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GEOLOGY OF PLACER DEPOSITS IN THE CARIBOO MINING DISTRICT, BRITISH COLUMBIA; IMPLICATIONS FOR EXPLORATION (93A, B, G, H)

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INTRODUCTION

This report provides details on field activities in placer geology conducted by the Applied Geochemistry and Surficial Geology Section of the British Columbia Geological Survey Branch. In 1989, the provincial government expanded the area open to placer mining substantially, and the need for new exploration techniques in these regions was recognized. Studies of gold-bearing placer deposits were undertaken with the objective of developing a set of geological criteria useful for recognizing placer potential in undeveloped or poorly explored areas. The results of these studies will be used to develop regionally applicable exploration models. The complexity of the geology observed during this field season indicates that detailed sedimentological studies are required in order to understand both the distribution of placer deposits in a regional sense and the location and extent of pay streaks at the local level.

The Cariboo Mining District was selected for initial study because of its long history of placer gold production. Since 1860 the district has produced almost 100 000 kilograms (about 2.5 to 3 million ounces) of gold, more than any other placer area in British Columbia (B.C. Ministry of Energy, Mines and Petroleum Resources, 1963; Boyle, 1979). Several large (>200 cubic metres per day processed) placer mines are now active in the region, as well as over 200 small operations, including hand mining and exploration projects. Shallow placer gold deposits in the Cariboo have been largely depleted. They were primarily in present-day river valleys,

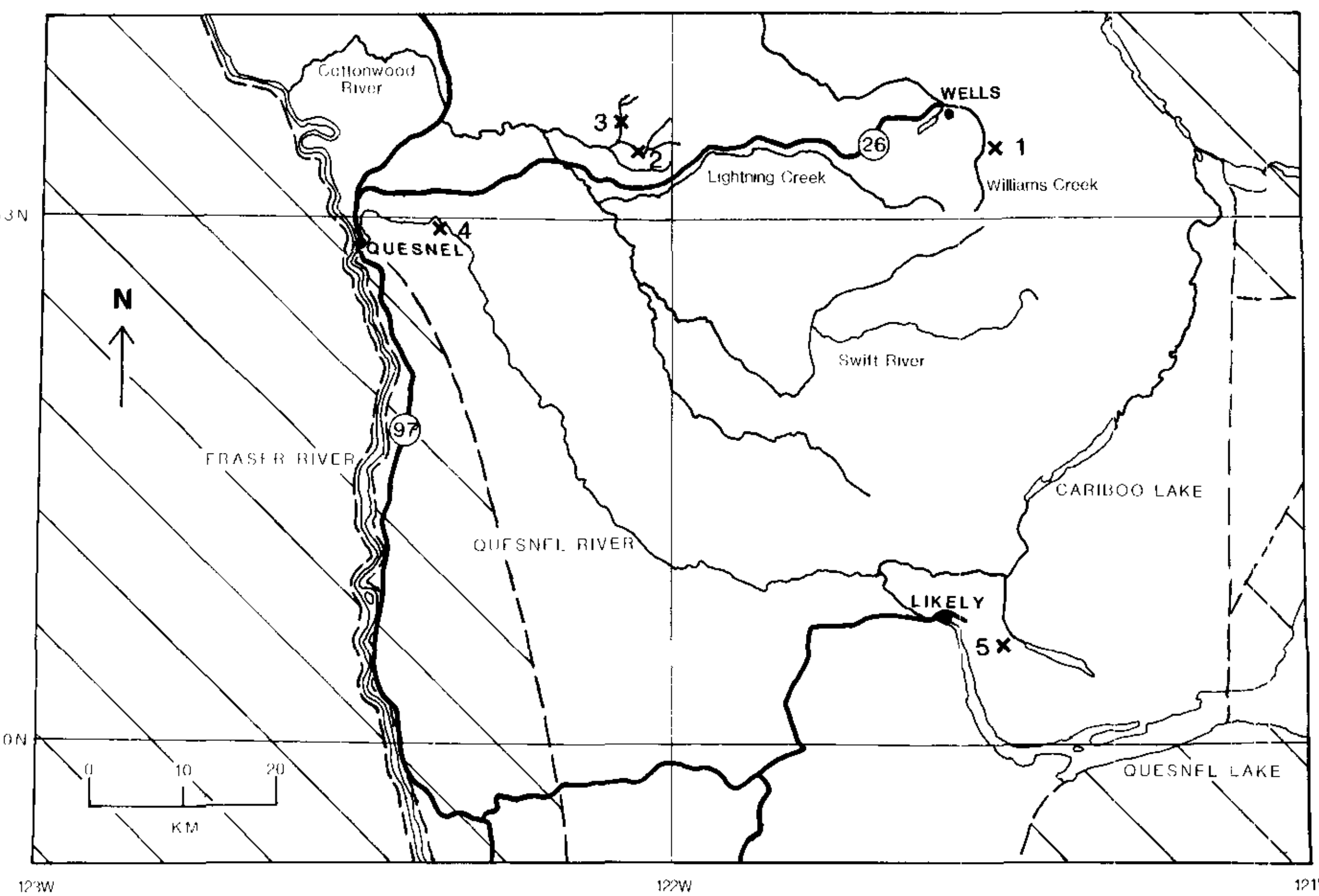


Figure 6-3-1. Location of the Cariboo placer mining area. Study sites discussed are numbered: (1) Ballarat mine, (2) Toop Nugget mine, (3) Alice Creek mine, (4) Quesnel Canyon, and (5) Spanish Mountain. Areas newly opened to placer mining are hachured.

where water for sluicing is readily available. Most large active operations (~70 per cent) are exploiting placers that are relatively deeply buried, or more distant from sources of water. Higher gold prices in the last 20 years have also allowed successful mining of previously uneconomic gravels, especially where large volumes of lower grade gravel are present. Although there are still many small operations in the Cariboo, the trend toward exploitation of deeper or larger volume placer deposits has resulted in the development of several large mines.

Detailed sedimentological evaluations of placer deposits have been made in unglaciated terrains such as on the White Channel gravels in the Klondike area of the Yukon Territory (Morison and Hein, 1987), however, the geology of placer deposits in glaciated areas is poorly understood. Regional studies in British Columbia have been done, but detailed sedimentological analyses are lacking. Sites selected for this study are producing mines offering good section exposure. Highwalls in the active mines were mapped and lithologic, pebble fabric and sedimentological studies were conducted. Samples were collected for textural, mineralogical and geochemical analysis. Gold production in each stratigraphic unit was determined, where possible, by discussions with miners. Detailed results of sample analyses are not presented in this report, rather a geological synopsis of several case studies is outlined. Additionally, a description of the placer geology at the Ballarat mine near Wells (Figure 6-3-1, Location 1) is given as an example of the on-going research.

PREVIOUS WORK

General descriptions of placer deposits in the Cariboo area first appeared in 1874 in British Columbia Minister of Mines Annual Reports. Johnson and Uglow (1926) completed descriptions of placer and lode gold deposits in the Wells-Barkerville area. Regional bedrock mapping was conducted by Tipper (1971) and more recently by Struik (1982). The Quaternary geology of the region was mapped by Tipper (1971) and recent investigations of the Quaternary and placer geology have been made by Clague (1987a, b and 1989). Depositional environments of Cariboo placer deposits have recently been discussed by Eyles and Kocsis (1988, 1989).

MAJOR PLACER DEPOSITS AND EXPLORATION IMPLICATIONS

TOOP NUGGET MINE

Discovered in 1972, the productive Toop Nugget mine (Figure 6-3-1, Location 2) lies in an area that has been frequently worked since the 1860s (*e.g.* shallow gravels at Mary, Alice and Norton creeks). Recent recognition of this deposit illustrates the potential for other new discoveries in equally well explored regions. At the Toop property, mining is mainly within a glacial meltwater channel that incised and removed much (at least 20 metres) of the overburden. Exploration for deeply buried auriferous gravels could benefit by focusing on meltwater channels where the overburden has been removed by natural processes.

Heavily oxidized and locally strongly cemented older (interglacial or preglacial) gravels (Plate 6-3-1) are overlain by two diamicton (till) units (1 and 3; Figure 6-3-2) which are separated in places by intertill sands and gravels (Unit 2). Early postglacial gravels (Plate 6-3-2) partially infill the meltwater channel and contain some gold, probably reconcentrated from underlying units. Gold recovered thus far comes mainly from the lower interglacial or preglacial gravels, but the intertill and early postglacial gravels have also produced gold. Some rich pay-zones were uncovered by the miners, with nuggets up to about 100 grams in size in the lower gravels (T. Toop, personal communication, 1989). The intertill and postglacial gravels also contain coarse gold nuggets. The hackly shape and presence of quartz in some nuggets suggests that the local bedrock may also be economically viable in this area.

The original exploration strategy of the miners assumed the older gravels represented a previous course of Lightning Creek. Similar buried valleys have been found locally (*e.g.* Alice Creek) and further potential is speculated, but as yet unrealized near Toop Nugget mine. In addition, the Toop

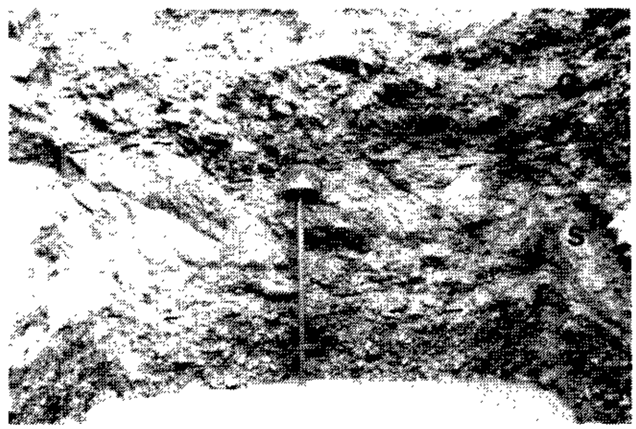


Plate 6-3-1. Oxidized and cemented auriferous sands (s) and gravels (g) in an active pit at the Toop Nugget mine. Poorly to moderately sorted, clast-supported, weakly imbricated pebble gravels are interbedded with faulted, pebbly sands and silts. The deposits are interglacial or preglacial in age.

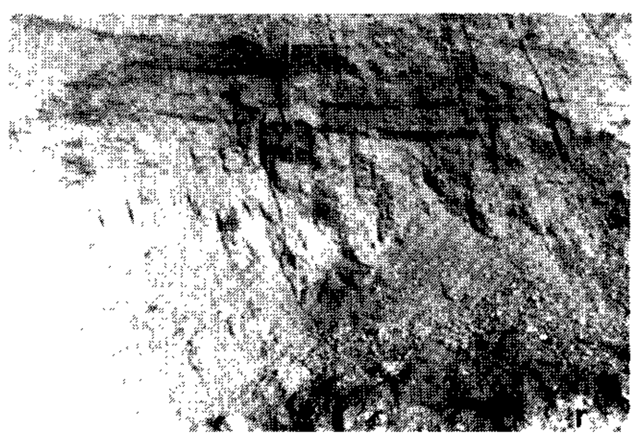


Plate 6-3-2. Horizontally stratified, auriferous sands and gravels at the Toop Nugget mine interpreted as early postglacial deposits. The sediments overlie bedrock (r). The measuring rod is 4 metres long.

mine illustrates that exploration in meltwater-channel valleys elsewhere may provide a cost-effective means of locating productive preglacial and interglacial placer deposits.

ALICE CREEK

Gold-bearing gravels at this site, near the Toop mine (Figure 6-3-1, Location 3), are overlain by about 30 metres of interbedded diamicton, gravel, sand, silt and clay (Figure 6-3-3). Two diamicton units (Units 1 and 3) are interpreted as tills. Within Unit 1, intercalated silts and clays are laterally extensive and are interpreted as glaciolacustrine sediments, deposited during a temporary retreat of ice from the region during the late Pleistocene. Intertill sands and gravels (Unit 2) were probably deposited by a glaciofluvial stream.

The gold-bearing deposits (Figure 6-3-3; Unit 4) consist of interbedded gravels and sands interpreted as low-sinuosity braided-river sediments (Eyles and Kocsis, 1989). Unit 4 is 9 to 14 metres thick but only the upper 5 metres, dominated by horizontally stratified sands, is presently exposed. The gravels are poorly to moderately sorted, clast supported, discontinuously cemented and manganese and iron stained. Gold values increase toward the base of the gravels with the main pay zone in the lower 3 to 5 metres over bedrock. Paystreaks are sporadic, producing an average of 4 grams per cubic metre with a maximum return of about 9 grams (all gold concentration values reported here are based on approximate mining records). From 1986 to 1988, a total of 135 000 cubic metres of material was moved, of which only 11 000 cubic metres was washed with a resulting production of 43 kilograms (1375 ounces) of gold (Bob Patrick, personal communication, 1989).

This site provides an excellent example of the mining potential of deeply buried placer deposits. The cost of removing large volumes of overburden is offset by the potential richness of the deep gravels. In deposits of this type, detailed sedimentological and stratigraphic data are required to predict overburden depths and to identify the extent and volume of gold-bearing strata at present mines and in areas of active exploration.

SPANISH MOUNTAIN

At the producing Spanish Mountain-McKeown mine (Figure 6-3-1, Location 5), gold is found in poorly sorted and crudely stratified coarse gravels interpreted as debris-flow deposits (Figure 6-3-4; Unit 2). Lenses of better sorted gravel, sand and silt occur throughout Unit 2 and are interpreted as fluvial channel deposits. The gold-bearing gravels are overlain by poorly exposed diamicton interpreted as till (Unit 1) suggesting that the placer deposits predate the last glaciation in the area. The gold-bearing sediments may be locally derived alluvium or subglacial deposits. Unit 2 appears to infill the upper part of an elevated erosional channel cut in bedrock. The orientation of the channel is not well defined but appears to be oblique to the regional northwesterly strike of bedrock and topography. The oblique orientation of the channel relative to ice flow would provide an ideal situation for the development of a subglacial cavity. Gold content is generally consistent throughout the mined sequence, averaging about 1 gram per cubic metre not including gold finer than 100 mesh (0.149 mm). The gold appears to originate locally and nuggets have been recovered (V. McKeown, personal communication, 1989). This illustrates that the upper part of buried channels can be productive even where sediments are relatively poorly sorted.

Drilling results indicate that the bedrock channel is up to 74 metres deep. The lower 50 metres of the channel is infilled with clean pebble and boulder gravels (P. McKeown, personal communication, 1989). The lower gravels have not been mined extensively but there is a high probability that they are gold bearing, particularly at their base. North of Spanish Mountain, along the Cariboo River, Clague (1987b) identified a buried channel similar to the Bullion mine near Likely (Plate 6-3-3) as a possible placer exploration target. The Bullion mine has produced over 3860 kilograms (120 000 ounces) of gold. There is a good probability that other rich buried-channel placer deposits occur in the Cariboo region and possibly other areas of British Columbia. The identification and testing of these, often obscure, channels should be a major focus for the placer exploration industry.

Plate 6-3-3. The Bullion hydraulic mine near Likely. Note the large volume of material removed and the typically stratified buried channel sediments.

QUESNEL CANYON

At least three distinct gravel units (Figure 6-3-5) have been identified along this portion of the Quesnel River (Figure 6-3-1, Location 4). The lower gravels (Plate 6-3-4; Figure 6-3-5, Unit 4) consist of well-rounded quartzite, chert and volcanic clasts. At the base they are strongly cemented with iron and manganese oxides. These texturally mature gravels are believed to be Tertiary in age. Lithologic and paleocurrent data indicate a substantially different drainage pattern to that of the present river. The overlying gravel deposits (Unit 3) show greater lithologic diversity and may be interglacial in age. The uppermost gravels (Unit 2), which are overlain by glaciolacustrine deposits (Unit 1), are similar to other glaciofluvial gravels in the area.

Postglacial terrace gravels, unconformably overlying the older gravel units (Plate 6-3-5), are presently being mined in the area. Mining of the Tertiary gravels is uncommon due in part to their induration. Much of the placer gold in the region is believed to have been reconcentrated, from the cemented

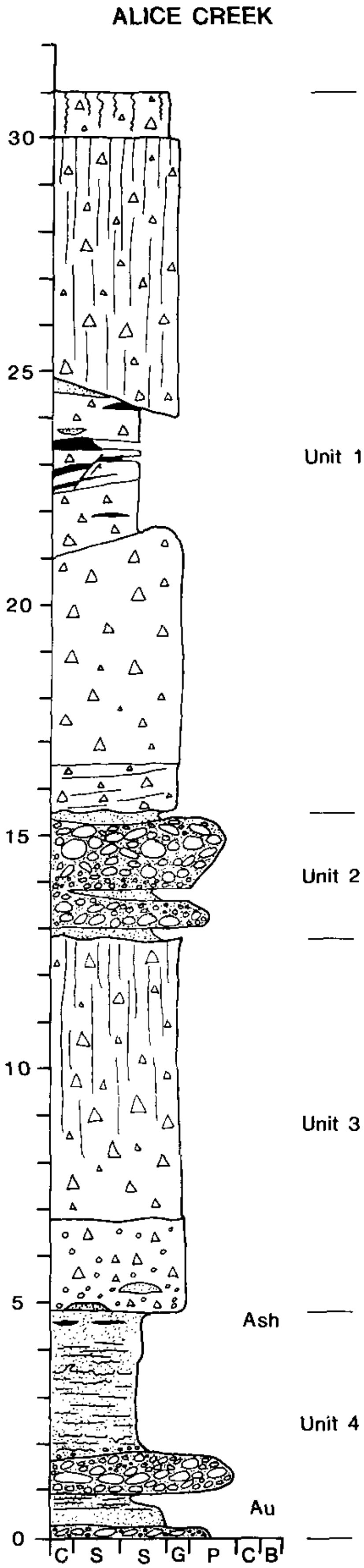


Figure 6-3-3. Composite stratigraphic column of old highwall exposures at Alice Creek mine.

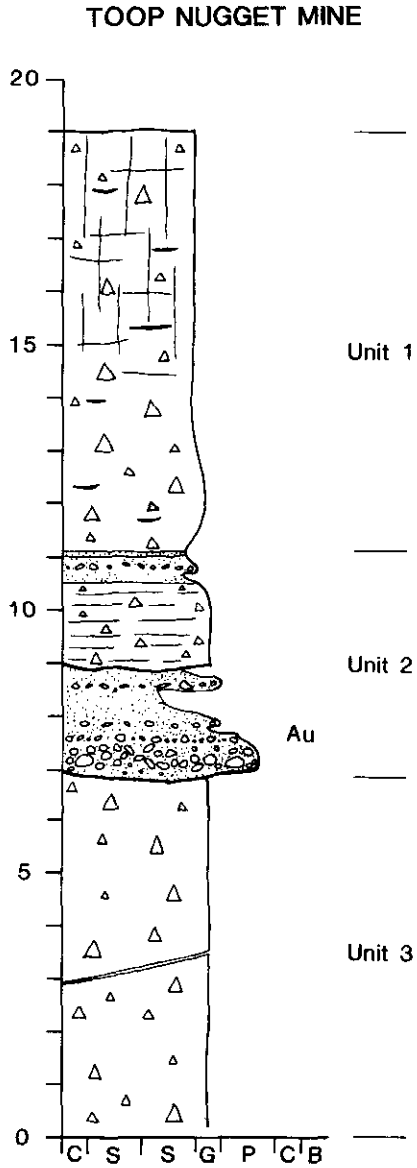


Figure 6-3-2. Stratigraphic column of old highwall exposure at Toop Nugget mine. See Figure 6-3-3 for legend. Horizontal scale: C–clay S–sand S–silt G–granule P–pebble C–cobble B–boulder

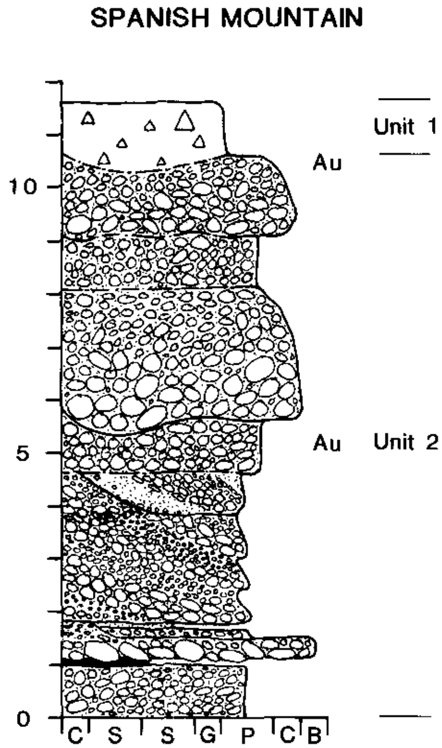
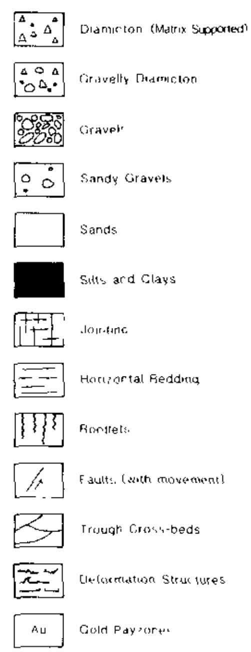


Figure 6-3-4. Stratigraphic column of highwall exposure at Spanish Mountain mine.



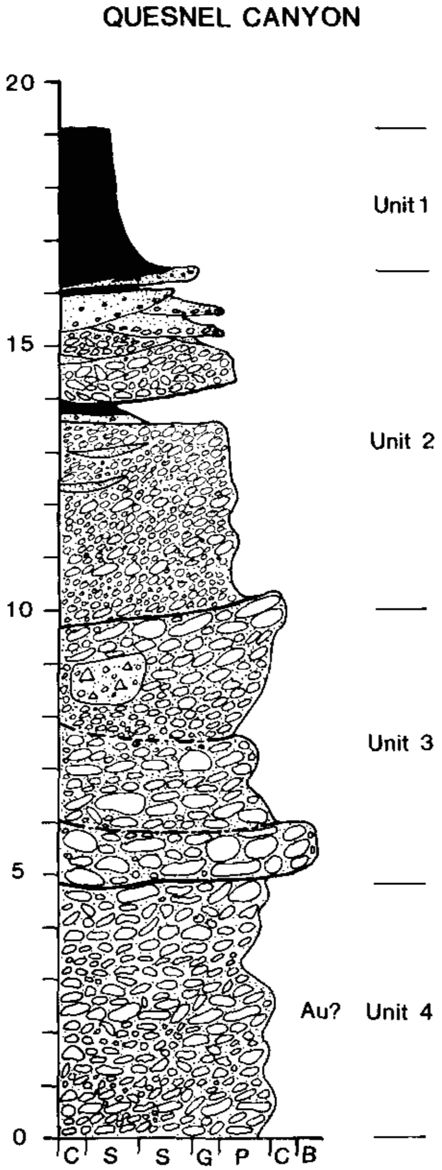


Figure 6-3-5. Stratigraphic column of exposure near Quesnel Canyon.

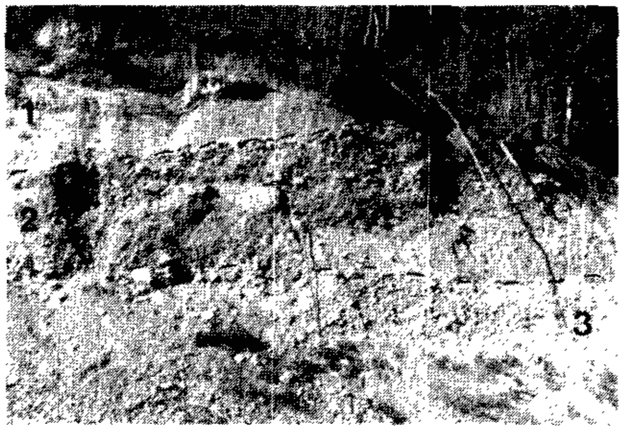


Plate 6-3-4. Silts, clays and glaciofluvial gravels of Unit 1(upper, grey units) unconformably overlying oxidized inter-glacial (Unit 2) and possibly Tertiary (Unit 3) gravels along the Quesnel River near Big Canyon.

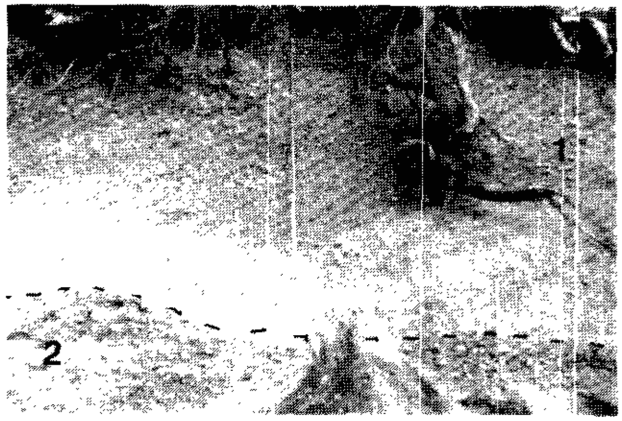


Plate 6-3-5. Holocene terrace gravels (1) unconformably overlying older interglacial or preglacial gravels (2). Exposure is along an actively mined terrace. The measuring rod is 4 metres long.

Tertiary gravels, by younger river systems. Sedimentological and stratigraphic studies of the older river deposits are needed to understand the present distribution of placers in the Cariboo (Clague, 1989).

CASE STUDY – BALLARAT MINE

The Ballarat pit is about 2 kilometres north of Barkerville and is adjacent to Williams Creek, one of the richest gold-producing streams in British Columbia (Figure 6-3-1, Location 1). Williams Creek produced at least 1460 kilograms (47 000 ounces) of gold in the 10-year period from 1874 to 1885 (Holland, 1950). The gold-bearing strata underlie 2 to 8 metres of till deposits and are of alluvial, glaciofluvial and fluvial origin. The deposits infill an ancient bedrock channel and the lowermost and presumably richest gravels are as yet unmined. Gold from the mine is almost entirely finer than very coarse sand [99 per cent is smaller than 16 mesh (1.19 mm)]. This site illustrates the potential for the presence of other rich placer gold deposits in regions that historically have been heavily explored and mined.

Several highwalls at the Ballarat mine were mapped and described in detail during the course of this study. The major stratigraphic units exposed in the main highwall, oriented approximately north-south, are shown on Figure 6-3-6. The details of the Ballarat case study are provided to illustrate the type of geologic information that will aid in future development and exploration.

BEDROCK (UNIT 1)

Bedrock (Unit 1) is exposed at the northern and southern ends of the main highwall at the Ballarat mine (Figure 6-3-6). At the south end it consists of strongly altered muscovite-talc schist and phyllite with quartzite beds 1 to 10 centimetres thick. The schist is crosscut by several discordant quartz veins generally less than 1 centimetre wide. Bedrock exposures at the north end of the mine site are interbedded limestone, bedded quartzites, schist and phyllite.

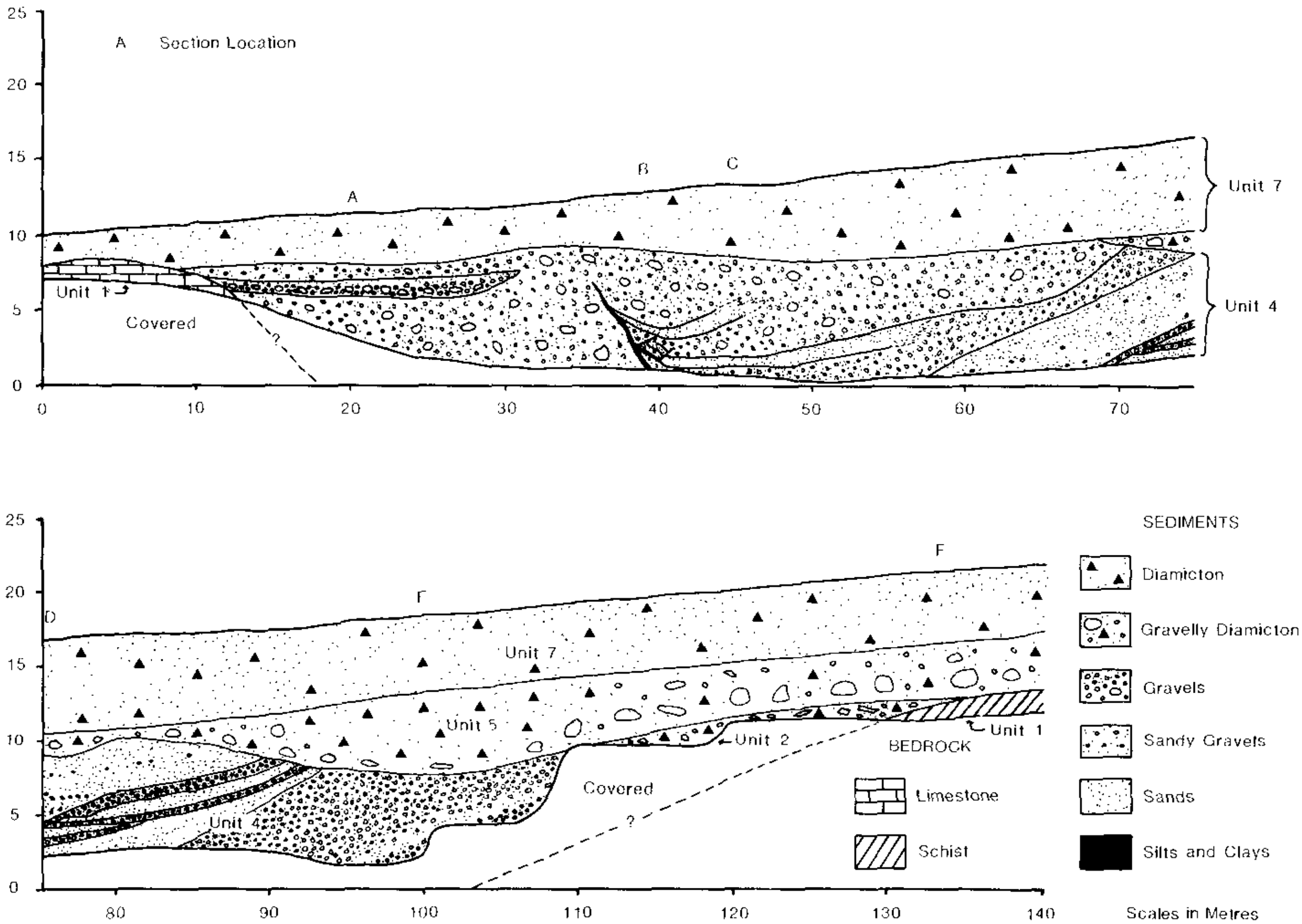


Figure 6-3-6. Major stratigraphic units exposed along the main highwall at the Ballarat mine.

Mineable Gold-Bearing Deposits

At least four stratigraphic units can be recognized in the deposits that are currently being mined. In general, gold increases with depth. The deepest and presumably the richest gravels were not exposed in October 1989. However, seismic results indicate that approximately 10 metres of gravel are present below the lowest exposed unit. Gold concentrations in the main pay gravels are up to approximately 2 grams per cubic metre (Figure 6-3-6; Units 3 and 4), 0.6 gram per cubic metre in gravelly diamictons (Units 2 and 5), and 0.1 to 0.2 gram per cubic metre in the upper diamicton (Bert Ball, personal commumication, 1989). The upper diamicton (Unit 7) is presently considered to be overburden but may be mined in the future with improved gold recovery techniques. Gold recovered is predominantly fine grained, with 99 per cent smaller than 16 mesh (1.19 millimetres). The gold has a fineness of about 840.

Lower Diamicton (Unit 2)

Discontinuous diamicton beds (Unit 2) overlie the bedrock highs along south and north sides of the Ballarat mine. These deposits are thin (<2 to 3 metres thick) and are restricted to areas adjacent to bedrock highs. The diamictons are matrix to clast supported with 50 to 80 per cent clasts. Locally derived angular schist, phyllite, quartzite and limestone dominate, but some subrounded to rounded pebbles are also present. The matrix is a sandy silt and contains abundant comminuted local bedrock material. The diamictons have a crude sub-horizontal stratification defined by horizontal tabular clasts, locally occurring in boudinaged and folded beds, and thin (<10 centimetres), tabular to trough-shaped lenses of fine sand. The sands are well sorted, have horizontal to wavy laminations and are locally interbedded with silts. Some beds directly overlying bedrock consist entirely of brecciated schist and, in places, vein quartz.

INTERPRETATION

The diamicton beds are interpreted to be debris-flow deposits derived from local bedrock highs. The clast lithology points to a local bedrock source that was probably originally disaggregated by *in situ* physical and chemical weathering. Previously rounded clasts were also incorporated into the flow deposits. Poorly sorted sediments with a fine matrix, disorganized fabric and gradational bed contacts are typical of modern debris-flow deposits (Bull, 1972;

Kochel and Johnson, 1984). Folded and boudinaged beds of local material indicate only minor transport. Stratified sands and silts were probably deposited by fluvial activity between debris-flow events.

Lower Gravels (Unit 3)

The lowest exposed gravels (Plate 6-3-6; Unit 3, not shown in Figure 6-3-6) in the Ballarat pit are moderately sorted, clast-supported, very compact pebbly gravels generally with a fine to medium sand matrix. Some beds exhibit planar and channel-fill crossbedding, and scoured lower contacts (<50 centimetres deep and 2 to 5 metres wide). These gravels generally dip 5° to the south and are unconformably overlain by large cobble to boulder gravels.

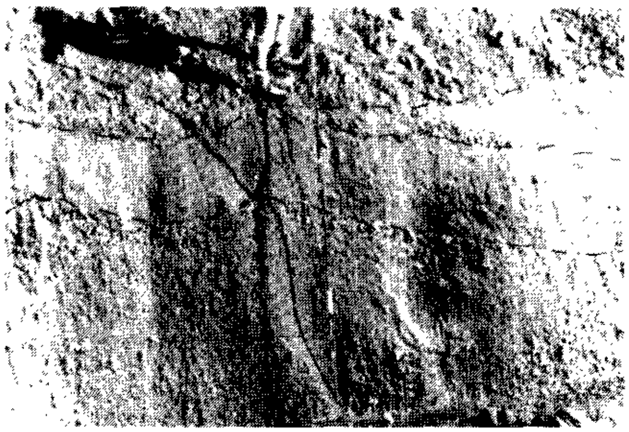


Plate 6-3-6. Lowest exposed gravels at the Ballarat mine (Unit 3). Note the stratification and scoured bed contacts (outlined).

INTERPRETATION

The degree of sorting, stratification and imbrication of the gravels suggests that they were fluvially deposited. Low-angle planar crossbeds probably represent deposition along the channel margins or as bar foreset beds. Scoured contacts indicate locally channelized flows, possibly in a braided-river system. The lithologic variability of these gravels (Figure 6-3-7) suggests that they were not derived solely from a local tributary but rather were deposited in the main valley system.

Middle Gravels and Sands (Unit 4)

A complex unit of sands and gravels (Unit 4), stratigraphically overlying Unit 3, is exposed along the main pit highwall. Lithologically, these gravels are composed almost entirely of quartzite, phyllite and schist.

At the base of the highwall (Figure 6-3-6, Section E), sand and gravel beds dip 25° north. Sandy beds are about 50 centimetres thick and consist of planar cross-stratified medium to coarse sand grading up into trough crossbedded medium sands and horizontally laminated silts. Convoluted bedding, normal faults, and load and flame structures are common. Gravel beds are up to 3 metres thick and are poorly

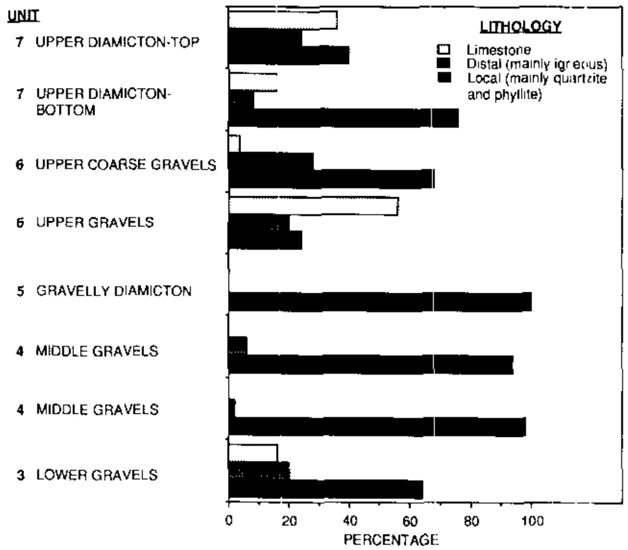


Figure 6-3-7. Lithology of main gravel and diamicton units at the Ballarat mine.

sorted and massive to crudely planar cross-stratified. Clasts are mainly small to large pebbles with few cobbles.

In the centre of the section (Figure 6-3-6, Section D; Plate 6-3-7) sandy units are 1 to 2 metres thick and dip consistently about 25° to the north. The dip of some beds decreases down-dip. Beds are 1 to 10 centimetres thick, laterally traceable for several metres, and mainly massive or normally graded. Thicker beds exhibit wavy parallel laminae with minor trough crosslaminae and low-angle climbing ripples. There are some small (10 cubic centimetres) angular inclusions of sandy gravel. Gravel beds are up to 30 centimetres thick, poorly sorted and massive. Bed contacts are sharp and conformable although lower contacts are locally scoured or marked by injection structures or sand intraclasts. Gravel beds generally pinch out down-dip or are eroded by more steeply dipping contacts of overlying units. Some gravel beds grade up-dip into the overlying gravel unit.

At Section C (Figure 6-3-6), moderately sorted, coarse sand and pebble-gravel beds occur in a deformed unit with a generalized trough shape. Poorly developed bedding in the sands is defined by textural changes between internally stratified sand beds up to 15 centimetres thick and sandy pebble beds up to 10 centimetres thick. Gravel beds are 5 to 20 centimetres thick and appear massive. Coarser beds are more poorly sorted, chaotic and in places they grade into pebbly sands. Beds either grade laterally into adjacent deposits or are eroded by overlying units. At the south end of this deformed zone, the sediments are generally better sorted, beds are thicker (up to 2 metres), and bed boundaries are sharper than to the north. The intensity of deformation increases to the north where the deformed zone is bounded by a steeply dipping lens of massive to poorly laminated silt and fine sand (Figure 6-3-6). Beds south of the silt lens are cut by reverse faults, folded and dip up to 35° to the south. The silt lens is folded, branched, locally boudinaged and characterized by soft-sediment deformation structures.

North of the silt lens (Section A, Figure 6-3-6), this unit consists mainly of a clast-supported, poorly sorted, sandy

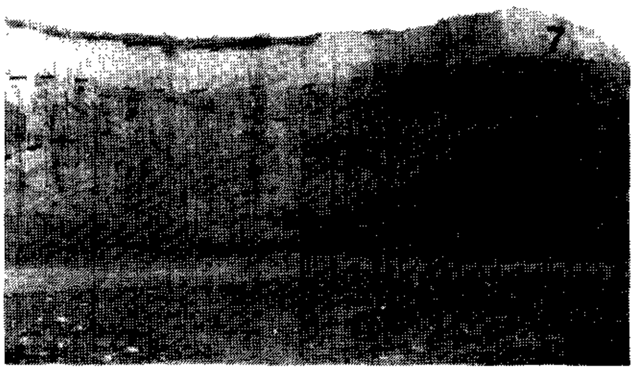


Plate 6-3-7. Steeply dipping sands and gravels in Unit 4 overlain by alluvium (Unit 5) and till (Unit 7). Section is about 15 metres high.

pebble-gravel with no apparent stratification. Cobble and boulder clusters up to 1 metre high and 3 metres wide are present. The clusters are clast supported and have a matrix that varies from moderately sorted sand to silty diamicton, locally with poorly developed convoluted laminae. Moderately sorted, locally openwork pebble-gravels occur adjacent to the clusters. In places the gravels grade into matrix-supported silty diamicton with clasts that are commonly angular, of local origin, and randomly oriented. The upper part of this unit contains a lens of poorly sorted gravel, 20 metres wide and up to 1.5 metres thick, that fines upward from cobbly gravel to medium pebble-gravel to coarse sand. The lens exhibits crude horizontal stratification and is trough shaped.

INTERPRETATION

Lithologic analysis of the gravels in this unit (Figure 6-3-7) and the general northerly dip of beds, indicate that they were derived almost entirely from a small tributary drainage to the south. The characteristically steep and consistent dip of beds and the topographic high to the south suggest a fan-delta environment. The lateral continuity of strata in this unit are suggestive of delta or fan-delta foreset beds. Massive, steeply dipping gravel beds with sharp planar contacts are typical of foreset beds. The foreset gravel beds pinch out or flatten in the down-dip direction and grade up-dip into overlying (topset) gravel beds. Massive and normally graded sands, horizontally laminated silts and fine sands, and climbing ripples are common in subaqueous environments. Load, flame and injection structures indicate rapid deposition onto saturated sediments. Sand intraclasts, local concave scouring, convoluted bedding, faults, and other deformation structures probably formed as a result of syndepositional slumping on over-steepened foresets. Massive to normally graded sands and gravels may reflect small sediment gravity-flow deposits which grade downslope into sand and silt beds. Angular gravel inclusions at the base of some sand beds are probably rip-up clasts.

Poorly sorted gravel and diamicton beds in this unit are interpreted as gravelly debris-flow deposits (*c.f.* Larsen and Steel, 1978; Burgisser, 1984). Disorganized to weakly imbricated, large clast clusters, such as those described above, form during the waning stage of high-discharge events (Brayshaw, 1984).

Deformation at the north end of the main highwall may be glaciotectonic in origin. High pore-fluid pressures in saturated sediments would result in deformation structures similar to those described. Compressive deformation would be expected along the margins of a glacier advancing from the east. This explanation is consistent with the observed decrease in deformation structures to the south.

UPPER GRAVELLY DIAMICTON (UNIT 5)

This unit is exposed only at the south end of the main highwall (Figure 6-3-6). The diamicton is clast supported and poorly sorted with a matrix of coarse sands and minor fines. Clasts are up to small cobble size and are weakly to moderately imbricated. The b-axes of tabular and disk-shaped clasts tend to dip to the southwest (Figure 6-3-8a). Some of the larger clasts have an irregularly laminated silt and clay armour up to 2 centimetres thick. Crude horizontal beds, up to 1 metre thick, exhibit normal grading with a poorly defined layer of cobbles to small boulders grading up into pebble gravels. Some beds display a thin, inversely graded zone at their base. Minor open work, moderately well sorted pebble beds occur. A large lens of diamicton occurs within the upper part of Unit 5. It is trough shaped and has gradational lower and upper boundaries.

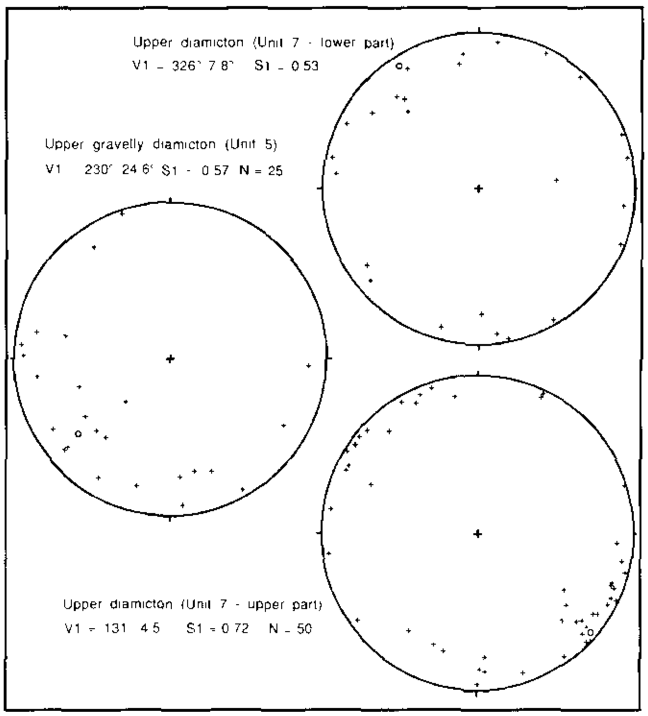


Figure 6-3-8. Stereo plots of the dip and dip direction of the intermediate axes of blade and disk-shaped clasts in gravelly diamicton (Unit 5), and the trend and plunge of the a–axes of elongated clasts in the upper and lower parts of Unit 7. V1 = orientation of maximum clustering (shown with a small circle) and S1 = normalized eigenvalue for V1.

INTERPRETATION

Diamicton beds in Unit 5 are interpreted as debris-flow deposits. Poor sorting and normal grading are typical and inverse grading is known to occur at the base of some debris-flow deposits (Burgisser, 1984). Indistinct stratification and weak imbrication have been observed in modern analogues (Kochel and Johnson, 1984). A preferred plunge of clast b-axes forming a girdled fabric (Figure 6-3-8) is also typical. Sorted beds indicate some fluvial activity, probably between debris-flow events. Lithologic and imbrication data (Figures 6-3-7 and 8) indicate that the flows originated from the southwest, and may therefore be associated with an alluvial fan.

UPPER GRAVELS (UNIT 6)

In the centre of the mine site the lower gravels (Unit 3) are unconformably overlain by chaotic to weakly imbricated, poorly sorted, large cobble to boulder gravels with a sand to pebble matrix (Unit 7, not shown on Figure 6-3-6). The coarse gravels are crudely stratified with beds up to 2 metres thick that dip 5° to 10° to the south. Bed boundaries are discontinuous and gradational. Clasts are mostly angular to subangular, especially near bedrock highs, but rounded cobbles and boulders dominate some beds. Stratification becomes more horizontal in the upper parts of the unit and the number of striated clasts increases toward the top.

INTERPRETATION

The coarse size of clasts, presence of striations, and high proportion of distally derived clasts (Figure 6-3-7) in these gravels suggests that they are glaciofluvial in origin. Deposits of this type are typical of proximal, braided gravel-bed rivers in glacial environments (Church and Gilbert, 1975). Gravelly braided streams are characterized by crude subhorizontal stratification (Hein and Walker, 1977). The increase in striated clasts towards the top of the unit may indicate the proximity of glacial ice, an interpretation which is further supported by the overlying diamicton, interpreted as till.

DIAMICTON (UNIT 7)

Unit 7 is generally 2 to 8 metres thick and consists primarily of massive, dense, matrix-supported diamicton. Clasts, often striated, are up to cobble size with rare boulders. They are mostly angular to subrounded with shattered and broken clasts common. The matrix is sandy silt. The lower contact of the diamicton is sharp and planar to gently undulatory.

The diamicton is highly variable in its sedimentary nature. At the south end of the main highwall (Figure 6-3-6) there are about 70 centimetres of interbedded silty diamicton and sandy silts at the base of the unit. Silt beds are horizontally laminated and laterally traceable for about 3 metres. They have few pebbles and some fine sandy laminae. Lineations of unknown origin on one bed trend at 160°. Irregular lenses and beds of poorly sorted coarse gravel up to 30 centimetres thick occur at the top of this unit and grade into the overlying massive diamicton.

In exposures west of the main highwall, Unit 7 consists of 4 metres of massive diamicton overlain by 2 metres of stratified diamicton and another 2 metres of massive diamicton. Diamicton beds within the stratified zone are 0.03 to 1 metre thick and vary in clast content and matrix texture. Contacts between beds are sharp and planar. Locally beds are separated by laminated clays, silts and fine sands with minor ripple-bedded sands. Some beds are deformed with clay beds containing rounded silt intraclasts and sand and silt beds with convoluted laminae. Beds are laterally traceable for two to several metres and have interbedded upper and lower contacts. Irregular gravelly lenses occur locally. Clast fabric data from the lower part of Unit 7 (Figure 6-3-8) indicate a strong preferred orientation of the long axis of clasts parallel to the main valley trend (northwest). Higher up in the diamicton clasts are more randomly oriented (Figure 6-3-8). The proportion of distal to local clasts decreases with depth (Figure 6-3-7).

INTERPRETATION

The massive diamicton of Unit 7 is interpreted as till deposited at the base of an over-riding glacier. Its massive, dense, matrix supported character is consistent with this interpretation. Diamictons with these characteristics, as well as with numerous striated and fractured clasts, a fine-grained matrix, a basal enrichment in local clasts, a strong a-axis fabric parallel to the main valley, and a sharp, planar lower contact, are typical of basal lodgement and meltout tills in mountain regions (Levson and Rutter, 1988 and references therein). Thin lenses of laminated clay, silt and sand probably are the result of pond sedimentation in small cavities at the glacier base. Diamictons interbedded with these sorted sediments were probably deposited as small debris flows within the cavities or by meltout of debris from the glacier base. Poorly defined gravel lenses may have been deposited in small cavities by subglacial streams. The random orientation of clasts in the upper part of the diamicton may be a result of resedimentation during postglacial times. Colluvial activity did not disrupt primary depositional characteristics in the lower part of the till.

GEOLOGIC SUMMARY – BALLARAT MINE

The sequence of deposits exposed at the Ballarat mine suggests that the following geologic events occurred during the late Quaternary. Prior to the last glaciation in the area, a bedrock-incised channel was occupied by a braided river that deposited the lower gravels (Unit 3). Coeval sedimentation along the margins of the channel was dominated by locally derived debris-flow deposits (Unit 2). Possibly as a result of the onset of glaciation, drainage in the vicinity of the mine was impeded, allowing development of a small fan-delta (Unit 4). Deposition of steeply dipping gravel and sand foreset beds initially dominated infilling of the channel. The upper gravelly diamicton (Unit 5) was deposited largely by a series of debris flows derived from the highlands to the south. The increase in locally derived debris-flow material, possibly due to the reduction in vegetative cover associated with glacial conditions, resulted in the progradation of alluvial fan sediments over the area. Coarse, glaciofluvial gravels (Unit 6) and basal lodgment and meltout tills (Unit 7) were deposited with the advance of glaciers. Some deformation of the underlying sediments occurred with the advance of ice.

Sorted sediments were deposited locally in subglacial cavities. Subsequent to deglaciation, resedimentation by colluvial processes was restricted to the upper part of Unit 7.

IMPLICATIONS OF BALLARAT CASE STUDY

Economic gold-bearing placer deposits at the Ballarat mine were deposited in a variety of sedimentary environments. The various units exposed'are characterized by significant differences in grain size, sorting, clast roundness and stratification. Sedimentological interpretations indicate deposition in braided stream, deltaic and alluvial fan environments. Detailed sedimentological and stratigraphic analyses are required to understand the complex geologic origin of placer deposits of this nature. This information is necessary to determine the relationships of pay-streaks to sediment facies and to help project pay-zones into unmined areas.

Presently, economically viable gold occurs only in reworked sediments that were deposited prior to the last glaciation. The richest deposits are preglacial fluvial gravels with gold contents of about 2 grams per cubic metre. Mineable gold-bearing deposits of colluvial and alluvial origin produce about 0.6 gram of gold per cubic metre. Gold concentrations in till and enclosed sediments at the Ballarat site are low (0.1 to 0.2 gram per cubic metre), but may be worth processing with improved recovery systems.

Other bedrock channels along the margins of present valley bottoms may represent largely untapped sources of placer gold. Similar bedrock channels to that described at the Ballarat mine may occur throughout the Cariboo region and elsewhere in British Columbia. Exploration activities should focus on regional airphoto interpretation, detailed seismic cross-sections, large-diameter drilling, and other methods for the identification and evaluation of these hidden placer deposits.

CONCLUSIONS

Information gathered from geologic studies at active placer mines in the Cariboo region has several important implications for the placer industry. Exploration and production of deeply buried placers may be facilitated in some areas where natural processes have removed the overburden, such as along former glacial meltwater drainage courses. Preglacial and interglacial placers, deeply buried by till deposits, may be mineable in areas where detailed stratigraphic and sedimentological information is available to trace gold-bearing strata. In addition, some high-elevation buried-channel placer deposits, such as on Spanish Mountain, have a relatively thin glacial overburden and good gold concentrations in their upper part, and can therefore be productively mined. The potential for placer gold discovery in buried channels is good in the Cariboo and other traditional placer mining areas throughout the province. Stratigraphic and sedimentological studies of existing exposures are needed to help understand the paleodrainage patterns of preglacial and interglacial rivers and thereby identify probable gold-bearing buried channels.

Detailed geologic studies at the Ballarat mine site have identified several stratigraphic units with distinct sedimentologic characteristics. Gold occurs in economically viable quantities in all of the sediments except the capping diamicton deposits. Comparisons of sediment facies at the Ballarat mine with the results of ongoing studies at other mine sites will lead to a better understanding of the relationships between gold concentrations and sedimentary environments. The analysis of sedimentary environments at the Ballarat mine illustrates the potentially complex geologic setting of placer gold deposits in glaciated areas. An understanding of the sedimentary origin of existing placers is needed to identify other sites where gold-bearing placers have been deposited and preserved from subsequent erosion. The Ballarat site also highlights the potential for locating new placer deposits in buried channels even in heavily exploited, traditional placer areas.

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