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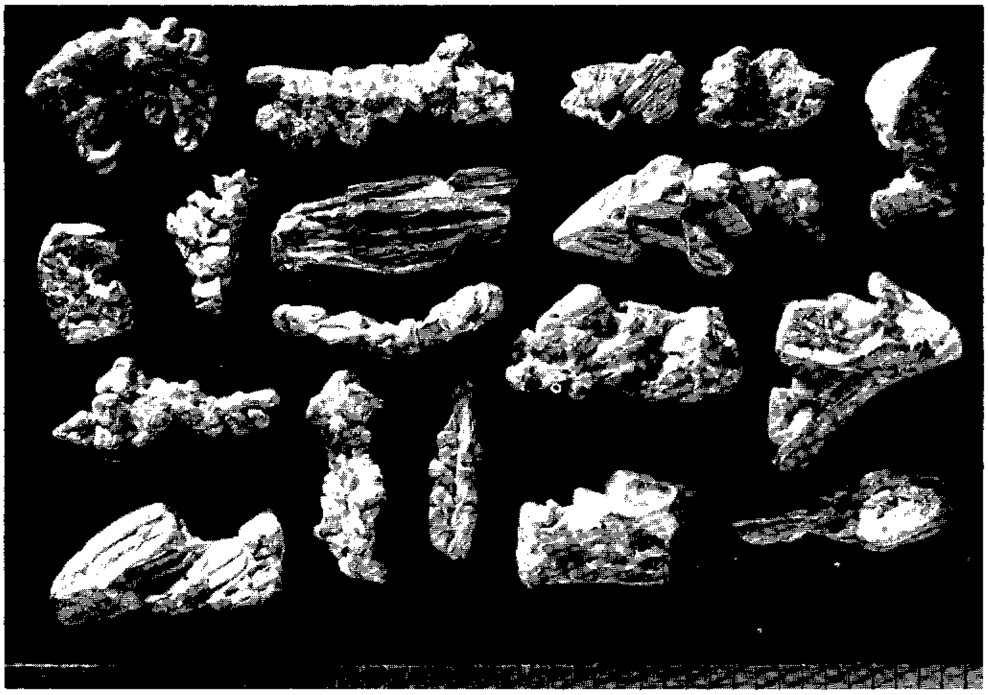
BULLETIN 3

SHAPE AND COMPOSITION OF LODE AND PLACER GOLD FROM THE KLONDIKE DISTRICT, YUKON, CANADA



J.B. Knight
J.K. Mortensen
S.R. Morison

1994

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EXPLORATION AND GEOLOGICAL SERVICES DIVISION
YUKON REGION
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PART 1:

THE COMPOSITION OF LODE AND PLACER GOLD FROM THE KLONDIKE DISTRICT OF WEST-CENTRAL YUKON, AND IMPLICATIONS FOR THE NATURE AND GENESIS OF KLONDIKE PLACER AND LODE GOLD DEPOSITS

PART 2:

THE RELATIONSHIP BETWEEN FLUVIALLY TRANSPORTED (PLACER) GOLD PARTICLE SHAPE, RIMMING AND DISTANCE OF TRANSPORT AS EXEMPLIFIED BY GOLD FROM THE KLONDIKE DISTRICT, YUKON, AND THE CORDILLERA OF BRITISH COLUMBIA

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Cover: Photograph of a selection of angular crystalline nuggets from Dago Hill on Hunker Creek (Sample AU305). Scale has 1 mm spacing. The origin of this unusual type of gold is discussed in Part 1, pages 32-34 and in Part 2, page 112 (Photo by E. Montgomery).

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PREFACE

The two papers in this bulletin are essentially a joint effort by the authors to quantify the relationship between lode and placer gold by describing the variations in their shape and composition. This was done with due consideration given to the bedrock geology and geomorphology of the area. Fieldwork for this study began in 1988, and electron microprobe analyses and shape classification of gold particles was performed by John Knight in subsequent years. This study would not have been possible without the cooperation and support of the placer miners, several of whom generously donated samples. It is hoped that succeeding workers will be able to make use of this study in later efforts to describe compositional and morphological variations in lode and placer gold.

S.R. Morison
Chief Geologist
Exploration and Geological Services Division

ACKNOWLEDGMENTS

We thank the many placer miners and mineral exploration geologists who contributed most of the samples that were used in this study. In particular we thank Scott Tomlinson of Arbor Resources and Bill LeBarge of the Exploration and Geological Services Division (INAC) for their assistance in obtaining some of the samples. Discussions with Ralph Rushton in the field are greatly appreciated. The study benefited from Ken McTaggart's ongoing support, enthusiasm and expertise. Ed Montgomery and Yvonne Douma also provided high quality technical assistance. Trevor Bremner (Exploration and Geological Services Division, Indian and Northern Affairs Canada) prepared all of the scatter plots, while he and Bill LeBarge provided much of the impetus for preparing the final version of the manuscript. We are grateful to several others who were involved in the final layout, including Forest Pearson and Paulina Mindermann. Assistance in preparing the final camera-ready manuscript was provided by Diane Nikitiuk and Rod Raycroft (Communications Services, Indian and Northern Affairs). Funding for the project was provided by the Exploration and Geological Services Division (Yukon), Indian and Northern Affairs Canada.

J.B. Knight
J.K. Mortensen
S.R. Morison

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THE COMPOSITION OF LODE AND PLACER GOLD FROM THE KLONDIKE DISTRICT OF WEST-CENTRAL YUKON, AND IMPLICATIONS FOR THE NATURE AND GENESIS OF KLONDIKE PLACER AND LODE GOLD DEPOSITS

Abstract

We have determined the major and trace element composition of approximately 2700 gold particles from 21 gold-bearing mesothermal quartz veins and 35 placer gold samples from the Klondike District in western Yukon Territory. Measured Au, Ag, Cu and Hg contents were used to define a characteristic geochemical signature for each of the vein samples. These signatures were then compared with the various compositional populations that we have distinguished within each of the placer samples. Preliminary conclusions derived from the study include: (1) placer gold in both recent stream deposits and in the Plio-Pleistocene White Channel Gravels is detrital in origin; (2) the placer gold is mainly, if not entirely, derived from mesothermal quartz veins; (3) all lode sources for the placer gold have not yet been located; and (4) composition data can be used to link placer gold to its specific lode source.

Résumé

Nous avons déterminé la composition en éléments principaux et en éléments à l'état de traces d'approximativement 2700 particules d'or provenant de 21 veines mésothermales de quartz aurifère et de 35 échantillons d'or placérien provenant du district du Klondike au Yukon occidental. Les teneurs mesurées en Au, en Ag, en Cu et en Hg ont été utilisées pour définir une signature géochimique caractéristique pour chacun des échantillons de veines. Ces signatures ont ensuite été comparées aux diverses populations de compositions que nous avons distingué à l'intérieur de chacun des échantillons placériens. Les conclusion préliminaires tirées de cette étude sont les suivantes : 1) l'or placérien dans les gisements alluvionnaires récents et dans les graviers plio-pléistocènes de White Channel est d'origine détritique; 2) l'or placérien provient principalement, si non totalement, de veines mésothermales de quartz; 3) toutes les sources filoniennes d'or placérien n'ont pas encore été localisées; et 4) les données sur la composition peuvent être utilisées pour relier l'or placérien à ses sources filoniennes spécifiques.

INTRODUCTION

Since the discovery of the rich placer gold deposits of the Klondike District in 1896 much effort has been expended in trying to determine the source of the gold. McConnell (1905, 1907) unraveled part of the mystery by showing that much of the gold in Bonanza, Eldorado and Hunker creeks was reworked from placer deposits hosted in an older gravel sequence, which he termed the "White Channel Gravels", of Pliocene-Pleistocene age (Morison, 1985). He argued that most of the gold in the Klondike was concentrated into the White Channel Gravels from nearby lode deposits, and that most of the gold in the present creeks came from the erosion of the White Channel Gravels. He concluded that very little gold has been added to the present placers since that time.

There are a considerable number of potential lode sources for the placer gold. Although at least 25 gold occurrences have been discovered in the Klondike (MINFILE, 1993), only 4 have been extensively explored. These were the MITCHELL (MINFILE #68), HUNKER DOME (MINFILE #67), VIRGIN (MINFILE #7) and LONE STAR (MINFILE #72) occurrences (Figure 1) (MINFILE, 1993). Only the LONE STAR, which was mined from 1912 to 1914, produced a significant quantity of gold. A total of 7650 tonnes of ore with an average grade of 5.1 grams/tonne Au was mined from this occurrence (MINFILE, 1993). The 1000 fine ounces of gold recovered from this ore represents the entire lode production for the Klondike district. This contrasts with the documented production of placer deposits in the Klondike of over 12 million fine ounces of gold (Debicki, 1983; Gilbert, 1983; LeBarge and Morison, 1990; Waroway and Latoski, 1991). This enormous discrepancy between lode and placer gold production is not unique to the Klondike District and has resulted in the postulation of numerous alternative origins for the gold found in placer deposits throughout the world. For the Klondike, possible sources for the placer gold include as yet undiscovered, gold-bearing mesothermal quartz veins, structurally controlled mineralization in altered ultramafic bodies, mid- to late-Tertiary epithermal systems, syngenetic gold in volcanogenic massive sulphide deposits within metavolcanic assemblages, gold related to hypogene fluids in altered White Channel Gravels, and paleoplacers such as the Cretaceous conglomerates in the Indian River area (e.g. Lowey, 1984; Mortensen 1990; Mortensen et al., 1992).

In this study we have attempted to shed new light on the nature and genesis of the gold in the Klondike placer deposits by examining the composition of the gold itself. We report on the compositional data for placer gold particles from a wide variety of placer deposit types, as well as gold from a number of lode occurrences in the Klondike. These data provide the first conclusive evidence for the ultimate source of Klondike placer gold, and have important implications for both the genesis of placer deposits and the lode potential in the area. The results of a separate study of placer gold particle shape in the Klondike, and implications for distance of transport are reported in Part 2 of this bulletin.

BEDROCK GEOLOGY OF THE KLONDIKE DISTRICT

The bedrock geology of the Klondike District is shown in simplified form in

Figure 1. The following brief description of the bedrock geology is summarized from Mortensen (1990). Bedrock units can be divided into four main groups; 1) schistose metamorphic rocks, 2) greenstones and ultramafic rocks, 3) volcanic and sedimentary rocks of mainly Cretaceous age, and 4) quartz-feldspar porphyry intrusions and related felsic tuffs of Eocene age. The schistose metamorphic rocks are mainly at the chlorite-biotite to locally garnet grade, and include a variety of metaplutonic, metavolcanic, and metasedimentary rocks, ranging in age from pre-Late Devonian to mid-Permian. These rocks display a penetrative foliation which generally parallels compositional layering, which formed during the first main deformation event in the area (F1). Younger deformation (F2), associated with chlorite grade metamorphism, produced macroscopic scale folds over much of the Klondike area.

Following the F1 event, the schistose metamorphic rocks were imbricated by regional scale thrust faults along which bodies of massive greenstone and altered ultramafic rocks were emplaced. Field observations suggest that the F2 event approximately coincided with the thrust faulting (Mortensen, 1990).

Two suites of undeformed and unmetamorphosed intrusive rocks which post-date thrust faulting have been recognized in the Klondike. These are hornblende-biotite granodiorite of Late Cretaceous age which forms a small plug along middle Hunker Creek (not shown in Figure 1), and a widespread bimodal suite of mid-Eocene quartz-feldspar porphyry and diabase and plagioclase-phyric porphyry which occur as dikes and as a large stock between lower Hunker Creek and the Klondike River (Mortensen, 1990), (Figure 1).

Unmetamorphosed andesite flows of probable Late Cretaceous age are interlayered with clastic sediments along Last Chance Creek (Figure 1). A sequence of Eocene felsic lapilli tuff and volcanic breccia near the mouth of Germaine Creek is considered to be the extrusive equivalent of the Eocene felsic porphyry intrusions.

Despite the close proximity of the Klondike District to the Tintina Fault, there is surprisingly little evidence for large-scale steep faults in the area.

LODE GOLD OCCURRENCES

There is a wide variety of mineral occurrences in the Klondike (MINFILE, 1993), however only some of these have been shown to contain even trace amounts of gold. These are disseminated pyritic base metal occurrences within felsic metavolcanic rocks of the Klondike Schist, and several types of quartz veins.

Pyritic quartz-muscovite schist at the LONE STAR (MINFILE #72), PLINC and BRONSON (MINFILE #113) occurrences (Figure 1) contain narrow conformable bands of pyrite, sphalerite, galena and chalcopyrite that are interpreted to be syngenetic in origin based on their conformable nature, geological setting, and lead isotopic composition (Mortensen, unpublished data). At the LONE STAR occurrence, a large body of this mineralized schist also carries low to moderate concentrations of gold (estimated reserves of 907,200 tonnes grading 2.1 grams/tonne; MINFILE, 1993) that are also thought to be syngenetic in origin.

Petrographic studies and metallurgical testing have shown that the gold is extremely small in size (< 10 microns),and is intimately associated with disseminated grains of pyrite

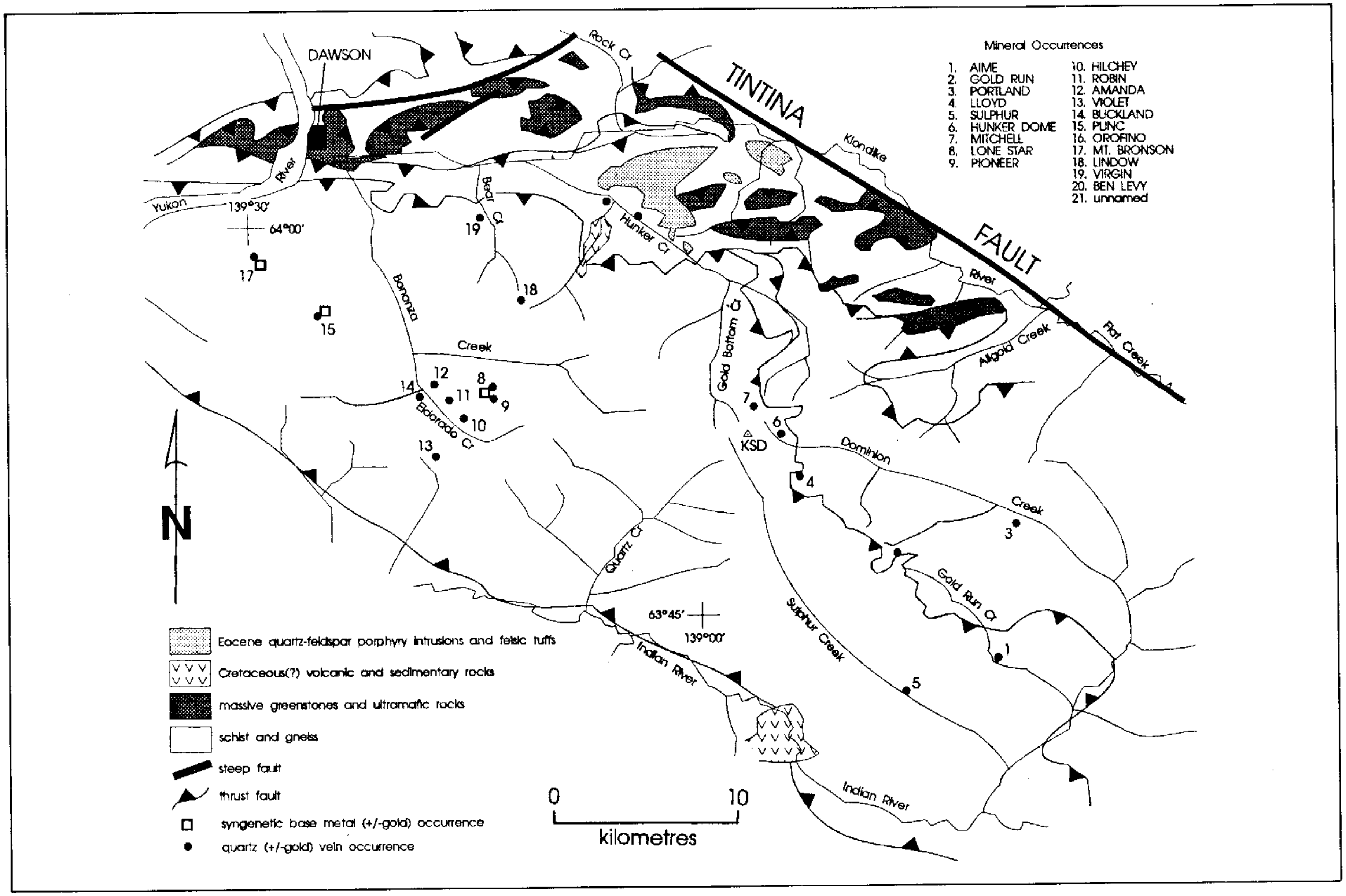

Figure 1. Simplified geology map for the Klondike District (from Mortensen, 1990), showing locations of known lode gold occurrences (from Debicki, 1984, 1985; MINFILE, 1993; Mortensen et al., *1992). KSD = King Solomon Dome. Numbered mineral occurrences are listed in upper right. Occurrences 8 (LONE STAR), 15 (PLINC), and 17 (MT. BRONSON) include both syngenetic and quartz vein mineralization.*

and base metal sulphides (S. Tomlinson and A. Troup, personal communication, 1989). The distribution of gold-bearing schist elsewhere in the Klondike is uncertain.

Several styles of veining have been identified in the Klondike District. The following brief descriptions are summarized from Mortensen et al. (1992). Four main styles of veining are recognized. These are:

1. Mesothermal quartz veins within schistose metamorphic rocks;
2. Quartz-carbonate veins cutting greenstones and ultramafic rocks;
3. Fluorite and chalcedony veins cutting igneous and sedimentary rocks of Eocene age;
4. Low-temperature epithermal veins of Quaternary age.

Of these, veins of the first type are by far the most widespread and abundant. Quartz vein material makes up a significant proportion of the schist and gneiss that underlies most of the Klondike District. Two main types of mesothermal veins can be distinguished based mainly on their structural setting. Foliaform veins form typically lensoid bodies oriented along F1 foliation planes. Discordant veins form tabular bodies that crosscut the main foliation in the wall rocks.

Foliaform veins range up to 3 m in thickness, and are typically discontinuous. They are present in all metamorphic rock units in the area, and are particularly abundant in the mica-rich lithologies (i.e. felsic schist, chloritic schist, and carbonaceous schist), where they locally comprise up to 10% of the rock volume. Foliaform veins consist almost entirely of quartz with locally abundant carbonate. Sulphides have not been observed in foliaform veins, nor has gold ever been detected in them. No visible alteration effects have been observed adjacent to the foliaform veins.

Discordant veins occur sporadically throughout the Klondike, although they appear to be most abundant in the central and southern parts of the district. Discordant veins are usually less than 2 m thick, and in some instances single veins can be traced up to 800 m along strike. Most of the veins occupy steeply dipping extensional structures, which locally appear to form en echelon arrays. An example of such an array includes the MITCHELL (MINFILE #68) and HUNKER DOME (MINFILE #67) occurrences north and east of King Solomon Dome, where the largest and most continuous veins present form a north-south trending, left-stepping, *en echelon* array. Discordant veins crosscut, and are therefore younger than, foliaform veins. Most veins appear to represent simple, single-stage, open space filling of extensional fractures. Post-vein faults produce minor offset (up to several metres) on veins in the LONE STAR mine area and zones of crush breccia along vein margins at the MITCHELL occurrence (Figure 1).

Like the foliaform veins, discordant veins consist mainly of quartz. Amethyst occurs within one vein at the HUNKER DOME occurrence and in a small vein east of Eldorado Creek (Figure 2). Barite, calcite, ferroan carbonate and rare rutile and feldspar occur locally as gangue in some of the veins. The discordant veins typically display very low sulphide concentrations. Pyrite is usually present in at least trace amounts, mainly as discontinuous selvages along vein walls or as irregular disseminations in vein interiors. Galena also commonly occurs in trace

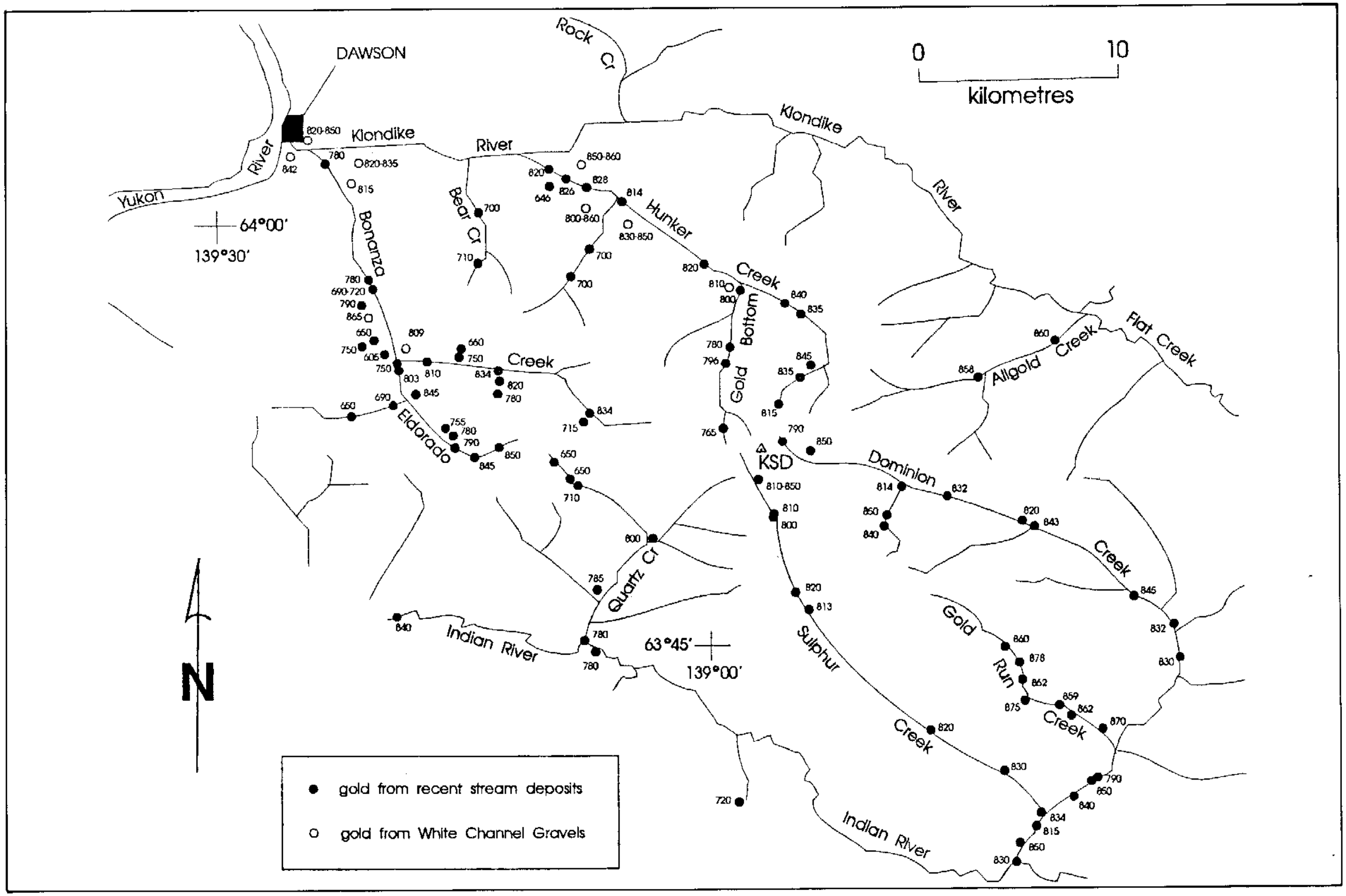

Figure 2. Map showing representative fineness values from bullion data (compiled from Gilbert, 1983; Debicki, 1983; LeBarge and Morison, 1990; and Waroway and Latoski, 1991). KSD = King Solomon Dome.

amounts, typically as disseminated grains and grain aggregates associated with pyrite in vein interiors. In relatively sulphide rich portions of the discordant veins, other sulphides and sulphosalts including sphalerite, chalcopyrite, tetrahedrite, and rare pyrrhotite, arsenopyrite and pyrargyrite have also been noted.

Visible gold is present in a number of discordant veins in the Klondike District. It is typically associated with sulphide (especially pyrite) concentrations, and occurs both in pyritic selvages and as disseminations in vein interiors. The gold occurs both as flakes and irregular inclusions up to 5 mm in diameter in pyrite (and in masses of limonite after pyrite) and as free particles of similar size in quartz. Crystalline gold has been reported from discordant veins at the LONE STAR occurrence (Tyrrell, 1912). Zones of relatively high gold grades appear locally in some veins; for example, assays of up to 48 grams/tonne have been reported for specimens of vein material from the HUNKER DOME occurrence (Figure 1), (MINFILE, 1993). Pyrite-rich discordant veins in the vicinity of the LONE STAR mine locally contain abundant visible gold (McLean, 1914; Mortensen et al., 1992).

Alteration is only visible where discordant veins cut a mafic schist unit, where the wall rocks are carbonatized up to 3 metres from the margins of the veins. Pyritization and sericitization are also locally evident in narrow zones adjacent to discordant veins in the chloritic schist. At the MITCHELL occurrence (Figure 1), fine to coarse euhedral pyrite grains locally comprise up to 40% by volume of bleached, strongly sericitized wall rock in zones within 1-4 cm of the vein walls. Samples of this material yielded Au assays of up to 32 grams/tonne (MINFILE, 1993).Other vein types in the Klondike do not appear to contain gold. Veins within greenstone and ultramafic rocks are generally sulphide-free, and even base metal sulphides have only been discovered in one locality (Mortensen et al., 1992). Fluorite-bearing veins cutting Eocene porphyry intrusions, and chalcedony veins in bedrock associated with large alteration zones of Quaternary age that overprint parts of the White Channel Gravels (Tempelman-Kluit, 1982; Dufresne et al., 1986) do not contain sulphide minerals and yield only low levels of gold. There is therefore little direct evidence available as yet that significant Eocene or Quaternary epithermal gold mineralization once existed in the Klondike District.

PHYSIOGRAPHY AND GEOMORPHIC HISTORY

The Klondike area consists of a plateau dipping gently to the south. The principal drainages are to the north and south. The White Channel and Klondike Gravels fill the valleys. The rivers flowing to the north are incised through these sediments (Figure 3).

The Klondike placer mining area is in the unglaciated portion of the western Yukon Plateau (Bostock, 1948; 1970). It is an uplifted erosional surface of Tertiary age characterized by dissected, rolling terrain of accordant ridges (Bostock, 1948, 1970; Tempelman-Kluit,1980). This subdued, mature landscape is the result of extensive subaerial Miocene(?) erosion with drainage patterns which were dominantly toward the southwest (Tempelman-Kluit, 1980). Differential uplift and terrain rejuvenation began around the Pliocene (Hughes, 1970). It is believed that this event initiated and maintained White Channel Gravel sedimentation in the Klondike area (Milner, 1976; Tempelman-Kluit, 1980). White

Channel aggradation ended in early Pleistocene with the onset of pre-Reid glacial activity and the deposition of the Klondike Gravels (Hughes et al., 1972; Morison and Hein, 1987). The Klondike Gravel sequence which overlies White Channel sediments represents glaciofluvial sedimentation during a pre-Reid gravel advance from the Ogilvie Mountains (Hughes et al., 1972) or possibly from the Stewart River valley in Tintina Trench. Subsequent to the deposition of the White Channel and Klondike gravels, differential uplift of the Yukon Plateau resulted in drainage reversals. The Yukon River basin now drained in a northerly direction. The reversals were completed with the onset of Pleistocene glaciation (Hughes et al., 1972; Tempelman-Kluit, 1980). Continued uplift during the Pleistocene resulted in downcutting and incision of drainage systems to their present levels (Hughes et al., 1972). It is believed that at least two periods of extensive downcutting occurred before the onset of the Reid glacial interval (Hughes et al. 1972). The initial phase of incision ended with the onset of terrace gravel sedimentation and the second phase ended with deposition of valley bottom stream deposits (Morison, 1985). These terrace and valley bottom deposits are those described by McConnell (1905, 1907); (Figure 3).

PLACER DEPOSITS IN THE KLONDIKE DISTRICT

McConnell (1905, 1907) divided auriferous gravel deposits in the Klondike District into four types; stream gravel, river terrace gravel, White Channel gravel, and high level river gravel or Klondike gravel (Figure 3).

The White Channel placer deposit forms high level terraces approximately 50 to 100 m above present day stream levels, with a maximum measured thickness of 35 metres (Morison, 1985). At the mouth of Bonanza Creek, high level terrace stratigraphy is characterized by an additional, 10 metre thick upper sequence of interbedded White Channel facies and glaciofluvial Klondike gravel. This interbedded relationship demonstrates contemporaneous deposition of these two gravelly deposits during the pre-Reid glacial interval (Hughes et al., 1972; Morison, 1985). Klondike gravel does not contain economic concentrations of placer gold. This is the result of a regional glacial origin for these sediments. McConnell (1907) further subdivided the White Channel deposit into white and yellow gravel units. This classification suggests that white and yellow gravel units are stratigraphically distinct. However, White Channel exposures in the Klondike area show there is no distinct break in gravelly sedimentation (Morison, 1985). The yellow gravel unit is interpreted to be a stained equivalent of the white unit. The yellow staining is probably the result of weathering and seepage of meteoric waters.

The White Channel placer deposit is characterized by 14 lithofacies types which range from laminated silt and clay to massive and disorganized boulder gravel (Morison, 1985). These lithofacies indicate that the White Channel alluvium was deposited in a proximal crudely braided to a distal well developed braided river environment in association with valley wall debris flow and tributary alluvial fan sedimentation. Sorting and stratification improves up section in the White Channel gravelly sequence. This suggests that placer concentration mechanisms and therefore gold content (assuming a constant supply of gold) should also improve up section. However economic concentrations of placer gold are reported to occur only in the lower few metres of poorly sorted gravelly sediment immediately above the bedrock surface (McConnell, 1907; Gleeson, 1970), with the exception of Paradise Hill where economic gold concentrations exist 1 to 4 metres above bedrock (McConnell 1907). These poorly sorted gravelly facies have been interpreted to represent deposition by mass emplacement and/or short lived high energy stream channel deposits (Morison, 1985). This apparent lack of a concentrating mechanism suggests that the most significant sources of gold were already available for incorporation into the White Channel depositional environment during the early stages of aggradation. There is no evidence of a pre-White Channel fluvial placer deposit which could have acted as a source for detrital gold in this setting. It is therefore suggested that placer gold was concentrated from lode sources into colluvium over a deeply weathered bedrock surface prior to ncorporation into White Channel sediments. This idea is supported by the observation of McConnell (1907) that the best pay was associated with a quartz-rich base.

The other placer deposit settings in the Klondike area (i.e. river terrace and valley bottom alluvium) were formed during downcutting after the deposition of the Klondike Gravel. It is thought that the placer gold found within these settings is the result of reworking from the older White Channel placer deposits and from lode sources which were eroded during downcutting (McConnell, 1905; 1907). The White Channel Gravel deposit has, in places, been altered by hydrothermal fluids (Dufresne et al., 1986; Dufresne, 1986). This alteration is manifested by the almost complete replacement of igneous and metamorphic silicate minerals by clays. The altered gravel is the "yellow gravel" of McConnell (1907). Some authors have argued that these hydrothermal fluids also introduced gold into White Channel sediment (e.g. Templeman-Kluit, 1982; Dufresne et al., 1986; Dufresne, 1986).

PREVIOUS STUDIES OF KLONDIKE GOLD DEPOSITS

Investigation and documentation of placer deposits in the Klondike District began soon after their discovery in 1896. McConnell and Tyrell (1899) and McConnell (1905, 1907) provided the first detailed descriptions of the placer gold and the sedimentary units in which it was found. They concluded that much of the placer gold was derived from gold-bearing veins. Everette (1907, 1908) noted the unworn condition of both pyrite and crystalline gold in Klondike placers, and rare occurrences of unworn gold particles apparently intergrown with mica schist. He concluded that at least some of the gold must have been precipitated in the gravels from ascending, possibly volcanically driven hydrothermal solutions.

Tyrrell (1912) also commented on the well preserved crystalline forms of placer gold (including twinned octahedra, dodecahedra, octahedra and hopper crystals). He described examples of such gold from Victoria Gulch and pointed out that identical crystals were present in quartz veins at the LONE STAR mine immediately upslope from gold-bearing gravels in Victoria Gulch. He concluded that most, if not all, of the placer gold in the district was detrital in origin, but he did not discount the possibility of precipitated gold.

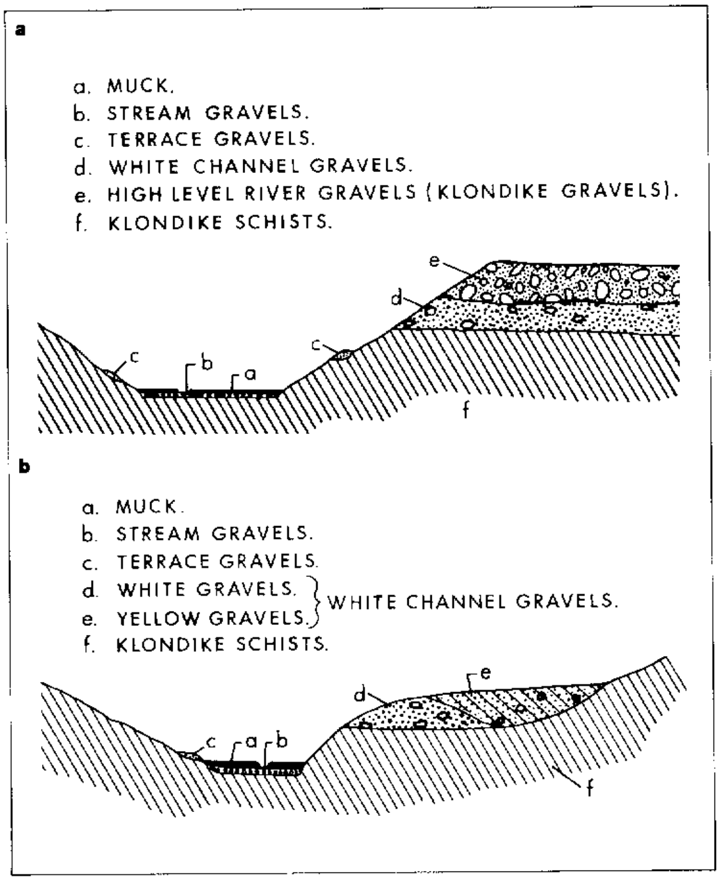

Figure 3. *Classification of placer deposits as illustrated by generalized sections (from McConnell, 1907). Figure 3a, lower part of the Bonanza valley; Figure 3b, below Eldorado Forks (junction of Bonanza and Eldorado valleys).*

Gleeson (1970) conducted a heavy mineral survey of the Klondike District, and demonstrated that gold particles are present not only in recent alluvial deposits and White Channel Gravels, but are also widely distributed in colluvium, particularly near and downslope from known lode gold occurrences.

Alteration in White Channel sediments and underlying bedrock was first recognized by Tempelman-Kluit (1982) and subsequently studied by Dufresne et al. (1986) and Dufresne (1986). Tempelman-Kluit (1982) postulated that the gold and alteration in the White Channel sediments may be genetically related with gold "growing" in place. Dufresne et al. (1986) and Dufresne (1986) demonstrated clearly that the White Channel alteration is the result of hydrothermal activity, and suggested there may be a widely disseminated style of gold mineralization which is extremely fine grained and accompanies the alteration products.

Although no previous work has been done on the composition of individual gold particles from the Klondike, there is a considerable volume of bulk fineness data from individual placer operations, and from the LONE STAR mine. These data are shown on Figure 2. Although there are some discrepancies between fineness values reported for some parts of the Klondike by different workers, the data are generally in reasonable agreement, and regional trends in fineness values have been interpreted in a variety of ways.

Hester (1970) observed that the fineness of the gold in any single creek fluctuates over a fairly narrow range of values, but generally tends to decrease upstream.

He also presented a compilation of fineness values for 655 bullion bars from various dredges which operated on the main placer creeks in the district. His data can be divided into two subgroups: one above 790 fine containing 90% of the population and the second below 790 fine with the remaining 10% of the population.

Milner (1976) summarized the bullion fineness data available at the time and concluded that the gold was from veins but did not rule out a significant contribution from in situ precipitation of gold within alluvial deposits. He speculated that gold rims on placer gold particles were formed by precipitation.

Debicki (1983) reported fineness values for many placer operations in the Klondike, and also discussed the occurrence of octahedral placer gold particles from Bear Creek. The crystalline nature of this gold, together with the finding of an apparently gold-plated nail from the Sixtymile placer gold district 80 km west of the Klondike, was used to support the idea that at least a significant proportion of Klondike placer gold was precipitated *in situ* in the creeks. Other workers (e.g., Tempelman-Kluit, 1982) have also used the "gold-plated nail" as evidence of gold migration and precipitation within alluvium. An SEM examination of the nail (Knight, unpublished data), however, revealed that the nail was not originally a copper nail on which gold has been precipitated (as it had previously been interpreted), but rather was originally made of brass, and zinc has been locally leached from the surface, leaving a copper-rich surface layer. No gold is present on the nail surface at all, thus the nail provides no evidence either for or against the possible *in situ* growth of gold in Klondike gravel deposits.

BASIS OF THIS STUDY

Knight and McTaggart (1986, 1988, 1989, 1990) studied the composition of placer and lode gold particles in the 0.1-1.0 mm size range from the Cariboo, Bralorne and Fraser River areas of southern British Columbia. They found that most placer particles have a nearly pure gold rim surrounding or partly surrounding a core of varying composition. They concluded that the core composition is unchanged by its passage from the lode to the placer and that the placer gold composition can therefore be used to identify the lode source of placer gold. They present strong evidence to show that the nearly pure gold rims have been formed by the removal of silver after the liberation of the particles from the lode source, and are not formed by *in situ* precipitation of gold on pre-existing cores. They concluded that there was no evidence for the precipitation of gold in their study area. Knight and McTaggart (1990) concluded from a literature review that for cases where the occurrence of gold grown *in situ* in alluvium or colluvium is well documented, it is usually <100μ in diameter.

Although, unlike southern British Columbia, the Klondike District was never glaciated, we believe that the same methods used by Knight and McTaggart (1986, 1989, 1990) in previous studies should be equally applicable in the Klondike.

Microprobe investigations of the composition of placer gold particles are limited by two considerations: rim formation and minimum volume available for analysis (represented on the surface by a circular area). Rim thickness typically ranges from <1μ-150μ with most falling in the <20μ range. The minimum area that can be analyzed by the microprobe for gold is of the order of 5μ diameter. The result of these two factors is that for particles smaller than 300μ in diameter there is a possibility that the original particle has been completely replaced by rim material. Also, cores smaller than about 7μ in diameter are very difficult to analyze making it difficult to separate the rim composition from the core composition for particles <300μ in diameter (depending on rim thickness and core size).

ANALYTICAL PROCEDURE

A total of 21 lode and 36 placer samples were collected from the Klondike District (Appendix C). Figures 4 and 5 show the sample localities for placer and lode gold samples, respectively. The lode samples were panned from decomposed material around old adits, tailings from crushing mills, and crushed vein specimens. Nearly all of the placer gold samples were donated by miners in the Klondike area. The placer samples with a mixture of heavy minerals were hand-picked to provide a pure gold concentrate. Gold particles typically ranged in size from 0.2-2 mm in diameter, with approximately 70% falling in the range 0.5-0.8 mm. Although the majority of gold samples were analyzed as recovered from the placer gravels, some of the samples had been chemically cleaned by the miners (apparently using an ammonia-based cleaning solution), and one sample is known to have been heated to >100°C. In a few cases, especially for the samples from or near old mills where amalgamation was used in the recovery process, evidence of Hg contamination was encountered. Where possible, contaminated particles were removed during the selection and preparation process.

A representative population of between 50 and 100 particles was selected from each sample; these were classified by shape and photographed. These samples are further described in Part 2 of this bulletin. After identifying each particle on the photograph, the particles were mounted in transoptic plastic (following the method described in Douma and Knight (in press) so that its intermediate and short axes are exposed after polishing. The polished samples were studied under a reflected light microscope. The average rim thickness was measured at high magnification, and the percentage of the particle that was rimmed was estimated visually in the plane of the section.

The sections were coated with 25 nm of carbon and analyzed for Au, Ag, Hg, Cu using a CAMECA SX-50 microprobe at the Department of Geological Sciences, University of British Columbia. Previous work has indicated that other elements are not commonly found at greater than about 0.05 wt% in native gold (e.g., Knight and McTaggart, 1986). Analytical conditions were 20KV, 100nA. Lines used were Au(Ma), Ag(La), Cu(Ka) and Hg(Mb). Counting times were 30 seconds on each peak, and 15 seconds on each of two backgrounds. A detailed investigation was undertaken to ensure that there was no interference between elements at the peak or background position for the elements analyzed, or for possible other interfering elements. Standards employed were pure Au, pure Ag, a Au-Cu alloy with 40% Cu (initially pure Cu was used) and synthetic HgTe. All runs included analyses of the complete NBS (National Bureau of Standards) Au-Ag series and part of the NBS Au-Cu series alloys. The detection limits (in wt%) in pure gold based on 3√N of the background counts were as follows: Au = 0.019; Ag = 0.013; Hg = 0.065; Cu = 0.025. The detection limit for Ag improves significantly as the proportion of Ag increases; however we assumed the above values throughout this study. An initial test of the analytical routines using the NBS standards indicated that the correction procedure supplied with the Cameca instrument (ΦPZ as determined by Pouchou and Pichoir, 1986) always produced totals which are low regardless of whether the Heinrich (1987) or the Pouchou and Pichoir (1986) correction procedure was used. The exact cause of this error is not known. It was corrected by altering the absorption correction values so that the average composition of some 15 analyses of the well tested NBS standards reported their compositions. The results reported in Appendix A show the accuracy and precision of the analyses taken over the two year duration of this study using the procedure described above. The low totals for the Cu-Au alloys indicate that the corrections used in these runs is still slightly in error. Analyses of the standards carried out in 1990 are reported separately in Appendix A because these results represent the capability of the machine after malfunctions in the instrument were identified and repaired.

Each particle was analyzed by microprobe once in the center of the section exposed. Random analyses were also made just inside the outer edge of the core. Where rims were sufficiently well developed, they were also analyzed, both to determine their composition and to check for surface contamination (Knight and McTaggart, 1990). Inhomogeneities and other unusual features noted during the light microscopic examination were also analyzed where possible. The statistics for the accuracy and precision of analyses of the cores of the unknowns in the study are given in Appendix B. It should be noted that a few poor analyses (thought to be caused by poor surface polish, small particle size, dirty surfaces, etc.) were not included in the calculation of these averages.

The data is plotted on X-Y scatter plots using the SYGRAPH program and the statistics calculated using the SYSTAT program (both written by Systat Inc.). Hg and Cu were plotted against fineness, where fineness is defined as ([Au/(Au + Ag)]*1000). These plots, together with the analytical statistics and the light microscope observations, form the main data base for this study.

ANALYTICAL RESULTS

General Observations

In general the lode and placer gold particles are homogeneous (compare core and edge analyses from Table 1.) with few unusual features. High purity gold rims are developed only on placer particles. The composition for the lode gold particles is given in Appendix D (sample localities shown in Figure 5), and shown in Figure 6. Compositions of cores and rims in placer gold particles are given in Appendix E (sample localities shown in Figure 4), and shown in Figure 7. The placer and lode gold generally show the same compositional range (Table 1, Figure 6, and Figure 7).

Where a trend in the relationship between fineness and Hg content within a sample is indicated by the data, it follows the general trend reported by Healy and Petruk (1990), with Hg content increasing with decreasing fineness. The VIOLET lode sample provides the best example of this inverse trend (sample 486, Appendix D).

High purity inhomogeneities (aside from the ubiquitous nearly pure gold rims on placer particles) were analyzed in 32 particles from 13 samples; these consist of two types. Narrow, high purity veins with straight, nearly parallel sides were noted in a small number of particles. Bends in these veins are sharp with angular corners. In some instances they form a network which appears to outline a polygonal form corresponding to the morphology of the gold grains forming the particles. These veins have very sharp contacts within the host gold particle (Figure 8). They are generally <10µ wide, and therefore usually too small to analyze with great accuracy. The second type consists of small, elongate, high fineness areas or patches with sharp boundaries. These are thought to represent either sections or terminations of the high purity veins, or partly developed veins. From a plot of composition (Figure 9), it appears that they have a very high fineness (about 990) with no Hg or Cu. Seven particles with fineness values between 447 and 883 and Hg values between 0 and 0.32 are not shown in Figure 9. It is not clear if these analyses represent poor analyses, misidentified low fineness inhomogeneities or an unrecognized low fineness vein type. Because of the difficulties of analyzing these features they may actually be pure gold. Petrovskaya and Fastalovich (1955) reported similar high purity veins or zones in placer gold particles from Siberia. They observed that where these zones reached the edge of a particle which had a high purity rim, the high purity veins are cut by the rims. They concluded that the veins formed prior to the rims but were not inherited from the lode.

Low fineness zones are also present in some of the gold particles. Although segments of the boundaries between these inhomogeneities with their host are locally sharp, the boundaries are more typically diffuse (Figure 10). In general these inhomogeneities are found near the edge of particles, usually as patches but in some cases covering a significant portion of the particle edge. In some instances three distinct compositional phases have been recognized within a single particle. Many of these zones are small, therefore the analyses should be considered less accurate than the host analyses. Compositional data for the low fineness inhomogeneities in 40 particles from 12 samples are plotted in Figure 11. There are too few data points to draw detailed conclusions; however the low composition parts fall within the low composition range of the placer gold in the area and are generally around 700 fine, while the bulk of the particle has a composition which falls within the range of the majority of the placer gold from that specimen. One notable exception is the gold from the VIOLET vein which has two distinct phases of distinctly different composition (see sample 486, Appendix D). Gold from the VIOLET occurrence is unique in that it has two distinct compositions. One is 800 fine with Hg-content to 2 wt% and the other has fineness from 350 to 750 and Hg varying from 1-9 wt%. All of these compositional variations likely represent temporal changes in the composition of gold which precipitated from the hydrothermal fluid, possibly

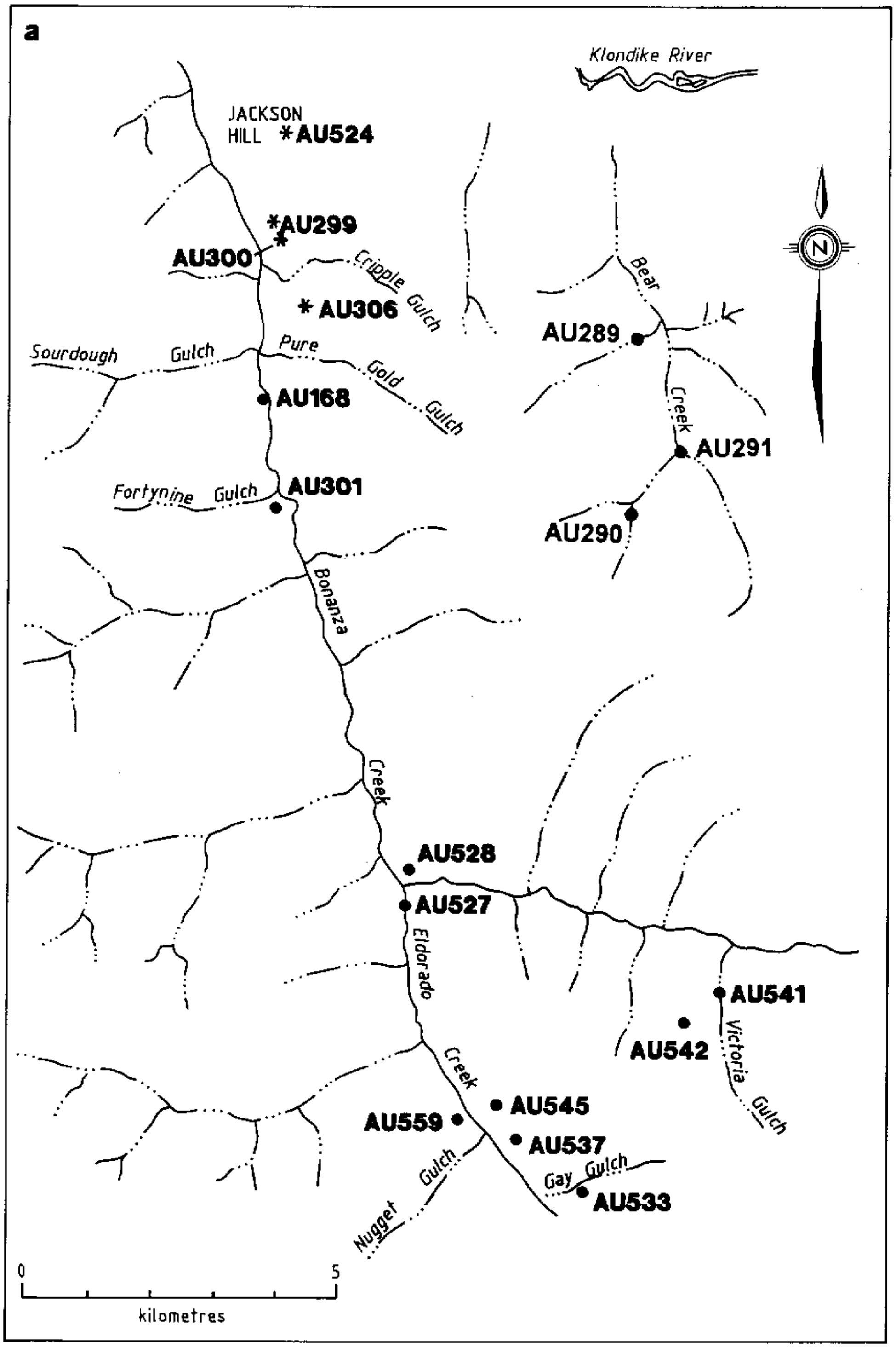

Figure 4a: Location map for placer gold samples analyzed in this study, northwestern Klondike District. Solid circles are samples from recent stream gravels, solid stars are samples from White Channel Gravel deposits.

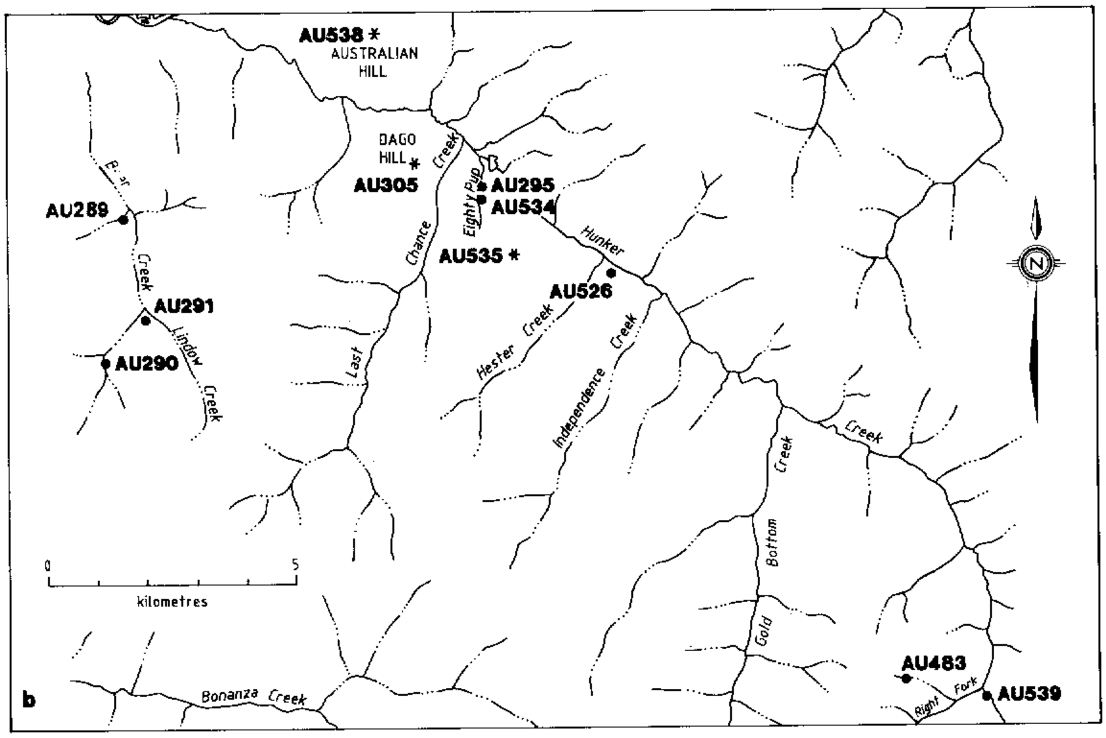

Figure 4b: Location map for placer gold samples analyzed in this study, northeastern Klondike District. Solid circles are samples from recent stream gravels, solid stars are samples from White Channel Gravel deposits.

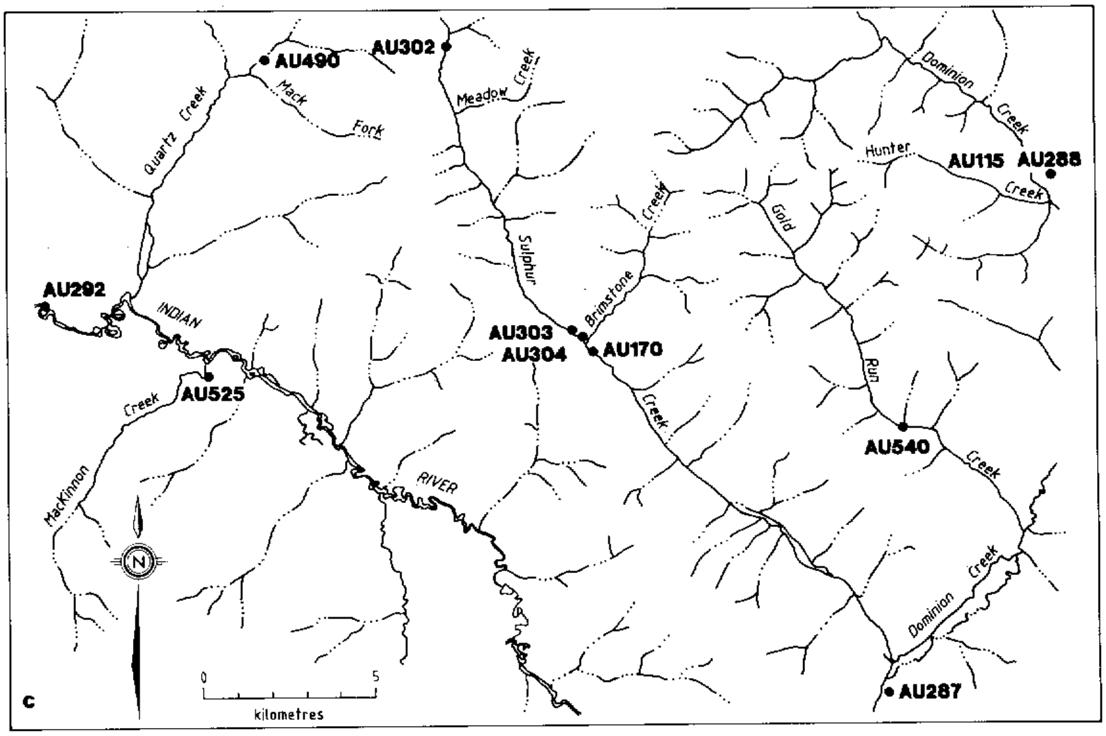

Figure 4c:Location map for placer gold samples analyzed in this study, southern Klondike District.

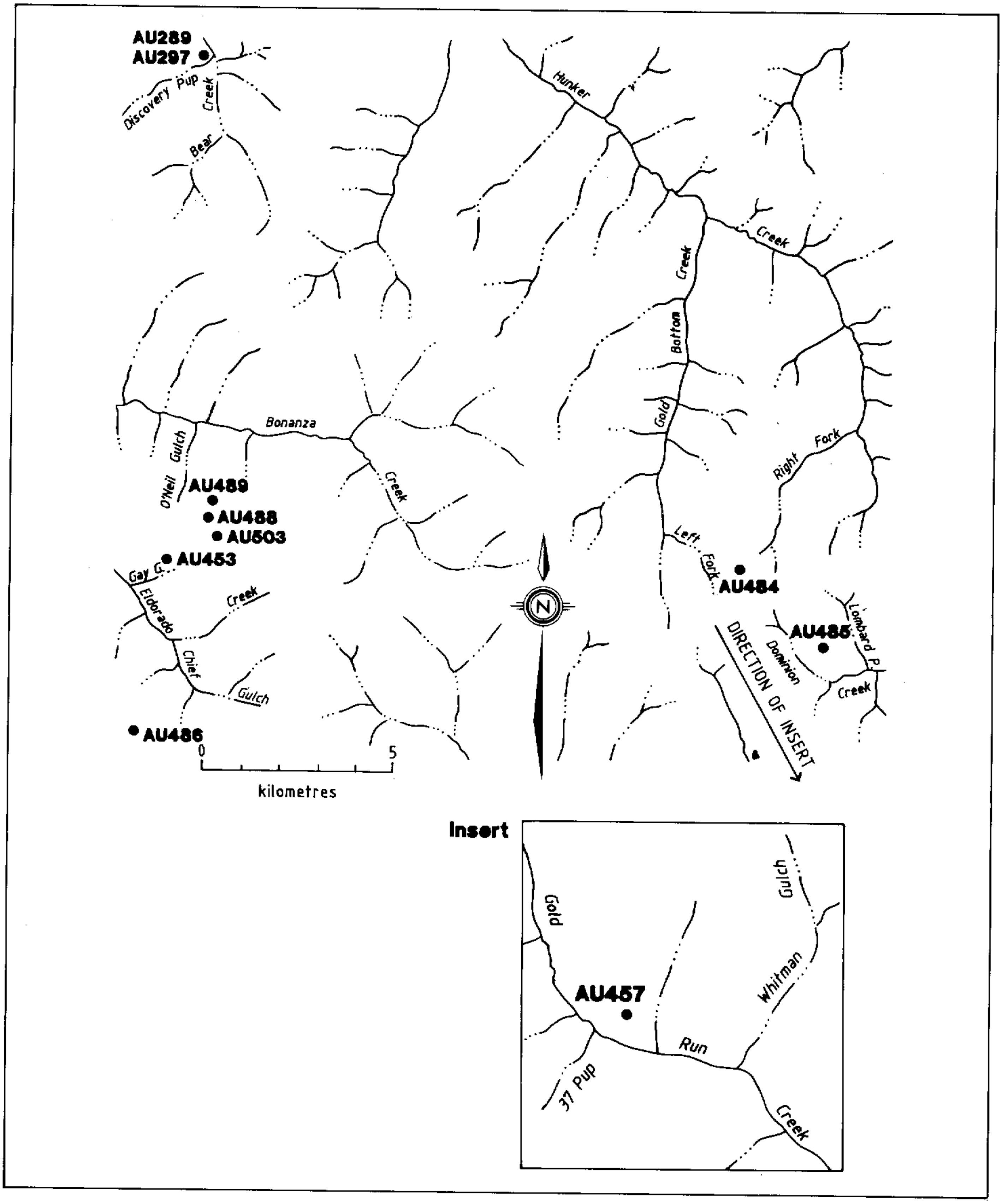

Figure 5. *Location map for lode gold samples analyzed in this study.*

TABLE 1. Average compositional characteristics of particles from lode and placer.

SAMPLE NUMBER	SAMPLE NAME	LOCATION ANALYZED	NUMBER ANALYZED	FINENESS MEAN	HG WT% MEAN	DOMINANT RANGE IN FINENESS
AU115	DOMINION	CORE	4	819.6	0.024	800
		EDGE	4	849.8	0.041	
AU168	BONANZA	CORE	98	747.5	0.295	760-860
		EDGE	30	737.5	0.216	
AU170	SULPHUR	CORE	111	788.9	0.222	740-870
		EDGE	25	755.9	0.333	
AU243	ELDORADO	CORE	46	706.4	0.337	680-760
		EDGE	29	704.6	0.185	
AU244	DOMINION	CORE	25	747.9	0.124	750-820
		EDGE	12	734.7	0.136	
AU287	LOWER DOMINION	CORE	80	811.9	0.104	750-910
		EDGE	5	844.6	0.243	
AU288	DOMINION	CORE	55	788.1	0.030	740-840
AU289	VIRGIN	CORE	27	697.3	0.543	660-720
		EDGE	9	701.7	0.422	
AU290	UPPER BEAR	CORE	48	672.2	0.390	580-700
AU291	BEAR	CORE	13	681.7	0.494	640-720
AU292	INDIAN	CORE	78	790.3	0.181	710-900
		EDGE	7	756.4	0.125	
AU295	HUNKER	CORE	50	759.7	0.036	720-820
		EDGE	4	804.7	0.018	
AU297	VIRGIN MILL	CORE	42	706.1	0.637	650-740
AU298	BEAR DISCOVERY	CORE	65	730.0	0.610	630-800
		EDGE	11	732.2	0.638	
AU299	TRAIL HILL	CORE	21	768.7	0.263	780-840
		EDGE	6	709.1	0.462	
AU300	TRAIL HILL	CORE	12	750.2	0.336	780-840
		EDGE	1	667.7	1.191	
AU301	49 BELOW PUP, BONANZA	CORE	53	772.5	0.235	750-850
		EDGE	8	769.8	0.101	
AU302	SULPHUR	CORE	51	809.3	0.108	740-880
		EDGE	12	801.3	0.074	
AU303	SULPHUR	CORE	53	786.8	0.142	730-850
		EDGE	9	764.5	0.085	
AU304	SULPHUR	CORE	54	797.7	0.116	750-860
		EDGE	10	785.9	0.211	
AU305	DAGO HILL	CORE	57	713.0	0.166	620-730, 740-820
AU306	CRIPPLE HILL	CORE	53	759.9	0.179	750-840
		EDGE	14	748.2	0.466	
AU450	VIRGIN DUMP	CORE	2	769.3	0.260	770
		EDGE	1	764.8	0.256	
AU453	HILCHEY	CORE	6	770.2	0.018	770
AU454	LONE STAR	CORE	6	845.6	0.004	830
		EDGE	2	843.3	0.006	
AU455	LONE STAR WEST DUMP	CORE	1	833.8	0.018	830
AU456	LONE STAR CENTER DUMP	CORE	33	823.0	0.006	830
		EDGE	11	816.1	0.018	
AU457	AIME DUMP	CORE	87	847.7	0.064	845
		EDGE	23	847.5	0.072	
	-1	CORE	25	854.8	0.051	855
		EDGE	6	854.7	0.062	
	-3	CORE	35	846.1	0.079	845
		EDGE	9	846.9	0.083	
	-4	CORE	25	843.4	0.054	840
		EDGE	7	843.3	0.063	

TABLE 1. Continued.

SAMPLE NUMBER	SAMPLE NAME	LOCATION ANALYZED	NUMBER ANALYZED	FINENESS MEAN	HG WT% MEAN	DOMINANT RANGE IN FINENESS
AU483	24 ABOVE PUP, HUNKER	CORE	72	822.9	0.061	780-860
		EDGE	17	824.0	0.072	
AU484	MITCHEL	CORE	28	813.8	0.005	800-830
		EDGE	6	811.3	0.005	
AU485	HUNKER DOME	CORE	27	836.2	0.022	810-860
		EDGE	6	840.7	0.025	
AU486	VIOLET	TOTAL	19			
	TYPE 1		13	800.1	1.17	780-810
	TYPE 2		22	627.4	2.49	350-740
AU487	HILCHEY	CORE	6	761.7	0.166	700-880
AU488	LONE STAR, BOULDER LODE	CORE	26	845.7	0.008	830-860
		EDGE	7	845.5	0.006	
AU489	LONE STAR, MILL	CORE	46	830.7	0.015	810-860
		EDGE	12	833.3	0.012	
AU490	QUARTZ CK.					
	ALL	CORE	105	760.3	0.310	650-850
		EDGES	22	780.6	0.168	
	LESS -4	CORE	81	747.8	0.304	650-820
	-4 ANGULAR	CORE	24	802.3	0.330	780-850
AU503	PIONEER	CORE	1	766.2	0.000	766
AU524	JACKSON	CORE	94	736.4	0.283	750-850, 640-730, 500?
		EDGE	22	738.5	0.157	
AU525	INDIAN AT McKINNON	CORE	123	783.9	0.250	875-900, as Hg increases fineness increases
		EDGE	4	808.3	0.180	
AU526	HUNKER, AT HESTER	CORE	117	783.0	0.022	780-860, 710-760
		EDGE	24	794.2	0.027	
AU527	ELDORADO MOUTH	CORE	81	741.3	0.189	580-730, 738-850
		EDGE	16	727.6	0.139	
AU528	BONANZA AT ELDORADO	CORE	82	784.2	0.019	720-880, 580-680
		EDGE	22	787.7	0.018	
AU533	GAY GULCH	CORE	64	788.4	0.026	760-840
		EDGE	15	785.1	0.020	
AU534	80 PUP, HUNKER	CORE	34	765.6	0.038	780-900, 630-710
AU535	PARADISE HILL	CORE	4	793.4	0.071	
AU536	AUSTRALIAN HILL	CORE	91	755.9	0.139	760-840, 640-760
AU537	ORO GRANDE	CORE	4	819.8	0.037	780-760
AU539	HUNKER LEFT FORK	CORE	74	853.6	0.016	820-910, Gap at 850
		EDGE	15	820.3	0.019	
AU540	GOLD RUN	CORE	68	832.6	0.144	830-890, 750-830
		EDGE	17	832.7	0.023	
AU541	VICTORIA GULCH	CORE	74	814.0	0.038	790-860
		EDGE	17	804.8	0.019	
AU542	7 ABOVE PUP, BONANZA	CORE	55	814.3	0.016	800-860
		EDGE	14	825.6	0.031	
AU545	27 ABOVE PUP, ELDORADO	CORE	97	765.2	0.035	750-810
		EDGE	24	747.9	0.021	
AU559	ELDORADO, AT 26 PUP	CORE	77	740.7	0.122	550-750, 750-840
		EDGE	20	775.6	0.037	

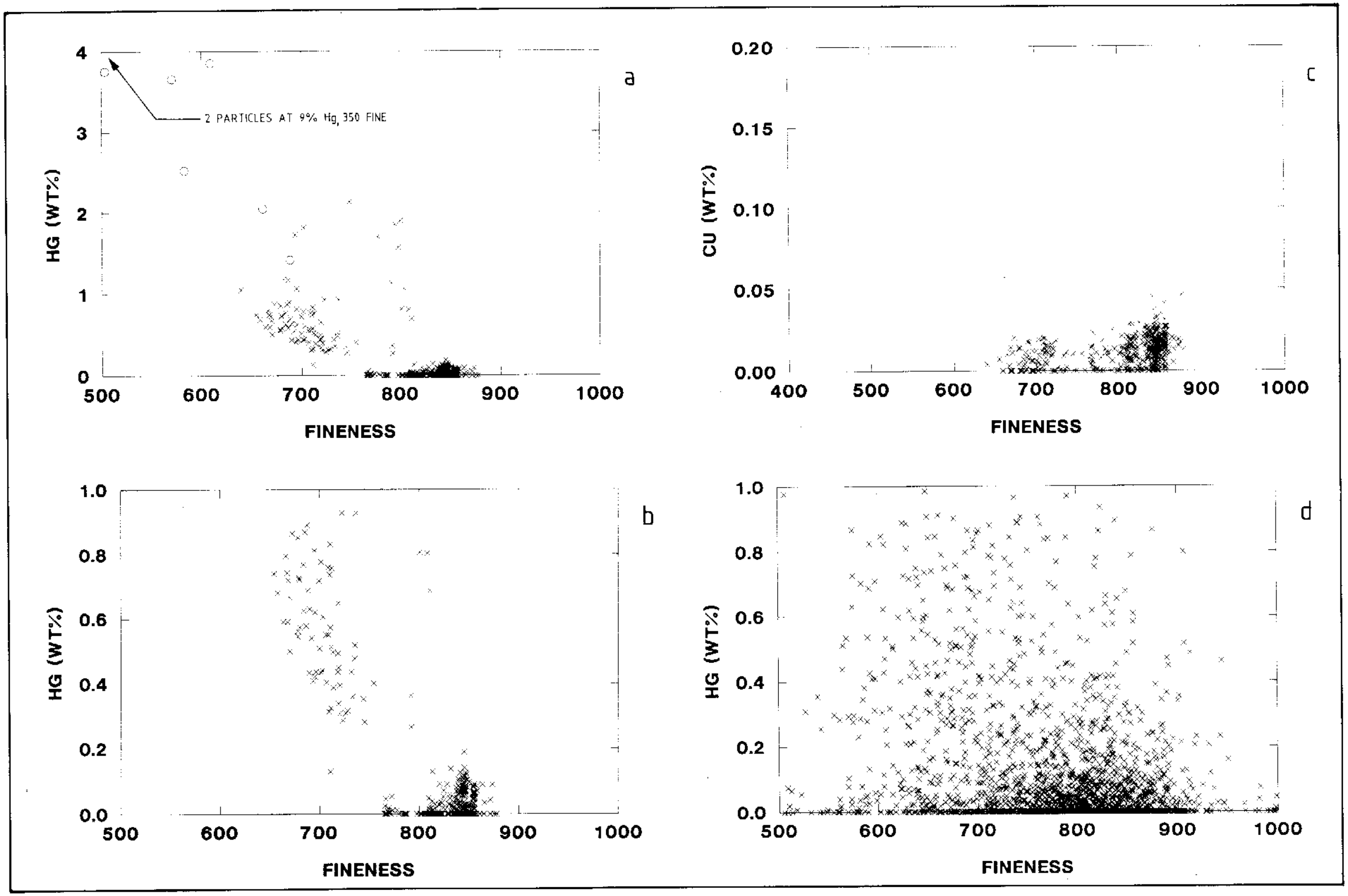

Figure 6. *Plots of Hg. vs. fineness (Figs. 6a and 6b) and Cu vs. fineness (Figure 6c) for all the lode gold particles analyzed from the Klondike District. For comparison Figure 6d displays the Hg vs. fineness plot for all the placer particles at the same scale. The circles in 6a correspond to the second phase of gold from the Violet showing.*

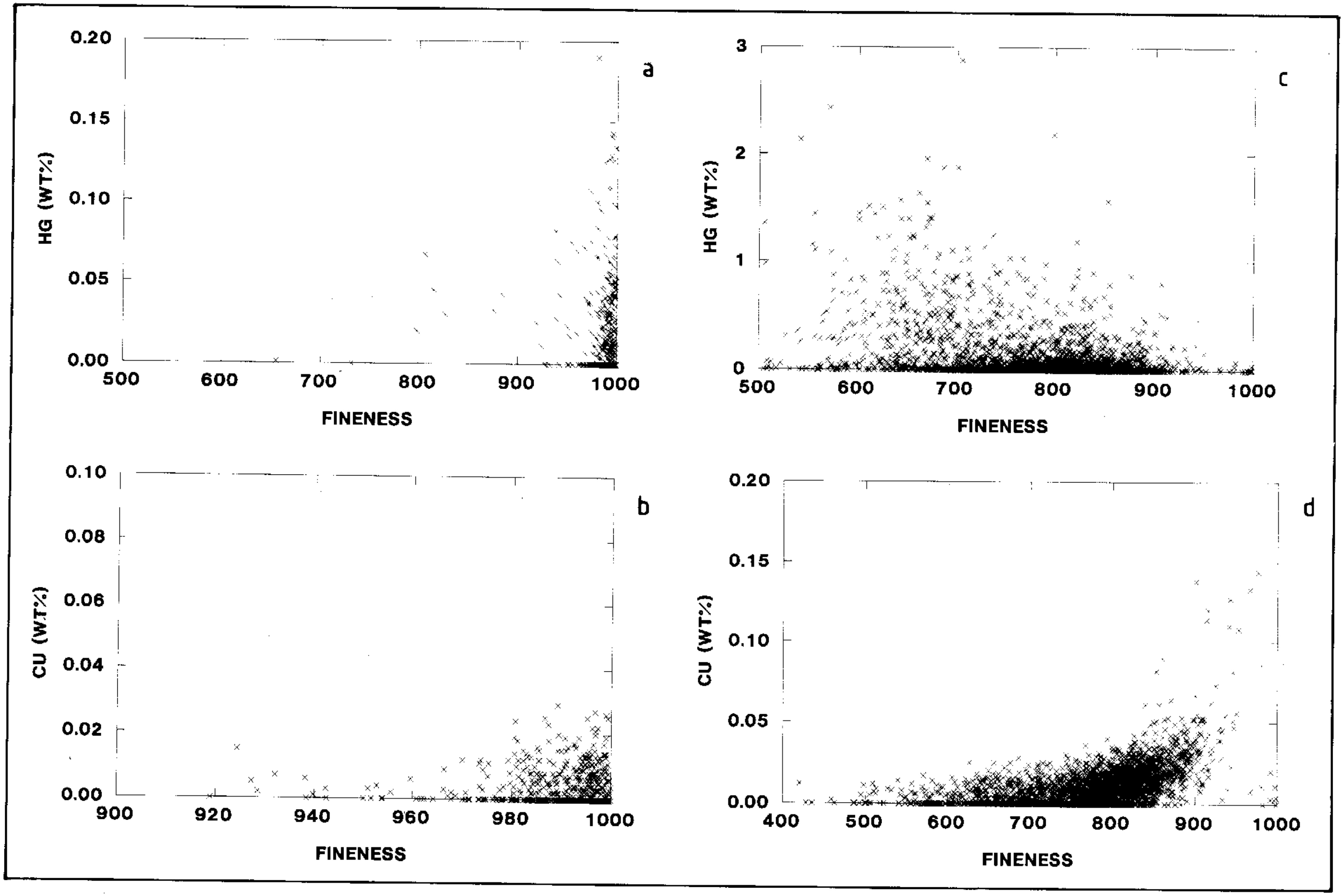

Figure 7. *Plots of Hg vs. fineness (Figure 7a) and Cu vs. fineness (Figure 7b) for all the rims of placer gold particles. Hg vs. fineness (FIgure 7c) and Cu vs. fineness (Figure 7d) for all the cores of placer gold particles analyzed from the Klondike District.*

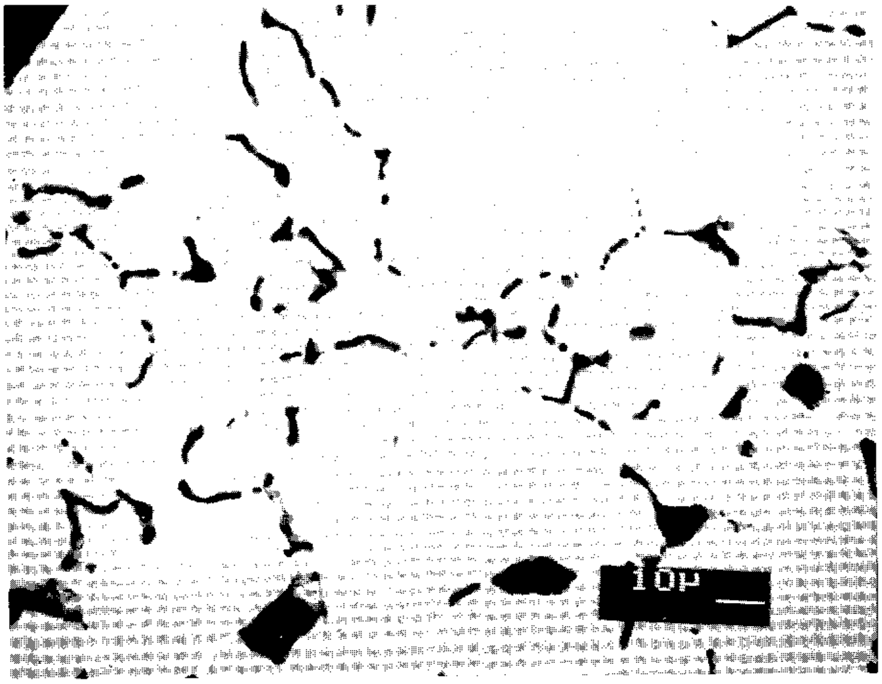

Figure 8. Backscattered electron photomicrograph of high fineness veins (light coloured) within a lower fineness gold particle. The veins have very sharp contacts, a constant thickness and are comprised of straight segments linked by angular segments. Sample # 168.

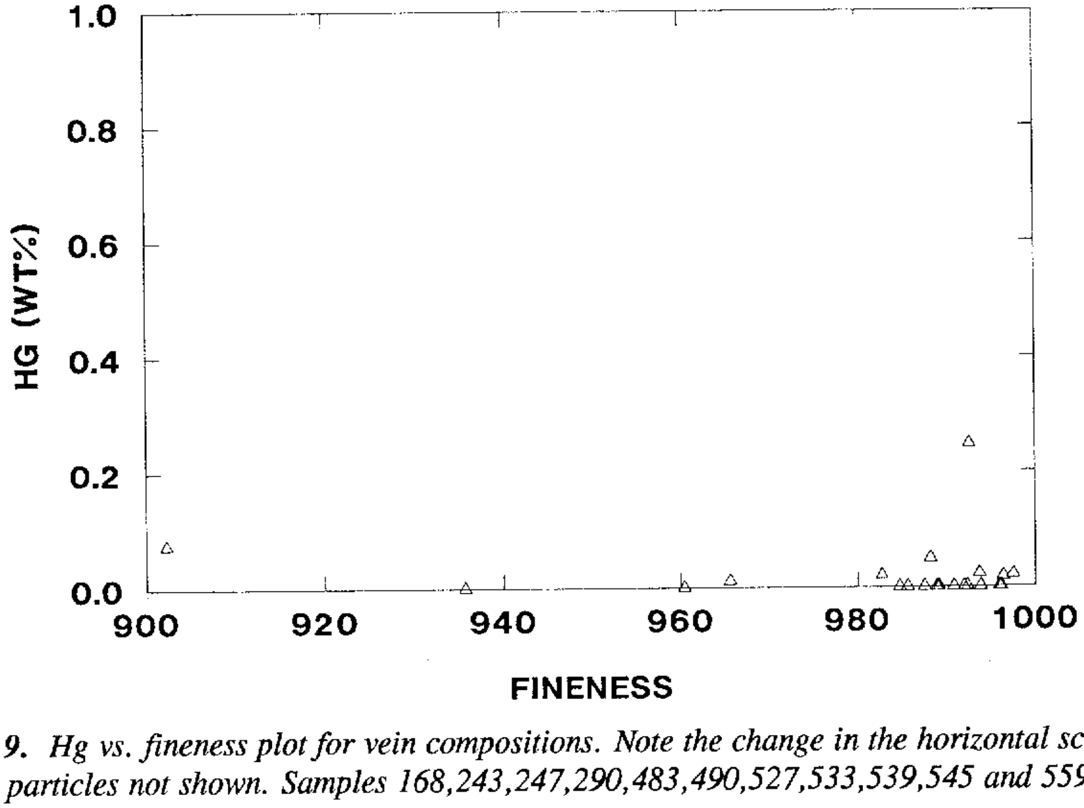

Figure 9. Hg vs. fineness plot for vein compositions. Note the change in the horizontal scale. 7 of 31 particles not shown. Samples 168,243,247,290,483,490,527,533,539,545 and 559.

reflecting a chemical and/or thermal evolution of the fluid. There is a weak correlation between samples with high fineness veining and low fineness inhomogeneities. The majority of the particles with these features occur on Eldorado Creek into the head of Quartz Creek, a location associated with large variations in gold composition. Other significant locations are the head of Hunker Creek and Jackson Hill, the latter perhaps reflecting the characteristics of lodes now eroded.

Mustart (1965) describes an Au-Sn alloy which from his descriptions appears to be a man-made alloy. One multiphase particle of an Au-Pb alloy was found during the present study in the Jackson Hill sample (AU524). It has low to moderate Hg and Cu contents, but from 36-66 wt% Pb. Although there is insufficient data to determine if this is the product of contamination or represents a natural occurrence, contamination is suspected.

Cu is generally only useful for fingerprinting gold when the fineness is greater than about 900 (McTaggart and Knight, 1990). Cu data is therefore only shown on compilation plots (Figs. 6 and 7). It is apparent in these plots that the amount of Cu increases with higher fineness in the same systematic way that it does for southern British Columbia gold specimens (Knight and McTaggart, 1990), and in Russia (Samusikov, 1983). Cu is present up to 0.15 wt% in gold with a fineness >900 and is usually present in gold with a fineness >800. Cu is not present above the detection limit for gold <750 fine.

Although Cu content has a limited use in outlining gold populations in the Klondike, it does provide insight into the possible sources or origins of placer gold. For example, the formation of high fineness (>980) veins in placer gold particles (such as those shown in Figure 8) has been shown to be a pre-rim formation (Petroyskaya and Fastlovich, 1955), but the exact timing was unknown. It could have formed in the late stages of lode formation or within the oxidized zone, although Petroyskaya and Fastlovich (1955) favored an origin in the oxidized zone during the weathering of the lode. If the veins were formed under similar conditions to the host gold particle then the Cu content in the veins would be expected to follow the trend seen in the host gold. Cu in these veins is always below detection limit. Rims, which have a similar low Cu content to the veins, are believed to represent the stable composition of gold in the surficial environment (see section on rims for discussion). The low Cu content in the veins therefore suggests formation at or near surficial conditions. Their structure suggests that they are associated with grain boundaries. We speculate that they may have formed by precipitation within the gold particle disrupted along grain boundaries either at a very late stage in the formation of the lode or during the oxidation of the lode under surficial conditions.

Lode gold

The fineness of lode samples analyzed in this study (Figure 6) ranges between 350 and 870, with Hg varying from 0 to 9.5 wt%. The majority of the lodes sampled, however, fall between 750 and 850 fine with Hg < 0.2 wt%. The lodes can be described in terms of several main compositional types (Figure 12). In order to simplify the following discussion, each of these types is named after the lode occurrences which best typifies each compositional type.

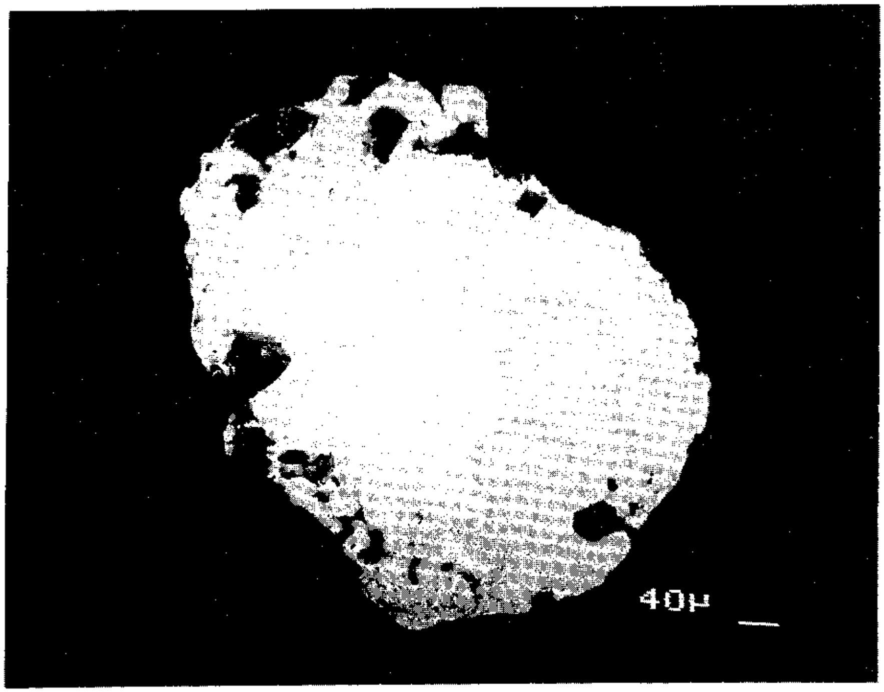

Figure 10. *Backscattered electron photomicrograph of a multi-phased gold particle. Note the gradational contact between the gold of different compositions. The lighter the tone the higher the fineness. Sample # 533.*

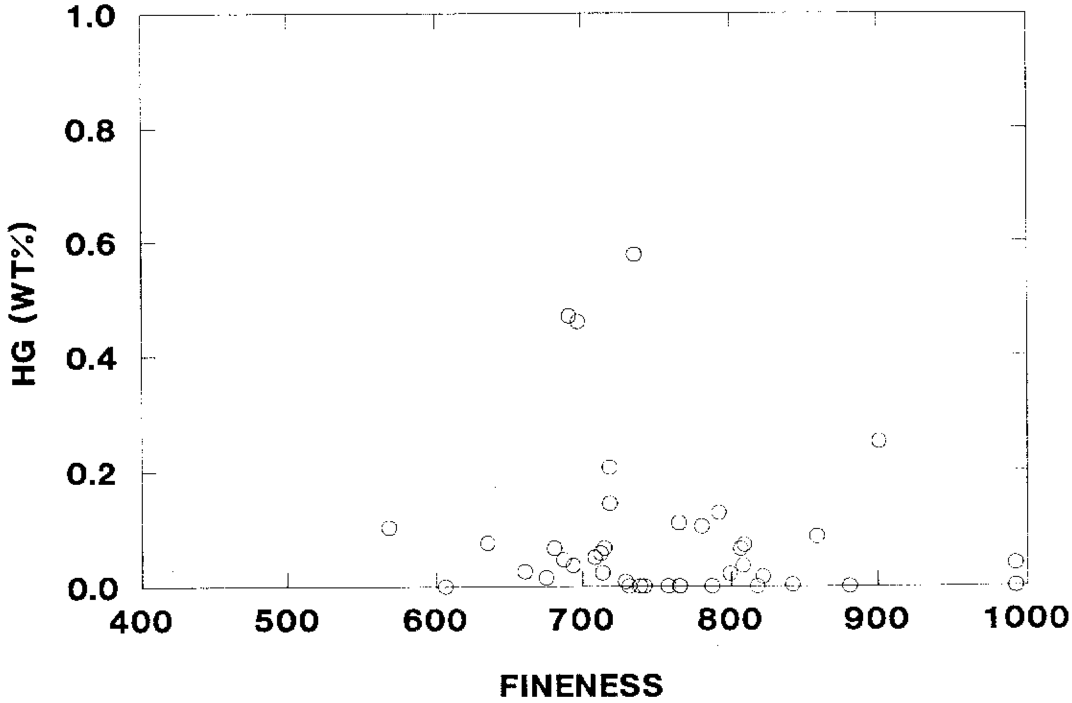

Figure 11. *Hg vs. fineness plot for 40 low fineness inhomogeneities analyzed in placer gold particles. Samples 483,490,524,525,527,528,533,539,541,547,542,545,and 559.*

The *LONE STAR-HUNKER DOME type* lode gold as exemplified by 113 analyses from these two occurrences ranges from 800 to 860 fine with no Hg. Data from both occurrences have a mean fineness of about 840.

The *MITCHELL type* lode gold, based on 28 analyses from the MITCHELL occurrence, has a mean fineness of 810 and contains no Hg. It falls within the LONE STAR-HUNKER DOME group but has a slightly lower mean fineness.

The *AIME type* lode gold is similar to the LONE STAR-HUNKER DOME type of gold but has Hg to 0.2 wt% and fineness of 850 to 880 with a mean of about 860. This type is based on 172 analyses from 4 hand specimens from the AIME mine dump.

The *HILCHEY type* lode gold is poorly sampled (6 analyses). It is represented by two samples from the HILCHEY occurrence and one from the PIONEER occurrence. Fineness values for this type range from 750 to 800 fine, with Hg generally absent except for a single high value of 0.6 wt%.

The *VIRGIN type* lode gold is represented by 71 analyses from the VIRGIN occurrence. Sample fineness varies from 650 to 750 with a mean value of about 700. Hg varies widely, from 0.3 to 1.2 wt%. This type is used to refer to all low fineness types of lode gold in the Klondike, even though the mean fineness and Hg values may differ from the Virgin.

The *VIOLET type* lode gold, from the VIOLET occurrence, has fineness values between 350 and 800, with Hg from 0.8 to 10.0 wt% based on the analyses of 19 particles. As discussed above, VIOLET type gold consists of two distinct phases. One has a fineness of 800 and Hg from 0.7 to 2.0 wt%, and the other has a fineness of 350 to 750, and Hg contents rising from 0.7 wt% at 750 fine to 9.5 wt% at 350 fine.

Placer Gold

Most placer gold samples from the Klondike yield compositions that can be described in terms of various combinations of the lode gold compositional types listed above (Figs. 6 and 12). Placer gold compositions are discussed on a creek by creek basis, and are interpreted in light of observations concerning the nature and possible provenance of the placer particles.

For completeness the signatures of placer gold which have no known lode equivalent (UNKNOWN types) are also shown in Figure 12. The UNKNOWN types may represent mixtures of sources; however the narrower the range of fineness and Hg values, the more likely the signature represents a single source. They include the following:

UNKNOWN 1 - from sample 302 near the head of Sulphur Creek. Fineness ranges from 750 to 850, with Hg to 0.2 wt%.

UNKNOWN 2 - has a fineness of 800 to 850 with Hg from 0.2 to 1.0 wt%, and is defined by sample 170 on upper Sulphur Creek.

UNKNOWN 3 - has a fineness of 750 to 850 with no Hg, and is recognized in samples from upper Dominion Creek. This type could be considered to be a combination of LONE STAR-HUNKER DOME type with HILCHEY type but occurs as a distinct unit.

UNKNOWN 4 - has a fineness of 700 to 850 with Hg to 0.3 wt%, and occurs in sample 490 from the upper reaches of Quartz Creek.

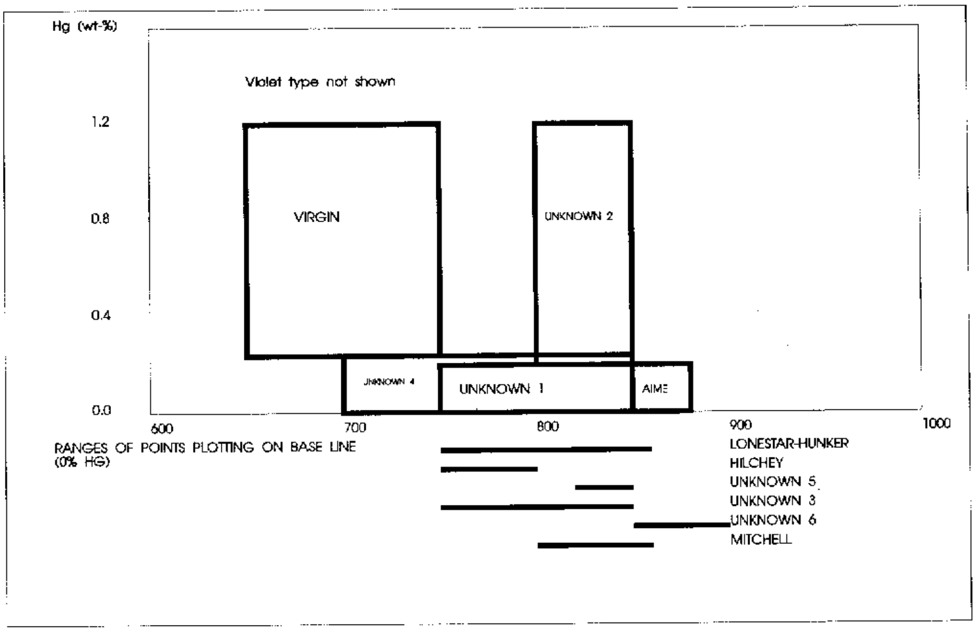

Figure 12. *Compositional signatures of populations recognized in placer and lode gold samples from the Klondike District.*

UNKNOWN 5, - from sample 539 on upper Hunker Creek, has a fineness of 820 to 850 and contains no Hg. This could be considered a LONE STAR-HUNKER DOME type but the narrower spread in fineness values suggests that a separate population should be distinguished.

UNKNOWN 6 - has a fineness of 850 to 900 and no Hg, and is defined by sample 539 from upper Hunker Creek.

Bonanza and Eldorado creeks (Figure 4a) were the richest placer creeks in the Klondike and produced the largest nuggets. The gold was typically coarse and rough, particularly in the upper reaches of the creeks. McConnell (1905) concluded, based on angularity and richness of the placers, that Victoria, Ready Bullion and O'Neil gulches were the sources for placer deposits in Upper Bonanza creek. He considered that Bonanza and Eldorado creeks derived much of their gold from a common lode source on the divide between the two. McConnell (1905, 1907) concluded that much of the gold in lower Bonanza Creek placers was reworked from paystreaks in the White Channel Gravels.

The compositions of placer gold from recent stream gravels in the Bonanza and Eldorado drainages can be defined as a mainly LONE STAR-HUNKER DOME type gold with variable components of HILCHEY, VIRGIN and UNKNOWN 3 type gold. The relatively low fineness and sporadically high Hg VIRGIN type gold occurs only in Eldorado Creek and to a lesser extent on lower Bonanza Creek (Figure 4a). VIRGIN type gold is broadly similar to the low fineness component of the VIOLET type, and it is likely that the VIRGIN type component in these drainages is from the VIOLET or related occurrences.

Placer gold samples recovered from White Channel Gravel deposits within the Bonanza and Eldorado drainages (Figure 4a) were obtained from Jackson, Trail and Cripple hills (Figure 4a). The Jackson Hill and Cripple Hill samples consist of UNKNOWN 3 plus VIRGIN type gold, and the Trail Hill sample consists mainly of LONE STAR-HUNKER DOME type gold with a scattering of outliers from undetermined sources.

Placer gold recovered from the Bear Creek drainage (Figure 4b) is rough and contains a small proportion of crystalline gold (Debicki, 1983). Bear Creek gold is marked by variations of the VIRGIN type. A sample from the upper reaches of the creek has a significant number of particles of 600 to 700 fine with low Hg.

Placer gold in recent stream gravels in the Hunker Creek drainage (Figure 4b) consists of a combination of UNKNOWN 3, 5 and 6, together with a small proportion of LONE STAR-HUNKER DOME and VIRGIN type gold.

Gold recovered from White Channel Gravel deposits on Dago Hill (Figure 4b) consists of the HILCHEY and VIRGIN types, whereas Australian Hill yields gold of the UNKNOWN 3 and VIRGIN types.

Gold in Dominion Creek (Figure 4c) is coarse and angular in its upper reaches, but generally decreases in size and angularity downstream. Most tributaries of Dominion Creek are low grade. Gold grades in Dominion Creek gravels were very low from the mouth of Jensen Creek to the mouth of Gold Run Creek, where a very rich paystreak consisting of relatively coarse, rough gold enters the main valley. No samples of placer gold were available from the upper reaches of Dominion Creek, and only one sample from the middle portion of the creek (Figure 4c). This sample consists of UNKNOWN 3 type gold.

Placer gold from Gold Run Creek has a AIME type signature with a scatter of fineness values between 750 and 850 and Hg generally between 0.1 and 0.5 wt%.

Placer gold from Sulphur Creek (Figure 4c) consists of UNKNOWN 1 and 2 type gold. Quartz Creek placer gold consists of UNKNOWN 4 plus a clustering of angular particles at 800-850 fine with 0.3-0.6 wt% Hg (similar to UNKNOWN 2) and a scattering of high Hg values at about 500 fine (perhaps a VIRGIN type).

Indian River placer gold is typically very small in size and worn. Fineness values from Indian River gold vary widely, and Hg contents range from absent to 0.4 wt%. Most samples are of UNKNOWN 1 and 4 and AIME type. Indian River gold at the mouth of McKinnon Creek (Figure 4c) is unique in that the fineness spread is from 500 to 950. For those analyses which contain significant Hg, the fineness drops from 900 to 600 as the Hg content rises from 0.1 to 0.4 wt%. This is the only drainage with a significant proportion of gold of fineness >900.

Rims on Gold Particles

No rims were detected on the lode gold samples using a reflected light microscope, and a brief investigation of a few particles from the AIME occurrence using back-scattered imaging did not reveal any rims within the resolution of this technique. It is thought that this is typical of all the lode gold.

In contrast, nearly all of the placer particles examined in this study have at least a partial rim of nearly pure gold. Although the rims are difficult to analyze because they are so thin (usually <10μ), we attempted to analyze even the thinnest rims. This information was used to determine whether the samples had been contaminated during the sample preparation procedure (Knight and McTaggart, 1990). Because of the large excitation volume relative to the rim thickness, and the possibility of low level contamination by Ag from the core during polishing, the Ag compositions for the rims are considered to represent maximum values. The composition of these rims is >980 fine with both Hg and Cu below detection limit. The composition of overthickened rims (>10um) found in placer deposits from altered White Channel Gravels is >988 fine with both Hg and Cu below detection limit.

In some placer gold particles (mostly in the samples from altered White Channel Gravels or in recent stream gravels reworked from these altered gravels), rims surround more than one core. These core fragments commonly consist of a few large fragments which outline the original shape of the core or, especially in samples from the altered White Channel Gravels, occur as numerous small to medium sized fragments scattered through a porous rim material (Figure 13). The compositions of these multiple cores (Table 2) are essentially identical, even in the altered White Channel Gravels, suggesting that they originally formed a single continuous core.

Other Observations

Only a cursory investigation of mineral inclusions within the gold particles was undertaken. Pyrite is the most common sulphide inclusion found in the placer gold, and is also the most common sulphide seen in the gold recovered from crushed lode specimens. Galena was observed in the AIME lode specimens and in a single specimen from Eldorado Creek. Mustart (1965) reports the presence of arsenopyrite inclusions from Discovery Hill in a 'dendritic' nugget, however no arsenopyrite was observed in our study. The most common silicate inclusion is the gold particles in quartz. Boyle (1979) reported that much of the gold contained quartz attachments which in his opinion was of the same type as seen in the quartz veins of the district. Other silicates and oxides observed include mica (muscovite?), K-feldspar, magnetite and kaolin.

No work was done in this study on the internal structure of gold particles. Mustart (1965) reported that most of the gold in the Klondike consists of a granular (apparently polygonal from photomicrographs in Mustart [1965]) texture where the subgrains were of unequal size. Some samples contain particles which etched in a octahedral pattern, with each grain having a different orientation of the octahedral axes. Mustart's observations are similar to those reported from other studies of placer gold (e.g., Petrovskaya and Fastalovich, 1955). Mustart (1965) also reported the presence of dendrites in a crystalline specimen from Discovery hill which was subject to prolonged etching.

The shape of placer gold particles in the Klondike was investigated in considerable detail. In general, specimens near their source (headwaters of the creek or lode) are

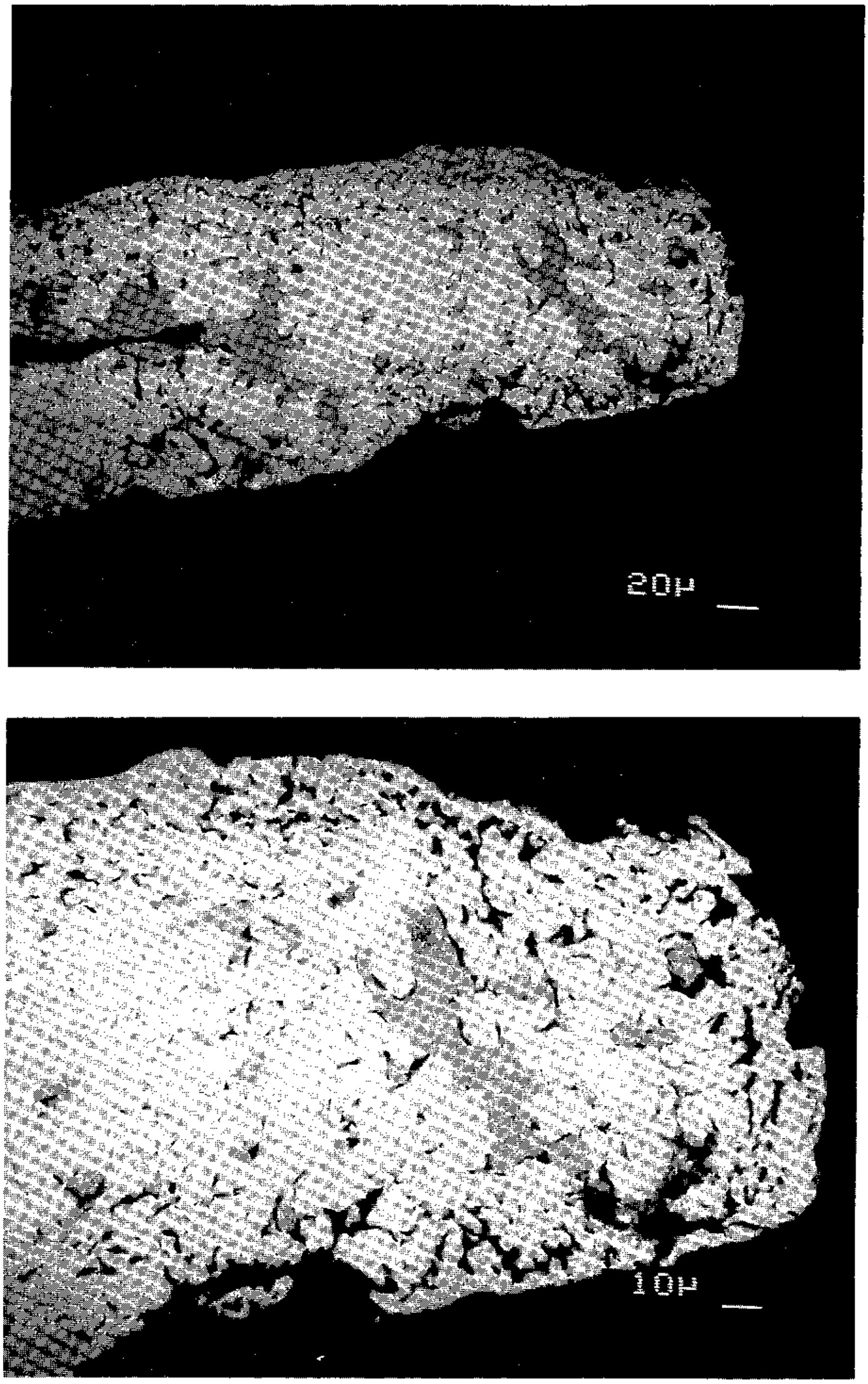

Figure 13. Backscattered electron photomicrograph of the multiple cores in a porous placer gold particle from altered White Channel Gravel on Australian Hill. Pores are black. The grey areas are remnants of core of the original folded particle. In 13a it is possible to discern the original rim as a $<10\mu m$, non porous zone on the outside of the particle. Figure 13b illustrates the variation in core remnant size and the pores associated with them. Sample AU 538-2-20.

TABLE 2. Composition of cores and rims in multiple cored particles.

* Difference = (other core) - (main core)
# Not used in calculations

NAME	MAIN CORE		OTHER CORES		DIFFERENCE*		SURROUNDING RIM		
	HG	FINE	HG	FINE	HG	FINE	HG	FINE	
168-02-06	0.00	617.52	0.00	613.83	0.00	-3.69	0.01	994.31	
168-03-08	0.00	818.89	0.01	807.93	0.01	-10.96	0.00	984.61	
168-10-10	2.51	494.75	2.92	496.86	0.41	2.11			
168-09-10	0.00	819.77	0.01	818.45	0.01	-1.33	0.00	999.02	
299-01-01	0.00	803.23	0.02	805.33	0.02	2.10	0.00	994.45	
303-01-21	0.02	859.50	0.00	860.95	-0.02	1.45	0.00	977.44	
303-01-22	0.00	772.18	0.06	772.07	0.06	-0.11			
305-02-01	0.04	816.86	0.00	815.38	-0.04	-1.48	0.00	997.02	
305-02-04	0.80	906.73	0.74	908.22	-0.06	1.49	0.03	982.32	
			0.84	908.26	0.04	1.53			
305-02-09	0.62	672.38	0.60	668.72	-0.02	-3.66	0.01	991.07	
305-02-18	0.04	806.27	0.06	772.05	0.00	-34.22	0.00	996.39	
305-02-19	0.00	675.75	0.09	687.30	0.09	11.54	0.00	992.10	
			0.02	686.85	0.02	11.10			
306-01-02	0.01	818.05	0.04	818.51	0.03	0.45	0.00	986.93	
							0.04	998.26	
306-01-05	0.01	778.70	0.00	774.44	-0.01	-7.27	0.00	980.88	
			0.04	772.94	0.03	-5.76			
			0.00	951.41	-0.01	172.71			#
			0.00	978.53	-0.01	199.83			#
306-01-11	0.00	781.22	0.00	783.62	0.00	2.40	0.00	999.93	
			0.01	818.41	0.01	37.19			
306-02-14	0.07	834.06	0.24	834.69	0.16	0.63	0.00	980.94	
306-02-19	0.02	807.09	0.00	806.93	-0.02	-0.16			
524-01-07	0.01	764.85	0.00	764.85	-0.01	0.00	0.00	989.04	
			0.01	767.67	0.00	-0.18			
525-03-08	0.00	704.75	0.00	695.04	0.00	-9.72	0.01	997.74	
525-03-24	0.01	735.55	0.01	735.31	0.00	-0.24	0.01	988.64	
second phase	0.00	553.71							
526-04-22	0.01	854.37	0.02	847.17	0.01	-7.20	0.01	985.49	
			0.00	849.05	-0.01	-5.32			
			0.01	845.87	0.00	-8.50			
526-05-23	0.01	829.04	0.02	826.38	0.01	-2.66	0.00	996.31	
			0.02	828.10	0.01	-0.94			
534-01-01	0.00	698.56	0.01	724.54	0.01	25.98	0.00	970.73	
			0.00	721.24	0.00	22.68			
534-01-06	0.00	549.27	0.00	548.45	0.00	0.83	0.00	991.92	
			0.00	550.62	0.00	1.35			
534-01-17	0.01	831.67	0.02	830.80	0.01	-0.87	0.00	994.15	
			0.01	830.83	0.00	-0.84			
534-01-21	0.01	702.12	0.00	701.52	-0.01	-0.60	0.00	991.64	
534-01-23	0.00	649.29	0.01	650.57	-0.01	1.28	0.00	992.50	
534-01-28	0.01	863.59	0.02	864.82	0.01	1.24	0.00	990.91	
			0.00	865.41	-0.01	1.82			
534-01-32	0.03	790.36	0.02	798.06	-0.01	7.70	0.01	993.07	

TABLE 2. Continued.

NAME	MAIN CORE		OTHER CORES		DIFFERENCE*		SURROUNDING RIM	
	HG	FINE	HG	FINE	HG	FINE	HG	FINE
534-01-33	0.00	789.96	0.00	790.53	0.00	0.57	0.00	984.12
			0.01	798.34	0.01	8.38		
534-01-34	0.00	691.54	0.00	691.48	0.00	-0.06	0.00	982.65
538-01-01	0.00	640.12	0.00	640.50	0.00	0.38	0.00	992.27
			0.00	639.88	0.00	-0.24		
538-01-02	0.03	768.18	0.03	753.84	0.00	-14.34	0.00	994.95
			0.01	772.59	-0.02	4.41		
538-01-06	0.02	787.35	0.02	774.75	0.00	-12.61	0.00	984.44
538-01-07	0.02	810.28	0.01	809.87	-0.01	-0.41	0.00	998.32
538-01-09	0.01	765.40	0.00	763.57	-0.01	-1.18	0.00	995.41
538-01-11	0.01	647.92	0.00	650.59	-0.01	2.67	0.00	993.14
			0.01	649.97	0.00	2.05		
538-01-15	0.00	716.46	0.01	718.17	-0.01	1.71	0.02	989.37
538-02-02	0.01	675.15	0.01	673.38	0.00	-1.77	0.00	938.40
538-02-04	0.00	667.75	0.01	692.85	0.01	25.10	0.01	982.31
538-02-11	0.01	776.06	0.01	777.26	-0.01	1.20	0.01	980.85
			0.02	777.05	0.01	0.99		
538-02-19	0.01	801.82	0.00	802.79	-0.01	0.97	0.01	997.53
538-02-20	0.00	654.90	0.00	663.86	0.00	8.95	0.02	991.30
			0.01	678.79	-0.01	23.89		
			0.00	657.31	0.00	2.40		
538-02-25	0.01	809.20	0.00	809.86	-0.01	0.66	0.00	983.50
			0.01	810.26	0.00	1.06		
538-03-05	0.00	656.77	0.01	661.47	0.01	4.70	0.01	985.32
			0.00	658.69	0.00	1.92		
			0.00	660.04	0.00	3.27		
538-03-09	0.01	700.16	0.00	669.19	-0.01	-30.96	0.00	992.15
538-03-17	0.00	838.71	0.01	837.55	0.01	-1.15	0.00	995.96
538-03-22	0.00	561.34	0.00	579.78	0.00	18.44	0.00	955.60
538-03-23	0.00	745.99	0.02	745.73	0.12	-0.26	0.00	952.81
538-03-27	0.02	815.05	0.02	816.60	0.00	1.55	0.00	994.48
538-04-01	0.00	720.65	0.02	710.01	0.02	-10.64	0.01	996.15
538-04-03	0.00	644.87	0.00	644.20	0.00	-0.67	0.00	995.65
			0.01	645.23	0.01	0.36		
			0.00	642.00	0.00	-2.06		
538-04-08	0.01	606.57	0.00	608.13	-0.01	1.57	0.00	991.04
538-04-09	0.00	713.83	0.011	714.93	0.01	1.10	0.00	992.42
538-04-17	0.01	823.10	0.002	822.13	-0.01	-0.98	0.02	985.12
			0.000	824.25	-0.01	1.14		
538-04-19	0.01	682.59	0.032	679.34	0.03	-3.25	0.01	985.01
538-04-21	0.01	741.60	0.016	758.93	0.01	17.33	0.00	993.05
						AVERAGE OF:		
					82 DIFFERENCES			55 RIMS
					0.01	-0.04	0.01	988.02
						STD DEVIATION		
					0.05	10.04	0.01	11.44

thicker and less round than those further from the source. This is in agreement with observations by other workers in the area (e.g. McConnell, 1905, 1907; Boyle, 1979). Details of the shape of placer gold from the Klondike and conclusions derived from the shapes are given in Part 2 of this bulletin. The conclusions about the source of the placer gold based on shape are consistent with those based on the composition data.

A few notes on the more unusual shapes are given here. Templeman-Kluit (1982) noted the crystalline nature of the gold on Dago Hill, and Debicki (1983) reported relatively abundant octahedral gold in Bear Creek placer deposits. Tyrrell (1912) described both octahedral gold particles and "hopper" crystals from Victoria Gulch. Mustart (1965) shows a photograph of a large, subangular gold particle from Discovery Hill which he describes as including "hopper shaped" crystalline form. This locality yielded a bulk fineness value of about 700. In this study, octahedral crystals were found in samples from Bear and Eldorado creeks, and in lode specimens from the LONE STAR mine. The composition of the crystals from Bear Creek falls within the general population of non-crystalline gold from that sample, as well as the VIRGIN lode specimens (about 650 fine). The single well developed octahedron recovered from sample AU545 on Eldorado Creek had a core fineness of 633 and an edge fineness of 604. The perfect octahedron from the LONE STAR lode had a composition of 851 fine. Much of the gold from one of the AIME lode specimens had partially developed octahedrons.

Debicki (1983) speculated that the crystals in Bear Creek were formed by *in situ* precipitation of gold within the stream gravels. The analyses reported here for this crystalline gold shows that they fit the VIRGIN signature, which strongly suggests that they were derived from local lode sources. The presence of octahedral gold particles in the LONE STAR lode and partial octahedrons in the AIME lode, together with the compositional data, indicate that all the octahedra in the placer deposits have a lode source.

Non-planar dendritic crystal forms are common in Klondike placer gold (see Part 2). The best examples were seen in placer specimens from Dago Hill, upper Hunker Creek and near the mouth of Gold Run Creek. Some of these dendrites appear to be groupings of octahedrons whereas others appear to have formed by the precipitation of gold in fractures controlled by the mineral host.

Although nuggets were not very common in the Klondike, large (thumbnail size and larger) gold particles were not rare, particularly on upper Bonanza and Eldorado creeks. Eldorado Creek has a low bullion fineness. McConnell (1907) reported fineness values which range from 539-670 for 5 nuggets from Bonanza Creek and from White Channel Gravel deposits on Trail and Dago hills. The fineness values are all low relative to the fineness values we have measured for lode gold throughout the Klondike. Furthermore, all the +10 mesh particles give values <600 fine. We tentatively conclude that the majority of the nuggets had their origin in the lower fineness lodes.

Gold in Altered White Channel Gravels

Several workers have argued that some, and perhaps most, of the placer gold recovered from large areas of highly altered White Channel Gravels on lower Hunker

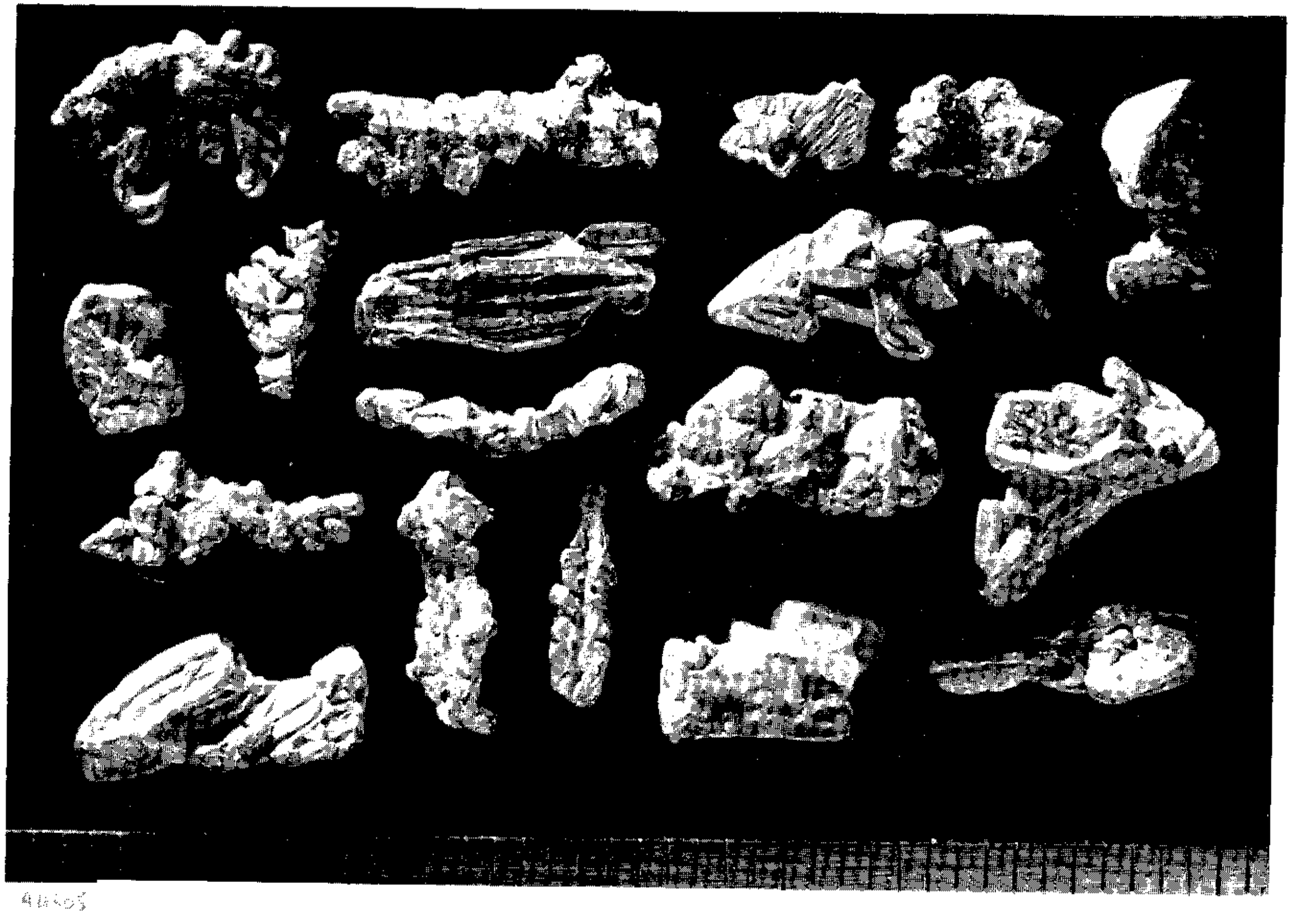

Figure 14: *A selection of angular crystalline nuggets from Dago Hill (Sample AU 305). Scale has 1 mm spacing. Note the rounding of the extremities for some of the particles (photo E. Montgomery).*

Creek was precipitated *in situ* during the alteration event (e.g. Tempelman-Kluit, 1982; Dufresne et al., 1986; Dufresne, 1986). The most detailed study of the altered gravels has been on Dago Hill, which is known to produce large, angular gold particles, some of which have crystalline outlines (see Figure 10 in Templeman-Kluit, 1982). A study of 18 selected larger (≥ 2 mm) crystalline gold particles (Figure 14) is reported here.

The particles typically have a non-planar dendritic form consisting of linked crystals or crystal fragments. The crystals are octahedral in form which in some cases have a hollow outline. Attachments to the particles include quartz (as noted by [McConnell, 1905]) and rare amethyst. Where the quartz has recently been removed a hexagonal cavity with bright, smooth faces is left. In some instances fragments of the quartz remain in the cavity. No fluvially rounded particles were found included in the gold to suggest that the gold was precipitated in place. All of the particles have rounded extremities which have a matte texture. This texture is typical of fluvially-transported gold. Some of the gold particles have a coating of limonite which covers the rounded, apparently worn surface, indicating that the limonite was deposited after transport. The exterior of all particles is golden in colour, including cavities, but those that were sectioned (6) had a silvery coloured interior, indicating a low fineness. Sections do not show the development of very thick complete rims, which is commonly seen on the smaller gold particles from the same placer deposit. Instead the sections show that the particles have rim fragments to 3 microns thick. However the presence of a yellow coloured external surface indicates that there are complete rims present but that the rims are < 1 micron thick, below the resolution of the study methods used. The cores of the 6 sectioned particles have a low fineness (500-700) and high Hg content (0.15 - 0.35, - see Appendix D, AU305). Based on the above evidence, we conclude that the majority of these particles were formed by the precipitation of gold between the crystals of quartz or some other host in a drusy cavity within a lode, and not by precipitation in the placer host. The gold quartz masses were subsequently eroded and transported to their present location in the White Channel Gravel host. During transportation the exposed gold was abraded and smeared to produce a matte texture. Substantial rim formation was limited to this exposed gold. In the White Channel Gravels, some rim formation may also have taken place during alteration of the gravel when warm reactive water could have moved onto the boundary between the gold and the encapsulating host. At or after this time the limonite would have been precipitated. The gold was then liberated from its host during mining. An estimate of the distance of transport based on shape (Part 2) will be biased because the sample probably represents gold which was transported partially or wholly encapsulated in quartz. The composition data shows that the gold is in part (3 analyses) from a population typical of Dago Hill while in part (3 analyses) from a unique population with a fineness around 500. Neither of these groupings are seen in the upper Hunker Creek samples. It is suggested that the source for the crystals and part of the Dago sample lies to the south, perhaps up Last Chance creek. The source may be related to the source of the nugget of 539 fineness from Treasure Hill reported by McConnell (1907). It is possible that the source is related to the Eocene volcanics exemplified by the BREMNER occurrence on Last Chance Creek, however similar rocks on Hunker creek do not have significant gold values. In addition the fineness distribution shows affinities to the VIRGIN type occurrence.

DISCUSSION

The similarity of the compositional signatures from the lode and placer gold samples is interpreted to mean that the placer gold had its ultimate source in the lodes, both those presently exposed and similar lodes that may have been completely removed by erosion.

Each creek has a characteristic compositional signature. This signature may vary somewhat over the length of the creek (e.g., Sulphur Creek), as noted both in this study and by Hester (1970), or may vary widely (e.g., Bear Creek). The variation of the signature between adjacent creeks is larger than the variations down a single creek. The creek signatures have been described in terms of 12 basic signatures. Six of these signatures can be directly related to those of known lode sources in the Klondike. In general the closer a sample is taken to the headwaters of a creek, the more distinct the separate signatures which comprise the overall creek signature becomes. Conversely the further a placer sample is collected from the head of a creek, the more homogeneous and the larger the population spread in the sample becomes. This is interpreted to be the result of a mixing of populations downstream, and is particularly pronounced for creeks in the Klondike which drain to the south. In north-draining streams the signatures tend to remain more distinct downstream. All of these observations can best be explained by the placer gold being derived dominantly from lodes located near to the headwaters of the creek. The principal exception is Hunker Creek. This does not imply, however, that additional gold sources may not exist part way down the creeks, only that their entry is masked by the accumulation of gold from upstream. A discussion on the limitations of shape to separate these contributions is given in Part 2.

McConnell (1907) concluded that variation in the fineness of the placer gold was the result of variation on the fineness of the lode source. He postulated source areas that are very similar to those proposed here. He suggested that two low fineness lode gold sources could be identified in the Klondike, one west of lower Hunker Creek on the ridge between Hester, Last Chance, Henry and Bear creeks, and another near Big Skookum Gulch west of Grand Forks on Bonanza Creek. McConnell (1907) also identified a high fineness source in the King Solomon Dome area that provided placer gold to upper Dominion, upper Hunker, Sulphur and Gold Bottom creeks.

The placer gold composition data presented here, together with the shape data (Part 2), composition of the known lodes and the bullion data compiled in Figure 2 can be used to postulate the general source areas for much of the placer gold. The main characteristics of each of these sources are listed below.

Bonanza-Eldorado area. Gold from this source area is 700-850 fine (mostly 750-850 fine) with no Hg. A minor signature of 650-750 fine with Hg to 1.0 wt% is also present in this area. It is likely derived from the French Gulch-Golden Gulch area (west of Eldorado Creek), with a fineness of 650-750 and Hg to >1 wt%.

Bear-Last Chance area. This area yielded gold that is 600-800 fine (mainly <750 fine) with Hg to about 2.0 wt%.

Hunker Dome area. Gold from this area is 750-850 fine with Hg up to 0.2 wt%.

Southwest King Solomon Dome area. Gold is 700-900 fine with Hg up to 0.6 wt%. The high Hg population in Sample AU170 from middle Sulphur Creek and the AIME deposit may be included in this group, perhaps extending this source area as far as the AIME occurrence.

The division into distinct high and low fineness sources is supported to some extent by the cumulative plot (probability plot) from Hester's (1979) Figure 6. This figure shows that two general types of gold were recovered from Klondike dredging operations; a low fineness type between about 750 and 780 comprising about 10% of the gold, and a high fineness type between about 780 and 840 comprising about 90% of the gold recovered.

Hester's (1979) data may be somewhat skewed to higher fineness values, because it is based on bulk placer bullion assays, and thus includes high fineness rims which likely comprise a significant fraction of the smaller particle fraction of the gold recovered.

The high fineness areas defined by our work do not seem to have a uniform fineness but appear to show a systematic variation in mean fineness from northeast to southwest. For the King Solomon Dome area the overall decrease in fineness to the southwest is inversely correlated with Hg content. In the Bonanza-Eldorado area the decrease in fineness to the southwest is even and gold is generally Hg-free. Near Eldorado Creek the low fineness component in the placer (and lode) gold shows a sudden appearance of Hg at high levels. This variation and range of composition should be related to fundamental factors controlling deposition of gold in the lodes. The regular change in composition for the high fineness areas could represent a regional variation in the conditions of formation. There may be a correlation between the changes in fineness and the changes in fluid inclusion characteristics reported by Rushton (1991) but the data is insufficient. The differences between the high and low fineness areas could be interpreted to indicate either different episodes of mineralization or sudden changes occurring during a single mineralizing event. It appears that on a particle scale the low fineness gold is younger than the high fineness gold. It is not clear if this reflects regional trends. There is a regional variation in fineness within the low fineness group of placer gold analyses, but there is insufficient data to detail regional trends.

General Characteristics of Klondike Lode Gold

The data indicate that for Hg-absent lodes, fineness is restricted to less than a 100 fineness unit spread. Particles from a single specimen within a lode where the gold has a low Hg content show a much smaller spread in fineness (10 units) than the lode. The spread in fineness from hand specimens for lodes where the gold has a high Hg content (e.g., VIRGIN) is much larger than for the Hg poor lodes, with lower finenesses having the higher Hg values. The lower fineness source areas also have the highest Hg values. It appears that the Hg content within a lode changes in two ways, as illustrated by the Sulphur creek 170 placer sample. Either the fineness is relatively constant even though the Hg content changes, or the fineness content decreases as the Hg content increases. Because this observation is based on a placer sample it must be considered tentative even though the available data from the lodes supports this conclusion. For the lodes within the low fineness area the Hg increases with decrease in fineness (e.g., VIRGIN, VIOLET).

The characteristics of Hg free lodes are interpreted to reflect conditions where the formation of a lode was constant with respect to Hg, Au, Hg and Cu, although geochemical conditions in different parts of the lode could vary slightly from one another. If Hg is present it appears that the Hg either records conditions of formation which affect the Hg content only, or, more commonly in lower fineness lodes, it records the conditions of formation where the Hg and Ag content are related. Based on the work of Healy and Petruk (1989) and Shikazano (1985) it appears that one of the principal variables linking the decrease in gold content to an increase in Ag and Hg content is temperature, with decreasing temperatures being associated with decreasing fineness. Whatever the cause the homogeneity of most of the gold suggests that during deposition conditions were stable. This suggests that for each fineness group that stable different conditions in different parts of the system were more important than a changing system.

The fineness values and their range do not fit the characteristics of gold from an epithermal source (Shikazono, 1985). They are more in keeping with gold from a mesothermal source (e.g., Nelson et al., 1990; Knight and McTaggart, 1986) in keeping with observations made on the lodes by Mortensen et al. (1992) and Rushton (1991).

Origin of Klondike Placer Gold

Most previous workers maintain that known lode gold sources in the Klondike are insufficient to provide the enormous amount of gold that has been recovered from Klondike area placer deposits. The potential sources that have been postulated for the placer gold fall generally into the following groups:

1) gold-bearing mesothermal quartz veins within metamorphic rocks (either already discovered, still undiscovered or completely removed by erosion);

2) gold-bearing epithermal veins and alteration zones associated with Eocene quartz-feldspar porphyry bodies;

3) disseminated gold in pyritic felsic schist such as that at LONE STAR;
4) gold-bearing epithermal alteration zones and vein systems in White Channel Gravels and in underlying bedrock;

5) gold grown *in situ* in recent alluvial and/or colluvial deposits.

The chemical signature determined in this study for both placer and lode gold from the Klondike clearly shows that all but the very low fineness gold is typical of gold from "mesothermal" vein systems (option 1). In general epithermal gold deposits show a much wider variation in fineness than mesothermal lodes (Shikazono, 1985, Shikazono et al., 1986, 1987). Field observations of lodes such as the VIRGIN in the Klondike which yield the lowest fineness values also indicate a mesothermal origin, (as does the fluid inclusion and light stable isotope data for this occurrence reported by Rushton [1991] and Mortensen et al. [1992]).

The presence of planar dendritic crystals of gold is considered by some workers (e.g., Petrovskaya, 1971) to be an indicator of a shallow level of formation of the lode. However, as discussed above, dendrites in Klondike placer concentrates are not planar. Specimens seen from Hunker Creek (24 Pup), Quartz Creek and Victoria Gulch (7 Pup) have a planar tendency, however this morphology appears to have formed on fracture and cleavage planes in the host mineral. There is therefore no strong evidence to indicate an origin other than mesothermal for the gold studied. Although no extensive investigation of inclusions in gold particles was undertaken in this study, no mineral inclusions which would preclude a mesothermal origin were found. Most minerals identified by Glenn (1970) in the heavy mineral fractions of Klondike placer operations are typical of a mesothermal environment. Exceptions to this include wood tin (cassiterite), topaz, and a single particle of cinnabar which was found on Dago Hill by Glenn (1970). Wood tin is relatively widespread in Klondike placer deposits, particularly in the northern part of the district, and topaz occurs sporadically on lower Hunker Creek. Both topaz and cassiterite have been found disseminated within Eocene quartz-feldspar porphyry bodies along lower Hunker Creek (S.B. Ballantyne, pers. comm., 1990), and are likely truly epithermal in origin. Although these porphyry bodies are commonly strongly altered and locally pyritized, they yield at most only weakly anomalous gold values.

It is possible that gold of a smaller particle size than that studied ($>$.2mm) could have been derived from sources other than the mesothermal lodes (e.g., disseminated syngenetic gold). However, as pointed out by Mortensen et al. (1992), the vast majority of historical placer production from the Klondike was similar or coarser in size than the particles examined in this study. Thus we conclude that at least the bulk of placer gold mined in this area was derived from the mesothermal occurrences.

The composition provided here indicates that gold particles in the White Channel Gravels were derived from erosion of lode sources. For the sample sizes studied we have found no evidence to support the idea that the particles or the rims were formed by the precipitation of gold in the White Channel Gravels. The difference in signature between gold in the White Channel Gravels and that in the present streams is likely due to the erosion of different lodes or different levels within the same, vertically zoned lodes, rather than different transport directions or episodes of precipitation. Similarly, the only difference between the gold in the altered and unaltered White Channel Gravels is that the rims on particles from the altered gravels are somewhat thicker. The signature of gold in the White Channel Gravel placer deposits near the mouth of Bonanza Creek and placers reworked from these deposits suggest that the low fineness lodes at the head of Bonanza Creek were not being eroded in White Channel Gravel time. The low fineness sources around Last Chance Creek, however, apparently were being eroded and were contributing gold placer concentrations at this time.

We therefore conclude that most if not all of the placer gold that was recovered from Klondike placer deposits was derived from mesothermal lodes similar to those that have been recognized throughout the district. The extreme disparity between the rich and abundant placer concentrations and the sporadically distributed and generally low grade mesothermal lodes must still be explained.

There are three possible explanations.

1) The known lodes may represent the roots of gold-bearing veins (or vein systems) that were originally of very considerable vertical extent, but have mostly been eroded away. Unlike epithermal vein systems, mesothermal vein systems commonly contain gold over a very thick vertical interval (up to 2 km).

2) The lodes may have had erratically distributed very high grade zones. Gleeson (1970) describes very rich pockets (6.19 oz/ton) of very limited extent at the LONE STAR mine. From his data the fineness of gold in these pockets is about 863. A similar occurrence from Gay Gulch assayed 817 fine (W. LeBarge, pers. comm., 1991). Small, high grade pockets have also been found in the MITCHELL and HUNKER DOME occurrences.

3) The main lodes that contributed to the placer deposits remain undiscovered.

It is very probable that all three of the above explanations together account for the discrepancy between placer production and available lode sources. The lodes appear to have localized high grade zones which probably contributed significantly to the grade of the placers. Based on this study it appears that although some of the significant gold producers have been identified many of the sources for the gold in the creeks have not been equivocally identified. Unfortunately it is not possible to say if the source is undiscovered (partly eroded) or totally eroded. Unidentified source lodes appear to have a mesothermal signature suggesting that gold was originally distributed through a thick section of rock. It is therefore possible that the gold was concentrated from essentially non economic deposits. Using the method of Loen (1992), a grade of 0.2 to 5.0 ppb distributed homogeneously within a volume of 225 to 560 km^3 could account for the gold recovered.

The presence of a large low grade lode gold deposit in the district cannot be ruled out, but it must either have a similar compositional signature as the other lodes, or consist largely of gold with a particle size less than 200µ.

CONCLUSIONS

The results of our study indicate that the placer gold in the Klondike District is detrital in origin. The range of compositions for gold from each creek is limited, providing both a creek and specimen fingerprint. These geochemical signatures provide a method of identifying the point of entry of a new source into the creek, as well as a means of linking individual placer deposits to a lode source. Although bullion data can be used to some extent to accomplish this, it does not provide the detail possible with the microprobe analysis of individual particles, and is complicated by the contribution of high fineness gold rims, Hg contamination and mineral inclusion contamination.

Compositional data for gold from lode sources indicates that the lodes can be divided into high fineness and low fineness types with Hg most commonly found in the low fineness group. The sources all appear to be mesothermal in character. The variation in composition on all scales records the change in the fundamental conditions controlling transport and deposition in the lodes. It is suggested that conditions varied over a fixed range in a lode but that at any given location within the lode, conditions were constant during deposition.

The rims on placer gold particles are a secondary phenomenon formed by the removal of Hg, Cu and Ag from the detrital gold. For the size of gold studied (200μ to 1mm) there is no evidence of significant precipitation of gold in the White Channel Gravels (altered or unaltered) or in the district in general. Octahedral crystals found in Klondike placers originate in the lodes, usually in lodes of the low fineness type. Nuggets are also detrital in origin and appear to come mostly from the low fineness lode sources.

Although some gold-bearing lodes have been discovered in the Klondike, some may have been completely eroded away. It is very probable that some lodes have not yet been discovered and that some of these lodes may be only now becoming exposed. Unfortunately it is not possible to determine the significance of the undiscovered sources.

A combination of shape and geochemical signatures of gold can potentially lead to the discovery of undiscovered gold lodes in areas where the ubiquitous presence of gold makes the interpretation of conventional soil or silt geochemical data difficult.

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APPENDIX A. Composition of the standards run during each analysis session for 1990 only (1 year) and all years (2 years) (rep = reported; det = determined).

	Au	σ	Ag	σ	total	σ	fine	σ
Number of analyses = 101 (1 year: March 1990 to Sept 1990)								
rep	100.00				100.00		1000.00	
det	99.85	0.33	0.0	0.0	99.84	0.33	999.98	0.054
Number of analyses = 245 (2 years: Dec 1988 to Sept 1990)								
det	99.91	0.42	0.01		99.93	0.41	999.98	
Number of analyses = 64 (1 year)								
rep	80.05		19.96	0.15	100.01		800.4	
det	79.96	0.22	19.96	0.139	99.93	0.217	800.24	1.34
Number of analyses = 150 (2 years)								
det	80.08	0.33	19.92	0.16	100.00	0.36	800.84	1.46
Number of analyses = 59 (1 year)								
rep	60.05	0.18	39.92	99.97		600.7	0.57	
det	60.19	0.208	39.84	0.193	100.03	0.284	601.71	1.434
Number of analyses = 128 (2 years)								
det	60.15	0.24	39.75	0.22	99.91	0.336	602.09	1.533
Number of analyses = 50 (1 year)								
rep	40.03	0.19	59.93	99.96		400.5	0.25	
det	39.93	0.173	60.07	0.187	100.02	0.279	399.33	1.15
Number of analyses = 105 (2 years)								
det	40.03	0.211	60.06	0.23	100.11	0.305	399.93	1.62
Number of analyses = 62 (1 year)								
rep	22.43	0.11	77.58	100.01		224.3	0.66	
det	22.56	0.468	77.40	0.429	99.96	0.229	225.62	4.494
Number of analyses = 116 (2 years)								
det	22.63	0.578	77.47	0.603	100.13	0.317	226.04	5.690
Number of analyses = 43 (1 year)								
rep			100.00		100.00			0.00
det	0.0	0.0	99.84	0.331	99.86	0.331	0.09	0.117
Number of analyses = 144 (2 years)								
det	0.01		99.97	0.562	99.99	0.565	0.09	0.126

	Au	σ	Cu	σ	total	σ
Number of analyses = 34 (1 year)						
rep	80.15	0.19	19.83		99.98	0.28
det	79.42	0.167	19.83	0.092	99.26	0.199
Number of analyses = 74 (2 years)						
det	79.50	0.108	19.62	0.816	99.12	1.54
Number of analyses = 47 (1 year)						
rep	60.36	0.37	39.64		100.00	
det	60.08	0.281	39.57	0.238	99.67	0.246
Number of analyses = (2 years)						
det	60.01	0.321	39.57	0.275	99.59	0.367

APPENDIX A. Continued.

	Hg	σ	Te	Total
Number of analyses = 37 (1 year)				
rep	61.12		38.88	100.00
det	57.1*	0.20		
Number of analyses = 75 (2 years)				
det	57.33#	0.693		

* This number is obtained by using a background stepoff suitable for trace Hg analysis. For large amounts of Hg, such as the standard, this means that the background is measured on the shoulder of the peak. The sigma value can therefore be considered a maximum. No correction for Te was made.

Larger sigma because various backgrounds, both smaller and larger than that for the final year were used. The various background did not significantly change the detection limit but caused a small systematic offset for the standard.

APPENDIX B. Statistics for the analyses of the unknowns. 'Total' is the average of the totals for the particles in each sample

SAMPLE	TOTAL	SIGMA
AU115	100.13	0.323
AU168	99.80	0.316
AU170	99.93	0.408
AU243	100.05	0.396
AU244	99.91	0.195
AU287	99.66	0.331
AU288	99.93	0.213
AU289	99.85	0.417
AU290	99.94	0.291
AU291	99.95	0.220
AU292	100.16	0.533
AU295	99.82	0.279
AU297	99.67	0.233
AU298	99.85	0.287
AU299	99.90	0.343
AU300	100.06	0.140
AU301	99.97	0.201
AU302	99.60	0.272
AU303	99.66	0.269
AU304	100.02	0.245
AU305	99.72	0.265
AU306	99.58	0.245
AU450	100.46	0.158
AU453	99.93	0.772
AU454	100.27	0.228
AU455	100.50	
AU456	99.96	0.203
AU457	100.11	0.235
AU483	100.00	0.218
AU484	99.75	0.258
AU485	99.97	0.322
AU486	99.68	0.373
AU487	99.85	0.231
AU488	99.71	0.270
AU489	99.97	0.212
AU490	99.89	0.244
AU503	100.14	
AU524	99.98	0.238
AU525	99.8	0.266
AU526	99.63	0.245
AU527	99.77	0.217
AU528	99.86	0.232
AU533	99.90	0.192
AU534	100.03	0.186
AU535	99.74	0.320
AU537	99.74	0.149
AU538	99.7	0.254
AU539	99.95	0.398
AU540	99.63	0.300
AU541	99.94	0.190
AU542	99.88	0.204
AU545	99.94	0.222
AU559	99.90	0.253

Unweighted Mean = 99.90; standard deviation of the mean = 0.19; mean standard deviation = 0.270

APPENDIX C. Detailed sample location information for all placer and lode samples.

AU115 DOMINION CREEK.
Donated in 1985 by L. Gatenby.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 122, property 47.
Sample from 13 miles south of the Summit on the east side of the river. Sample from cleanup.

AU168 BONANZA
Donated in 1985 by J. Hamilton from Mr. Kholman.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 155, property 123 and Yukon: Placer Mining Industry 1983-1984. Department of Indian and Northern Affairs, pg 151, property 116.
The sample is from Bonanza creek above Sourdough and Pure gold creek and below 49 gulch.

AU170 SULPHUR
Donated in 1985 by J. Hamilton.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 122, property 59.
From the Teck property on Sulphur creek. Sample is from below Brimstone gulch.

AU243 ELDORADO
Donated by W. Danner. Collected 1973.
Exact locality unknown.

AU244 DOMINION
Donated by W. Danner. Collected 1973.
Exact locality unknown.

AU287 INDIAN - LOWER DOMINION
Donated in 1986 by J. Brown.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 137 property 52.
Sample located just upstream from the old #6 dredge on a bedrock high.

AU288 DOMINION
Donated in 1986 by L. Gatenby
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 122, property 46 and 47.
Sample located about 1.5Km downstream from the old dredge on the east side of the river on the second bench.

AU289 VIRGIN
Collected by J. Knight in 1986.
R. Debicki. 1984. Bedrock Geology and Mineralization of the Klondike Area, 115 O/14, 15 and 116 B/2, 3. (WEST). Department of Indian and Northern Affairs, 1984 Open File. Property number 6, Virgin, Jean.
Au from a large quartz boulder located near the crest of the ridge about 500 feet directly above the old mill. Sample from near the end of the road close to an area of apparant placer working. Rock crushed and panned.

AU290 UPPER BEAR.
Donated in 1986 by L. Van Kalsbeek.
From the upper reaches of Bear Creek. Sample from a test pit to 4m (not from bedrock). Area of extensive old workings.

AU291 BEAR
Collected by J. Knight 1986.
From just above property 137 as listed in Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs.
Collected from the bottom of cut at confluence of Bear and Lindow creek on the Bear Ck side.

AU292 INDIAN
Donated in 1986 by P.Risby.
East side of Indian river about 1 mile (by road) below the confluence of Quartz creek with Indian river.

AU293 INDIAN
Donated in 1986 by V. Esterbrook.
East side of Indian river about 1.5 miles (by road) below the confluence of Quartz creek with Indian river.

AU294 INDIAN
Donated in 1986 by S. Schmidt.
West side of Indian river about 2.5 miles (by road) below the confluence of Quartz creek with Indian river. This property was, to 1986, one of the richest producers on Indian river.

AU295 HUNKER
Donated in 1986 by F. Short and V. Hall.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 125, property number 11.
80 Below pup. About 1 mile above the confluence of 80 Below Pup and Hunker creek. Note: This sample heated to greater than 160oC.

AU297 VIRGIN
Collected by J. Knight in 1986.
R. Debicki. 1984. Bedrock Geology and Mineralization of the Klondike Area, 115 O/14, 15 and 116 B/2, 3. (WEST). Department of Indian and Northern Affairs, 1984 Open File. Property number 6, Virgin, Jean.
Sample from the old mill. Sample panned from material taken from beneath the floor next to the crusher. Free mercury from recovary process with the gold.

AU298 DISCOVERY
Donated in 1986 by L. Steigenberger.
From the top of the property at the mouth of Discovery gulch. About 400' up from the confluence with Bear creek. Native mercury conspicuous in the concentrate. Probably from the Virgin Mill.

AU299 TRAIL HILL
Collected in 1986.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 157 property 128.
From the face of an old cut a short distance to the north of of an old adit. The sample comes from S. Morison's White channel gravel facies 3, an unsorted unit, near the base of the exposed section.

AU300 TRAIL HILL
Collected in 1986.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 157 property 128.
From the face of a new cut a short distance to the south of an old adit. Sample panned from a bedrock low, on bedrock dirctly below Morison's facies 3.

AU301 BONANZA
Donated in 1986 by P. Foth.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 154, property 120.
A short distance upstream from the confluence of Bonanza with 49 pup. Sample from a 'bench' on the south side of Bonanza about 30' above the present river level. It is uncertain if the bench was cut by Bonanza or 49 pup, although the operator considers the gold to have Bonanza characteristics.

AU302 SULPHUR
Donated in 1986 by N. Sprockreef and D. Ball.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 140, property 64.
Gold is from the 1985 cut in Sulphur creek, about 2 claim lengths below the confluence of Green and Sulphur creeks.

AU303 SULPHUR
Donated in 1986 by C. Kana and L. Gibson.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 139, property 60.
From the furthest downstream part of the lease, immediately adjacent to the Teck property and above Brimstone creek on Sulphur creek.

AU304 SULPHUR
Donated in 1986 by Teck Mining.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 138, property 59.
From the claim on Sulphur creek immediately upstream from the confluence with Brimstone creek. Immediately below AU303.

AU305 DAGO HILL
Donated in 1986 by M. Sutter and B. Warmsby.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 124, property 8.
From the cut mined in 1986. Expected life of mine at that time was 2 more years.

AU306 CRIPPLE HILL
Donated in 1986 by P. Foth. Collected in 1962.
From the middle of Cripple hill. Mined by hydraulic methods. Sample from mining "near an old adit".

AU450 VIRGIN DUMP
Donated in 1989 by J. Mortensen. His number HLB-88-109
R. Debicki. 1984. Bedrock Geology and Mineralization of the Klondike Area, 115 O/14, 15 and 116 B/2, 3. (WEST). Department of Indian and Northern Affairs, 1984 Open File. Property number 6, Virgin, Jean. Sample from the mill, from the ore bin.

AU453 HILCHEY
Donated in 1989 by J. Mortensen. His number K-658.
R. Debicki. 1984. Bedrock Geology and Mineralization of the Klondike Area, 115 O/14, 15 and 116 B/2, 3. (WEST). Department of Indian and Northern Affairs, 1984 Open File. Property number 33 (not shown on map).
About 1.5Km upslope from Gay gulch.

AU454 LONE STAR
Donated in 1989 by J. Mortensen.
R. Debicki. 1984. Bedrock Geology and Mineralization of the Klondike Area, 115 O/14, 15 and 116 B/2, 3. (WEST). Department of Indian and Northern Affairs, 1984 Open File. Property number 33.
From Boulder open pit.

AU455 LONE STAR, WEST DUMP
Donated in 1989 by J. Mortensen.
R. Debicki. 1984. Bedrock Geology and Mineralization of the Klondike Area, 115 O/14, 15 and 116 B/2, 3. (WEST). Department of Indian and Northern Affairs, 1984 Open File. Property number 33.
From the Western most dump at the head of the old tramline.

AU456 LONE STAR, CENTER DUMP
Donated in 1989 by J. Mortensen.
R. Debicki. 1984. Bedrock Geology and Mineralization of the Klondike Area, 115 O/14, 15 and 116 B/2, 3. (WEST). Department of Indian and Northern Affairs, 1984 Open File. Property number 33.
From the centre dump at the head of the old tramline.

AU457 AIME DUMP
Donated in 1989 by J. Mortensen. His number MLB-88-135.
R. Debicki. 1985. Bedrock Geology and Mineralization of the Klondike Area, 115 O/9, 10, 11, 14, 15, 16 and 116 B/2. (EAST). Department of Indian and Northern Affairs, 1984 Open File. Property number 10.
Sample from the dump at mouth of old adit.

AU483 24 ABOVE PUP, HUNKER.
Donated in 1989 by G. Ahnert.
At 2300' elevation on 24 pup .5 mile below watershed. Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 129, property 28.

AU484 MITCHELL
Collected by J. Mortensen and J. Knight in 1989.
R. Debicki. 1984. Bedrock Geology and Mineralization of the Klondike Area, 115 O/14, 15 and 116 B/2, 3. (WEST). Department of Indian and Northern Affairs, 1984 Open File. Property number 20.
From dump.

AU485 HUNKER DOME.
Collected by J. Mortensen and J. Knight in 1989.
R. Debicki. 1984. Bedrock Geology and Mineralization of the Klondike Area, 115 O/14, 15 and 116 B/2, 3. (WEST). Department of Indian and Northern Affairs, 1984 Open File. Property number 25.
From dump of '200' shaft.

AU486 VIOLET.
Collected by J. Mortensen and J. Knight in 1989.
R. Debicki. 1984. Bedrock Geology and Mineralization of the Klondike Area, 115 O/14, 15 and 116 B/2, 3. (WEST). Department of Indian and Northern Affairs, 1984 Open File. Property number 28.
From dump.

AU487 HILCHEY.
Collected by J. Mortensen and J. Knight in 1989.
R. Debicki. 1984. Bedrock Geology and Mineralization of the Klondike Area, 115 O/14, 15 and 116 B/2, 3. (WEST). Department of Indian and Northern Affairs, 1984 Open File. Property number 33 (not shown on map).
About 1.5Km upslope from Gay gulch. 100' to East of AU453.

AU488 BOULDER.
Collected by J. Mortensen and J. Knight in 1989.
R. Debicki. 1984. Bedrock Geology and Mineralization of the Klondike Area, 115 O/14, 15 and 116 B/2, 3. (WEST). Department of Indian and Northern Affairs, 1984 Open File. Property number 33.
From Boulder open pit. Same location as AU454.

AU489 LONE STAR MILL
Collected by J. Mortensen and J. Knight in 1989.
R. Debicki. 1984. Bedrock Geology and Mineralization of the Klondike Area, 115 O/14, 15 and 116 B/2, 3. (WEST). Department of Indian and Northern Affairs, 1984 Open File. Property number 33.
From stamp at mill site.

AU490 QUARTZ CREEK
Donated by Schmidt - Tatlow in 1989.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 141, approximately property 68

AU503 PIONEER.
Donated by J. Mortensen in 1989. His number MLB-89-271.
R. Debicki. 1984. Bedrock Geology and Mineralization of the Klondike Area, 115 O/14, 15 and 116 B/2, 3. (WEST). Department of Indian and Northern Affairs, 1984 Open File. Property number 31 (Eldorado Dome).
From dump at the Pioneer (Eldorado Dome) adit.

AU524 JACKSON HILL
Donated by W. Hinnek and S. Tomlinson. Collected 1988-89.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 157, property 133. Underground mine in White Channel Gravels.

AU525 INDIAN RIVER
Donated by S. Tomlinson in 1989.
On Indian river at the mouth of McKinnon Creek. Sample from both sides of the mouth of McKinnon creek within 1km of the Indian river.

AU526 HUNKER CREEK
Donated by Crawford and S. Tomlinson in 1989.
300m upstream from Hester creek on the South bank of Hunker creek.

AU527 ELDORADO CREEK
Donated by H. Reinink and S. Tomlinson in 1989.
Claim number 5 above Eldorado Discovery. This is first claim on Eldorado. Sample from left limit (facing downstream).

AU528 BONANZA
Donated by H. Reinink and S. Tomlinson in 1989.
6 above Bonanza Discovery on right limit (facing downstream) of Bonanza. 200m from Bonanza just above Eldorado.

AU532 INDIAN RIVER
Donated by Dr. P Richardson in 1989. Collected Sept. 1988.
Indian River at Dominion. Immediately above Australian creek. Below Sulphur - Dominion junction.

AU533 GAY GULCH
Donated by Dr. P. Richardson in 1989. Collected Sept. 1988.
From creek bottom on claim P7388 approximately 1.5 km up from the mouth.

AU534 80 PUP HUNKER
Donated by Dr. P. Richardson in 1989. Collected Sept. 1988.
Reported to come from to location where the paystreak on Paradise Hill crosses 80 pup.

AU535 PARADISE HILL
Donated by Dr. P Richardson in 1989. Collected Sept. 1988.
From White channel gravel on Paradise Hill. On claim P0683 (Jacksons bench).

AU537 ORO GRANDE
Donated by B. & R. Beron and W. LeBarge in 1989.
Claim P 0263 at the mouth of Oro Grande.

AU538 AUSTRALIAN HILL
Donated by D. Johnson and W. LeBarge in 1989.
From Claim block P8479, 8480, 8482, 8498, 35384. From all over hill during a sampling program. Sample from White Channel Gravels.

AU539 HUNKER (LEFT FORK)
Donated by P. Mahoney and W. LeBarge in 1989.
Claim P8969 just above junction of right and left fork of Hunker creek. Near source of Creek.

AU540 GOLD RUN
Donated by G. Klein and W. LeBarge in 1989.
Claim P34012 about 5 miles from mouth of Gold Run Creek. Above Whitman Gulch.

AU541 VICTORIA GULCH
Donated by V. Trainer and W. LeBarge in 1989.
Composite sample from claims P 4431, 4432, 42391, 4638, 4147, 42327, 42881, 7961, 29396, 7688, 38782, 9991, 42014 along the length of the creek from its mouth to 13 pup..

AU542 7 PUP BONANZA
Donated by J. Bryde and W. LeBarge in 1989.
Claim P31352 at head of 7 pup, 'immediately below' the Lonestar workings.

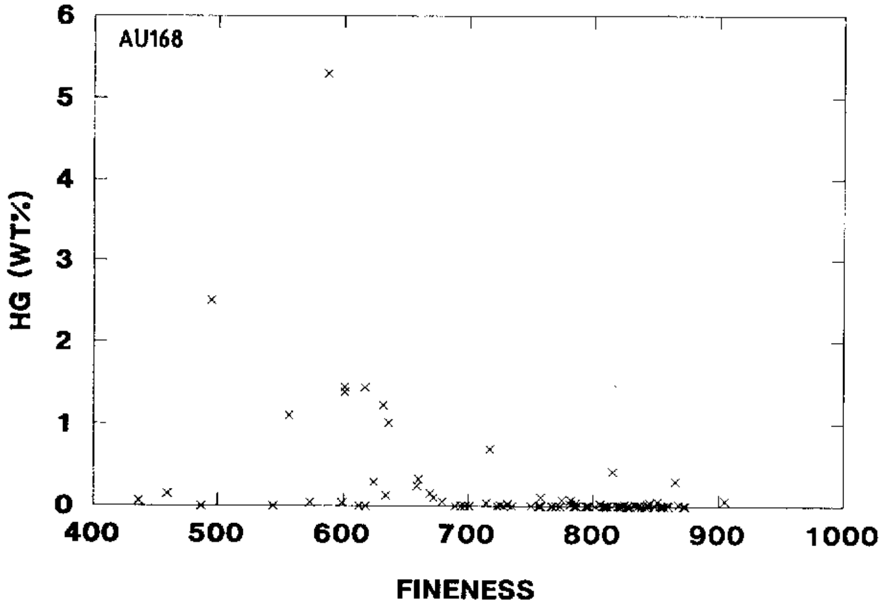
AU543 INDIAN RIVER
Donated by P. Risby and W. LeBarge in 1989.
Claim P30358 and Western end of Indian River flats, just before the canyon.

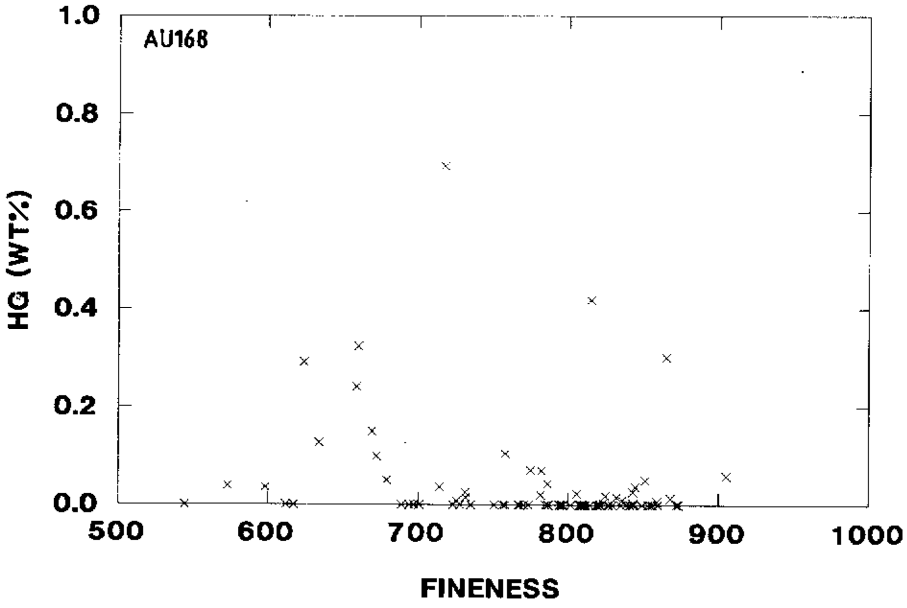
AU544 THISTLE
Donated by Goldmark Minerals and W. LeBarge in 1989.
Claims P3405, 4450, 4451, 6017 -6176. Sample from just above the confluence with Narrow Gulch on Thistle creek.

AU545 27 PUP ELDORADO
Donated by D. Johnson and W. LeBarge in 1989.
Claim P22054 at the mouth of 27 pup. Sample from the left bench of 27 pup.

AU559 26 ABOVE ELDORADO
Donated by Dr. P Richardson and W. LeBarge in 1989.
Eldorado creek at 26 above Eldorado Discovery, from the side opposite 27 gulch.

Appendix D. Hg vs. fineness plots for individual placer samples. Samples are arranged by principal drainage as in Figure 4. On the AU490 Quartz Creek plot, the squares represent the angular particles. On the AU305 Dago Hill plot, the circles represent crystalline particles greater than 2 mm in size.



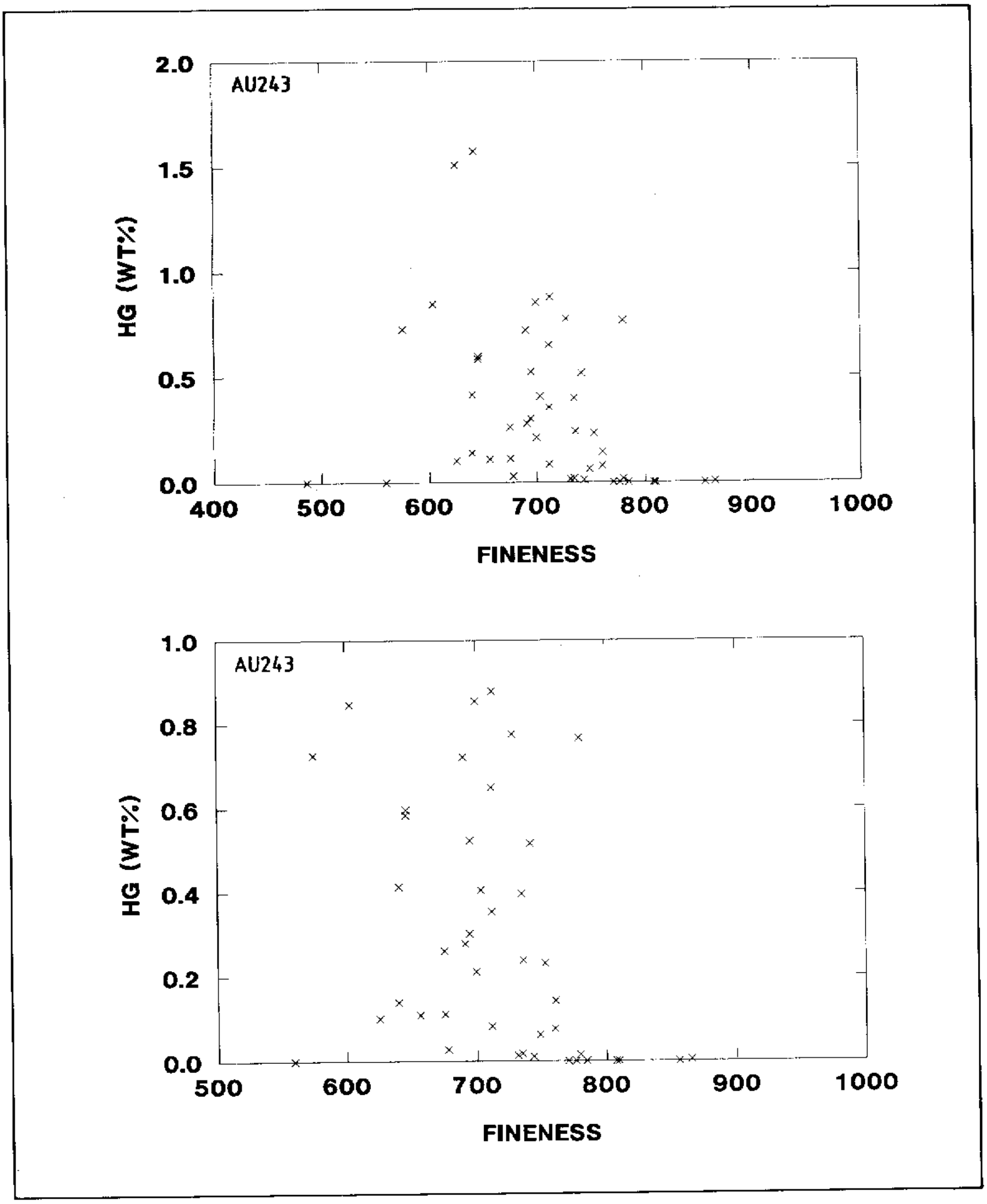


AU168 BONANZA

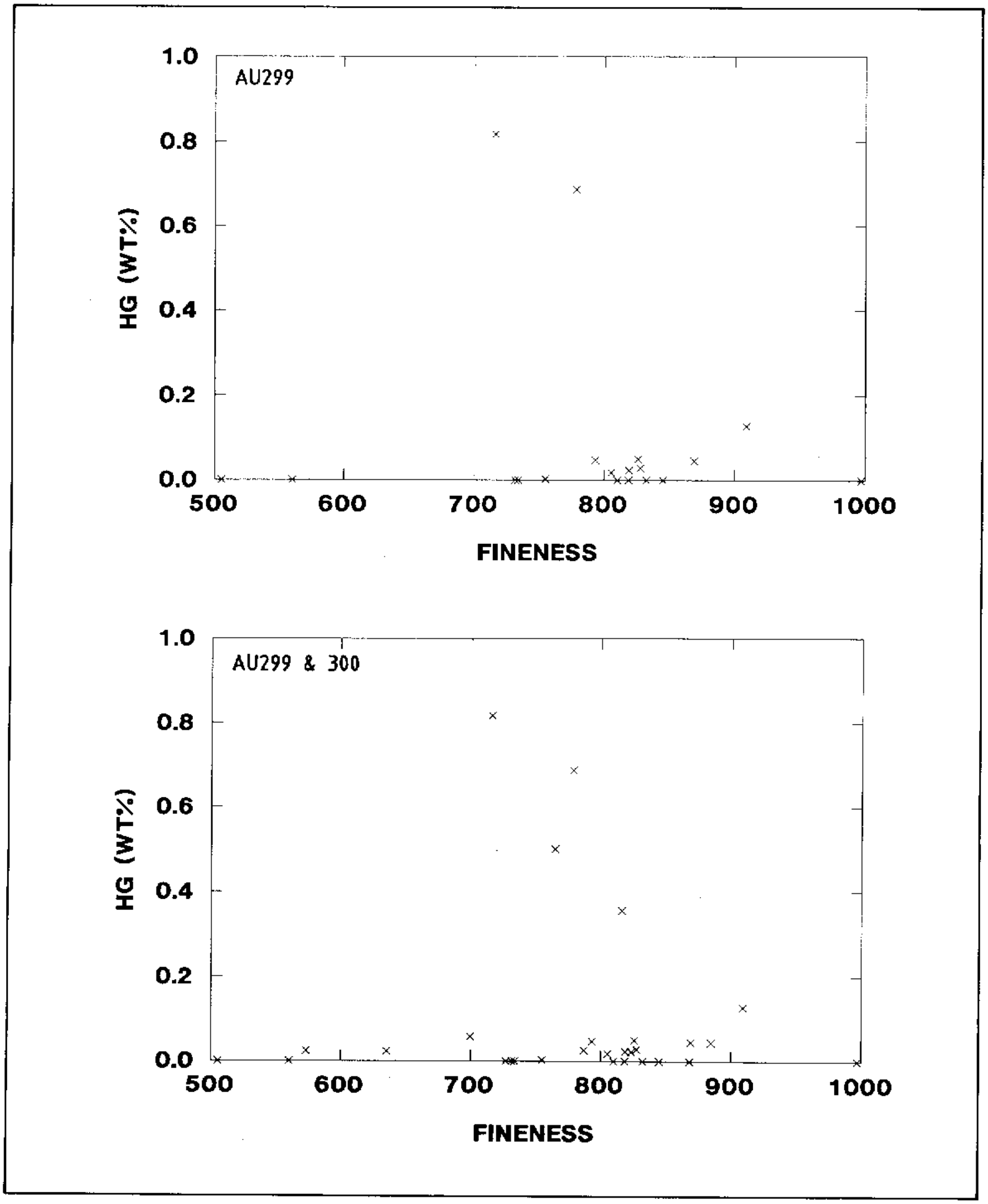
Donated in 1985 by J. Hamilton from Mr. Kholman.

Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 155, property 123 and Yukon: Placer Mining Industry 1983-1984. Department of Indian and Northern Affairs, pg 151, property 116.

The sample is from Bonanza creek above Sourdough and Pure gold creek and below 49 gulch.

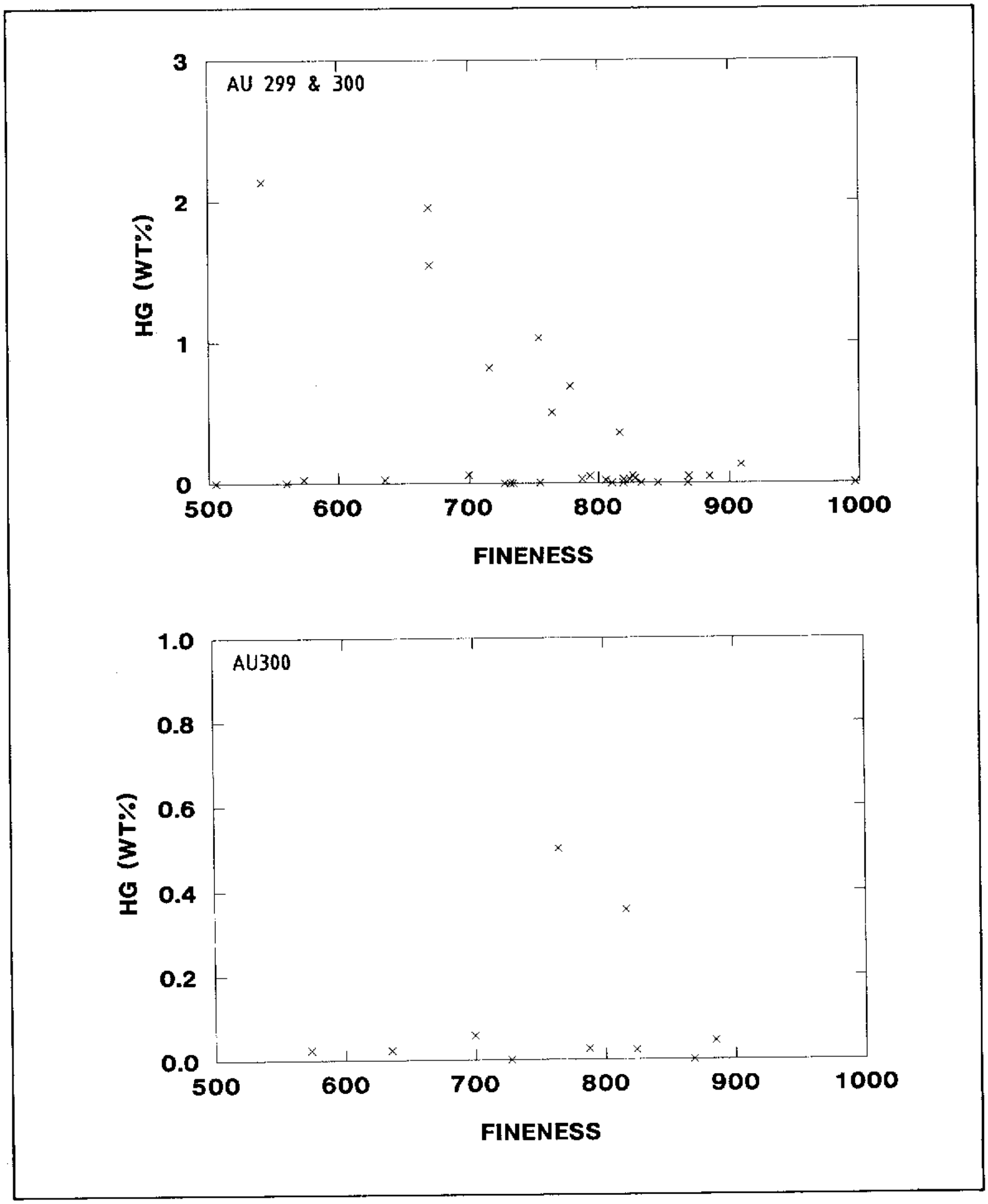


AU243 ELDORADO
Donated by W. Danner. Collected 1973.
Exact locality unknown.



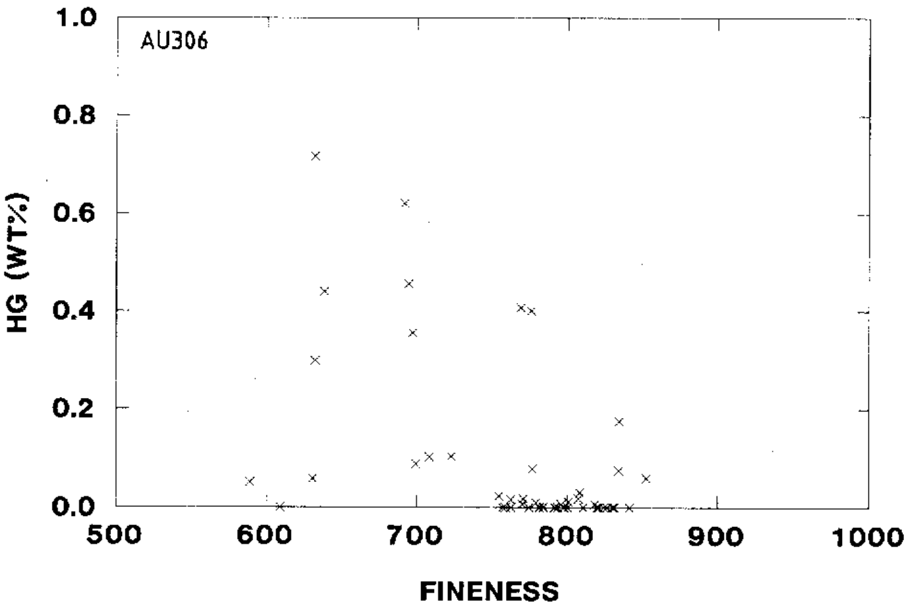
AU299 TRAIL HILL
Collected in 1986.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 157 property 128.
From the face of an old cut a short distance to the north of of an old adit. The sample comes from S. Morison's White channel gravel facies 3, an unsorted unit, near the base of the exposed section.

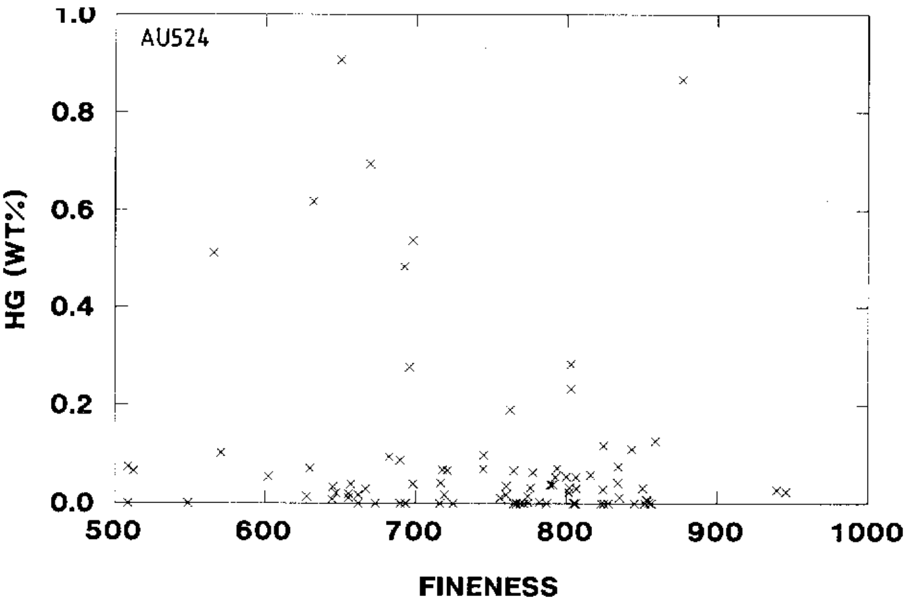
AU300 TRAIL HILL
Collected in 1986.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 157 property 128.
From the face of a new cut a short distance to the south of an old adit. Sample panned from a bedrock low, on bedrock dirctly below Morison's facies 3.



AU299 TRAIL HILL
Collected in 1986.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 157 property 128.
From the face of an old cut a short distance to the north of of an old adit. The sample comes from S. Morison's White channel gravel facies 3, an unsorted unit, near the base of the exposed section.

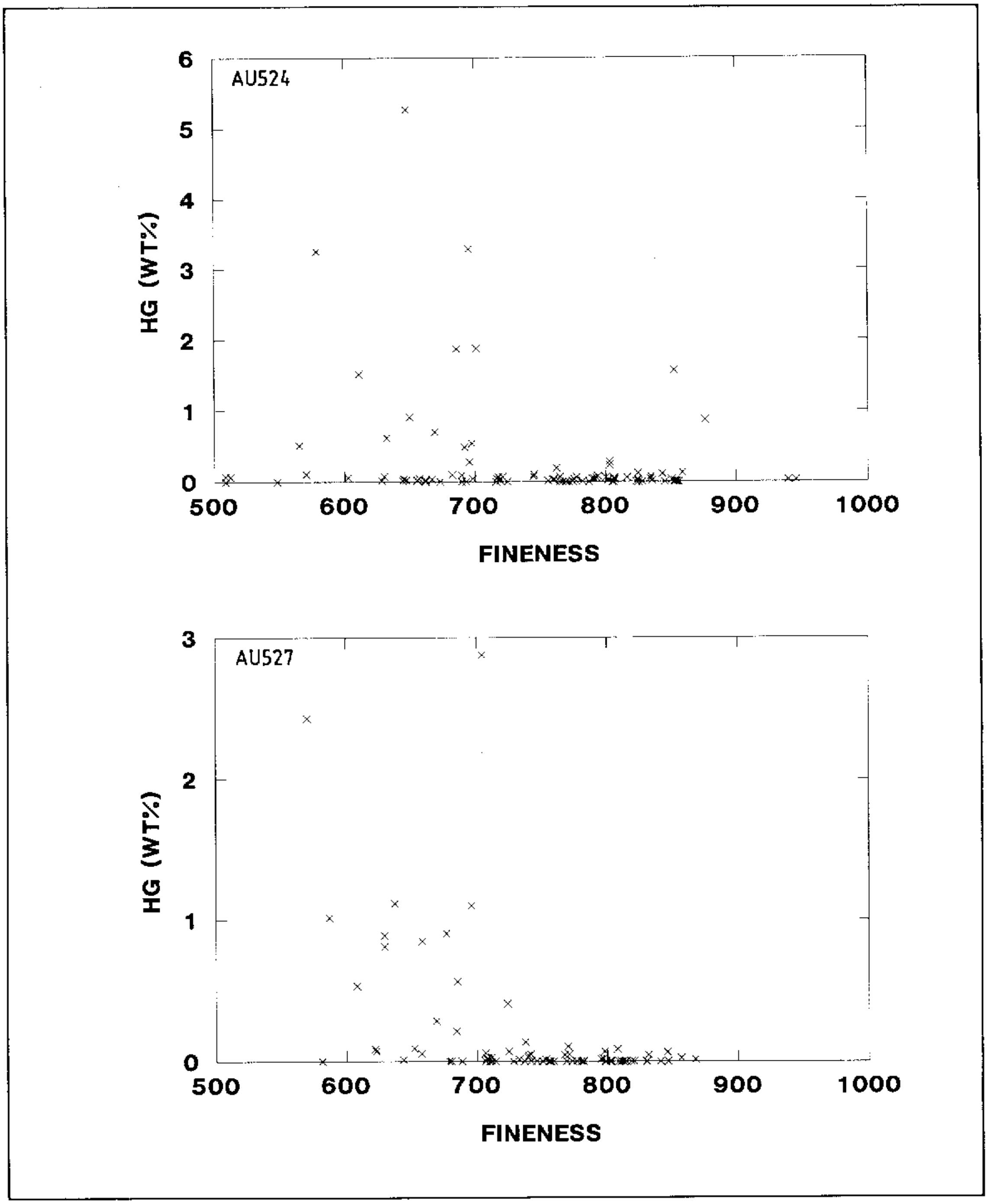
AU300 TRAIL HILL
Collected in 1986.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 157 property 128.
From the face of a new cut a short distance to the south of an old adit. Sample panned from a bedrock low, on bedrock directly below Morison's facies 3.





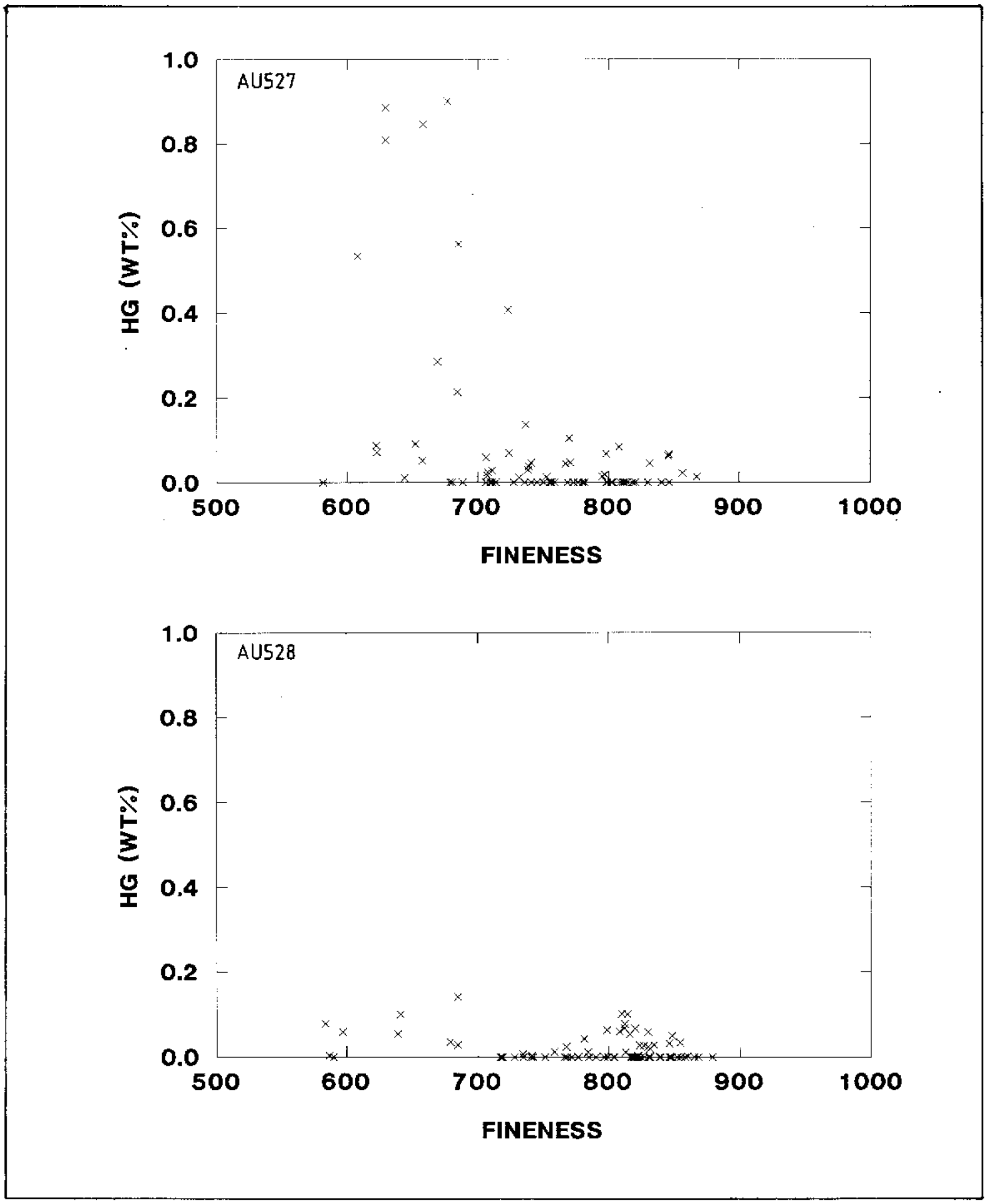
AU306 CRIPPLE HILL
Donated in 1986 by P. Foth. Collected in 1962.
From the middle of Cripple hill. Mined by hydraulic methods. Sample from mining "near an old adit".

AU524 JACKSON HILL
Donated by W. Hinnek and S. Tomlinson. Collected 1988-89.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 157, property 133. Underground mine in White Channel Gravels.



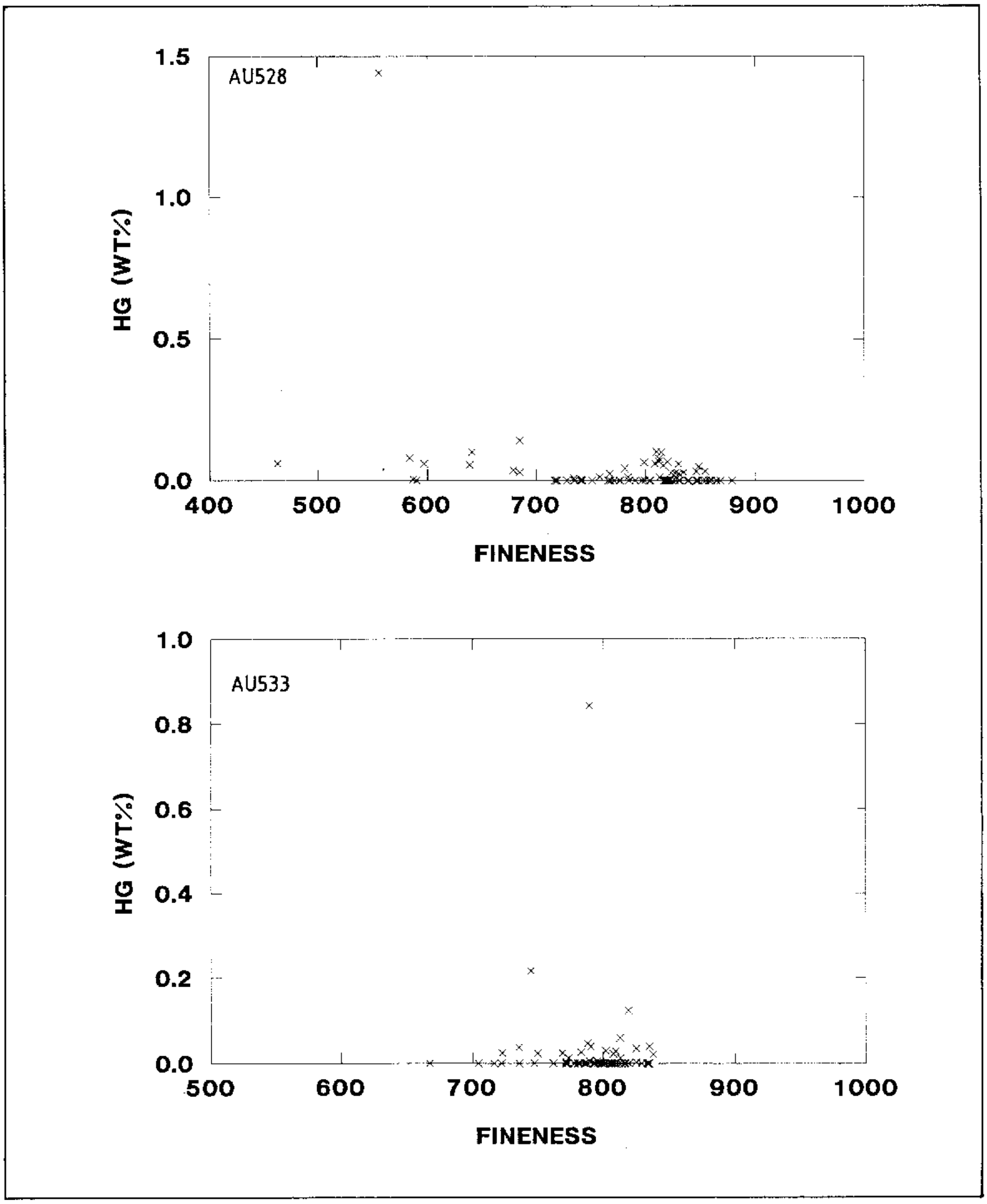
AU524 JACKSON HILL
Donated by W. Hinnek and S. Tomlinson. Collected 1988-89.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 157, property 133. Underground mine in White Channel Gravels.

AU527 ELDORADO CREEK
Donated by H. Reinink and S. Tomlinson in 1989.
Claim number 5 above Eldorado Discovery. This is first claim on Eldorado. Sample from left limit (facing downstream).



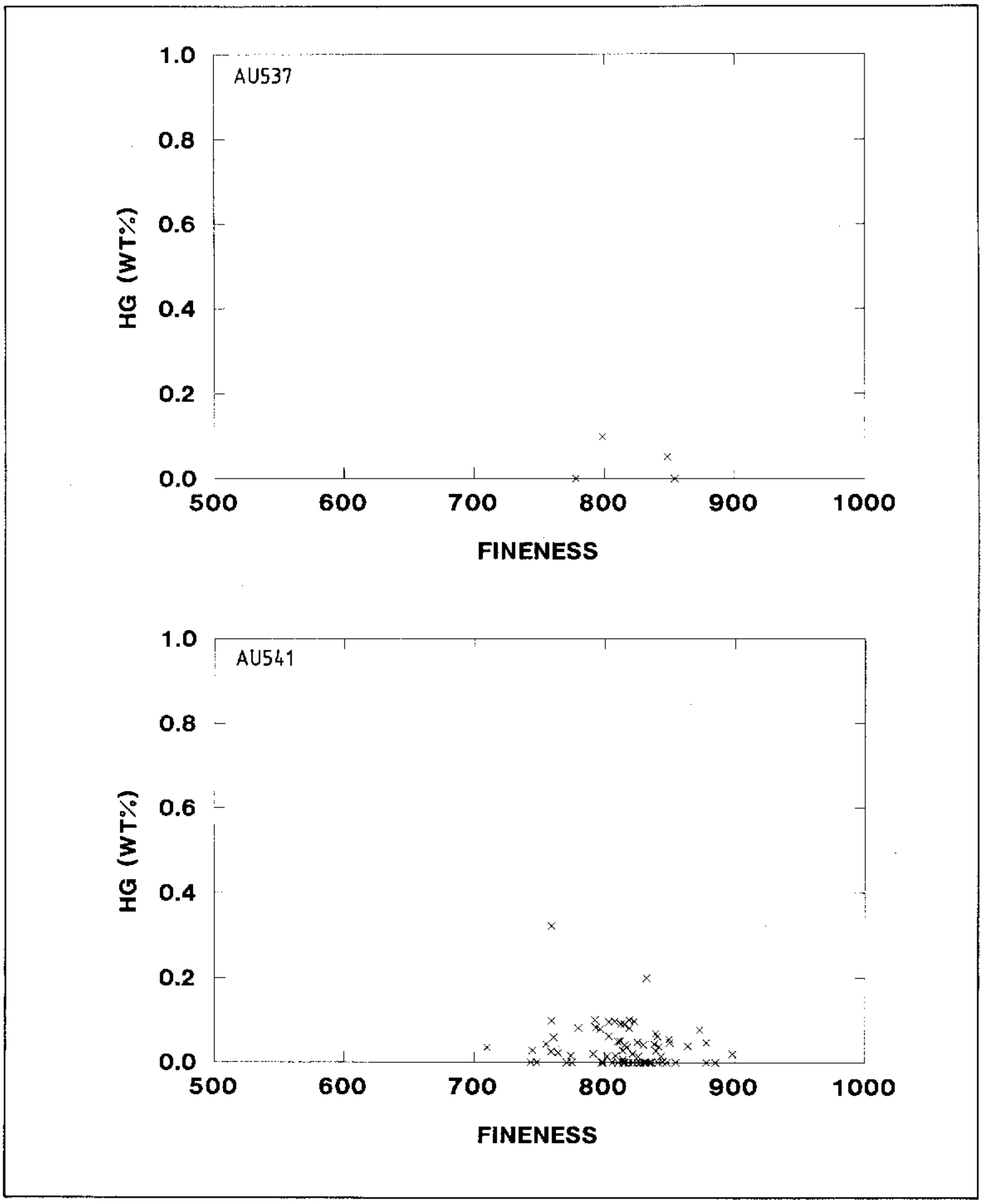
AU527 ELDORADO CREEK
Donated by H. Reinink and S. Tomlinson in 1989.
Claim number 5 above Eldorado Discovery. This is first claim on Eldorado. Sample from left limit (facing downstream).

AU528 BONANZA
Donated by H. Reinink and S. Tomlinson in 1989.
6 above Bonanza Discovery on right limit (facing downstream) of Bonanza. 200m from Bonanza just above Eldorado.



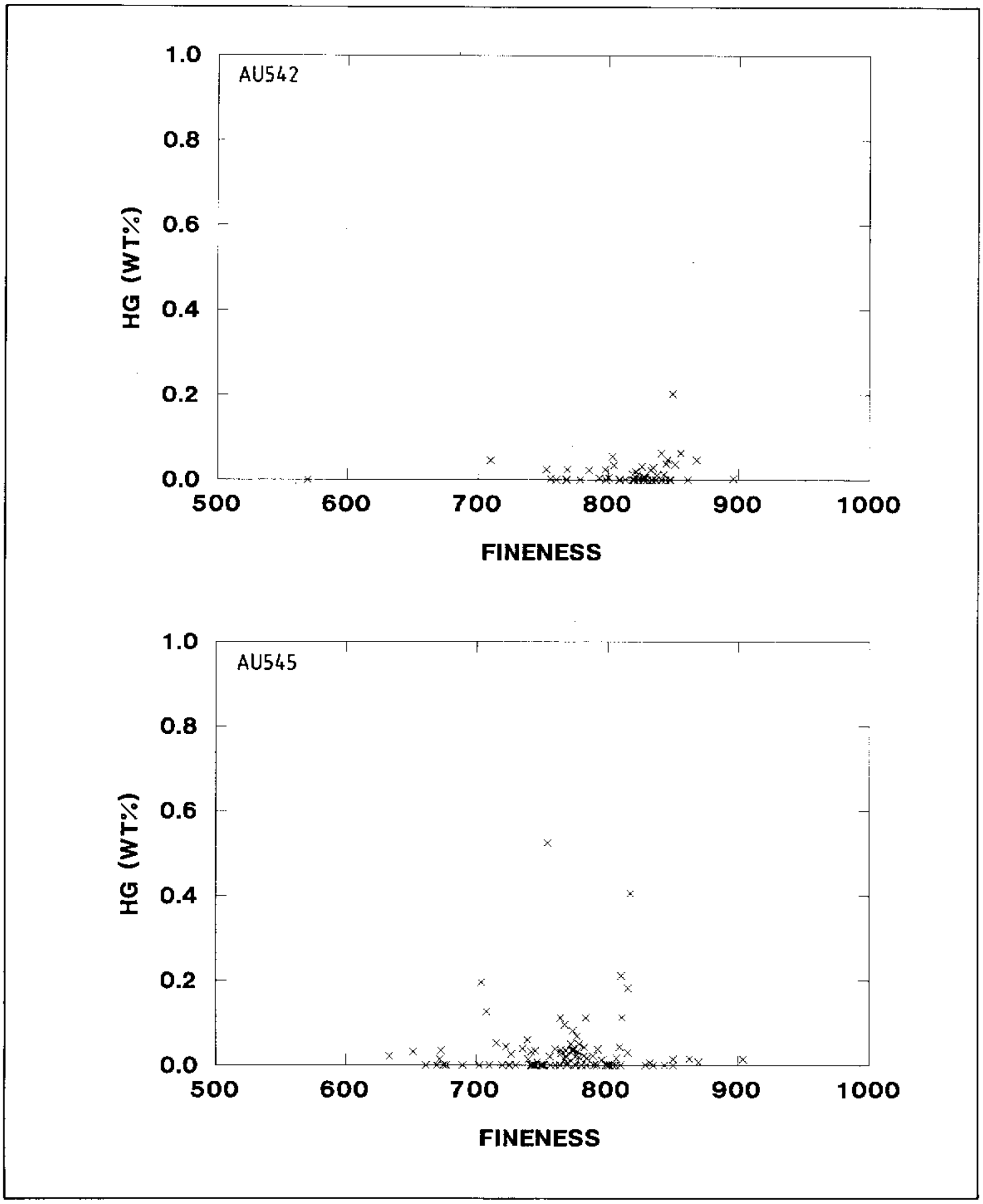
AU528 BONANZA
Donated by H. Reinink and S. Tomlinson in 1989.
6 above Bonanza Discovery on right limit (facing downstream) of Bonanza. 200m from Bonanza just above Eldorado.

AU533 GAY GULCH
Donated by Dr. P. Richardson in 1989. Collected Sept. 1988.
From creek bottom on claim P7388 approximately 1.5 km up from the mouth.



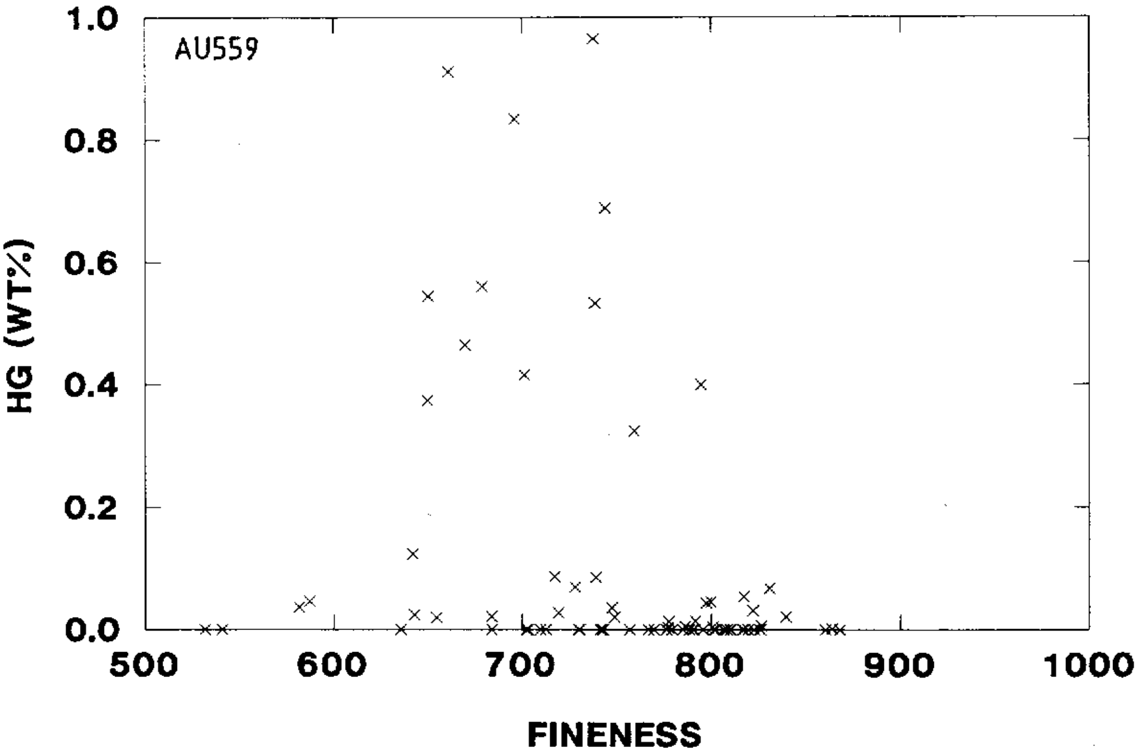
AU537 ORO GRANDE
Donated by B. & R. Beron and W. LeBarge in 1989.
Claim P 0263 at the mouth of Oro Grande.

AU541 VICTORIA GULCH
Donated by V. Trainer and W. LeBarge in 1989.
Composite sample from claims P 4431, 4432, 42391, 4638, 4147, 42327, 42881, 7961, 29396, 7688, 38782, 9991, 42014 along the length of the creek from its mouth to 13 pup.

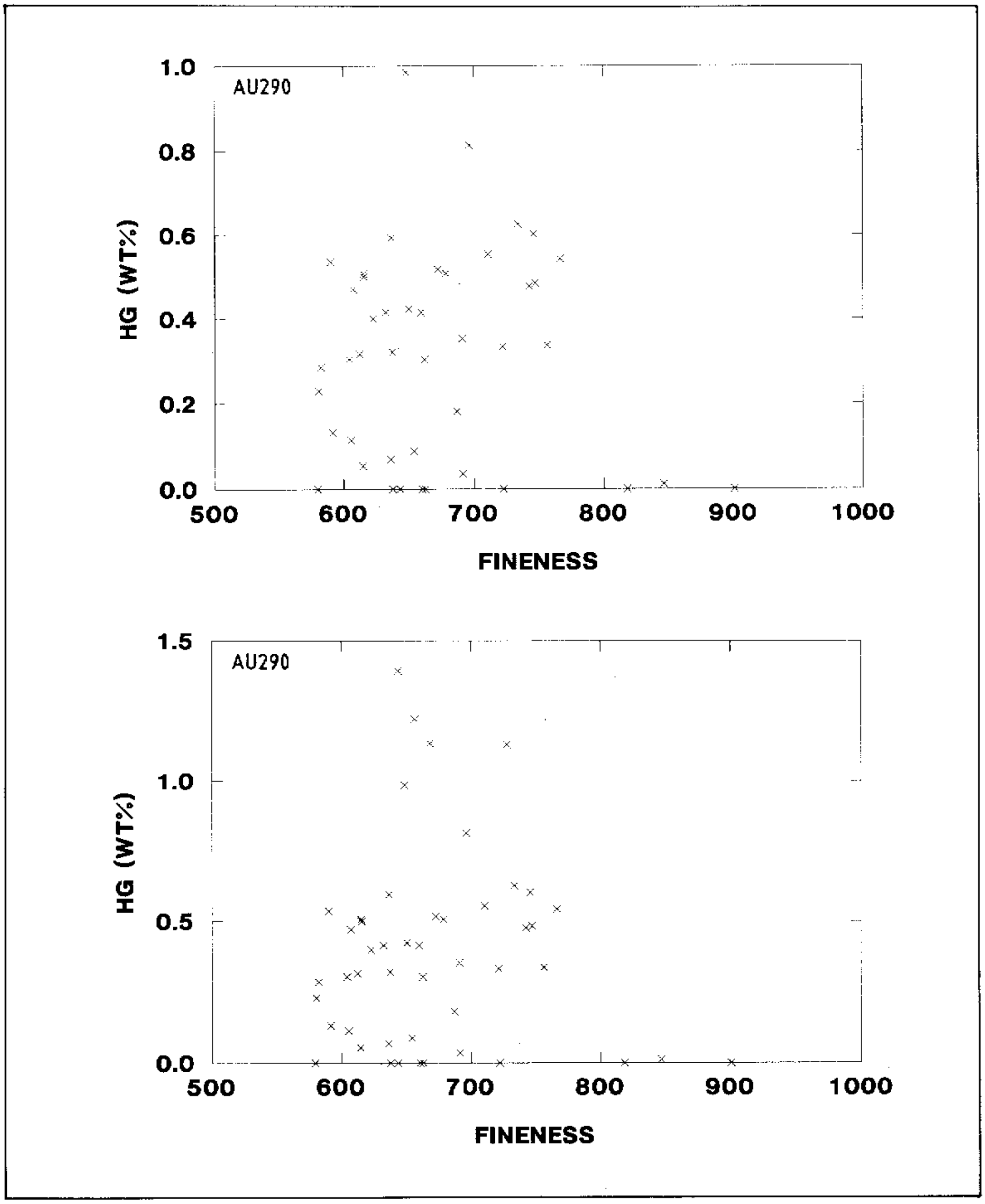


AU542 7 PUP BONANZA
Donated by J. Bryde and W. LeBarge in 1989.
Claim P31352 at head of 7 pup, 'immediately below' the Lonestar workings.

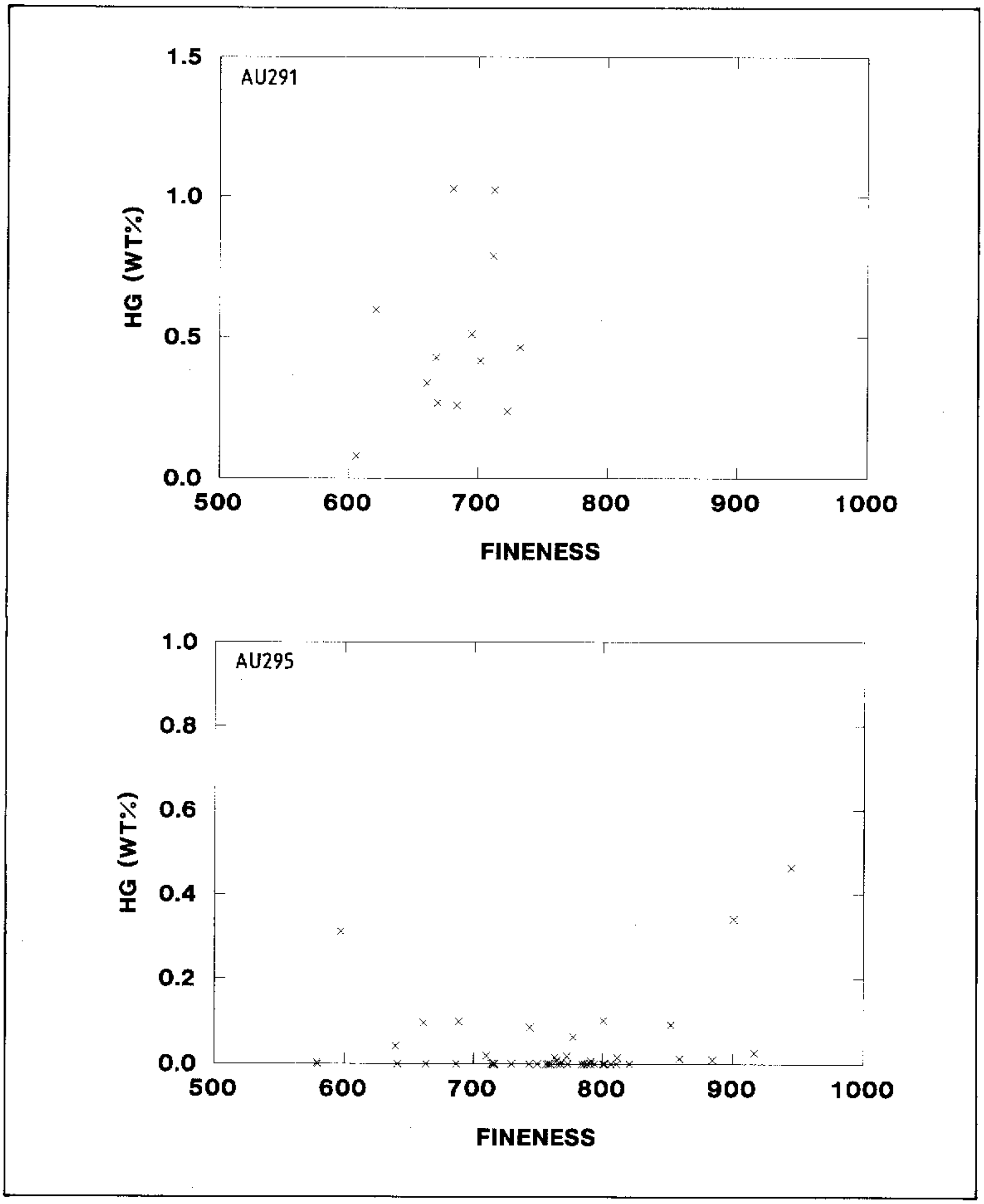
AU545 27 PUP ELDORADO
Donated by D. Johnson and W. LeBarge in 1989.
Claim P22054 at the mouth of 27 pup. Sample from the left bench of 27 pup.



AU559 26 ABOVE ELDORADO
Donated by Dr. P Richardson and W. LeBarge in 1989.
Eldorado creek at 26 above Eldorado Discovery, from the side opposite 27 gulch.

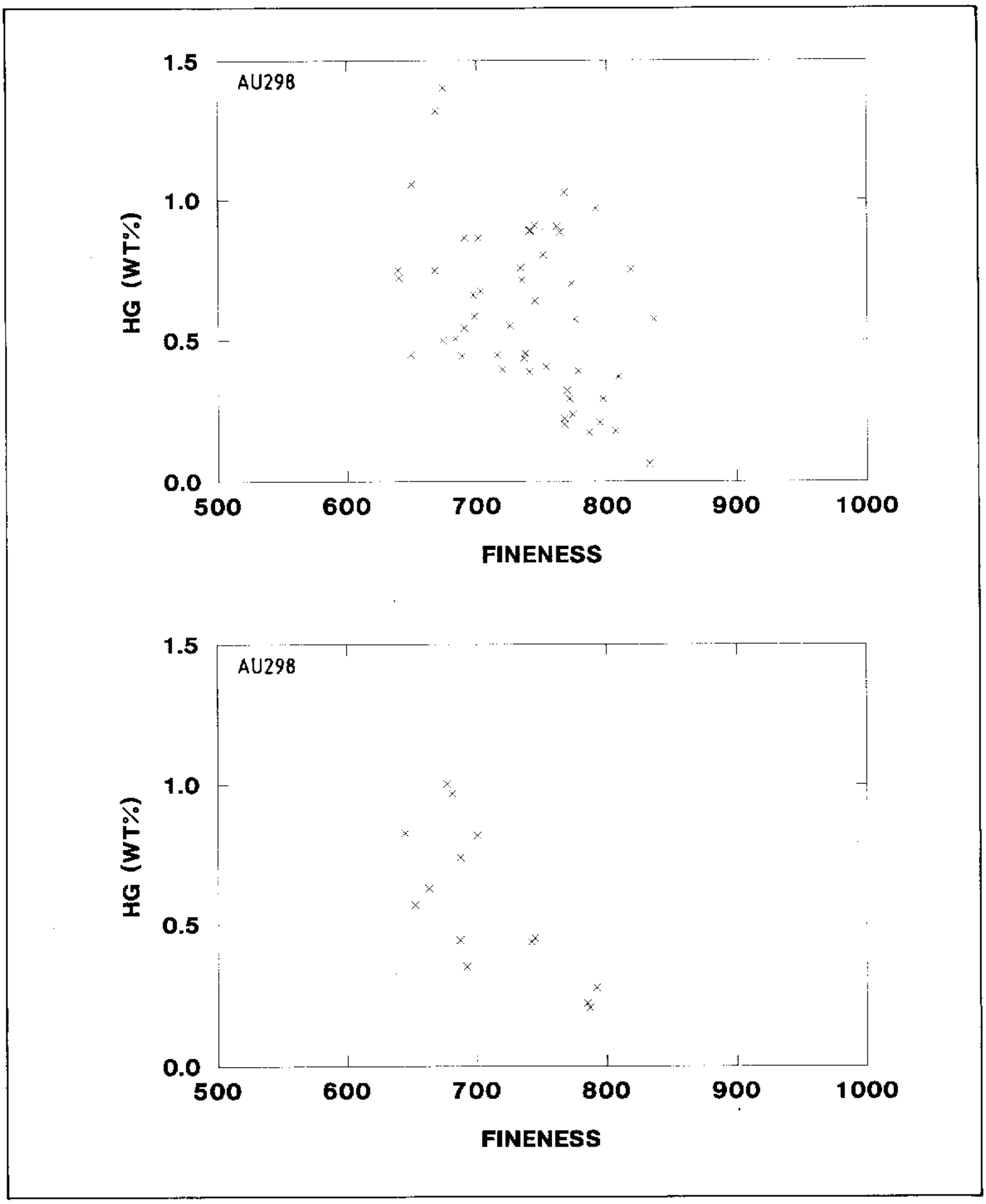


AU290 UPPER BEAR.
Donated in 1986 by L. Van Kalsbeek.
From the upper reaches of Bear Creek. Sample from a test pit to 4m (not from bedrock). Area of extensive old workings.

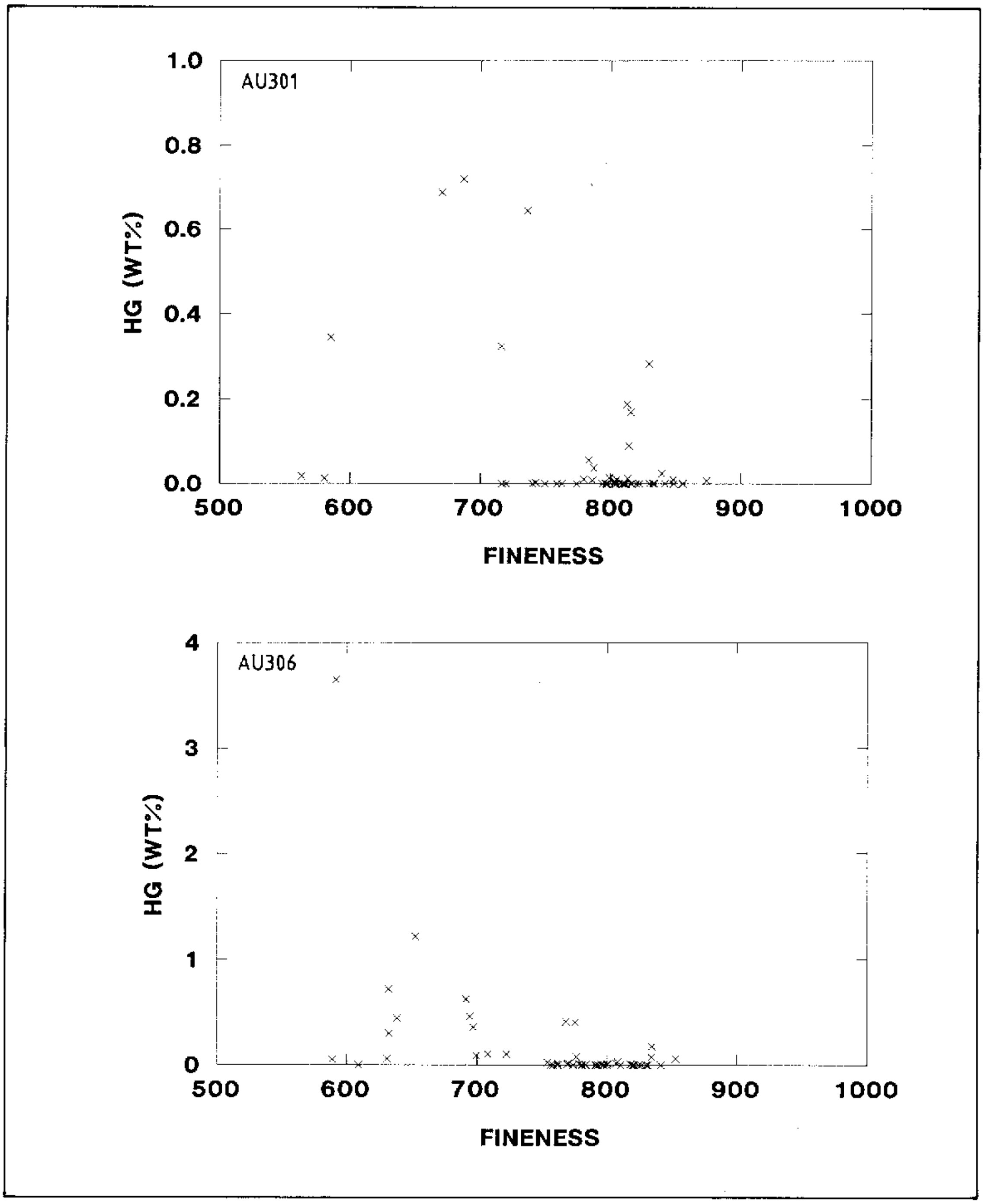


AU291 BEAR
Collected by J. Knight 1986.
From just above property 137 as listed in Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs. Collected from the bottom of cut at confluence of Bear and Lindow creek on the Bear Ck side.

AU295 HUNKER
Donated in 1986 by F. Short and V. Hall.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 125, property number 11.
80 Below pup. About 1 mile above the confluence of 80 Below Pup and Hunker creek. Note: This sample heated to greater than 160°C.

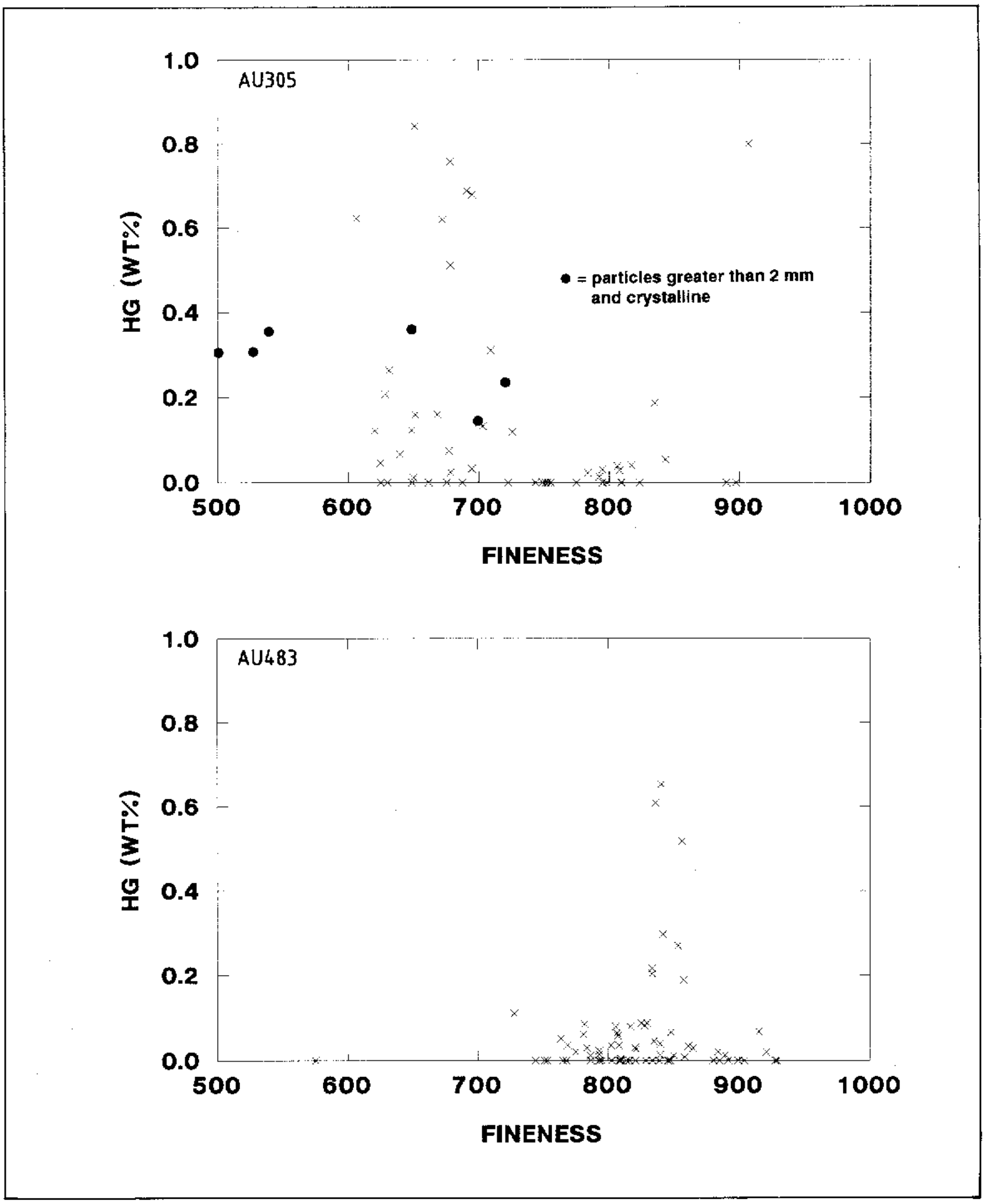


AU298 DISCOVERY
Donated in 1986 by L. Steigenberger.
From the top of the property at the mouth of Discovery gulch. About 400' up from the confluence with Bear creek. Native mercury conspicuous in the concentrate. Probably from the Virgin Mill.



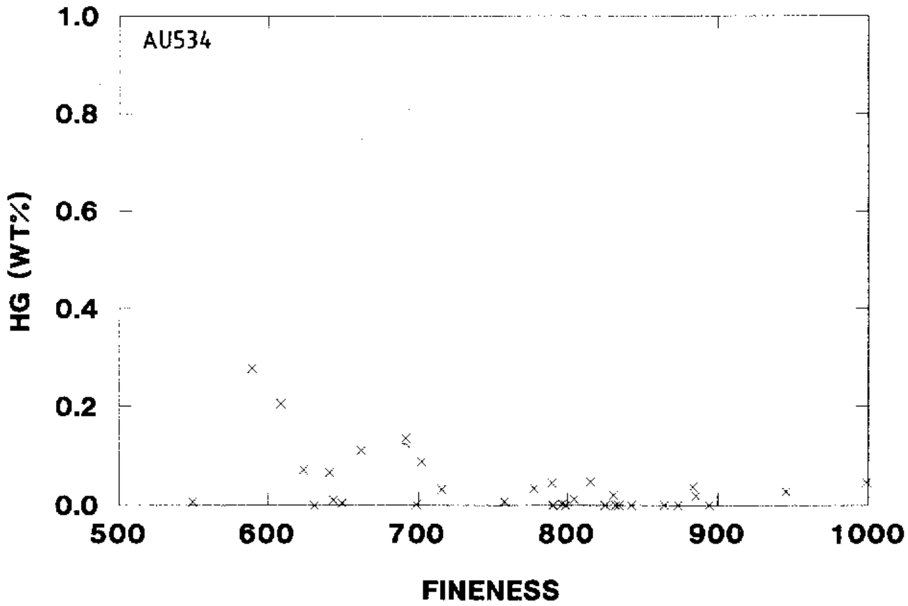
AU301 BONANZA
Donated in 1986 by P. Foth.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 154, property 120.
A short distance upstream from the confluence of Bonanza with 49 pup. Sample from a 'bench' on the south side of Bonanza about 30' above the present river level. It is uncertain if the bench was cut by Bonanza or 49 pup, although the operator considers the gold to have Bonanza characteristics.

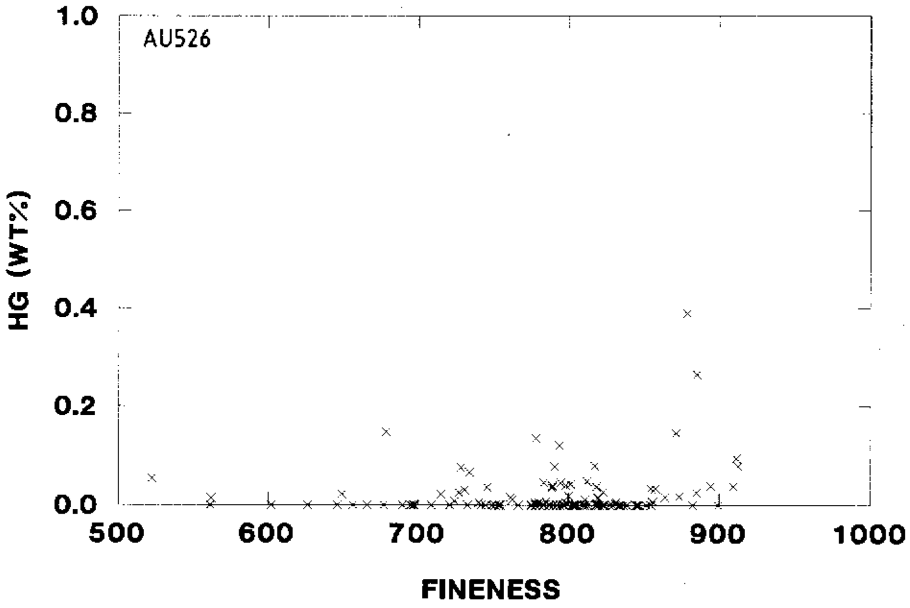
AU306 CRIPPLE HILL
Donated in 1986 by P. Foth. Collected in 1962.
From the middle of Cripple hill. Mined by hydraulic methods. Sample from mining "near an old adit".



AU305 DAGO HILL
Donated in 1986 by M. Sutter and B. Warmsby.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 124, property 8.
From the cut mined in 1986. Expected life of mine at that time was 2 more years.

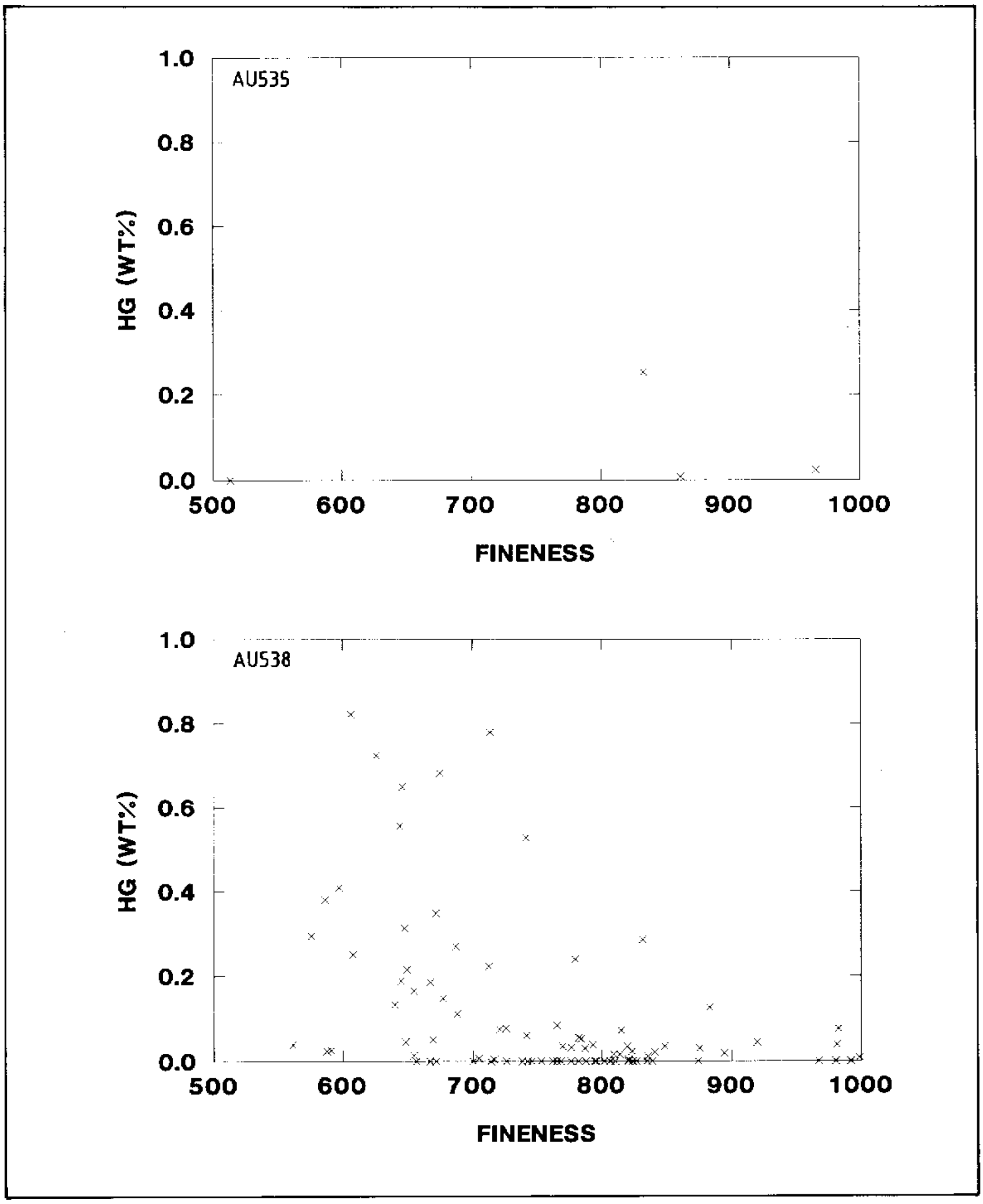
AU483 24 ABOVE PUP, HUNKER.
Donated in 1989 by G. Ahnert.
At 2300' elevation on 24 pup .5 mile below watershed. Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 129, property 28.





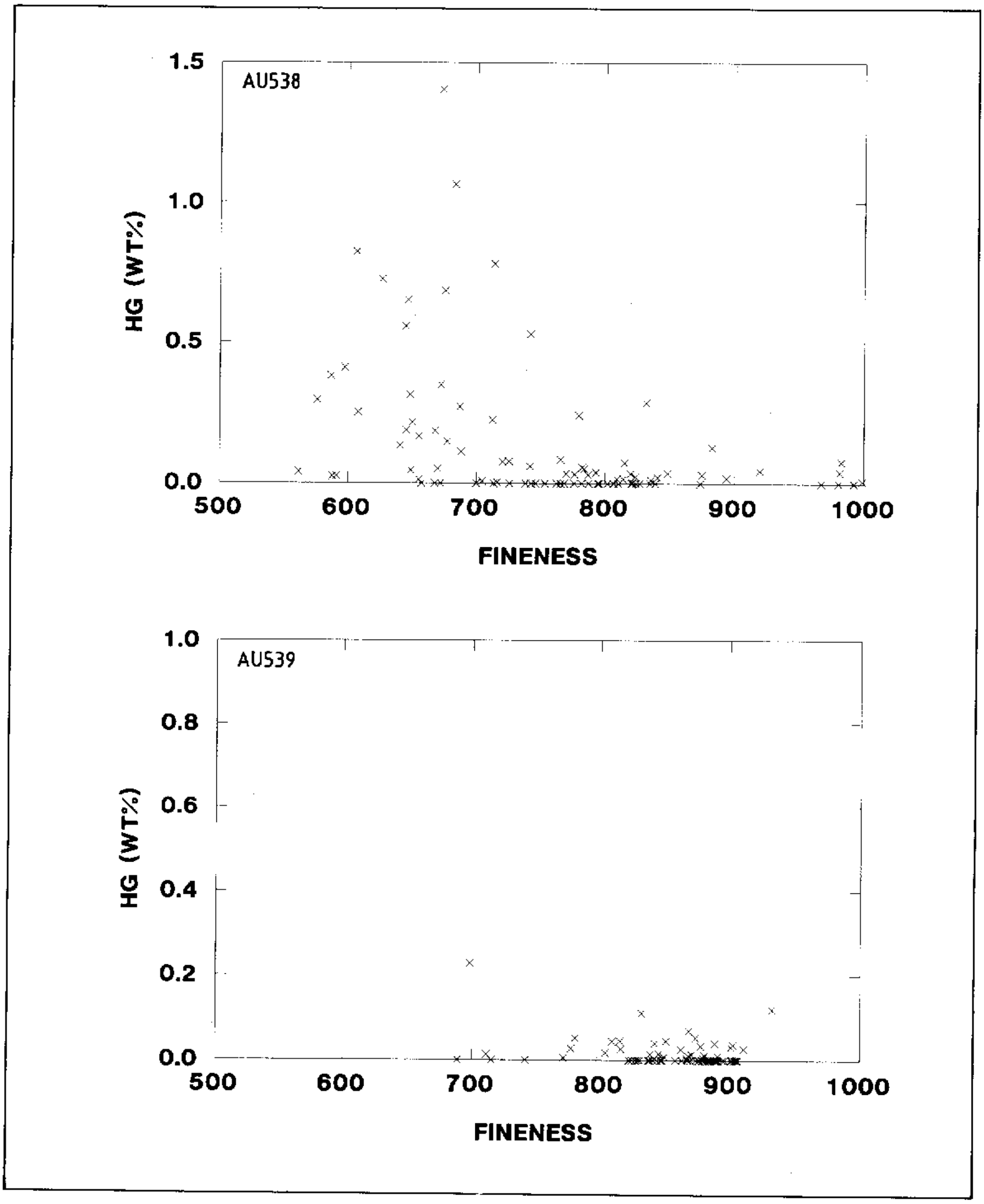
AU534 80 PUP HUNKER
Donated by Dr. P. Richardson in 1989. Collected Sept. 1988.
Reported to come from to location where the paystreak on Paradise Hill crosses 80 pup.

AU526 HUNKER CREEK
Donated by Crawford and S. Tomlinson in 1989.
300m upstream from Hester creek on the South bank of Hunker creek.



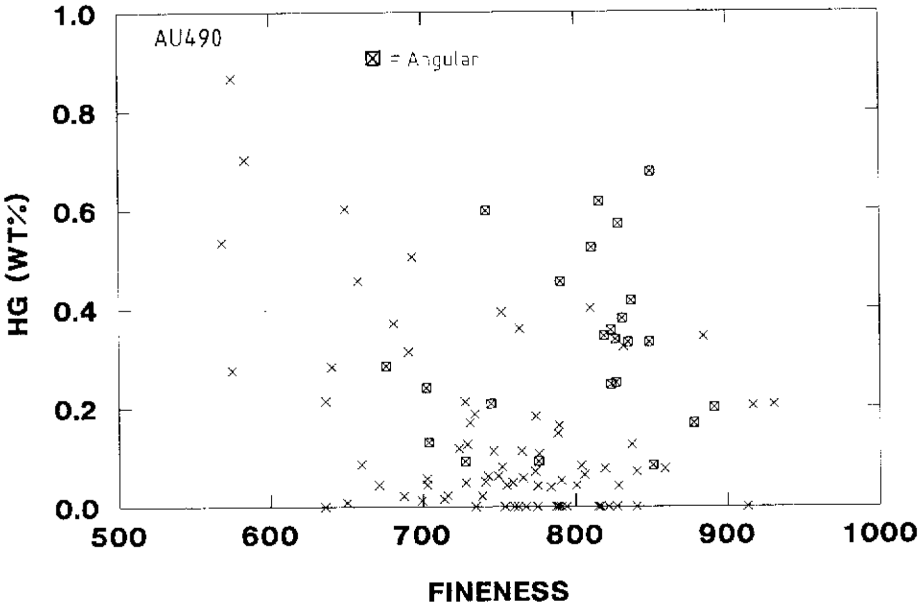
AU535 PARADISE HILL
Donated by Dr. P Richardson in 1989. Collected Sept. 1988.
From White channel gravel on Paradise Hill. On claim P0683 (Jacksons bench).

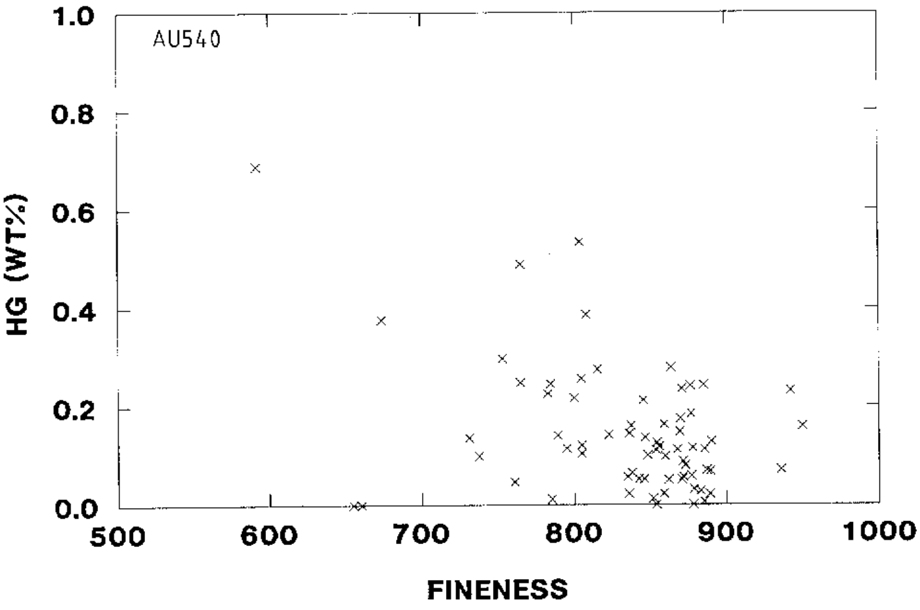
AU538 AUSTRALIAN HILL
Donated by D. Johnson and W. LeBarge in 1989.
From Claim block P8479, 8480, 8482, 8498, 35384. From all over hill during a sampling program. Sample from White Channel Gravels.



AU538 AUSTRALIAN HILL
Donated by D. Johnson and W. LeBarge in 1989.
From Claim block P8479, 8480, 8482, 8498, 35384. From all over hill during a sampling program. Sample from White Channel Gravels.

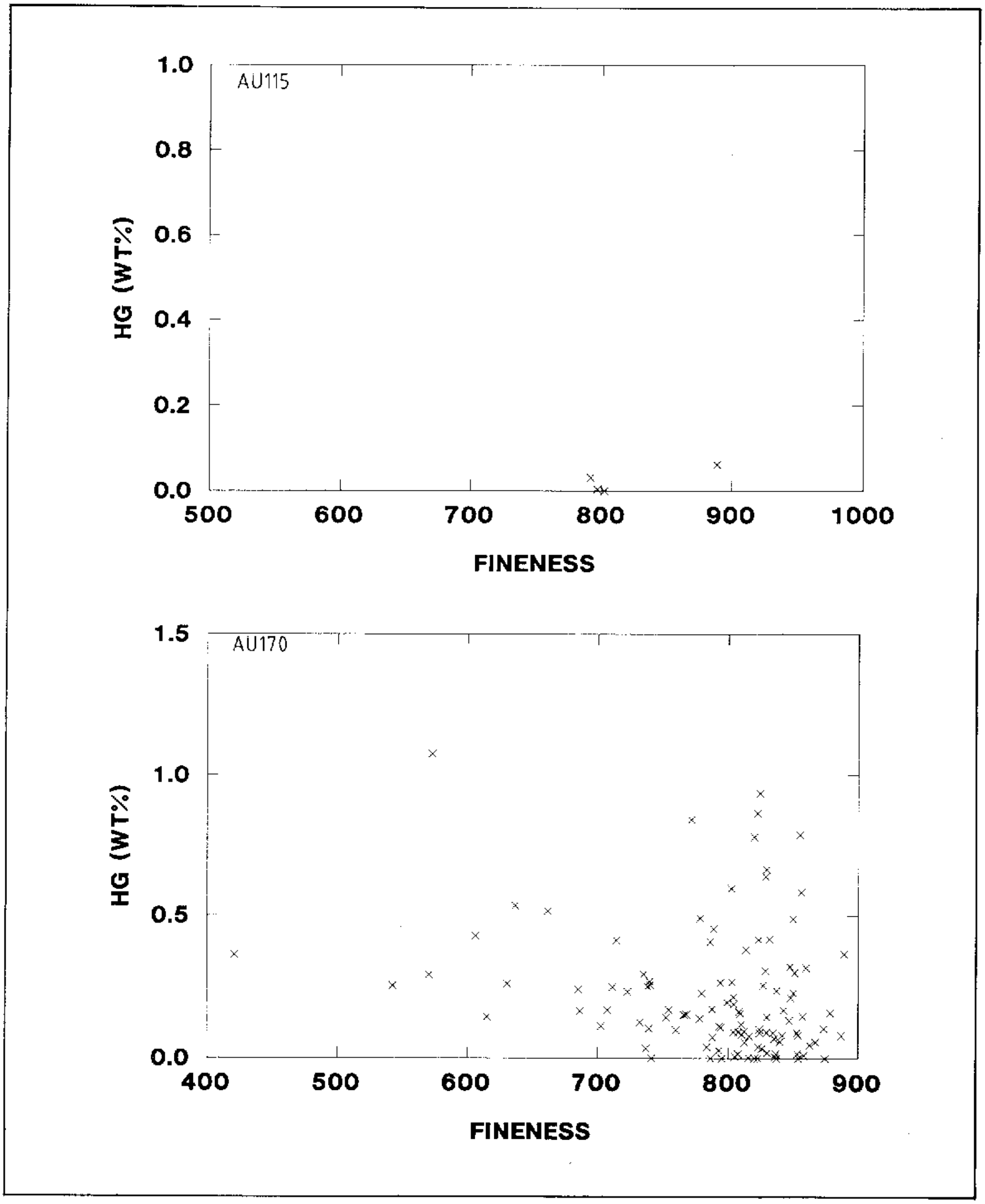
AU539 HUNKER (LEFT FORK)
Donated by P. Mahoney and W. LeBarge in 1989.
Claim P8969 just above junction of right and left fork of Hunker creek. Near source of Creek.





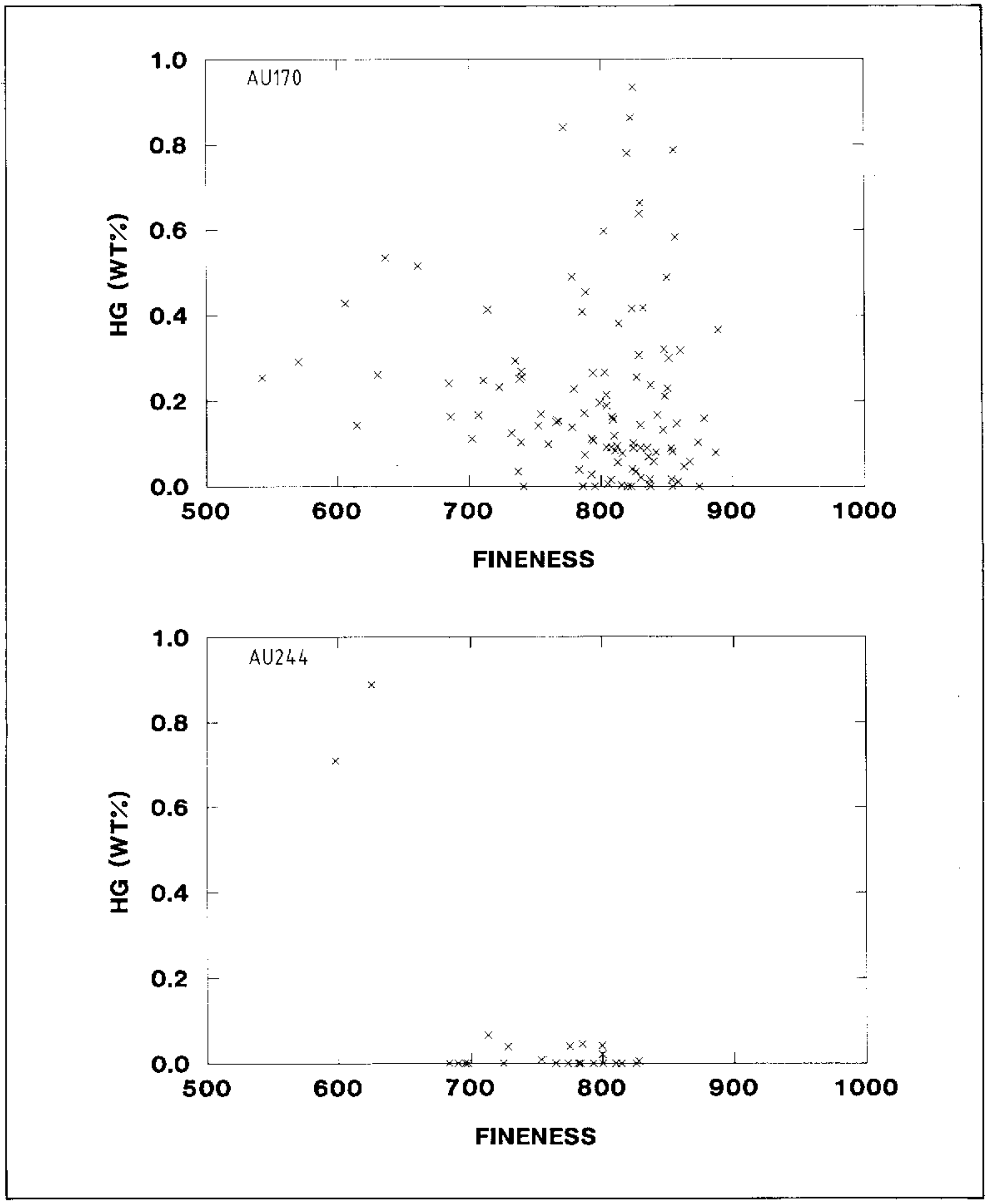
AU490 QUARTZ CREEK
Donated by Schmidt - Tatlow in 1989.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 141, approximately property 68

AU540 GOLD RUN
Donated by G. Klein and W. LeBarge in 1989.
Claim P34012 about 5 miles from mouth of Gold Run Creek. Above Whitman Gulch.



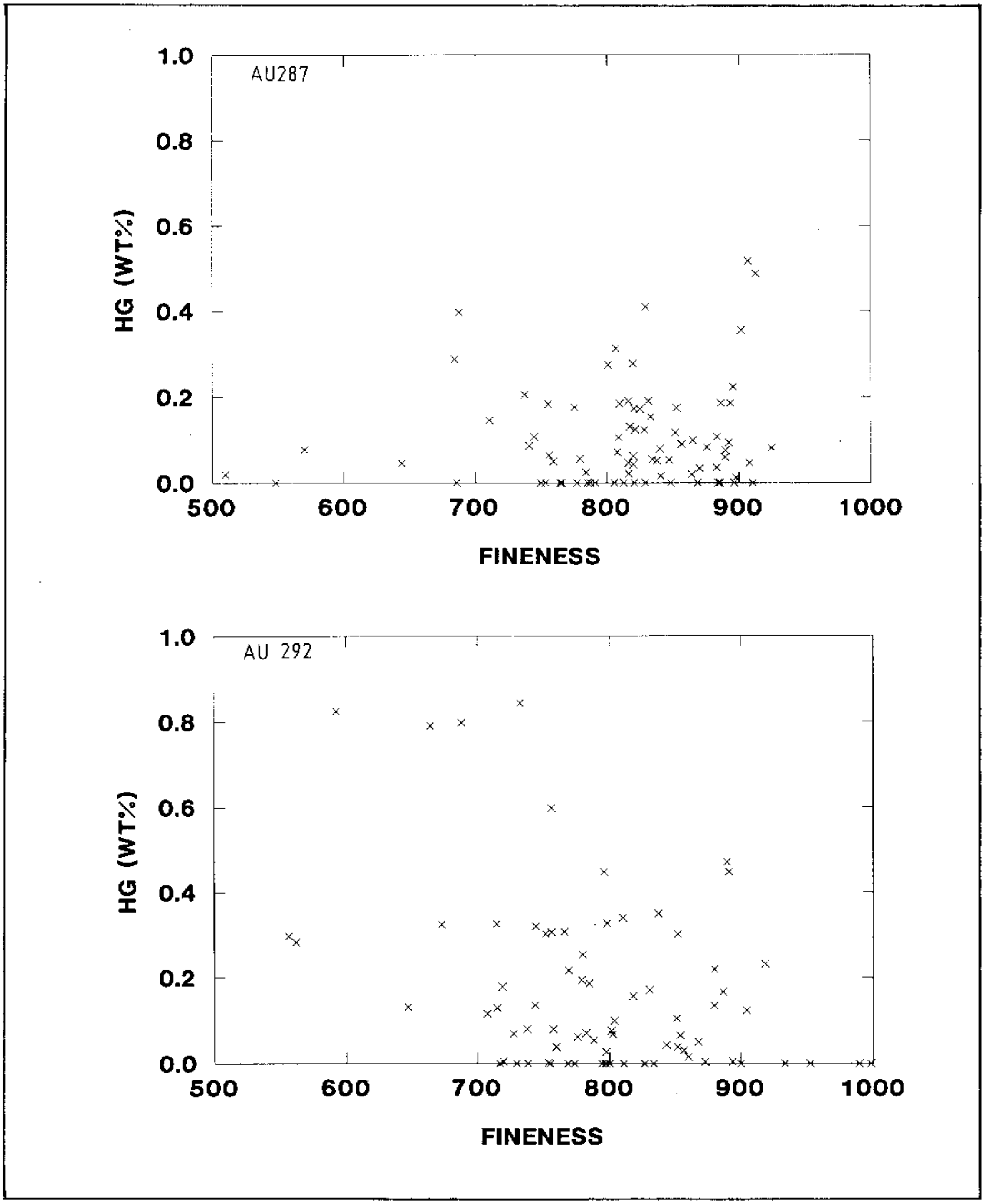
AU115 DOMINION CREEK.
Donated in 1985 by L. Gatenby.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 122, property 47.
Sample from 13 miles south of the Summit on the east side of the river. Sample from cleanup.

AU170 SULPHUR
Donated in 1985 by J. Hamilton.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 122, property 59.
From the Teck property on Sulphur creek. Sample is from below Brimstone gulch.



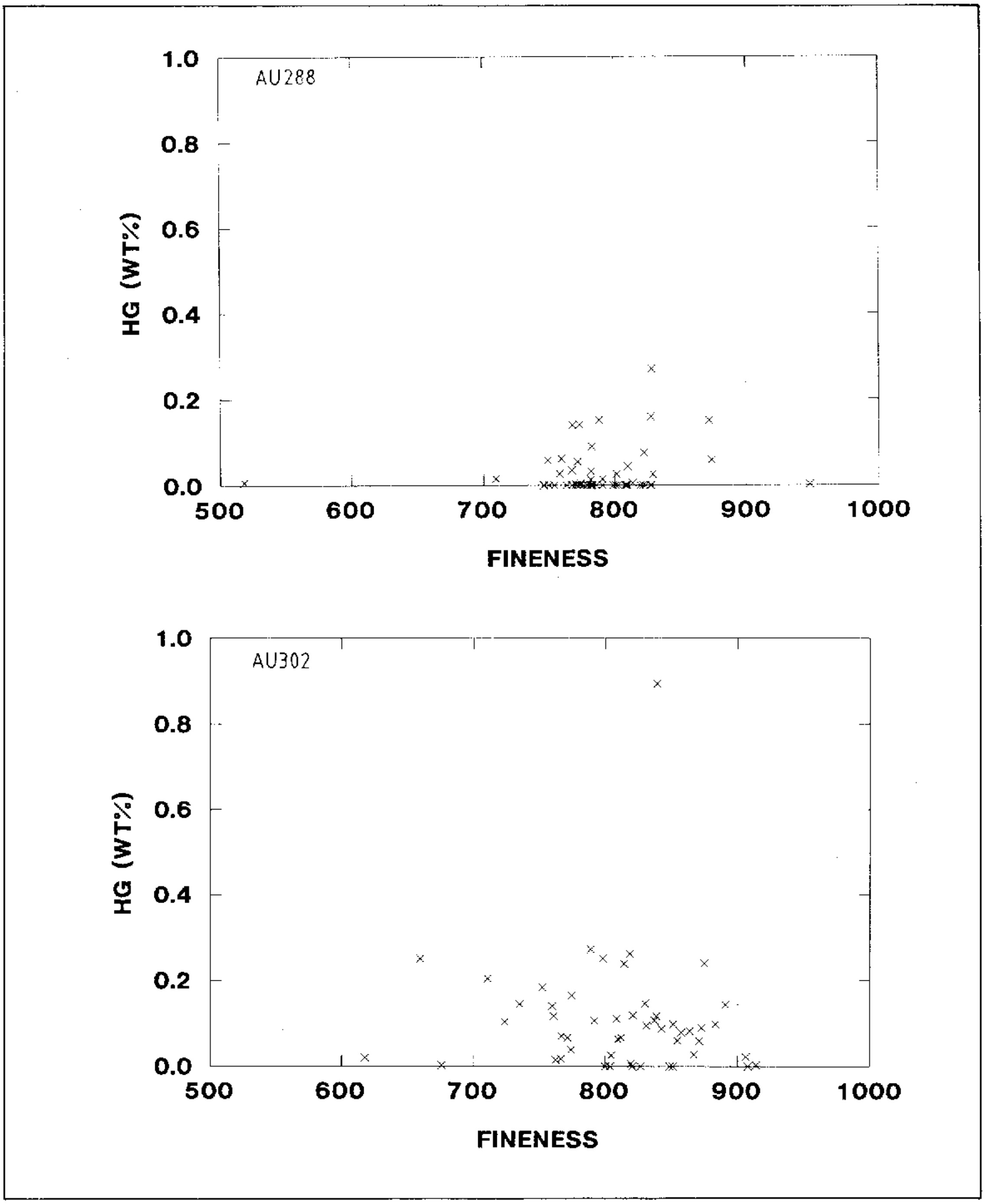
AU170 SULPHUR
Donated in 1985 by J. Hamilton.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 122, property 59.
From the Teck property on Sulphur creek. Sample is from below Brimstone gulch.

AU244 DOMINION
Donated by W. Danner. Collected 1973.
Exact locality unknown.



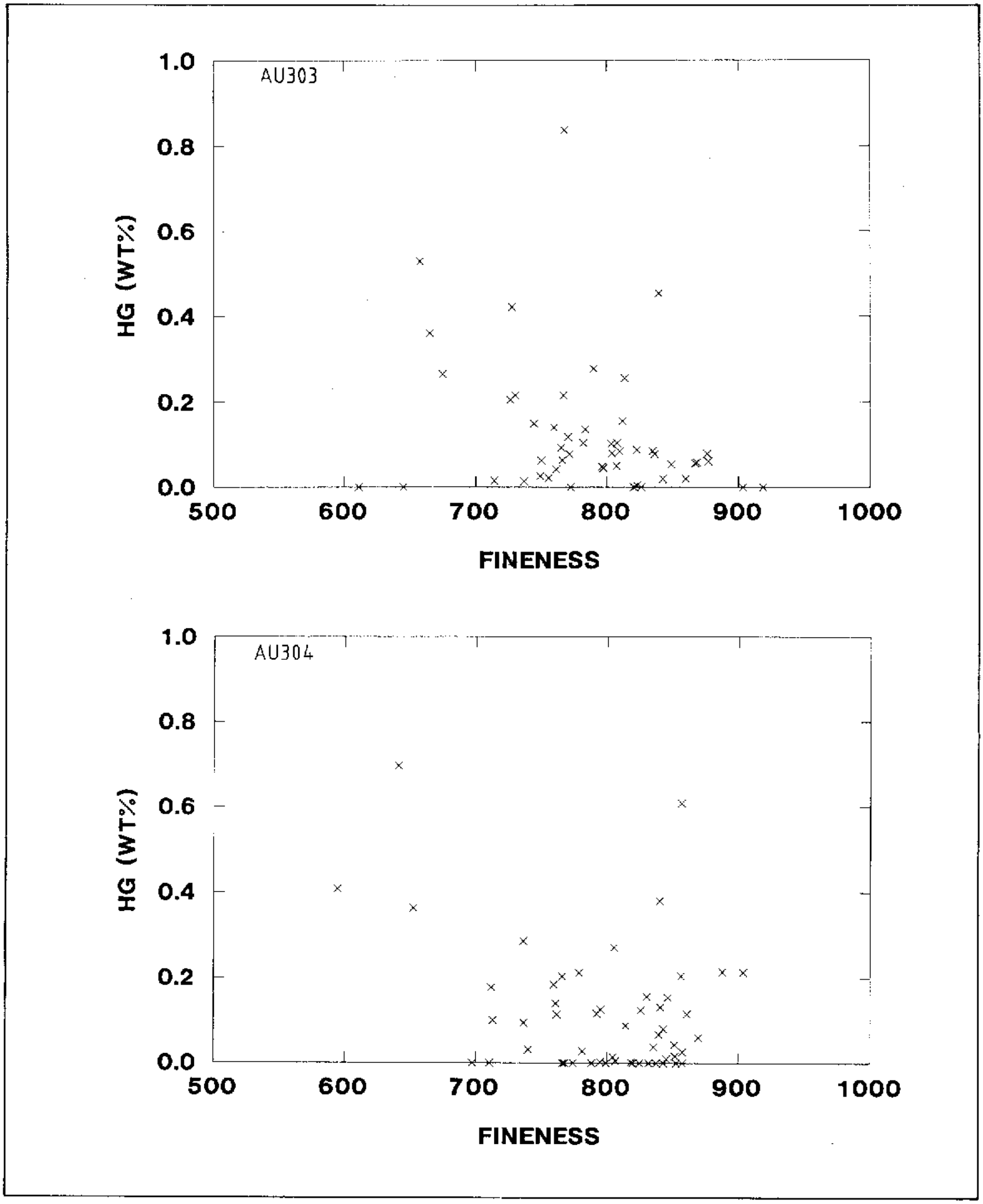
AU287 INDIAN - LOWER DOMINION
Donated in 1986 by J. Brown.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 137 property 52.
Sample located just upstream from the old #6 dredge on a bedrock high.

AU292 INDIAN
Donated in 1986 by P.Risby.
East side of Indian river about 1 mile (by road) below the confluence of Quartz creek with Indian river.



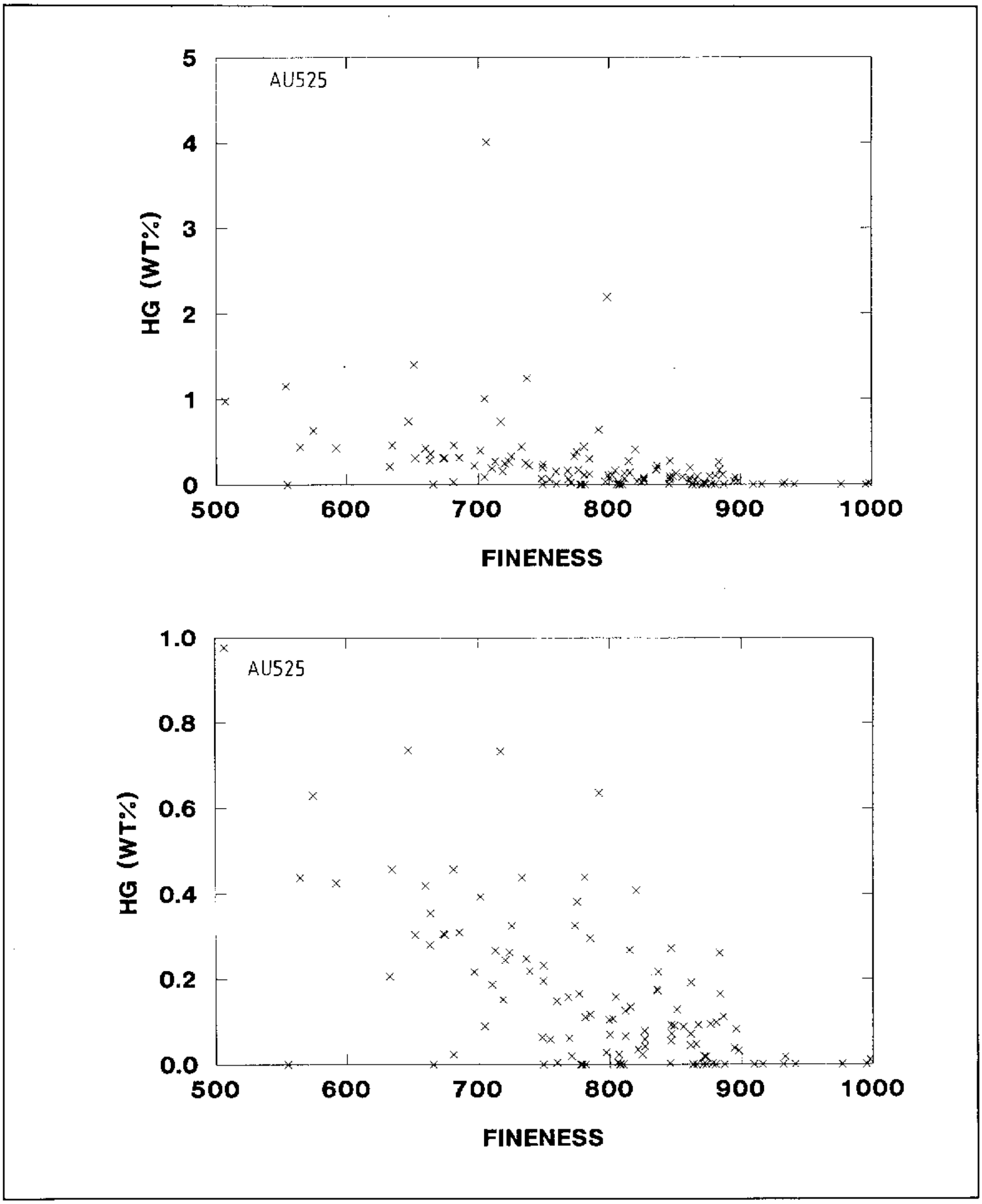
AU288 DOMINION
Donated in 1986 by L. Gatenby
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 122, property 46 and 47.
Sample located about 1.5Km downstream from the old dredge on the east side of the river on the second bench.

AU302 SULPHUR
Donated in 1986 by N. Sprockreef and D. Ball.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 140, property 64.
Gold is from the 1985 cut in Sulphur creek, about 2 claim lengths below the confluence of Green and Sulphur creeks.



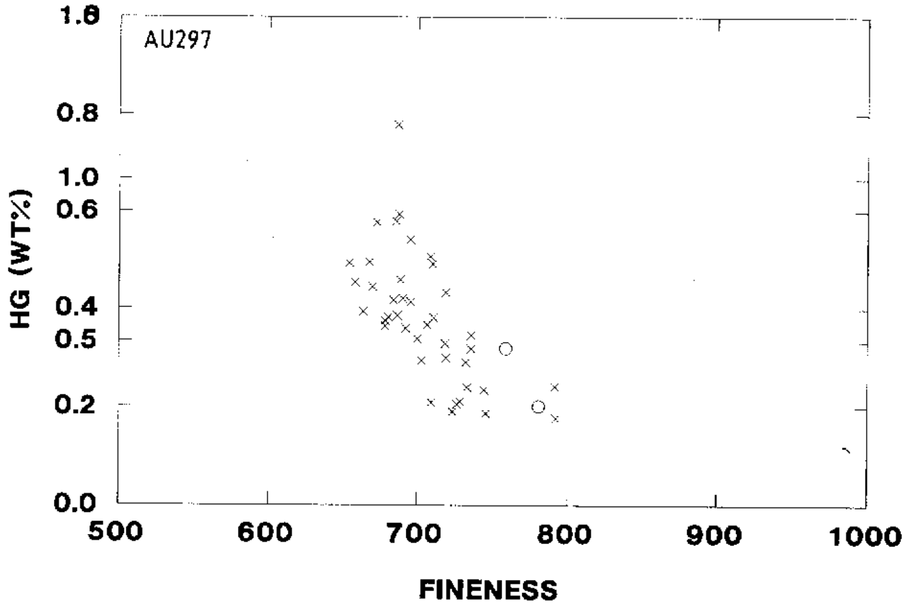
AU303 SULPHUR
Donated in 1986 by C. Kana and L. Gibson.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 139, property 60.
From the furthest downstream part of the lease, immediately adjacent to the Teck property and above Brimstone creek on Sulphur creek.

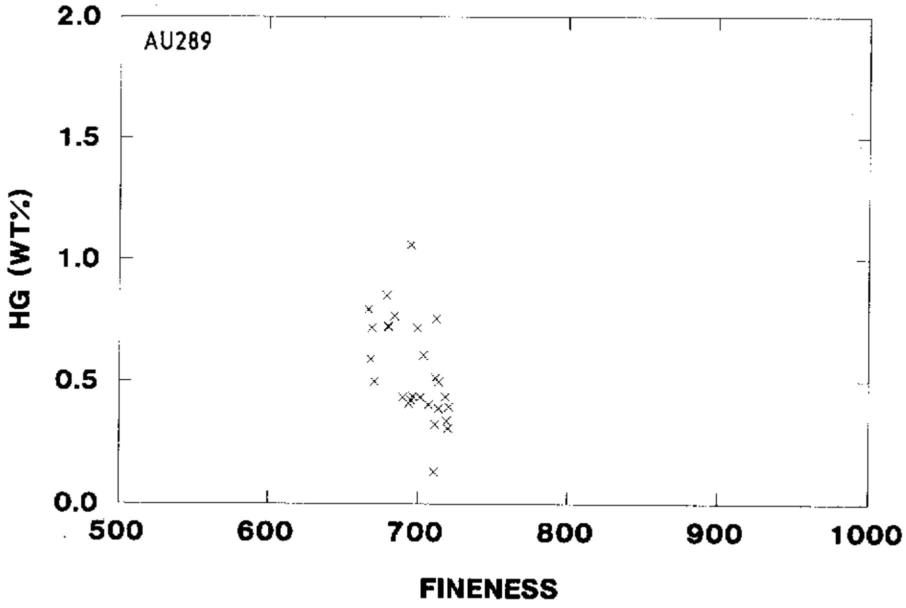
AU304 SULPHUR
Donated in 1986 by Teck Mining.
Yukon: Placer Mining Industry 1978-1982. Department of Indian and Northern Affairs, pg 138, property 59.
From the claim on Sulphur creek immediately upstream from the confluence with Brimstone creek. Immediately below AU303.



AU525 INDIAN RIVER
Donated by S. Tomlinson in 1989.
On Indian river at the mouth of McKinnon Creek. Sample from both sides of the mouth of McKinnon creek within 1km of the Indian river.

Appendix E. Hg vs. fineness plots for individual lode samples. On the AU297 Virgin Mill plot, the circles represent sample location AU450. On the AU453 Hilchey plot, the circles represent sample location AU487. On the AU486 Violet plot, the squares represent the second phases.





AU297 VIRGIN

Collected by J. Knight in 1986.

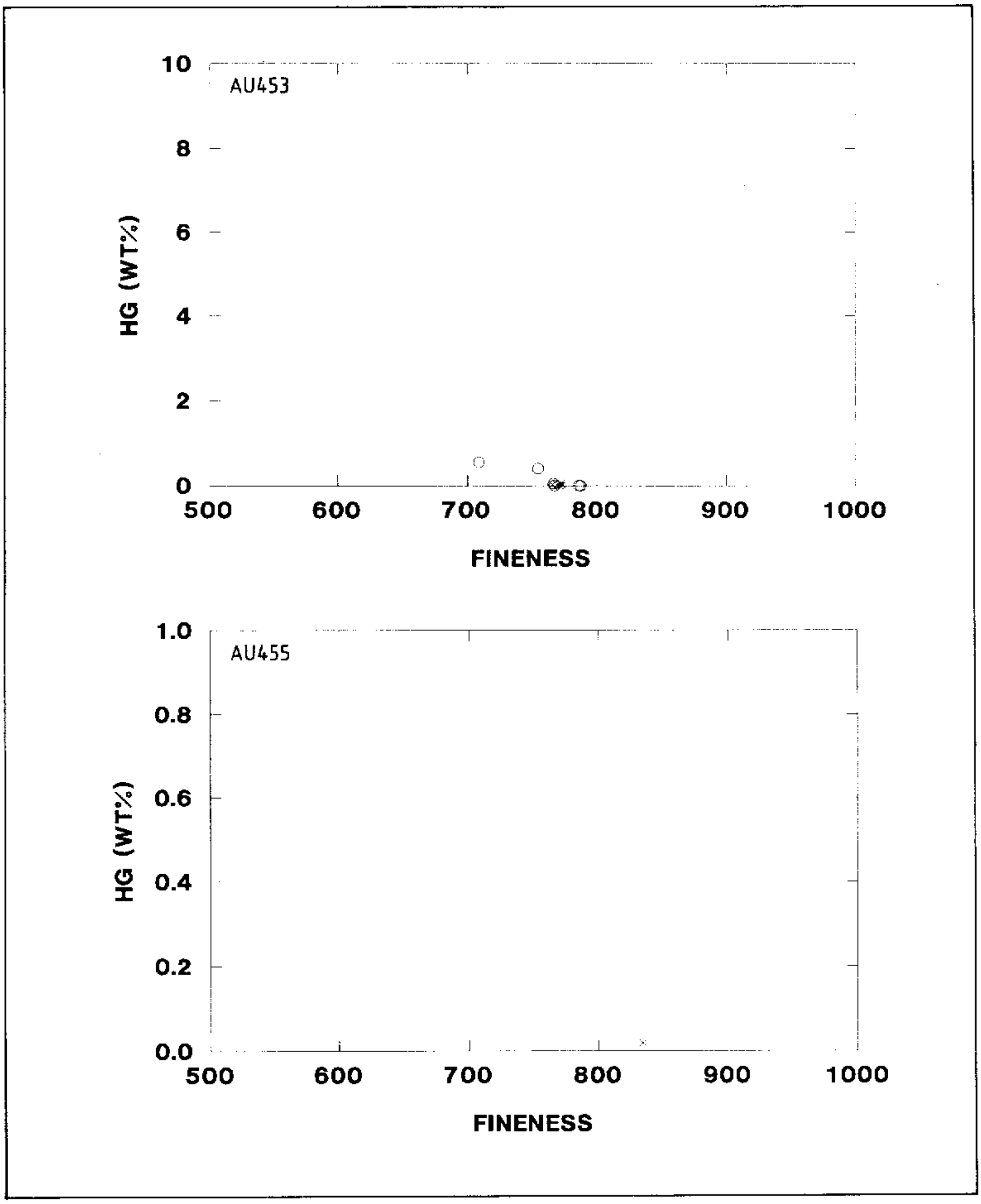
R. Debicki. 1984. Bedrock Geology and Mineralization of the Klondike Area, 115 O/14, 15 and 116 B/2, 3. (WEST). Department of Indian and Northern Affairs, 1984 Open File. Property number 6, Virgin, Jean.

Sample from the old mill. Sample panned from material taken from beneath the floor next to the crusher. Free mercury from recovary process with the gold.

AU298 DISCOVERY

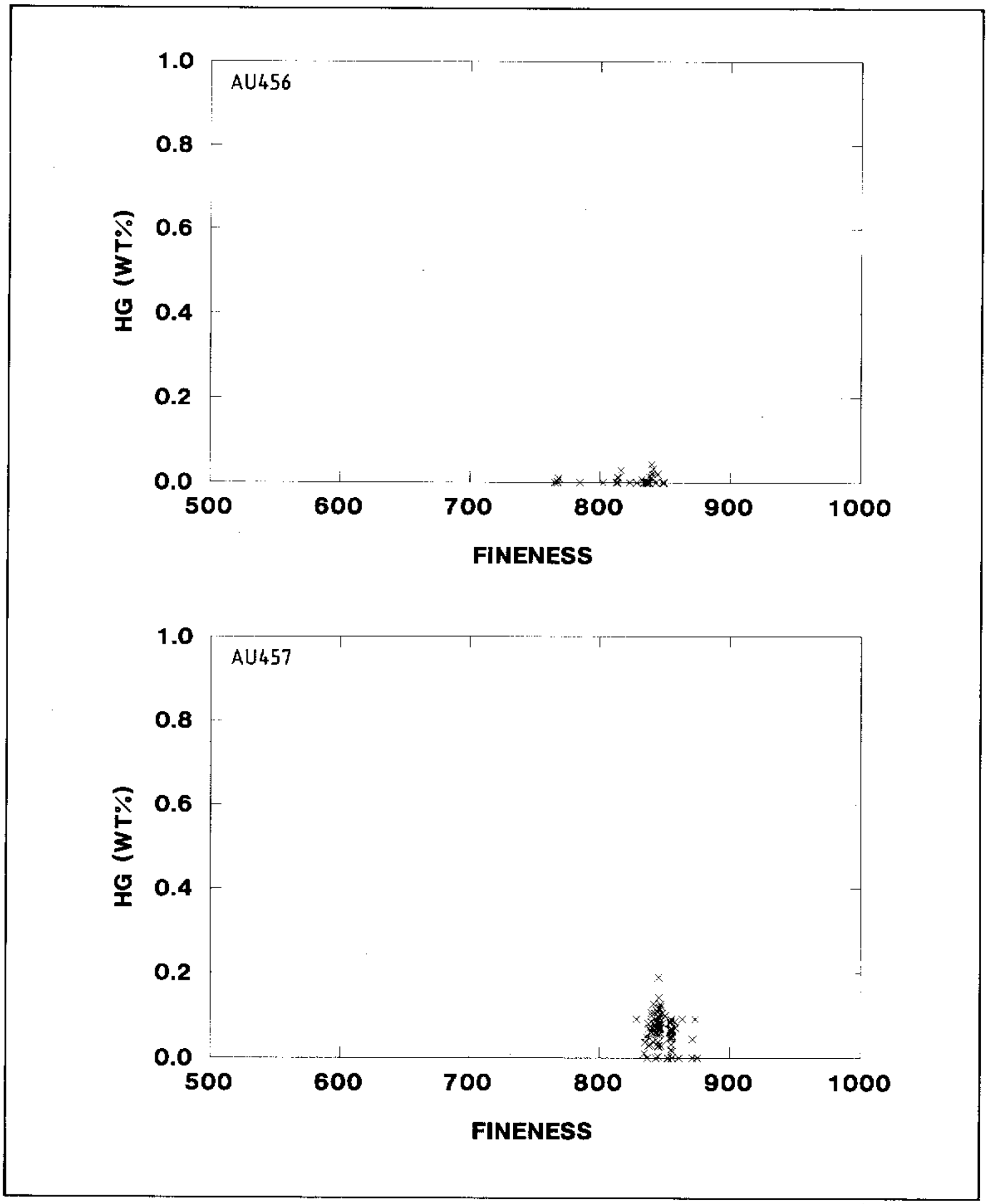
Donated in 1986 by L. Steigenberger.

From the top of the property at the mouth of Discovery gulch. About 400' up from the confluence with Bear creek. Native mercury conspicuous in the concentrate. Probably from the Virgin Mill.



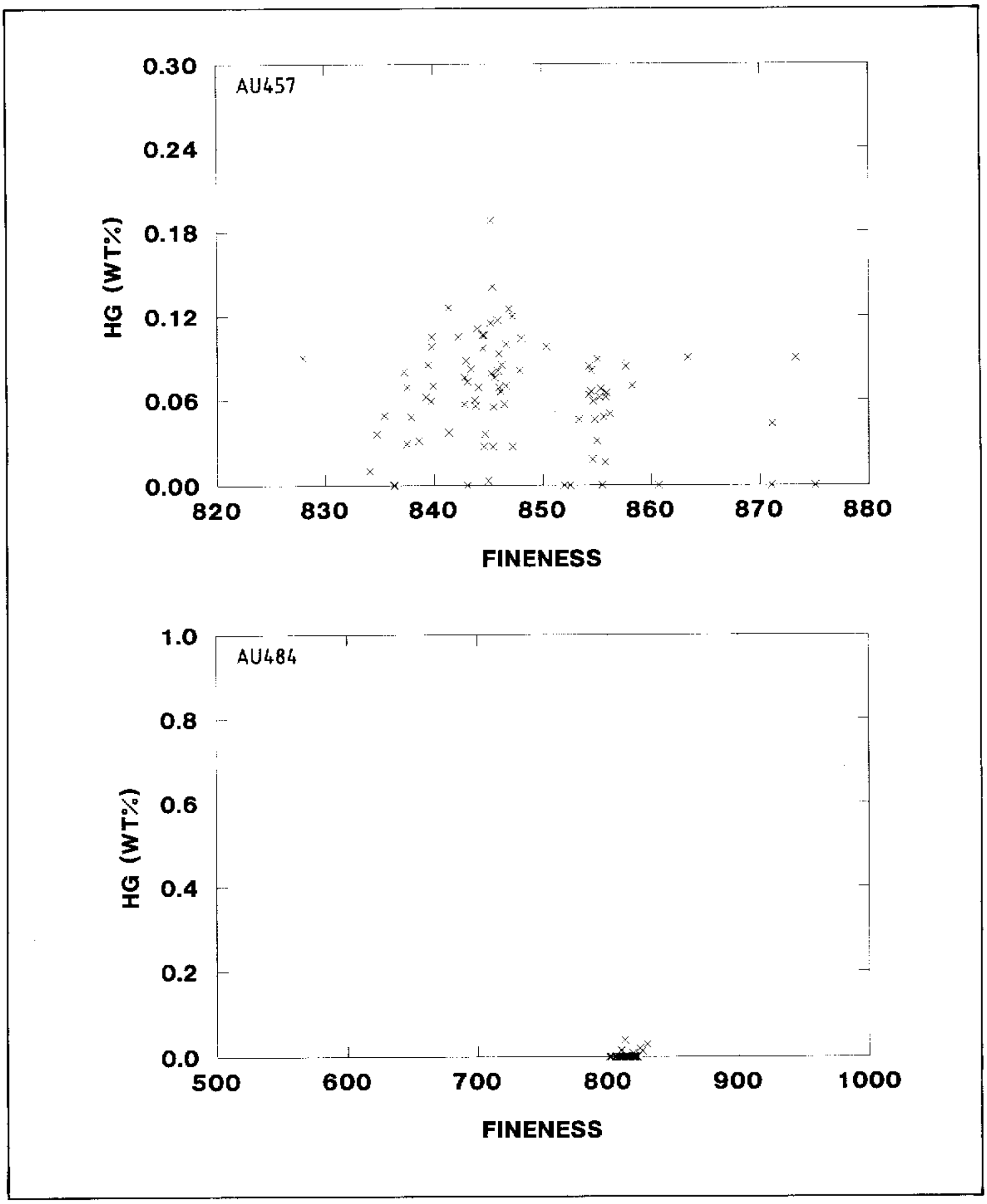
AU453 HILCHEY
Donated in 1989 by J. Mortensen. His number K-658.
R. Debicki. 1984. Bedrock Geology and Mineralization of the Klondike Area, 115 O/14, 15 and 116 B/2, 3. (WEST). Department of Indian and Northern Affairs, 1984 Open File. Property number 33, (not shown on map).
About 1.5 km upslope from Gay Gulch.

AU455 LONE STAR, WEST DUMP
Donated in 1989 by J. Mortensen.
R. Debicki. 1984. Bedrock Geology and Mineralization of the Klondike Area, 115 O/14, 15 and 116 B/2, 3. (WEST). Department of Indian and Northern Affairs, 1984 Open File. Property number 33.
From the Western most dump at the head of the old tramline.



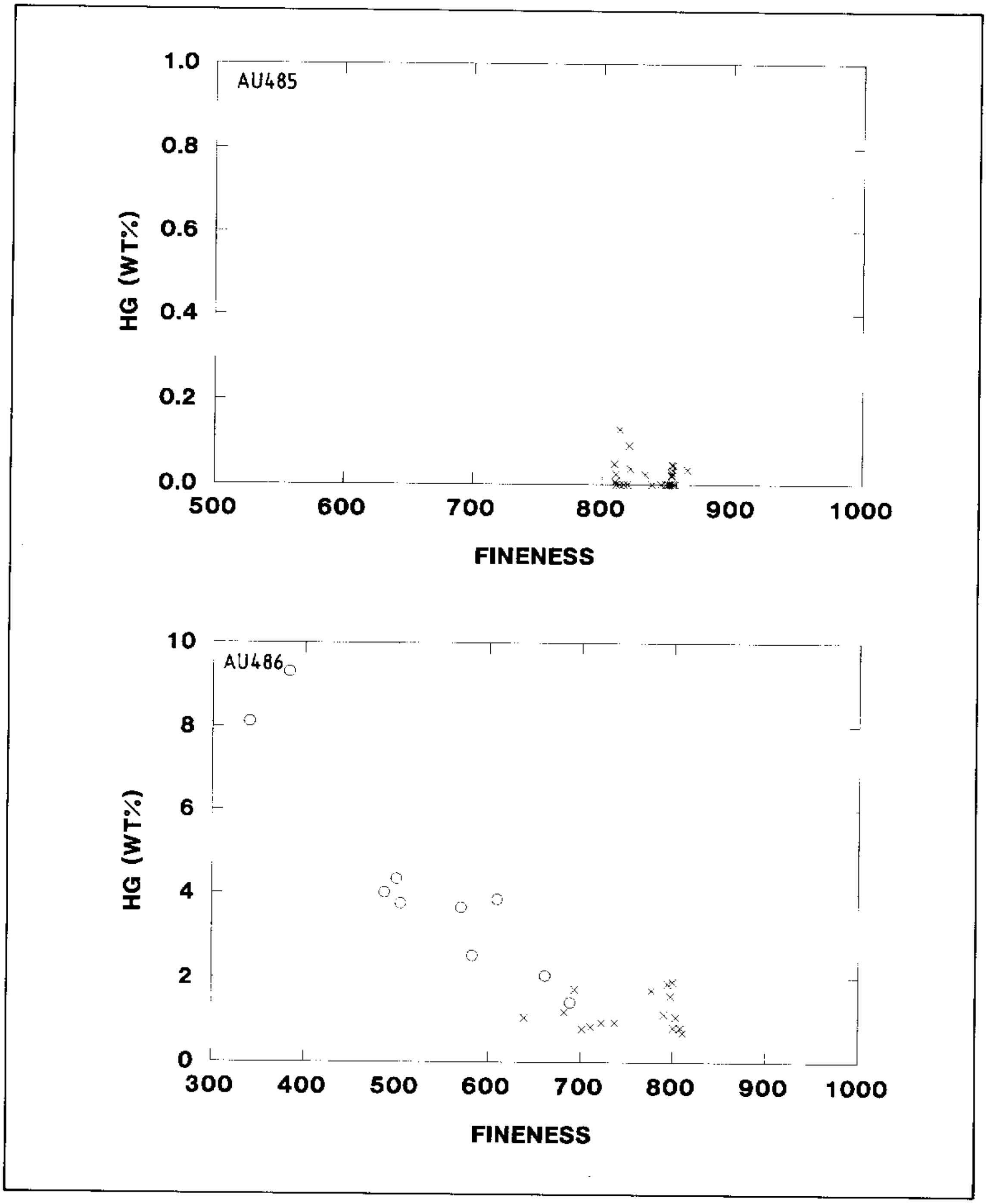
AU456 LONE STAR, CENTER DUMP
Donated in 1989 by J. Mortensen.
R. Debicki. 1984. Bedrock Geology and Mineralization of the Klondike Area, 115 O/14, 15 and 116 B/2, 3. (WEST). Department of Indian and Northern Affairs, 1984 Open File. Property number 33.
From the centre dump at the head of the old tramline.

AU457 AIME DUMP
Donated in 1989 by J. Mortensen. His number MLB-88-135.
R. Debicki. 1985. Bedrock Geology and Mineralization of the Klondike Area, 115 O/9, 10, 11, 14, 15, 16 and 116 B/2. (EAST). Department of Indian and Northern Affairs, 1984 Open File. Property number 10.
Sample from the dump at mouth of old adit.



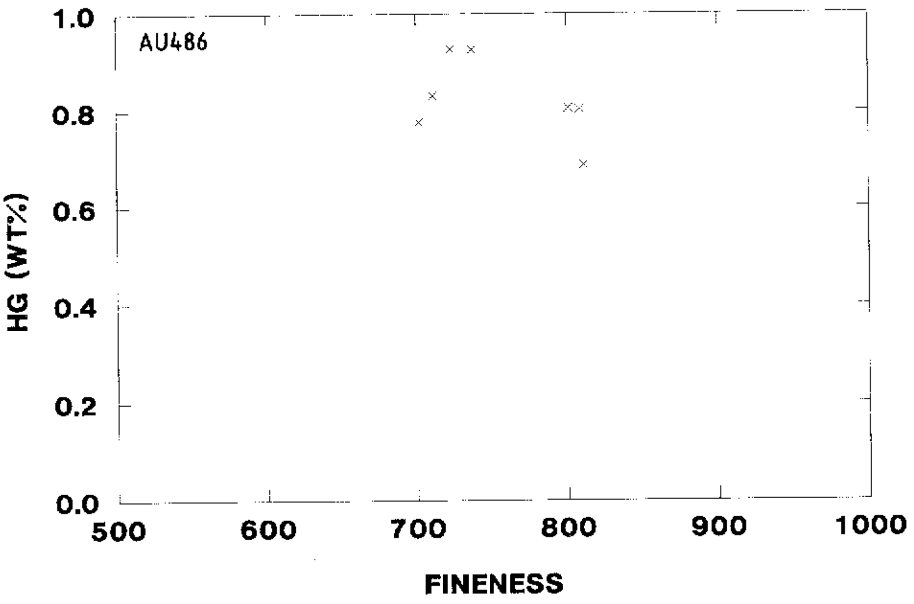
AU457 AIME DUMP
Donated in 1989 by J. Mortensen. His number MLB-88-135.
R. Debicki. 1985. Bedrock Geology and Mineralization of the Klondike Area, 115 O/9, 10, 11, 14, 15, 16 and 116 B/2. (EAST). Department of Indian and Northern Affairs, 1984 Open File. Property number 10.
Sample from the dump at mouth of old adit.

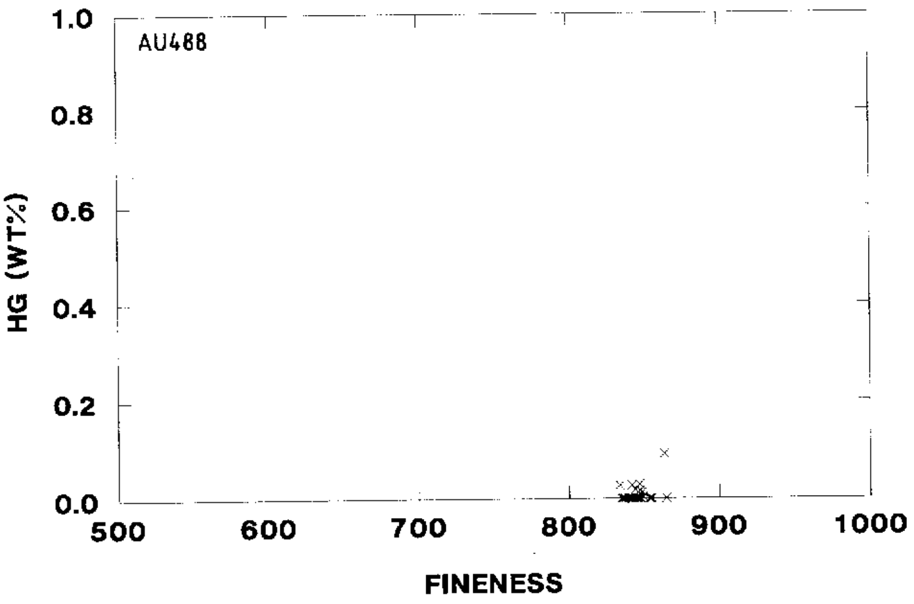
AU484 MITCHELL
Collected by J. Mortensen and J. Knight in 1989.
R. Debicki. 1984. Bedrock Geology and Mineralization of the Klondike Area, 115 O/14, 15 and 116 B/2, 3. (WEST). Department of Indian and Northern Affairs, 1984 Open File. Property number 20.
From dump.



AU485 HUNKER DOME.
Collected by J. Mortensen and J. Knight in 1989.
R. Debicki. 1984. Bedrock Geology and Mineralization of the Klondike Area, 115 O/14, 15 and 116 B/2, 3. (WEST). Department of Indian and Northern Affairs, 1984 Open File. Property number 25.
From dump of 200' shaft.

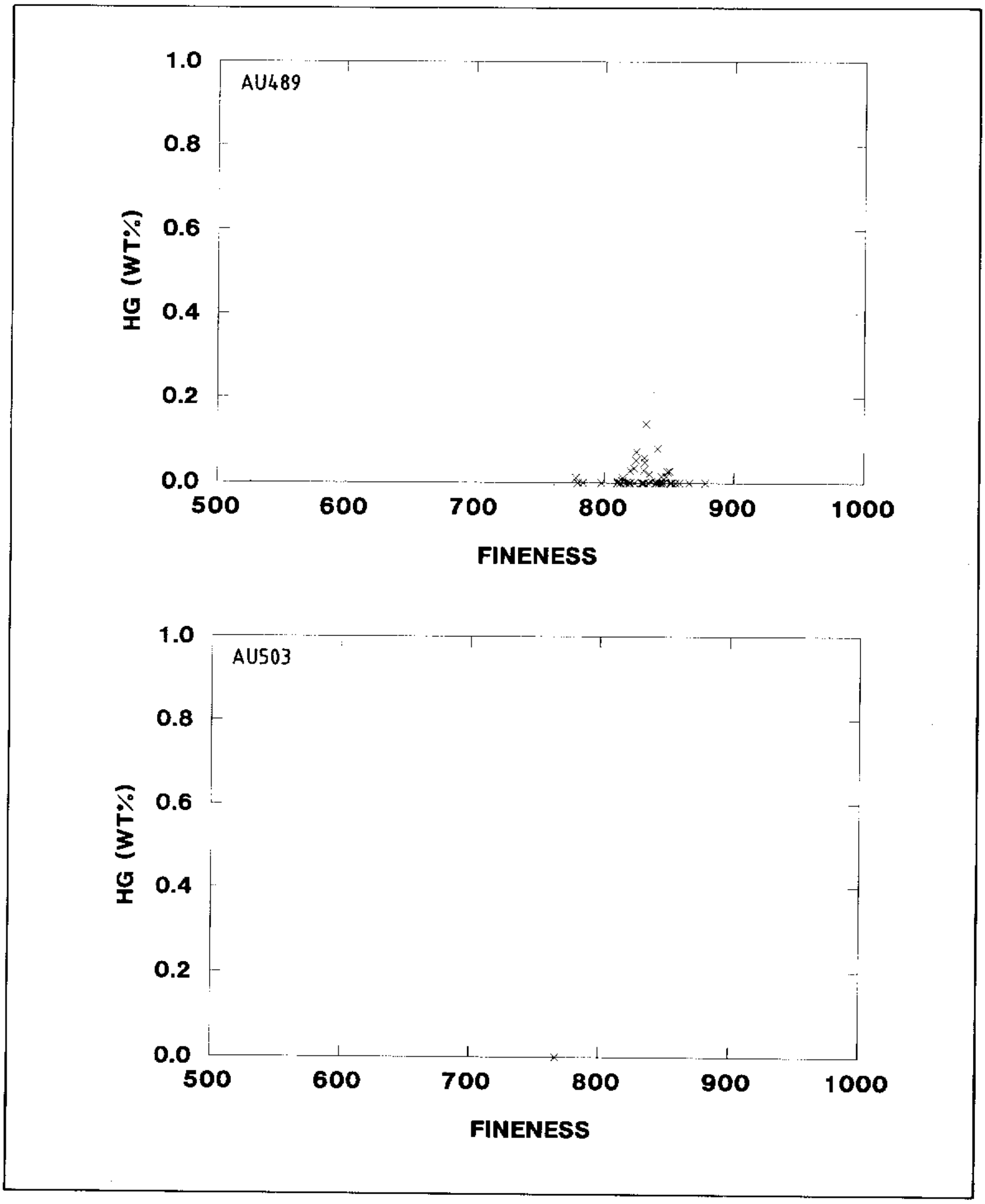
AU486 VIOLET.
Collected by J. Mortensen and J. Knight in 1989.
R. Debicki. 1984. Bedrock Geology and Mineralization of the Klondike Area, 115 O/14, 15 and 116 B/2, 3. (WEST). Department of Indian and Northern Affairs, 1984 Open File. Property number 28.
From dump.





AU486 VIOLET.
Collected by J. Mortensen and J. Knight in 1989.
R. Debicki. 1984. Bedrock Geology and Mineralization of the Klondike Area, 115 O/14, 15 and 116 B/2, 3. (WEST). Department of Indian and Northern Affairs, 1984 Open File. Property number 28.
From dump.

AU488 BOULDER.
Collected by J. Mortensen and J. Knight in 1989.
R. Debicki. 1984. Bedrock Geology and Mineralization of the Klondike Area, 115 O/14, 15 and 116 B/2, 3. (WEST). Department of Indian and Northern Affairs, 1984 Open File. Property number 33.
From Boulder open pit. Same location as AU454.



AU489 LONE STAR MILL
Collected by J. Mortensen and J. Knight in 1989.
R. Debicki. 1984. Bedrock Geology and Mineralization of the Klondike Area, 115 O/14, 15 and 116 B/2, 3. (WEST). Department of Indian and Northern Affairs, 1984 Open File. Property number 33.
From stamp at mill site.

AU503 PIONEER.
Donated by J. Mortensen in 1989. His number MLB-89-271.
R. Debicki. 1984. Bedrock Geology and Mineralization of the Klondike Area, 115 O/14, 15 and 116 B/2, 3. (WEST). Department of Indian and Northern Affairs, 1984 Open File. Property number 31 (Eldorado Dome).
From dump at the Pioneer (Eldorado Dome) adit.

THE RELATIONSHIP BETWEEN FLUVIALLY TRANSPORTED (PLACER) GOLD PARTICLE SHAPE, RIMMING AND DISTANCE OF TRANSPORT AS EXEMPLIFIED BY GOLD FROM THE KLONDIKE DISTRICT, YUKON, AND THE CORDILLERA OF BRITISH COLUMBIA.

Abstract

A semi-quantitative study of various physical features of approximately 2700 gold particles from 21 lode deposits and 36 placer deposits in the Klondike District, Yukon, was undertaken. The shape parameters of roundness and flatness, and the characteristics of the high fineness rims including thickness and percentage that each particle is rimmed were determined using a classification method. There appears to be a systematic variation between these parameters. There is also a relationship between these parameters and the distance of transport of the particle. These relationships were confirmed by quantitative measurements on critical samples.

Gold particle roundness and flatness show a rapid increase within the first 5 km from the lode source and a slower more linear increase beyond. In the Klondike area, shape data can be used to estimate the distance of transport to the source of placer gold. The relationship between the shape of a gold particle and the thickness and the percentage of the particle which is rimmed supports the conclusion that rims are formed by the removal of Ag, not the precipitation of Au. Thus rim thickness and the associated high fineness is the result of Ag removal to create the rim and stream abrasion which erodes the rim.

Hammering is the main cause of shape change in fluvially transported gold particles. Its principal effect is to flatten particles. Abrasion has its most marked effect on surface texture. Hammering and abrasion both decrease the mass (size) and increase the roundness of the gold particles.

Résumé

On a entrepris une étude semi-quantitative de différentes caractéristiques physiques sur environ 2700 particules d'or qui proviennent de 21 gisements en filon et de 36 gisements placer dans le district de Klondike au Yukon. Les paramètres que sont l'émoussé et la planéité anisi que les caractéristiques des rebords à titre élevé, notamment l'épaisseur et le pourcentage d'enrichissement des rebords de chaque particule, ont été déterminés au moyen d'une méthod de classification. Il semble que ces paramétres varient systématiquement. Il y a aussi un rapport entre ces paramètres et la distance sur laquelle les particules sont tranportées.Ces relations ont été confirmées par des mesures quantitatives faites sur des échantillons critiques. L'émoussé et la planéité des particules s'accroissent rapidement dans les 5 premiers km à partir du filon, et ensuite de manière plus lente et plus régulière. Dans la région de Klondike, les données sur la forme peuvent servir à l'estimation de la distance de transport à partir de la source de l'or placer. La relation entre la forme d'une particule et l'épaisseur ainsi que le titre de la particule dont le rebord a un titre supérieur, confirme l'hypothèse selon laquelle les rebords sont formés par enlèvement de l'Ag plutôt que par concentration de l'Au. Anisi, l'épaisseur du rebord et le titre élevé qui y est associé résultent de l'enlèvement de l'Ag, qui est à l'origine du rebord, et de l'abrasion dans le cours d'eau, qui érode le rebord.

Le battement est la principale cause du changement de forme des particules transportées dans l'eau. Son principal effet d'aplatir les particules. L'effet le plus marqué de l'abrasion s'observe au niveau de la texture. Le battement et l'abrasion ont pour effet combiné de diminuer la masse (la taiile) et d'accroitre l'émoussé des particules d'or.

INTRODUCTION

Although the shape of placer gold particles has been used to characterize gold for at least a century (e.g. Boyle, 1979, pg. 336) and has been used in arguments about the source of placer gold (e.g. Hallbauer and Utter, 1977) there are few comprehensive studies on the relationship between the distance of transport and the change in particle shape. (Tishchenko and Tishchenko, 1974; Tishchenko, 1981; Yeend, 1975; Herail et al., 1989). Most placer particles have a partial to complete zone, or rim, of nearly pure gold at their outer surface (Groen et al., 1990; Desborough, 1970; Knight and McTaggart, 1990; Boyle, 1979). There has been considerable debate about the origin of and changes to these rims with distance (Fisher, 1935; Groen et al., 1990; Bowles, 1989) but there is little quantitative data on which to base this discussion. In this study of gold from the Klondike Area, central Yukon Territory, the writers develop a rapid method for the estimation of the critical shape parameters for placer gold particles. Based on this method they demonstrate that for an adequate number of particles at a sample site there is a semi-quantitative relationship between average shape (flatness and roundness), average rim characteristics (thickness and rim percentage) and the distance of transport of the particle from the lode source. The results of this study are used as a framework to comment on the deformation of gold, the evolution of the shape and the formation of the rims in the fluvial environment.

LITERATURE REVIEW

Conventional knowledge holds that the larger, more equant and less flat the gold in a placer, the nearer the gold is to a lode source (Boyle, 1979, pg. 337; Gorbunov, 1959; Slingerland, 1984). More specifically, gold shape (Yeend, 1975; Herail et al., 1989) and size (Yeend, 1975; Antweiler and Lindsay, 1968) changes with distance of transport. The work of Yeend (1975) showed that both the velocity of transport and the host sediment particle size is important in the comminution of gold particles. The larger the host sediment particle size the more efficient the comminution process. The photographs of Yeend (1975) show that gold develops a very smooth surface when abraded with dry sand, a pitted surface with pits to 1 micron when abraded by wet sand and cobbles, and scratches wider than 10 microns when abraded with cobbles and water only. He did not discuss flattening. Fisher (1945) describes particles 8 km (5 miles) from the source as rough and nuggety, at 13 km (8 miles) they are small nuggety and water worn, at 17.5 km (11 miles) fine granular and at 40 km (25 miles) fine scaly. Unfortunately these terms are imprecise. Tishchenko and Tishchenko (1974), and Tishchenko (1981) in two important papers, have demonstrated that the flatness of gold particles increases downstream. Tishchenko (1981) showed that from a particular lode source, the flatness increases while the size decreases in a downstream direction from the lode. Furthermore, flattening was dominant in the 1 to 2 mm size while particles between 8 to 16 mm and less than 60 microns underwent little flattening. He concluded that flattening was greatest in the high energy environment and that the change in the size-flatness relationship was in part the result of flattening downstream and in part the result of sorting during fluvial transport. In addition, Tishchenko (1981) postulated that the reason for finding a higher proportion of folded particles in fossil placer was probably due to the fact that these particles had been in the fluvial environment for a long time. In agreement with Tishchenko, Utter (1980) concluded that the minimum grain diameter below which abrasion of detrital gold would not take place is 32 microns. Petrovskaya (1973) has proposed a scheme for the evolution of some specific shapes. Giusti (1986) describes the sequence needed to form a complexly folded particle from a placer. Antweiler and Lindsey (1968) reports that the average weight of a 0.125 mm particle is halved over 640 km (400 miles) but does not discuss the mechanism. Herail et al., (1989) describes the systematic linear change is flatness with distance over 100 km in Bolivia.

Shape has been used in some areas as an exploration tool to locate lode gold occurrences. Fedchuck et al., (1983) used shape and chemical composition to distinguish between gold of different origins including; lode sources (bedrock sources), supergene sources (oxidized ore sources) and precipitated sources (surficial sources). Yablokova (1972), described the uniformity of gold shape over 25,000 km^2 and used the results to discuss the origin of the gold particles. Averill and Zimmerman (1986) and Sauerbrei, Pattison and Averill (1987) have successfully used the shape of gold particles recovered from till to determine the distance and direction to a buried lode source.

Gold occurs in a wide variety of shapes in lodes (e.g. Kang, 1974; Weinig, 1960). Gold is malleable and ductile; hence it occurs in placer deposits in a wide variety of shapes which commonly differ from the original shape(s) in the source lode(s). Current shape description systems are designed primarily for minerals which fracture or cleave rather than deform, and as a result are inadequate to describe gold shapes. Examples of shape classification systems include the Zingg system (Zingg, 1935) and shape factors such as the Corey, Wentworth, and Heywood shape factors, and the Sneed and Folk, Briggs, and Winkelmolen shape classification systems (Willetts and Rice, 1983). These classification systems either ignore (e.g. Zingg) or do not separate out (e.g. Briggs) the roundness of the gold particles, and are time consuming to use. Tourtelot and Riley (1973) point out that shape factors using length x breadth in the denominator (as in Corey) cannot distinguish between particles having different elongations. Tourtelot (1968) notes that the Corey shape factor is often used because of the ease of measuring the required parameters.

Shape factors provide a variable which, when inserted in transport or settling equations, allows for adequate descriptions of the hydraulic behavior of low density minerals of restricted shape variability. The validity of these shape factors for the description of the hydraulic behavior of gold particles has had limited testing for simple shapes (Tourtelot, 1968; Shilo, 1970) and has not been tested for unusual or complex shapes. Even for the simple shapes there is still some argument about which of these shape factors is the "correct" shape descriptor. The possibility that entrainment sorting is more important than settling in hydraulic sorting

(Slingerland, 1984) further illustrates the importance of gold shape during the formation of placer deposits.

STUDY AREA

The Klondike placer mining area is found in the unglaciated portion of the western Yukon Plateau (Bostock, 1948; 1970). This plateau was formed during the late Tertiary and plunges gently to the south. The Pliocene-early Pleistocene White Channel Deposit and the Pleistocene glaciofluvial deposit termed the Klondike Gravels filled these valleys. Subsequent to the deposition of these high level gravel deposits incision by downcutting occurred which created at least two terrace levels in the Klondike area.

McConnell (1905; 1907) divided auriferous gravel deposits in the Klondike district into four types; stream gravel, river terrace gravel, White Channel gravel, and high level river gravel or Klondike gravel. The White Channel placer deposit forms high level terraces approximately 50 to 100 metres above present day stream levels, with a maximum measured thickness of 35 metres (Morison, 1985). The other placer deposit settings in the Klondike area (e.g. river terrace and valley bottom alluvium) were formed during downcutting after the deposition of the Klondike Gravel. It is thought that the placer gold found within these geomorphic settings is the result of reworking from the older White Channel Gravel placer deposits and from lode sources which were eroded during downcutting (McConnell, 1905; 1907). The White Channel Gravel deposit has, in places, been altered by hydrothermal fluids (Dufresne et al., 1986; Dufresne, 1986). This alteration is manifested by the almost complete replacement of igneous and metamorphic silicate minerals by clays. Some authors have argued that these hydrothermal fluids also introduced gold into White Channel sediment (e.g. Templeman-Kluit, 1982; Dufresne et al., 1986; Dufresne, 1986). For further discussion of the study area, see this volume, Part 1.

METHOD

This paper is a part of a larger study which was undertaken to determine the origin of the placer gold in the Klondike placer area through a study of the chemical and morphological characteristics of lode and placer gold (this volume, part 1). The reader is referred to that paper for more details of the study. A summary of the salient points are repeated here for clarity.

Samples

Twenty one lode gold samples and 36 placer gold samples were collected in the Klondike area (see Figure 2, this volume, Part 1). The lode gold samples were panned from decomposed bedrock and vein material around old adits, panned from tailings and more rarely panned from crushed vein material. Nearly all the placer samples were donated by the miners of the Klondike mining area. The gold particles from both lode samples and placer samples range in size from 0.2 mm to 2 mm with some 70% falling in the range of 0.5 mm to 0.8 mm. This corresponds to the size which shows a maximum degree of flattening during fluvial transport (Tishchenko, 1981). In general the placer gold samples gathered for this study were not modified by placer mining, however some samples had been cleaned by the donors (apparently using an ammonia based cleaning solution) and one sample is known to have been heated to greater than 100°C. In a few cases, especially for the samples from or near old mills, Hg contamination was found. Contaminated particles were removed during the preparation process whenever possible. The samples were sieved to determine the particle size distribution. For the size range of .2 mm to 1.5 mm a sub-sample of up to 100 particles was classified into outline shape, roundness and flatness categories (Table 1). All of the measurements and observations were made by one person to avoid the need to accommodate a systematic observer error. The particles were then photographed and mounted in transoptic plastic (following the method described in Douma and Knight, in press) so that the intermediate-short axis would be exposed upon polishing. The polished samples were then studied under a reflected light microscope. Estimates of rim thickness were made by measuring the most common rim thickness at high magnification. The percentage of the particle which was rimmed was estimated visually (Table 2). In addition, the intermediate and long axis distance was measured from the photograph and the short axis measured from the exposed section (Table 1) The rim thickness, the percentage of rimming, and for 14 samples, the mean values for the Shilo and Corey shape factors were calculated (Table 3). The shape classification system which is being proposed in this paper and the associated calculation for the mean values of flatness and roundness are described below.

Development Of An Empirical Shape Classification System

The shape of a gold particle can be described by three parameters; a) the degree to which the particle is flattened or flatness; b) the degree to which the particle is rounded or roundness and c) the texture of the surface. One other feature of interest is the outline shape of the particle as it lies on its preferred side (i.e., the side with the largest surface area). It is important to maintain the distinction between roundness and surface texture. For example, roundness is affected by large features of a particle which the eye readily interprets as affecting the shape. A term commonly used to describe particles with a low roundness would be hackly. Surface texture is comprised of those features which affect the appearance of the surface of the particle. Terms used to describe surface texture includes matte, mirror-like, scratched, pitted, etc. As the particles become smaller, the features impacting roundness approach that of features impacting surface texture. This relationship seems to become important for particles less than 200 microns in size. As DiLabio (1990) pointed out, the shapes of small gold particles are more easily described from a Secondary Electron Image. Surface texture will not be discussed in detail except in the section on the mechanism of gold shape evolution.

TABLE 1. Data for average gold shape characteristics. NUM = sample number, LOC = location (B=Bonanza, S=Sulphur, E=Eldorado, D=Dominion, I=Indian, W=White Channel Gravels, R=Bear, H=Hunker, L=Lode, Q=Quartz Creek, G=Gold Run, T=Thistle), TYPE = type (L=Lode, P=Placer), LSIZE = smallest size, HSIZE = largest size, TOTAL = number of particles studied for shape, FLAT = flatness in percent, ROUND = roundness in percent, RIMP = percentage of the particle edge that is rimmed, RIMT = thickness of the rim in microns, DFLAT = distance in Km estimate based on flatness, DROUND = distance in Km estimate based on roundness, DRIMP = distance in Km estimate based on rim percentage, DRIMT = distance in Km estimate based on rim thickness, EDIST = Estimate of the distance from lode source based on chemical signatures.

NOTES: * These distance estimates were NOT used to create the distance curves. SM = Small, LA = Large, RO = Rough, TO = Total of all particles, IN = Intermediate (the remainder after the rough are removed), AU = Gold coloured, AG = More silvery coloured. A = Altered White Channel Gravels, (- = partly altered), F = derived in part from White Channel.

NUM	LOC	TYPE	LSIZE	HSIZE	TOTAL	FLAT	ROUND	RIMP	RIMT	DFLAT	DROUND	DRIMP	DRIMT	EDIST	NOTE
168	B	P	0.5	1.0	236	61.3	67.4	42.3		17.0	3.5	10.5		15.0	
170	S	P	0.4	0.6	483	37.4	63.0	32.5		2.5	2.5	6.5			
243	E	P	0.8	1.2	53	32.4	58.8	13.0	1.92	1.5	2.0	1.5	1.5		
244	D	P	1.2	1.5	25	55.3	64.7	27.1	4.92	12.0	3.0	4.0	9.0		
287	I	P	0.2	0.5	86	67.8	81.8	73.7	5.65	22.0	30.0	27.0	13.0	25.0	
288	D	P	0.5	0.8	59	63.6	77.7	92.4	7.85	20.0	11.0	44.0	30.0	19.5	
290	R	P	0.5	0.8	48	29.9	52.1	14.0	2.0	1.5	1.5	2.0	2.0	1.0	
291	R	P	0.8	2.0	13	37.2	50.0	52.3	5.46	2.5	1.0	18.0	12.0	2.0	
292	I	P	0.5	0.8	81	55.8	74.3	67.3	6.59	12.0	7.0	31.0	20.0	14.5	
293	I	P	0.5	0.8	56	49.4	83.3	62.6	8.72	6.5	40.0	25.0	>40	14.5	
294	I	P	0.5	0.8	57	50.6	74.0	63.0	8.60	7.5	6.0	26.0	>40	15.5	
295	H	P	0.5	0.8	57	46.5	74.0	85.3	28.73	5.0	6.0	>40	>40		F A
297	L	L	0.2	0.8	29	19.0	31.6	0.0	0.0	0.3	0.5	0.0	0.0	0.0	
298	R	P	0.5	0.8	73	24.4	39.5	6.5	1.03	0.5	1.0	1.0	1.0	0.5	
299	W	P	0.2	1.2	24	59.7	73.6	91.8	8.84	15.0	6.5	>40	>40		A-
300	W	P	0.3	0.8	15	45.6	81.1	87.5	16.58	4.5	26.0	>40	>40		A-
301	B	P	0.5	0.8	55	46.4	79.1	80.8	9.39	5.0	16.0	>40	>40	12.0	F
302	S	P	0.5	0.65	26	28.2	62.8			1.0	2.0				SM
302	S	P	0.65	0.8	28	42.9	69.0			4.0	4.0				LA
302	S	P	0.5	0.8	54	35.8	66.0	30.2	1.53	2.0	3.0	5.5	1.0	3.0	TO
303	S	P	0.5	0.8	58	54.6	55.7	46.9	6.90	10.0	1.5	14.0	22.0	12.0	
304	S	P	0.5	0.7	57	47.7	71.1	49.3	5.39	5.5	4.5	15.5	11.0	12.0	
305	W	P	0.5	0.8	52	45.3	64.6	84.7	38.6	4.5	2.5	>40	>40		IN A
305	W	P	0.5	0.8	5	29.6	18.5	58.3	15.0	1.0	0.0	23.0	>40		RO
306	W	P	0.5	0.8	57	54.1	72.8	88.7	7.94	10.5	5.0	>40	32.0		A-
454	L	L			6	22.2	33.3	0.0	0.00	0.5	0.5	0.0	0.0	0.0	
456	L	L			0	-1.0	-1.0	0.0	0.00			0.0	0.0	0.0*	
457	L	L			80	25.0	18.3	0.0	0.00	0.5	0.5	0.0	0.0	0.0	
483	H	P	0.5	0.8	129	21.6	45.1	1.0	1.58	0.5	1.0	0.0	1.0	1.0	
484	L	L	0.5	0.8	34	24.5	16.7	0.0	0.00	0.5	0.0	0.0	0.0	0.0	
485	L	L	0.4	0.6	27	34.0	24.1	0.0	0.00	2.0	0.5	0.0	0.0	0.0	
486	L	L			26	29.5	41.0	0.0	0.00	1.0	1.0	0.0	0.0	0.0	
487	L	L			7			0.0	0.00			0.0	0.0	0.0*	
488	L	L			28	33.3	19.1	0.0	0.00	1.5	0.5	0.0	0.0	0.0	
490	Q	P	0.6	1.0	24	16.7	16.7	0.1	0.00	0.0	0.0	0.0	0.0		RO
490	Q	P	0.6	1.0	86	44.2	68.6	21.7	3.21	4.5	3.5	3.0	3.0	4.5	IN
503	L	L			1			0.0	0.00			0.0	0.0	0.0*	
524	W	P	0.3	0.7	103	73.6	77.2	73.7	4.94	27.0	9.0	36.0	9.0		
525	I	P	0.2	0.5	131	48.5	80.0	49.2	2.41	6.0	22.0	15.0	2.5		
526	H	P	0.5	0.8	127	72.8	78.9	48.5	5.28	27.0	16.0	15.0	11.0		
527	E	P	0.5	0.8	83	48.8	73.3	31.5	4.3	6.0	5.0	5.0	7.5	6.0	
528	B	P	0.5	0.8	84	56.0	77.8	33.1	6.01	12.0	11.0	6.0	9.5	8.0	
532	I	P	0.2	0.5	121	79.2	77.5	48.6	3.55	33.0	11.0	15.0	4.0	25.0	
533	E	P	0.8	1.0	67	21.6	41.0	3.8	1.74	0.5	1.0	1.0	1.5	1.0	
534	H	P	1.0	2.0	34	58.8	65.7	89.0	30.97	14.5	3.5	>40	>40		F A
535	W	P	1.0	1.5	4	66.7	66.7	37.5	1.75	21.5	3.5	7.5	1.5		A
537	E	P	2.0	2.5	4	16.7	25.0	0.0	0.00	0.0	0.5	0.0	0.0	1.0*	
538	W	P	0.3	0.7	109	69.9	78.4	84.7	26.3	24.5	16.0	>40	>40		A

TABLE 1. Continued.

NUM	LOC	TYPE	LSIZE	HSIZE	TOTAL	FLAT	ROUND	RIMP	RIMT	DFLAT	DROUND	DRIMP	DRIMT	EDIST	NOTE
539	H	P	0.8	1.6	77	44.8	70.8	14.3	0.91	4.5	4.5	2.0	1.0	3.0	
540	G	P	0.4	0.8	72	66.7	68.1	27.3	3.12	22.0	3.5	4.0	3.0		
541	B	P	0.5	0.8	78	29.1	47.0	3.3	0.38	1.0	1.0	0.5	0.5	2.0	
542	B	P	0.5	0.8	64	24.5	18.8	0.0	0.00	0.5	0.1	0.0	0.0	0.5	
543	I	P	0.5	0.8	101	74.7	75.4	50.1	5.94	30.0	7.0	15.5	9.5	25.0	
544	T	P	0.5	1.5	99	76.3	76.9	28.5	4.49	31.0	9.0	4.0	8.0		
545	E	P	0.5	0.8	102	22.9	30.7	7.7	1.66	0.5	0.5	1.0	1.0	1.0	
559	E	P	0.5	1.0	85	42.5	59.4	26.5	5.41	4.5	2.0	4.0	12.0	3.0*	TO
559	E	P	0.5	1.0	74	46.4	65.8			5.0	2.5			3.0*	AU
559	E	P	0.5	1.0	11	16.7	16.7			0.0	0.0				AG

TABLE 2. Summary of rim characteristics. Cu is always less than the detection limit. "NUMBER ANALYZED" refers to analyses of the rims. The number of particles used to calculate the "PERCENTAGE MEAN" and "THICKNESS MEAN" can be found from Table 1. "PERCENTAGE MEAN" refers to the percentage of the outline of the particle that is covered by a rim. The thickness of the rim is given in "THICKNESS MEAN". DL = Detection Limit. M = Most of the particles <DL.

SAMPLE NUMBER	SAMPLE NAME	NUMBER ANALYZED	FINENESS MEAN	FINENESS SIGMA	HG WT% MEAN	FINENESS MAXIMUM	PERCENTAGE MEAN	THICKNESS MEAN(10-6m)
AU115	DOMINION	1	998.1		<DL	998.1		
AU168	BONANZA	23	992.7	5.3	<DL	999.1	42.3	
AU170	SULPHUR	13	994.4	6.4	<DL	999.7	32.5	
AU243	ELDORADO	3	989.7	7.9	<DL	997.9	13.0	1.92
AU244	DOMINION	7	992.2	2.2	TO 0.1	998.9	27.1	4.92
AU287	LOWER DOMINION	22	994.6	4.9	<DL	1000.0	63.6	5.65
AU288	DOMINION	27	995.9	5.8	<DL	1000.0	92.4	7.85
AU289	VIRGIN	0					0.0	0.00
AU290	UPPER BEAR	3	986.4	16.4	<DL	998.6	14.0	2.00
AU291	BEAR	6	981.9	22.6	<DL	997.4	52.3	5.46
AU292	INDIAN	25	986.8	14.9	<DL	998.8	67.3	6.59
AU293	INDIAN	0					62.6	8.72
AU294	INDIAN	0					63.0	8.60
AU295	HUNKER	35	990.3	8.0	TO 0.1	999.6	85.3	28.73
AU297	VIRGIN	0					0.0	0.00
AU298	DISCOVERY	1	985.8		<DL	985.8	6.5	1.03
AU299	TRAIL HILL	10	992.0	6.7	<DL	998.6	91.8	8.84
AU300	TRAIL HILL	5	997.6	1.	<DL	999.4	87.5	16.58
AU301	BONANZA	23	988.6	10.7	TO 0.1	1000.0	80.8	9.39
AU302	SULPHUR	3	983.9	3.3	<DL	987.6	30.2	1.53
AU303	SULPHUR	12	990.6	6.5	TO 0.1	999.6	46.9	6.90
AU304	SULPHUR	11	989.7	9.2	<DL	997.2	49.3	5.39
AU305	DAGO HILL	63	987.0	10.8	TO 0.1	999.2	84.7	38.60
AU306	CRIPPLE HILL	19	988.3	13.6	<DL	999.9	88.7	7.94
AU450	VIRGIN DUMP	0					0.0	0.00
AU453	HINCHEY	0					0.0	0.00
AU454	LONE STAR	0					0.0	0.00
AU455	LONE STAR WEST	0					0.0	0.00
AU456	LONE STAR CENTER	0					0.0	0.00
AU457	AIME DUMP	0					0.0	0.00
AU483	24 ABOVE PUP HUNKER	0					1.0	1.58
AU484	MITCHEL	0					0.0	0.00
AU485	HUNKER DOME	0					0.0	0.00
AU486	VIOLET	0					0.0	0.00
AU487	HILCHEY	0					0.0	0.00
AU488	LONE STAR BOULDER LODE	0					0.0	0.00
AU489	LONE STAR MILL	0					0.0	0.00
AU490	QUARTZ CK.							
	-1, -2, -3	11	985.9	7.4	TO 0.08	996.2	21.7	3.21
	-4	0					0.1	0.04
AU503	PIONEER	0					0.0	0.00
AU524	JACKSON HILL	23	986.1	11.2	M TO 0.27	998.9	73.7	4.94
AU525	INDIAN @ McKINNON	19	982.3	41.6	M TO 0.6	998.8	49.2	2.41
AU526	HUNKER @ HESTER	41	992.9	21.1	<DL	999.4	48.5	5.28
AU527	ELDORADO MOUTH	16	978.4	26.0	TO 0.08	996.2	31.5	4.30
AU528	BONANZA AT ELDORADO	22	991.3	6.4	M TO 0.13	998.6	33.1	6.01
AU532	INDIAN	0					48.6	3.55
AU533	GAY GULCH	6	989.5	5.8	<DL	995.5	3.8	1.74
AU534	80 PUP, HUNKER	30	988.5	13.6	M TO 0.08	997.5	89.0	30.97
AU535	PARADISE	1	998.0		<DL	998.0	37.5	1.75
AU537	ORO GRANDE	0					0.0	0.00
AU538	AUSTRALIAN HILL	68	988.6	12.3	<DL	999.7	84.7	6.30

TABLE 2. Continued.

SAMPLE NUMBER	SAMPLE NAME	NUMBER ANALYZED	FINENESS MEAN	FINENESS SIGMA	HG WT% MEAN	FINENESS MAXIMUM	PERCENTAGE MEAN	THICKNESS MEAN(10-6m)
AU539	HUNKER LEFT FORK	6	993.0	5.5	<DL	999.2	14.3	0.91
AU540	GOLD RUN	14	994.0	5.2	M TO 0.13	999.1	27.3	3.12
AU541	VICTORIA	1	942.5		<DL		3.3	0.38
AU542	7 ABOVE PUP BONANZA	0					0.0	0.00
AU543	INDIAN	0					50.1	5.94
AU544	THISTLE	0					28.5	4.49
AU545	27 PUP ELDORADO	11	979.1	25.0	M TO 0.13	998.1	7.7	1.66
AU559	ELDORADO AT 26 PUP	10	991.6	6.6	TO 1.8	997.9	26.5	5.41

Table 3: Listing of Corey and Shilo Shape Factors

Sample No.	Number	Shape Factor	
	of particles	Shilo	Corey
287	86	5.583	0.175
288	59	6.430	0.150
290	48	1.777	0.456
291	13	1.426	0.448
292	81	4.341	0.246
293	56	3.856	0.272
294	57	5.308	0.203
295	57	4.553	0.210
300	15	4.893	0.201
301	55	3.080	0.295
302	54	2.332	0.340
303	58	5.294	0.213
304	57	3.924	0.233
305 (smooth)	52	4.376	0.220
305 (rough)	5	3.976	0.269
305 (all)	57	4.334	0.225

$$\text{Shilo shape factor} = \frac{(\text{large} + \text{small dimension})}{(2 \times \text{small dimension})} - 1$$

$$\text{Cory shape factor} = \frac{\text{thickness}}{\sqrt{\text{length} \times \text{width}}}$$

The terms angular and rounded are used as descriptors of roundness, however the term angular can also be used to indicate the size of the angle between adjacent surfaces (Pettijohn, 1975). This distinction is important in describing the shape of gold grains. The term 'edge angularity' is used here to describe the angle between surface features while angular is used as a roundness descriptor. Commonly, but not always, the less round a particle the greater the edge angularity. The shape classification system used in this study is referred to as an Empirical Shape Classification System which combines roundness and flatness to form nine shape classes each labeled by a 3 digit number (Figure 1a). Four outline shape classes were created each labeled with a 2 digit number (Figure 1b). A particle is uniquely classified by adding the 3 and 2 digit numbers. The numbers simplify computer manipulation without complicating particle description. Particles were classified empirically by comparison to charts (for roundness and outline shape) and flatness estimates were based on arbitrary limits. The roundness classifications have three classes which were adapted from Power's (1982) six category scheme (Figure 1a). In order to verify the results of this proposed empirical system described above it is necessary to compare the results with those of a quantitative classification system. There is no simple quantitative measure for roundness to which this method can be compared. This flatness classification system can be compared to the Shilo and Corey shape factors. The empirical outline shape classification (Figure 1b) can be compared with the quantitative Zingg (1935) classification scheme.

The mean values for roundness and flatness for each sample were calculated by using the equation for averaging classed data (Folk 1974), where:

$$Mean = \frac{\Sigma fm}{n}$$

and:

f = frequency of each grain size grade (or class) present

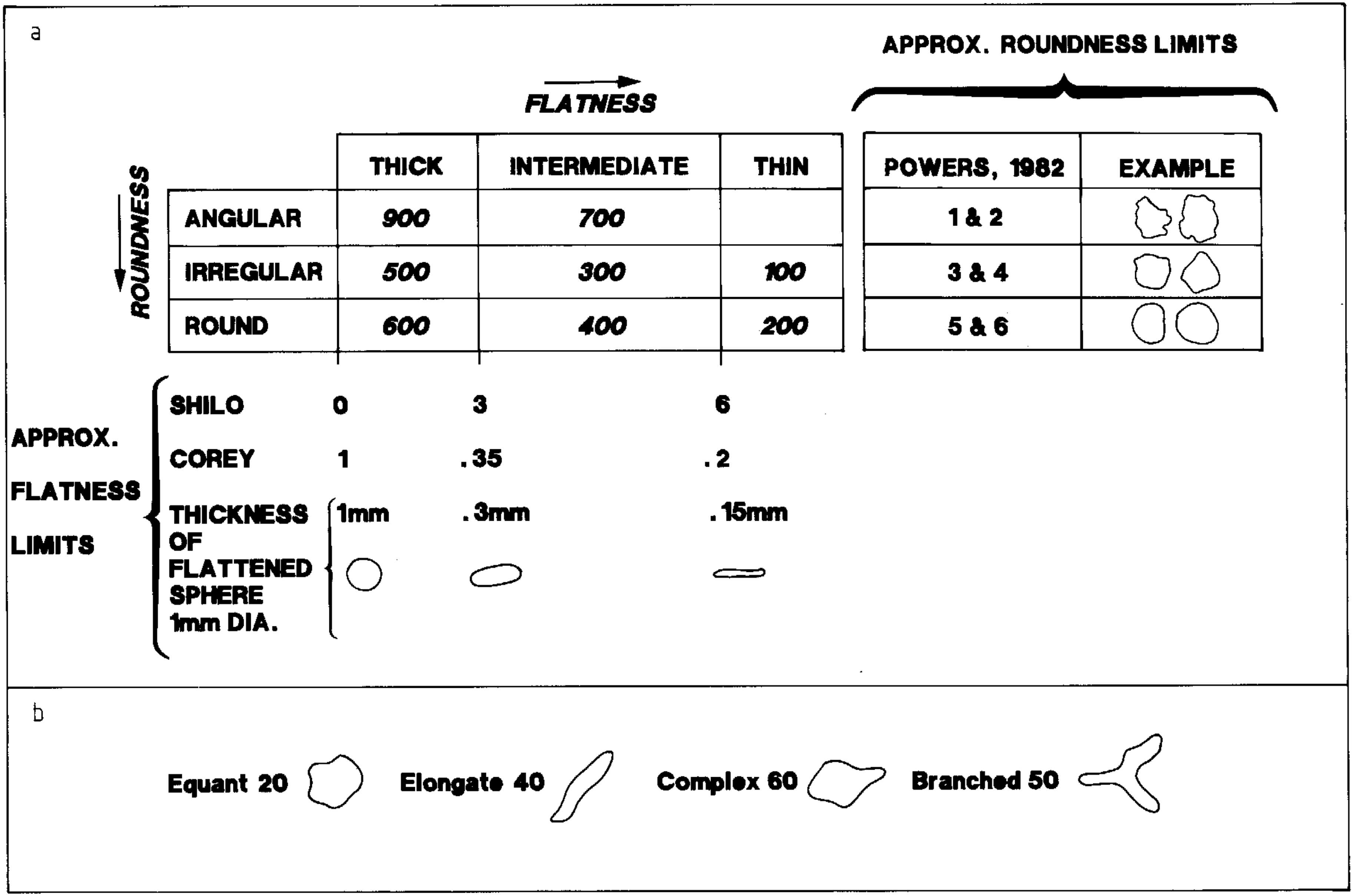
m = midpoint of each grain size grade (or class mark)

n = total number of particles in sample.

The mean data are presented on a plot which uses the range for individual particles. Therefore the minimum and maximum values for the mean are the minimum and maximum class marks, 16.67% and 83.33% respectively. Unless otherwise stated the relationships described below refer to averaged data.

Limits to the data and procedure

We recognize that our samples cannot be considered to be completely representative of the placer deposits in the Klondike. We also recognize that the placer gold for each sample does not represent the complete size and shape distribution at each sample site. For example, some samples are not representative due to circumstances where gold particles were taken from heavy mineral concentrates which had already been picked for gold. However for the size range studied, the data from Wang and Poling, (1983) indicates that the recovery for gold samples used for this study is good and can be considered to be representative. Where possible, a representative sub-sample of gold was selected by coning and quartering. For populations with simple



a

FLATNESS →

ROUNDNESS ↓

	THICK	INTERMEDIATE	THIN
ANGULAR	*900*	*700*	
IRREGULAR	*500*	*300*	*100*
ROUND	*600*	*400*	*200*

APPROX. ROUNDNESS LIMITS

POWERS, 1982	EXAMPLE
1 & 2	
3 & 4	
5 & 6	

APPROX. FLATNESS LIMITS

SHILO	0	3	6
COREY	1	.35	.2
THICKNESS OF FLATTENED SPHERE 1mm DIA.	1mm	.3mm	.15mm

Figure 1. *Shape Classification System: a) flatness and roundness; b) particle outline as it lies on its preferred side*

Table 4 - Legend for Plots

Status of White Channel Gravel

UNALTERED	WEAKLY ALTERED	ALTERED		
○	◒	●	ALL	PROPORTION OF SAMPLE WHICH IS OF WCG ORIGIN
△	◭	▲	PART	

KLONDIKE:INDIVIDUAL SHAPE DATA

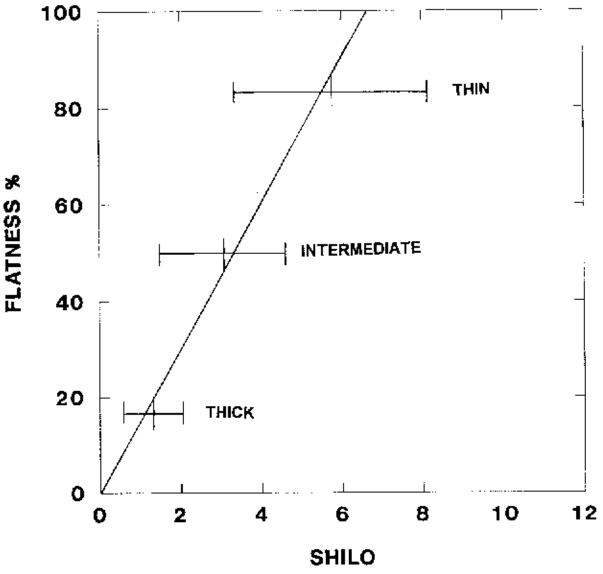


Figure 2. A Plot Of Flatness Vs. Shilo Shape Factor For Individual Particles From Samples For Which Quantitative Measurements Were Made. The horizontal bar represents 1 sigma on either side of the mean.

KLONDIKE:INDIVIDUAL SHAPE DATA

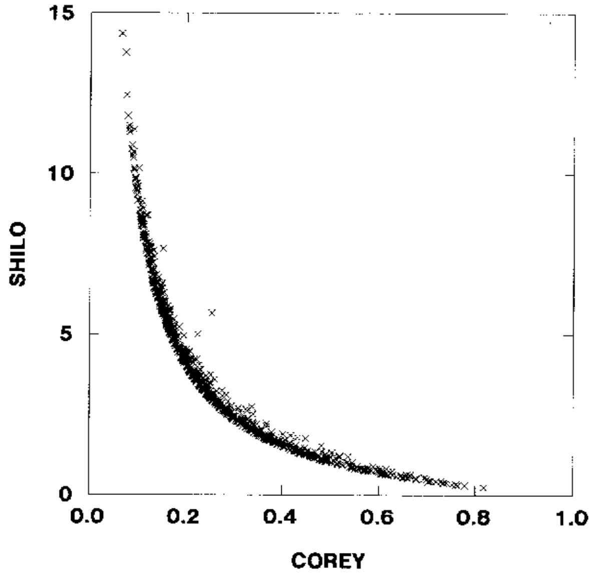


Figure 3. A Plot Of Shilo Vs. Corey Shape Factor For Individual Particles From Samples For Which Quantitative Measurements Were Made

shape characteristics 25 to 50 particles may suffice (e.g. Bear Creek), however for populations with complex shapes 100 or more particles are required. Samples with less than 14 particles were not used for data analysis purposes. In summary, it is considered that the samples used for shape characterization are adequate for this type of study.

Reliability of method

Because of the empirical nature of the classification scheme it is necessary to establish its reliability. This can be done by comparing the empirical shape classifications for individual particles with that of a more quantitative method. There are basically two groups of shape factors represented by the Corey and Shilo shape factors. The plot of Shilo versus Flatness Percent (Figure 2) for individual data shows a reasonable spread in the estimated flatness for the thick and intermediate particles, however there is a significant spread for thin particles. The relationship between the mean flatness estimates and the Shilo factor is nearly linear. This provides a simple method of quantifying and checking the proposed empirical classification system. Figure 2 indicates that the thick particles (<33.33 flatness) have a Shilo value from 0 to 3, intermediate (33.3 to 66.67 flatness) from 3 to 6 and thin (>66.67 flatness) from 6 to some large value near 20. Fortunately in this study there were very few particles with a Shilo value >9 and the relationship can be considered linear. For studies where a significant number of particles have a Shilo >9 it would be necessary to add one or more flatness categories to maintain the linear relationship between the empirical flatness and Shilo classifications. Figure 1 also provides a comparison of Shilo values for a flattened sphere of a fixed diameter for the empirical shape classes. We conclude that the eye (the empirical shape classification) is capable of compensating for the change in flatness with size and is therefore able to classify individual particles for flatness in a similar way to the Shilo and related shape factors.

Because the conclusions in this study are based on averaged data the reliability of the averaged empirical classification data is checked by comparing it with averaged Shilo data for 14 samples. A comparison of the curve on the Shilo versus Corey plot (Figure 3) of the individual particle data with the curve for the averaged Shilo versus Corey data (Figure 4) reveals a small offset which indicates that the mean may not be the best method of averaging the data The difference is not critical to this study. The Flatness versus Shilo plot (Figure 5) for the averaged shape data is nearly linear. The line must pass through 16.6% on the flatness axis at Shilo = 0 because of the method of calculating the means. The empirical classification system commonly underestimates the flatness as shown in Figure 5.

The Flatness versus Corey plot for individual particles (Figure 6) and Flatness versus Corey plot for averaged data (Figure 7) shows that the Corey factor is non-linear with respect to flatness. As a result the Shilo factor is the preferred comparison with the Empirical Classification system. Approximate Corey values for the empirical shape classes are shown in Figure 1.

The relationship between outline and shape as quantified by Zingg (1935) and this empirical classification system is illustrated in Figures 8, 9, 10, and 11. There is good correspondence between the empirical outline shape classification (i.e., 2 digits) and the Zingg classification. No fundamental relationship between outline shape and other parameters such as flatness was seen. An example of the potential usefulness of the outline shape classification is given by the comparison between the distribution shown in Figure 12 and that distribution reported by Minter (1990) for particles from the Witwatersrand gold deposits. The similarities between these two (the Precambrian placer setting and the Quaternary placer setting used in this study) shows that the Witwatersrand gold particles have preserved their detrital placer origin.

It is concluded that the empirical classification system provides data which can be reliable used to draw conclusions about gold particle shape.

Estimates Of Distance Traveled From Lode Sources

Based on the results of the composition analysis of the gold it has been concluded that the placer gold in the Klondike represents the erosion of lode sources with time, rather than the remobilization and precipitation of the gold in gravel deposits (this volume, Part 1). It was also shown that each creek has a unique gold compositional signature which represents the lode sources within that drainage basin. By the manner in which the geochemical signature varies down each creek it was concluded that there are only minor additional lode sources in tributary creeks which contributed gold to the main valley setting. In the cases of Bonanza Creek, Eldorado Creek, Sulphur Creek, Dominion Creek, and possibly Indian River it appeared that the most important lode source of the gold was localized near the head of these drainage basins. This observation allows for an estimate of the distance of transport to be made. In some cases it was possible to match the geochemical signature of placer gold populations within a specific drainage basin to a known lode signature and therefore estimate the distance traveled (Table 1).

RESULTS

No simple mathematical procedure or statistical analysis was found which could generate a consistent set of curves for this data set. The curves were therefore generated by hand by starting with the least ambiguous set of data (e.g. flatness versus distance) which was in turn used to influence the choice of curve for the next least ambiguous set of data. By doing this procedure iteratively a consistent set of curves were generated. In cases where only a few data points were available the selected curve was superimposed, unaltered, onto the data in order to check for large potential errors. No samples with less than 14 gold particles were used for data analysis.

Figure 13 shows the relationship between flatness and roundness and illustrates that roundness increases more rapidly than flatness for poorly-rounded particles. In addition, for particles which have a high roundness, the flatness increases rapidly. Samples from the White Channel Gravel deposits (as shown in Figure 13 and Table 4) have a high flatness and high roundness. Figure 14 illustrates the variation of flatness and roundness with distance traveled for a single creek (Eldorado) and shows that rounding

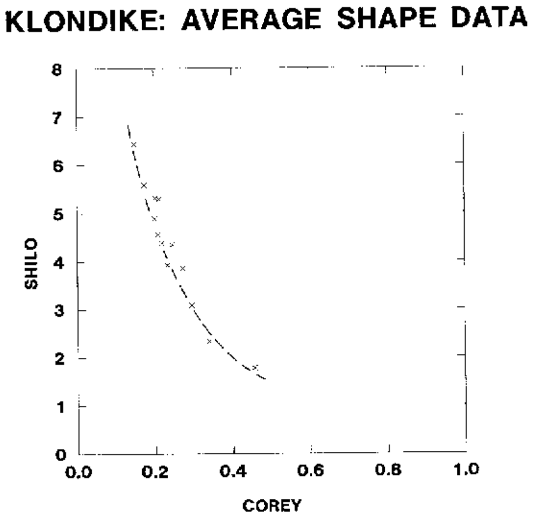


Figure 4. A Plot Of The Average Shilo Vs. Average Corey Factor From 13 Samples For Which Quantitative Measurements Were Made

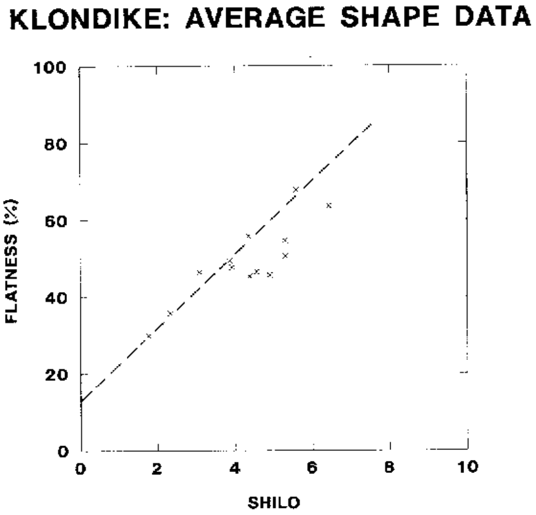


Figure 5. A Plot Of The Average Flatness Vs. The Average Shilo Factor For 13 Samples For Which Quantitative Measurements Were Made. The curve indicates that the estimated flatness values are likely to err towards a lower flatness.

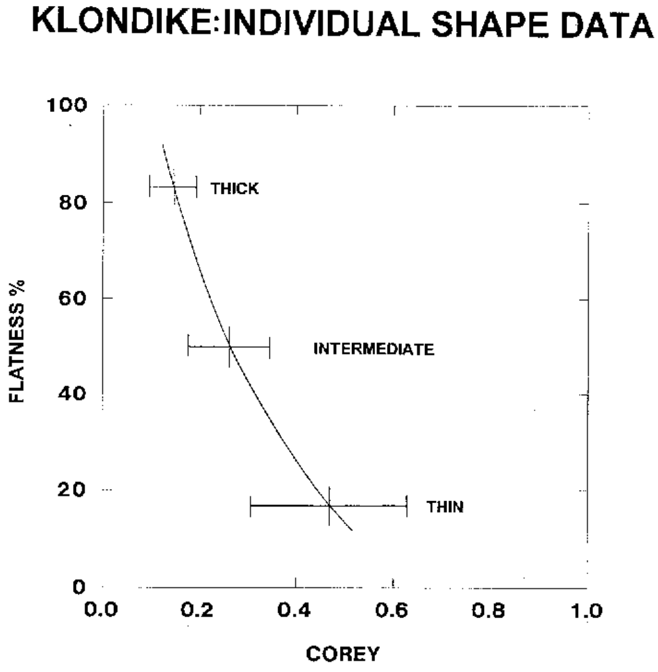


Figure 6. A Plot Of The Flatness Vs. Corey Shape Factor For Individual Particles From Samples For Which Quantitative Measurements Were Made. The horizontal bar represents 1 sigma on either side of the mean.

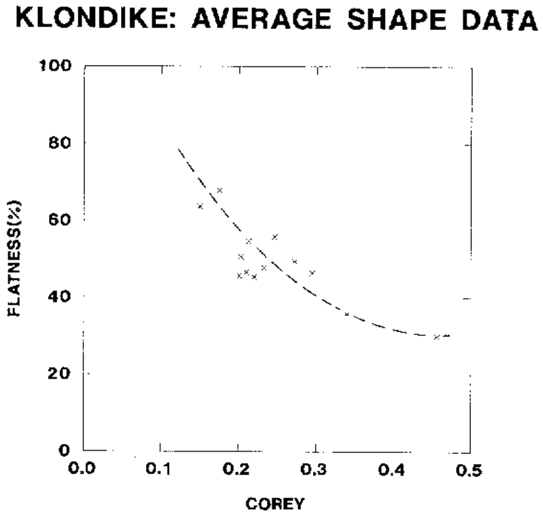


Figure 7. A Plot Of The Average Flatness Vs. The Average Corey Shape Factor For 13 Samples For Which Quantitative Measurements Were Made.

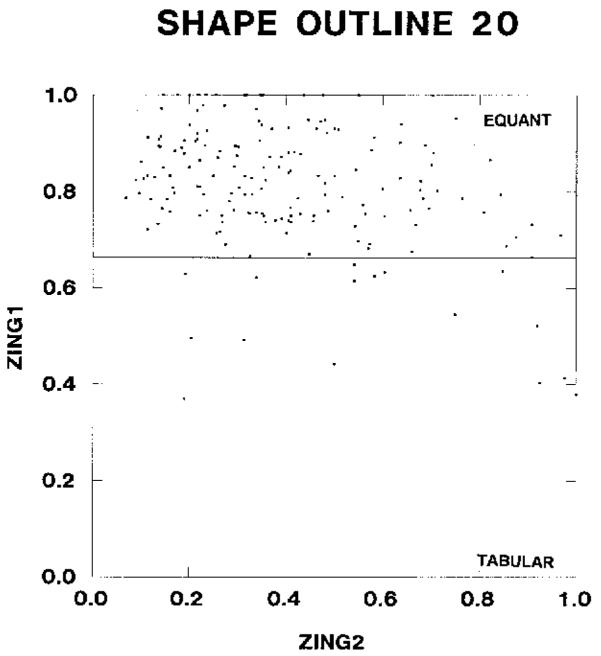


Figure 8. Plot Of Zing1 Vs. Zing2 For Particles With A 20 Or Equant Outline. Shapes above the line will have an equant outline. For all plots, Zing1 = b\a, Zing2 = c\b, (a=maximum dimension, b=intermediate dimension, and c = minimum dimension). Field a represents tabular shape, b represents the equant shape, c represents the bladed shape and d represents the prolate shape.

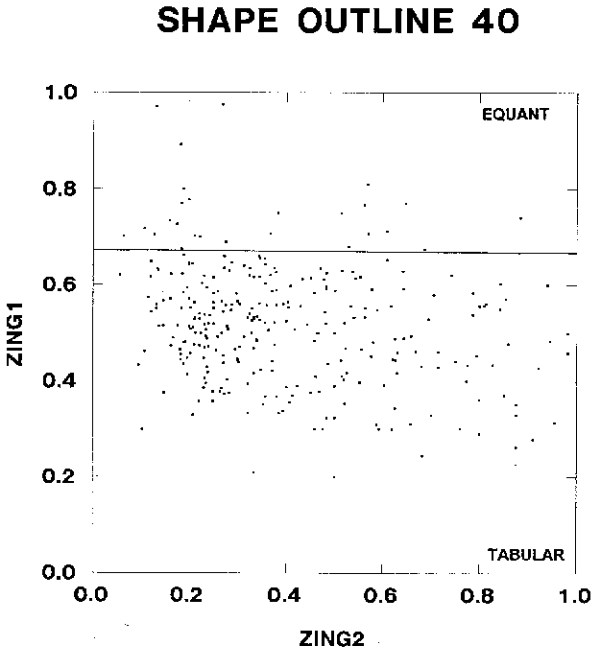


Figure 9. Plot Of Zing1 Vs. Zing2 For Particles With A 40 Or Elongated Outline. Shapes below the line will have an elongated outline

dominates particle morphology (shape) change for distances up to 1.5 km.

Distance Plots

The Distance versus Flatness plot (Figure 15) indicates that the flatness increases rapidly in the first 5 km and more slowly thereafter. The rapid rate of flattening within the first 5 km of distance traveled from a lode source implies that the difference in shapes within the lode will be destroyed upon incorporation into a proximal placer setting. It also implies that flatness is not a simple method to distinguish between multiple sources in a creek if the sample is more than 5 km from the lode source.

A measure of reproducibility can be obtained by comparing the results from two locations were duplicate and triplicate samples were taken. Samples AU292, AU293 and AU294 (approximately 15 km from the lode source) were all taken near one another, as were samples AU287 and AU532 (approximately 25 km from source). The measured data (see ROUND, FLAT, RIMP, RIMT, Table 1) are similar, indicating that the empirical method of shape classification gives reproducible results. Based on flatness, each sample predicts a different distance to source. It appears that at 15 km distance traveled, a reasonable error in distance prediction using flatness as an estimator is +/- 3 km while at 25 km it is +/- 5 km.

The Distance versus Roundness plot (Figure 16) has, as expected, a trend similar but opposite to that of the Distance versus Flatness trend. The roundness is reduced rapidly in the first 3 km and changes very little after 8 km. This observations shows that roundness is a sensitive indicator of distance traveled from the lode source within 5 km but is not useful beyond 8 km.

Rim Characteristic Plots

The Rim Percentage versus Rim Thickness plots (Figures 17 and 18) show a correlation between these two variables. There is a positive correlation between the rim thickness and the percentage that a particle is rimmed up to a rim thickness of 10 microns where particles are 90% rimmed. This relationship is predicted by any of the models proposed for the formation of rims (e.g. Au precipitation or Ag removal., Desborough, 1970; Groen et al., 1990). The samples with greater than 15 micron rims come either from altered White Channel Gravel sediments or from samples which contain significant gold reworked from the altered White Channel Gravels (this volume, Part 1).

The curves on the plots of Distance Traveled versus Rim Thickness (Figure 19) and Distance Traveled versus Rim Percentage (Figure 20) show that rims develop most rapidly within the first 10 km of the release from the lode source. The curves on the Roundness Percentage versus Rim Percentage plot (Figure 21) and Roundness versus Rim Thickness plots (Figures 22 and 23) show little scatter and suggest that highly rounded particles have larger changes in rim characteristics. The curves on the Flatness versus Rim Percentage plot (Figure 24) and Flatness versus Rim Thickness plots (Figures 25 and 26) are considered to be the best fit. This indicates that rim thickness has a direct relationship to flatness.

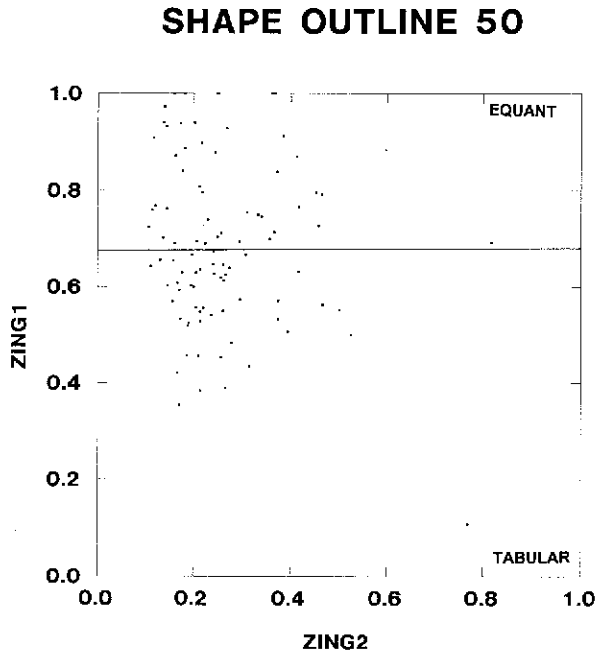


Figure 10. *Plot Of Zing1 Vs. Zing2 For Particles With A 50 Or Branching Outline. Branching shapes do not have a specific field on this diagram.*

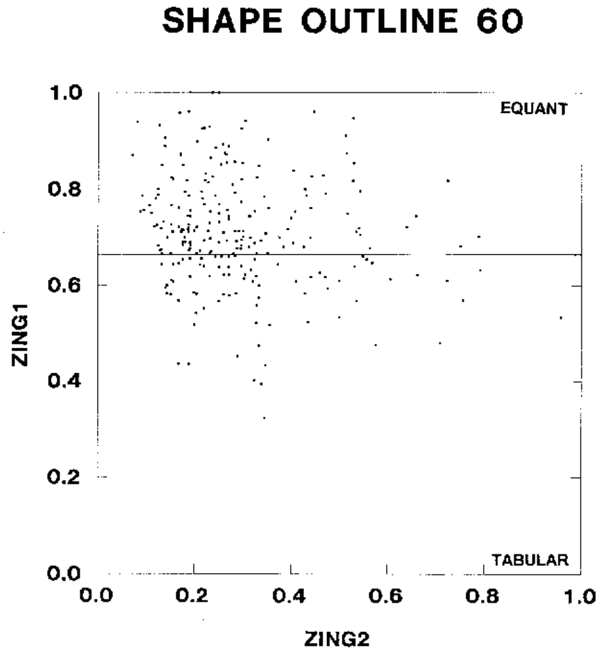


Figure 11. *Plot Of Zing1 Vs. Zing2 For Particles With A 60 Or Complex Outline. Complex shapes should fall close to the line unless they have a significant branching component.*

DISTANCE PREDICTIONS FOR KLONDIKE DRAINAGE BASINS

Predictions for distance of transport for gold particles are given in Table 1. Sample locations are given in this volume, Part 1, Figures 4 and 5.

Bonanza - Eldorado

The well-developed and identifiable composition populations (this volume, Part 1) indicate that this system can be treated as a simple system with no complex sources up and down valley but few readily defined sources. The predictions of distance traveled for placer gold (Table 1) in these drainages is in agreement with the compositional data and supports the conclusion that the lode source for most of the gold is at the headwaters of Bonanza Creek and Eldorado Creek. The sample from 49 Below (AU301) is contrary to this conclusion and also has abnormally thick rims. It is thought that this sample was eroded from the old Bonanza channel which was cut by 49 Pup. Its distance to source is 5 to 16 km.

Sulphur

Above Brimstone Creek the distance traveled estimates suggest that the majority of gold came from the headwaters of this creek. In terms of flatness and roundness, AU170 is difficult to interpret because the shape data was gathered at an early stage in the development of the shape classification system. However the compositional data shows that a new population appears in this sample. The shape data may therefore indicate that the sample is derived from a mixing of populations from Sulphur Creek and from Brimstone Creek.

Dominion

The composition data indicates that the system can be treated as a simple system with the major lode source at the headwaters of Dominion creek.

Indian River

Below Dominion Creek

Two samples came from the same area and they produce similar results except that one has unusually thick rims and the other not. It is thought that this difference may have been caused by one sample having come from recently reworked sediments, while the other (AU532) was derived from long dormant sediment or an intermediate collector. The succeeding section in this paper provides a more detailed discussion of rim formation. The predicted distance to source is around 25 km, which, when combined with the chemical signature, indicates that most of the gold comes from the headwaters of Sulphur Creek rather than Dominion Creek. The implication is that the contribution from Gold Run Creek is small.

McKinnon Creek

For this sample (AU525), the distance given by the roundness is right at the change in slope of the curve (Figure 16). A small error in the roundness results in a large error in the distance. Therefore the flatness, rim thickness and rim percentage were used to estimate the distance. The distances vary between 3 and 15 km. The flatness distance of 6 km is taken as the most reliable. The discrepancy

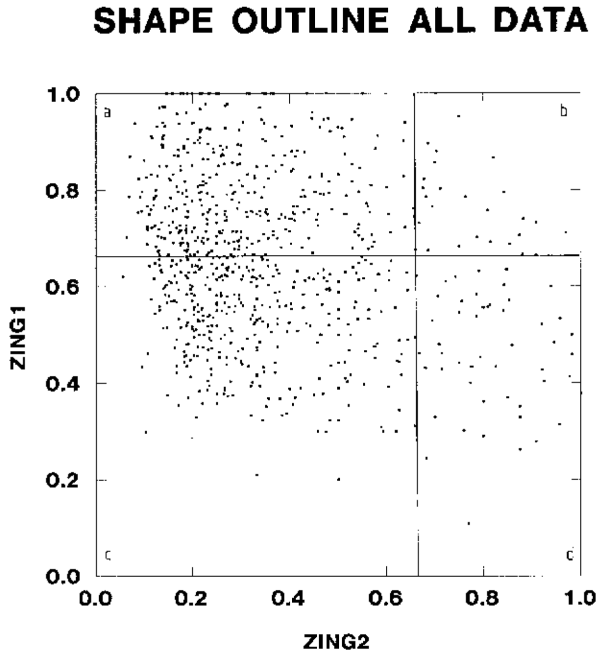


Figure 12. Plot Of Zing1 Vs. Zing2 For Particles From 13 Samples For Which Quantitative Measurements Were Made.

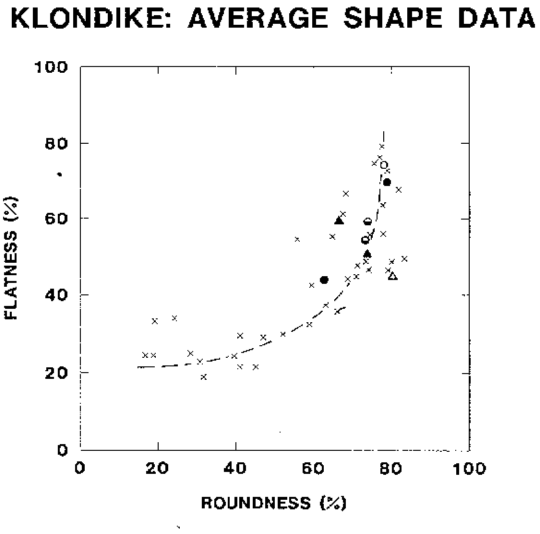


Figure 13. A Plot Of The Average Flatness Vs. The Average Roundness For All Samples (see Table 4 for symbol legend)

between the rim percentage and rim thickness distance estimates could indicate that the rim characteristics result from the reworking of gold in an intermediate collector. It is speculated that the gold comes from the headwaters of McKinnon creek but a source from higher up Indian River is possible. The compositional data seems to support the former possibility. Clearly this gold has not come from the Dominion - Sulphur Creek drainages.

Below Quartz creek

All of these samples have abnormally thick rims. This is interpreted to mean that the rims formed during a long period of dormancy (i.e., the sediments were not being reworked) in Indian river. The distance estimates to source for the sample 3 km from the Quartz Creek mouth (AU292) are between 6 and 12 km. Sample AU543, some 8 km further down the creek, provides an estimate of about 30 km. AU543 has thinned rims indicating recent movement of the gold. The composition data indicates that the McKinnon creek sample is not a major gold source and may have contributed little to the gold in Indian river (see this volume, Part 1). The distance estimate is interpreted to indicate that the major source of gold for these samples is near the head of Quartz creek.

Gold Run Creek

This sample (AU540) was recovered from the black sand after cleanup and is therefore probably biased towards flatter particles. The distance estimates based on the other parameters are therefore considered for this sample. The distance estimate of 3-4 km indicates that the AIME occurrence (sample AU457) is probably not the only lode source. This conclusion is in agreement with the composition data.

Quartz creek

The single sample (AU490) indicates a source near the headwaters of the creek. A subgroup of angular particles is distinct both in shape and in composition. The presence of well-rounded corners indicates that the particles probably traveled to their present location in the host mineral from the lode. The composition data indicates that they represent a significant portion of the source. It is therefore concluded that the general source for this subgroup is less than 2 km distant.

Bear Creek

The source of the gold in sample AU298 is the *VIRGIN* lode gold occurrence, and other known sources or undiscovered sources within 1 km of the occurrence.

The lode gold source of samples AU290 and AU291 are estimated to lie within 2 km. Sample AU291 has abnormally thick rims indicating a long period of time in dormant sediments.

Hunker Creek

Sample AU539 has an estimated distance to source of 1 to 4.5 km, approximately near the head of the Left Fork. Sample AU483 has its source within 1 km.

Distance estimates to source for sample AU526 vary between 16 and 30

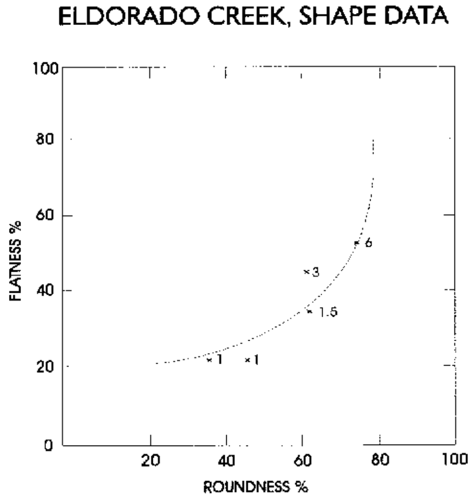

ELDORADO CREEK, SHAPE DATA

__Figure 14.__ A Plot Of The Average Flatness Vs. The Average Roundness For Eldorado Creek. The curve is from Figure 13. the number next to each sample point is the assumed distance, in km, from the source

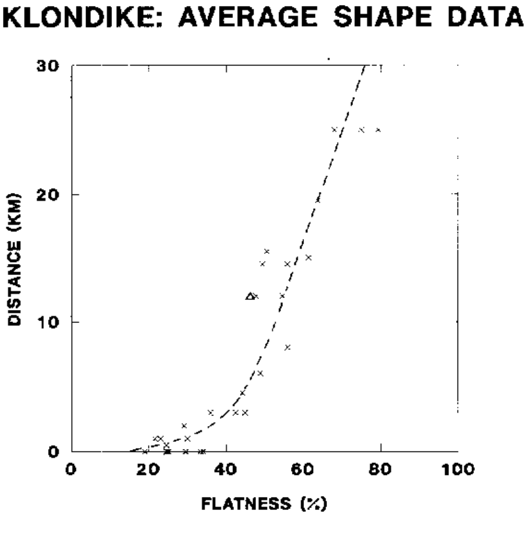

KLONDIKE: AVERAGE SHAPE DATA

__Figure 15.__ A Plot Of The Estimated Average Distance To Source Vs. The Average Flatness For All Samples (see Table 4 for symbol legend)

km. The distance to the headwaters of Hunker creek is only 15 km indicating that the flatness must be in error. The roundness, rim thickness and percentage values are in good agreement indicating that the source is within 15 - 16 km. This is in agreement with the composition when compared with sample AU483. The sample was taken from the tail of the sluice box probably accounting for the bias in flatness.

Although samples AU534 and AU295 come from the same creek (Eighty Pup - see Figure 4b, this volume, Part 1) they have markedly differing characteristics. Sample AU534 has a distance to source estimate of approximately 15 km while sample AU295 has a distance estimate of 5 to 6 km. Although the possibility of sample bias cannot be ruled out there is other evidence to support the validity of this difference. The two chemical signatures are markedly different. It is postulated that sample AU534 has its source near the head of Hunker Creek whereas sample AU295 has its source nearby. Sample AU534 is reported to have been taken from immediately below the pay streak in the White Channel Gravels from Paradise Hill. Gold from Dago Hill has fineness values that vary from 798 to 859 fine (Placer Mining Section 1993), therefore it is possible that there are numerous small sources in the immediate vicinity of Dago, Preido and Paradise Hills or that the locations are the mixing point for 2 or more significant sources. Both of these samples have abnormally thick rims.

White Channel Gravels

All the samples from the White Channel Gravels with the exception of Jackson Hill have abnormally thick rims.

The distance to the source from sample AU538 (Australian Hill) lies between 16 and 25 km which places it at the mid-reaches of Gold Bottom or Hunker Creek. The composition signature clearly shows the influence of a second source, similar in part to that of Dago Hill which may account for the inconsistent shape data.

The distance to the source of sample AU305 (Dago Hill) is 2.5 to 4.5 km. Composition data shows that the source is most likely up Last Chance Creek. A thorough discussion of the source of this and neighboring samples is found in this volume, Part 1. The mixed data from Eighty Pup suggests that there may be several lode sources in the immediate area between Last Chance and Hester creeks.

Samples AU299 and AU300 (Trail Hill) appear to have a source 6.5 to 15 km distant.

Sample AU306 (Cripple Hill) is apparently 5 to 10.5 km distant from its source.

The similarity in the predictions of distance for Trail, Cripple and 49 Below Pup (sample AU301) could be interpreted to mean that during the time of deposition of the White Channel Gravels there were two lode gold sources feeding the creek, one from Bonanza Creek headwaters and one from nearby. At this time the Eldorado source (the *HILCHEY* lode gold occurrence) was not outcropping and a second source nearer to the mouth of Bonanza creek was contributing to the gold in the creek. This conclusion is consistent

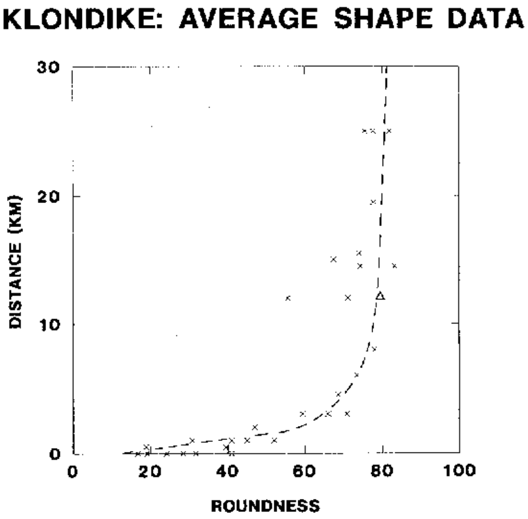


Figure 16. A Plot Of The Estimated Average Distance To Source Vs. The Average Roundness For All Samples (see Table 4 for symbol legend)

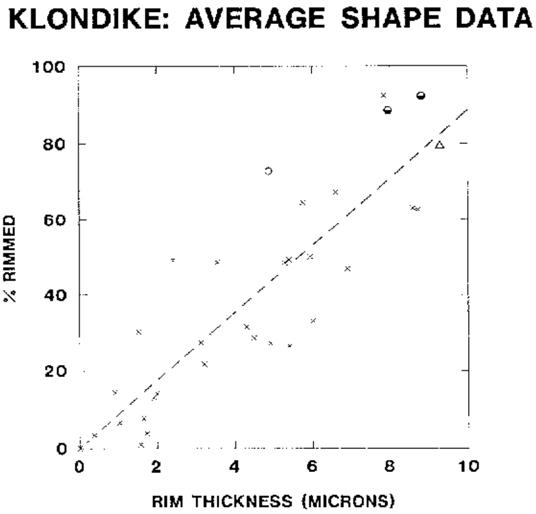


Figure 17. A Plot Of The Average Percentage That The Edge Of A Particle Is Rimmed Vs. The Average Thickness Of The Rims For All Samples: To 10 Microns (see Table 4 for symbol legend)

with the composition data (this volume, Part 1).

Sample AU534 (Jackson Hill) has its source approximately 9 to 25 km distant but the sample is not necessarily representative. One possible interpretation of this sample is that it represents White Channel Gravels from Bonanza Creek but has a separate nearby source. An alternative interpretation is that it has a contribution from Hunker Creek.

In general, a relatively simple picture emerges with the main sources of gold matching those traditionally identified by earlier workers. The most significant contribution is to recognize the distance to sources of the gold in the Hunker Creek drainage and in the White Channel Gravels.

RIM FORMATION

Knight and McTaggart (1990) concluded that the rims on gold particles were formed by the removal of Ag, Hg and Cu from the gold and not the precipitation of Au. Although they provided data as evidence they were unable to detail the process. The following observations from the Klondike support their conclusion and further describe the process (see also this volume, Part 1).

The rims in all samples are free of large inclusions and none enclose rounded sedimentary particles. Smaller particles (<5 microns) are present in varying amounts (see Figure 27a). Samples from or containing particles from altered and unaltered White Channel Gravels (Figures 23 and 26) have the thickest rims. Samples nearest the lodes have the thinnest rims and the lowest percentage of rims (Figures 19 and 20). In all cases the contact between the rim and core is sharp, even for the smallest core fragments in the White Channel Gravel samples (Figure 28c). For all but the White Channel Gravel samples the rims parallel the surface of the particle. For the White Channel Gravel samples the core has been fragmented and commonly consists of both a larger core fragment partly outlining the particle shape and numerous smaller core fragments scattered throughout a porous rim (Figures 28a and 28b). The multiple cores in a particle from altered White Channel Gravels all have the same composition (see this volume, Part 1) showing that they were joined when the particle was deposited in the White Channel Gravels. The rims from all but the White Channel Gravel samples are massive, and in some White Channel Gravel samples a massive rim from an earlier transport episode can be seen outlining the edge of the particle (Figure 28d and this volume, Part 1). The rims in the samples from the altered White Channel gravel samples are extremely porous (Figure 28b). The pores vary in size from less than a micron to 10 microns. The rims have a composition greater than 988 fine with Cu and Hg below detection limit (Table 2). The composition of the rims probably approaches pure gold (see also this volume, Part 1).

Rim thickness and percentage rimmed have a direct relation to flatness (Figures 24, 25 and 26). The White Channel Gravels are an exception because their rims are "over-thickened" relative to the curve. Figures 24, 25 and 26 have the largest scatter of the rim characteristics plots. This is considered to be a function of the rim formation process and not an artifact of measurement. Figures 21, 22 and 23 show that the rim characteristics are subordinate at low roundness values but

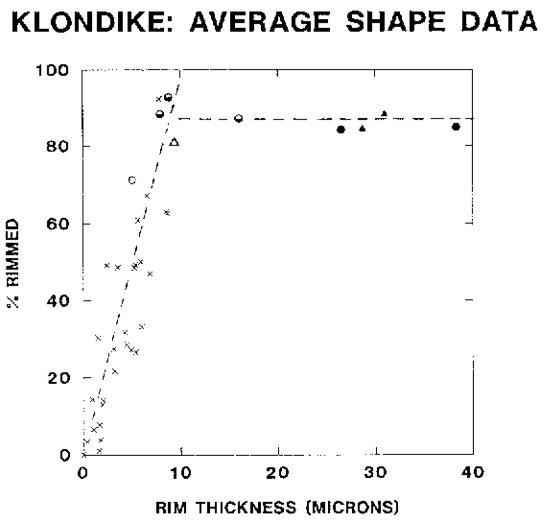


Figure 18. *A Plot Of The Average Percentage That The Edge Of A Particle Is Rimmed Vs. The Average Thickness Of The Rims For All Samples: To 40 Microns (see Table 4 for symbol legend)*

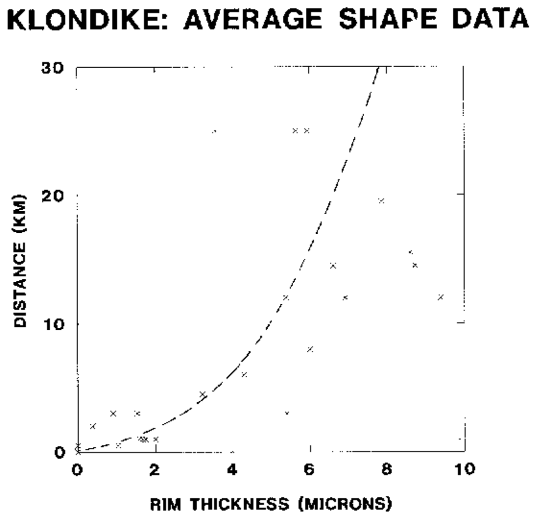


Figure 19. *A Plot Of The Estimated Average Distance To Source Vs. The Average Rim Thickness For All Samples.*

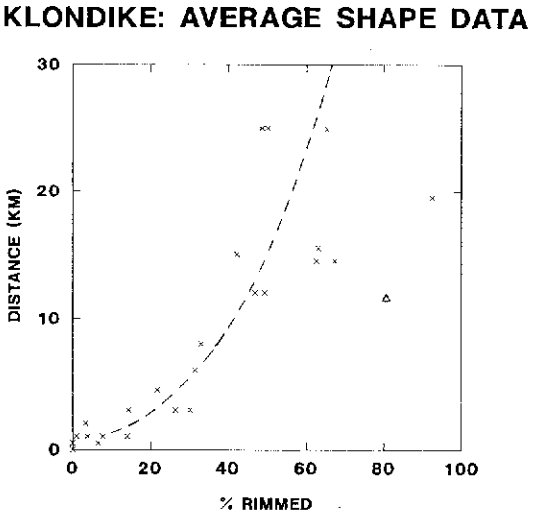


Figure 20. A Plot Of The Estimated Average Distance To Source Vs. The Average Percentage Of The Edge Of A Particle That Is Rimmed (Percentage Rimmed) For All Samples (see Table 4 for symbol legend)

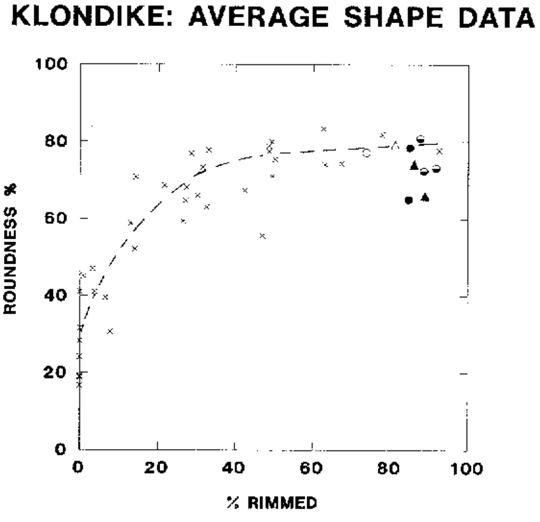


Figure 21. A Plot Of The Average Roundness Vs. The Average Percentage That The Edge Of A Particle Is Rimmed For All Samples (see Table 4 for symbol legend)

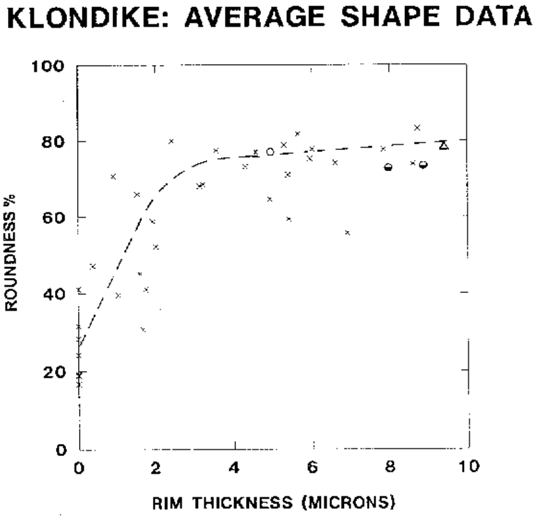


Figure 22. A Plot Of The Average Roundness Vs. The Average Thickness Of The Rims For All Samples: To 10 Microns (see Table 4 for symbol legend)

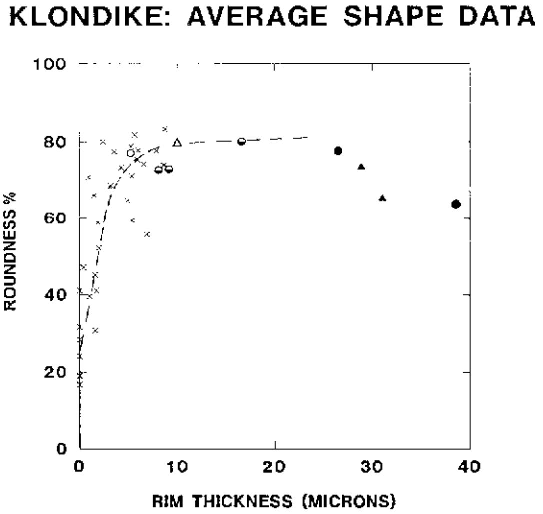


Figure 23. A Plot Of The Average Roundness Vs. The Average Thickness Of The Rims For All Samples: To 40 Microns (see Table 4 for symbol legend)

dominate at high roundness values. The White Channel Gravels have the highest rim characteristic values on roundness plots (Figures 21 and 23) but the overthickening is not as clear as on the flatness versus rim characteristic plots.

We interpret this data to infer that the rim formation process is not a simple process. Low fineness gold particles from the eluvial environment (e.g. Bear Creek, Sample AU289) have a gold colour thus suggesting that the rim formation process begins as soon as the gold is exposed to surficial conditions. When the particle enters the fluvial system, there are two competing processes: the continuing formation of the rim, and rim removal. Flattening apparently does not play a significant role in the removal of the rim. The dominant role appears to be played by one of the rounding processes, abrasion (see following section, "Evolution of Gold Particle Shape"). Gold particles do not move downstream continuously; part of the time they are in the active stream, and part of the time they are in dormant placers. During the dormant stage it is speculated that the rims thicken and when they are in the active fluvial environment rim abrasion dominates. It is speculated that at low roundness values protuberances are more numerous, abrasion rates will be high and rounding and abrasion will be dominant over rim formation. At higher roundness values abrasion rates are lower and rim formation dominates. Because flattening has only a minor effect on the rim formation and destruction process there is a poor correlation between the flatness and distance with the rim characteristics. The samples that are more distant from the source deviate from the distance versus rim characteristic curves (Figures 19 and 20) more markedly because they have been through more cycles of erosion and stagnation, and at the time of collection could be in a dormant or active stage. The data from the unaltered and (in particular) the altered White Channel Gravels fossil placer samples provides further evidence in support of this model of rim formation.

Details of the mechanism of Ag, Cu, and Hg removal in rim formation can be deduced from a multiphase particle of gold from the 60 Mile area (Figures 29a and 29b) and samples from the altered White Channel Gravels (Figures 28a, 28b, 28c and 28d). The gold particle from the 60 Mile area consists of a inner zone of exsolved Cu-rich and Cu-poor gold, surrounded successively by a middle zone of Cu-rich gold and an outer zone of Cu-free, moderate Ag gold. The whole particle is surrounded by a non-porous, high purity Au rim similar to those commonly seen on most placer particles. A fracture across the particle exposes the inner zones to the surface. The middle Cu-rich zone can be divided into three areas: 1) a massive, Cu-rich area furthermost from the fracture, followed by 2) a low Cu, low porosity zone and 3) a Cu-free, high porosity area. The latter is nearest to the fracture. The boundary between the massive and partly porous area is sharp while that between the low and high porosity area is well defined.

It is concluded: 1) that the removal of Cu leaves a porous, pure Au residue and 2) that Cu is removed faster than Ag. A similar process is thought to occur for the outer Ag-rich zone but the porosity has been destroyed by deformation. Groen et al., (1990) have shown that Ag cannot diffuse at a fast enough rate through a single massive crystal of gold to account for the formation of the rims. If the gold is undeformed then the porosity generated by the Ag removal would provide the channelways for more Ag removal from the core. Because pure gold is more malleable and ductile than the less pure core and because the rims are on the outside of the particle, deformation is preferentially concentrated in them (Petrovskaya and Fastalovich, (1955)). Any porosity in the rim will quickly be destroyed by deformation. When incompletely collapsed the pores could provide a restricted channel for Ag removal. In cases where the porosity has been completely destroyed the deformation process itself may play a role in rim formation. Deformation may influence the rate of rim formation through the creation and annealing of strained grains within the particle and by fracture formation (e.g. Figure 29a).

The anomalously thick rims in the altered White Channel Gravels are thought to represent an accelerated rim formation process in response to the conditions causing the alteration of the White Channel Gravels sediment. The alteration process is thought to have taken place at temperatures less than 200° C (Dufresne et al., 1986). The anomalously thick rims and the accompanying porosity are well preserved because they have not been subject to deformation (Figures 28a and 28d). In these particles very small core remnants with sharp rim-core contacts are associated with pores which could act as channelways for the removal of Ag (Figure 28c). These examples provide further support for the conclusion (see also this volume, Part 1) that the stable composition of gold in the surficial environment is at least greater than 988 fine, and probably approaches pure gold.

Alternatively, the samples which have undersized rims (Figure 24b) are thought to have been formed by the abrasion of the rims during recent active erosion and transport similar to that in the Erickson area (Nelson et al., 1990).

If the Distance versus Rim Percentage and Rim Thickness plots are taken to indicate the dynamic balance between rim formation and rim removal, then it should be possible to obtain a rate of formation for this process. An estimate of the rim formation rate can be obtained by assuming that the gold from the Lone Star mine has traveled at least 7 km (to sample AU528) since the formation of the White Channel Gravels. The Lone Star chemical signature matches AU528 (see this volume, Part 1). The measured average rim thickness at this distance is approximately 6 microns. The uplift which terminated White Channel Gravels formation took place in the Miocene / Pliocene approximately 7 x 10^6 mY ago. Therefore the dynamic (removal and formation) rate of rim formation is in the order of 0.71 microns/my. For sample AU527 on Eldorado the rim thickness is 4.3 microns and the estimate of the distance of transport is 6 km. This gives a dynamic rim formation rate of 0.61 microns/my.

Therefore as a first approximation dynamic rim formation takes place at approximately 0.65 microns/my. For sample AU528 an estimate of the travel rate for the gold of 1 km/my can be made.

The percentage of the particle that is rimmed for sample AU528 is 33.1%. Using the age of 7 my this infers a rim percentage formation rate of 4.7%/my. The TOOP placer (Sample AU146) in the Cariboo was not affected by glaciation. This placer was sampled by Knight and McTaggart in 1988 and dated by Rouse et al. (1990) at between 13.5 and 17 my. Measurements from 303 particles gave a flatness of 50.7%, roundness of 28%, a rim thickness of 7.22 microns and a rim percentage of 66.1%. The age predicted by the rim thickness is 11.1 my. Based on the age of 15 my the rim percentage formation rate is 4.4% /my which is comparable with the rate for sample AU528. Based on 11 my this rate changes to 6.0% /my. This implies that the rim thickness can be used in this area as a rapid method of determining if the placer is pre- or post-glaciation.

Sample points fall some 2 microns from the curve on the Distance versus Rim Thickness plot (Figure 19). Based on a 0.65 micron/my dynamic rim formation rate this suggests that placers may have been stagnant for up to 3.1 my. This is based on a dynamic rim formation rate so this should be considered a maximum.

APPLICATION TO OTHER AREAS

In order to evaluate the general applicability of these curves and conclusions they were tested on two areas within the Cordillera of British Columbia, the Erickson and Coquihalla gold camps. Worldwide data was also compiled and compared.

Erickson

The chemical signatures from the placers in this area indicate an origin in the Erickson mine area. (Nelson et al., 1990). The mineralized area in this case is of limited extent, thus enabling a reasonable estimate of distance of transport from the source to be made. Even though the Erickson area has been extensively glaciated the distance estimates based on flatness and distance estimates from a map (Table 5) are in remarkable agreement. This suggests that the gold was not transported directly by the glaciers, or, alternatively, that glacial and fluvial transport both deform gold in a similar manner. The most striking difference in characteristics between these samples and those from the Klondike are the near absence and thinness of rims. It is concluded that the most important change in the gold since glaciation has been the removal of the rims by abrasion. If it is assumed that the rim loss has mostly taken place in the fluvial environment since the end of the last glaciation some 10,000 yrs ago then an abrasion rate of 0.6 microns/1000 yrs can be estimated from Figure 26.

Coquihalla

The study of Knight and McTaggart (1990) provided the data in Table 6. The area has also been extensively glaciated. Gold near its source has been recovered from post-glacial streams while that more distant has been recovered from kame terraces and rivers which have incised through them. Both the estimates of transport distance from flatness and roundness correspond well with the distance estimates from the map. Although not as clear as the Erickson case, the low values of the rim characteristics and the resulting distance estimates are taken to indicate recent abrasion or removal of the rims. This implies that the gold particles have recently been actively transported. The location of the placers in a high energy environment caused by the melting of the glaciers at the end of the last ice age and the presence of numerous abrasion and smearing features in cross section are evidence which supports this conclusion.

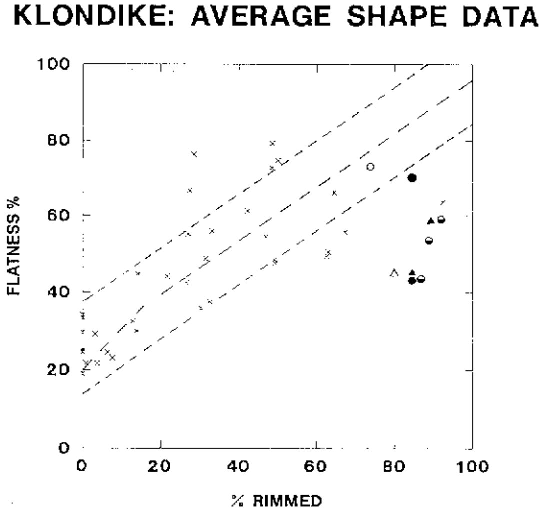


Figure 24. A Plot Of The Average Flatness Vs. The Average Percentage That The Edge Of A Particle Is Rimmed For All Samples (see Table 4 for symbol legend)

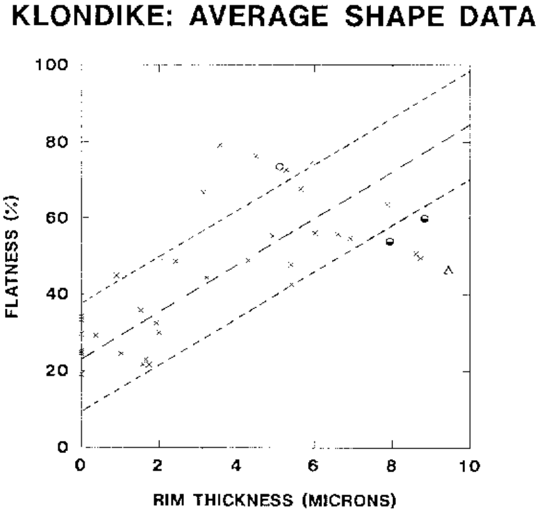


Figure 25. A Plot Of The Average Flatness Vs. The Average Thickness Of The Rims For All Samples: To 10 Microns (see Table 4 for symbol legend)

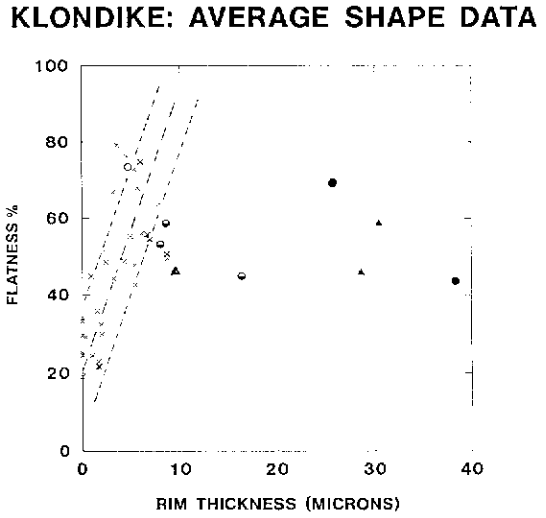


Figure 26. A Plot Of The Average Flatness Vs. The Average Thickness Of The Rims For All Samples: To 40 Microns (see Table 4 for symbol legend)

Worldwide Data

A compilation of worldwide data relating shape factor to distance of transport is given in Figure 30. The data has varying levels of reliability. For example the histograms in figure 5 of Herail et al. (1989) suggest that the data for Tipuani is simple while that from Rio Mapiri may be complex. Based on the data at hand it is predicted that a significant source exists some 20 km further up the Rio Mapiri than the presumed source. The data of Tishchenko (1981) is based on averages of numerous placers. The method of distance estimate is unknown. The data in Figure 30 indicates that the curves for the Klondike are a good first approximation of the variation of flatness with distance for many fluvial environments throughout the world and points to common processes.

In conclusion, the flatness versus distance curves appear to apply worldwide. Roundness the most reliable shape characteristic for short distances of transport, and the rim characteristics versus distance curves are strongly influenced by local transport conditions.

THE EVOLUTION OF GOLD PARTICLE SHAPE

Review

Although the general curves (e.g. Figure 13) show that gold particle shape evolves by an increase in flattening and roundness it does not suggest a process. Some discussion of the process of shape change is in order. It is during this discussion that the remaining shape descriptor, surface texture, becomes important.

Illustration and Discussion

A sample from Granite Creek (AU413) in the Tulameen District of southern British Columbia is used to illustrate the formation of the features seen during the change in shape of a particle.

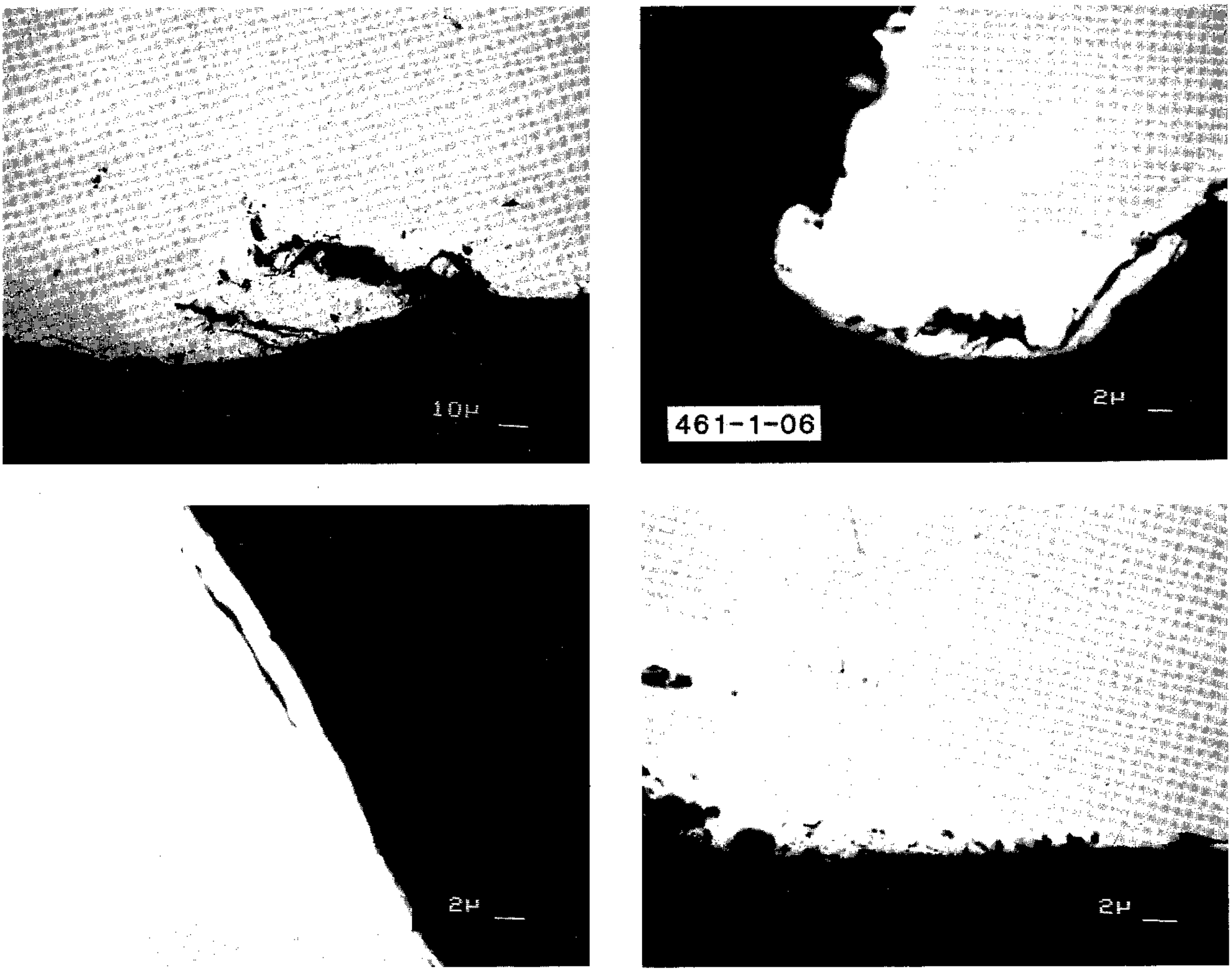


Figure 27. *Backscattered Electron Photographs Showing How The Rim (Light Tone) Acts As A Marker For Studying Deformation Of Both The Rim And The Core (Dark Tone). Figure 27a (top left) shows smearing of the rim (the black irregular holes in 27a are thought to be caused by plucked sedimentary particles incorporated into the rim by smearing. Figures 27b (top right) and 27c (lower left) show folding and Figures 27a, 27b, and 27d (lower right) highlight the deformation of the core. They all illustrate mechanisms for the incorporation of sedimentary particles into the outer edges of the rim. Figure 27a is sample 531-4-17, 27b is sample 461-1-6, 27c is sample 205-3-9 and 27d is sample 461-4-15*

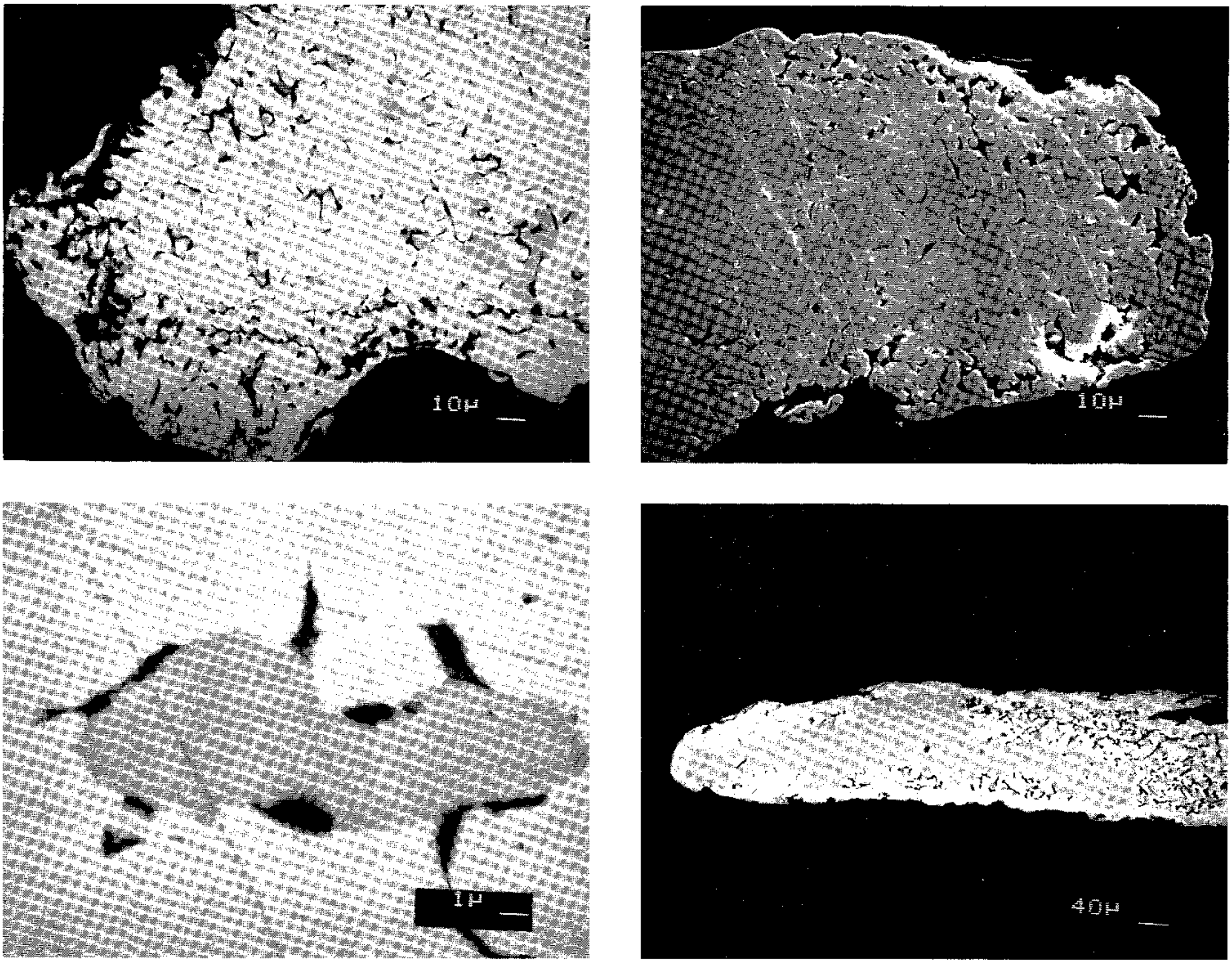


Figure 28. *Figure 28a (top left). Backscattered electron photograph of a polished placer particle from altered White Channel Gravel sediments. The gray areas are low fineness. All the low fineness areas have the same composition. The black areas are pores enclosed within a porous pure gold (light tone) rim (SampleAU538-2-12). Figure 28b (top right). Secondary electron image showing the size variation and distribution of pore spaces (Sample AU538-2-20). Figure 28c (lower left). Detail of the relationship between the pores and the cores (Sample AU538-2-20). Figure 28d (lower right) illustrates the preservation of the original rim as a pore free outer zone (Sample AU534-1-32).*

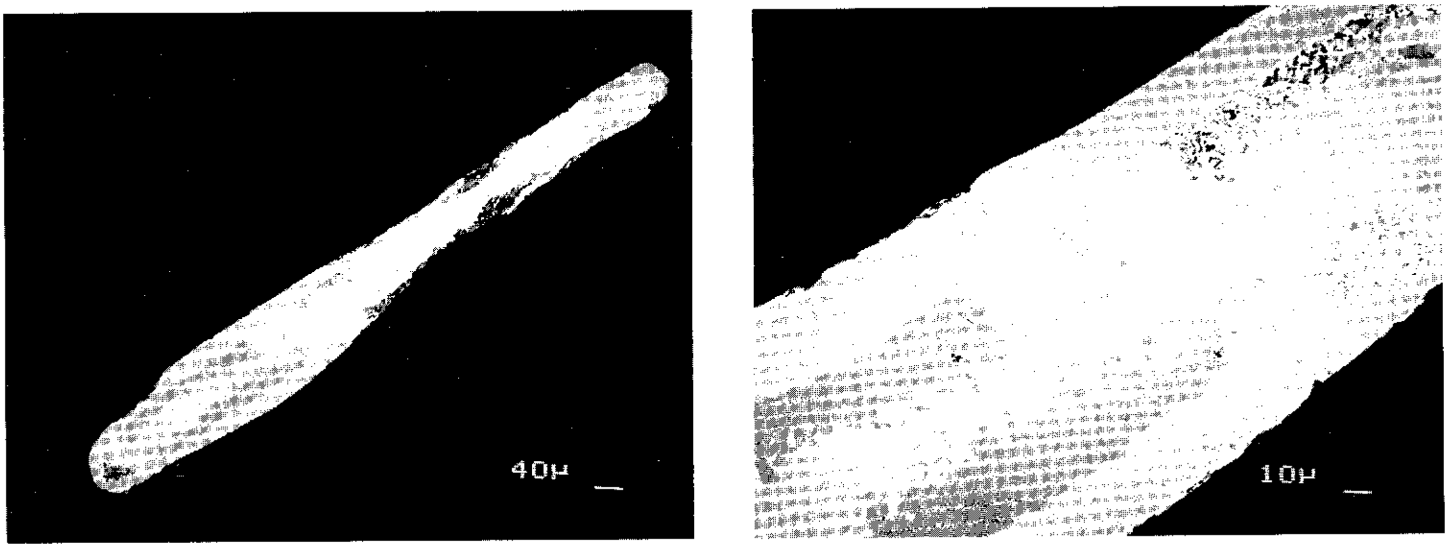


Figure 29. *Figure 29a (left) is a backscattered electron photograph from the 60 mile district (Sample 312) illustrating a possible rim forming mechanism. The white area is pure gold, the outer light grey zone is gold of moderate fineness and the area in dark grey indicates Cu-rich and Cu-poor exsolution. The inner most grey zone is one of low Cu and low Ag gold content. The outer zone is breached by a fracture and between this fracture and the Cu-rich zone there is an increase in porosity and a decrease in Cu content. The porous zone is protected from compaction while the outer rim is not. Figure 29b (right) shows the increase in porosity and the decrease in Cu (increase in whiteness) in 3 distinct zones that lie within the central zone.*

Granite Creek is a very high energy stream in a V-shaped valley. The valley was formed when the creek cut into bedrock after removing the glacial overburden left after the end of the last ice age some 10,000 years ago. The valley floor is covered with a thin lag (covering) including boulders up to 3 metres in diameter. Sand and gravel bars are developed where the valley widens. The range of sediment types and the wide range of morphology and textures of the gold particles suggests that all three of the processes studied by Yeend (1975) are represented.

During the deformation process the original particle shape is changed. The gross changes are seen as an increase in flattening and rounding (Figures 13, 15 and 16), and a decrease in size. The processes causing this deformation are hammering and abrasion. Hammering affects both the flatness and surface texture of the particle while abrasion only affects the surface texture. Both processes result in the comminution of the gold by the

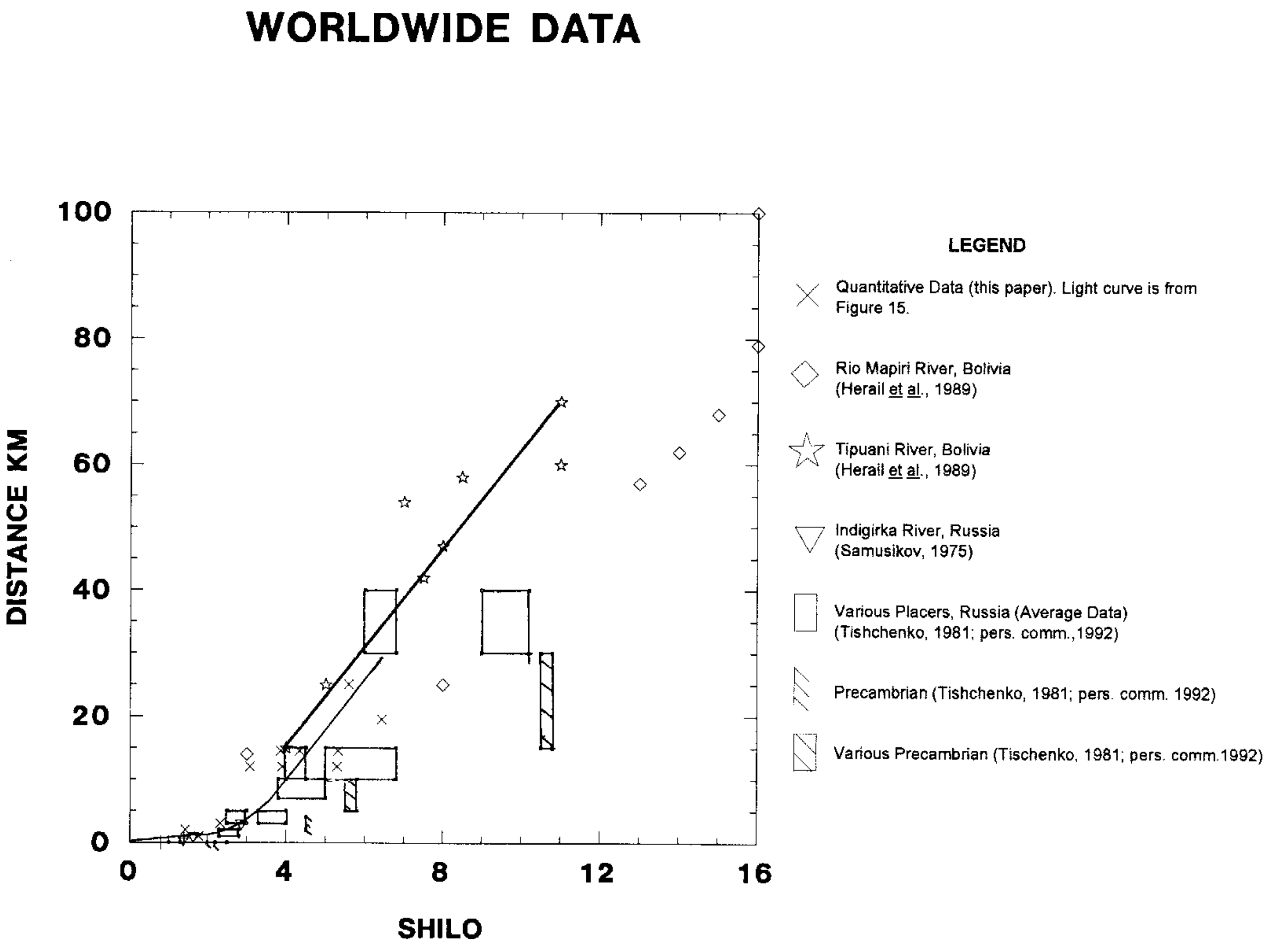


Figure 30. The Compilation Of World Data Of The Distance Vs. Shilo Shape Factor. The solid curve is from this paper. The squares are the quantitative shape factors fitted to qualitative distance estimates from various rivers in Russia.

Table 5 - Placer Gold Characteristics - Erickson Gold Camp

Sample	low size	high size	total particles	flatness %	roundness %	rim %	rim thickness μm	distance from map (km)
473	0.1	0.5	19	78.1	83.3	0.02	0.12	23
474			18	20.4	37.0			0
477	0.2	0.5	102	61.1	77.5	1.34	1.71	16
478			3	16.7	16.7			0
479	0.2	0.5	99	80.6	82.3	16.07	1.78	35
480	0.2	0.8	52	69.2	82.1	4.18	0.66	25
481	0.5	0.8	80	72.5	77.1	13.54	1.97	33

				Estimated Distance (km) From:				
Sample	low size	high size	total particles	flatness %	roundness % #	rim %	rim thickness μm	distance from map (km)
473	0.1	0.5	19	32	>30	*	*	23
474			18	0	1	*	*	0
477	0.2	0.5	102	16	8	*	*	16
478			3	0	0	*	*	0
479	0.2	0.5	99	34	30	*	*	35
480	0.2	0.8	52	24	>30	*	*	25
481	0.5	0.8	80	26	8	*	*	33

NOTE:

#For roundness values close to 80%, a very small error in the roundness estimate will result in a very large change in the distance estimate.

*No attempt is made to estimate distance from this data. The low values of the rim characteristics are taken to indicate recent abrasion or removal of the rims thus indicating that the gold particles have recently been actively transported.

removal of small pieces of the particle or by breakage. The artifacts and overall affect of these processes are discussed and illustrated below.

Figure 31 illustrates the artifacts interpreted to represent the hammering process. Figures 31a and 31b illustrate samples flattened by hammering. Figure 31a also illustrates the formation of a ridge by the extrusion of gold into a cavity. Figure 31c illustrates hammering that caused flattening, a depression and as a result, the fracturing of the gold particle. The particle in Figure 31d is hammer flattened and also shows a depression formed when a protrusion is forced into the gold. The fracturing illustrates one of the communition processes. Nikifirova and gold. The fracturing illustrates one of the communition processes. Nikifirova and Filippov (1990) have documented the deformation of gold particles which conform to the shape of the host in deeply-buried paleoplacers. This creates gold of a "pseudo-ore" appearance.

Figures 13 and 16 indicate that gold particle evolution ends with very flat, well-rounded particles. If a particle 5 mm in diameter were flattened to a thickness of 0.5 mm, it would be 11.2 mm in diameter, and if it were flattened to 0.25 mm it would be 15.8 mm in diameter. Equant 5 mm particles are common. Although 5 mm particles with these thicknesses are common, 10 mm particles not. Therefore hammering of very flat particles results not only in flattening but also folding and breakage. Figures 32a and 32b illustrate folding, which is most commonly seen when the particles are extremely flat. However, as Figure 32a illustrates, extreme flattening is not essential. Folded particles can also break along the fold. This results in particles with straight edges. In some instances more than one break has occurred and unusual rectilinear outline shapes are found. It is conjectured that both the thinness of the particle and the attendant work hardening contribute to the increased breakage of the flatter particles. If particles are hammered hard enough they can break by shearing before they become extremely flattened. Figure 33 shows a segment almost separated from the main particle by a fracture. This fracturing, shearing or tearing leaves the edges of the particle extremely rough. This is in contrast to the breakage of a folded particle which always leaves a relatively smooth straight edge. The switch from shape change by flattening to one of folding and breakage suggests that there is a minimum stable "thickness to diameter" ratio that a particle can reach. Once particles reach this ratio they must break before being further flattened. Breakage may explain the linear flattening to distance relationship for distances greater than 10 km in Figure 15 and implied in Figure 30.

Abrasion is the process whereby material is removed during grinding and polishing. An example of this process might be the procedure for making, for example, a surface suitable for viewing under a petrographic microscope. Scratches and pits are products of abrasion.As in sample preparation the size and shape of the abrading particle will largely determine the efficiency of material removal and the shape of the artifact left by its removal (Yeend, 1975). Particles formed as a result of abrasion will be smaller than particles resulting from shearing and breakage. When very little material is removed the term polishing is appropriate. Polishing is the result of abrasion by very small particles.

The surface texture is a record of both hammering and abrasion. The principal difference between the processes is that abrasion is a surface process, while flattening affects the whole particle. Petrovskaya and Fastalovich (1955) noted that the deformation of placer gold seen in section is concentrated in the rim or edge of the particle, suggesting a depth limit of around 20 to 50 microns. Hammering will deform the whole particle suggesting that the deformation Petrovskaya and Fastalovich recorded is principally the result of abrasion processes. Surface texture features are usually less than 20 microns in size. Two common surface texture features are pits (Figures 34b, 34c, 34d) and scratches (Figures 34b, 34d). Some of the ways in which pits can be formed are: casts

Table 6 - Placer gold characteristics for the Coquihalla Region

Sample	low size	high size	total particles	flatness %	roundness %	rim %	rim thickness (μm)	distance from map (km)
349	0.3	0.8	80	51.2	74.2	5.2	*	5
363	10.5	0.8	12	47.2	80.6	*	*	4
363	0.2	0.8	88	45.5	68.2	4.2	*	4
410	0.1	1.0	37	32.0	23.0	0.0	0.0	0
412	0.1	0.7	38	43.0	36.0	5.6	0.51	0.5
418	0.1	1.4	225	30.9	45.1	*	*	1
418xs	0.1	0.2	55	25.8	35.5	*	*	1
418s	0.2	0.5	57	34.2	42.0	*	*	1
418m	0.5	0.8	50	35.3	58.7	*	*	1
418 l	10.8	1.4	29	33.9	47.7	*	*	1
419			77	48.3	63.4	0.0	0.0	5
466	0.2	0.5	19	34.2	20.2	0.0	0.0	0
467	0.2	0.5	7	31.0	16.7	2.8	0.71	0
514			96	43.4	49.0	0.0	0.0	1

NOTE:

* Edges of these particles have considerable Hg contamination making estimates of rim characteristics unreliable.

				Estimated Distance (km) From:				
Sample	low size	high size	total particles	flatness %	roundness %	rim %	thickness (μm)	distance from map
349	0.3	0.8	80	8	5	0.5		5
363	10.5	0.8	12	5	17			4
363	0.2	0.8	88	5	4	0.5		4
410	0.1	1.0	37	1	0	0.0	0.0	0
412	0.1	0.7	38	4	1	0.5	0	0.5
418	0.1	1.4	225	1	1			1
418xs	0.1	0.2	55	0.5	1			1
418 s	0.2	0.5	57	2	1			1
418 m	0.5	0.8	50	2	2			1
418 l	10.8	1.4	29	2	1			1
419			77	6	2.5	0.0	0.0	5
466	0.2	0.5	19	2	0.5	0.0	0.0	0
467	0.2	0.5	7	1	0	0.5	0.5	0
514			96	4	1.5	0.0	0.0	1

NOTE:

xs = very small particles
s = small particles
m = medium particles
l = large particles

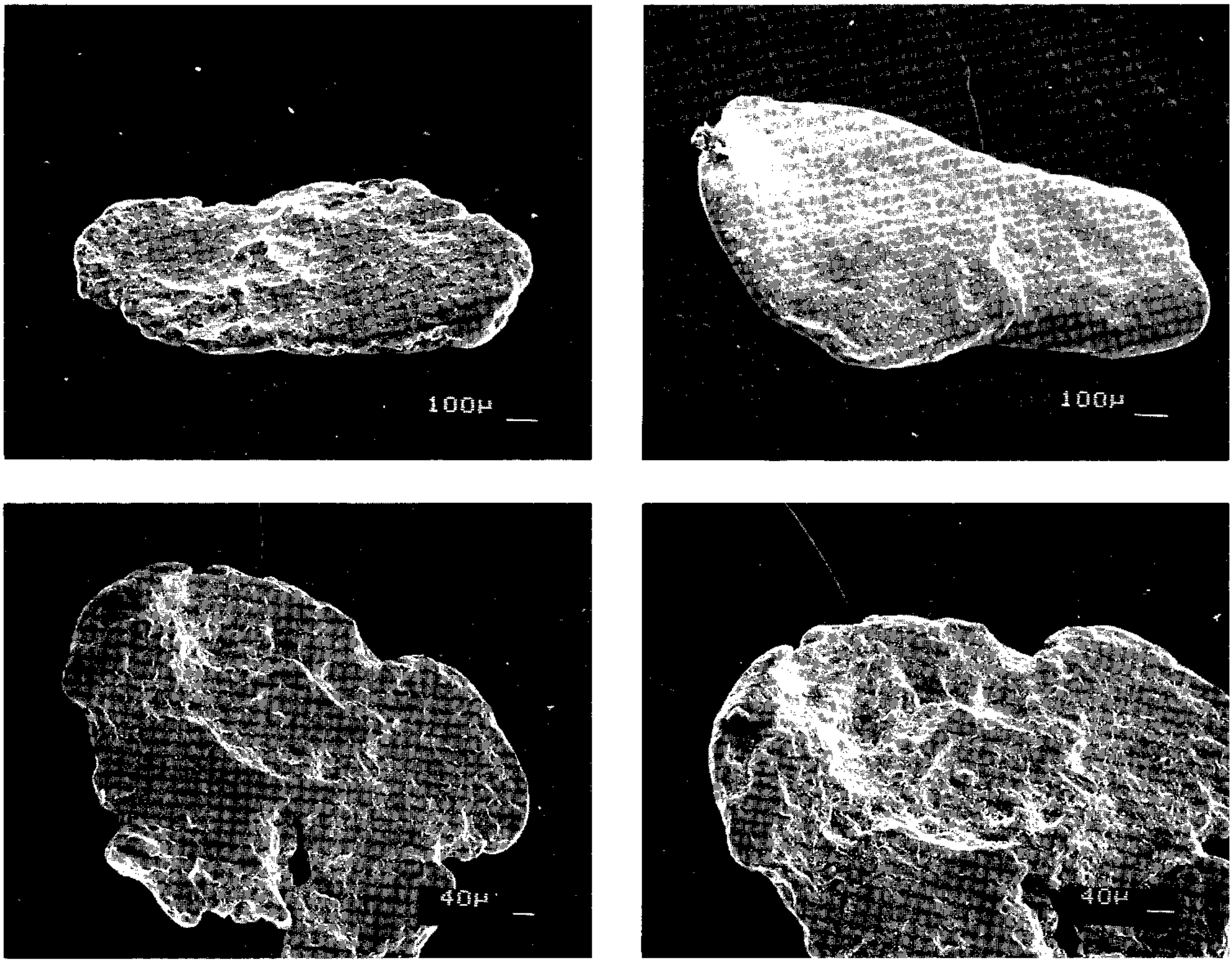


Figure 31. *Secondary Electron Photographs Of The Gold Deformed Principally By Hammering (Sample AU413). Figures 31a (top left) and 31b (top right) illustrate particles flattened by hammering. Figure 31a also shows the formation of a ridge by the extrusion of gold into a cavity. Figure 31c (lower left) illustrates hammering that caused flattening, a depression and as a result, the fracturing of the gold particle. Figure 31d (lower right) is hammer flattened and shows a depression formed when a protrusion is forced into the gold.*

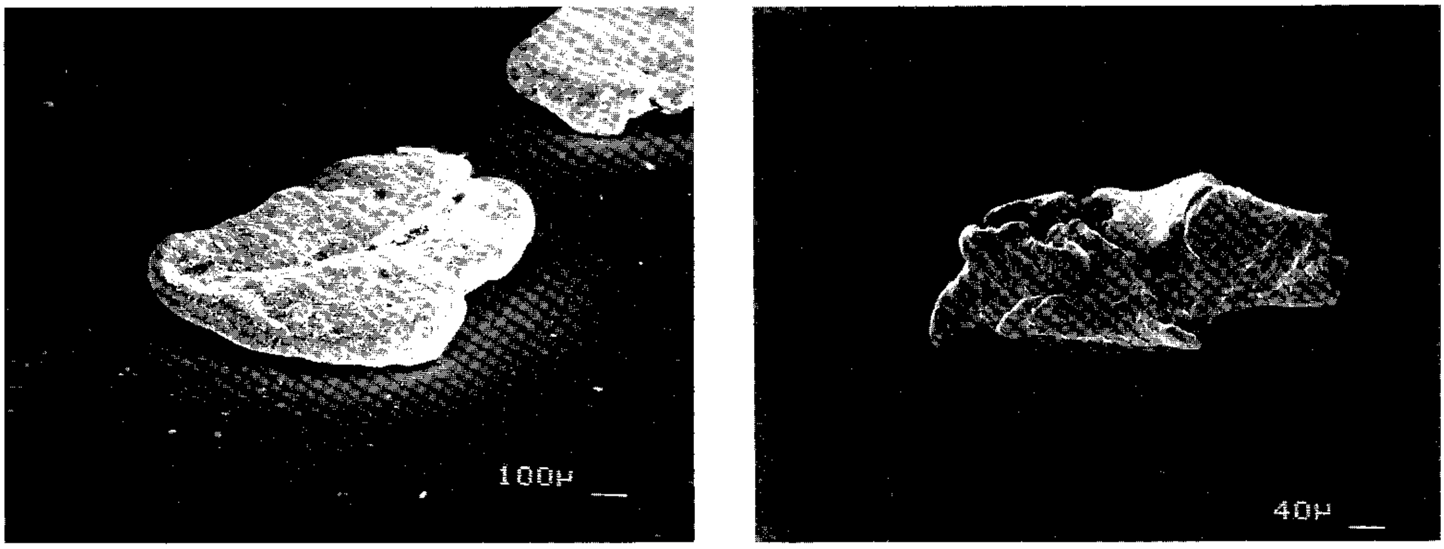


Figure 32: *Particles With A High Degree Of Flattening Are Further Deformed By Folding. Figure 32a (left) is an example of a single fold to form a 'sandwich' (Sample AU413). Figure 32b (right) is an example of multiple folding (Sample AU50).*

of smaller sedimentary particles, folding or smearing, abrasion and etching.

Occasionally the small (< 10 micron) particles which created the cast in the Granite Creek gold are found still embedded in the particle. The presence of pitting is often used to identify the process of corrosion or etching. Because of the many other ways of forming pits in gold, caution should be exercised when identifying the process which caused the pits. Scratches (Figures 34b, 34d) can be formed with or without the removal of material.The particle causing the scratching can become embedded in the gold as illustrated in Figure 35. Figures 34b and 34d illustrate how scratches and other larger defects are altered by later deformation, probably by smaller particles. Polishing alone is thought to have formed the smooth surfaces such as seen in Figure 34a. Although Yeend (1975) noted that wet sand produced a smooth pitted surface and that only dry sand produced a very smooth surface, it appears that deformation in the alluvial environment can also cause a very smooth surface although perhaps of a more limited extent. Based on these observations it is suggested that the deformation process is best determined from the overall surface texture rather than the presence of a specific surface texture feature. Yeend (1975) provides a good example.

Both hammering (Figures 31a, 31b) and abrasion (Figure 34b) cause gold to flow and smear. Sections of gold with well developed rims where rim formation predates a deformation illustrate the flow and smearing phenomenon well (Figures 27a, 27b, 27c and 27d). The core rim interface illustrates localized flow while the

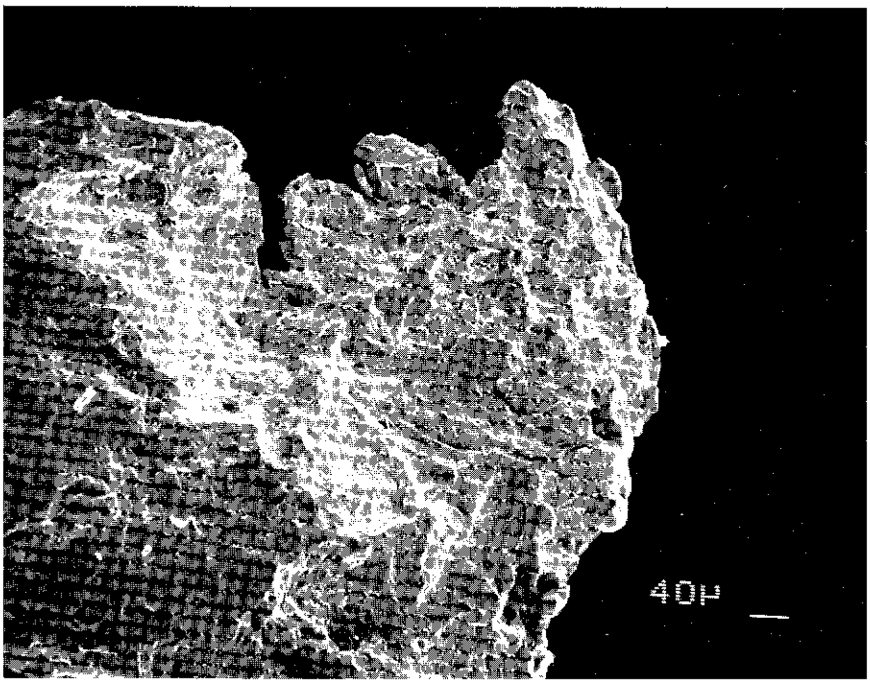


Figure 33. *An Illustration Of How Extreme Hammering Can Shear A Particle. (Sample AU413).*

rim surface illustrates the formation of long thin platelets of gold attached to the gold particle at one end. Details of the changes to the internal structure of the rims and the core of the particles is given by Petrovskaya and Fastlovich, (1955). Rounding and curling of edges (Figures 34a, 32a) by polishing and smearing is thought to be a poorly developed version of the rounded and curled edges seen on toroidal and spheroidal gold deformed under eolian conditions (Filippov and Nikiforova; 1988, 1990). Figure 34b illustrates the smearing of gold on the micron scale at the end and to the sides of scratches caused by abrasion. When no material is removed and the gold is merely smeared, the term burnishing may be used. Hammering, abrasion and smearing all trap host particles within the gold. Folding can entrap large particles (Giusti, 1986). Particles trapped by abrasion and smearing are usually very small (< 5 microns) and always confined to the very edge of the gold particle (Figures 27a and 27d). Because gold particles which are being polished for microscopic observation are subject to the same deformation, care must be taken to ensure that particles of polishing compound or host rock fragments are not incorporated into the gold.

Summary

There are two processes involved in the evolution of gold particle shape; hammering and abrasion. It is suggested that for particles in the 0.2 to 2.0 mm size range, hammering is the main process involved in the flattening of placer particles. Hammering also removes and deforms the protuberances in angular particles. The most significant effect of

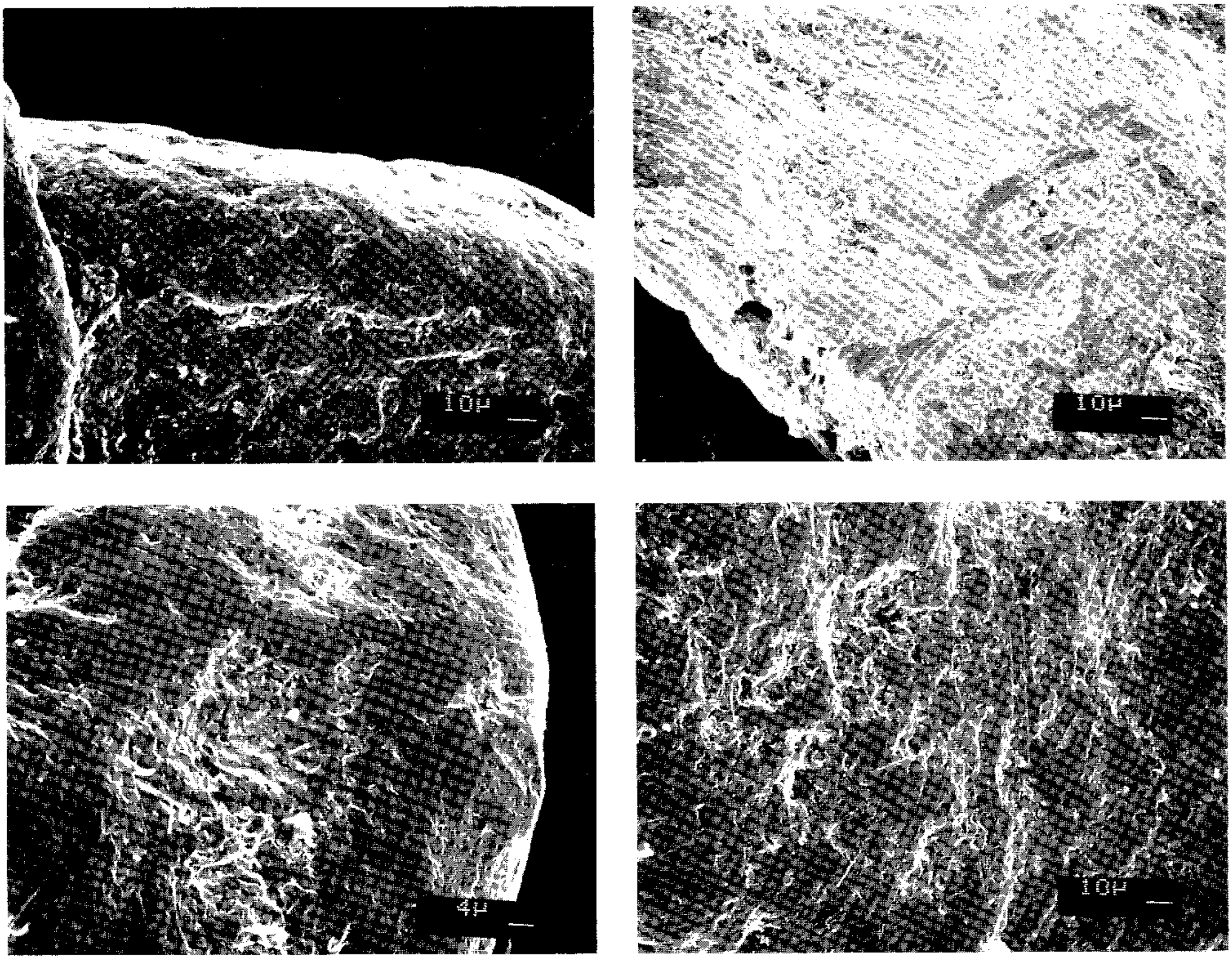


Figure 34. *Secondary Electron Photograph Of The Surface Texture Of Gold Deformed By: 34a (top left), Polishing and Smearing; 34b (top right), Abrasion And 34c (lower left), Polishing. Abrasion and polishing contribute to the comminution of the gold and generates small (< 10 microns) gold particles. Figure 34d (lower right) illustrates a composite surface texture with pits of an unknown origin that are partly obliterated by scratching and polishing (Sample AU413).*

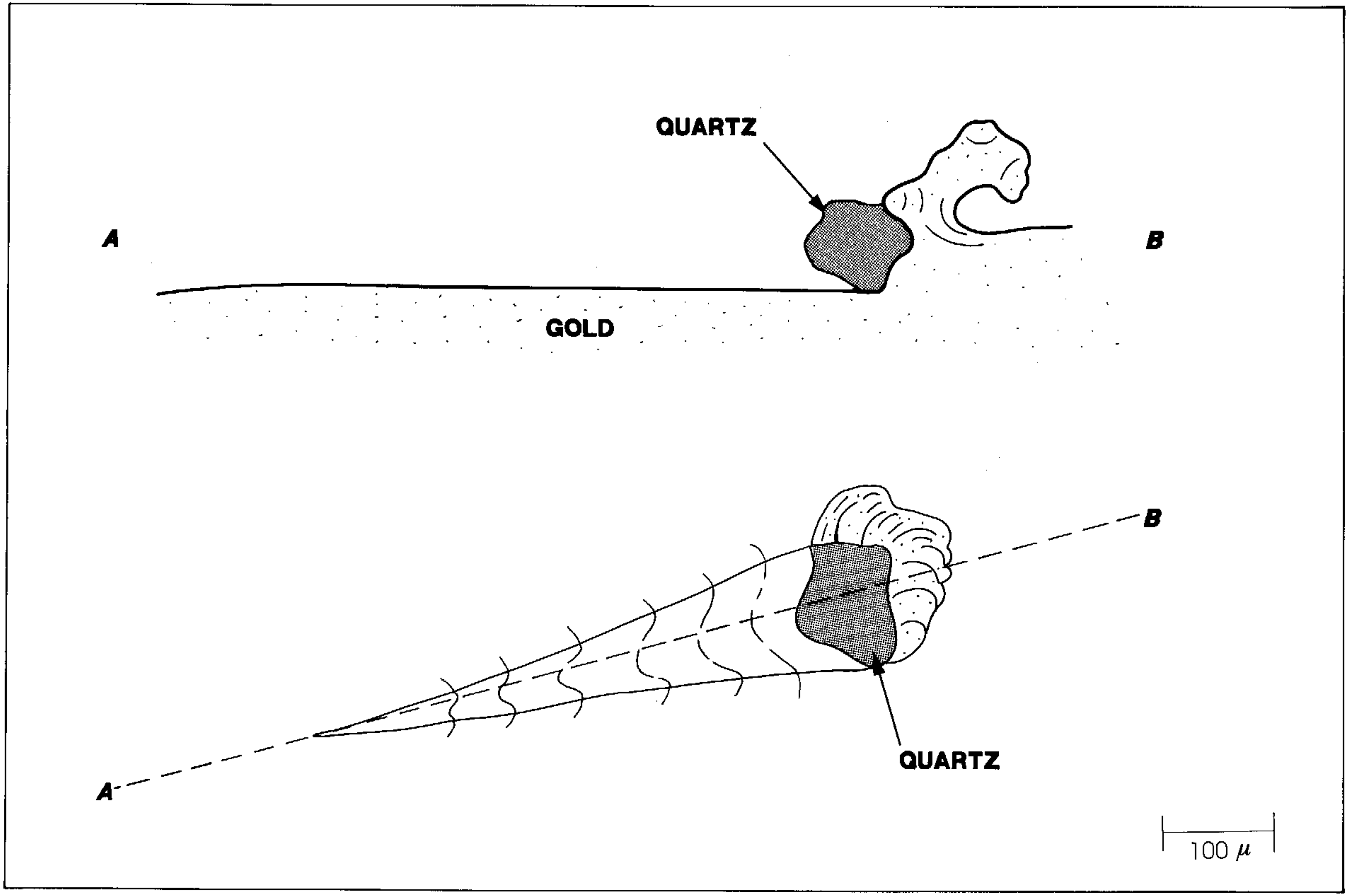


Figure 35. A Plan And Profile Of A Mechanism of Abrasion Which Illustrates How Sedimentary Particles Can Become Embedded In The Outer Surface Of The Gold Particle

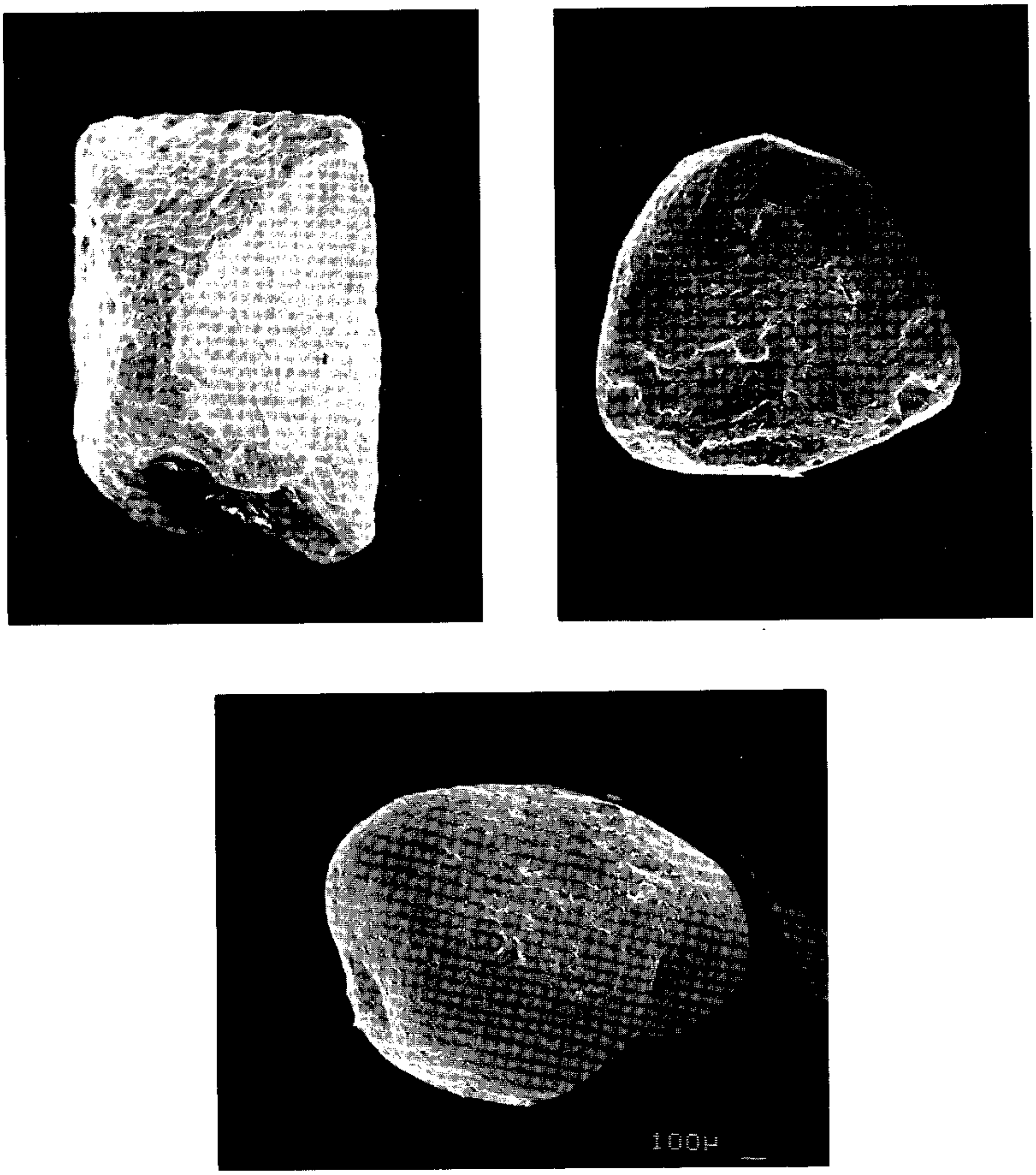


Figure 36. *Secondary Electron Images Of Crystals And Deformed Crystals From The Discovery Claim On Bear Creek (Sample AU298). This series illustrates the various degrees of rounding and polishing of the crystal shapes, and highlights the lack of flattening and scratching. Note the smearing on the edge of Figure 36a (top left, sample AU298-1-1). Figure 36b (top right) is Sample AU298-1-3 and Figure 36c (bottom) is Sample AU298-1-4. The scale bar in Sample AU298-1-4 applies to all three photographs.*

hammering is found proximal to the lode source where gold particles are the thickest, sediment particle size is the coarsest and the energy of the streams is high.

Abrasion is limited to near the surface (generally < 50 microns) of the gold particle and is concentrated in the rim, if present. Abrasion is largely responsible for smoothing the shape resulting from hammering. Surface texture will rapidly evolve in response to the change in sediment host size distribution and stream energy. Surface texture records the abrasion events and in particular the last abrasion event . This is in contrast to the shape which records the aggregate of deformation events. It is expected that scratches will be most common in the upper reaches of a stream while polishing will predominate in the lower reaches. Smearing will occur at all stages of deformation. Hammering and abrasion of gold particles in the fluvial environment decrease the particle size by breakage and removal of material.

Change in gold particle shape in the short term is effected by: 1) the energy and size distribution of the environment causing the change in shape; 2) the length of time available, and 3) the size of the particle. The distance of transport curves reflect the averaging of these parameters over a long time period. The above discussion explains why roundness and in particular flatness are good estimators of distance of transport while rim thickness and percentage are not.

EXAMPLE OF AN UNUSUAL FEATURE PRESENT IN THE KLONDIKE

Octahedral crystals have been recovered from placers in several areas of the Klondike. Figures 36a, 36b, and 36c show the variation in the degree of rounding of octahedral particles from the Bear Creek placer (Sample AU289). The placer is located immediately below (0.1 to 0.5 km) the probable lode source. The similarity in composition signature of the crystals and the lode indicates that the crystals did not grow in the placer (see this volume, Part 1). The sequence of photographs (Figures 36a 36b, and 36c) shows an increase in smoothness and loss of edge angularity but no flattening. There are no scratches but there is evidence of smearing. The lack of scratches and flattening show that the particles could not have spent time in a moderate to high energy environment with large sediment particles as are found in this placer. The particles must have only recently been incorporated into the placer. We conclude that the smoothing took place by abrasion from small particles in the eluvial environment as the gold moved toward the fluvial placer from the lode. The abrasion could have taken place under conditions of soil creep, surface runoff, or by wind-blown sand and silt. The conclusion of Yeend (1975) that dry sand can form a smooth surface, and the work of Filippopv and Nikiforova (1988, 1990) on gold deformed under eolian conditions both support the idea that the gold was deformed in part in an eolian environment. The presence of loess in the area supports this conclusion.

CONCLUSIONS

Despite the simplicity of the collection procedures the samples provide useful information.

The empirical semi-quantitative shape classification system is faster than more quantitative methods and can provide reliable data. Checks against quantitative data indicate that empirical classification of flatness provides data directly comparable to the Shilo shape factor. The outline shapes can also be successfully be classified using this method.

The shape characteristics of placer gold in the 0.2 to 1.5 mm range can be used to estimate the distance of transport of placer gold from its lode source. Ideally particles between 0.5 and 1 mm should be used. Gold particle shape changes by increasing flatness and decreasing roundness. Gold particle roundness and flatness increase rapidly within the first 5 km from the source. After approximately 5 km the flatness continues to slowly increase while the roundness remains essentially unchanged. Flatness is the most reliable distance estimator particularly for distances greater than 5 km. Roundness is a more sensitive estimator for distances less than 5 km but appears to be less reliable than flatness.

Due to the dynamic nature of rim formation, rim thickness and rim percentage are not reliable distance estimators. However because these characteristics are sensitive to the last abrasion event, they do provide an indication of the amount of relative time since the gold was last transported. They also serve to determine if a placer has been long dormant or recently active. This is particularly useful in areas of complex glaciation.

The estimates of distance to source in the Klondike based on morphology compliment the conclusions based on chemical composition, specifically that the placer gold in the Klondike has been eroded from lodes, most of which have not been expressly identified.

The relationship between the shape of a particle and the thickness and percentage of the rims supports the conclusion that rims are formed by the removal of Ag, not the precipitation of Au. Rim formation is a dynamic process which balances the formation of the rim by Ag removal with the removal of the rims by abrasion. The relationship between the flatness of a particle and the thickness and percentage of the particle that is rimmed can be used to determine if the latest event was rim forming or rim removal, i.e. if the placer was dormant or active. At approximately 10 km from the source dynamic rim formation takes place at a rate of approximately 0.65 microns per million years. In the Erickson area rim abrasion took place at a rate of 0.6 microns per 10,000 yrs.

Hammering is the main cause of shape change in fluvially-transported gold particles. Not only does it flatten particles but it contributes to the increase in roundness. Abrasion is mostly responsible for surface texture but it also plays a role in the increase in roundness. Hammering and abrasion decrease the size of the particles by removal of material and breakage. Surface texture is altered by abrasion and smearing, and records the latest transportation event.

These conclusions and the curves appear to apply to fluvial environments worldwide.

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