# CLASSIFICATION AND INTERPRETATION OF THE SHAPES AND SURFACE TEXTURES OF GOLD GRAINS FROM TILL

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ABSTRACT Glacial dispersal trains are three-dimensional bodies of till that contain measurable amounts of distinctive clasts or minerals (such as gold) that can be traced back to a mineralized bedrock source. Gold-bearing dispersal trains show many of the structural features seen in all dispersal trains, such as extreme attenuation, abrupt lateral and vertical contacts, and shallow dip. Many, but not all trains show a marked down-ice decrease in the abundance of the distinctive components, resulting from deposition of the components in till and dilution of the glacial load by newly eroded debris. The shape of gold grains in dispersal trains also changes along the down-ice path from "pristine" to "modified" to "reshaped", reflecting increasing distance of transport. The relative proximity to mineralized bedrock can be estimated by observing the abundances of gold grains in the three shape classes.

RESUMEN Les traînées de dispersion glaciaire sont des masses de till en trois dimensions qui contiennent des quantités mesurables de fragments ou de minéraux distinctifs (tels que l'or) qui peuvent remonter à un socle d'origine minéralisé. Les traînées de dispersion porteuses d'or exposent plusieurs des caractéristiques structurales observées dans toutes les traînées de dispersion, telles que l'atténuation extrême, les contacts latéraux et verticaux abrupts et l'inclinaison faible. La plupart, mais non toutes les traînées, indiquent une décroissance, vers l'aval glaciaire, des composantes caractéristiques, résultant de la déposition des composantes du till et de la dilution de la charge glaciaire par les nouveaux débris arrachés. La forme des grains d'or dans les traînées de dispersion change également en direction de l'aval glaciaire, d'"intacte" à "modifiée" à "refaçonnée", indiquant une distance de transport accrue. La proximité relative du socle minéralisé peut être estimée en observant l'abondance des grains d'or classifiés selon ces trois formes.

## INTRODUCTION

Exploration of glaciated terrain by means of drift prospecting would be simplified greatly if the exploration geologist or prospector had some examples on what patterns of glacial dispersal he could expect to find in a given area. The variations in gold grain morphology can also be applied to the mapping of auriferous dispersal trains. This

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first part of this paper contains descriptions of dispersal trains that were deposited by the Laurentide Ice Sheet in Canada, in order to show what features they have in common. The second part describes gold grain shapes and surface textures.

## CHARACTERISTICS OF DISPERSAL TRAINS

What characteristics do we see in examining dispersal trains that have been traced back to their sources? Miller (1984) has published a model that is applicable (Fig. 1). Based on observations of small trains that were studied during mineral exploration, this model shows a plan view and cross-sections through a hypothetical train. Small dispersal trains have at least five features in common. First, they are extremely thin in comparison to their length and width. Second, they are areally hundreds to thousands of times larger than their bedrock sources, hence they form large targets for geochemical and lithological exploration. Dispersal trains of distinctive boulders, minerals, trace elements or major elements, and radioactive components may increase the size of mineral exploration targets by several orders of magnitude. Third, they

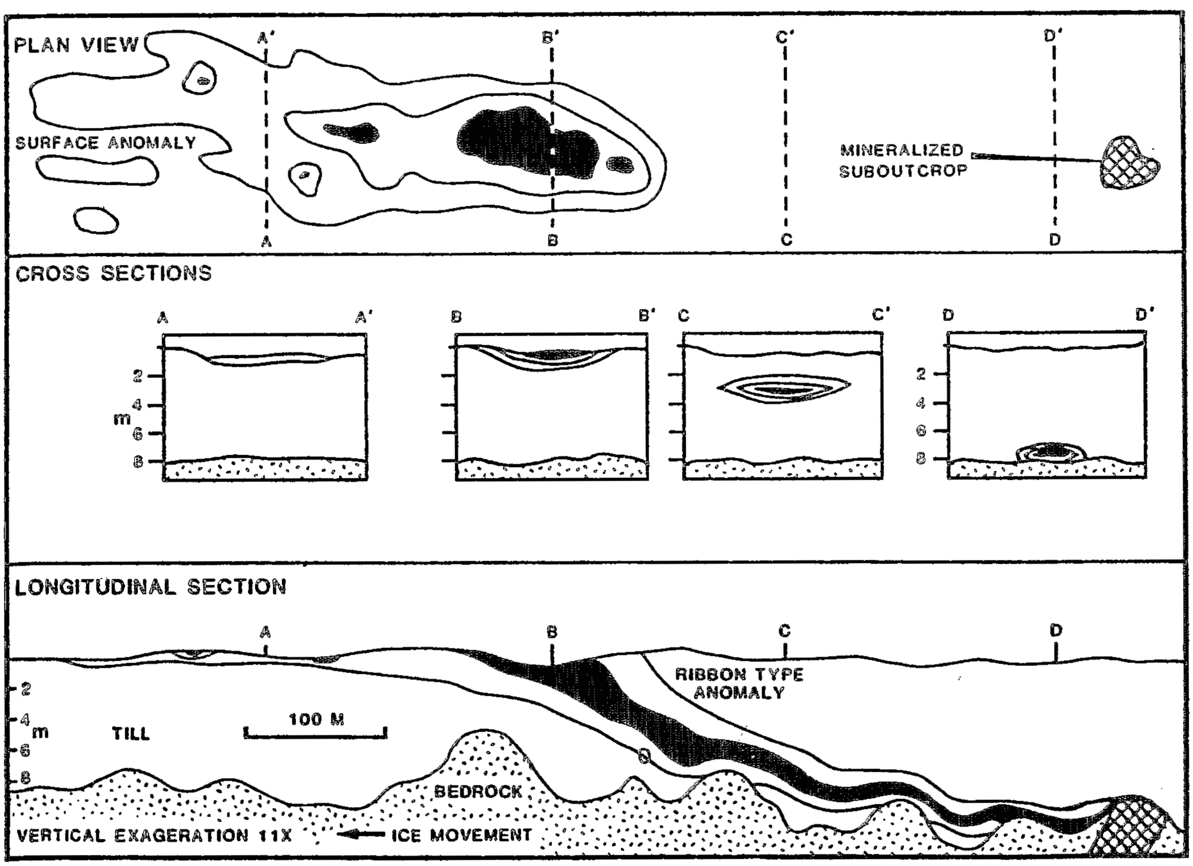



Fig. 1: Idealized model of a glacial dispersal train (modified from Miller, 1984).

have abrupt lateral and vertical contacts with the enclosing till. Fourth, they climb gently within the enclosing till as they are followed down-ice from their sources. Fifth, many, but not all, show a down-ice decrease in content of distinctive components from the 'head' to the 'tail' of the train. The tail of a dispersal train is generally many times longer than the head and is usually the part of the train that is detected first by mineral exploration programs using till geochemistry or boulder tracing. The major objective of drift prospecting is simply to detect the tail of a dispersal train, trace it back to its head, and find its source.

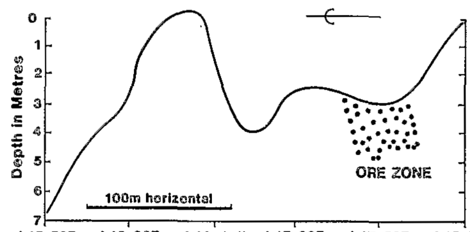
The size and shape of a dispersal train are controlled by the orientation of the source relative to ice flow, by the size and erodibility of source, and by the influence of topography on ice flow in the source and dispersal areas. Dispersal occurs at a variety of scales ranging from continental (100's of kilometres), to regional (100 to 10's of kilometres), to local (<10 kilometres), to property-scale (final stages of mineral exploration in the 100's to 10's of metres) (Shilts, 1984).

## EXAMPLES OF GOLD-BEARING DISPERSAL TRAINS

It is clear that only through careful studies of the internal structure ('anatomy') of dispersal trains can the exploration geologist learn how to use them to find mineralized bedrock. Many trains have been described in the past few years, particularly in Fennoscandia and Canada (Hyvärinen et al., 1973; Nurmi, 1976; Minell, 1978; Bolviken and Gleeson, 1979; Salonen, 1986; Puranen, 1990; Coker and DiLabio, 1989; Hartikainen and Damsten, 1991; Saarnisto et al., 1991). Those chosen for this paper illustrate most of the main characteristics given above and are small ones that have been mapped by 'detailed' sampling of exploration properties (sampling at about 100 metre spacing).

A reverse circulation overburden drilling program carried out at the Golden Pond gold deposit, Casa Berardi, Québec by (Sauerbrei et al., 1987) identified a thin till containing anomalous gold values and abundant gold grains. Of note was the discovery that glacial dispersal of gold was very limited, in the order of 200 to 400 m. This was because the ice that deposited the lower till moved subparallel to the strike of the mineralized structure, itself recessive and a bedrock trough, which confined the dispersal train.

In the Hemlo, Ontario area, at the Page-Williams gold deposit – "A" zone, (Gleeson and Sheehan, 1987) found that an exotic upper till gave little indication of the gold mineralization. The underlying locally derived till gave good response to the gold mineralization in all size fractions and heavy minerals, in gold, arsenic, antimony, molybdenum, mercury, tungsten, and barium (Fig. 2). Once again, dispersal was short (i.e. 200 m), partly because the deposit lies in the lee of a bedrock high and is protected, and partly because dispersal is truncated against a bedrock high down-ice.




| Metal Values in Basal Till (-250 mesh) | | L15+50E | L16+00E | L16+50E | L17+00E | L17+50E | L18+00E |
|---|---|---|---|---|---|---|---|
| ppb | Au | 12 | 13 | 45 | 300 | +15,000 | 11 |
| ppb | Hg | 70 | 155 | 790 | 1,390 | 297,000 | 30 |
| ppm | As | 2 | 3 | 11 | 25 | 700 | 4 |
| ppm | Sb | 2 | <1 | 7 | 46 | 804 | <1 |
| ppm | Mo | 3 | 3 | 6 | 7 | 98 | 1 |
| ppm | W | 2 | 4 | 6 | 4 | 34 | <2 |
| ppm | Ba | 560 | 8,413 | 1,420 | 788 | 1,404 | 572 |

Fig. 2: Page-Williams gold deposit, A zone, Hemlo, Ontario: bedrock topographic profile and till geochemistry across the ore (after Gleeson and Sheehan, 1986).

An overburden drilling program led to the discovery of the EP gold zone at Waddy Lake, Saskatchewan (Averill and Zimmerman, 1986). The authors mapped a dispersal train (Fig. 3) in which heavy mineral concentrates from the till contained abundant gold, electrum, copper, galena, chalcocite, and pyromorphite. This classic dispersal train is ribbon-shaped, with sharp edges, and is at least 600 m long and 50 to 100 m wide.

Near Timmins, Ontario, an overburden drilling program was carried out by (Bird and Coker, 1987) at the Owl Creek gold mine. The drilling revealed two tills (Fig. 4), each of which was associated with a different ice flow direction. In the lowest ('Older') till, which rests on bedrock, dispersal is localized because the till pinches out against a bedrock ridge. The highest gold levels in this till are on top of the subcropping gold mineralization. The overlying (Matheson) till has not been in direct contact with mineralized bedrock, but has derived its gold by recycling the much older lower till. Down-ice dispersal in the Matheson Till is about 600 m, and its area of maximum gold content, which could be called its head, is displaced about 300 m down-ice from the subcropping gold mineralization. This example emphasizes the effect of bedrock topography and sediment recycling on dispersal and shows the importance of understanding the glacial stratigraphy and glacial flow history in any region under study.

The other main type of train is that found in present-day mountain glaciers, where medial and lateral moraines can be traced back to their sources in tributary valleys (Stephens et al., 1983).

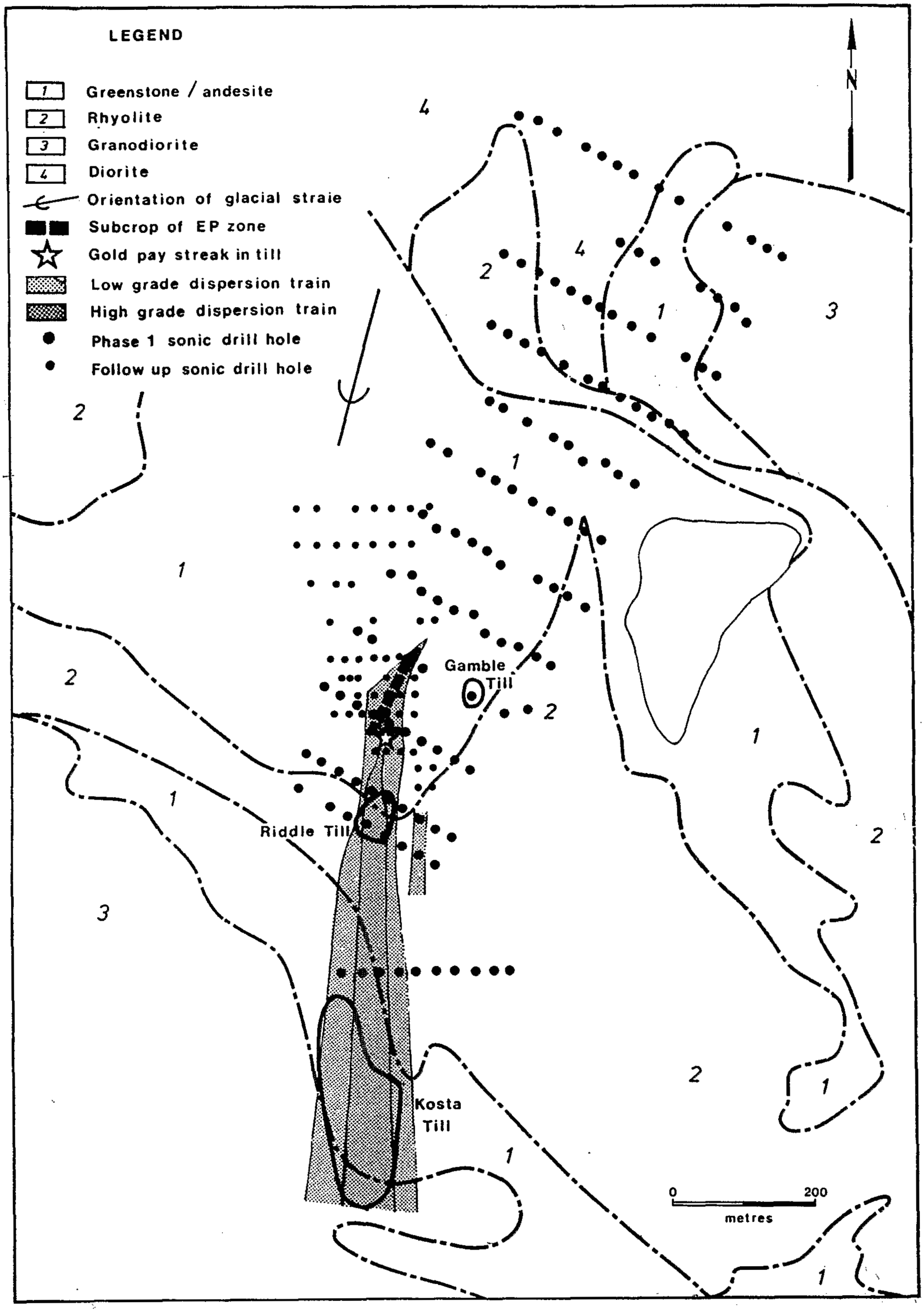



Fig. 3: Glacial dispersal train from the EP gold zone, Waddy Lake, Saskatchewan (after Averill and Zimmerman, 1986).

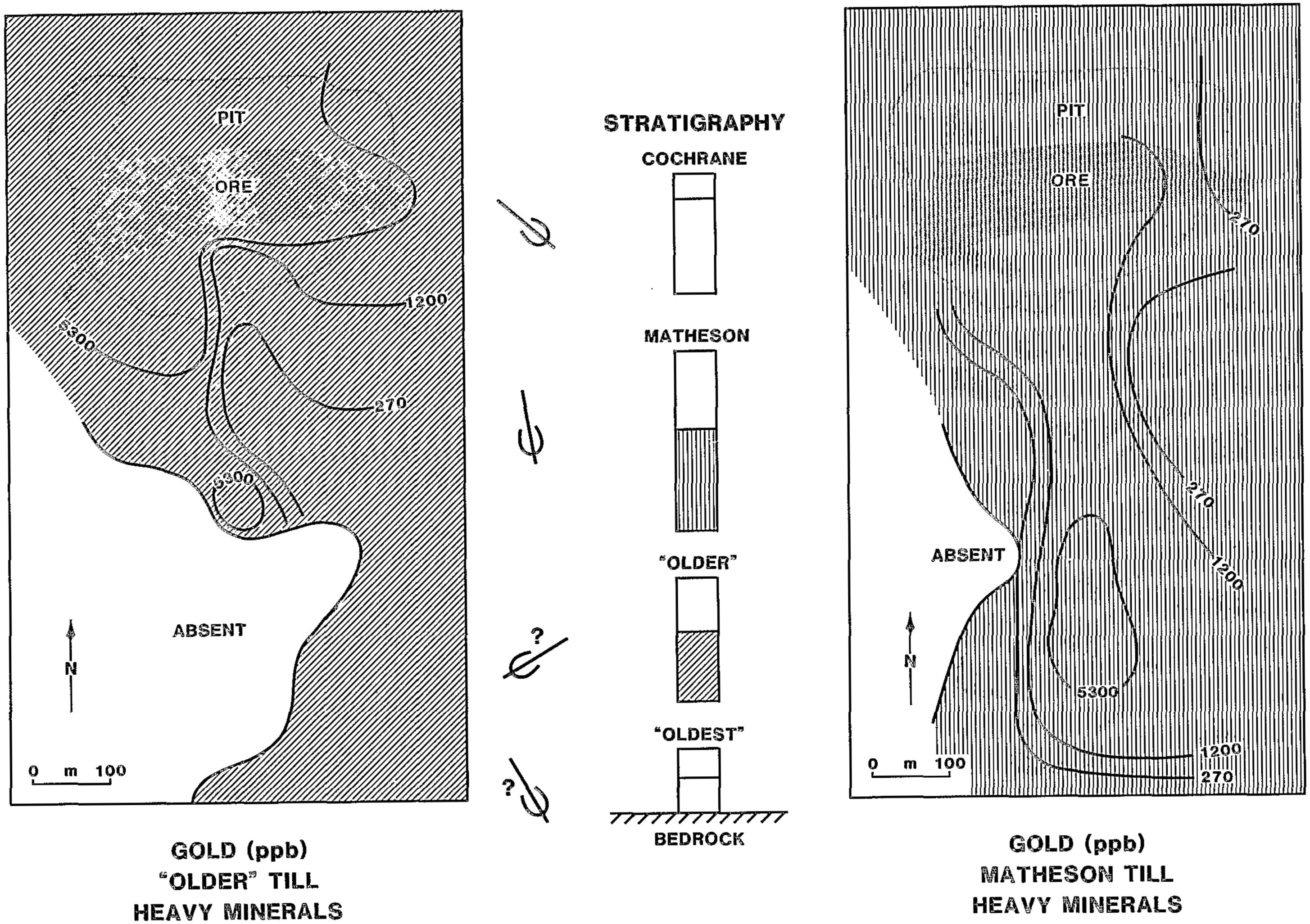



Fig. 4: Gold levels in heavy mineral concentrates from the "Older" and Matheson till at the Owl Creek gold mine, Timmins, Ontario (after Bird and Coker, 1987).

## GOLD GRAINS

Since the adoption of drift prospecting in the search for gold deposits in glaciated terrain, several tens of thousands of till samples have been processed in commercial and government laboratories to recover heavy minerals by shaking table, heavy liquid, and panning methods (Averill, 1988). In addition to preparing the samples for geochemical analysis, these separation methods permit inspection and counting of minerals in the heavy concentrates. Gold grains in the concentrates are examined to estimate the relative distance that the grains have been transported from their bedrock source, by observing the degree of rounding, polishing, and bending of the grains. Most of these observations have been made using a binocular microscope, which has limited the size of grain and surface feature that could be resolved.

The dominance of silt- and clay-sized gold grains in Canadian gold deposits and the tills derived from them (Averill, 1988; Brereton et al., 1988) has prompted laboratories to improve recovery rates for fine gold, mainly by modifying the procedures used with the shaking table, by making slight design changes to the table, and by panning the heavy concentrate. When examined with a binocular microscope, however, small ($<60$ $\mu$m) gold grains are not seen clearly. In this study, scanning electron microscopy (SEM) has been employed, taking advantage of the higher depth-of-field even at high magnification of the SEM (compared to light microscopy) to view the shapes and surface textures of gold in greater detail. A scanning electron microscope equipped for backscattered electron imaging (BEI) and energy-dispersive spectrometry has the added advantage of discriminating among the ore, gangue, and secondary minerals that may be present; it can also analyze their compositions. In BEI, a phase with high average atomic number (e.g., gold) appears white, and most other phases appear in shades of grey. This high contrast allows one to see the shape and texture of the gold, even where coatings and other minerals partly obscure the gold in normal secondary electron imaging. From SEM observations of shapes and surface textures, the analyst estimates the mineralogy and texture of the source mineralization and the transport and weathering history of the gold grains.

Existing classification schemes for detrital gold morphology were developed mainly for gold from lateritic and fluvial sediments in Africa and South America (Hérail, 1984; Hérail et al., 1988; Freyssinet et al., 1989,1990; Vasconcelos and Kyle, 1989; Colin et al., 1989). Preliminary studies of gold grain shapes from till have been published by (DiLabio, 1990 and Nikkarinen, 1991). The only scheme that is specific to glacial sediments is a threefold scheme devised by S.A. Averill ("delicate-irregular-abraded") that is based solely on binocular microscope examination of grains (Averill, 1988). The new scheme presented here is intended to complement Averill's, because only those analysts with access to a SEM can use it.

In order to make the study representative of different styles of mineralization, till samples from nine Canadian localities were examined. Five of the localities were sampled within 500 m of the presumed bedrock source, the other four from 1 to 5 km down-ice of the presumed bedrock source. As far as is known, the gold in the bedrock at these sites is present in free form, as leaves in quartz-carbonate veins, grain boundary films, fracture fillings, and blebs within gangue minerals. Most of the till samples are from shallow test pits and represent the oxidized C horizon of soil developed on till. Most of the till is interpreted as lodgment till, some as subglacial melt-out till. Samples were prepared by shaking table and panning methods; the resulting heavy concentrates were viewed under a binocular microscope and gold grains were picked out and mounted on adhesive-coated stubs, carbon-coated, and examined and photographed with an SEM. Most of the gold grains are silt-sized; a few are medium to fine sand-sized.

## CLASSIFICATION SCHEME FOR GOLD GRAIN SHAPES

The scheme (Table 1) is designed to facilitate communication by being graphically descriptive and nongenetic so that someone reading grain descriptions would be able to visualize the variety of shapes and surface textures present in a sample. The vast number of morphological terms that have been applied to detrital gold grains (Boyle, 1979; Hérail, 1984; Freyssinet et al., 1989) has made it difficult to choose terms that are the most useful. The most commonly used were chosen first and a few particularly vivid ones were added. Terms should be used in combination to describe grains as clearly as possible. This is not meant to imply that the classification is complete; users are encouraged to add terms that are suitable. The main shapes and surface textures are described below.

The classification does not prejudge the issue of the possible secondary or supergene origin of large, globular or smooth, ovoid nuggets that have been found in Canada's glaciated terrain. Terms that would describe secondary or supergene gold have been omitted because of the rarity of such grains in till (Warren, 1982; MacEachern & Stea, 1985), although the classification could be redesigned to consist of terms to describe primary and secondary gold separately.

### Pristine

The pristine class of grains is analogous to the "delicate" class of Averill, but the new name has been used because many pristine grains are not delicate at all, being robust blocky shapes. The term "fresh" could be substituted for pristine in most cases, but the term "primary" is avoided because of the possibility that some gold crystals are secondary authigenic precipitates in weathered till (Warren, 1982), as they seem to be in lateritic soils (Vasconselos and Kyle, 1991; Freyssinet et al., 1990). Euhedral dodecahedral gold crystals (Fig. 5a) were found in one sample, and at first they were believed to be authigenic. Later, similar crystals were observed in fluid inclusions in vein quartz at the Tangier mine in Nova Scotia (Smith and Kontak, 1988) and at the Sigma mine in Quebec (Robert and Kelly, 1987), so crystals in till cannot be assumed to be authigenic.

**Table 1.** Classification of shapes and surface textures of gold grains in till.

| Class | Shape | Surface Texture |
|---|---|---|
| Pristine | - block<br>- rod or wire<br>- leaf<br>- crystal<br>- star<br>- globule or bleb | - smooth surfaces<br>- angular edges<br>- grain moulds clearly visible<br>- thin edges not curled<br>- some striae |
| Modified | - all pristine shapes damaged, but visible | - leaf edges and wires bent, curled<br>- blunted and clubbed edges<br>- grain moulds preserved where protected<br>- moderately striated<br>- felty texture where damaged |
| Reshaped | - well rounded grain outline<br>- folded rod, wire, flake<br>- rounded block<br>- typical discoid placer flake<br>- nugget | - porous, scaly, felty, or spongy<br>- rarely striated |

Pristine grains appear not to have been damaged in glacial transport. The most impressive shapes in the class are angular wires or rods and delicate leaves that were fracture fillings or grain boundary films in the mineralized rock (Fig. 5b-h). Equant silt-sized grains such as block, blebs, and globules are common, and they do not appear to be pristine until they are viewed at high magnification ($\simeq$1000x). All grains in this class retain primary surface textures such as crystal faces or grain moulds, which probably held gangue minerals that have been broken out or weathered out of the gold. They have smooth surfaces that are bright in reflected light and have surface roughness of the order of 0.1 $\mu$m or less.

The surprising feature of the pristine grains is their relative abundance. Most samples contained a few pristine grains, but samples collected near mineralized bedrock are dominated by this type of grain. At three localities, samples collected within 200 m of their sources contained >90% pristine grains. It is possible, of course, for pristine grains to have weathered out of a carbonate- or sulphide-rich host clast that was glacially transported a great distance, giving a false impression of the nearness of a sample site to mineralized bedrock. This type of problem can be evaluated by comparison of the anomalous data to those from nearby sites, and by resampling the original site.

## Modified

In the modified class (analogous to Averill's "irregular" class), original shapes and some primary surface textures are visible, but all edges and protrusions have been damaged and appear curled, crumpled, blunted, clubbed, and bent, presumably through grain-to-grain impact and abrasion during transport (Fig. 6a-d). Damaged surfaces have a felty texture, having lost their original smoothness. Grain moulds and other primary surface features are preserved only where they were protected in concavities in the grains (Fig. 6e-f).

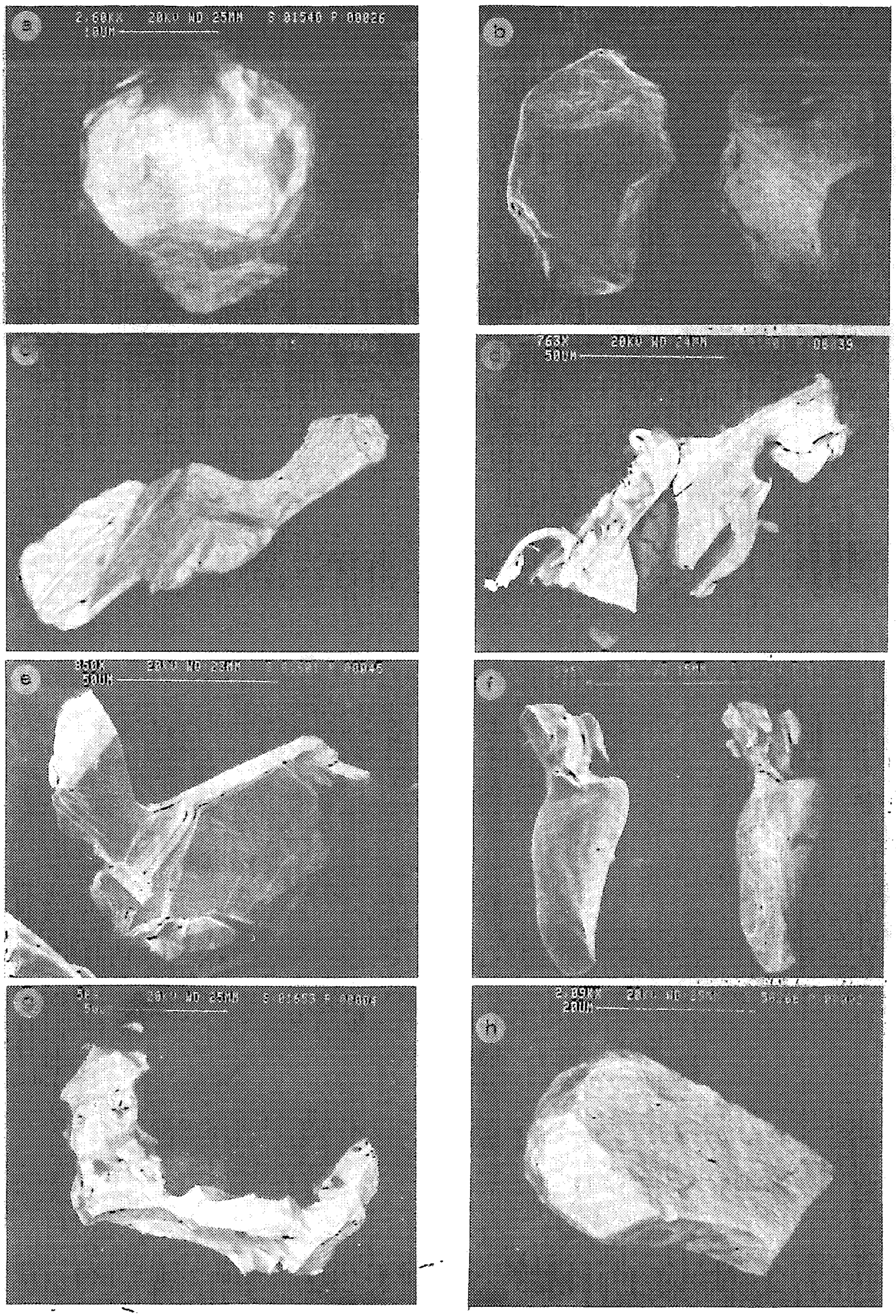
Although present on some pristine grains, striae are more common on modified ones (Fig. 6 g,h). The striae are 1.0 to 0.1 $\mu$m across and appear in overlapping sets that give the surfaces the appearance of spread butter or wax. The striae are inferred to be glacial; only in a few cases could the striae have been formed during sample collection (e.g., drill-induced abrasion) or processing. The glacial striae probably were not cut by individual grains in the 1.0 to 0.1 $\mu$m size range, but were cut by the surface roughness of larger grains, which would account for their extremely small size. The rare artificial striae found on the grains were formed during mounting of the grains, when excessive pressure with a needle scratched only the topmost part of the grains. Tectonic striae have also been ruled out because the striae occur in isolated patches on grain protrusions and not on whole sides of grains, and because they form randomly oriented sets, not consistently oriented sets.

Striated, modified grains are strong evidence of glacial transport, but inferring an absolute distance of transport from them is difficult. It is safe to say that where modified grains are abundant (well above local background abundance), the bedrock source should be up-ice and "nearby", probably within a few hundred metres to a few kilometres, based on the sites investigated so far. Of course, where striated pristine grains are abundant, the source should be closer, so mapping the relative abundances of pristine and modified grains should indicate where the source lies.

## Reshaped

Reshaped grains retain none of their pristine shapes or textures. Most have a distinctly rounded outline. The term rounded is used here solely to denote the silhouette of the grains and it does not necessarily imply abrasion rounding in the sedimentological sense. Some are simple rounded blocks and others are repeatedly folded leaves, wires, and rods. The end-product shape of reshaped grains seems to be the classic placer flake, a flat or toroidal disc (Fig. 7a-d). Classic "nuggets" are placed in this group, although some retain enough primary surface textures in recesses to warrant their inclusion in the modified group.

Fig. 5: Pristine gold grains. Scale bar in µm at top of each photo. →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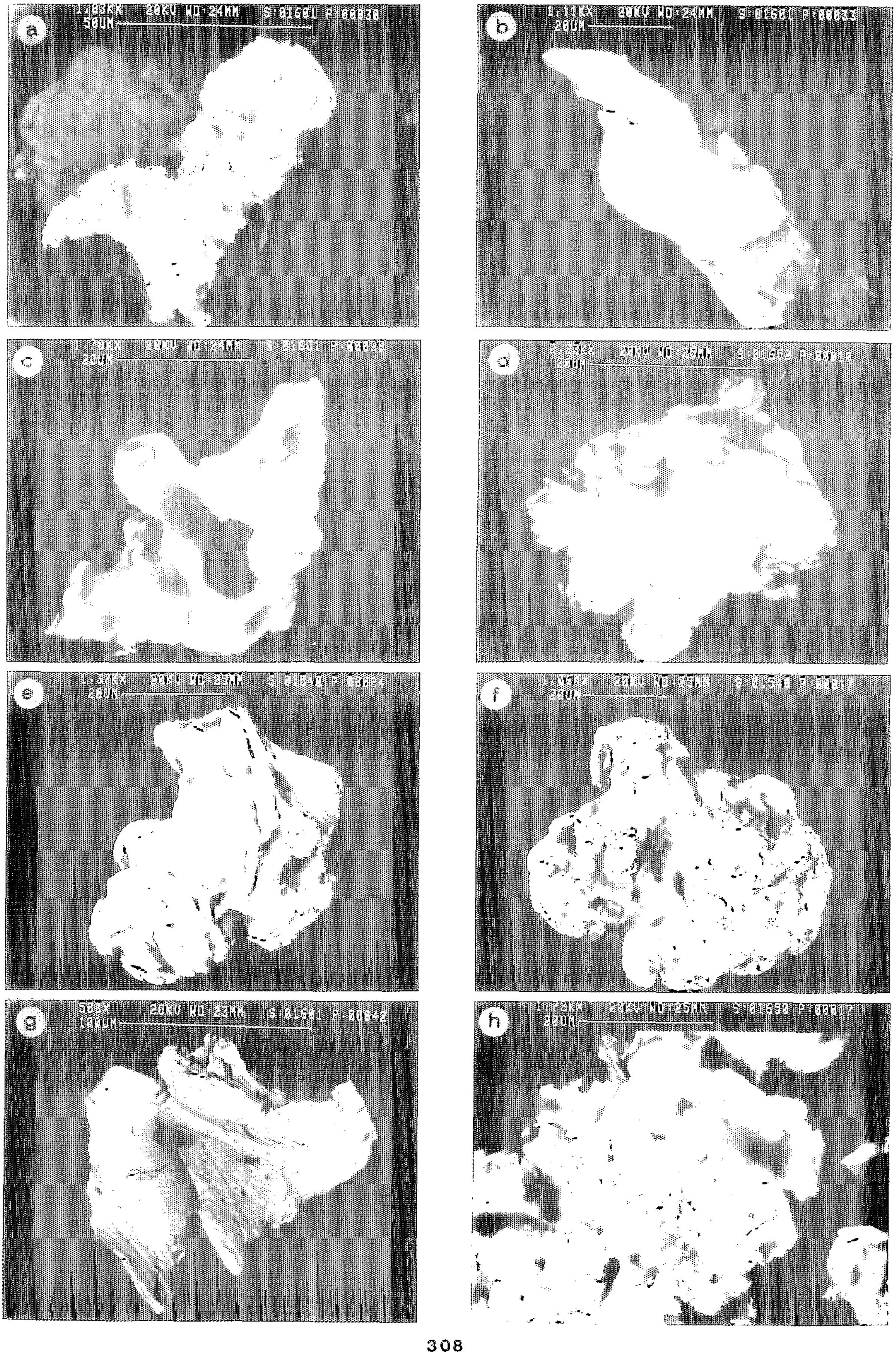
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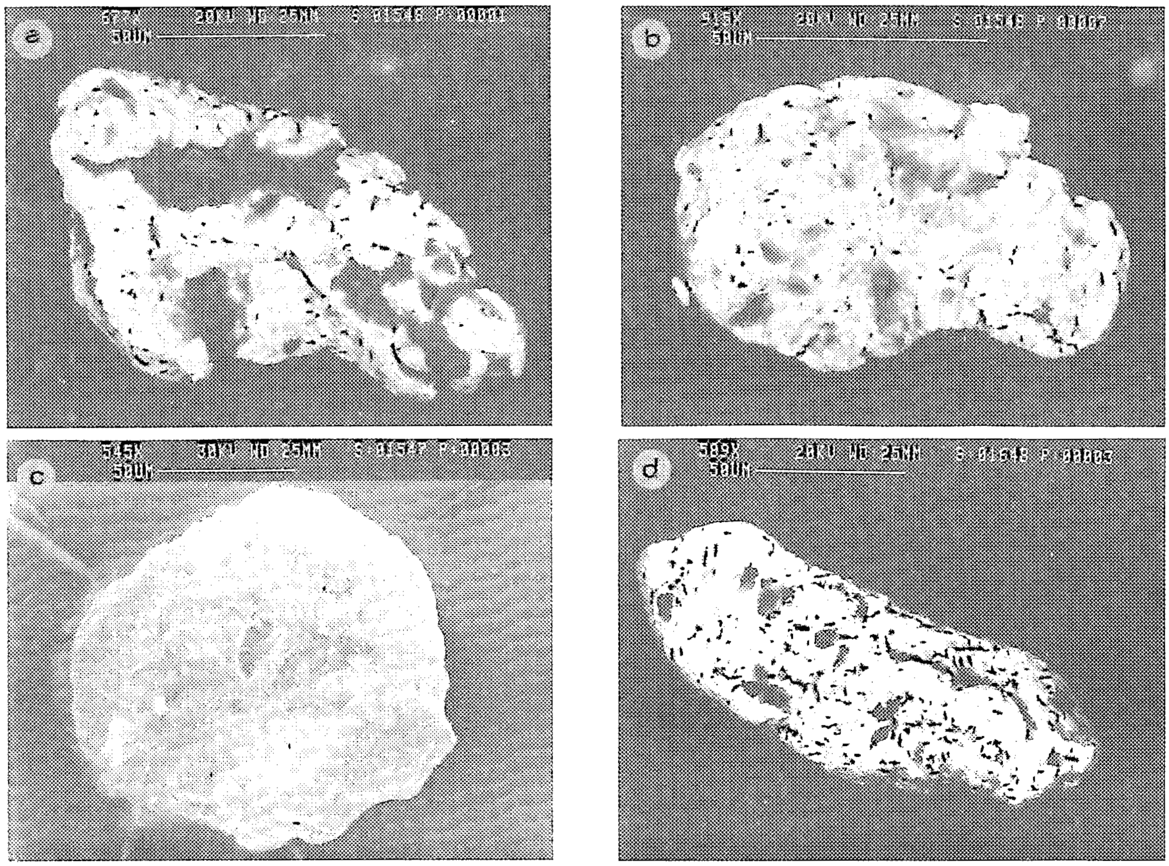


Fig. 7: Reshaped gold grains. Scale bar in µm at top of each photo.

Striated reshaped grains are rare. The surface of reshaped grains is characteristically scaly or felty, presumably from fluvial abrasion. Some are riddled with pores about 0.1 $\mu$m in diameter. The most porous have a spongy appearance. Electron microprobe analysis of porous grains shows that a porous rim of high purity gold, usually 1 to 5 $\mu$m thick, surrounds a massive core of primary gold that contains significant silver. Leaching of silver from the rim, not secondary precipitation of gold, is indicated by the presence of pores through glacially striated surfaces on a very small number of grains, because any glacial striae would have been obscured by secondary gold. The silver-depleted rim on placer gold grains is well known (Desborough, 1970; Giusti, 1986; Knight & McTaggart, 1986; Groen et al., 1990); these results indicate that silver removal has been going on rapidly during the 10 000 years or so that the tills have been weathering, if one assumes that the striae are late glacial and the pores are Holocene in age. The destruction of primary surface textures by silver leaching might make it difficult to recognize pristine or modified grains, but the survival of striated surfaces indicates that most original surface textures should be visible on weathered grains. Unfortunately, the vast majority of reshaped grains are classic placer flakes that show evidence only of stream transport and weathering.

Fig. 6: Modified gold grains. Scale bar in µm at top of each photo.

Reshaped grains are present in small numbers in many samples. They are the rare "background" detrital gold grains that are essentially ubiquitous in surficial sediments. Because the surface texture and shape of these grains mainly result from weathering and fluvial abrasion, not glacial abrasion, they cannot be used to infer a distance of glacial transport. Most importantly, because they could have been recycled in fluvial or glaciofluvial streams many times over a long period, even the entire Quaternary, the history of these grains and their ultimate source are usually impossible to estimate. They can be problematic where they are found in large numbers recycled in till or, where gold grains were concentrated by glaciolacustrine or glaciofluvial processes into small placers that have no discrete, known sources.

## DISCUSSION

The classification scheme (Table 1) is intended as an aid in describing gold grains and in grouping them into types that represent stages in their history. Moving from pristine to reshaped should represent increased distance of transport, so the relative proportions of the types should indicate nearness to the bedrock source, at least qualitatively. For the grain abundances to be useful, however, the number of pristine or modified grains in each sample must be large, say about 100 at a frequency of >10/kg. Only then can the mapped distribution of gold abundances be used as a guide to mineralized bedrock.

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