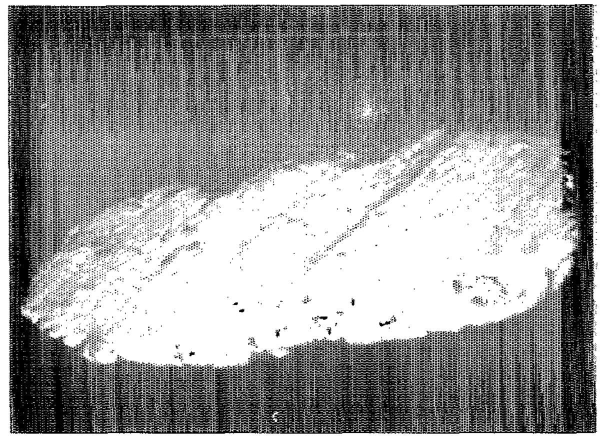

Fig. 10. SEM photomicrograph of striated alluvial gold grain

at chemically suitable sites in the soil or possibly near the soil/till interface.

Other alluvial gold grains have been found with very fresh crystal outlines (Fig. 9). The full genetic implications of such textures on alluvial grains are uncertain, but they probably indicate a very short residency on the streambed. They may have resulted from a solution/precipitation process similar to the one invoked for the grain in Fig. 8, or perhaps they point a bedrock source in close proximity.

Some grains show evidence of detrital transport. Figure 10 is a typical well-rounded, discoid-shaped placer gold grain that is striated in one direction. The striae are probably "old" because the striated surface seems to show evidence of chemical or mechanical abrasion younger than the striae (dull appearance, micropits, etc.). Although various mechanisms such as landslide activity or fluvial transport could have striated this grain, it is highly possible that it is the result of glacial transport. Originally, the grain was probably a classic placer gold grain in preglacial alluvium which was glacially transported and abraded.

CONCLUSION

Mapping the distribution of gold (and associated elements) in surficial materials at a regional scale provides a useful framework for exploration and should always be part of grass-roots exploration programs. Heavy mineral concentrates are the samples of choice for gold and other precious metals because of the increased detection, a consequence of concentrating the elements into a small fraction of the original volume. HMCs are also more representative and reproducible than other sample types, but certain precautions are necessary during data interpretation. Furthermore, HMCs allow for follow-up mineralogical and geochemical investigations on individual grains, often providing revealing clues on their origin and dispersal mechanisms.

In southern Quebec, detrital gold is widespread due to glacial removal and dispersal of deeply-weathered gold-bearing Tertiary saprolites that are thought to have developed over most of the sulphide-bearing rock formations in the region. The dispersal patterns point to distinct concentrated bedrock sources in a few cases, but generally the sources are believed to be lowgrade sedimentary rock units that offer minimal economic potential for primary gold deposits. As far as the placers themselves are concerned, there is virtually no hope of locating economic concentrations in the Quaternary and Recent deposits, but there may still be some rich uneroded Tertiary gravels under Quaternary deposits in some deeply incised valleys. The regional geochemical gold map presented in this study may help locate these by identifying rock units that have produced gold-bearing Tertiary saprolites near which Tertiary placers may have formed, and by outlining patterns that could derive from the partial erosion of Tertiary placers.

ACKNOWLEDGMENTS

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