New results on the stratigraphy and placer gold potential of Indian River, Dawson, central Yukon

William LeBarge[1]
Yukon Geological Survey

Vladimir Naumov, Ilya Mukhanov and Vitalii Bryukhov
Institute of Natural Sciences, Perm State University[2]

Robert J. Chapman
School of Earth and Environment, University of Leeds[3]

LeBarge, W., Naumov, V., Mukhanov, I., Bryukhov, V. and Chapman, R.J., 2009. New results on the stratigraphy and placer gold potential of Indian River, Dawson, central Yukon. *In:* Yukon Exploration and Geology 2008, L.H. Weston, L.R. Blackburn and L.L. Lewis (eds.), Yukon Geological Survey, p. 147-159.

ABSTRACT

Most of the historic placer gold recovered from the Indian River has been from the modern river gravel; however, a significant amount of placer gold has been mined from older deposits, including low-level, intermediate-level and high-level gravel terraces.

Significant placer gold reserves exist in Indian River drainage in various forms. Prospective targets include 1) modern (Holocene) alluvial channels, alluvial fans and tributary gulches; 2) modern (Holocene) low-level buried and/or abandoned alluvial terraces; 3) early to late Pleistocene intermediate-level buried abandoned terraces and alluvial fans; 4) early Pleistocene (pre-Reid) glaciofluvial gravel sequences; 5) Pliocene high-level alluvial terraces (White Channel Gravel); and 6) technogenic (tailings) deposits.

Fine-grained placer gold existing in size ranges not recovered efficiently by conventional sluicing operations has been found in alluvial and glaciofluvial gravel and tailings deposits. These deposits may represent an important resource and any future mining operations must address the metallurgical implications to maximize recovery.

RÉSUMÉ

La plus grande partie de l'or placérien extrait à ce jour de la rivière Indian provient du gravier contemporain de la rivière. Cependant, une quantité importante d'or placérien a également été extraite de dépôts plus anciens, y compris les terrasses de gravier de niveau inférieur, intermédiaire et supérieur.

D'importantes réserves d'or placérien existent sous diverses formes dans le bassin hydrologique de la rivière Indian. Les cibles de prospection comprennent 1) les chenaux alluviaux et les ravins affluents contemporains (Holocène); 2) les terrasses alluviales abandonnées et enfouies de niveau inférieur contemporaines (Holocène); 3) les terrasses abandonnées et enfouies de niveau intermédiaire et les cônes alluviaux de vallées latérales du Pléistocène précoce à tardif; 4) les séquences de gravier fluvioglaciaire du Pléistocène précoce (antérieur à la Glaciation de Reid); 5) les terrasses alluviales de niveau supérieur du Pliocène (gravier de White Channel); 6) les dépôts résultant du développement technologique.

De l'or placérien à grain fin qui n'est pas récupérée efficacement par les méthodes de concentration conventionelles se retrouve dans des unités de gravier fluvioglaciaire ainsi que dans des dépôts résultant du développement technologique (résidus) dans le cadre d'activités minières antérieures. Ces dépôts pourraient contenir d'importantes ressources et devront être considérés lors de futures opérations minières afin d'en améliorer la récupération.

[1]*bill.lebarge@gov.yk.ca*

[2]*Institute of Natural Sciences,15, Bukireva St., Perm State University, Perm, Russia, 614990*

[3]*School of Earth and Environment, Earth Science Building, The University of Leeds, Leeds, LS2 9JT, United Kingdom*

INTRODUCTION

In 2003, a resurgence in placer exploration and mining activity by several mining companies in the Indian River area resulted in the creation of new exposures which became available to be studied and sampled. Subsequently, a joint Canada/Russia project was initiated in 2006 in order to develop a better understanding of the evolution of placer gold deposits and gold potential of the Indian River drainage. The study was divided into several components consisting of the stratigraphic framework (led by William LeBarge of the Yukon Geological Survey, [YGS]); the nature and recovery of fine and thin gold particles (led by Dr. Vladimir Naumov of Perm State University, Russia); and a geochemical comparison between placer gold particles and local sources of bedrock gold (led by Dr. Rob Chapman, University of Leeds and Dr. Jim Mortensen, University of British Columbia). This paper presents some results from the first two components, while the third component will be presented in a later publication which will integrate the results of all three aspects of the study.

PREVIOUS WORK

High-level terraces along the Indian River were studied by Morison (1998) and more recently by Nelson and Jackson (2003). Lowey (1985) studied the conglomerates at McKinnon Creek (a left-limit tributary to Indian River) and grouped placer deposits along Indian River into several classes (Lowey, 1999). Lowey (2004) later described parts of the Indian River drainage and included this stratigraphy as part of a larger study of the Klondike Placer District. In 1999, Duk-Rodkin re-mapped the glacial limits which were initially defined by Bostock (1942, 1966) and Hughes *et al.* (1969). Glacial limits were later re-interpreted by Jackson *et al.* (2001). Froese *et al.* (2001) described the setting of placer deposits of Dominion Creek, a right-limit tributary of Indian River. Placer activity of the Dawson area was compiled by Lipovsky *et al.* (2001). The surficial geology of the Klondike and Indian River areas was mapped by Jackson (2005) and Froese and Jackson (2005a,b,c) as part of the Ancient Pacific NATMAP project.

PROJECT OBJECTIVES

The project was designed to yield two types of information: 1) to describe the mineralogy of gold in context with the stratigraphic framework; and, 2) to describe the physical characteristics of the sampled gold grains from the study area. To date, there have been no detailed mineralogical studies of placer gold from the Indian River drainage and little work has been completed on the overall stratigraphic framework, specifically the stratigraphy of intermediate and low-level terraces. This project aims to better understand the relationship between the bedrock sources of gold and the placer gold in order to create a broader stratigraphic framework which can be used for exploration for new deposits of bedrock and placer gold, both within Indian River drainage and in adjacent areas of central Yukon. The combined studies of gold characteristics and stratigraphy may make it possible to re-trace the evolution of gold grains from their present location in modern river alluvium, back through the intermediate hosts of Tertiary gravel and Cretaceous conglomerate, and finally, to their original lode sources. The physical characterization of the gold grains recovered from sampling permits evaluation of the efficiency of past and current processing techniques used in placer mining. This information will be especially useful for miners wanting to redesign their processing methods in order to maximize gold recovery.

PLACER GOLD PRODUCTION

The Indian River Placer District, which is on the southern boundary of the Klondike Placer District, includes highly productive creeks such as Quartz and Dominion creeks and their respective tributaries, as well as less productive, but significant tributaries such as Ninemile, Ophir, Ruby, McKinnon, Montana, Eureka, Wounded Moose and Australia creeks (Fig. 1). Government royalty records (Yukon Mining Recorder, 2008) indicate the total cummulative recorded placer gold production to the end of 2008 to be 1 509 186 crude ounces (46 940 966 g) for the Indian River and its tributaries; approximately 71% of that came from Dominion, Sulphur and Gold Run creeks. No recorded mining took place on the main Indian River prior to 1983, and most placer gold production took place in the late 1980s, peaking at 30 482 crude ounces (948 097 g) in 1988. Only 3736 crude ounces (116 203 g) were recorded as royalties in 2008.

METHODOLOGY

FIELD METHODS

Between 2005 and 2007, over 50 sites were visited; these included active mine sites and natural exposures (Fig. 1). Sedimentary structures and stratigraphy were described, and more than 90 samples were collected from gravel units, organic-rich silt, wood (for ^{14}C dating) and tephras

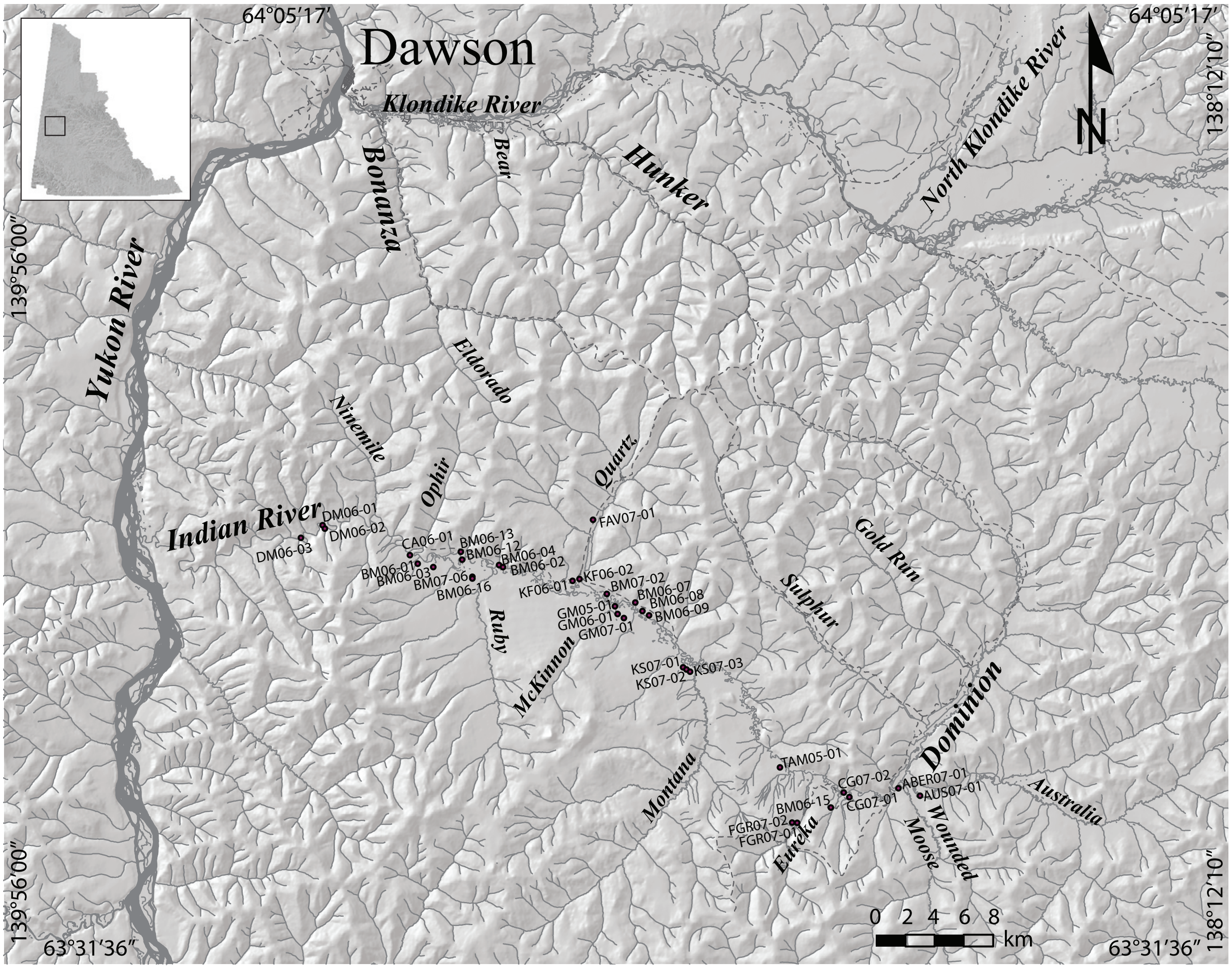

Figure 1. Location map including site locations studied from 2005 to 2007.

(for tephra chronology). Gravel units were sampled in vertical transects and were approximately 20 L in volume. These samples were processed according to the methods described by Lunev (1967) and Lunev and Osovetskiy (1987). Initially, samples were wet-screened in the field to size fractions of +4 mm and +1 mm. Size fractions of +4 mm were kept for lithological analyses and +1 mm size fractions were examined later in the lab to determine the presence of coarse gold. The -1 mm size fraction was mixed into a slurry and processed through a spiral concentrator ('Screw Sluice', Fig. 2). At the bottom of the spiral concentrator, material was separated into two fractions, with the heavier material on the inside of the spiral. Both mineral fractions were retained for laboratory analyses.

Figure 2. Dr. Vladimir Naumov operating a 'Screw Sluice' test plant on the banks of Indian River.

LABORATORY METHODS

At the Institute of Natural Sciences in Perm University, Russia, gold and heavy minerals were separated out of the collected samples using heavy liquids. Gold was separated from the heavy minerals and individual grains were counted. The gold grains were further separated into the following size fractions: +1.0 mm, -1.0 to 0.5 mm, -0.5 to +0.25 mm, -0.25 to +0.1 mm and -0.1 mm; the total mass of each of these size fractions was recorded. Gold grains were photographed using a scanning electron microscope (SEM) and were described in detail, along with the composition of each of the heavy mineral fractions.

Beta Analytic Inc., Miami, Florida, analyzed the wood and silt samples using standard AMS radiocarbon dating, and selected tephras were geochemically analyzed by Dr. John Westgate at the University of Toronto.

RESULTS

GENERAL STRATIGRAPHIC SETTING

Three major levels of terraces are known in the Indian River drainage. High-level terraces occur throughout the length of the valley and likely correlate to the Pliocene White Channel Gravel (WCG) which is found on Bonanza and Hunker creeks (Fig. 1; Nelson and Jackson, 2003). These high terraces are capped by a thin layer of glaciofluvial outwash and sand which was deposited during the first pre-Reid glaciation (Nelson and Jackson, 2003; Jackson, 2005; Froese and Jackson, 2005a,b,c). Intermediate-level terraces are exposed mainly upstream of the mouth of Quartz Creek, whereas low-level terraces occur on several closely spaced levels, primarily downstream of the mouth of Ruby Creek (Fig. 1). Modern river gravel is within, and immediately adjacent to, the active channel of the Indian River.

PRELIMINARY STRATIGRAPHIC FRAMEWORK

Field examinations from this study resulted in the construction of a preliminary stratigraphic framework for the Indian River placer deposits. Recent field work refined the general stratigraphy by providing age constraints to units formerly grouped into the high and intermediate-level terraces. The lithostratigraphic classification scheme is divided into the following six divisions:

- modern (Holocene) alluvial channels, alluvial fans, tributary gulches and colluvium;
- modern (Holocene) low-level buried and/or abandoned alluvial terraces;
- early to late Pleistocene intermediate-level buried abandoned terraces and alluvial fans;
- early Pleistocene (pre-Reid) glaciofluvial gravel sequences;
- Pliocene high-level alluvial terraces (White Channel Gravel); and
- technogenic (tailings) deposits.

Sampling and recent mining has shown that all of these contain placer gold (Mukhanov, 2007). Table 1 is a list of sections studied from 2005 to 2007, with their proposed lithostratigraphic classifications. Site locations for the studied sections are labeled in Figure 1.

DESCRIPTION AND INTERPRETATION OF SELECTED KEY STRATIGRAPHIC SECTIONS

The following sites were chosen for description as they have expanded the Indian River stratigraphy and provided new age control on high and intermediate-level landforms. A more comprehensive description of each of the lithostratigraphic units will be prepared as part of an Open File report to be released in 2009.

Section BM06-01 (Table 1, Figs. 1 and 3) consists of an alluvial fan sequence (lithostratigraphic classification 3 — early to late Pleistocene alluvial fan) unconformably overlying a White Channel Gravel terrace (lithostratigraphic classification 5 — Pliocene high-level alluvial terrace). Radiocarbon dates indicate the lower, probably WCG gravel sequence, is >45 000 years old (Beta 226704; bottom inset, Fig. 3), whereas the upper gravel is overlain by organic pods dated at 43 550 ± 2000 years (Beta 216446; top inset, Fig. 3). These pods were once a continuous layer, but were subjected to intense cryoturbation after deposition. An overlying silt unit dated at 33 970 ± 610 years (Beta 216447) is flat-lying which indicates cessation of the cryoturbation, likely due to a warming period. These dates suggest a late Pleistocene age for the alluvial fan sequence. Gold values from gravel samples in the lower WCG unit varied from 461.5 mg/m^3 on bedrock, upwards to 213 mg/m^3 (samples WL06-65 and WL06-64, respectively, Appendix 1). A nearby transect from the bedrock contact through to the upper alluvial fan varied from 138.3 to 42.5 mg/m^3 (samples WL06-67 and WL06-66, respectively, Appendix 1). Generally, the gold grain size decreased vertically from the bedrock surface and laterally from the modern valley centre.

Table 1. *Lithostratigraphic classifications for sections studied in the Indian River area from 2005 to 2007.*

Section number	Drainage	Preliminary lithostratigraphic classification	Owner	Latitude	Longitude
GM05-01	Indian River	1	Gimlex Enterprises	63° 44' 6"	139° 4' 43"
TAM05-01	Indian River	1	Tamarack Mining	63° 38' 15"	138° 51' 50"
BM05-02	Indian River	5	Boulder Mining	63° 45' 56"	139° 20' 55"
KF05-01	Indian River	3	Kim Ferguson	63° 45' 15"	139° 7' 39"
BM05-01	Indian River	5	Boulder Mining	63° 45' 53"	139° 21' 9"
DM05-01	Indian River	2	Dave McBurney	63° 47' 22"	139° 29' 4"
BM06-02	Indian River	3	Boulder Mining	63° 45' 42"	139° 14' 23"
BM06-01	Indian River	3,5	Boulder Mining	63° 45' 53"	139° 21' 3"
BM06-03	Indian River	5	Boulder Mining	63° 45' 48"	139° 19' 59"
BM06-04	Indian River	1	Boulder Mining	63° 45' 44"	139° 14' 31"
BM06-05	Indian River	5	Boulder Mining	63° 44' 21"	139° 4' 14"
BM06-05	Indian River	4	Boulder Mining	63° 44' 21"	139° 4' 20"
BM06-06	Indian River	5	Boulder Mining	63° 44' 12"	139° 3' 31"
BM06-07	Indian River	3	Boulder Mining	63° 44' 2"	139° 3' 12"
BM06-08	Indian River	5	Boulder Mining	63° 43' 53"	139° 2' 39"
BM06-09	Indian River	5	Boulder Mining	63° 43' 40"	139° 2' 3"
BM06-10	Indian River	1	Boulder Mining	63° 44' 42"	139° 9' 1"
BM06-11	Indian River	1	Boulder Mining	63° 46' 6"	139° 17' 8"
BM06-12	Indian River	1	Boulder Mining	63° 46' 4"	139° 17' 18"
BM06-13	Indian River	1	Boulder Mining	63° 46' 15"	139° 17' 38"
BM06-14	Indian River	4	Boulder Mining	63° 36' 35"	138° 46' 25"
BM06-15	Indian River	4	Boulder Mining	63° 36' 29"	138° 47' 28"
BM06-16	Diversion Creek	2	Boulder Mining	63° 45' 10"	139° 16' 46"
CA06-01	Indian River	5	Cam Arkenstall	63° 46' 3"	139° 21' 31"
DM06-01	Indian River	2	Dave McBurney	63° 47' 25"	139° 29' 0"
DM06-02	Indian River	2	Dave McBurney	63° 47' 21"	139° 29' 3"
DM06-03	Indian River	5	Dave McBurney	63° 46' 57"	139° 30' 49"
GM06-01	Indian River	1	Gimlex Enterprises	63° 43' 53"	139° 4' 42"
KF06-01	Indian River/Quartz Creek	3	Kim Ferguson	63° 45' 7"	139° 8' 18"
KF06-02	Quartz Creek	6	Lavona McNeil/Kim Ferguson	63° 45' 13"	139° 7' 26"
KF07-01	Indian River/Quartz Creek	3	Kim Ferguson	63° 45' 8"	139° 7' 57"
FAV07-01	Quartz Creek	5	Favron	63° 47' 10"	139° 6' 27"
CG07-01	Indian River	2	Colonial Gold	63° 36' 39"	138° 45' 44"
CG07-02	Indian River	2	Colonial Gold	63° 36' 43"	138° 45' 52"
CG07-03	Indian River	2	Colonial Gold	63° 36' 39"	138° 45' 45"
FGR07-01	Eureka Creek	5	Fine Gold Resources	63° 35' 58"	138° 50' 41"
FGR07-02	Eureka Creek	5	Fine Gold Resources	63° 35' 57"	138° 50' 33"
KS07-01	Indian River	3	Klondike Star	63° 41' 32"	138° 59' 33"
KS07-02	Indian River	3	Klondike Star	63° 41' 30"	138° 59' 23"
KS07-03	Indian River	3	Klondike Star	63° 41' 27"	138° 59' 18"
ABER07-01	Australia/Wounded Moose creeks	2	Tamarack	63° 37' 0"	138° 41' 59"
TAM07-01	Indian River	1	Tamarack	63° 36' 42"	138° 42' 55"
BM07-04	Indian River	4	Boulder Mining	63° 44' 21"	139° 4' 20"
BM07-05	Indian River	4	Boulder Mining	63° 44' 18"	139° 3' 40"
BM07-03	Indian River	4	Boulder Mining	63° 44' 18"	139° 4' 28"
BM07-02	Indian River	4	Boulder Mining	63° 44' 35"	139° 5' 19"
BM07-01	Indian River	6	Boulder Mining	63° 44' 42"	139° 8' 30"
BM07-06	Diversion Creek	1	Boulder Mining	63° 45' 10"	139° 16' 47"
GM07-01	Indian River	1	Gimlex Enterprises	63° 43' 43"	139° 4' 11"
AUS07-01	Australia Creek	2	open	63° 36' 48"	138° 40' 20"

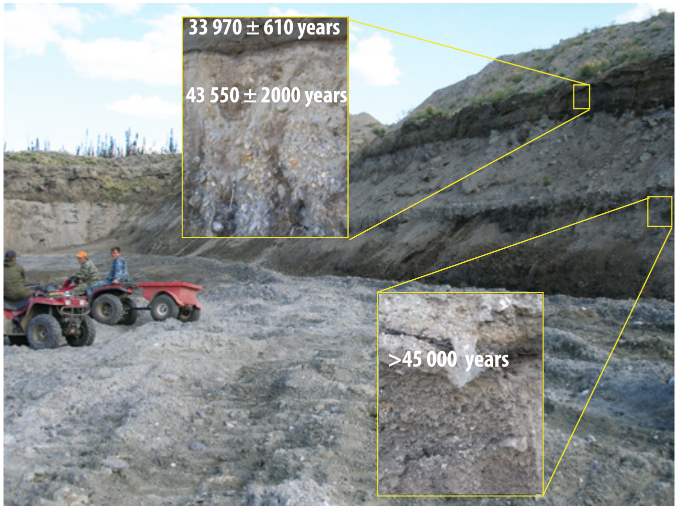

Figure 3. *Section BM06-01 at Boulder Mining's main pit on the Indian River. Exposure consists of an alluvial fan sequence (lithostratigraphic classification 3; inset top) unconformably overlying a White Channel Gravel terrace (lithostratigraphic classification 5; inset bottom).*

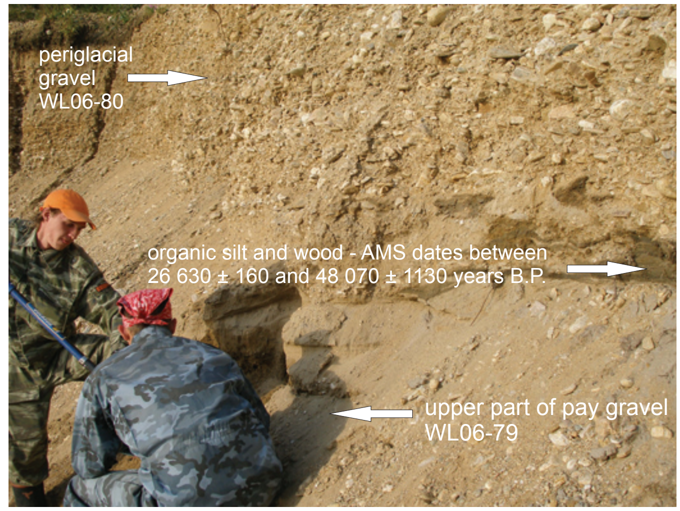

Figure 5. *Ilya Mukhanov and Vitalii Bryukhov taking a sample from section KF06-01 on Indian River at Quartz Creek. Exposure consists of an early to late Pleistocene intermediate-level buried terrace (lithostratigraphic classification 3).*

Section BM06-02 (Table 1, Figs. 1 and 4) is interpreted to belong to lithostratigraphic classification 3 — an early to late Pleistocene alluvial fan. Geochemical analyses show that a volcanic ash located in the upper third of this alluvial fan sequence near Ophir Creek is the 80 Pup tephra, which is approximately 140 000 years old (J. Westgate, pers. comm., 2008). A lower tephra has been identified as the Ophir Creek tephra which has not been dated. Several of these fans appear to cut the high-level terraces and they are in turn truncated by the modern Indian River. According to the tephra chronology, these fans likely have a periglacial origin coincident with the end of the marine isotope stage 6 cold period (Reid glaciation). Coarse gravel from this alluvial fan contained fine gold, less than 0.25 mm in size (Appendix 1, sample WL06-63). This fan has not been surficially mapped (Froese and Jackson, 2005c) as it has no significant surficial expression and is not discernable on air photos.

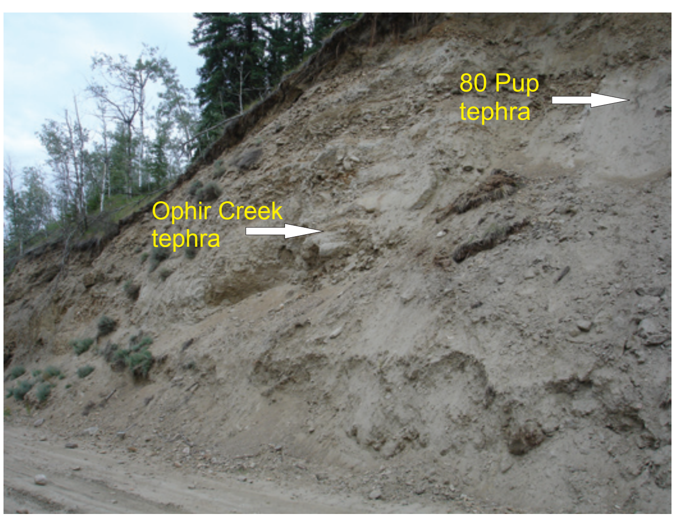

Figure 4. *Section BM06-02 consists of an exposure of early to late Pleistocene alluvial fan sediments (lithostratigraphic classification 3).*

Section KF06-01 (Table 1, Figs. 1 and 5) is interpreted to belong to lithostratigraphic classification 3, an early to late Pleistocene intermediate-level buried terrace. This terrace consists of quartz-rich gravel that is overlain by locally derived, angular gravel of possible periglacial origin (sample WL06-80, Appendix 1). Organic-rich silt and wood from the contact between the two units yielded AMS radiocarbon dates of 26 630 ± 160 years (Beta 226703); 27 760± 170 years (Beta 226702); 33 960 ± 290 years (Beta 226701) and 48 070 ± 1130 years (Beta 227956). Inter-stratification of the lower organic-rich silt and upper pay gravel (sample WL06-79, Appendix 1) indicates that they are of a similar age and were likely deposited during periglacial conditions at the onset of the Late Wisconsinan-McConnell glaciation. This terrace is surficially mapped as colluvium (Froese and Jackson, 2005c) as it has little surface expression. The underlying gold-bearing gravel is only exposed through mining cuts.

GOLD GRAIN SIZE DISTRIBUTION AND CONCENTRATION

Selected samples that contained gold grains were grouped into the preliminary lithostratigraphic classifications in order to discern any notable trends. These are shown in Appendix 1 which notes the grain size distribution of gold, the mass of gold in each size fraction, and the overall concentration of gold in the sample (calculated from the total gravel sample volume, not shown).

DISCUSSION

The small number of samples and relatively low sample volumes, restrict us from making comprehensive statements about the grain size distribution and concentration in the various deposits sampled, however, the results of this study may be used as a preliminary indicator. Previous mining activity and past research has shown that the Indian River placer deposits contain mainly fine-grained gold (LeBarge, 2007). However, in areas where the placer gold deposit contains coarser gold than average, the amount and size of gold in our samples is likely less representative of the overall deposit (Lunev, 1967; Lunev and Osovetskiy, 1987).

Our gold grain size distribution results indicate that in the majority of samples, 30% of the total concentration consists of gold less than 0.25 mm in size. In several samples, the concentration of gold less than 0.1 mm in size may be up to 50% of the total concentration. Samples which were taken from early Pleistocene (pre-Reid) glaciofluvial deposits (lithostratigraphic classification 4) have very fine gold with up to 80% of their total concentration represented in the -0.25 mm size fraction. Gold greater than 1.0 mm in size was recovered in only a few samples, notably in lithostratigraphic classification 2 — modern low-level buried and/or abandoned alluvial terraces. Interestingly, this classification also had the highest average gold concentration of all the samples taken, which indicates that even a moderate amount of coarse gold in a sample can dramatically increase the grade of the overall sample. This theory would hold true at the larger deposit scale.

A coarsening-downstream trend was observed when examining gold grain size distribution of all the samples as a whole. This could indicate either a reversal in drainage, or a major influence of local bedrock sources. A local bedrock source would explain the presence of wire and angular gold found in some of the samples. There is no evidence in our study to date (*e.g.*, paleoflow data) to support a reversal in drainage, therefore we believe that there may be an unknown local lode gold source. In fact, the gold grain size and morphology data point to a possible undiscovered bedrock gold source somewhere on the Indian River downstream of the mouth of Ruby Creek.

Figure 6 shows the cumulative percent of gold finer than 0.25, 0.5 and 1 mm for each of the lithostratigraphic classifications calculated from the data presented in Appendix 1. However, some groupings of weights in different particle size fractions precluded their use in this Figure.

Table 2 was compiled from data in Appendix 1 and shows the average grade of gold lost if there is no recovery of -0.25 mm gold fraction, grouped by lithostratigraphic classification for selected samples.

For example, gold grain samples from lithostratigraphic classification 4 (column 1) had 93.2% of their weight on average fall into the -0.25 mm size fraction (column 2), and only 6.8% of their weight on average fall into the +0.25 mm size fraction (column 3). Since grade information is available from each sample (Appendix 1), an average grade was calculated for all grain sizes in all

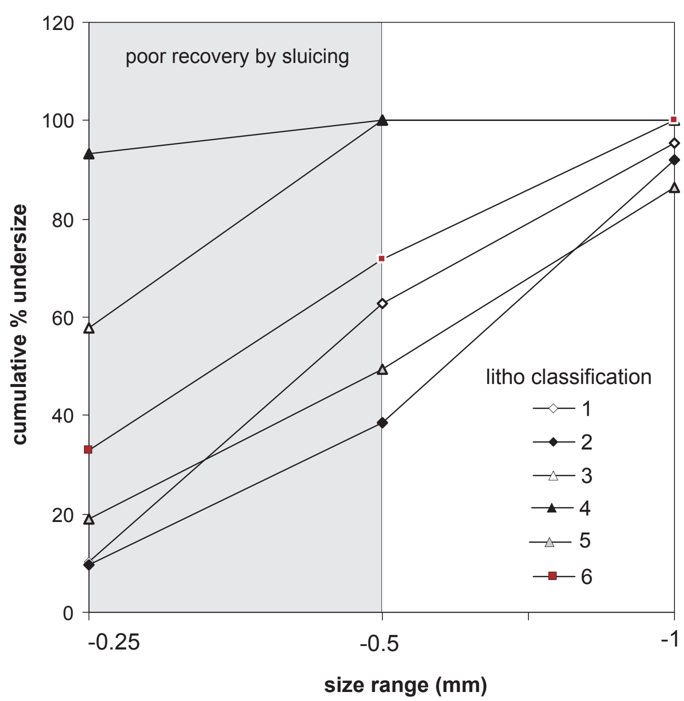

Figure 6. *Gold weight by grain size for different lithostratigraphic classifications, cumulative percent.*

Table 2. *Cumulative percent undersize gold and potentially recoverable gold by lithostratigraphic group in selected samples.*

Lithostratigraphic classification	Percentage of gold by weight, averaged over group:		Average grade of total samples in group, mg/m^3	Average grade of gold in:	
	-0.25 mm fraction	+0.25 mm fraction		+0.25 mm fraction, mg/m^3	-0.25 mm fraction (possible loss) mg/m^3
1	10.3	89.7	352	316	36
2	9.7	90.3	733	662	71
3	57.9	42.1	19	8	11
4	93.2	6.8	102	7	95
5	18.9	81.1	314	255	59
6	54.3	45.7	146	67	79

the samples in the group which had compatible weight and grain size ranges (102 mg/m — column 4). The average grade of only the +0.25 mm size in the group was then calculated (6.8% of 102 mg/m^3 = 7 mg/m^3 — column 5) followed by the average grade of gold in only the -0.25 mm size (102 mg/m^3 — 7 mg/m^3 = 95 mg/m^3 — column 6). The -0.25 mm size range is generally acknowledged to be difficult to recover by conventional gravity concentration (*e.g.*, Fricker 1984), however, an average of 95 mg/m^3 of gold were recovered in our samples from lithostratigraphic subdivision 4, which normally would be lost using conventional mining methods.

By the same method, it can be seen that lithostratigraphic classifications 3 and 6 are also low in recoverable gold, with 57.9 and 54.3% of their overall weights (respectively) falling into the -0.25 mm size fraction. Our data therefore show that Indian River placer deposits containing fine gold (*i.e.*, grains smaller that 0.25 mm) may require unconventional processing equipment and metallurgical expertise, which is discussed in the following sections.

IMPLICATIONS FOR GOLD RECOVERY

The study of gold recovery from placer deposits by gravity concentration methods is, in general, under studied. Most authors focus on the implications of sluice design for improving the recovery of ‘coarse’ gold (*e.g.*, Fricker, 1984), rather than investigating relationships between fine gold size and recovery. An evaluation of the performance of sluice boxes in Yukon is provided by Clarkson (1994), which focused on the recovery of gold larger than 0.2 mm, since gold of finer particle size was not believed to form an important resource. However, the results obtained in this study indicate a high proportion of fine gold in most samples and, consequently, the size distribution of fine gold could be of great importance when determining appropriate concentration techniques. For example, this might include using ‘enhanced G’ concentrators such as the Knelson concentrator to effectively recover finer gold particle sizes. ‘Enhanced G’ is a term used to describe gravity concentrators which effect particle separation in a high gravitational environment resulting from centrifugal action.

Although reliable data is difficult to obtain, there is a general consensus that sluice boxes are not efficient tools for the recovery of fine gold and if set up incorrectly, they are also inefficient across a wide range of grain size fractions. This applies not only to small-scale operations but also to large dredges (Fricker, 1984). The use of spiral concentrators for this study permitted collection of fine gold more efficiently than commercially operated gold recovery circuits (Lunev and Osovetskiy, 1987; Mukhanov, 2007) and therefore provides a better indication of the potential recoverable resource. Although some small studies have investigated the relative performances of traditional gravity concentrators versus the Knelson concentrator (*e.g.*, Apling *et al.*, 1997), overall, there is an absence of comprehensive studies comparing the efficiency of different gravity concentration devices to each other. In addition, dedicated studies of placer gold grain shape are important because of the effect on hindered settling velocity and hence recovery (Chapman and Houseley, 1996; Houseley *et al.*, 1997). This is particularly important in the context of recovery of placer gold where fluvial transport equates to progressive flattening. As placers evolve, the gold becomes more difficult to recover even though there is no change in the mass of the gold particles.

METALLURGICAL CONSIDERATIONS

Figure 6 shows that in the majority of samples, gold less than 0.25 mm in size comprises over 30% of the total concentration, while in a number of the gravel samples, the concentration of gold less than 0.1 mm in size reaches up to 50%. Samples which were taken from glaciofluvial deposits had gold in the -0.25 mm size fraction representing 80% of the total concentration. While few studies have been conducted elsewhere in the world, comprehensive metallurgical studies on placer gold of this size range have been conducted in Russia (Lunev and Osovetskiy, 1987; Mukhanov, 2007; Naumov *et al.,* 1992; Patyk-Kara and Lalerov 1997; and Shilo, 2002). These studies demonstrated that only a small fraction of placer gold is recovered by conventional sluicing. This approach has important consequences for the design of future recovery plants and the potential for profitable amounts of gold remaining in tailings (lithostratigraphic classification 6), both in the study area and throughout the Klondike.

SUMMARY OF RESULTS AND IMPLICATIONS FOR FUTURE EXPLORATION

A preliminary stratigraphic framework of six lithostratigraphic subdivisions is proposed into which all exposures in the study area are classified. Stratigraphic settings are complex and in some cases landforms are comprised of multiple overlapping lithostratigraphic assemblages. Radiocarbon dating and tephra chronology, relative stratigraphic position, geomorphic expression and preliminary gold geochemical analyses have all been used to refine this preliminary framework.

All stratigraphic subdivisions sampled contained placer gold, however, some are more problematic than others for placer exploration. Notably, since gold-bearing low-level and intermediate-level terraces may exist in areas mapped as colluvium or alluvial fans, alternate methods of exploration should be used to detect these deposits. For example, electrical resistivity followed by drilling or test-pitting would be a logical approach. In addition, detailed surficial geological mapping could identify reaches within the drainage to focus exploration.

Morphological variations in gold along the course of the Indian River strongly suggest progressive influx of material from currently undiscovered bedrock sources. Our data also suggests the possible existence of an undiscovered bedrock gold source on Indian River downstream of the mouth of Ruby Creek.

Fine gold was shown to occur throughout the different deposits and, in some cases, comprised the majority of the gold in the sample. This gold is currently not recovered by conventional sluicing operations and could represent a considerable resource. Further study of the gold size and distribution within placer mine tailings as well as within fine-grained, low-grade gravel deposits throughout the Indian River and Klondike district would quickly identify the potential of this resource. It is recommended that this evaluation occurs in conjunction with suitable metallurgical test work.

FUTURE WORK

Tools available to further refine the stratigraphic framework include detailed gold geochemical analyses of placer gold (and potential bedrock sources) as well as lithological provenance studies. These are currently in progress and a comprehensive report which synthesizes all new results is due to be released in 2009. Ongoing fieldwork examining the stratigraphy in context with the preliminary lithostratigraphic framework is also planned. This will include additional sampling of potential placer and bedrock gold sources.

Using the methods outlined in this study to assess gold particle-size analysis in both virgin and previously worked areas has potential for identifying easily accessible, large gold resources. This methodology could also be applied advantageously in other Yukon placer districts.

ACKNOWLEDGEMENTS

Local placer miners are thanked for unfettered access to their properties, especially Pete Risby, Boulder Mining, Klondike Star, Cam Arkenstall, Gimlex Enterprises Ltd., Dave McBurney and Kim Ferguson.

The academic staff at the Faculty of Geology at Perm State University, especially Dr. B. Osovetskiy and Dr. B. Lunev, are thanked for their insightful theories and the university technicians are thanked for their diligent and detailed work. Dr. Jim Mortensen is thanked for his advice on the local bedrock history. Dr. Duane Froese is thanked for his interesting discussions on the Quaternary history. We are grateful to Dr. John Westgate at the University of Toronto for the preliminary tephrochronology results. Jeff Van Zandvoort is thanked for his assistance in the compilation of figures and tables. This paper benefited greatly from a thorough review by Jeff Bond, Yukon Geological Survey.

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APPENDIX 1. DISTRIBUTION OF PLACER GOLD WEIGHT BY GRAIN SIZE AND TOTAL PLACER GOLD CONCENTRATION IN SELECTED SAMPLES, GROUPED BY LITHOSTRATIGRAPHIC CLASSIFICATION

<table>
<tr><th rowspan="2">Sample numbers</th><th rowspan="2">Lithostratigraphic classification</th><th colspan="5">Weight by grain-size classification, mg</th><th rowspan="2">Calculated concentration, mg/m^3</th></tr>
<tr><th>-0.1 mm</th><th>0.1 to 0.25 mm</th><th>0.25 to 0.50 mm</th><th>0.5 to 1.0 mm</th><th>+1 mm</th></tr>
<tr><td>WL06-71</td><td>1</td><td colspan="3">0.9</td><td>0</td><td>0</td><td>31.6</td></tr>
<tr><td>WL06-91</td><td>1</td><td colspan="2">0.75</td><td>7.05</td><td>0</td><td>0</td><td>421.6</td></tr>
<tr><td>WL06-92</td><td>1</td><td colspan="2">0.9</td><td>1.3</td><td>1.35</td><td>0</td><td>295.8</td></tr>
<tr><td>WL06-103</td><td>1</td><td colspan="2">0.4</td><td>2.2</td><td>5.85</td><td>0</td><td>384.1</td></tr>
<tr><td>WL06-104</td><td>1</td><td colspan="3">0.25</td><td>0</td><td>0</td><td>11.9</td></tr>
<tr><td>WL06-105</td><td>1</td><td colspan="3">0.3</td><td>0</td><td>0</td><td>11.1</td></tr>
<tr><td>WL06-106</td><td>1</td><td colspan="2">0.35</td><td colspan="2">0.65</td><td>0</td><td>66.7</td></tr>
<tr><td>WL07-120</td><td>1</td><td>0.07</td><td>0.1</td><td>0.46</td><td>0.46</td><td>0</td><td>49.5</td></tr>
<tr><td>WL07-139</td><td>1</td><td>0.18</td><td>0.68</td><td>0.17</td><td>0</td><td>0</td><td>85.8</td></tr>
<tr><td>WL07-140</td><td>1</td><td>0.11</td><td>0.42</td><td>7.28</td><td>3.77</td><td>1.57</td><td>876.7</td></tr>
<tr><td>WL06-85</td><td>2</td><td colspan="2">0.75</td><td>1</td><td>0</td><td>0</td><td>83.3</td></tr>
<tr><td>WL06-87</td><td>2</td><td colspan="2">4.95</td><td>15</td><td>20.2</td><td>4.4</td><td>2475</td></tr>
<tr><td>WL06-88</td><td>2</td><td colspan="2">3.9</td><td>10.05</td><td>22.9</td><td>4.2</td><td>2052.5</td></tr>
<tr><td>WL06-102</td><td>2</td><td>0.05</td><td>0</td><td>0</td><td>0</td><td>0</td><td>2.5</td></tr>
<tr><td>WL06-108</td><td>2</td><td colspan="3">1.65</td><td>5</td><td>0</td><td>369.4</td></tr>
<tr><td>WL07-138</td><td>2</td><td>0</td><td>0.22</td><td>4.79</td><td>14.44</td><td>0</td><td>1215.6</td></tr>
<tr><td>WL07-143</td><td>2</td><td>0.12</td><td>0.16</td><td>0</td><td>0</td><td>0</td><td>14</td></tr>
<tr><td>WL07-144</td><td>2</td><td>0</td><td>0.12</td><td>0</td><td>0</td><td>0</td><td>8.6</td></tr>
<tr><td>WL07-145</td><td>2</td><td colspan="2">0.16</td><td>0</td><td>0</td><td>0</td><td>11.4</td></tr>
<tr><td>WL06-63</td><td>3</td><td>0.025</td><td>0.025</td><td>0</td><td>0</td><td>0</td><td>1.85</td></tr>
<tr><td>WL06-66</td><td>3</td><td colspan="2">0.55</td><td>0.3</td><td>0</td><td>0</td><td>42.5</td></tr>
<tr><td>WL06-76</td><td>3</td><td colspan="2">0.05</td><td>0</td><td>0</td><td>0</td><td>2.6</td></tr>
<tr><td>WL06-79</td><td>3</td><td colspan="3">0.2</td><td>0</td><td>0</td><td>16.7</td></tr>
<tr><td>WL06-80</td><td>3</td><td colspan="2">0.25</td><td>0</td><td>0</td><td>0</td><td>13.2</td></tr>
<tr><td>WL06-84</td><td>3</td><td colspan="3">0.25</td><td>0</td><td>0</td><td>13.2</td></tr>
<tr><td>WL07-131</td><td>3</td><td>0</td><td>0.17</td><td>0.53</td><td>0</td><td>0</td><td>46.7</td></tr>
<tr><td>WL07-132</td><td>3</td><td colspan="2">0.07</td><td>0</td><td>0</td><td>0</td><td>5</td></tr>
<tr><td>WL06- 74</td><td>4</td><td colspan="2">11.45</td><td>0.7</td><td>0</td><td>0</td><td>450</td></tr>
<tr><td>WL06-122</td><td>4</td><td colspan="3">0.25</td><td>0</td><td>0</td><td>11.9</td></tr>
<tr><td>WL06-123</td><td>4</td><td colspan="3">0.25</td><td>0</td><td>0</td><td>11.1</td></tr>
<tr><td>WL06-124</td><td>4</td><td colspan="3">0.2</td><td>0</td><td>0</td><td>9.5</td></tr>
<tr><td>WL07-126</td><td>4</td><td colspan="2">0.09</td><td>0</td><td>0</td><td>0</td><td>4.3</td></tr>
<tr><td>WL07-127</td><td>4</td><td colspan="2">0.1</td><td>0</td><td>0</td><td>0</td><td>6.3</td></tr>
<tr><td>WL07-128</td><td>4</td><td>0</td><td>0.2</td><td>0.19</td><td>0</td><td>0</td><td>26</td></tr>
<tr><td>WL07-129</td><td>4</td><td>0.2</td><td>0.1</td><td>0</td><td>0</td><td>0</td><td>21.4</td></tr>
<tr><td>WL06-64</td><td>5</td><td colspan="2">0.55</td><td>2.9</td><td>2.3</td><td>0</td><td>213</td></tr>
<tr><td>WL06-65</td><td>5</td><td colspan="2">2.7</td><td>4.3</td><td>2</td><td>0</td><td>461.5</td></tr>
<tr><td>WL06-67</td><td>5</td><td colspan="2">0.75</td><td>2.05</td><td>1.35</td><td>0</td><td>138.3</td></tr>
<tr><td>WL06-72</td><td>5</td><td colspan="3">0.55</td><td>0</td><td>0</td><td>30.6</td></tr>
<tr><td>WL06-73</td><td>5</td><td colspan="3">0.25</td><td>0</td><td>0</td><td>15.6</td></tr>
<tr><td>WL06-75</td><td>5</td><td>1.85</td><td>0.6</td><td>0.65</td><td>0</td><td>0</td><td>110.7</td></tr>
<tr><td>WL06-77</td><td>5</td><td colspan="2">0.6</td><td>0.7</td><td>0</td><td>0</td><td>65</td></tr>
<tr><td>WL06-78</td><td>5</td><td colspan="3">0.05</td><td>0</td><td>0</td><td>2.4</td></tr>
<tr><td>WL06-89</td><td>5</td><td colspan="2">3.9</td><td>5.05</td><td>9.7</td><td>0</td><td>981.6</td></tr>
</table>

<table>
<tr><th rowspan="2">Sample numbers</th><th rowspan="2">Lithostratigraphic classification</th><th colspan="5">Weight by grain-size classification, mg</th><th rowspan="2">Calculated concentration, mg/m^3</th></tr>
<tr><th>-0.1 mm</th><th>0.1 to 0.25 mm</th><th>0.25 to 0.50 mm</th><th>0.5 to 1.0 mm</th><th>+1 mm</th></tr>
<tr><td>WL06-95</td><td>5</td><td colspan="2">1.15</td><td>4.3</td><td>1.35</td><td>0</td><td>302.2</td></tr>
<tr><td>WL06-96</td><td>5</td><td colspan="2">0.15</td><td>0</td><td>0</td><td>0</td><td>6.7</td></tr>
<tr><td>WL06-97</td><td>5</td><td colspan="2">0.55</td><td>1</td><td>0</td><td>0</td><td>77.5</td></tr>
<tr><td>WL07-121</td><td>5</td><td>0.31</td><td>0.45</td><td>0</td><td>0</td><td>0</td><td>54.3</td></tr>
<tr><td>WL07-122</td><td>5</td><td>0.19</td><td>0.18</td><td>0</td><td>0</td><td>0</td><td>26.4</td></tr>
<tr><td>WL07-123</td><td>5</td><td>0.07</td><td>0.03</td><td>0</td><td>0</td><td>0</td><td>20.6</td></tr>
<tr><td>WL07-124</td><td>5</td><td>0.28</td><td>0.44</td><td>0.53</td><td>0</td><td>0</td><td>89.3</td></tr>
<tr><td>WL07-125</td><td>5</td><td>0</td><td>0.13</td><td>2.5</td><td>12.57</td><td>10.64</td><td>1845.7</td></tr>
<tr><td>WL07-136</td><td>5</td><td colspan="3">2.7</td><td>0</td><td>0</td><td>168.8</td></tr>
<tr><td>WL06-69</td><td>6</td><td colspan="3">1.2</td><td>0</td><td>0</td><td>47.1</td></tr>
<tr><td>WL06-70</td><td>6</td><td colspan="3">0.2</td><td>0</td><td>0</td><td>11.1</td></tr>
<tr><td>WL06-107</td><td>6</td><td>0</td><td>0.05</td><td>0</td><td>0</td><td>0</td><td>2.6</td></tr>
<tr><td>WL06-125</td><td>6</td><td colspan="2">0.45</td><td>0.3</td><td>0.7</td><td>0</td><td>322.2</td></tr>
<tr><td>WL07-135</td><td>6</td><td>1</td><td>1.51</td><td>1.2</td><td>0</td><td>0</td><td>185.5</td></tr>
<tr><td>WL07-137</td><td>6</td><td>0.17</td><td>0.63</td><td>0.42</td><td>0</td><td>0</td><td>81.3</td></tr>
<tr><td>WL07-148</td><td>6</td><td>0.44</td><td>0.84</td><td>0.28</td><td>1.38</td><td>0</td><td>140</td></tr>
<tr><td>WL06-90</td><td>bedrock</td><td>0</td><td>0.25</td><td></td><td>0</td><td>0</td><td>8.3</td></tr>
<tr><td>WL07-119</td><td>bedrock</td><td>0</td><td>0.34</td><td>1.69</td><td>0.92</td><td>0</td><td>184.4</td></tr>
<tr><td>WL07-130</td><td>bedrock</td><td>0</td><td>0.08</td><td>0.22</td><td>0</td><td>0</td><td>15.8</td></tr>
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