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AN EVALUATION OF THE GOLD RECOVERY OF PLACER DRILLS USING RADIOTRACERS (PART II)

By

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This work is dedicated to the men and women of the Yukon who endured hardship and deprivation in their quest for gold and who through their hard work, resourcefulness and determination have helped develop this remarkable frontier.

May they continue to mine and prosper.

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AN EVALUATION OF PLACER DRILLS USING RADIOTRACERS II

1 SUMMARY AND CONCLUSIONS

1.1 SUMMARY

In the last few years, eroding gold prices, increasing production costs and the depletion of reserves have resulted in a dramatic increase in the use of drilling to evaluate placer deposits. Accurate sampling and deposit evaluation would enable planning for cost-effective mining and reclamation. However, sampling placer gravels accurately is an extremely difficult task due to the nugget effect (inclusion or loss of a single particle of gold) and any errors are compounded by the small size of drill samples. Additional sampling errors result from contamination, splitting and fire assaying. More placer mine failures can be attributed directly to improper sampling and sample processing practises during property evaluation than to any other cause.

There is very little impartial, accurate information available to guide the selection of modern drills. Drillers and their equipment are often selected for their penetration rate or cost-per-foot rather than for sampling accuracy or gold recovery. A brief description of several types of drills including churn, auger, rotary tri-cone, normal circulation, Becker hammer, reverse circulation, down-the-hole hammer and Sonic drills is summarised in Section 6 from references.

Three solid auger drills, two types of fully cased normal circulation (N/C) drills and two types of reverse circulation (R/C) drills were evaluated under typical Yukon field conditions using radioactive placer gold as tracers (radiotracers). A frozen cylindrical core of compacted gravels containing four sizes (1.2-1.7, 0.60-0.84, 0.30-0.42 and 0.15-0.21 mm) (-10+14, -20+28, -35+48 and -65+100 mesh) of radiotracers was placed in 44 drill holes and the holes were redrilled. Hand held scintillometers were used to track gold losses during drilling, sample recovery and sample processing. Radiotracers lost due to spillage and blow-by around the collar (top) of the hole, and those trapped in drilling equipment (carry-over) were easily located. The results of these tests are summarised in following Table 1.

There was no significant difference between the recovery of the four sizes of gold particles with any of the fully cased normal circulation, reverse circulation or auger drills tested. Observations and down-hole scintillometer records indicate that the radiotracers did not follow the bit down the hole and were either carried out of the hole or forced onto the sides of the hole at or above the depth at which the radiotracer core was positioned.

TABLE 1a (metric)
A Comparison of Drill Performance

	CASED-NORMAL		REVERSE-CIRCU			-AUGER-DRILLS-			AUGER
Parameters	Rotary	Dual	Tri-Cone		DTH*	Large	Mid-sz	Smal	Average
	Tri-cone	DTH	Sma	Lg	Sma				
Bit Diameter mm	152	127	115	200	110	175	198	181	185
Rod/Auger Dia mm	114	114	89	194	95	140	178	143	154
Casing O/D mm	184	184	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Tracer Depth m**	24	11	17	5	13	3	5	9	6
No of Holes Traced	3	6	4	4	6	13	3	4	20
Prod/Drill/Shift m	31	33	50	60	47	24	21	17	21
Prod/Person/Shift	16	17	25	30	24	24	21	17	21
Penetratn Rate m/h									
Muck & Thawed Soil	11	16	23	N/A	19	15	24	11	17
Thawed Gravels	6	8	15	N/A	N/A	N/A	24	11	12
Frozen Gravels	N/A	N/A	N/A	N/A	18	5	12	4	7
Boulders	*^ 1	2	1	N/A	12	1	1	N/A	1
Bedrock	2	6	3	N/A	14	2	2	2	2
Avg Net Recovery %	75%	78%	25%	56%	38%	63%	87%	49%	66%
Theo Recovery***	100%	100%	100%	100%	100%	64%	81%	62%	69%
Avg/Theoretical %	75%	78%	25%	56%	38%	98%	108%	79%	96%
Highest Recovery %	84%	87%	82%	86%	88%	88%	97%	74%	86%
Lowest Recovery %	64%	66%	0%	11%	0%	31%	75%	30%	45%
Range of Recovery	20%	21%	82%	75%	88%	57%	22%	44%	41%
Spillage Losses	18%	11%	4%	N/A	16%	0%	0%	0%	0%
Carry-over losses	2%	5%	2%	>14%	14%	0%	0%	1%	0 %
Blow-by loss****	3%	0.4%	18%	N/A	1%	1%	1%	1%	1%
Remain in Hole***	3%	5%	51%	N/A	31%	36%	12%	49%	32%

Notes: *DTH was a down-the-hole hammer drill using a conventional cross-over system (Figure 8). The reverse circulation tri-cone drill holes did not have a sealed collar, and this caused excessive blow-by loss.

**The average tracer depth is the depth in metres at which the radiotracer core was placed in the hole. Occasionally the cores hung up above the bottom of the hole. However, down-hole scintillometer records indicated that these cores were pushed to the bottom by the drill rods.

***The theoretical recovery of auger drills is the ratio of the area of the augers over the area cut by the drill's bit. The remainder (100%-theoretical) would be expected to stay packed against the annulus of the hole. The net recoveries don't include losses due to spillage, blow-by and carry-over.

Notes: To Table 1 continued

****Blow-by losses are blown along the outside of the reverse circulation drill rods and end up around the collar of the hole. For normal circulation, blow-by refers the leakage around the swivel seal. In auger drilling, blow-by refers to tracers stuck just below the collar of the hole.

*^ When this fully cased rotary tri-cone drill encountered hard boulders it would try to break up the boulder by advancing its tri-cone drill bit. Occasionally this procedure was unsuccessful. In Atlin, one drill hole was stopped short while another was abandoned and restarted.

TABLE 1b (Imperial)
A Comparison of Drill Performance

	CASED-NORMAL		REVERSE-CIRCU			-AUGER-DRILLS-			AUGER
Parameters	Rotary	Dual	Tri-Cone		DTH*	Large	Mid-sz	Smal	Average
	Tri-cone	DTH	Sma	Lg	Sma				
Bit Diameter in	6.0	5.0	4.5	7.9	4.3	6.9	7.8	7.1	7.3
Rod/Auger Dia in	4.5	4.5	3.5	7.6	3.7	5.5	7.0	5.6	6.0
Casing O/D in	7.2	7.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Tracer Depth ft**	79	36	56	6	44	10	17	28	18
No of Holes Traced	3	6	4	4	6	13	3	4	20
Prd/Drill/Shift ft	102	108	164	197	154	79	69	56	68
Prod/Person/Shift	51	54	82	98	77	79	69	56	21
Penetratn Rate f/h									
Muck & Thawed Soil	37	54	75	N/A	62	49	79	34	54
Thawed Gravels	19	27	49	N/A	N/A	N/A	79	113	64
Frozen Gravels	N/A	N/A	N/A	N/A	59	16	39	13	23
Boulders	*^ 3	7	3	N/A	39	3	3	N/A	3
Bedrock	7	19	10	N/A	46	5	7	7	6
Avg Net Recovery %	75%	78%	25%	56%	38%	63%	87%	49%	66%
Theo Recovery***	100%	100%	100%	100%	100%	64%	81%	62%	69%
Avg/Theoretical %	75%	78%	25%	56%	38%	98%	108%	79%	96%
Highest Recovery %	84%	87%	82%	86%	88%	88%	97%	74%	86%
Lowest Recovery %	64%	66%	0%	11%	0%	31%	75%	30%	45%
Range of Recovery	20%	21%	82%	75%	88%	57%	22%	44%	41%
Spillage Losses	18%	11%	4%	N/A	16%	0%	0%	0%	0%
Carry-over losses	2%	5%	2%	>14%	14%	0%	0%	1%	0 %
Blow-by loss****	3%	0.4%	18%	N/A	1%	1%	1%	1%	1%
Remain in Hole***	3%	5%	51%	N/A	31%	36%	12%	49%	32%

In August 1994, Walsh (1995) tested a reverse circulation rotary tri-cone drill using tantalum visual tracers in Alaska. The tantalum test procedure was similar to that developed for radioactive gold except that two different sizes (1.2-2.4 & 0.6-1.2 mm) (-8+14 & -14+28 mesh) tantalum particles were used in each frozen core. The tantalum tracer distribution in the redrilled hole interval and subsequent hole intervals was recorded by visually observing the recovery of the tantalum tracers during panning. The tantalum tracers were not radioactive and it was much more difficult and/or impractical to locate tracers lost due to spillage, blow-by and those trapped in drilling or recovery equipment. It would also be extremely difficult to use and recover finer size tantalum tracers. Walsh's data are listed in Table 1 as the large (Lg) reverse-circulation tri-cone drill.

1.2 CONCLUSIONS - FULLY CASED NORMAL CIRCULATION DRILLS

There are several types of fully cased normal circulation drill systems used for evaluating alluvial gold-bearing gravels. The casing may be driven down with a pneumatic hammer (Atlin Schramm drill, section 8.1.1), diesel operated hammer (Becker hammer drill, section 6.7) or rotated and pulled down with a separate lower rotary table (Barber Dual Rotary, sections 6.6 & 8.1.2). Two normal circulation drilling systems were evaluated with radiotracers: a Schramm pneumatic hammered casing with an inner rotary tri-cone drill in Atlin; and a Barber Dual Rotary with a down-the-hole hammer at Fort Steele.

Three deep holes (average tracer depth of 24 m, 79 ft) and six shallower holes (11 m, 36 ft) were tested in the Atlin and Fort Steele mining districts of British Columbia. Net radiotracer recoveries (not including spillage, blow-by and carry-over losses) for both drills tested were relatively high (averages of 75-78%) and consistent (20-21% range of recovery). These high radiotracer recoveries occurred regardless of whether the frozen tracer cores were placed above, below or at the same elevation as the casing shoe.

Most of the relatively minor losses were due to spillage when water was encountered in the hole, as carry-over in the swivel of the dual rotary drill and as blow-by past a worn out seal in the swivel of the Atlin Schramm drill. Blow-by losses were reduced when the swivel "doughnut" seal was replaced. Sample spillage losses at Atlin were increased when high-density/high-viscosity drill cuttings slurries kept radioactive gold particles and other heavy mineral particles in suspension. Sample spillage and sample volumes were increased at Fort Steele when high pressure ground water was encountered in the gravel seams.

The two normal-circulation drilling systems were more expensive to operate than auger or reverse circulation drills and they drilled more slowly than reverse circulation drills. However, the two drills provided immediate and relatively accurate samples under very difficult, bouldery and deep drilling conditions.

The capital cost of the Barber dual rotary drill was higher than the Schramm used at Atlin but its lower rotary table allowed it to drill through boulders more quickly and easily. The dual rotary drill was able to keep its casing below the drill bit while drilling boulders and probably obtain more accurate samples. The lower rotary table also allowed the driller to change and pull his rods and casings more quickly.

1.3 CONCLUSIONS - REVERSE CIRCULATION DRILLS

There are several drilling systems utilising reverse circulation (R/C) and only two types (a rotary tri-cone with no seal at the collar and a down-the-hole hammer with a conventional cross-over system) were evaluated with radiotracers (Clarkson, 1993) and with tantalum tracers (Walsh, 1995). In the Cariboo, only four of the nine R/C rotary drill holes were tested with radiotracers due to caving of the unfrozen soils. In the Klondike, six holes which were drilled with a R/C down-the-hole hammer drill were tested with radiotracers. In Alaska, Walsh (1995) tested four holes with tantalum visual tracers.

The net radiotracer recoveries (not including spillage, blow-by and carry-over losses) for the three R/C drills were very low (averages of 25, 38 and 56%). In addition, their extreme range of net recoveries (from 0 to 88%) would make it very difficult to determine the grade of the drill sample with any precision. However, these reverse circulation drills provided immediate drill cutting samples which were suitable for determining the depths of various materials in the hole.

Water injection was generally required to keep the center sample recovery tube from plugging whenever moist or thawed gravel or muck was encountered. Water injection dramatically increased segregation, entrapment (carry-over) and spillage losses and made it very difficult to collect and contain the samples (Photo 10). The Alaskan reverse circulation drill probably reduced its potential spillage losses by piping its drill cuttings directly to the hopper of a gold recovery trommel/sluice system for immediate processing (Walsh 1995).

The erosive action of the high pressure air and water, which was used to flush the cuttings, increased the tendency for caving in the holes. This erosion also created a rough surface along the walls of the hole which helped trap an average of 31 to 51% of the radiotracers in the drill holes.

Even though surges of high pressure air and water were used to flush the long length of the sample recovery systems, many tracers remained trapped in the rotary head, hose, hose fittings and sampling cyclones. To remove these tracers, the cyclone and hose fittings had to be taken apart and cleaned (Photos 19 and 20). This contamination and carry-over of values would have created errors in estimated gold grades. The splitting cyclone used with the Klondike R/C drill was especially difficult to clean due to its many compartments (Photos 21 and 22). In addition, placer samples should not be split, especially from such a small diameter hole 110 mm (4.25 in) (refer to Figures 3 and 5).

Walsh (1995) noted that his tantalum tracers were also recovered from several intervals beyond the interval where the tracer core was added and as many as four holes beyond the hole in which the tracer core was introduced. Walsh's tracers were not radioactive and therefore he was unable to locate the mechanical traps within the drilling and/or recovery system which were the cause of these carry-overs.

The Klondike R/C drillers installed 3 m (10 ft) of casing and sealed the collar of their holes. These casings were required to promote effective reverse circulation of the drill cuttings and eliminate blow-by losses (Photo 18). In the Cariboo, the R/C drillers did not install casings at the collar and there was almost always a small geyser of blow-by around the collar of the hole (Photo 17). In the absence of a seal, blow-by sample losses were excessive (an average of 18%, almost equal to the recovery of the sampling system).

The Alaskan reverse circulation drill used a larger tri-cone bit (200 mm, 7.9 in diameter) and closely sized rods (194 mm, 7.6 diameter) to promote a seal between the drill rods and the wall of the hole. However, Walsh (1995) noted bad blow-by (poor collar seal) conditions occurred on two of the four holes he tested. He also noted that the ability of the Alaskan drill to recover his tantalum tracers seemed closely tied to the blow-by conditions of the drill.

The Klondike reverse-circulation down-the-hole hammer drill used a conventional compressed air cross-over system. Drill cuttings had to be forced outside the button bit and travel 1.3 m (4.3 ft) up and around the outside of the hammer to two small sample return ports in order to enter the center sample recovery tube (Figure 8). The conventional cross-over sample recovery arrangement may have reduced sample recovery and/or diluted the sample with additional material from the sides of the hole. Newer down-the-hole hammers such as the Digger or Samplex have sample ports right in the bit face and use a venturi vacuum which may increase and improve sample recovery.

During the testing period, the penetration rates for the reverse-circulation (R/C) drills were generally higher than for fully-cased normal-circulation or auger drills. The down-the-hole hammer drill used more compressed air than the rotary drill but was much faster than any other drill type in boulders and bedrock. However, plugging of the hammer was a concern in muck and thawed soils and its penetration in these materials was slower than the rotary tri-cone reverse circulation and almost the same speed as the auger drills. Each R/C drill was operated with two drillers and their production was twice that of any auger drill (which was operated with a single driller). The R/C drills were heavier and much more powerful than the auger drills and were thus able to drill deeper holes in much poorer (wet, thawed or caving) ground conditions. The Klondike R/C drill completed a drill program which had been aborted earlier by the mid-sized auger drill.

1.4 CONCLUSIONS - SOLID AUGER DRILLS

Three different auger drills were tested, at five sites in the Klondike. The average net recoveries of 64%, 81% and 62% (not including spillage or carry-over) of the three drills were very close to their expected (theoretical) recoveries. The auger drills had higher and more consistent recoveries (than the two types of R\C drills which were tested) and would be more suitable for determining the grade of a placer deposit in permafrost gravels. In addition, the auger drill holes were larger and would be less sensitive to errors caused by the nugget effect. Auger drill cuttings also provided information regarding the depths of various materials in the hole, however, it often took a few minutes for the cuttings to work their way up to surface.

The auger drills did **not** use a hammer, compressed air or water. The rotational screw action of the auger drills was less erosive and less likely to cave a potentially unstable drill hole than with reverse circulation drills. The augers left some of the drill cuttings compressed against the sides (or annulus) of the hole as the larger diameter bit cut its way down the hole. Some of this annulus may slough into the hole when the rods are pulled. This sloughing may dilute or contaminate samples if the rods are pulled between the sampling intervals. However, the drill holes were usually smooth walled and relatively stable even under moist and/or partially thawed conditions. The theoretical recovery of an auger drill is the ratio of the area cut by the bit over the area of the hole carried away by the augers.

There was rarely any carry-over of radiotracers when the auger flights were brushed thoroughly. Water is not used for drilling so the samples are much drier, easier to handle and have much lower spillage losses. Most of the holes were drilled to bedrock before the rods were pulled. A few holes were sampled by pulling and cleaning the augers at regular intervals of 1.5 m (5 ft). With interval sampling, between 0-3% of the gold values in a drill hole were carried over between samples.

In general, auger drills are less expensive to own and operate, have less weight and are easier to operate compared to R/C drills. Drilling is slower than with R/C drills, but usually only one driller is required. Due to their light weight, auger drills are limited to relatively shallow holes (30-50 m depending on the size of the drill) and to areas without many large, hard boulders.

1.5 GENERAL RECOMMENDATIONS

An experienced placer sampler/driller should be at the drill to collect and clearly identify the samples, record their volumes and make notes concerning the depths and geology of the hole and any variations in sample volumes. Efficient sample collection and processing systems should be in place before the drilling program begins to ensure that data will be available on a timely basis and allow the drill to be utilised efficiently. Instead of making complicated sample volume corrections in the field, it is preferable to measure sample volumes and note poor drilling conditions and nuggets on the drill hole location maps so that the deposit can be evaluated by an experienced placer geologist or engineer. Bulk samples may be required to calibrate evaluations based on drilling.

1.6 RECOMMENDATIONS - SOLID AUGER DRILLS

Solid auger drills are recommended to help evaluate placer gravels in permafrost gravels and similarly consolidated materials where boulders and wet or deep ground is not generally encountered. Their drill holes should be at least 150 mm (6 in) in diameter and preferably 200 mm (8 in) to reduce errors caused by the nugget effect.

The diameter of the augers should be maintained at 25 mm (1 in) smaller than the drill bit with regular welding maintenance. Unevenly worn augers will produce less consistent samples and are more likely stick in a hole. Small augers will pack too much of the sample against the sides of the hole. The rotational speed of the augers should be kept relatively low (10 to 20 rpm). Auger drills should be fitted with hydraulic leveling jacks and mounted on a Nodwell or similar wide-track vehicle to allow them to travel and drill on muskeg and in muddy areas.

The auger samples should be collected in a large flat pan similar to that in Photos 23 and 25. The samples should be shovelled into pails and kept in order of depth. Holes may be drilled to bedrock without pulling and cleaning the rods every 1.5 m (5 ft) if the gold values are known to be concentrated directly above bedrock. However, auger drill holes should occasionally be sampled in intervals (of 1.5 m or 5 ft) to check for variations in gold grades with depth. When the auger rods are pulled, their flights should be brushed and scraped thoroughly to remove the sample and reduce any potential contamination of gold carry-over.

Auger drill grade and volume calculations are based on the volume displaced by the auger flights and not on the volume displaced by its larger diameter bit.

Auger drills are limited to relatively shallow, frozen or consolidated gravels which do not contain many boulders.

1.7 RECOMMENDATIONS - NORMAL CIRCULATION DRILLS

Fully-cased normal-circulation drills should be used for thawed or unconsolidated placer gravels and for deep, wet, or bouldery ground. The casing shoe should be drilled or driven at least 1 m (3 ft) ahead of the drill bit when placer gravels are being sampled. If high pressure ground-water is encountered, the separation between the drill bit and casing shoe may have to be increased. The drill bit may have to be advanced below the casing shoe if hard boulders are encountered, however, this practice will probably produce poorer samples and should be avoided when practical.

To reduce spillage losses, the drill cuttings slurry should be piped directly to a gold recovery device. A less desirable alternative is to collect the slurry in large sealable rigid containers. Allow several minutes before attempting to decant water from the containers and check the overflow for evidence of solids. Sample bags are very susceptible to spillage and loss and are not recommended. Measure and record all sample volumes.

Fully-cased drill grade and volume calculations are based on the volume displaced by the casing shoe and not on the volume displaced by the smaller diameter bit.

A good seal must be maintained between the swivel and its casing and drill rods to avoid blow-by losses. To avoid carry-over losses and potential contamination, radiotracer tests should be performed to identify and help remove any gold traps in the drilling, sample recovery or gold recovery systems.

1.8 RECOMMENDATIONS - REVERSE CIRCULATION DRILLS

The three types of reverse circulation drills which were tested, two rotary tri-cones with no casing at the collar and a down-the-hole hammer with a conventional cross-over, are not recommended for sampling placer gravels in thawed or frozen ground. Without further radiotracer testing and modification of techniques, these two drill systems appear only to be suitable to determine the depths of various materials in the hole and the presence or absence of gold. The determination of grade with these drills is very problematic.

Losses due to blow-by can often be eliminated by installing 3-6 m (10-20 ft) of casing into the hole and sealing off the drill rods with a packing case. Carry-over losses from the sampling hose, fittings and cyclones could be reduced by redesigning the fittings and cyclones to eliminate the gold traps after testing with radiotracers. Otherwise, they would have to be completely disassembled and thoroughly washed between samples.

Other types of R/C drills such as the Digger down-the-hole hammer (Figure 8) should be tested with radiotracers.

1.9 RECOMMENDATIONS - SAMPLE PROCESSING

The total volume of the sample should be processed with equipment similar to that which would be used for full-scale recovery. A simple sampling sluice-box (Long Tom) can provide consistent high recoveries (97-100%) of gold particles at least as small as 0.15 mm (100 mesh). The Long Tom must be constructed with a washing hopper and fitted with medium weight expanded metal riffles and either unbacked Nomad matting or paper-box conveyer belting as described in Section 8.4. The Long Tom and matting must be thoroughly cleaned between samples. Careful hand panning and mercury amalgamation can be effective for recovering the gold from the Long Tom concentrates.

Many types of screening and gold recovery equipment have gold traps which can retain and release gold particles which contaminate samples. Most commercially available trommel and vibrating screens have traps around the edges of the screen cloth and around retainers. Ensure that all equipment used for sample processing can be easily and thoroughly washed and inspected for cleanliness.

To prevent accidental contamination (salting), sample processing equipment and containers must not be used for processing other concentrates and must not be located within 100 m (300 ft) of a concentrate upgrading, weighing or storage area. Placer samples must not be split or fire assayed. Once the gold particles have been removed from the heavy mineral concentrates (black sands), samples of these concentrates should be saved for analysis for other valuable minerals.

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President

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3 OBJECTIVES

The objectives of the Yukon Placer Drilling Research Program are:

1) to measure the performance of different types of drills in placer deposit evaluation by testing for gold recovery and general performance in frozen and thawed placer gravels under typical Yukon field conditions using radioactive gold particles as tracers, followed by statistical analysis of the resulting data; and

2) to describe the types of drills currently used and provide placer miners, drilling contractors and geologists with recommendations for effective drilling and sample processing during placer deposit evaluation programs.

4 RADIOTRACER TESTING TECHNOLOGY

Walsh (1985) was the first to research and develop the use of radioactive gold (Au198) as a tool in testing gold recovery systems and equipment. He has conducted several laboratory evaluations of gravity concentrators (Walsh 1986-1995). Clarkson (1990, 1991, 1993) developed field testing procedures using radioactivated gold as tracers to provide a statistically valid, rapid, simple, cost-effective and safe method of evaluating the gold recovery efficiency of virtually any device which recovers gold including sluiceboxes, jigs and drills. Radiotracer testing technology avoids both the high costs and the unpredictable error levels common when conventional testing procedures are applied to placer gold gravels.

When placer gold particles are placed in a nuclear reactor, some of their nuclei capture an extra neutron and form gold's radioactive isotope (Au198) which can be used as a tracer. Radioactive gold has a very short half-life of 2.69 days and rapidly disintegrates to normal background levels of radiation within a few weeks. This short half-life eliminates the long term storage problems normally associated with other radioactive materials. Placer gold is irradiated to very low levels for tracer testwork and is therefore entirely safe to work with. With their very short half-life, the radiotracers are useful for testing for only 10 to 14 days.

Radiotracers emit gamma and X-rays which are readily identified with a hand-held scintillometer. They can be located in a drill hole, on drill rods or bits, in sample recovery equipment and on the ground if spillage occurs. Sample preparation and analysis can be performed outdoors and in adverse field conditions without fear of radiotracer losses or sample contamination. To evaluate gold losses, the tracers which have been recovered in a sample are removed from the sample and counted.

(When a drill hole is salted with radioactive gold, the gravel samples and other gold particles are not affected by the radiation and are still useful for evaluating grades of virgin pay-gravel horizons.)

The easy detection of radiotracers eliminates the possibility of losses during sample preparation and evaluation procedures. Broken or ground up gold can be identified by its lower than average level of radioactivity. Radiotracers can easily be protected from intentional contamination because their possession and use is licensed and strictly controlled by regulatory agencies.

Radiotracer tests are very suitable for placer gold testwork because they have low standard errors which can be predicted before the testwork is undertaken. Unlike conventional sampling techniques which are influenced by the "nugget effect", the recovery or loss of any of a given number of radioactivated gold particles is best described with binomial probability theory. The standard errors from radiotracer tests can be estimated with the equation:

$$SE = \{(n*p*q)^{\wedge}0.5)/n,$$

where n is the total number of radiotracers added, p is the proportion recovered and q is the proportion lost. The true recovery is within one standard error of the recovery estimate (14 times out of 20) and almost always within two standard errors of the recovery estimate (19 times out of 20).

TABLE 2

Magnitude of Standard Errors for Increasing Numbers of Radiotracers at Selected Rates of Recovery

	Number of Tracers Added to Frozen Core					
Recovery	10	20	40	50	100	400
10%	9%	7%	5%	4%	3%	2%
20%	13%	9%	6%	6%	4%	2%
30%	14%	10%	7%	6%	5%	2%
40%	15%	11%	8%	7%	5%	2%
50%	16%	11%	8%	7%	5%	3%
60%	15%	11%	8%	7%	5%	2%
70%	14%	10%	7%	6%	5%	2%
80%	13%	9%	6%	6%	4%	2%
90%	9%	7%	5%	4%	3%	2%

Note: The standard error decreases as the number of tracers increases. The largest standard errors occur at 50% recovery.

5 FORMATION OF YUKON PLACER DEPOSITS

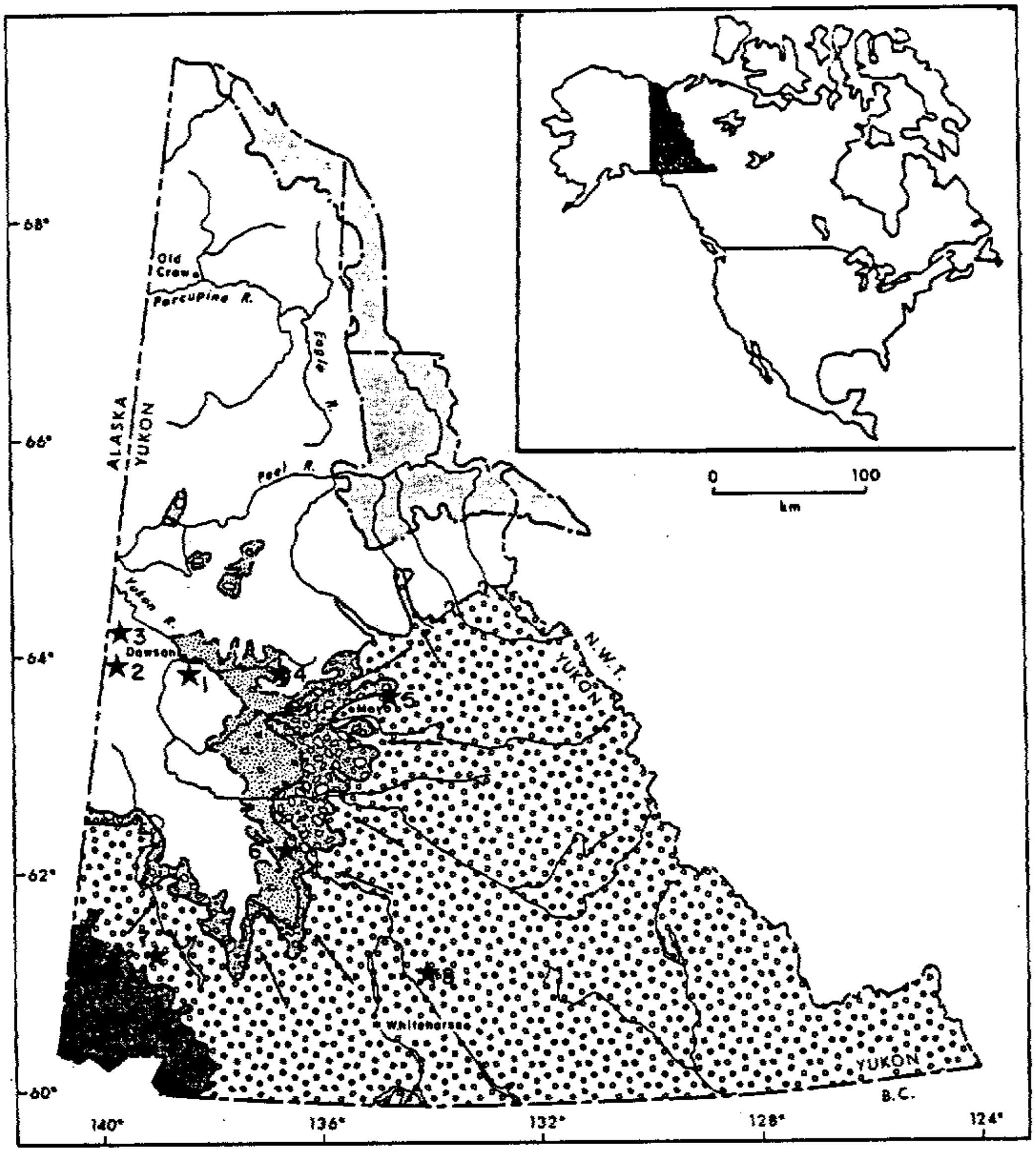
Placer deposits of the Yukon have been formed through the interaction of weathering and erosion processes over long periods of time. In general, the richest placer deposits occur where the formation processes have gone without interruption for the longest time. Important Yukon placer areas such as the Klondike, Sixty-mile and Forty-mile districts were formed in areas that were not glaciated during the Pleistocene period some 10,000 to 2 million years ago (Figure 1).

Glaciation interrupts the formation of placer deposits and may destroy deposits by scouring surficial gravels and the weathered bedrock surface. However, in some instances ice sheets override placer deposits leaving them buried beneath layers of till or glacial debris, while other deposits may be partially scoured and reworked by ice and melt-water streams. Yukon placer deposits buried or affected to some degree by glaciation are found in the Mayo, McQuesten, Clear Creek, Big Creek and Livingstone areas. Placer areas located within strongly glaciated regions usually have complicated glacial/stream environments such as those in the Burwash-Kluane district.

In the Yukon, economic placer gold deposits fall within three broad categories: residual, slope and alluvial (Figure 2). Residual deposits form from weathering of hard-rock sources and the residual accumulation of gold near those sources. The mechanical and chemical decay of the host rock results in the enrichment of the surface zone through the elimination of barren rock. Residual placers have been noted in the Klondike (Milner, 1972), Burwash, Dublin Gulch and Sixty Mile camps. Residual placers are generally small and not well concentrated.

Slope placer deposits (also known as elluvial deposits) are transitional between the residual and alluvial types. Slope deposits are usually found on hillsides forming a sheet-like mass below the hard-rock source. These deposits may slowly move downhill, allowing the lighter portions to be removed by rain-wash and wind. A rough stratification and/or concentration may develop and result in an economic deposit. Yukon examples of slope placers include the lower sections of some residual placers in the mining camps and districts listed above.

FIGURE 1
Glacial Limits and Major Mining Areas in the Yukon Territory
(from Morrison, 1986)



LEGEND

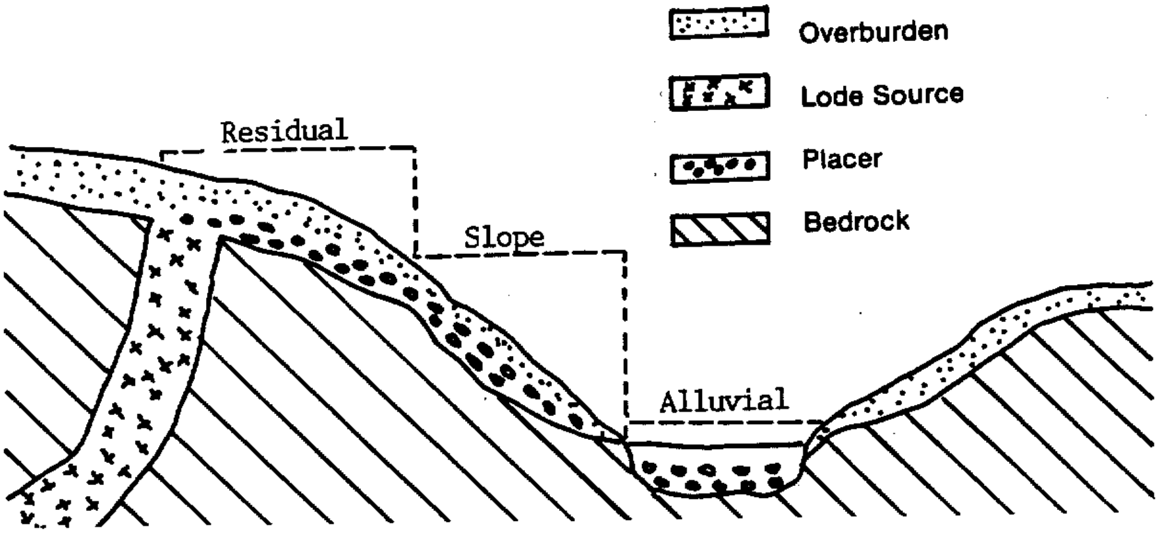
Glacial Limits
Cordilleran ice sheet
——— Limit of McConnell glaciation (Late Wisconsinan)
——— Limit of Reid glaciation (Illinoian?)
——— Limit of pre-Reid glaciation(s)
Laurentide ice sheet
—·— Limit of Hungry Creek (Buckland) glaciation (Late Wisconsinan?); and also the maximum Laurentide limit.
——→ General direction of ice movement

Unglaciated Terrain
☐ Undifferentiated nonglacial deposits

Glaciated Terrain
▨ McConnell glacial deposits
▨ Reid glacial deposits
▨ pre-Reid glacial deposits
☐ Hungry Creek or Buckland glacial deposits
■ Icefields, glaciers

MAJOR PLACER MINING AREAS ★
1-Klondike 2-Sixty-mile 3-Forty-mile 4-Clear Creek 5-Mayo 6-Big Creek
7-Burwash Creek 8-Livingston Creek

FIGURE 2
Residual, Slope and Alluvial Placer Deposits



Alluvial placer deposits (also known as stream deposits) are the most common and economically important type of placer deposit. Alluvial deposits are found where gold has been concentrated as a result of the action of flowing streams. Concentrations develop in response to changing conditions in the stream bed. Bedrock that forms natural riffles perpendicular to the water course or fractured and pitted bedrock are favourable for trapping gold particles. The insides of turns in a meandering stream or a decrease in the stream gradient may cause gold to be dropped out of the sediment load due to a reduction in stream velocity and its sediment carrying capacity.

Nuggets and smaller particles of placer gold found in alluvial deposits display a variety of textures and physical characteristics that are related to conditions in the stream and distance of transport. When near the hard rock source, the gold particles are usually rough, relatively large and often attached to quartz particles. With distance, the gold particles become smoother, more rounded, flatter and smaller.

Alluvial placer deposits have been subdivided into four categories: gulch, creek, river and bench. Gulch deposits are usually confined to small areas within minor drainages, commonly at the head of creeks, where a permanent stream may or may not exist. Gulch deposits tend to be thin, poorly sorted and discontinuous due to the steep gradient of the host stream. Gold found in gulch deposits tends to be coarse, concentrated on bedrock and is occasionally combined with quartz.

Creek deposits are the most important source of placer gold in the Yukon. Bonanza, Eldorado and Hunker Creeks, in the Klondike district, are among the richest creeks in the world. In a stable environment the formation of a creek deposit may be visualised as the continuously increasing concentration of gold particles along the stream bed as the processes of weathering and erosion evolve through time. Creek gravels become progressively more sorted and rounded as the landscape matures, and more resistant rocks and minerals such as quartz, garnet and gold remain in the stream. Less resistant materials are broken down and carried off by the water. Gold becomes concentrated in the lower gravels and extends into fractures and fissures penetrating into bedrock. In this situation, the upper bedrock also forms part of the creek deposit.

In nature, instability and change in stream environments are far more common than long term stability. Changing environments lead to complexity in the geometry and grade of the creek deposits that may be developed. Higher flows in stream may result in accelerated erosion and the reworking of older deposits. The resulting creek deposits may be far less homogeneous and continuous than the original. In unstable valleys, a false bottom (false bedrock) made up of slide rock or clay-rich material may be formed and a concentration of gold may develop above it, in the same way that a pay streak is formed above bedrock. Streams may meander or change course and the new stream bed may no longer coincide with the previous channel or pay streak. If a stream changes course and continues to deepen its new channel it may cut down through older creek deposits leaving remnants perched along its banks. Good examples of this are the White Channel deposits of the Klondike district which form prominent benches along Bonanza and Hunker Creeks.

The White Channel gravels of the Klondike are thought to have been deposited in the Pliocene 5 to 6 million years ago (Boyle, 1979) prior to the area being uplifted some 200 m (650 ft). The White Channel gravels are now found on wide benches bordering the present valleys at elevations 50 to 100 m (150 to 300 ft) above the valley floor (Boyle, 1979). Virtually all the gold in the present lower level valley bottoms has been reworked from the elevated alluvial placer deposits. Remnants of gravels similar to the White Channel gravels can be found as far west as the Sixty mile and as far east as Clear Creek.

River deposits are similar to creek deposits but usually contain lower grade concentrations of finer and flatter gold in well-rounded gravels (Robinson, 1980). River deposits, due to their low gradient and great width, can support large-scale mining ventures. The dredged Klondike River valley below Hunker Creek contained rich river deposits.

Aside from the deeper buried pay streaks, rivers may host flood deposits consisting of minute particles of gold that have been concentrated on the surface (or near the surface) of skim bars during periods of high water. Skim bars were mined on Yukon rivers prior to the Klondike Gold Rush in 1898 and are still being mined on some rivers (e.g. Stewart River). Although skim bars are very thin and localised, they can be fairly rich in gold values.

Placer deposits associated with glacial processes generally consist of glacial material reworked by stream processes. Glaciers usually destroy existing placers or bury the deposits with barren till. Very few, if any, glacial deposits, such as moraines and eskers, contain economic concentrations of gold. However, glacial streams have the power to sort, winnow and concentrate gold from unsorted gold-bearing glacial material. Reworked glacial deposits are found in the Tintina Trench, in the Burwash camp (Gladstone and Fourth of July Creeks), in Clear Creek and in the Mayo district. Placer deposits buried by glacial debris are found in the Livingstone Creek and Sidney Creek areas. In the Dezdeash area, placer deposits are found in the lee of hills, where they were largely protected from the northerly advancing glaciers. In addition to being buried by glacial debris, placer deposits can be buried by younger rocks, commonly volcanic rocks such as basalts (eg Atlin, BC).

6 PLACER DEPOSIT EVALUATION

6.1 HISTORY

Placer mining activity and placer deposit evaluation expertise peaked during the 1930's in association with the proliferation of efficient high-capacity bucket-line dredges. The churn drill was the primary tool used for property evaluation and reserve delineation. By the 1940's, most of the higher grade deposits had been mined out. Rising production costs against a fixed gold price forced an inevitable drop in world production. By the 1950's, exploration and new development were almost at a standstill.

In the Yukon, the Yukon Consolidated Gold Corporation (YCGC) was formed in 1923 to consolidate and manage the numerous dredge operations in the Klondike district. The company pioneered many innovative exploration and production techniques particularly suited to placer mining in permafrost terrain. YCGC conducted extensive churn drilling programs to locate and define reserves for future production. However, rising post-war production costs forced the company to close down in 1966.

In the late 1970's the sharp rise in gold prices caused a dramatic re-emergence of the Yukon's placer mining industry. While mechanised heavy equipment allowed the modern miners to process large volumes of placer gravels, the old evaluation techniques were considered to be too labour intensive and expensive to be economically viable. At the time there did not appear to be any modern methods or machines particularly suited to placer evaluation in permafrost. Many producers felt that evaluation costs could not be justified and relied instead on existing YCGC drill data, the extent of old workings and production-scale bulk testing to guide their mining operations.

In the last five years, eroding gold prices, increasing production costs and the depletion of reserves have renewed the interest in placer exploration and deposit evaluation in the Yukon. Most producers now realise that they cannot risk the high capital and operating costs required to start a new mine, or even continue production at an existing mine, without evaluation data. There has been a dramatic increase in the use of drilling, especially auger drilling, to evaluate and delineate placer deposits in the Yukon. An increasing number of Yukon placer miners have purchased drills and drilling services with varying degrees of success.

6.2 PLACER SAMPLING AND PROCESSING

One cannot over-emphasise the difficulties associated with sampling and evaluating placer deposits. More placer mine failures can be attributed directly to improper sample handling and processing practises during property evaluation than to any other reason. The investigation of a placer deposit should be made only by persons experienced in placer sampling. A bad sample is worse than no sample at all.

Placer gravels usually contain a very small number of gold particles in a given sample volume. The inclusion or loss of a single particle of gold (nugget effect) usually has a large impact on the estimated grade of the sample (Figure 3). These errors are further magnified when the incorrect grade from the sample is applied to a larger volume of material during the estimation of mine reserves. Other sampling problems include accidental or intentional contamination and the use of inappropriate sampling, sample processing and evaluation methods.

Large samples are more likely to be representative, especially if gold particles in the deposit are relatively coarse. However, the size of the sample must be balanced with the increased cost and difficulty of obtaining and processing large samples. In gold deposits with a high percentage of boulders it may not be practical to have a sample large enough to include the boulders. In this case the volume of the boulders must be estimated and factored into the sample volume calculations.

Placer gravel samples will swell when they are dug out of the ground and the "loose" volume will be 20 to 30% more than the "bank" or in-place volume. An allowance for this swell must be included in sample volume measurements. A simple procedure to estimate the amount of swell includes the following steps: dig a hole; measure the volume of loose gravel removed; line the hole with sealed polyethylene (plastic); then fill the hole with a measured amount of water. The swell of the gravel is equal to the loose volume of material removed from the hole divided by the volume of water required to fill the hole. In this procedure, bank volume and the volume of water required to fill the hole are the same.

Clifton (1969) indicates that "to ensure adequate representation, a field sample should be sufficiently large to contain at least 20 gold particles." This assumes an even distribution of uniform sized gold particles. In reality, gold particles are usually unevenly distributed within the gravels. While some more uniform placer deposits may be adequately assessed with a few samples, it may be impractical to evaluate a deposit with extremely erratic gold distributions regardless of how many samples are taken.

In unconsolidated placer deposits, the higher density gold particles are not bound to the remainder of the gravel sample and will tend to segregate (especially in the presence of water). Due to the limited number of gold particles and their tendency to segregate, splitting is not an acceptable practise and is fraught with error. Any analytical procedure such as geochemical methods or fire assays which rely on splitting the sample are also unacceptable. These methods will also tend to overestimate the value of the gravel by including chemically and physically bound gold in the analysis.

The total volume of each placer sample should be processed with equipment similar to that which would be used for full-scale recovery. In the Yukon, the sluicebox is the most popular full-scale gold recovery unit. Recent research using radiotracers (Clarkson, 1991) has proven that sluiceboxes operating under recommended parameters provide very high recoveries of gold particles coarser than 0.15 mm (100 mesh) at very high concentration ratios (in excess 20.000:1). Therefore placer samples are usually upgraded with a small testing sluice known a Long Tom followed by hand panning and amalgamation (see section 8.4 for detailed descriptions of each process).

If a large proportion of the gold particles are expected to be smaller than 0.15 mm (100 mesh), other gold recovery methods such as centrifuges or mercury amalgamation may have to be used. Jigs are not recommended for sample processing due to the difficulty and time involved in thoroughly cleaning the screens and ragging between each sample. Thorough cleaning of all sampling and processing equipment is required to prevent contamination of samples by gold particles entrapped while processing earlier samples, a problem known as carry-over

To prevent accidental salting, Long Toms or other drill sample processing equipment must not be used for processing concentrates from operating mines. Sample processing equipment must never be located in the same room or even within 100 m (330 ft) of a concentrate upgrading, weighing or storage area. Placer gold particles are usually among the only particles remaining in a receptacle which has not been thoroughly cleaned and will contaminate samples. Mechanical screens and testing sieves contain several pockets which can hold gold and contaminate samples.

Once the gold particles have been removed from the heavy mineral concentrates (black sands), samples of these concentrates should be saved for analysis for other valuable minerals including platinum, tin, tungsten and rare earth elements.

6.3 PLACER DRILLS

Drills are now commonly found at many Yukon placer mines and have the potential to greatly reduce the risks of placer mining by helping evaluate and delineate deposits. If the locations, quantities and values of the gold bearing gravels are accurately determined, placer miners will be able to plan for cost-effective mining and reclamation.

Miners may choose from several basic types of drills including the traditional churn drill, auger drills, normal circulation (rotary) drills, reverse circulation drills, Becker hammer drills, down-the-hole hammer drills and Sonic drills. In addition, there are many variations of each basic unit and at least as many manufacturers. Unfortunately there is very little impartial, accurate information available on cost and performance to guide the selection of modern drills. Drilling equipment is often selected for its penetration rate or cost-per-foot rather than for sampling accuracy or gold recovery. Most of the comparisons of drilling performance are based on personal preferences rather than on analytical data. A brief description of placer drilling methods has been included in this report to help determine which type of drill is most suitable for a particular application.

Sampling placer gravels accurately is an extremely difficult task and these difficulties are compounded by the relatively small size of drill samples. Placer drilling requires great care and attention to all aspects of drilling, sample recovery and sample processing. The overall accuracy is dependent on the drill's ability to recover a sample which accurately represents the grade of the ground drilled. The accuracy of the sample analysis depends on accurately measuring the sample's volume, recovering all the gold and accurately weighing the gold.

The smaller the drill hole the more sensitive the sample is to random errors caused by the inclusion or loss of grains of gold. Figure 3 displays the effect of a 1 mg particle of gold on the estimated grade of samples from 300 mm (1 ft) intervals from various drill hole diameters. The figure shows that larger holes, preferably 150 mm (6 in) diameter and larger, should be used whenever possible to sample placer gravels.

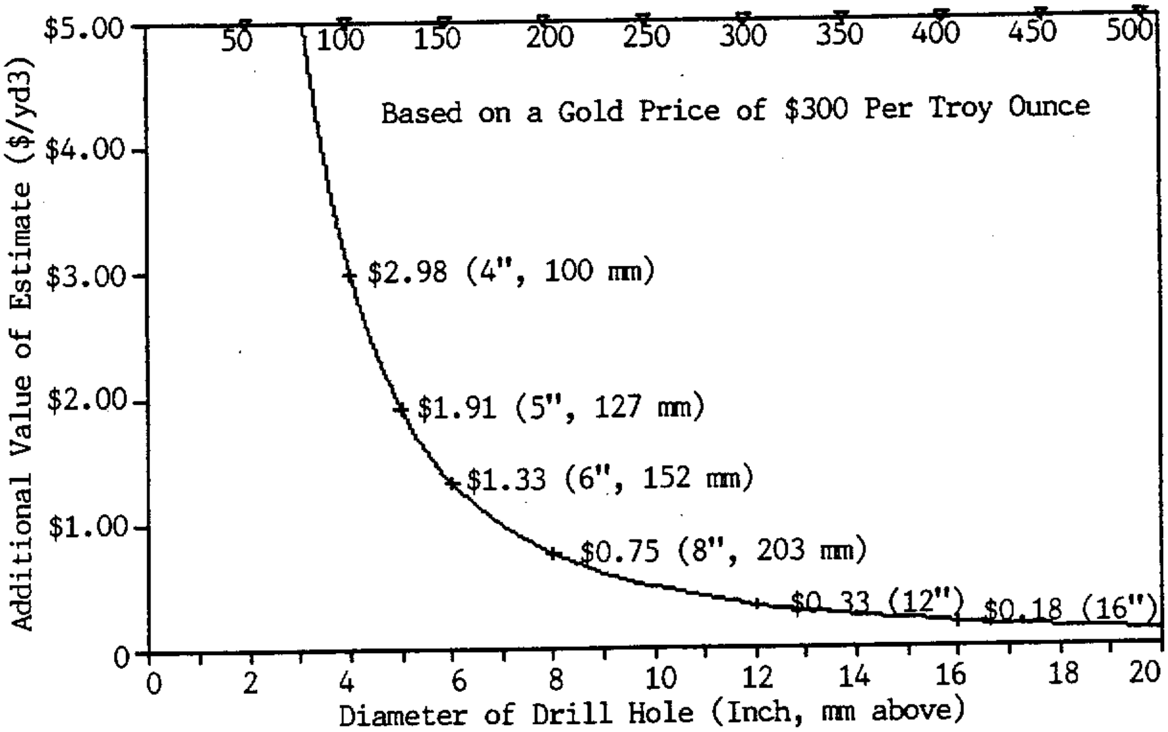
Modern reverse circulation drills produce large quantities of samples and can very quickly overwhelm anything but the most efficient and well organised sample collection and processing system. Sampling and processing systems should be in place prior to drilling activity to ensure that their results will be available on a timely basis so that the drill can be directed to new locations efficiently. When water is used in reverse circulation drilling systems or when water is encountered in the hole, the samples can be extremely difficult to collect and contain without spillage. Many large tubs and buckets will be required to contain the various samples. **High solids density (slimy) drill fluids generally cannot be decanted to remove excess water without losing fine gold particles.**

The success of a drill program relies heavily on the competence and cooperation of the driller. The purpose of a drill program is sample recovery and a good driller will care at least as much about the careful recovery of the sample as he does about the completion of the hole. The basic operation of a drill can be learned relatively easily but drilling competence is developed through extensive experience under a wide variety of drilling conditions. Unfortunately, competence or the lack thereof is often not apparent until after a drill program is well under way and it is too late to salvage the program. It is unwise to choose a driller strictly on the basis of lowest cost; it is better to ask for references and check with contacts in the industry. The operating condition of the drill and its regular maintenance should also be inspected.

An experienced placer sampler should be at the drill to collect and clearly identify the samples, record their volumes and make notes concerning the depths and geology of the hole. This person should also note any variations in the performance of the drill which may lead to any deviations in sample volumes or recovery. Potential variations include reduced penetration rates due to boulder horizons, clay zones, plugging and sticking or freezing of the bit. The occurrence of water or use of water for drilling purposes will also tend to reduce sample quality.

There is a danger in making sample-specific volume corrections when volumes retrieved are deficient, especially if the adjustments are complex or tend to increase estimated grades. It is preferable to note on the drill location maps and logs where all factors creating analysis problems were encountered such as wide variations in sample volumes, poor drilling conditions or large nuggets. This allows an experienced placer geologist or engineer to apply corrections on the basis of the layout of the deposit and on comparison to bulk tests or previous mining. Complex sample volume corrections can often further confuse the interpretation of the geology and the estimation of gold values.

FIGURE 3
Sensitivity of Drill Hole Size
(Effect of a 1 mg Gold Particle on the Value Estimate)

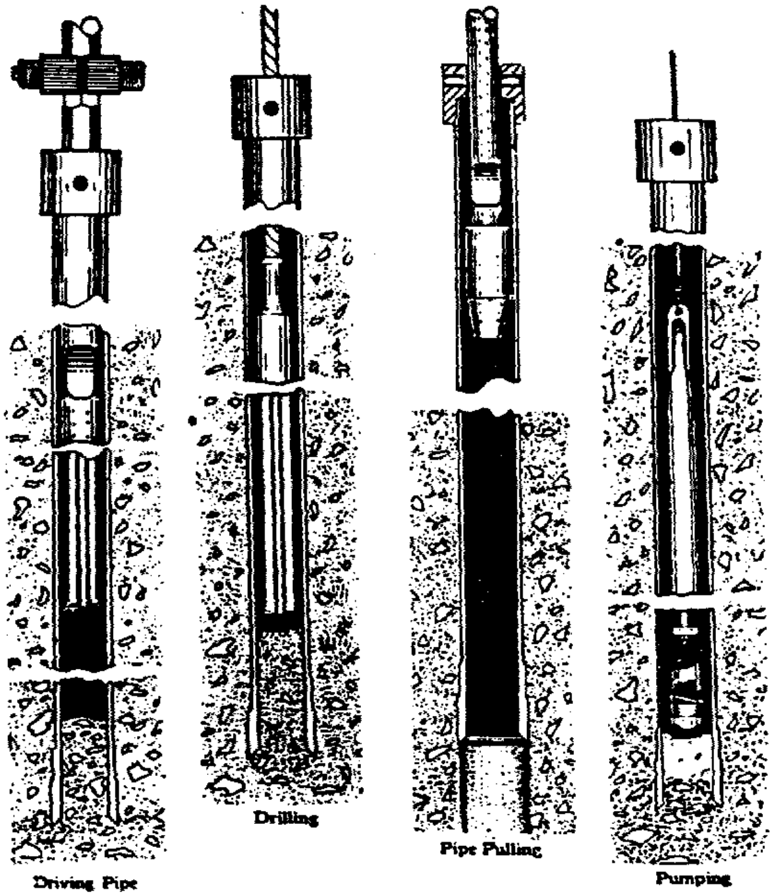


6.4 CHURN DRILLS

The churn drill is the oldest drilling equipment adapted to placer evaluation. The first churn drills were hand operated and included the Banka, Empire and Ward drills. These drills were very portable but extremely labour intensive and very slow. Later mechanised versions of the churn drill included the lightweight Hillman Airplane drill and the American made Keystone drill. These were followed by the Koehring Speedstar, Bucyrus Erie and Loomis churn drills. These relatively newer (1940-1950's) and larger drills required less labour and could drill deeper holes with larger diameter casings. However, they were still relatively slow and had difficulties drilling through boulders.

In unfrozen ground, the churn drill drives a casing into the ground ahead of the drill bit in order to obtain a relatively undisturbed sample core (Figure 4). A drive shoe on the bottom of the casing provides a cutting edge and forces the gravels into the casing as it is driven down. Inside the casing, a chisel bit connected to a rope or wire line is dropped repeatedly onto the core of gravels to break it up and prepare it for removal. Water (if not already present) is added to the hole and a bailer is dropped to the bottom of the hole to remove the sample sludge. The bailer is a cylinder with a one way check valve on the bottom which allows the sludge to enter. After a loaded bailer is hoisted out of the drill casing, its contents are washed out into a mud box and the bailing process is repeated until all the sludge is removed from the hole. The process of driving the casing, drilling the core and bailing the sample continues for each sample interval until bedrock or the bottom of the pay gravel horizon is reached.

FIGURE 4
Churn Placer Drilling Operations
(Harrison, 1954)



To avoid contamination of the sample, the drillers tried to avoid drilling and bailing below the casing and usually left a 50 to 75 mm (2 to 3 in) plug of sample above the casing shoe. However, whenever boulders were encountered in a hole, the drill bit would hammer below the casing shoe and try to break the rock so that further drilling could continue. Deficient (small) samples resulted from rocks partially blocking the drive shoe or from tight ground which moved down with the casing and forced the gravels outside of the casing. Pressure from ground water could also force excess material in from below the casing. The drill cuttings were slurried to allow recovery with the bailer and higher density particles such as gold may have been carried down the hole either to salt the lower portions or be lost.

Wolff (1969) reported that it was very difficult to drive and pull casings in frozen ground and as a consequence almost all frozen ground was drilled and sampled without casings. However, casings were often installed at the thawed collar of the hole to prevent seepage water from entering the hole. With open holes (not fully cased), a smaller sample was obtained and caution had to be exercised to keep the bit from sticking in the hole. Two of the most serious problems encountered were sloughing from recently thawed soils and sticking of the drill tools due to ice or frozen muck on the sides of the hole. Upon completion of the hole, the varying volumes of the hole intervals were measured using a water measurement technique described in detail by Wolff (1969).

The effective diameter of the drive shoe determined the area of the gravel cut as the casing was driven into the ground. When each sample interval was completed, the volume of sample obtained by drilling was compared to the theoretical (calculated) volume. Actual sample volumes were normally lower than theoretical volumes and various correction factors were often applied either to specific samples or on a deposit-wide basis. Both Wells (1969) and Colp (1982) indicate that the adjusted value given to a placer deposit should be based on the specialised experience of a placer engineer rather than on the rigid application of any particular formula.

Blakestad (1982) states that churn drilling can be expected to proceed at a rate of 1.2 to 2.4 m/h (4 to 8 ft/h) of operation and would average approximately 9 m (30 ft) per shift including moving and set-up time. Experienced churn drill operators are very difficult to find, however older churn drills are still available and may be suitable for very small placer mines or mines in developing countries where labour costs are low.

6.5 SOLID AUGER DRILLS

The most important applications of solid auger drills for placer sampling are in permafrost gravels or in dry or semi-dry clays where the wall of the hole is consolidated and prevented from caving by the frost or dry clay. Auger drills are very popular in the Yukon due to their low capital and operating costs, ease of operation and relatively rapid penetration rates in permafrost gravels.

A solid auger's drill rods are made of solid steel bar which has steel flights welded in a helical path around it (Photo 27). There is no hammer action and neither air nor water are used to remove cuttings from the hole. Penetration is achieved by down pressure and rotation of the bit. The rotational screw action of the auger flights brings drill cuttings to the surface where they are collected in a shallow steel pan located around the collar of the hole (Photo 23 and 25). Some of the drill sample is left compressed against the sides (or annulus) of the holes as the larger diameter bit cuts it way down the hole. A variety of drill bits are used including a hard-faced, fish-tail bit for clays and frozen organic muck and a fish-tail modified with the inclusion of tungsten carbide buttons (Photo 24) for frozen gravels or bedrock.

Sampling is conducted continuously or by interval. For continuous sampling, the auger rods are drilled through to bedrock or the bottom of the pay gravel horizon, the rotation is stopped and the rods are removed and brushed clean. The total sample is collected in a large shallow pan surrounding the collar of the hole. The sample is comprised of material which comes up the augers during drilling as well as the material cleaned from the augers when they are pulled out of the hole. Continuous samples are taken when it is assumed that the gold values are located in only one interval (e.g. directly above bedrock) or when there may be caving or sloughing in the hole.

With interval sampling the procedure is the same as in continuous sampling except that the augers are pulled and cleaned for each desired interval. Some operators prefer interval cleaning to help determine the various depths of the gold values. However, even in consolidated ground the removal of the drill rods usually disturbs the gravels which are normally compressed around the annulus of the hole. It follows that more contamination and sample loss should be anticipated with interval sampling. The volume of all samples (interval or continuous) should be measured and they should be kept in order of depth prior to processing.

Unlike normal and reverse circulation drills, auger drills do not provide instant samples. However, variations in the sound and vibration of the drill help determine the depths at which soil changes occur, moments before different material arrives on the auger flights. Auger drills are usually relatively light-weight drills that can be easily mounted on Nodwell or similar wide-track all-terrain vehicles. However this light weight and lack of power restricts their application to relatively shallow holes with few large, hard boulders.

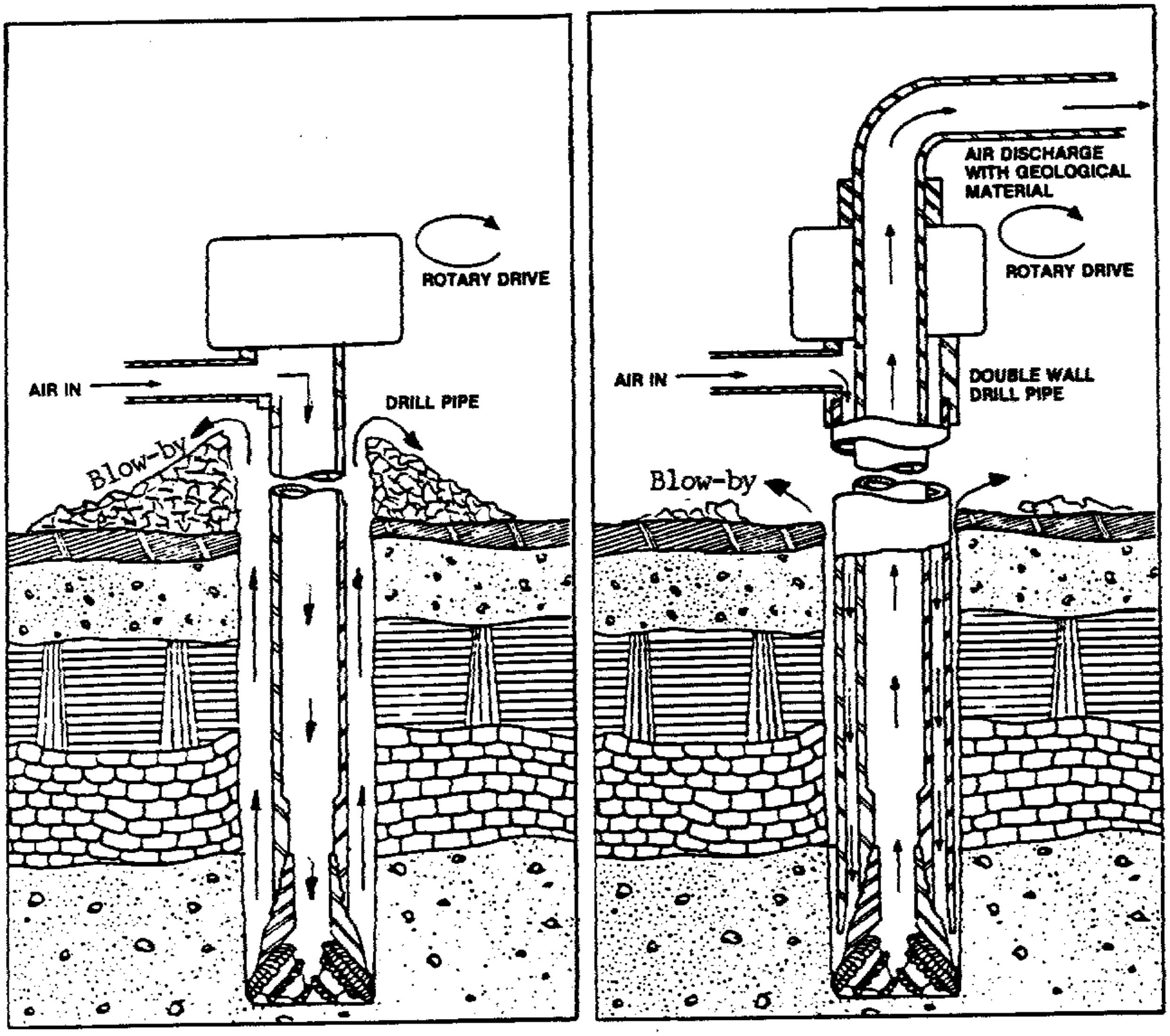
Many authors including MacDonald (1983) and McDonald (1990) consider that auger drilling is too risky to use for final evaluation. However, auger drills are commonly used successfully by many operators and geologists in the Yukon for exactly that purpose.

6.6 NORMAL CIRCULATION

In normal circulation drilling without casing, the drill cuttings are carried up between the hole walls and the outside of the single-tube drill rods along with the compressed air and/or water or mud which is used to flush the cuttings away from the face of the drill bit (Figure 5). The drill cuttings which return to surface are usually deposited in a pile around the collar (top) of the hole. The potential for the drill cuttings to be caught in sticky material or in voids on the sides of the hole and for caved material to dilute the cuttings makes this method of drilling generally unacceptable for the evaluation of gold grades in a placer deposit. The presence or addition of water further aggravates these sample contamination and loss problems by increasing the segregation and carry-over of gold values. However, normal circulation drills without casings may still be suitable for determining the depth to bedrock, assessing the geology and determining the presence or absence of gold.

When a casing is drilled or driven in conjunction with normal circulation drilling, sample loss and dilution is usually reduced. The drill cuttings can also be directed through a hose to a sampling cyclone for more convenient and complete retrieval. It is almost always faster to drill with the bit below the casing shoe and many fully cased drilling systems must occasionally drill ahead of the casing to penetrate hard boulders. However, whenever drilling is conducted below the casing there is no control over the amount of sample that is drawn into or blown outside the casing, and sampling accuracy suffers dramatically. Allowances must be made to reflect the resulting variations in sample volumes and sampling accuracy when the value of the gravels are estimated.

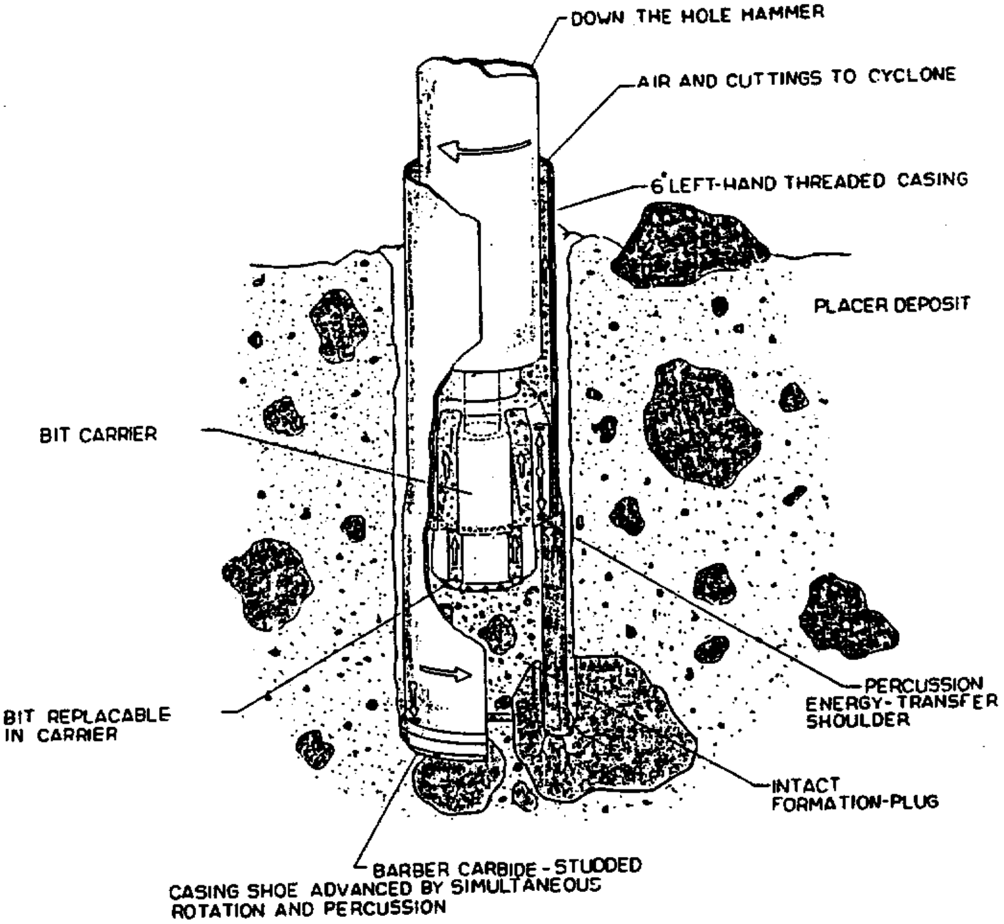
FIGURE 5
Normal and Reverse Circulation Rotary Drills



A relatively recent development to overcome these problems, the Barber DR Placer Sampling System, (now Foremost Industries of Calgary) was developed using an integral casing (Figure 6). The impact energy from the down-the-hole hammer bit is transferred to the casing shoe through a shoulder which keeps the casing well ahead of the bit. The plug that remains behind the casing helps to reduce contamination and maintain uniform sample volumes. The casing is advanced through simultaneous rotation and percussion.

The long length of the sample discharge system may result in the contamination of succeeding samples by mixing gold particles from previous samples (carry-over). Every effort, therefore, should be made to identify and eliminate gold traps in the sampling system. All hoses and sample cyclones should also be flushed and cleaned out thoroughly between each sampling interval.

FIGURE 6
Barber DR Placer Sampling System

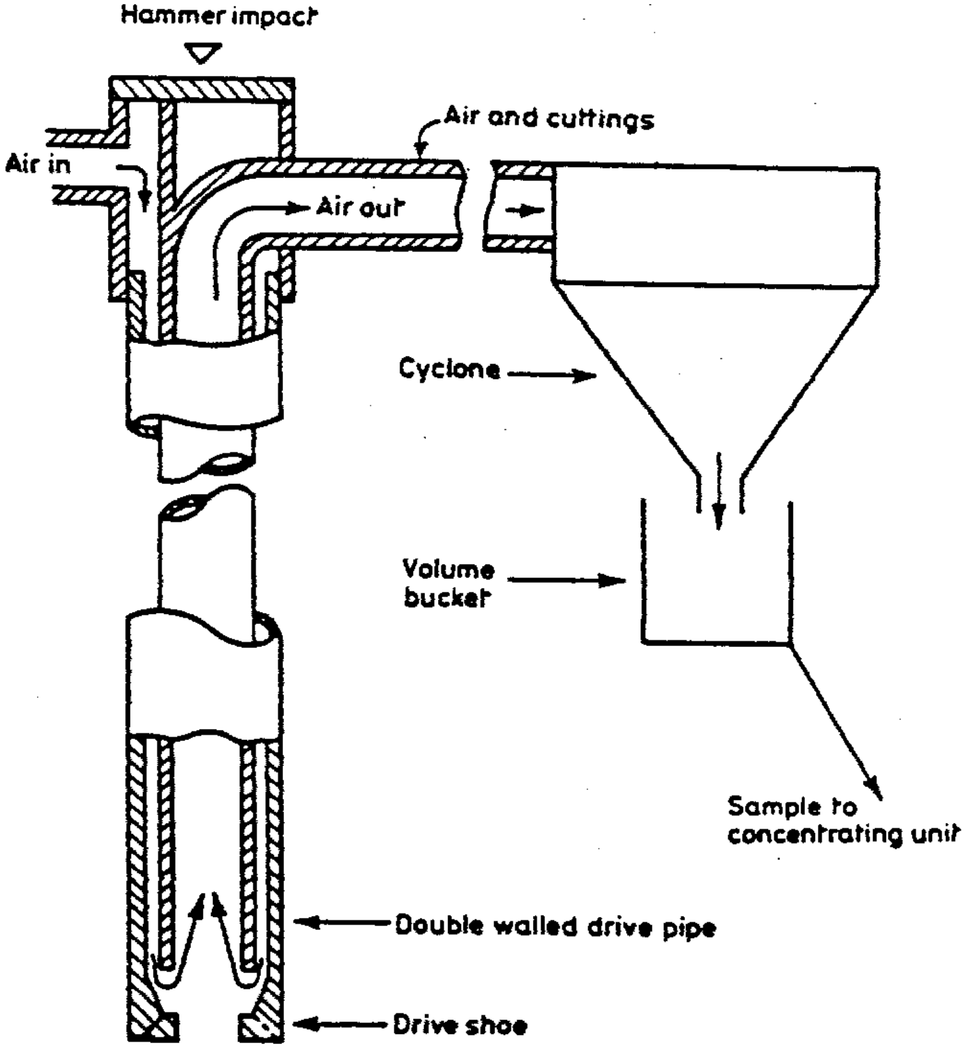


6.7 BECKER HAMMER DRILLS

The Becker hammer drill concept was adapted from pile driving and has been successful in drilling shallow placer deposits including the offshore deposits at Nome, Alaska. Even though it is slower and has a shallow drilling limit when compared to more modern reverse circulation drills, it has been reported to drill between 5 and 10 times faster than a churn drill (Richardson, 1992).

A double wall drive pipe is driven into the ground by a diesel-operated pile hammer delivering 95 blows/min at 7,600 ft-lbs/blow. The drive shoe on the bottom of the outer pipe is designed to break up the soils and force them inside the inner pipe (Figure 7). Compressed air is sent down the annular opening in the double walled pipe and transports broken material to surface through the inner pipe at an air speed of approximately 5000 ft/min (reverse circulation). The manufacturer indicates that the large inner pipe can transport material up to 75 mm (3 in) in size and provides an instant sample of the material at the sampling cyclone. When drilling below the water table it is necessary to use water for the drilling fluid, instead of air.

FIGURE 7
Becker Hammer Drills



The Becker hammer drills and cases the hole in the same operation. Only the outer pipe takes impact during the hammering cycle and it is not rotated. When it is unable to hammer through large hard boulders, the Becker hammer can use a hydraulically driven rotary tri-cone bit. The drive pipe then acts as an overburden casing. Hydraulics operate all other functions including truck levelling, raising the mast and handling the casings. On completion of the hole, the casing is withdrawn by a puller system comprised of two 50 ton hydraulic cylinders operating tapered slips that grip the casing. It is the pulling capacity of these rams which limits the depth penetration of the Becker hammer system.

The Becker hammer drill can drill at angles up to 45 degrees but is faster with vertical holes. Richardson (1992) states that "it is effective to a depth of 140 feet and has been used to 340 feet. Depending on the formation, an auxiliary compressor may have to be used when drilling below 130 ft. A crew of two men can normally operate a Becker drill but they must be well trained in its use." The Becker drill has three standard drive pipes with outside diameters of 140 mm (5.5 in), 168 mm (6.625 in) and 228 mm (9 in).

The Becker hammer drilling process minimises grinding of the cuttings. It can produce good samples because the casing shoe remains at the bottom of the hole and is sealed against the overburden with a plug of material between it and the inner transport pipe. However, the sample volumes should be measured because rocks may block the shoe and interfere with sample recovery.

The long length of the sample discharge system may result in the contamination of succeeding samples by mixing gold particles from previous samples (carry-over). Every effort, therefore, should be made to identify and eliminate gold traps in the sampling system. All hoses and sample cyclones should also be flushed and cleaned out thoroughly between each sampling interval.

6.8 REVERSE CIRCULATION

Dual tube reverse circulation drilling (also known as R/C or center sample recovery) is commonly used for placer evaluation (Figures 5 and 7). This drill system uses a double wall drill pipe and a variety of potential bit types using compressed air and/or water to flush drill cuttings away from the bit face and to carry the cuttings to surface. When equipped with a down-the-hole hammer (Figure 8) the compressed air is also used to power the hammer. Air is sent down the annular space between the outer and center tubing to the bit face where it picks up cuttings and carries them up the center tube to the surface.

To be effective, there must be sufficient air velocity in the inner tube (1200 to 1500 m/min [4000 to 5000 ft/min]) to carry coarse gold particles to the surface. The size of the inner tube must be matched to the drill bit to ensure that it is large enough to carry the anticipated volume and coarseness of the drill cuttings to surface. The collar of the hole must be sealed so that cuttings are not forced up outside of the rods to land on the ground near the collar of the hole as blow-by losses. A seal on the collar of the hole is usually accomplished by drilling or driving at least 3 to 6 m (10 to 20 ft) of casing at the collar (top) of the drill hole and sealing the top of the casing against the drill rods.

Reverse circulation allows an almost immediate examination of the drill cuttings from the face of the bit. It is used in the Becker hammer drill and many other non-coring drills. The samples return to surface through the center tube and are directed through a swivel head and hose to a cyclone (Figure 7). The long length of the sample discharge system may result in the contamination of succeeding samples by mixing gold particles from previous samples (carry-over). Every effort, therefore, should be made to identify and eliminate gold traps in the sampling system. All hoses and sample cyclones should also be flushed and cleaned out thoroughly between each sampling interval.

6.9 DOWN-THE-HOLE HAMMER DRILLS

Down-the-hole (or in-the-hole) hammer drills use a hammer which is operated directly above the drill bit with compressed air supplied through sealed drill rods. They can be used on almost any rotary drill rig after adding the necessary air compressor capacity. They are used in hard to medium hard formations (such as permafrost gravels, bouldery ground or in rock) where they have much faster penetration rates and drill straighter holes than most other conventional drilling systems. Down-the-hole hammer drills are not suitable for soft materials, especially wet clays, and may plug up if drilling in these materials is attempted. Their effectiveness is reduced in water.

Down-the-hole hammers are bottom-hole tools that transmit the rapid impacting action directly to the bit without losing any percussive force through the string of drill rods (as in other hammer drills). The spent compressed air is used to continually flush the cuttings from the bit face and to lift the cuttings up the hole. An adequate air supply is essential to their operation and to lift the cuttings out of the hole. Velocities of 1200 to 1500 m/min (4000 to 5000 ft/min) are required.

A rotational speed of between 10 to 25 rpm is required to promote long bit life. Too fast rotation will reduce bit life, too slow rotation will cause jerky and irregular rotation, reduced chip clearance and slow penetration. In general, slower rotational speeds should be used in harder formations.

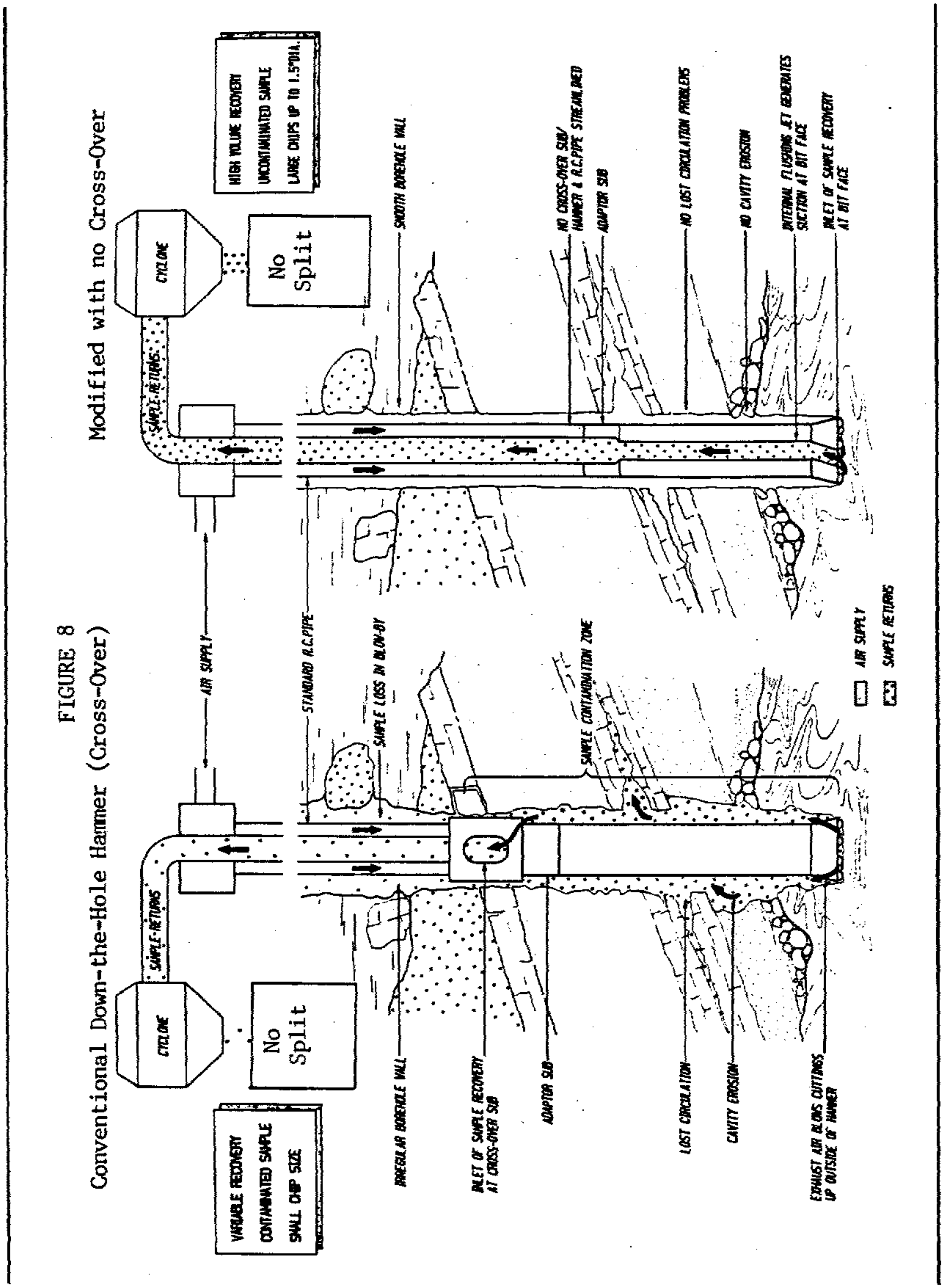
Extreme care should be taken to keep foreign material from getting into the drill string and into the hammer. Before connecting a rod to the drill string, the opening in the lower rod should be covered and the new rod should be blown clean and the threads should be lubricated. Before drilling is stopped, the hammer should always be raised off the bottom and blown clean. The hammer should never be left in a wet hole without some air circulating through it to keep muck from entering the hammer. Drill rods which are stored or moved should have male and female thread protectors. Button bits can be resharpened and the regrinding interval can be 3 to 5 times longer than with full-head bits.

Drills fitted with down-the-hole hammers have relatively high capital and high hourly operating costs and tend to be very heavy units. Their extra power and weight allows them to drill deeper holes. Their higher penetration rates, especially under difficult drilling conditions, often justify these higher costs.

Unlike some skirted tri-cone rotary bits, most down-the-hole hammers do not discharge their cuttings directly into the center tube of a reverse circulation system. An air cross-over located about 1.5 m (5 ft) above the bit face redirects air from the annulus of the double tube to the center of the tube for the hammer (Figure 8). Drill cuttings which have been flushed from the bit must travel up and around the entire length of the hammer and enter inlets located above the cross-over. In this 1.2 to 1.5 m (4 to 5 ft) of travel along the raw walls of the hole, gold losses and contamination can occur.

Skirting around the outside of the bit may also help to prevent drill cuttings from exiting outside of the rods and may help prevent sloughed material from entering the sample stream. Some drill bits, including rotary tri-cone bits and recent developments in down-the-hole hammers such as the Samplex and Digger down-the-hole bits, have sample cutting inlets directly in the bit face (Figure 8). Both the Samplex and Digger bits also use a venturi to create a vacuum in the center return tube which may increase sample recovery. Air consumption is higher and penetration rates may be lower with these latter down-the-hole hammer drills.

FIGURE 8
Down-the-Hole Hammer Drills



6.10 SONIC DRILLS

Sonic drills (also known as Resonant drills or the Superdrill 150) generate high speed (150 cycles/second) vibrations with a variable amplitude of up to 6 mm (0.25 in), (Blakestad, 1982). These high speed vibrations allow the drill stem to penetrate by fluidizing and/or shearing through soil particles and by fragmenting rocks by impact. Penetration is achieved without any fluid or air circulation. A rotational speed of up to 60 rpm can be applied to assist in drilling through rock. The drill head contains the oscillation, rotation and vibration isolation system (Dance, 1981). Conventional pull-down and hoisting operations are used to move the drill column up or down.

The vibration-induced fluidization of the soils at the surface of the drill stem decreases the friction on the steel and allows the sample core to enter the stem in a relatively undisturbed form. This provides an intact sample core which allows accurate volume and geological measurements to be made. In permafrost the core must be thawed before it can be processed. If rocks are encountered they may push the sample outside of the path of the drill and reduce sample recovery. The rods are 6 m (20 ft) in length and must be pulled to remove the core. This limits their application in wet or caving ground to height of the drill tower. In frozen or consolidated ground it is possible to drill deeper holes. The highest penetration rates are in sands and gravels with reduced rates in harder materials.

Sonic drills have high operation costs, frequent vibration-induced maintenance problems and penetration difficulties when boulders or other hard material is encountered. There are also very few experienced operators available. Sonic drills have been used in the Yukon but have been confined to relatively shallow holes (6 to 12 m [20 to 40 ft]). The Yukon's remaining Sonic driller has fitted his drill with auger equipment to reduce his drilling costs.

6.11 BULK SAMPLING

Bulk samples can provide valuable information about a placer deposit, including the presence of boulders and clays, water inflow and other potential mining or processing problems, provided that good records are maintained. Due to their large size, properly excavated and collected bulk samples have the potential to eliminate some of the statistical problems (such as the nugget effect) which are normally encountered with smaller placer gravel samples. The application of bulk sampling is limited in unstable ground and where there are excessive in-flows of ground water.

Bulk sampling is normally conducted in three ways: by sinking shafts, by excavating trenches and by digging pits.

Shafts are normally excavated by hand and are very labour intensive. However, they may be useful in ground which is too deep for machine excavated trenches or pits. In thawed ground, shafts usually must be cribbed with timbers or metal caissons to prevent caving or sloughing. In permafrost, the ground must be thawed with steam or drilled and blasted. Shafts have also been excavated with hydraulically driven caissons and clam shell bucket digging equipment. However, the high operation and mobilisation costs and the extreme difficulties with rocky or cemented ground preclude the use of this equipment for most placer mines.

To maximise sample volume, it is usually preferable to process the entire volume of gravels removed from the shaft. The volume calculation may have to be adjusted to account for boulders which jut out from the walls or where free running soils have diluted the sample.

Other shaft sampling methods include channel samples (measured side cuts) and continuous samples from the bottom of the shaft. Richardson (1992) recommends using a cut box for sampling the bottom of shafts in loose or fine-gravel deposits or in wet ground.

Wells (1969) indicates that shafts may in some cases be essential to correct the interpretation of drilling values. However, shafts are not necessarily a valid check on drill results due to potential erratic variations in the distribution of placer gold particles in any given deposit and also due to the inaccuracies in sampling with both drilling and shafting.

7 FIELD RADIOTRACER TESTWORK PROCEDURE

The purpose of the field testwork undertaken during this drilling research program was to measure, using radioactive gold tracers, the performance and gold recovery efficiency of different types of drills, and to provide recommendations for effective drilling and sample processing during placer deposit evaluation programs.

7.1 RADIOTRACER TESTING PROCEDURE DEVELOPED IN 1989

In 1989 NEW ERA tested six auger drill holes with radiotracers. Only forty tracers were used for each hole and the preliminary results indicated wide variations in gold recoveries, ranging from 30 to 90% due to variations in the drilling conditions and the low numbers of tracers inserted in each hole. Some of the losses were due to the drilling method, however other losses were demonstrated by tracers stuck to drill rods and bits, tracers remaining in the collar of the hole and tracers lost during sample processing (especially during panning).

Due to the limited number of tests and tracer particles used in each test, these data were not a good indicator of the gold recovery or variability of auger drills. However, a successful field testing procedure to evaluate drilling methods was developed and proven. In 1992 and 1994, the drilling research duplicated this procedure but used larger numbers of tracers, more tests per drill and a greater variety of drilling conditions to improve the accuracy of the results.

7.2 THE 1992 AND 1994 RADIOTRACER TEST PROCEDURES

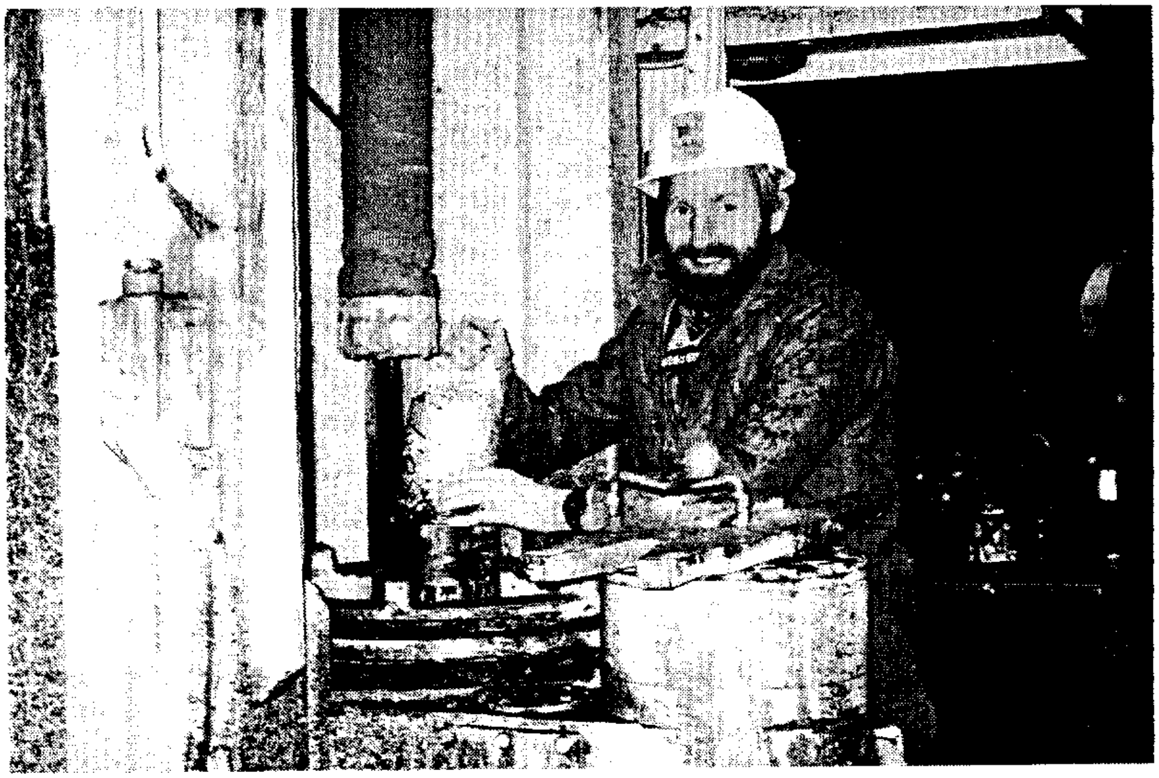
The 1992 and 1994 testing procedures included the following steps:

a) a cylinder slightly smaller than the diameter of the drill holes and 300 mm (1 ft) long was partially filled with compacted barren gravels (Photo 1) from tailings typical of the area being drilled. Each portion of tailings was carefully panned to ensure that it was barren and would not contaminate the hole;

b) selected sizes of radioactive placer gold particles (radiotracers) were mixed with more barren gravels and placed in a hollow in the center of the cylinder. Four gold particles sizes (-10+14, -20+28, -35+48 and -65+100 mesh) (1.2-1.7, 0.60-0.84, 0.30-0.42 and 0.15-0.21 mm) were chosen because previous research by Clarkson (1990) indicated that these were the most common sizes of placer gold particles found in the Yukon;

PHOTO 1
Placing Radiotracers and Tailings in a Cylindrical Mold

PHOTO 2
Dropping (Air Mailing) the Radiotracer Test Core



c) more barren gravels were placed above the radiotracers and compacted to completely fill the cylinder;

d) the cylinder was then sealed in two layers of polyethylene (plastic) bags and frozen with its contents in a portable freezer;

e) the frozen gravel cylinders were transported to the drilling area where the frozen cores were removed from their containers and bags;

f) once the desired depth of drilling was completed the drill rods were pulled out, the hole depth was measured and the frozen core was dropped (air mailed) down the hole (Photo 2);

g) the depth to the top of the core was measured and additional barren gravel (stemming) was dumped on top of the core. This stemming was tamped down whenever possible. The presence of the stemming allowed the drill and its sample recovery equipment to operate more closely to steady state conditions before intersecting the frozen core. The stemming also helped to hold the frozen core in place;

h) the bit and rods were lowered back into the hole and the hole was redrilled;

i) the collar of the hole, drill cuttings, drill equipment, sample collection equipment and personnel were checked for radiotracers with a scintillometer during and after completion of drilling (Photo 3). The retrieval, loss and carry-over of radiotracers during drilling, sample removal and sample processing was noted; and

j) after sample processing was completed (usually with a small sluice and by hand panning) (Photo 4) the tracers were identified and removed from the concentrate and their radioactivity recorded.

For normal and reverse circulation drills, the impact of added water (used to flush drill cuttings) and the design of the drill bits, drill rods, cyclones and other sample collection apparatus on gold recovery and/or carry-over were examined. In auger drilling, different procedures for sampling (continuous versus interval) and varying depths of bedrock penetration were examined to determine their impact on gold recovery. The gold recovery efficiency of sample retrieval and gold recovery methods and equipment, as commonly used by drillers and miners, were examined.

The evaluation of gold recovery by the various types of drills was performed on an on-going basis, to try to optimise recovery under field conditions. When poor recoveries were encountered, drilling methods and/or equipment were modified and retested where practical.

PHOTO 3
Checking the Ground for Blow-by Losses

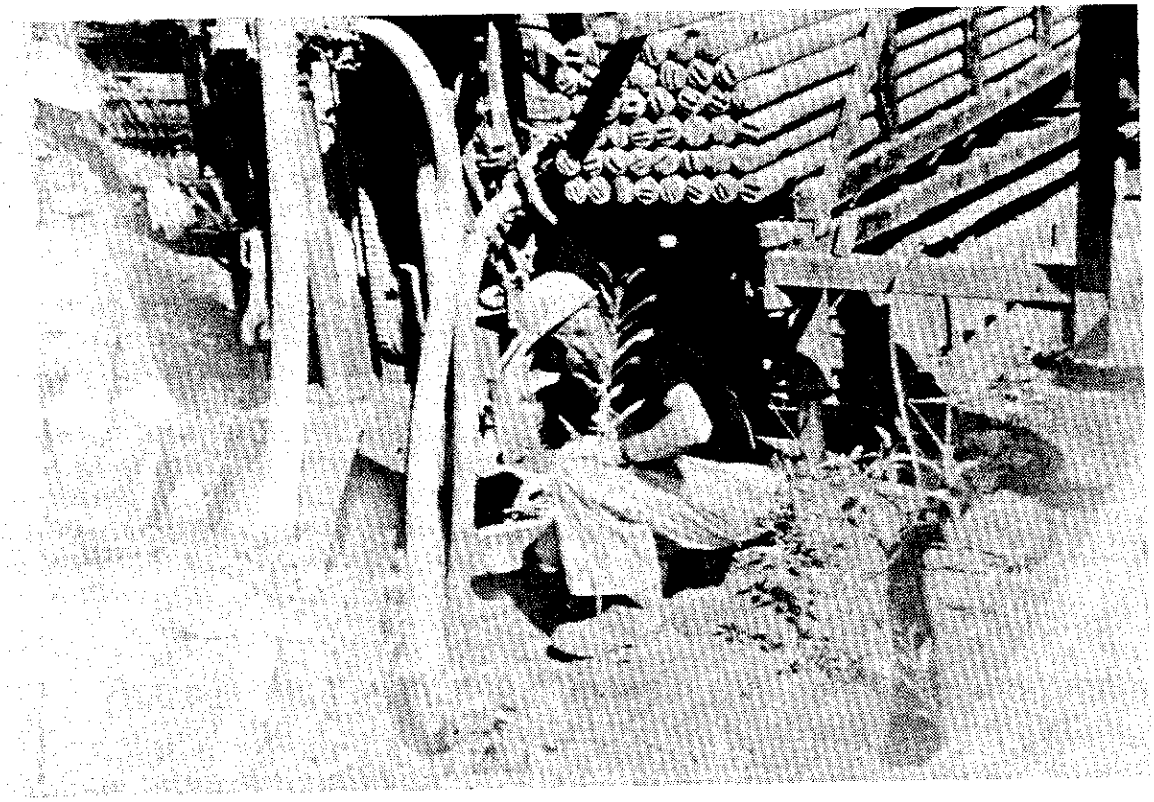


PHOTO 4
Concentrating Drill Samples with a Long Tom

There are many variables which can influence placer drilling results and these are often extremely difficult to control under field conditions. It is impossible to make any two holes absolutely identical, even if drilled side by side with the same equipment. Many conditions, such as the ground geology, are not controllable for experimental analysis; however, many other conditions such as bit size, bit speed, penetration pressure and drilling rates were kept as constant as practical.

The drill hole's normal gravel samples were not affected by the radiotracers and were still useful for evaluating grades or depths of virgin pay gravel horizons. Absolutely no information regarding virgin gravel grades at the test sites has been or will be released to the public.

7.3 THE 1994 TANTALUM VISUAL TRACER TEST PROCEDURE

Due to the inability of the U.S. Nuclear Regulatory Commission (NRC) to permit radiotracer test work in time to conduct an evaluation of a reverse circulation drill in Alaska in August 1994, Dan Walsh (Mineral Industry Research Laboratory, University of Alaska, Fairbanks) decided to employ tantalum tracers.

Tantalum (Ta), element 73 on the periodic table, is a hard, grey, malleable metal with a high melting point (3000 C) and is insoluble in water. It is non-toxic, though some industrial skin injuries have been reported from exposure to fine powders. The density of tantalum (16.6 grams/cm3) is close to that of placer gold (17-19 grams/cm3) and its grey, metallic character makes it easily recognisable as a visual tracer.

The tantalum tracers were introduced into four partially drilled placer exploration holes and the distribution of the tantalum tracers was recorded after drilling resumed. The tantalum tracer test procedure was similar to the 1992/94 radiotracer test procedures except for the following:

a) the cores were longer at 610 mm (2 ft) instead of 300 mm (1 ft);

b) ten 1.2-2.4 mm (-8+14 mesh) and ten 0.6-1.2 mm (-14+28 mesh) tantalum tracers were placed in 100 mm lifts of tailings until a total of 100 tracer particles were included in each frozen cylindrical core; and

c) the tantalum tracer distribution in the redrilled hole interval and subsequent hole intervals was recorded by visually observing the recovery of the tantalum tracers during the panning of the drill sample concentrates.

8 OBSERVATIONS

8.1 FULLY CASED NORMAL CIRCULATION DRILLS

Two different fully cased normal circulation drills were tested with radiotracers, one in the Atlin and one in the Fort Steele (Cranbrook) Mining Districts of British Columbia.

8.1.1 Atlin Cased Normal Circulation Drill Tests

From July 6-17, 1994, three drill holes from a fully-cased normal-circulation drilling system were tested in the Atlin Mining District.

The placer gold occurred in rounded coarse gravel/ boulder layers which appear to have been deposited in a glacial/fluvial (glacial stream) setting. The gold-bearing gravels were covered with layers of silty glacial tills containing fine gravels, sticky clay-rich silts and clays, and coarse mixed sandy gravels. More layers of silty tills containing fine gravels were located under the gold-bearing coarse gravels. The bedrock was never encountered even in the deepest holes which were drilled through the bottom of a deep pit to a total depth greater than 60 m (200 ft).

The truck-mounted Schramm T66H drill (photo 5) also had a 280 l/s (600 cfm) air compressor. Another truck was fitted with extra fuel tanks, air compressor, welder, a hydraulic lifting arm and a deck for carrying the 6 m (20 ft) long drill rods and casings (Photo 6). The hollow drill rods had an outside diameter of 114 mm (4.5 in) and an inside diameter of 50 mm (2 in). The drill rods transferred down-pressure and rotation at about 23 rpm to the 152 mm (6 in) diameter rotary tri-cone drill bit. A tri-cone bit was used because the driller anticipated that the silts and clays would plug a down-the-hole hammer.

The casing shoe had an inside diameter of 159 mm (6.25 in) and an outside diameter of 184 mm (7.25 in) (Photo 9). The shoe and 6 m (20 ft) lengths of 6 mm (0.25 in) thick wall pipe casings were welded together one-at-a-time as the hole deepened. The casing did not rotate but was driven down by a pneumatic (compressed air) hammer at 78 blows/min.

About 150 l/s (320 cfm) of compressed air at 0.4 MPa (60 psi) pressure was forced down the center of the drill rods to flush drill cuttings from the bit face and up the annular space between the casing and drill rods. At the top of the casing, a rubber "doughnut" ring sealed the casing swivel head to the drill rods. From the swivel head, the drill cuttings were then directed through a hose to a sampling cyclone (Photos 8 & 10). The drill was stopped every 600 mm (2 ft) to change the sample bags under the cyclone.

The drilling system's penetration rate varied from 11 m/h (37 ft/h) in sandy till to less than 1 m/h (3 ft/h) on hard boulders. The drilling rate averaged 3 m/h (10 ft/h) or about 31 m (102 ft) per day for a two person crew when other operations such as adding rods, welding casings, pulling rods, pulling casings and moving were included. About 30 minutes was required to add a drill rod and weld a-new casing onto the drill string.

The casing was usually driven ahead of the drill bit except when hard boulders were encountered and the bit was advanced to break up the boulder. All holes were drilled without water addition but water was encountered in most of the drill holes. The water mixed with the cuttings and created a high-density, high-viscosity, slurry which kept black sands (mostly magentite) and fine placer gold in suspension. **The slurry was extremely difficult to collect and contain without spillage and almost all spillage losses contained radiotracers. It was impossible to decant the slurry without losing fine radiotracers, even after allowing several minutes for settling** (Photo 10).

Tracer cores were dropped down holes #2 and #3 after the casing had been driven down to a depth of 24 m (80 ft) and 29 m (96 ft) respectively. For both of these holes the drill bit was 600 mm (2 ft) above the casing shoe. The third tracer core was dropped down hole #6 after the drill bit had drilled 1.2 m (4 ft) below the casing shoe. This was done to test gold recovery with the tracer core well below and beyond the casing. The drill casing was lowered down hole #6 until it was 600 mm (2 ft) below the drill bit.

For all the test holes, two other barren cores and stemming were dropped on top of the tracer cores, the drill rods and/or casing were lowered and drilling was continued. Most of the tracers (64 to 84%) were recovered in the sample from the sample interval. Most of the losses were due to spillage with minor carry-over losses in the swivel head and onto the next sample interval. Minor amounts of tracers were also lost when blow-by sprayed past the "doughnut" swivel seal.

The columns in the following Table 3 display the depth at which frost starts (there was no permafrost in this location), the moisture in the hole (or if 'Water' was used during drilling), the bottom of various soil horizons such as (Grav)el and the bottom (Bot) of the hole in metres. The adjacent columns indicate the depth at which the drill rods were pulled (Pull) prior to adding the radiotracer core and depth at which it stuck (Locn) when dropped. The final five columns display the net recovery (Rec) of tracers in the sampling system, the losses due to spillage (Spil), carry-over (C/O) and blow-by (Blo) around the collar of the hole as well as the total (Totl) percentage of tracers removed from the hole.

TABLE 3

A Summary of Normal Circulation Drill Holes at Atlin

Hole	Frost	Wet?	Till	Gravl	Bot	Pull	Locn	Rec	Spil	C/O	Blo	Totl
#2	N/A	Wet	22.6	30.5	30.5	24.4	24.4	64%	26%	4%	2%	96%
#3	N/A	Wet	6.1	18.3	30.5	29.3	6.1	84%	10%	0%	2%	96%
#6	N/A	Wet	12.2	15.2	31.1	18.9	18.9	76%	17%	1%	4%	98%
Average			13.6	21.3	30.7	24.2	16.5	75%	18%	2%	3%	97%

Note: The tracer recovery for hole #6, in which the tracer core was placed below the casing, is similar to the other two holes #2 and #3.

Only drill hole (#2) had any tracers carried over into the next sample interval.

Spillage losses were reduced in holes #3 and #6 by using bigger containers and with greater care in the collection, handling and transferring of the samples.

The higher blow-by losses in hole #6 were due to a worn out rubber "doughnut" in the swivel which seals the swivel hose connection assembly to the drill rods. The doughnut was replaced for the next hole.

No permanent gold traps were located in the drilling or sample retrieval equipment and all the tracers which lodged temporarily in the swivel assembly or sample cyclone were removed with a blast of compressed air. The lack of traps may be due to some recent welding and/or the high density/viscosity of the drill cuttings slurry.

The few tracers which were unaccounted for, were probably ground up by the drill bit.

PHOTO 5
Schramm T66H Fully Cased Drill with Pneumatic Hammer & Swivel

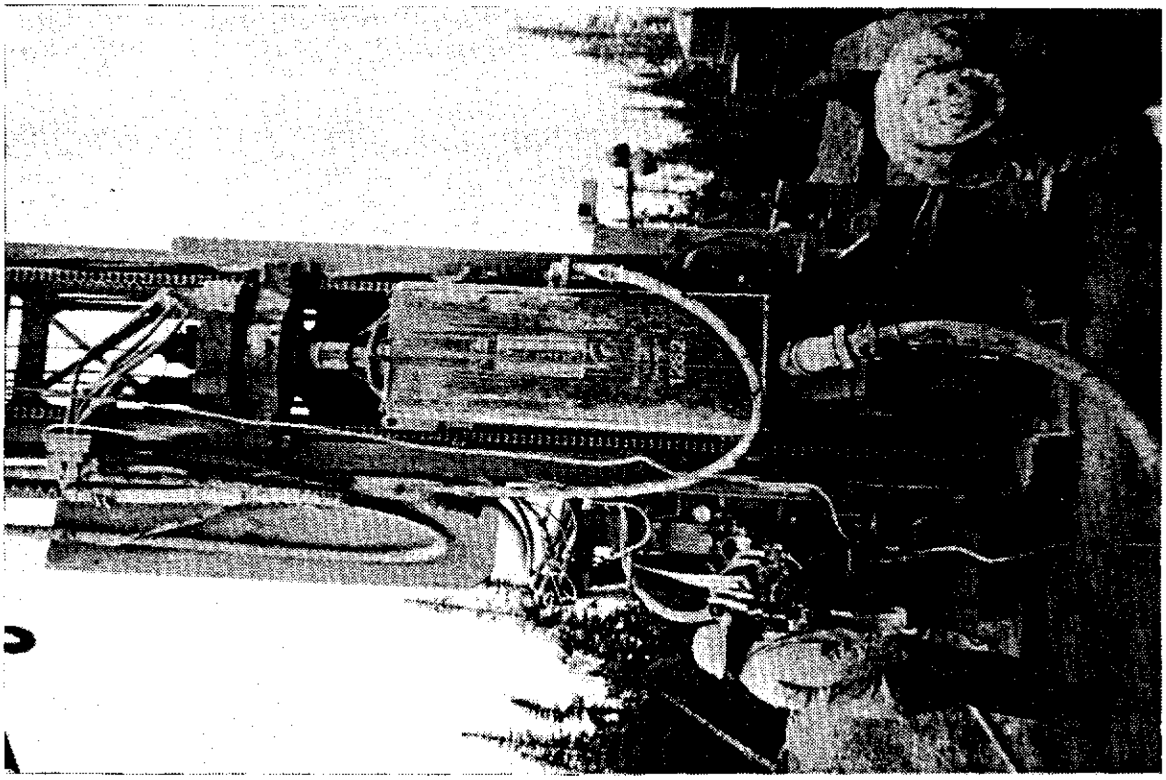


PHOTO 6
Schramm T66H Drill Slinging and Connecting Rods and Casings

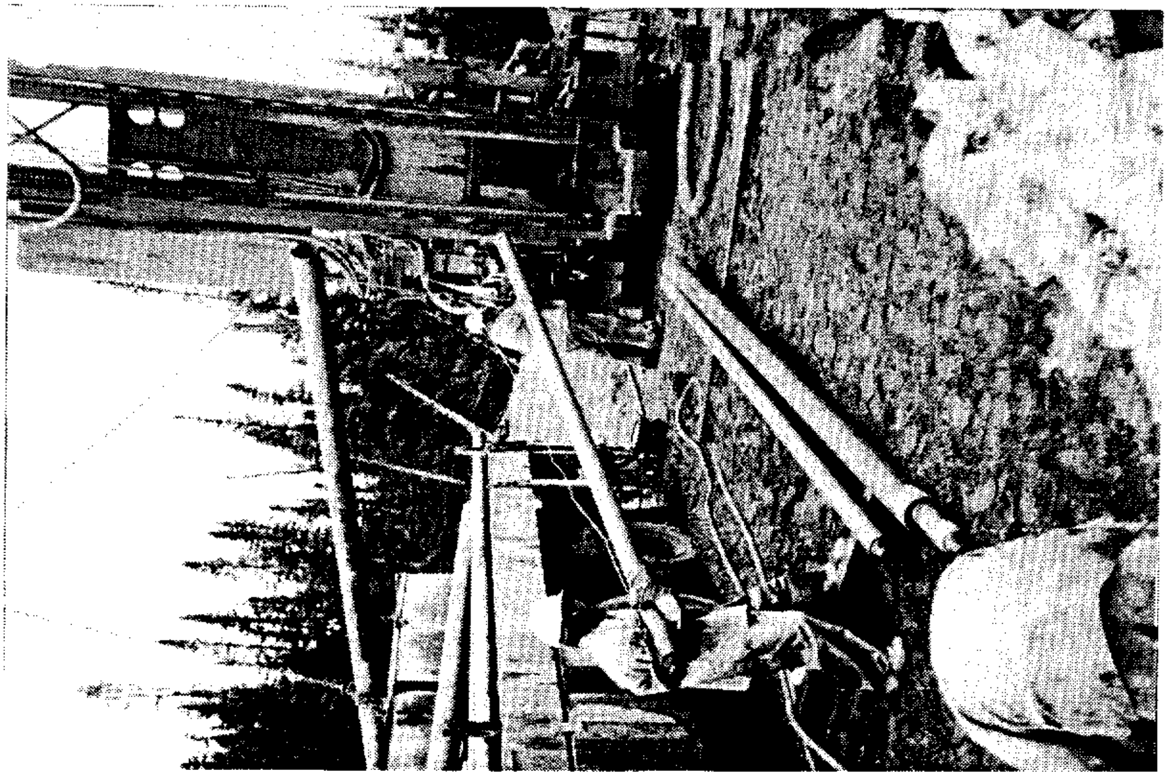


PHOTO 7
Schramm T66H Drill Disconnecting Rods

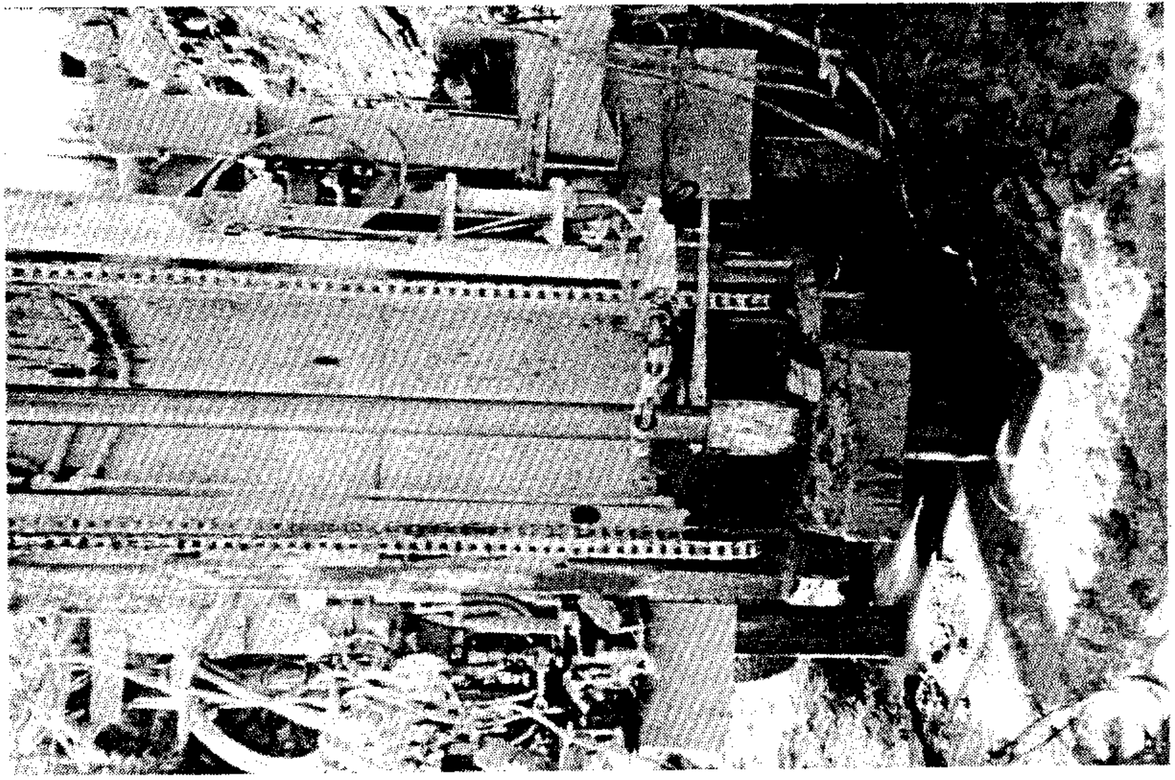


PHOTO 8
Schramm T66H Drill Pulling Casings (note Sampling Swivel)

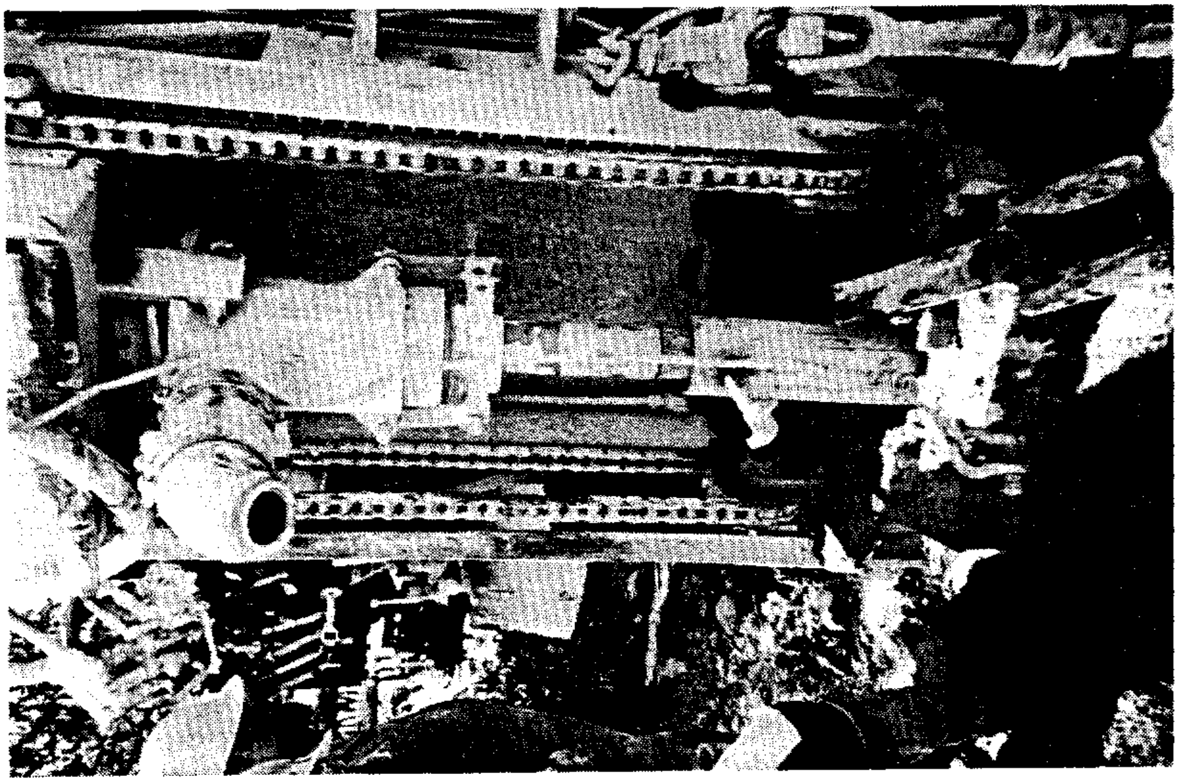


PHOTO 9
Schramm T66H Fully Cased Drill Casing Shoe

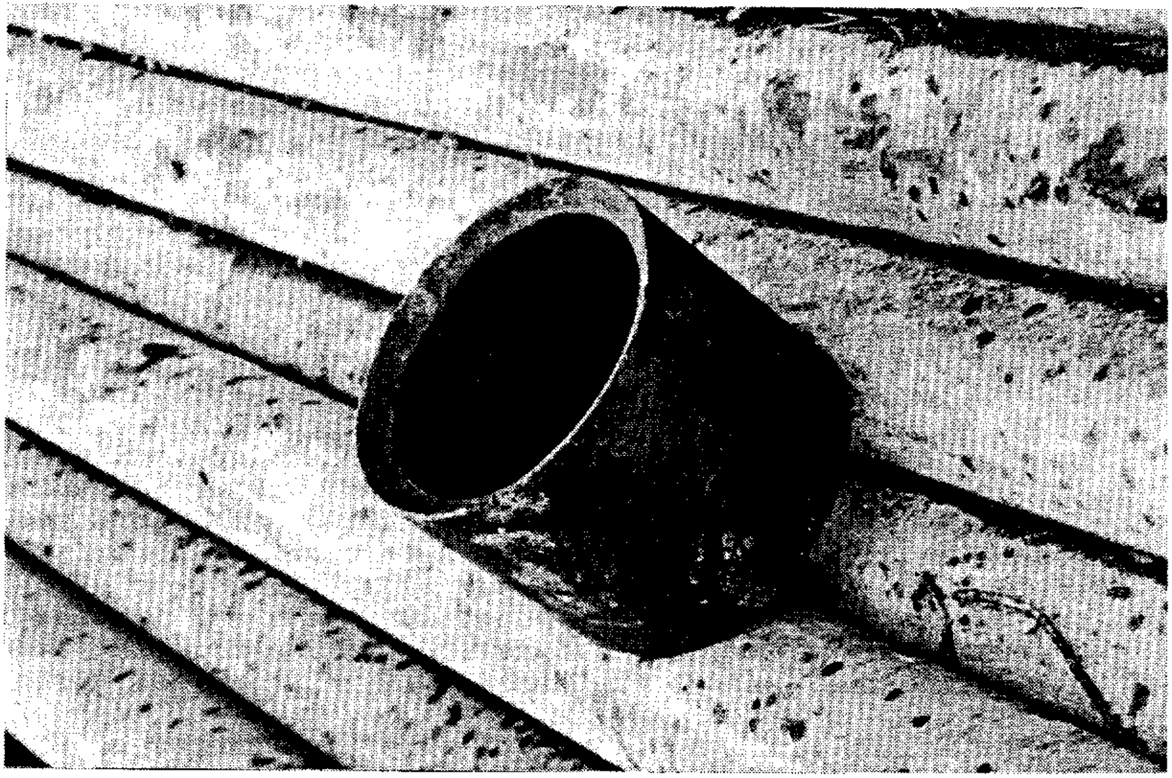
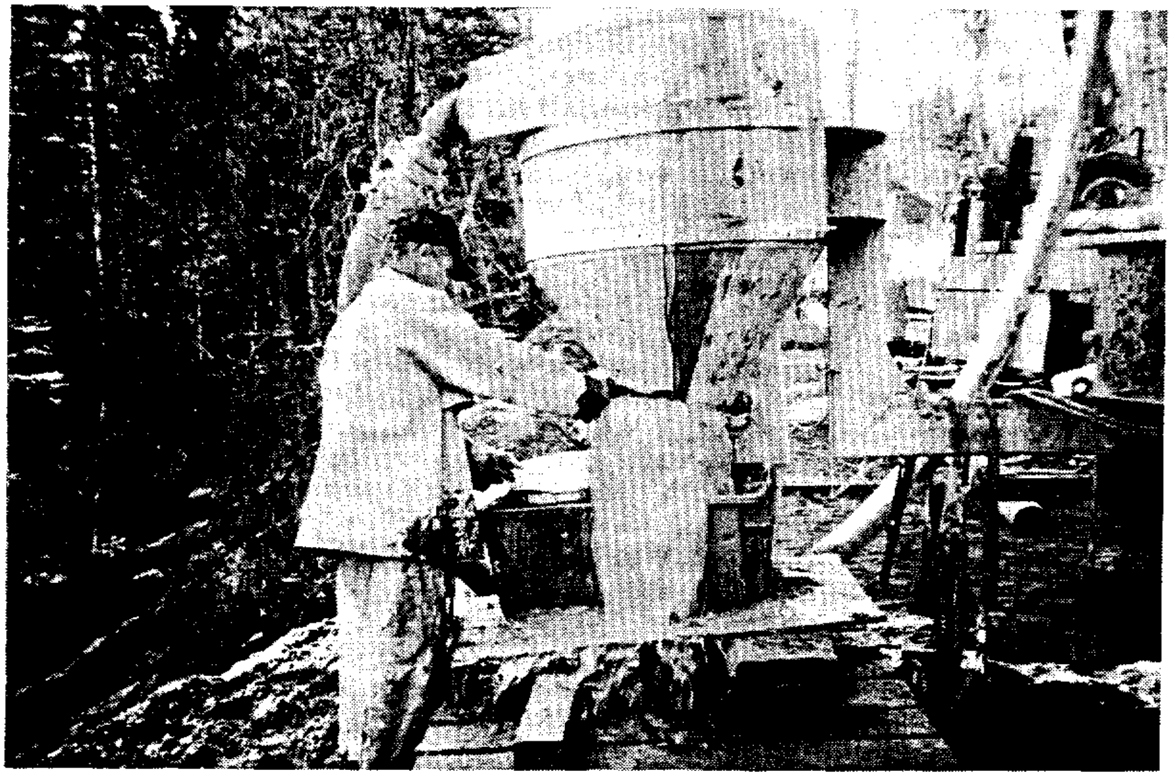


PHOTO 10
Oveflow Spillage at the Sampling Cyclone



8.1.2 Fort Steele Normal Circulation Drill Tests

From October 12-19, 1994 a normal-circulation, Barber Dual Rotary (DR) was tested with radioactive gold tracers at the Moyie River in the Fort Steele (Cranbrook) Mining District of British Columbia. All six of the holes drilled were tested with radioactive gold tracers.

The placer gold occurs in pre-glacial gravels in a bedrock trough. The bedrock walls of the trough appear to have protected the placer gold deposit from glacial scouring. This channel is 1.5 to 2.5 m (5-8 ft) thick and is buried by 12 to 18 m (40-60 ft) depth of compact silty boulder till.

The truck-mounted Barber Dual Rotary drill model no DR7/26P (Photo 11 and Figure 6) was equipped with a 350 l/s (750 cfm) air compressor, a top rotary head to advance the drill string and a lower rotary casing driver to advance casing through unconsolidated overburden. The top rotary head was hydraulically tilted from a vertical to a horizontal position to facilitate the picking up or laying down of drill pipe and casing (Photo 11). A separate truck was fitted with extra fuel tanks, welder, hydraulic lifting arm and a deck for carrying the 6 m (20 ft) long drill rods and casings.

The hollow drill rods had an outside diameter of 114 mm (4.5 in). The drill rods transferred down-pressure, rotation and compressed air to drive the down-the-hole hammer. The hammer used a 127 mm (5 in) diameter button bit and conventional air cross-over assembly (Figure 8). Penetration rates varied from 16 m/h (54 ft/h) in sandy silts to 2 m/h (7 ft/h) on hard quartz boulders. The drilling rate averaged about 4.5 m/h (15 ft/h) or about 33 m (108 ft) per day when other operations such as adding rods, welding casings, pulling rods and moving were included. About 20 minutes was required to add a drill rod and weld a new casing onto the drill string (Photo 14).

About 280 l/s (600 cfm) of compressed air at 1.03 to 1.4 MPa (150-200 psi) pressure was forced down the center of the drill rods to operate the down-the-hole hammer and flush drill cuttings up the annular space between the casing and drill rods. The drill cuttings continued through to a discharge swivel, hose and sampling cyclone. The swivel was attached to the casing and used rubber seals to prevent leakage between the casing, swivel and drill rods. Radiotracers were frequently trapped in dead areas in the swivel head (as carry-over) (Photo 13).

PHOTO 11
Barber DR Drill with Pivoted Rotary Head

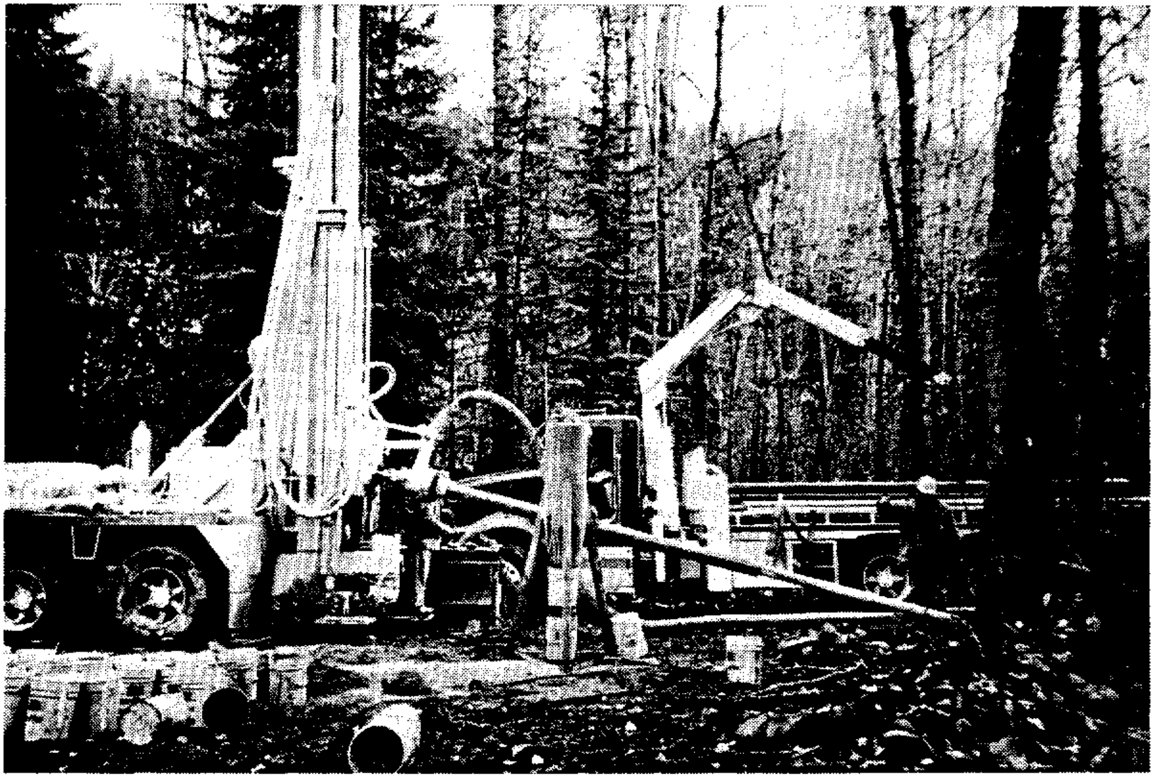
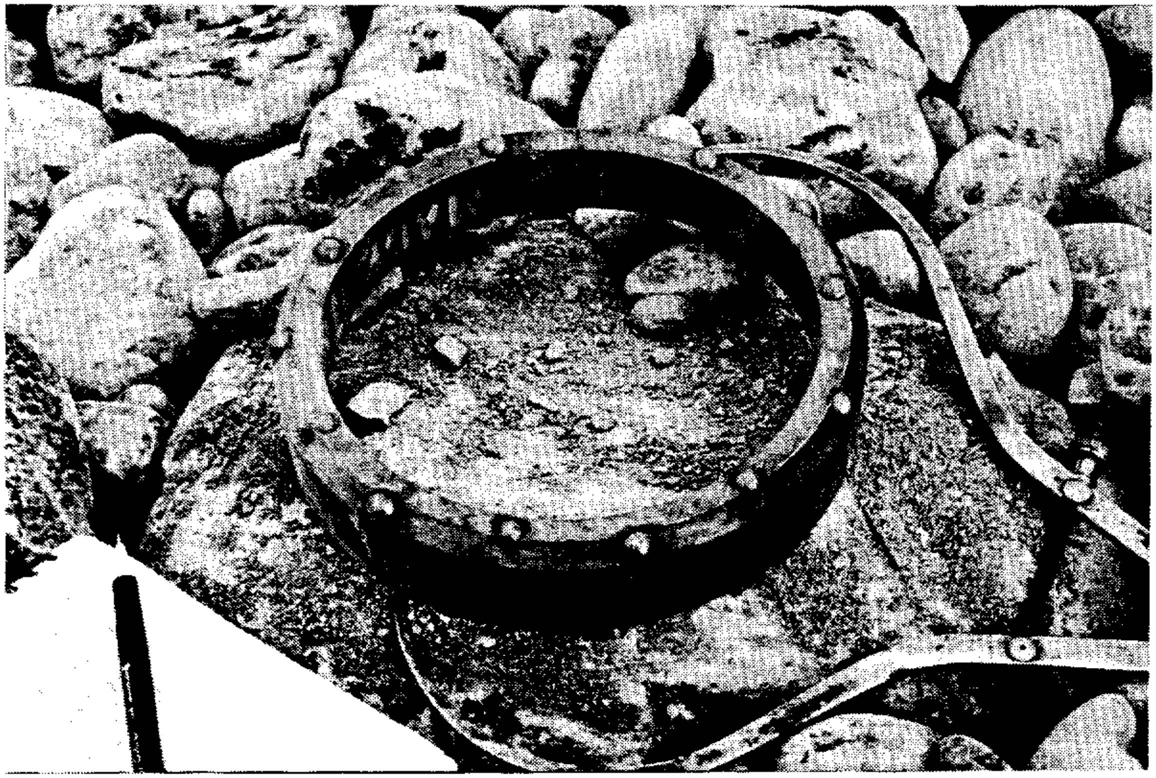


PHOTO 12
Barber DR Casing Shoe Studded with Carbides



A down-the-hole hammer was used instead of a rotary tri-cone bit because of the numerous large, hard, granitic and quartz-rich boulders located in the glacial till. The driller exercised some caution and was able to keep the glacial clays and silts from plugging the hammer without any water addition. The driller indicated that he had used the hammer in sticky clays at other locations but required water addition to flush the clay away from the hammer.

The drill rods rotated at 18 rpm and the casing rotated much more slowly at 5 rpm. The casing shoe was studded with carbides and had an inside diameter of 152 mm (6 in) and an outside diameter of 184 mm (7.25 in) (Photo 12). The shoe and 6 m (20 ft) lengths of 6 mm (0.25 in) thick wall pipe casings were welded together one-at-a-time as the hole deepened. Powered jaws gripped the casing and transferred the rotation and pull-down forces from the lower rotary casing driver and direct-connected hydraulic cylinders. The lower rotary driver also was used to easily break and spin out the drill string joints (Photo 14).

This driller felt that the casings were not worth the time required to pull them and left the casings in the drill holes. The casings were useful as permanent markers of the location of the drill hole.

The ability to apply independent rotation and pull-down force to the casing shoe allowed the shoe to remain 0.6 to 1.2 m (2-4 ft) below the drill bit even through the hard boulders. The drill bit did not have be advanced to break up the boulders and all holes were drilled without water addition. Despite these precautions, high pressure ground water in the relatively porous gravel layers forced large quantities of sample from outside and below the casing shoe into the sample recovery system. Sample volumes in gravel sections were often well in excess of the theoretical (calculated) volumes of the casing interval. The ground water mixed with the drill cuttings and created a low density slurry which was extremely difficult to collect and contain without spillage. Almost all spillage losses contained radiotracers.

The tracer cores in holes B1 and B2 were dropped down the holes when the casing shoe was at 12.2 m (40 ft) and the drill bit was at 11.6 m (38 ft). Unfortunately, during the drilling of the tracer core in hole B2, the sampling cyclone fell over and spilled the drill cuttings on the ground. For holes B3, B4 and B6, the drill bit went through to 1 m (3 ft) below the casing shoe which was at 12.2 m (40 ft), 11.6 m (38 ft) and 12.2 m (40 ft) respectively. Hole B4 was dry and partially in bedrock when the tracer core was added. The tracer core was added to hole B5 when both the drill bit and casing shoe were at 6.1 m (20 ft).

PHOTO 13
Barber DR Lower Rotary Head with Sampling Swivel

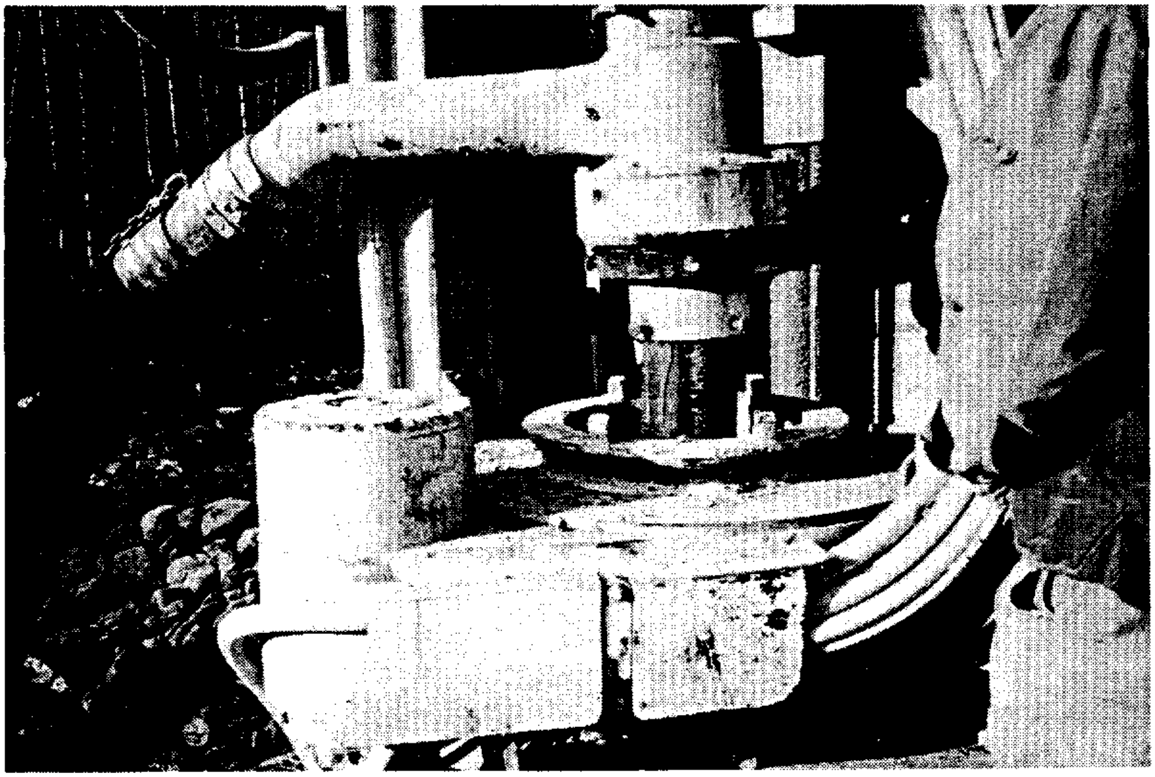
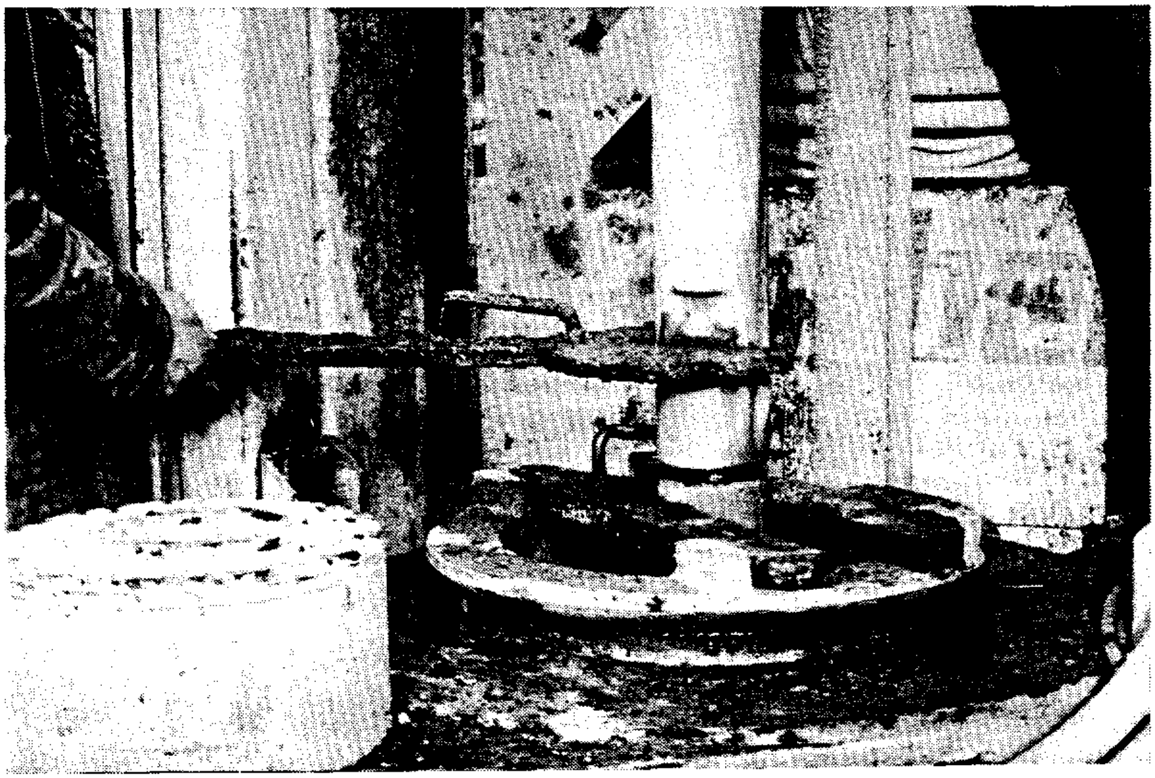


PHOTO 14
Barber DR Drill Disconnecting Rods with Lower Table



For all the test holes, one other barren core and stemming were dropped on top of the tracer cores. For holes B3, B4 and B6 the casing was advanced until it was 0.6 to 1.2 m (2-4 ft) below the drill bit, then drilling was continued. Most of the tracers (66% to 87%) were recovered in the sample from the sample interval. Most of the losses were due to spillage with minor carry-over losses in the swivel head and the next sample interval.

The columns in the following Table 4 display the depth at which frost starts (there was no permafrost in this location), the moisture in the hole (or if 'Water' was used during drilling), the bottom of various soil horizons such as (Grav)el and the bottom (Bot) of the hole in metres. The adjacent columns indicate the depth at which the drill rods were pulled (Pull) prior to adding the radiotracer core and depth at which it stuck (Locn) when dropped. The final five columns display the net recovery (Rec) of tracers in the sampling system, the losses due to spillage (Spil), carry-over (C/O) and blow-by (Blo) around the collar of the hole as well as the total (Totl) percentage of tracers removed from the hole.

TABLE 4
A Summary of Normal Circulation Drill Holes at Fort Steele

Hole	Frost	Wet?	Till	Grav	Bot	Pull	Locn	Rec	Spil	C/O	Blo	Totl
B1	N/A	Wet	15.8	16.8	17.6	11.6	11.6	74%	13%	6%	0%	93%
B2	N/A	Dry	14.6	17.1	18.3	11.6	11.6	16%	74%	2%	0%	92%
B3	N/A	Wet	12.8	19.5	20.1	13.1	13.1	74%	16%	4%	0%	94%
B4	N/A	Dry	12.2	12.2	12.8	12.5	12.5	87%	2%	11%	0%	100%
B5	N/A	Wet	12.2	12.8	13.1	6.1	6.1	66%	24%	0%	0%	90%
B6	N/A	Dry	13.1	14.6	16.2	12.2	12.2	87%	1%	6%	2%	97%
Average			13.5	15.2	16.1	11.1	11.1	67%	22%	5%	0.3%	94%
Without B2 where cyclone fell on ground								78%	11%	5%	0.4%	95%

Note: The sampling cyclone fell over and spilled its contents while drilling the tracer core in hole B2.

Except for hole B2 the radiotracer recovery was relatively high (66-87%) and consistent.

The tracer cores in holes B1 and B2 were located 0.6 above the casing shoe. For holes B3, B4 and B6 the tracer cores were located 1 m (3 ft) below the casing shoe. The tracer core was added to hole B5 when both the drill bit and casing shoe were at 6.1 m (20 ft). Hole B4 was dry and partially in bedrock when the tracer core was added.

Holes B1 and B6 recovered 2% of the tracers in a sample interval 3 m (10 ft) below the tracer core location. Hole B3 recovered 4% of the tracers 1 m (3 ft) below the tracer core. All other carry-over losses were tracers which remained in the swivel head and had to be physically removed at the end of each hole.

The radiotracers in almost all the holes showed signs of impact or grinding from the down-the-hole hammer bit. The few tracers which were unaccounted for, are assumed to have been ground up by the drill bit.

In hole B3, a blast of air to clear the hammer prior to drilling may have pushed some of the lost tracers into the sides of the hole.

Except for hole B2, there is no significant difference between the recovery of tracers, however, spillage losses were higher for the wet holes.

8.2 REVERSE CIRCULATION DRILLS

Two different reverse circulation drills were tested in 1992 with radiotracers by Clarkson (1993). One drill was tested one at several mine sites in the Cariboo Mining District of British Columbia and the other at two locations in the Klondike placer mining area near Dawson City, Yukon Territory. In 1994, due to the inability of the U.S. Nuclear Regulatory Commission to permit the test work in time Dan Walsh used non-radioactive tantalum visual tracers in 1994 to test a reverse circulation drill in the Melozitna mining district of Alaska.

8.2.1 Cariboo Reverse Circulation Drill Tests

From August 15-22, 1992, a reverse circulation drill was tested with radioactive gold tracers at various sites in the Quesnel-Cariboo placer district of British Columbia. Four of the nine holes drilled were tested with radioactive gold. The remaining five holes were not tested due to caving in the unfrozen unconsolidated gravels.

The placer gold occurred in alluvial gravel deposits covered with varying depths and sequences of silty gravels of glacial origin (till). Bedrock cuttings were generally easy to recognise due to their hardness and black sooty appearance.

The Mobile B80 drill (Photo 15 and Figure 5 [R/C]) was fitted with a 115 mm (4.5 in) diameter, skirted rotary tri-cone bit and 89 mm (3.5 in) diameter drill rods. The rods consisted of a center tube to transport sample cuttings from the bottom of the hole and an outer annulus to carry the compressed air used to flush the drill cuttings. Approximately 250 l/s (540 cfm) of air compressed to 2.4 MPa (350 psi) was forced down the outer annulus of the rods.

There was no down-the-hole or other hammer action. Penetration was achieved with down pressure and rotation of the bit. The penetration rate varied from 23 m/h (75 ft/h) in loose soils, to 15 m/h (50 ft/h) in glacial tills and gravels, to 3 m/h (10 ft/h) on bedrock and to 1 m/h (3 ft/h) in quartzite boulders. The drilling production rate was approximately 40-60 m (130-200 ft) per day for a two person crew including about 2-4 hours each day for set-up and moves.

All holes were drilled with water addition, which was injected into the compressed air stream. The driller indicated that water injection was required to keep the center tube in the rods from plugging. When the water injection was stopped upon request, the rods plugged and had to be pulled out of the hole and cleaned with compressed air which was forced through a cross-over fitting. The addition of water to the drill's compressed air flushing system increased segregation and entrapment of gold tracers. Water addition also increased spillage losses and made it very difficult to collect and contain the samples.

PHOTO 15
Mobile B80 R/C Drill Used in the Cariboo

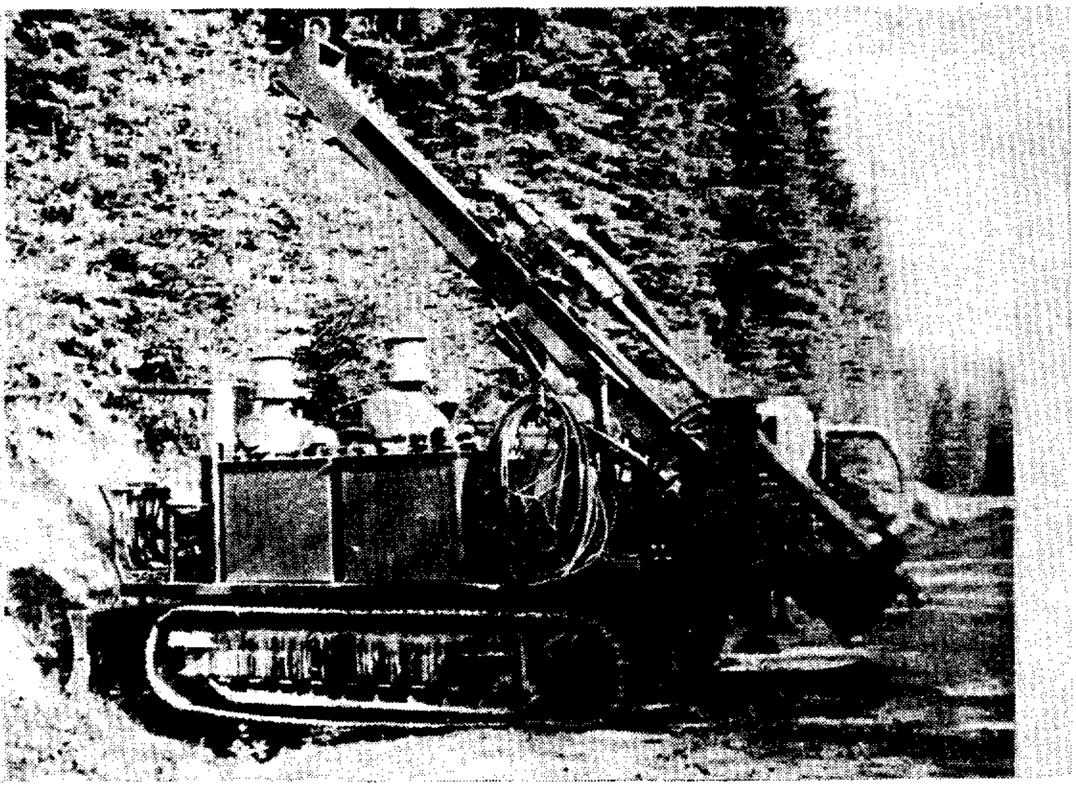


PHOTO 16
Schramm TH64 R/C Drill Used in the Klondike

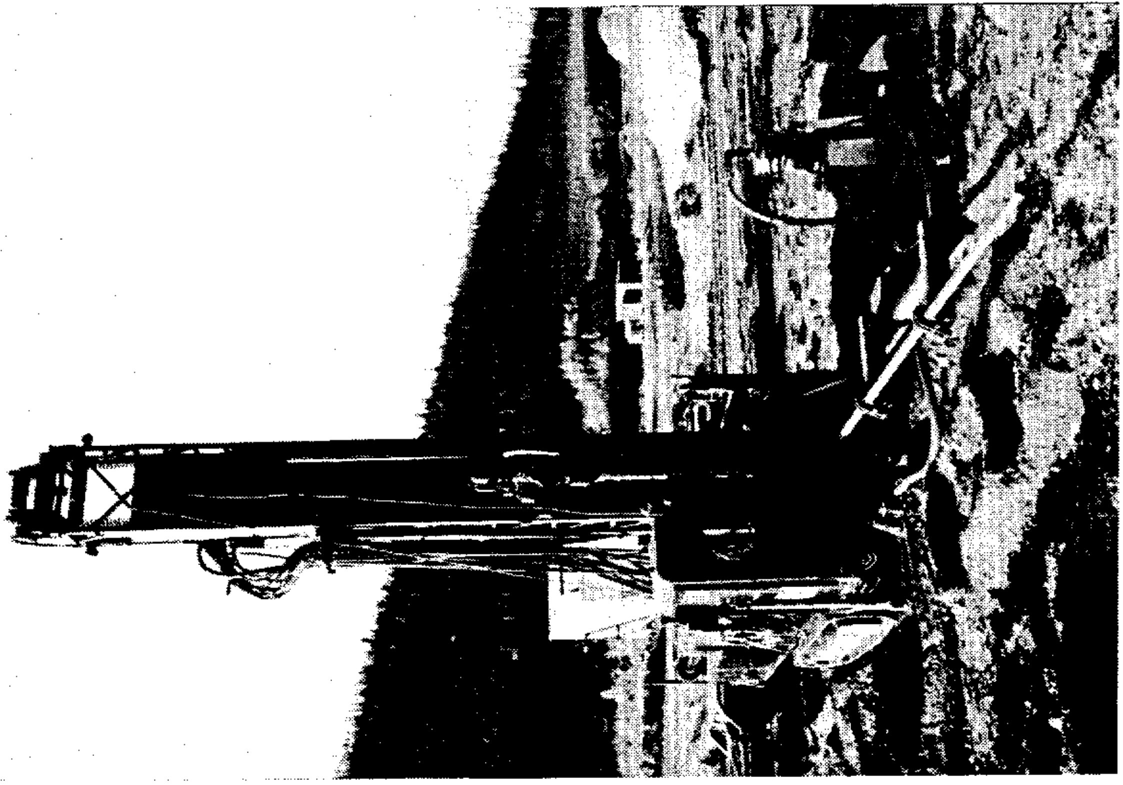
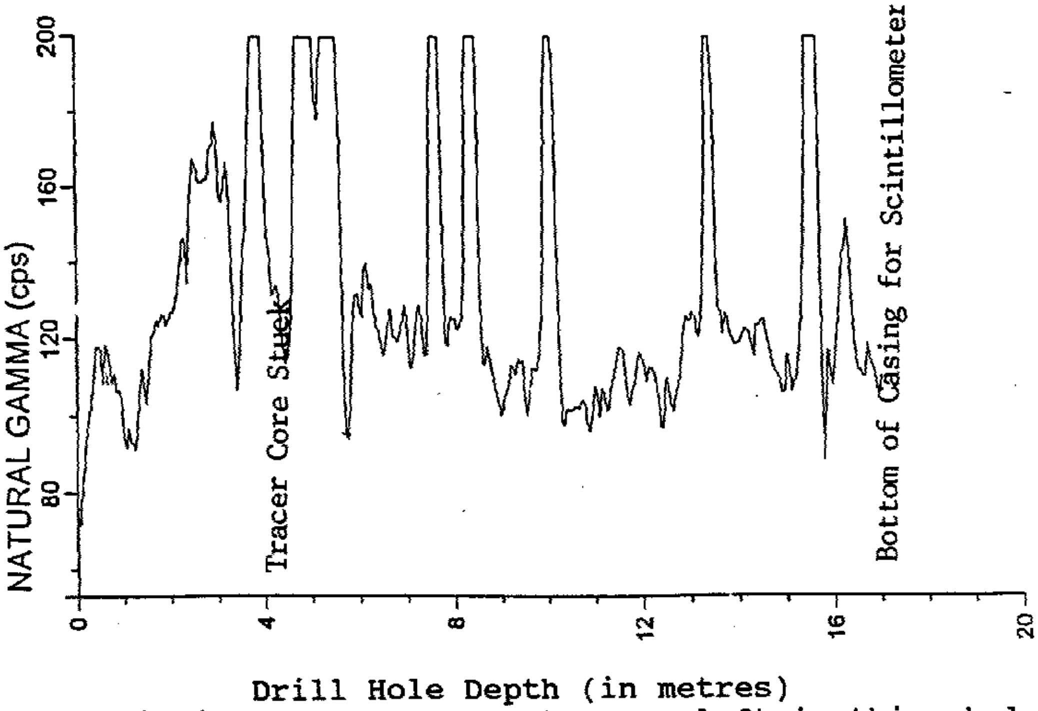


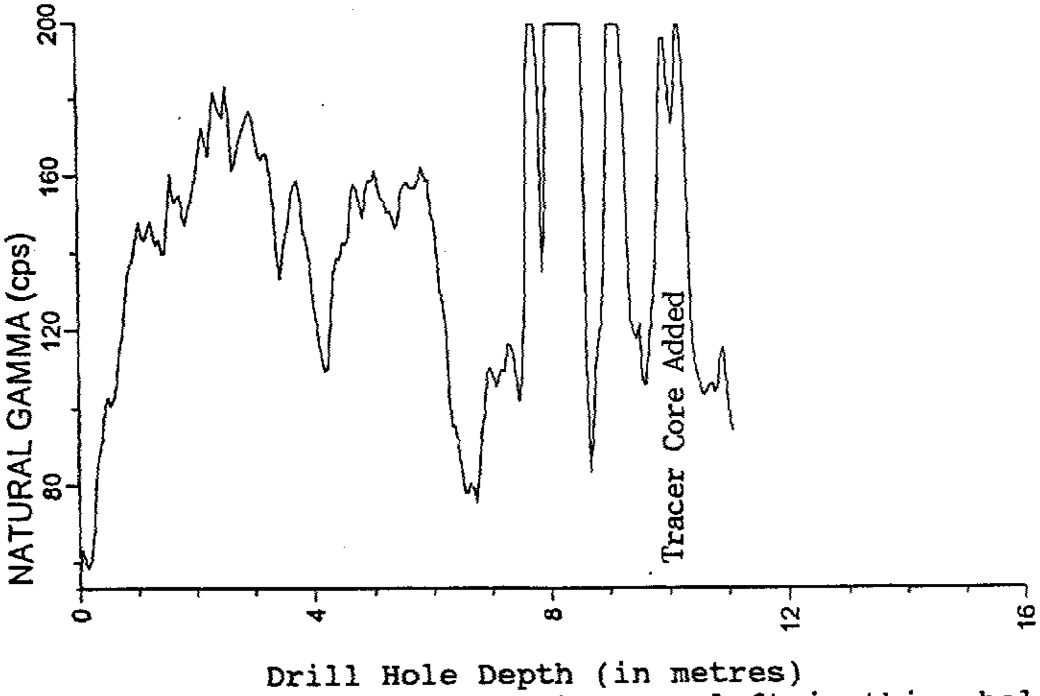
FIGURE 9
Down-Hole Scintillometer Logs for Hole 92-4 (Cariboo)



Depth of the Hole was 36 m When the Tracer Core was Added to the Hole.

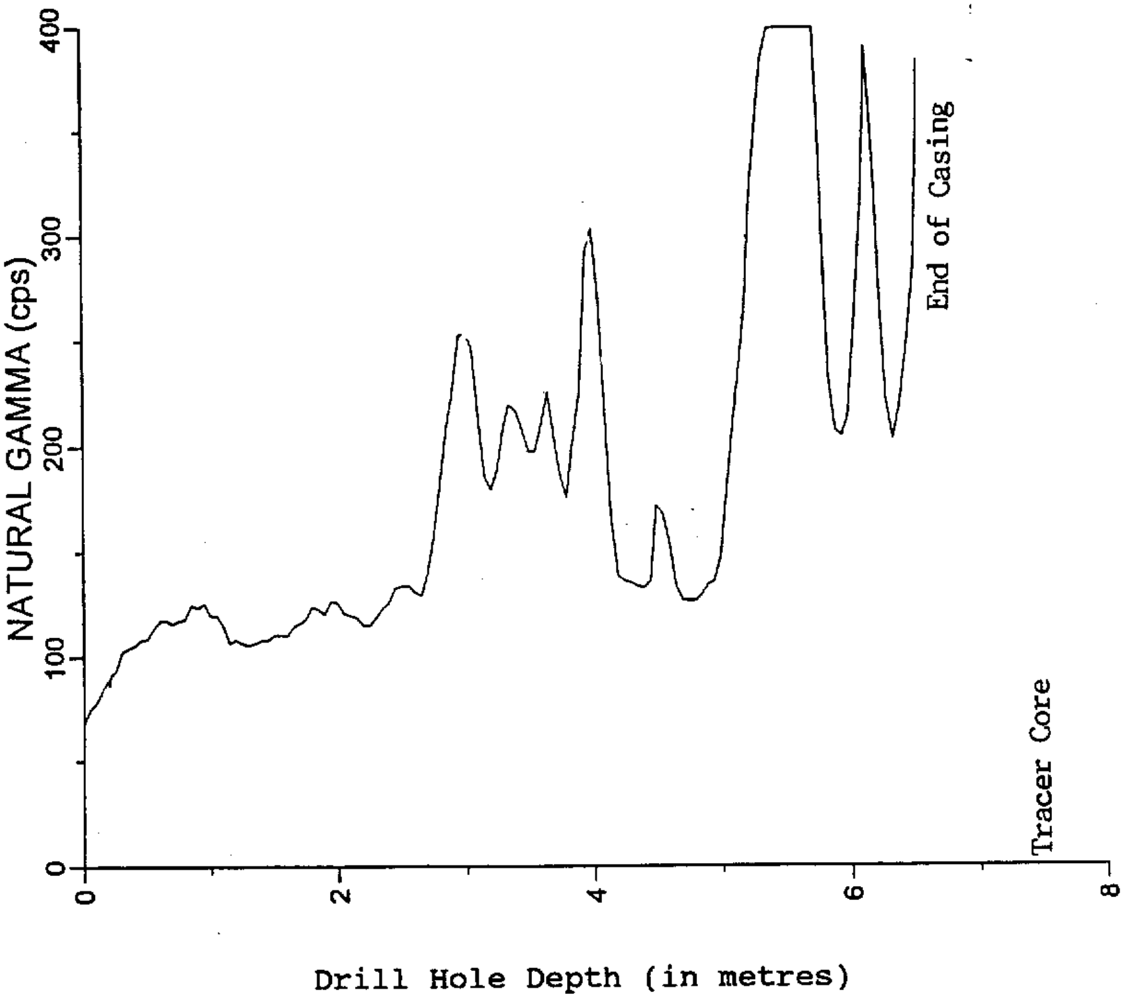
Note: The peaks indicate there were tracers left in this hole at the depths of 3, 5, 7, 8, 10, 13 and 15 metres.

FIGURE 10
Down-Hole Scintillometer Logs for Hole 92-7 (Cariboo)



Note: The peaks indicate there were tracers left in this hole at depths of 8, 9, and 10 metres. Some of the tracers were carried part way up and stuck on the side of the hole.

FIGURE 11
Down-Hole Scintillometer Logs for Hole 92-9 (Cariboo)



Note: The peaks indicate there were tracers left in this hole at the depths of 3, 4, 5, and 6 metres of depth also show that some of the tracers which were lost were carried part way up and stuck on the side of the hole.

The holes were drilled without any casings. With no casings in the collar of the hole, it was impossible to seal the hole and provide effective reverse circulation of drill cuttings. During drilling, there was almost always a small geyser of blow-by solids and water around the collar of the drill hole (Photo 17, Figure 5 [R/C]). A large proportion of the cuttings and tracers were forced up along the outside of the drill rods and landed on the ground near the collar of the hole.

Some of the drill cuttings were forced through ports on the inside of the rotary bit, up the drill rod's center tubing, through the rotary head, through the hose and into a sampling cyclone and were collected in buckets. All of the tracers which were recovered were blown out of the hole (one way or another) by the time the bit had drilled 3 m (10 feet) past where the tracer cores were originally placed.

Even though surges of high pressure air were used to flush the systems, many tracers were caught and remained in the hose, hose fittings and sampling cyclone. To remove the tracers, the cyclone and hose fittings often had to be taken apart and cleaned out (Photos 19 and 20). This contamination and carry-over of values would have an adverse affect on grade determinations.

Anywhere from 2 to 98 percent of the tracers were blown out of the holes. In the deepest hole (35 m, 115 ft) only two percent of the tracers were blown out of the hole with the rest remaining in the hole. One of blown tracers was on the ground next to the collar, and the other was trapped in the cyclone, yielding a net recovery of zero percent. Even in shallower holes (10 m, 33 ft) with relatively high recoveries, many of the tracers were lost due to spillage and to blow-by around the collar of the hole. Some of the tracers remained trapped in the sample cyclone or its plumbing and would have contributed to significant errors in grade estimation.

Any holes which remained open after completion of drilling were cased with 50 mm (2 in) diameter plastic (PVC) pipe to as great a depth as possible to accommodate a down-hole scintillometer at a later date. Figures 9, 10 and 11 display the gamma logs of the three holes which remained open. The peaks on Figure 9 for hole no 92-4 indicate that there were tracers left in this drill hole at the various depths of 3, 5, 7, 8, 10, 13 and 16 metres. The peaks on Figure 10 for hole no 92-7 at 8, 9 and 10 metres of depth indicate that some of the tracers which were lost in the hole were carried part way up and stuck on the side of the hole. The peaks of Figure 11 for hole no 92-9 at 3, 4, 5 and 6 metres of depth also show that some of the tracers which were lost in the hole were carried part way up (in blow-by) and stuck on the side of the hole.

PHOTO 17
Blow-by at Collar of Drill Used in the Cariboo

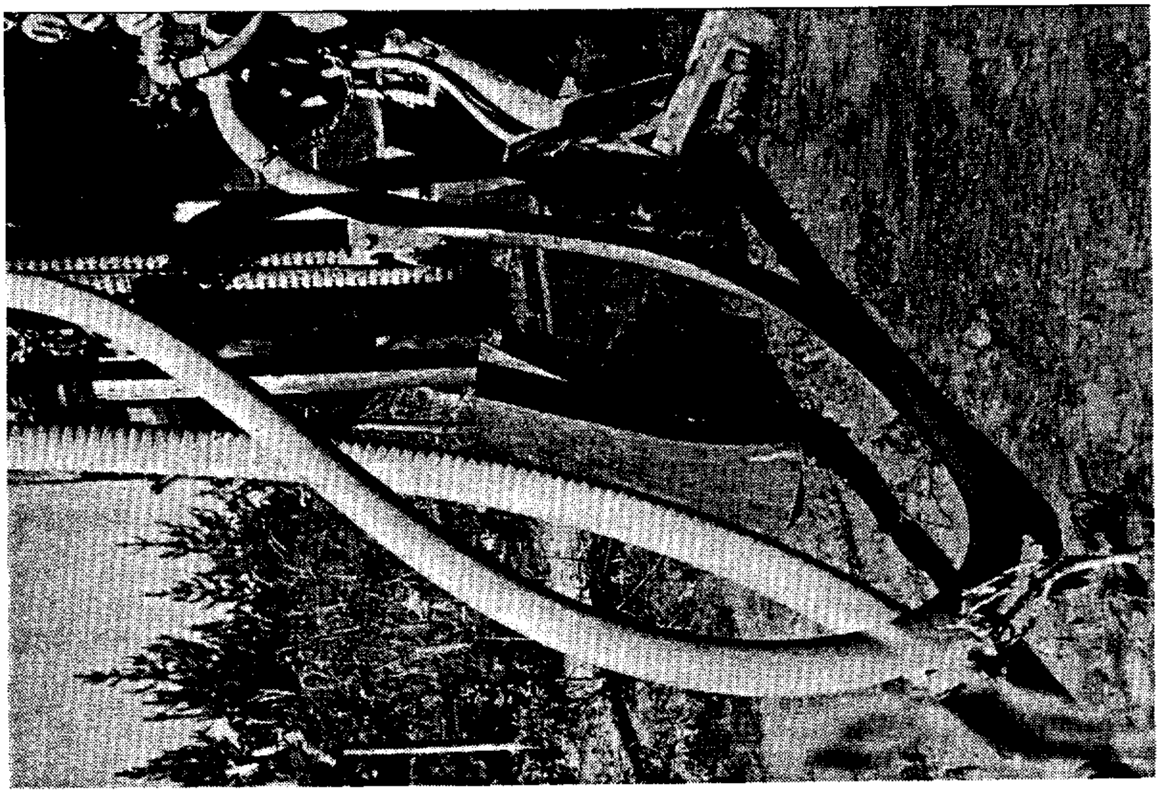
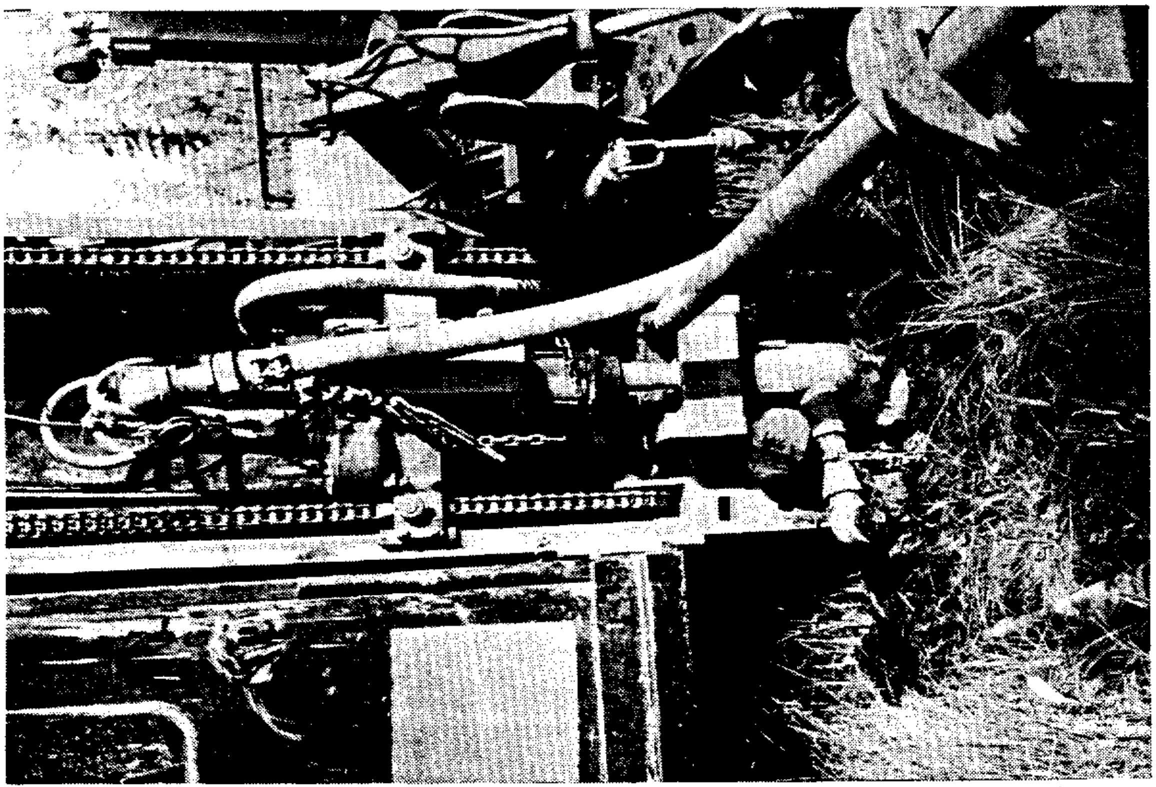


PHOTO 18
Cased and Sealed Collar Eliminates Blow-by Losses



The columns in the following Table 5 display the depth at which permafrost starts (if applicable), the moisture in the hole (or if 'Water' was used during drilling), the bottom of various soil horizons such as (Grav)el and the bottom (Bot) of the hole in metres. The adjacent columns indicate the depth at which the drill rods were pulled (Pull) prior to adding the radiotracer core and depth at which it stuck (Locn) when dropped. The final five columns display the net recovery (Rec) of tracers in the sampling system, the losses due to spillage (Spil), carry-over (C/O) and blow-by (Blo) around the collar of the hole as well as the total (Totl) percentage of tracers removed from the hole.

TABLE 5
A Summary of Reverse Circulation Drill Holes in the Cariboo

Hole	Frost	Wet?	Muck	Till	Grav	Bot	Pull	Locn	Rec	Spil	C/O	Blo	Totl
92-4	N/A	Water	0.3	19.5	36.6	38.1	36.6	4.0	0%	0%	1%	1%	2%
92-7	N/A	Water	0.3	8.2	27.1	29.0	10.7	10.0	16%	1%	7%	46%	70%
92-9	N/A	Water	0.0	?	17.4	18.3	10.4	7.6	1%	0%	0%	23%	24%
92-10	N/A	Water	0.3	10.7	15.2	16.8	10.7	10.1	82%	16%	0%	0%	98%
Average			0.2	9.6	24.1	25.5	17.1	7.9	25%	4%	2%	18%	49%

Note: The poor overall recovery in holes 92-4, 92-7 and 92-9 is due to caving in these drill holes which is aggravated by the erosive action of the compressed air and water.

A high proportion of tracers were lost to blow-by due to the absence of a seal at the collar of the hole.

The radiotracer core was stuck above the bottom in holes 92-4 and 92-9.

PHOTO 19
Detecting Radiotracer Carry-Over in Cyclone

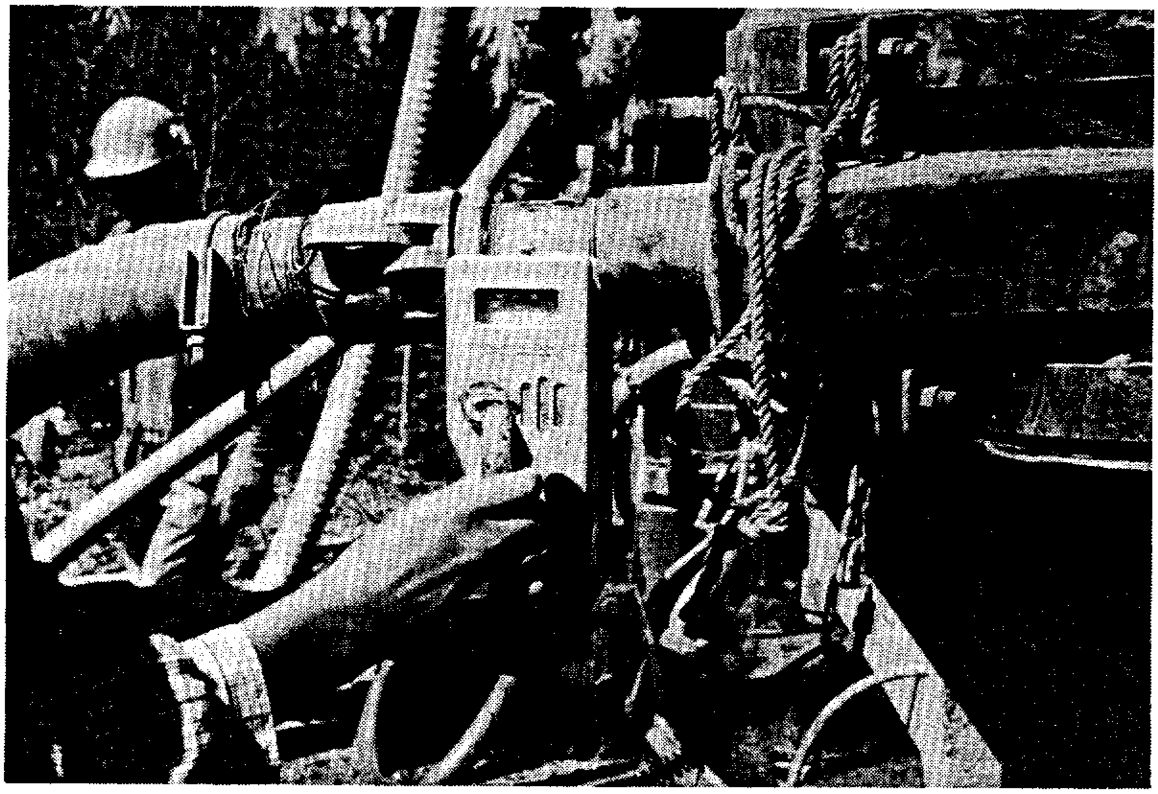
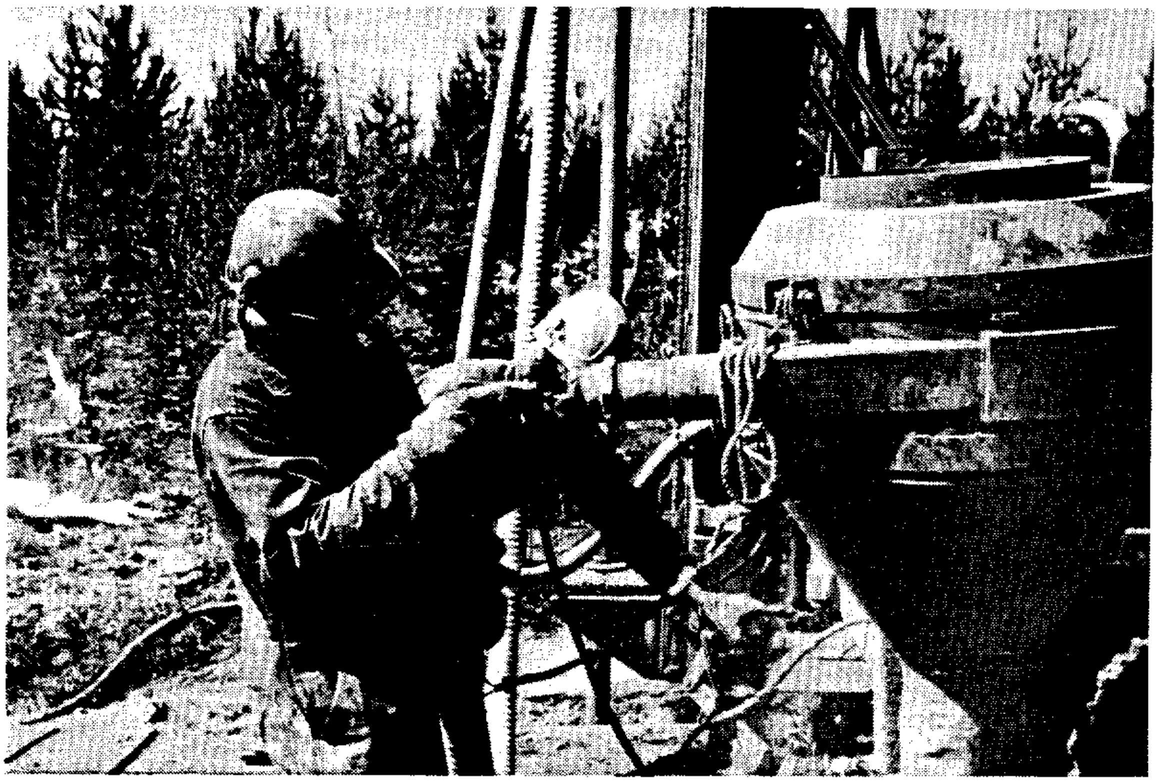


PHOTO 20
Cleaning Radiotracers Out of the Sampling Cyclone



8.2.2 Klondike Reverse Circulation Drill Tests

From September 2-7, 1992, a reverse circulation drill with a down-the-hole hammer was tested with radioactive gold tracers at two locations in the Klondike placer mining area.

The placer gold at the first location occurred on the left limit of a major river valley characterised by very great depths of organic black muck followed by shallow, pay-gravel lenses and bedrock of Klondike schist. It was very difficult to drill in this area due to a combination of deep black muck and water inflow problems. An auger drill had previously attempted to drill holes here and had aborted after losing several rods in the deep, partially-frozen muck of its second hole. Two of the four holes drilled here were tested with radiotracer cores. The net recovery ranged from 70% in the first hole to 0% in the second hole.

The second drilling location was on the low benches of a narrow creek valley. This area had a much thinner black muck layer and permanently frozen gravels more typical of Klondike placer mines. There was evidence of older underground workings near some of the drill sites. Net recovery ranged from 88% to 0% for the five holes tested.

The Schramm TH64 drill (Photo 16) was fitted with a down-the-hole hammer and 110 mm (4.25 in) diameter carbide button bit. The 95 mm (3.75 in) diameter reverse circulation drill rods consisted of a 48 mm (1.88 in) diameter center air/cuttings return tube and an outer annulus which supplied compressed air to the hammer. The air cross-over fitting was located between the hammer and the drill rods. The cross-over redirected compressed air from the drill rod annulus to the center of the hammer and contained two slotted ports above the air cross-over to allow spent compressed air and drill cuttings to return up the center tube of the drill rods.

Drill cuttings had to be forced outside the button bit and travel 1.3 m (4.25 ft) up and around the outside of the hammer to these two sample return ports (Figure 8 [cross-over]). From the top of the drill rods, spent air and cuttings were directed through a swivel head assembly and hose to a multi-chamber sampling cyclone (Photos 21 and 22). Approximately 0.28 cms (600 cfm) of compressed air at 1.72 MPa (250 psi) was forced down the outer annulus of the drill rods to power the down-the-hole hammer and flush cuttings away from the button bit.

PHOTO 21
Multi-Chamber Sampling and Splitting Cyclone

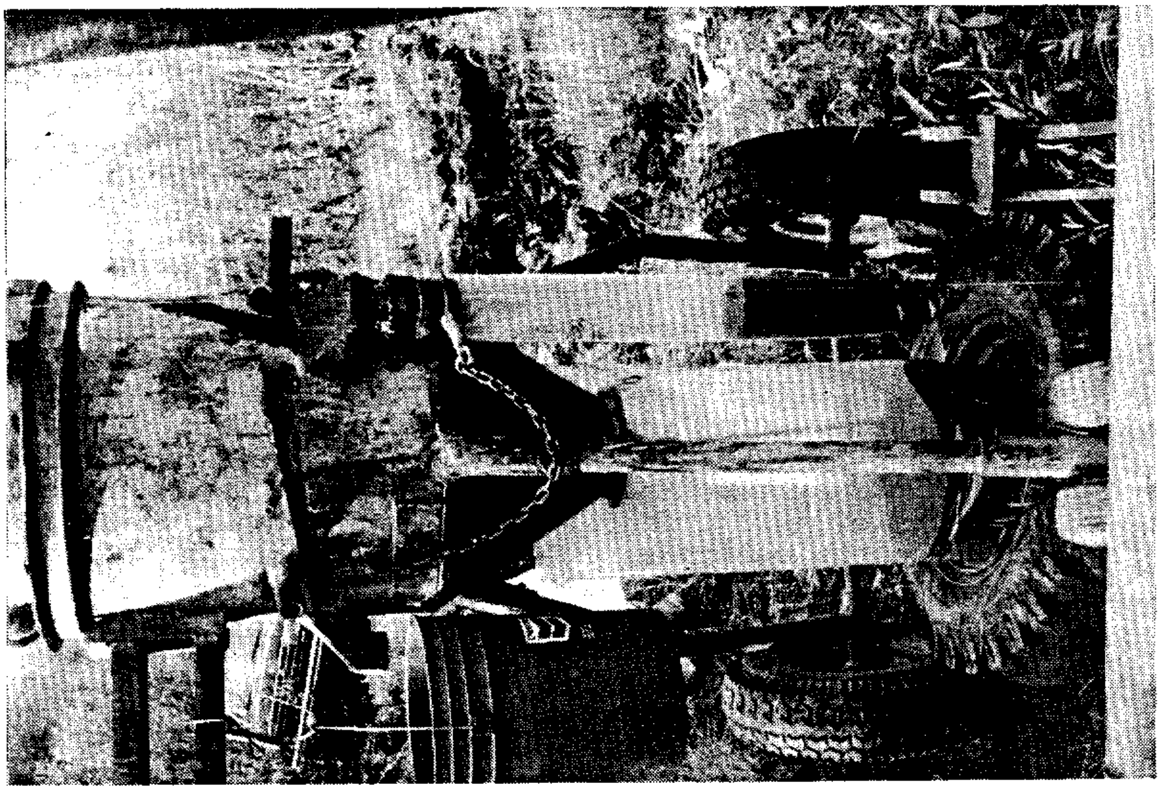
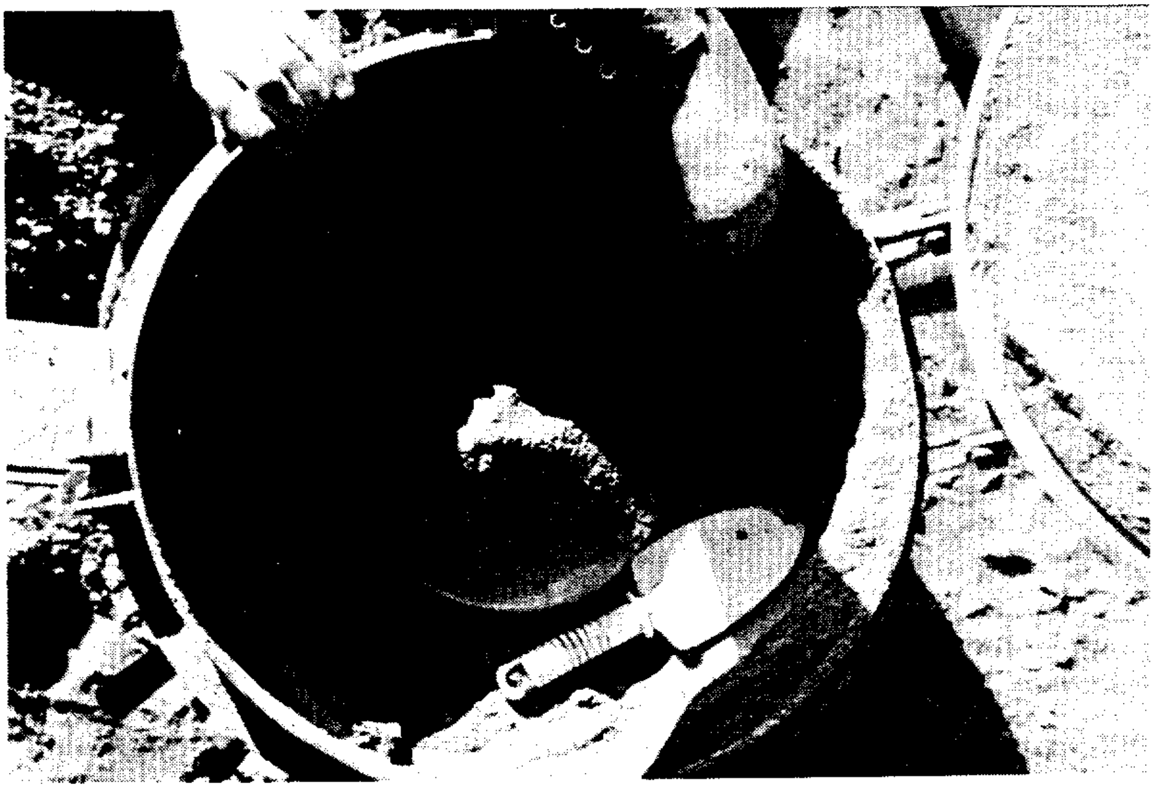


PHOTO 22
Cleaning Radiotracers Out of Multi-Chamber Cyclone



Penetration was achieved with the down-the-hole hammer, down pressure and rotation of the bit. The penetration rate varied from 8-30 m/h (26-100 ft/h) in frozen black muck (slower with higher water content), to 13-23 m/h (42-75 ft/h) in frozen gravel, to 12 m/h (40 ft/h) in boulders and to 14 m/h (47 ft/h) in bedrock. From 30 to 90 minutes was required to drill and install the 3 m (10 ft) of casing and to remove the Odex bit assembly and replace it with the down-the-hole hammer for each hole. Drilling production rate was approximately 15-47 m (50-155 ft) per day for a two person crew including about 3-6 hours each day for set-up and moves.

Four of the six holes were drilled with water addition which was pumped from nearby ponds. This driller advised that water injection was required to prevent plugging the rods whenever moist or thawed gravels or muck were encountered. The addition of water to the drill's compressed air flushing system increased segregation and entrapment (carry-over) of gold tracers. Water addition also increased spillage losses and made it extremely difficult to collect and contain the samples.

A 140 mm (5.5 in) diameter casing was driven 3 m (10 ft) into the collar of every hole to create a seal of the collar and to promote efficient reverse circulation. The casing hole was drilled with a specialised pilot and 152 mm (6 in) diameter retractable "Odex" reaming bit assembly. This bit assembly had no cross-over and forced the spent air and cuttings to the outside of the rods where they were directed at the top of the hole (normal circulation) through a packing box and hose to the sampling cyclone.

The casings were pushed into the hole using hydraulic pressure. Once the casings were installed, the Odex bit assembly was retracted and removed from the hole to be replaced with a conventional button bit, down-the-hole hammer and cross-over assembly. The sealed casing at the collar of each hole virtually eliminated the blow-by air and drill cuttings losses encountered while drilling in the Cariboo (Photos 17 and 18). Radiotracers still occasionally stuck in the swivel, hose and cyclone (Photos 21 and 22) and there were still large losses from spillage and carry-over.

The columns in the following Table 6 display the depth at which permafrost starts (if applicable), the moisture in the hole (or if 'Water' was used during drilling), the bottom of various soil horizons such as (Grav)el and the bottom (Bot) of the hole in metres. The adjacent columns indicate the depth at which the drill rods were pulled (Pull) prior to adding the radiotracer core and depth at which it stuck (Locn) when dropped. The final five columns display the net recovery (Rec) of tracers in the sampling system, the losses due to spillage (Spil), carry-over (C/O) and blow-by (Blo) around the collar of the hole as well as the total (Totl) percentage of tracers removed from the hole.

TABLE 6
A Summary of Reverse Circulation Holes in the Klondike

Hole	Frost	Wet?	Muck	Till	Grav	Bot	Pull	Locn	Rec	Spil	C/O	Blo	Totl
K1	0	Water	16.8	N/A	19.8	21.3	18.3	18.3	70%	6%	16%	0%	92%
K2	0	Water	4.6	N/A	?	15.2	15.2	6.1	0%	0%	0%	4%	4%
T1	0	Dry	0.3	N/A	13.7	15.2	13.1	13.1	52%	26%	22%	0%	100%
T3	0	Dry	0.0	N/A	10.4	13.7	12.2	12.2	88%	0%	12%	0%	100%
T4	Part	Water	0.0	N/A	12.5	13.7	6.1	5.2	0%	2%	18%	2%	22%
T5	Part	Water	14.0	N/A	15.2	19.8	15.2	3.7	15%	59%	15%	0%	90%
Average			5.9		11.9	16.5	13.4	9.8	38%	16%	14%	1%	68%

Note: Holes K1 and K2 were frozen deep black muck holes. Hole K2 ran into water and was then drilled with water injection and without reverse circulation due to plugging in the down-the-hole hammer. This hole (K2) had no net tracer recovery but blew 4% of the tracers out the collar. Blow-by losses were much lower than with the reverse circulation drill used in the Cariboo due to the use of 3 m (10 ft) of casing and a packing box at the top of each hole (Photo 18).

Holes T1 through T5 were drilled in permafrost on low creek benches. Water injection was used for holes T4 and T5 due to potential hammer plugging problems. Many of the losses in hole T5 were related to spillage and the difficulty of containing sloppy samples. Potential spillage losses were extreme whenever water was mixed with the samples.

The extremely low tracer recovery in drill holes K2, T4 and T5 is due to caving which was aggravated by the erosive action of the compressed air and water. The potential carry-over of values from hole to hole was increased compared to the Cariboo drill due to the use of a complicated sample splitting cyclone with many compartments and resulting gold traps.

8.2.3 Alaskan Reverse Circulation Drill Tests

Dan Walsh tested a reverse circulation drill with a rotary tri-cone bit using tantalum visual tracers in the early August, 1994 in the Melozitna mining district of Alaska (pers comm Walsh).

The Schramm T685 DHH drill was mounted on a Nodwell 360 all-terrain transporter which was fitted with a 425 l/s (900 cfm) air compressor. The drill consisted of a relatively large 200 mm (7.9 in) diameter skirted tri-cone bit and 194 mm (7.6 in) diameter drill rods. The drill rods were only slightly smaller in diameter than the bit and helped create a seal to promote better reverse circulation. No surface or other casings were drilled to seal the hole. The rods consisted of a 61 mm (2.4 in) diameter center tube to transport sample cuttings from the bottom of the hole and an outer annulus to carry the compressed air used to flush the drill cuttings. Approximately 425 l/s (900 cfm) of compressed air at 0.69 GPa (100 psi) was forced down the outer annulus of the rods.

There was no down-the-hole or other hammer action. Penetration was achieved with down pressure and rotation of the bit. The penetration rate averaged about 9 m/h (30 ft/h). A two person crew drilled a total of about 60 m (200 ft) per day including moves, set-ups, sample processing and tantalum tracing for the shallow 8 m (25 ft) holes (pers comm Walsh).

Most of the potential spillage losses due to sample collection, storage and handling were avoided by piping the drill cuttings slurry directly from the drill into the hopper of the gold recovery unit. No sampling cyclone or buckets were used to transfer the drill cuttings. A combined small trommel screen and small sluice run (Denver Gold Saver) was used to process the samples. The sluice run trays were removed between sample intervals, cleaned and the concentrates were hand panned. The sample tailings from the first two tests were checked for losses and only one tantalum tracer was found in the tailings from the first test (pers comm Walsh).

The columns in the following Table 7 display the depth at which permafrost starts, the moisture in the hole (or if 'Water' was used during drilling), the bottom of various soil horizons such as (Grav)el and the bottom (Bot) of the hole in metres. The adjacent columns indicate the depth at which the drill rods were pulled (Pull) prior to adding the radiotracer core and depth at which it stuck (Locn) when dropped. The final columns display the net recovery (Rec) of tracers in the sampling system at the sampling interval the tracer core was placed and the carry-over (C/O) into other sampling intervals or drill holes and the total (Totl) percentage of tracers removed from the hole. **Non-radioactive tantalum tracers do not readily allow the determination of the losses due to spillage (Spil) and blow-by (Blo) around the collar of the hole or the presence of tracers still remaining in drilling or gold recovery equipment.**

TABLE 7
A Summary of Reverse Circulation Holes in Alaska
(from Walsh, 1995)

Hole	Frost	Wet?	Muck	Till	Grav	Bot	Pull	Locn	Rec	Spil	C/O	Blo	Totl
1	Yes	No	4.0	N/A	6.7	10.7	5.2	5.2	86%	N/A	12%	N/A	98%
2	No	Wet	0.6	N/A	3.7	6.1	3.4	3.4	72%	N/A	16%	N/A	88%
3	Yes	Wet	1.2	N/A	7.0	9.1	5.2	5.2	11%	N/A	18%	N/A	29%
4	Yes	Wet	1.8	N/A	7.6	12.2	4.9	4.9	56%	N/A	9%	N/A	65%
Average			1.9		6.2	9.5	4.6	4.6	56%	N/A	14%	N/A	70%

Note: Walsh (1995) indicates that tracer recoveries for the interval where the tracer core was introduced ranged from 10-82% and 12-88% for fine (0.6-1.2 mm, -14+28 mesh) and coarse (1.2-2.4 mm, +8-14 mesh) tracers respectively. Tracer recoveries for the entire hole where the tracer core was introduced ranged from 32-84% and 16-90% for fine and coarse tracers respectively.

The ability of this R/C drill to recover tantalum tracers from a hole seems closely tied to the blow-by conditions of the drill hole. Tracer tests 1 and 2 occurred in holes with average to good blow-by conditions (where the collars were well sealed). Bad blow-by (poor collar seal) conditions existed for tracer tests 3 and 4 and tantalum tracer recoveries suffered (Walsh 1995).

Tantalum tracers were also recovered from several intervals beyond the interval where the tracer was added and as many as four holes beyond the hole in which the tracer core was introduced. These carry-over recoveries (potential contamination) ranged from 2-18% for coarse tracers and from 8-24% for fine tracers.

Carry-over losses seem unrelated to the quantity of tracers recovered from the drill interval where the tracer core was introduced and must be attributed to mechanical traps within the drill's cutting recovery system, perhaps occurring within the drill bit, pipe fittings and the gold recovery unit.

8.3 AUGER DRILLS

Three different auger drills were tested at five locations in the Klondike. A large Westquip B80 was tested on several low river benches. A smaller Mobile auger drill was tested on a high bench White Channel deposit and adjacent to a major river. A much smaller converted seismic blast hole drill was tested at two narrow valley areas, one with deep frozen black muck.

There was no hammer action in the auger drills and they did not use compressed air or water. Penetration was achieved by down pressure and rotation of the bit. In general, the rotational screw action of auger drills was less erosive and less likely to cave a potentially unstable drill hole than the action of reverse circulation drills. Auger drill holes were usually smooth walled and relatively stable even under relatively wet and/or thawed conditions.

The augers attached to the drill rods leave some of the drill sample compressed against the sides (or annulus) of the hole as the larger diameter bit cuts its way down the hole. Usually the density of the soils in the annulus is lower than the original pay gravels, but the actual density of this material is very variable, depending on the amount of compression, moisture and freezing occurring in this part of the drill hole. The theoretical maximum average gold recovery of an auger drill is the ratio of the area cut by the bit over the area of the hole carried away by the augers. For example, with a 175 mm (6.9 in) bit and a 140 mm (5.5 in) auger, this ratio or theoretical recovery is 64%. The average recovery listed in Table 5 is 63%.

Unlike reverse circulation drills, auger drills do not provide an instant sample of the drill cuttings. The drillers had to wait until the cuttings worked their way up the augers to surface to confirm the depths of soils inferred from changes in the sound and vibration of the drill. In general, auger drills are also less expensive to own and operate, and have less weight and are easier to operate.

The auger flights carried some of the sample to surface where it was contained in a large flat pan around the drill hole (Photos 23 and 25). The remaining sample volume was scraped and brushed from the auger flights when the auger rods were pulled. There was rarely any potential carry-over of tracers when the auger flights were brushed thoroughly (Photo 27).

The location of tracers recovered in the sample while drilling as well as their location in material brushed from the auger flights (while the rods were being pulled) were noted in each hole to help understand the drilling action. In general, tracers were only found on the auger flights which were located above the original depth of the tracer core. This indicated that the tracers did not follow the bit down the hole but were either carried out of the hole or forced with other loose material onto the annulus of the hole. With every hole except AF2H2 (Table 9) the stemming (20-40 litres of barren gravels) which was dropped down on top of the tracer core returned to surface ahead of any tracers.

8.3.1 Large Auger Drill

From June 22 to July 1, 1992, a large auger drill was tested with radiotracer cores on several low lying benches next to a small river in the Klondike placer mining area of the Yukon Territory. A total of 13 holes were tested. In one partially thawed hole (C3H5) the tracer core was pushed through a caved zone to the bottom of the hole and still resulted in a high tracer recovery (65%).

The Westquip B80 Mobile auger drill was mounted on a Nodwell wide track carrier (Photo 23) . The driller used a fish-tail bit for deep sections of frozen or thawed black muck and a modified fish-tail bit fitted with carbide buttons for gravels and bedrock drilling (Photo 24). The fish-tail bit was less likely to plug in black muck but had poor penetration and wore out quickly in the frozen gravels. The bits were 175 mm (6.9 in) in diameter. The drill rods consisted of a set of auger flights welded onto round 67 mm (2.6 in) bar. The auger flights ranged from 140 mm (5.5 in) to 130 mm (5.2 in) in diameter depending on their wear.

The drill rotated relatively slowly at between 16-20 rpm. The penetration rate varied from 15 m/h (50 ft/h) in loose sand to 5 m/h (18 ft/h) in frozen gravels and to 1.5 m/h (5 ft/h) in hard bedrock. Drilling rates with a one person crew ranged from 18 m (60 ft) to 30 m (100 ft) per day with an allowance of 2 to 4 hours for moves.

The first eight holes were drilled with a wide (140 mm) auger section on the bottom of the drill string. This made the augers more difficult to pull and also scraped unconsolidated material from the annulus of the upper sections of the drill hole onto the bottom augers.

PHOTO 23
Westquip B80 Large Auger Drill

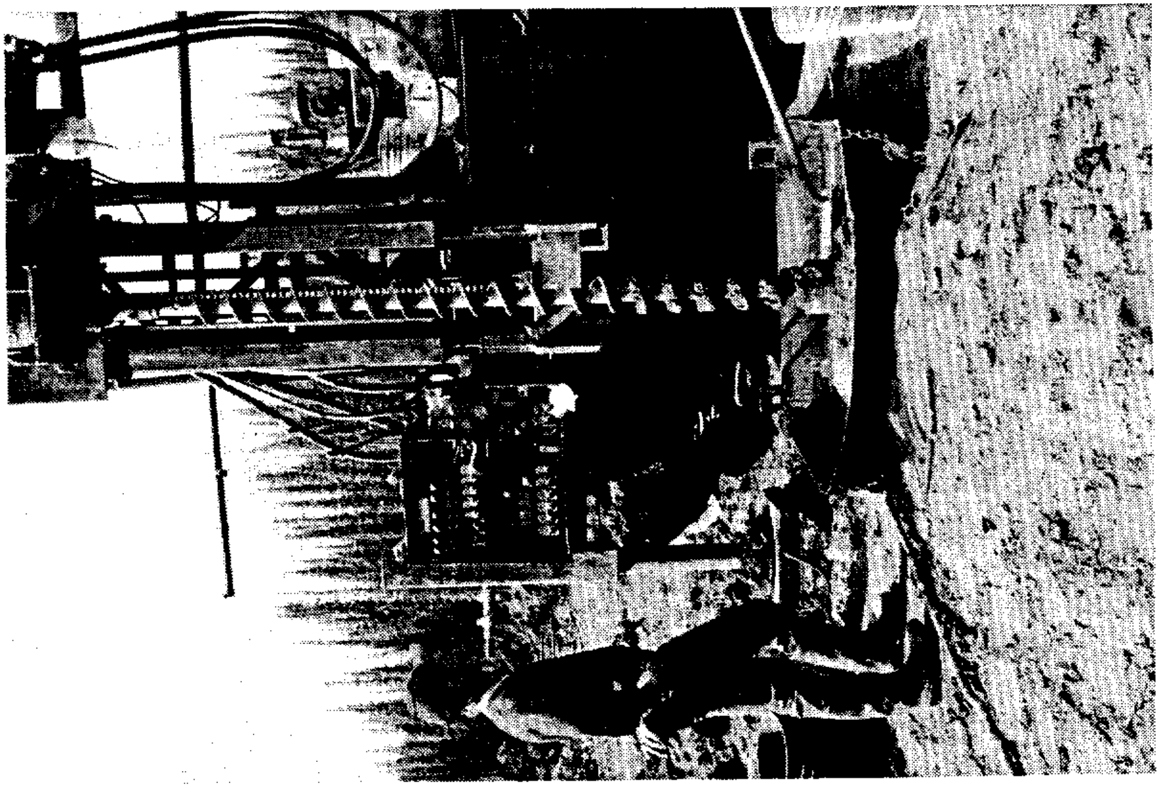
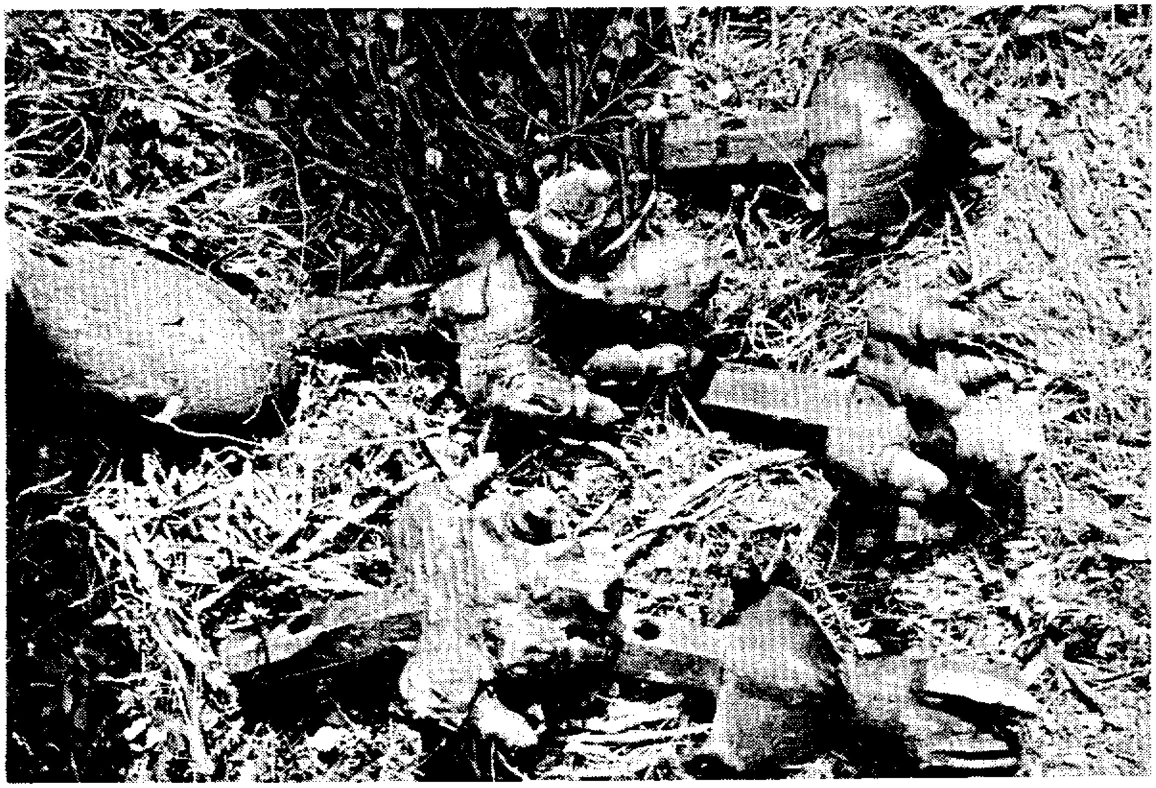


PHOTO 24
Auger Drill Bits (fish-tail on upper right)



The columns in the following Table 8 display the depth at which permafrost starts (if applicable), the moisture in the hole (or if 'Water' was used during drilling), the bottom of various soil horizons such as (Grav)el and the bottom (Bot) of the hole in metres. The adjacent columns indicate the depth at which the drill rods were pulled (Pull) prior to adding the radiotracer core and depth at which it stuck (Locn) when dropped. The final five columns display the net recovery (Rec) of tracers in the sampling system, the losses due to spillage (Spil), carry-over (C/O) and blow-by (Blo) around the collar of the hole as well as the total (Totl) percentage of tracers removed from the hole.

TABLE 8
A Summary of Auger Drill Holes (Large Auger Drill)

Hole	Frost	Wet?	Muck	Till	Grav	Bot	Pull	Locn	Rec	Spill	C/O	Blo	Totl
B9H1	0.0	Dry	1.5	N/A	3.0	3.7	2.4	2.4	82%	0%	0%	0%	82%
B9H3	0.0	Dry	1.8	Sand	4.6	5.5	2.7	2.7	78%	0%	0%	0%	78%
B10H1	2.1	N/A	0.6	N/A	3.7	4.6	2.4	0.7	35%	0%	0%	2%	37%
B10H2	2.1	Wet	1.5	N/A	4.0	4.9	2.7	0.8	68%	0%	0%	0%	68%
C1H1	0.0	Dry	1.8	N/A	3.4	4.9	3.7	1.1	38%	0%	0%	10%	48%
C1H2	2.1	Moist	0.6	N/A	4.3	4.9	4.3	1.3	70%	0%	0%	0%	70%
C1H3	2.1	Moist	0.6	N/A	4.3	5.2	3.7	1.1	74%	0%	0%	2%	76%
C2H4	1.8	Moist	0.9	N/A	4.3	6.1	3.7	1.1	31%	0%	0%	1%	32%
C3H5	1.5	Wet	2.7	N/A	3.4	4.3	3.4	0.9	65%	0%	0%	1%	66%
O4H1	0.0	Moist	1.5	N/A	1.5	3.4	2.1	0.7	48%	0%	0%	0%	48%
O4H2	0.0	Moist	9.0	N/A	4.6	5.8	4.6	1.4	61%	0%	0%	0%	61%
O4H3	1.0	Dry	5.0	N/A	5.2	6.1	3.0	0.9	86%	0%	0%	0%	86%
O4H4	0.0	Dry	3.0	N/A	4.3	4.9	3.0	0.9	88%	0%	0%	0%	88%
Avera	1.0		2.4		3.9	4.9	3.2	1.2	63%	0%	0%	1%	65%

Note: These relatively shallow holes were all drilled on low benches in a narrow river valley. All of the holes were in permafrost but some minor thawing near the collar of the holes was encountered where the area was stripped and/or right next to the river.

The average net recovery (63%) is close to the maximum theoretical recovery of 64%. The theoretical recovery is based on the ratio of the areas of the 175 mm (6.9 in) diameter bit and 140 mm (5.5 in) diameter augers. The recovery for each hole is very consistent compared to reverse circulation data.

The tracer core was pushed down 2.5 m (8 ft) past a thawed and caved area of Hole C3H5 and still resulted in a good overall gold recovery (65%).

The sampling procedures for drill holes O4H3 and O4H4 were modified from continuous to interval sampling. The auger rods for hole O4H3 were pulled and cleaned at 4.6 m (15 ft) and again at 6.1 m (20 ft), and three more tracers were scraped off the annulus of the hole on the second pull. The augers for hole O4H4 were pulled at 4 m (13 ft) of depth and again at the 4.9 m (16 ft) of depth, however, no more tracers were recovered on the second pass of drilling. These data indicate that between 0 and 3% of the gold values in a drill hole could be carried over when separate intervals of 1.5 m (5 foot) were sampled with an auger drill.

8.3.2 Mid-size Auger Drill

From August 2-10, a mid-size auger drill was tested drilling permafrost high bench White Channel gravels and shallow thawed river gravels. Due to scheduling constraints, only three holes were salted with radioactive gold tracers. The recovery of radiotracers averaged 87% overall with very high recoveries in the moist, thawed river gravels.

The Mobile auger drill was mounted on a small Nodwell wide track carrier (Photo 25). The driller used a fish-tail bit for deep black muck and had developed a modified fish-tail button bit for frozen gravel and bedrock drilling (Photo 24). The bits were 198 mm (7.8 in) in diameter. The 178 mm (7 in) diameter auger flights were welded onto round 67 mm (2.6 in) bar. The flights were checked and refaced regularly to ensure a consistent diameter.

The drill rotated at 17-18 rpm with a penetration rate ranging from 24 m/h (80 f/h) in thawed sand to 12 m/h (40 ft/h) in frozen gravels. Drilling rates with a one person crew ranged from 15 m (50 ft) to 27 m (90 ft) per day with an allowance of 2-3 hours per day for moves.

PHOTO 25
Mid-size Mobile Auger Drill

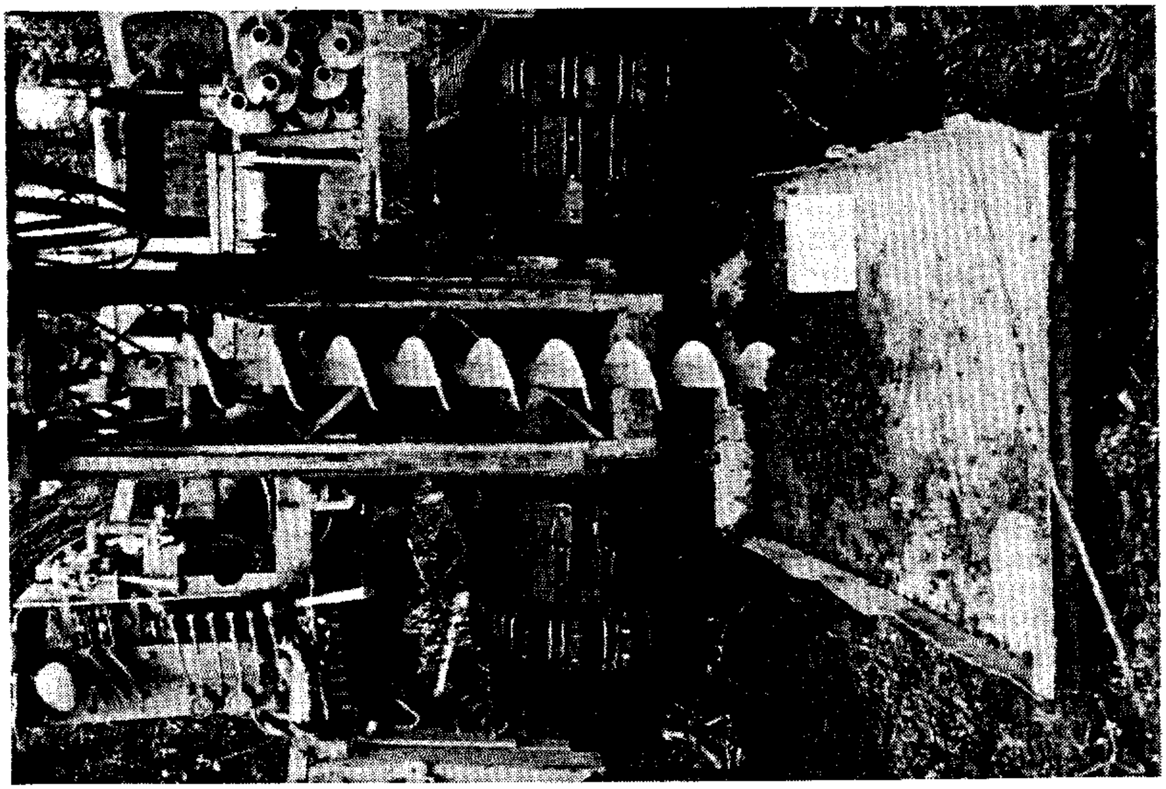
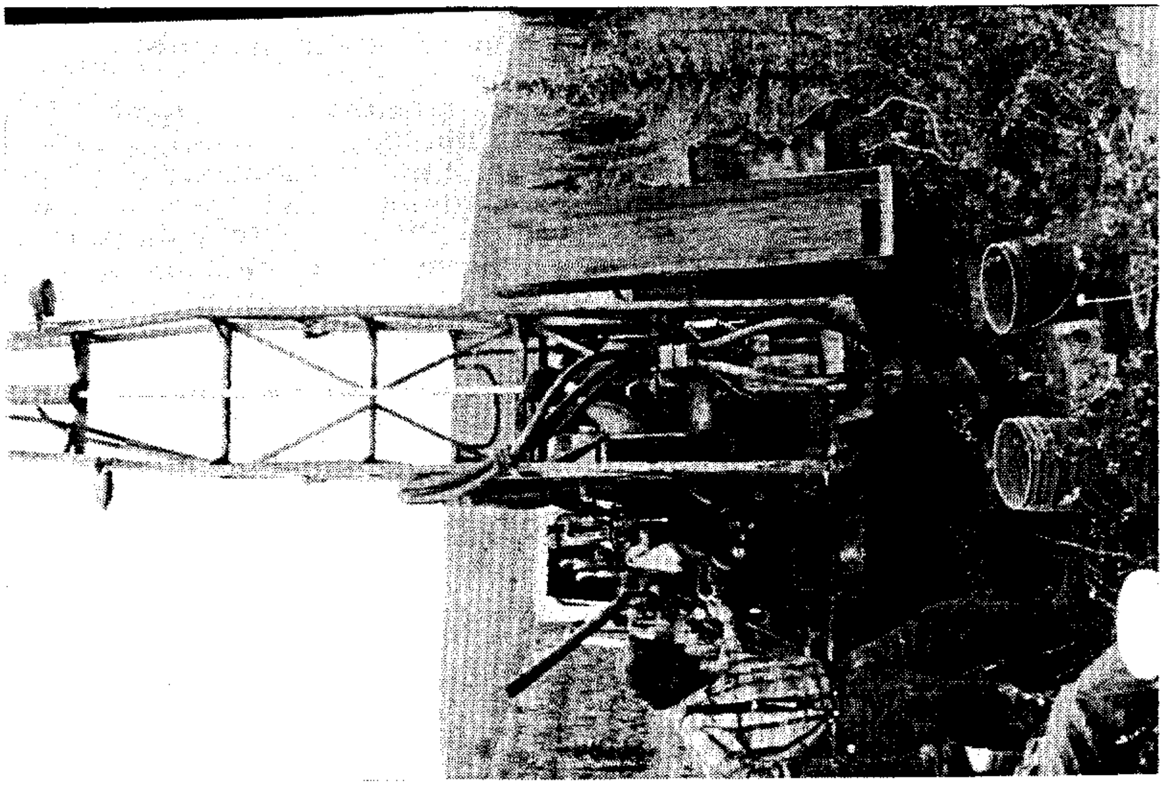


PHOTO 26
Failing FA-100 Small Auger Drill



The columns in the following Table 9 display the depth at which permafrost starts (if applicable), the moisture in the hole (or if 'Water' was used during drilling), the bottom of various soil horizons such as (Grav)el and the bottom (Bot) of the hole in metres. The adjacent columns indicate the depth at which the drill rods were pulled (Pull) prior to adding the radiotracer core and depth at which it stuck (Locn) when dropped. The final five columns display the net recovery (Rec) of tracers in the sampling system, the losses due to spillage (Spil), carry-over (C/O) and blow-by (Blo) around the collar of the hole as well as the total (Totl) percentage of tracers removed from the hole.

TABLE 9
A Summary of Auger Drill Holes (Mid-size Auger Drill)

Hole	Frost	Wet?	Muck	Till	Grav	Bot	Pull	Locn	Rec	Spill	C/O	Blo	Totl
AF2H2	0.0	Dry	8.2	N/A	11.6	13.1	9.1	9.1	72%	0%	0%	3%	75%
ASGH4	N/A	Moist	2.4	Sand	3.0	4.6	3.0	3.0	97%	0%	0%	N/A	97%
ASGH6	N/A	Moist	3.4	Sand	3.4	4.6	3.0	3.0	92%	0%	0%	N/A	92%
Average			4.7		6.0	7.4	5.1	5.1	87%	0%	0%	1%	88%

Note: AF2H2 was drilled in a deep frozen, high-bench, White Channel deposit. Only 20 litres of gravel stemming was dropped on top of the tracer core in this hole. It was not enough stemming and tracers were among the first sample to arrive at the collar of the hole. Several tracers remained near the collar of the hole.

A scintillometer was lowered down AF2H2 to determined the location of the tracers remaining in the hole (Table 9 and Figure 18).

ASGH4 and ASGH6 were drilled on the thawed and moist, low benches adjacent to a major river system. In each hole the drill was stopped because it was unable to penetrate a layer of large hard river boulders at a depth of 15 feet.

The average net recovery (87%) is very high compared to the maximum average theoretical recovery of 81% (based on the ratio of the areas of the bit and augers). This may be due to the smaller size of the annulus of the hole (10 mm for the medium vs 18 mm on the large auger drill), the relatively smaller size of the drill shaft and the relatively shallow depth (4.6 m) of two of the holes.

PHOTO 27
Cleaning a Radiotracer from a Sticky Auger

PHOTO 28
Lowering Scintillometer Down Auger Drill Hole

8.3.3 Small Auger Drill

A small auger drill was tested while drilling two very deep permafrost black muck holes on July 8-9. The same drill was tested again with a different operator on August 6-9 while drilling two shallower holes in a narrow valley setting. A total of four holes were tested with radiotracer cores. Low overall recoveries (30-32%) were recorded on the holes with deep black muck, whereas higher recoveries (60-74%) were achieved on the shallower holes. The 14-16 m depths of the first two holes were as deep as this small drill could go in frozen black muck.

The small converted seismic blast hole auger drill had no serial number or identification, but was later identified from photos as an FA-100 auger drill (Photo 26). The FA-100 was manufactured by George E Failing Rig and Drilling Supply of Calgary, Alberta. The drill was very light weight and was mounted on a 'Bombardier Muskeg' carrier with no hydraulic levelling pads.

The drillers used a fish-tail bit for deep black muck and had developed several similar modified fish-tail button bits for frozen gravel and bedrock drilling (Photo 24). The bits were 181 mm (7.1 in) in diameter. The auger flights were welded onto round 67 mm (2.6 in) bar and ranged from 140 to 146 mm (5.5 to 5.75 in) diameter depending on wear. The larger augers were used on the top of the hole.

This drill operated with a higher speed of between 19 to 45 rpm and a much lower push down force than the other two auger drills. The penetration rate varied from 7 to 14 m/h (20 to 45 ft/h) in frozen black muck to 4 m/h (13 ft/h) in frozen gravel and about 2 m/h (6 ft/h) in bedrock. Drilling rates with a one person crew ranged from 12 m (40 ft) to 22 m (72 ft) per day with an allowance of 2 to 4 hours for moves.

The columns in the following Table 10 display the depth at which permafrost starts (if applicable), the moisture in the hole (or if 'Water' was used during drilling), the bottom of various soil horizons such as (Grav)el and the bottom (Bot) of the hole in metres. The adjacent columns indicate the depth at which the drill rods were pulled (Pull) prior to adding the radiotracer core and depth at which it stuck (Locn) when dropped. The final five columns display the net recovery (Rec) of tracers in the sampling system, the losses due to spillage (Spil), carry-over (C/O) and blow-by (Blo) around the collar of the hole as well as the total (Totl) percentage of tracers removed from the hole.

TABLE 10
A Summary of Auger Drill Holes (Small Auger Drill)

Hole	Frost	Wet?	Muck	Till	Grav	Bot	Pull	Locn	Rec	Spil	Car	B/O	Totl
GCH14	0.0	Dry	6.1	Sand	12.2	13.7	11.3	9.1	30%	0%	0%	0%	30%
GCH15	0.0	Dry	15.8	N/A	N/A	15.8	12.5	10.3	32%	0%	1%	2%	35%
GM8	0.0	Dry	4.6	N/A	6.4	7.9	5.2	5.2	74%	0%	1%	0%	75%
GM9	0.0	Moist	5.2	N/A	6.4	7.9	5.2	5.2	60%	0%	2%	3%	65%
Avera	0.0		7.9		6.2	11.4	8.5	7.5	49%	0%	1%	1%	51%

Note: The relatively deep holes in frozen black muck had a low overall recovery of 30-32%.

Both GM8 and GM9 were drilled with a much higher rotational speed in shallower gravels.

The overall recovery of holes GM8 and GM9 (67%) compare favourably with the maximum theoretical recovery of 60% (based on a ratio of the areas of the augers over the bit).

8.3.4 Mid-size Auger Drill (1989 Tests)

The same auger drill as in section 8.2.2 was tested on a trial basis in 1989. However, a smaller bit and smaller 140 mm (5.5 in) diameter augers were used. The holes were drilled in a wide valley placer deposit in the Klondike mining area. All holes were drilled in permafrost black muck, gravels and Klondike schist bedrock typical to the Klondike area. The data listed in Table 8 are from these tests.

The columns in the following Table 11 display the depth at which permafrost starts (if applicable), the moisture in the hole (or if 'Water' was used during drilling), the bottom of various soil horizons such as (Grav)el and the bottom (Bot) of the hole in metres. The adjacent columns indicate the depth at which the drill rods were pulled (Pull) prior to adding the radiotracer core and depth at which it stuck (Locn) when dropped. The final five columns display the net recovery (Rec) of tracers in the sampling system, the losses due to spillage (Spil), carry-over (C/O) and blow-by (Blo) around the collar of the hole as well as the total (Totl) percentage of tracers removed from the hole.

TABLE 11
A Summary of Auger Drill Holes (Mid-size Auger Drill 1989)

Hole	Frost	Wet?	Muck	Till	Grav	Bot	Pull	Locn	Rec	Spil	C/O	Blo	Totl
515H	0.0	Dry	?	?	?	?	?	?	43%	?	?	?	43%
516H	0.0	Dry	?	?	?	?	?	?	68%	?	?	?	68%
530H	0.0	Moist	0.9	N/A	4.3	4.9	1.2	1.2	90%	?	?	?	90%
531H	0.0	Moist	2.4	N/A	4.6	5.8	3.7	3.7	74%	?	?	?	74%
539H	0.0		0.9	N/A	4.0	4.3	2.1	2.1	46%	?	?	?	46%
Avera	0.0		0.9	0.0	2.6	3.0	1.4	1.4	64%				64%

Note: These tests were performed in 1989 on a trial basis during sluicebox gold recovery research testwork and some of the data are not available.

The average recovery of 64% and relatively consistent recovery (43-90%) compares favourably with 1992 test data for the mid-size auger drill.

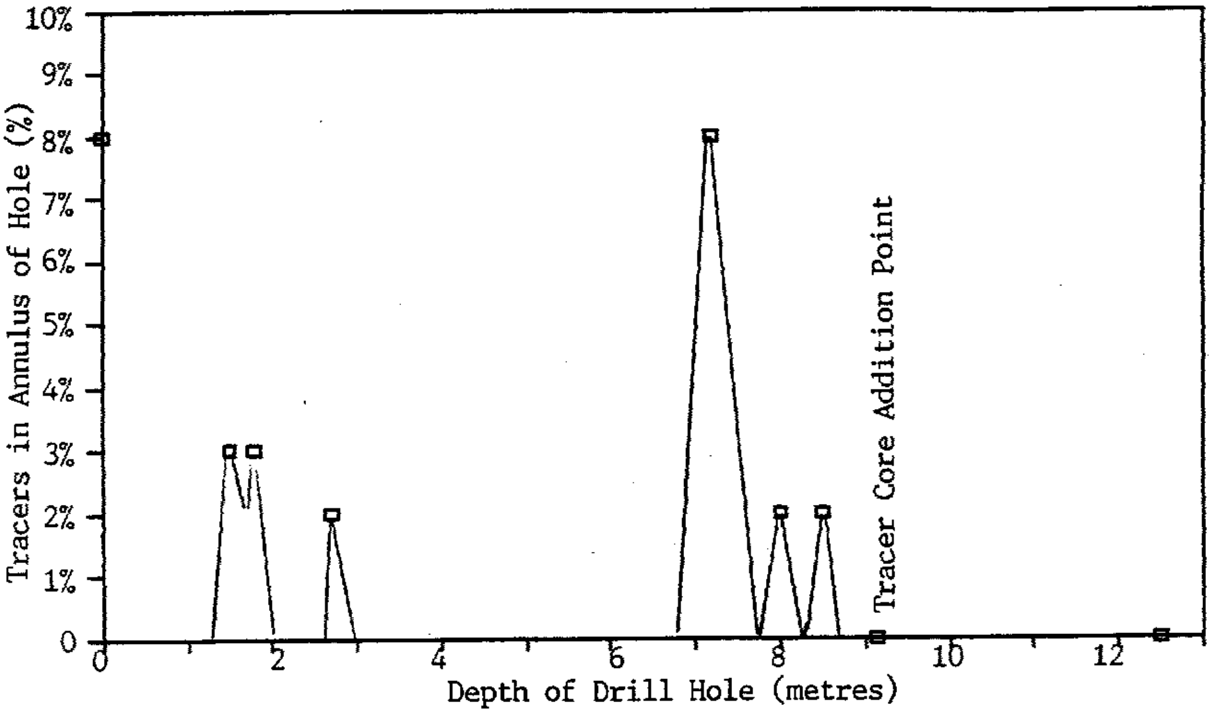
8.3.5 In-The-Hole Location of Tracers

The following Table 12 is a record of the location of tracers which remained in the annulus of the drill hole AF2H2 after testing. The locations of the tracers were determined by lowering a scintillometer down the 180 mm (7 in) diameter hole (Photo 28). All of the other holes were too small or too unstable to permit similar tests with a hand-held scintillometer.

TABLE 12
Location of Lost Tracers in Hole AF2H2
(These data are graphed on Figure 12)

Depth m	Depth ft	Tracers	Comments
0.0	0.0	8%	Hot Collar of Hole
1.5	4.9	3%	Small signal
1.8	5.9	3%	Small signal
2.7	8.9	2%	Small signal
7.2	23.6	8%	Medium signal
8.0	26.2	2%	Small signal
8.5	27.9	2%	Small signal
9.1	30.0	0%	Added Tracer Core
12.5	41.0	0%	Bottom Hole
Total		28%	

FIGURE 12
Down-Hole Scintillometer Logs for Auger Hole AF2H2



Note: Tracers are located at 2, 3, 7 and 8 metres of depth in hole AF2H2.

Most of the tracers which were not recovered from the hole were located just above the original placement of the radiotracer core and near the collar of the hole. Tracers appeared in the very first sample which was augured to surface. This indicated that a lot of material normally packed against the sides (annulus) of the hole had sloughed after the rods were pulled and the 20 litres of stemming (gravel) added was not sufficient to refill these gaps prior to drilling the radiotracer core.

8.4 STATISTICAL ANALYSIS OF DRILLING RESULTS

8.4.1 Analysis with Binomial Probability

To help evaluate which factors affecting the drilling may have had a significant effect on gold recovery, the standard errors for each size of radiotracers, each hole and each group of holes were determined and listed in the following tables. The standard errors from these radiotracer test were estimated from binomial probability theory with the equation:

$$SE = \{(n*p*q)^{0.5}\}/n,$$

where n is the total number of radiotracers added, p is the proportion recovered and q is the proportion lost. According to binomial probability theory, the true recovery should be within one standard error of the recovery estimate (14 times out of 20) and almost always within two standard errors of the recovery estimate (19 times out of 20).

The following Tables 13 through __ display the number of radiotracers used for each test and the corresponding recovery for each size of tracer (1.2-1.7, 0.6-0.8, 0.3-0.4, 0.15-0.2 mm) (+14-10, +28-20, +48-35 and +100-65 Tyler mesh). The recovery does not include losses due to spillage, carry-over or blow-by.

TABLE 13

Atlin Cased Normal Circulation Drill Tests

	Total Tracers in Core					Recovered in Drill				Samp	Hole Stnd
Hole	+14	+28	+48	+100	Total	+14	+28	+48	+100	Totl	Error
#2	25		25		50	68%		60%		64%	7%
#3	25		25		50	84%		84%		84%	5%
#6	25	25	25	25	100	86%	88%	71%	60%	76%	4%
Total	75	25	75	25	200	79%	88%	72%	60%	75%	3%
Standard Error by Size						5%	6%	5%	10%	3%	

Note: There is no significant difference between the recoveries of various sizes of gold particles in any given hole. The average recoveries are within two standard errors of each other.

The overall recovery of hole #6 where the tracer core was located well below the casing shoe is comparable to the overall recoveries of holes #2 and #3 where the tracer core was placed well above the casing shoe.

TABLE 14
Fort Steele Normal Circulation Drill Tests

Hole	Total Tracers in Core +14	+28	+48	+100	Total	Recovered in Drill +14	+28	+48	+100	Samp Totl	Hole Stnd Error
B1	25		25		50	96%		52%		74%	6%
B3	25		25		50	80%		68%		74%	6%
B4	25		25		50	92%		82%		87%	5%
B5		25		25	50		76%		76%	76%	6%
B6		50			50		87%			87%	5%
Total	75	75	75	25	250	89%	82%	67%	76%	80%	3%
Standard Error						4%	4%	5%	9%	3%	

Note: During the drilling of hole B2, the sampling cyclone tipped over and spilled the sample. Therefore the analysis does not include this hole.

There is no significant difference between the recovery of the five drill holes or between the recovery of all four sizes of gold.

TABLE 15
Reverse Circulation Drill Holes in the Cariboo

Hole	Total Tracers in Core +14	+28	+48	+100	Total	Recovered in Drill +14	+28	+48	+100	Samp Totl	Hole Stnd Error
92-4	25	25	25	25	100	0%	0%	0%	0%	0%	0%
92-7	25	25	25	25	100	32%	4%	4%	24%	16%	4%
92-9	25	25	25	24	99	4%	0%	0%	0%	1%	1%
92-10	25	25	25	25	100	84%	77%	84%	84%	82%	4%
Total	100	100	100	99	399	30%	20%	22%	27%	25%	2%
Standard Error by Size						5%	4%	4%	4%	2%	

Note: This drill also recovers all four sizes of gold equally well.

The significantly lower recovery of holes 92-4 may have been related to the caving at 4 m (13 ft) prior to the addition of the tracer core. However, 92-10's had caving in the hole and a much higher tracer recovery.

TABLE 16
Reverse Circulation Drill Holes in the Klondike

Hole	Total Tracers in Core					Recovered in Drill				Samp Totl	Hole Stnd Error
	+14	+28	+48	+100	Total	+14	+28	+48	+100		
K-1		25		25	50		76%		64%	70%	6%
K-2	25		25		50	0%		0%		0%	0%
T-1		24		22	46		54%		50%	52%	7%
T-3	25		25		50	88%		88%		88%	5%
T-4	25		25		50	0%		0%		0%	0%
T-5		25		24	49		12%		19%	15%	5%
Total	75	74	75	71	295	29%	47%	29%	44%	38%	3%
Standard Error by Size						5%	6%	5%	6%	3%	

Note: There is no significant difference between the recoveries of various sizes of gold particles in any given hole. The average recoveries are within two standard errors of each other.

TABLE 17
Reverse Circulation Drill Holes in Alaska

Hole	Total Tracers in Core					Recovered in Drill		Samp Totl	Hole Stnd Error
	-8+14		-14+28		Total	-8+14	-14+28		
1	50		50		100	88%	84%	86%	3%
2	50		50		100	74%	70%	72%	4%
3	50		50		100	12%	10%	11%	3%
4	50		50		100	50%	62%	56%	5%
Total	200	0	200	0	400	56%	57%	56%	2%
Standard Error by Size						4%	4%	2%	

Note: There is no significant difference between the recoveries of various sizes of gold particles in any given hole. The average recoveries are within two standard errors of each other.

TABLE 18
Auger Drill Holes (Large Auger Drill)

Hole	Total Tracers in Core +14	+28	+48	+100	Total	Recovered in Drill +14	+28	+48	+100	Samp Totl	Hole Stnd Error
B9H1	25	0	25	0	50	88%		76%		82%	5%
B9H3	0	25	0	25	50		84%		72%	78%	6%
B10H1	0	24	0	25	49		54%		16%	35%	7%
B10H2	25	0	25	0	50	72%		64%		68%	7%
C1H1	25	0	25	0	50	26%		50%		38%	7%
C1H2	0	25	0	25	50		84%		56%	70%	6%
C1H3	25	0	25	0	50	76%		72%		74%	6%
C2H4	25	25	25	25	100	34%	20%	32%	36%	31%	5%
C3H5	25	25	25	25	100	40%	68%	76%	76%	65%	5%
O4H1	25	25	25	25	100	48%	52%	28%	64%	48%	5%
O4H2	25	25	25	25	100	76%	36%	60%	72%	61%	5%
O4H3	25	25	25	15	90	88%	84%	92%	80%	86%	4%
O4H4	16	14	13	8	51	94%	100%	85%	75%	88%	4%
Total	241	213	238	198	890	64%	65%	63%	61%	63%	2%
Standard Error by Size						3%	3%	3%	3%	2%	

Note: The recoveries of the various gold sizes are equal.

TABLE 19
Auger Drill Holes (Mid-size Auger Drill)

Hole	Total Tracers in Core +14	+28	+48	+100	Total	Recovered in Drill +14	+28	+48	+100	Samp Totl	Hole Stnd Error
AF2H2	25	25	25	25	100	84%	72%	84%	48%	72%	4%
ASGH4	25	25	25	0	75	100%	96%	96%		97%	2%
ASGH6	25	25	25	0	75	96%	92%	88%		92%	3%
Total	75	75	75	25	250	93%	87%	89%	48%	87%	2%
Standard Error by Size						3%	4%	4%	10%	2%	

TABLE 20
Auger Drill Holes (Small Auger Drill)

	Total	Tracers	in Core			Recovered	in Drill			Samp	Hole Stnd
Hole	+14	+28	+48	+100	Total	+14	+28	+48	+100	Totl	Error
GCH14	25	25	25	25	100	49%	16%	12%	44%	30%	5%
GCH15	25	25	25	25	100	34%	26%	34%	34%	32%	5%
GM8	25	25	25	25	100	80%	68%	68%	80%	74%	4%
GM9	25	25	25	20	95	60%	44%	64%	70%	60%	5%
Total	100	100	100	95	395	56%	39%	45%	57%	49%	3%
Standard Error by Size						5%	5%	5%	5%	3%	

Note: There is no significant difference between the recoveries of various sizes of gold particles in any given hole. The average recoveries are within two standard errors of each other.

TABLE 21
Auger Drill Holes (Mid-size Auger Drill 1989)

	Total	Tracers	in Core			Recovered	in Drill			Samp	Hole Stnd
Hole	+14	+28	+48	+100	Total	+14	+28	+48	+100	Totl	Error
515H	10	10	10	10	40	40%	40%	20%	70%	43%	8%
516H	10	10	10	10	40	70%	60%	60%	80%	68%	7%
530H	10	10	10	10	40	90%	90%	90%	90%	90%	5%
531H	10	10	10	10	40	60%	70%	65%	100%	74%	7%
539H	10	10	10	10	40	30%	40%	50%	65%	46%	8%
Total	50	50	50	50	200	58%	60%	57%	81%	64%	3%
Standard Error by Size						7%	7%	7%	6%	3%	

Note: There is no significant difference between the recoveries of various sizes of gold particles in any given hole. The average recoveries are within two standard errors of each other.

8.4.2 Analysis of Variance

An Analysis of Variance (ANOVA) was conducted in 1992 by Dan Walsh at the University of Alaska, Fairbanks to help determine whether a number of factors could be shown to have a statistically significant effect on the gold recoveries observed for the various test results. The first ANOVA used one factor, gold particle size, versus recovery and determined that at a 95% confidence level there were no significant differences in the recovery of the four sizes of gold particles. Based on these results, further Anova tests were conducted using the recoveries of the four sizes of gold as replicate values.

A four factor ANOVA was conducted to determine if drill type (R/C vs Auger), moisture in the hole (wet vs dry holes), hole depth and tracer addition depth had significant effects on gold recovery. The ANOVA indicated that the presence of moisture in the hole and the hole depth were not significant factors in the recovery of the gold particles. The presence of moisture was probably not significant because most of the auger holes were dry while most of the reverse circulation holes were drilled with water; hence these two factors were not independent.

Finally, a two factor ANOVA was conducted using only drill type and the location of the radiotracer core. This analysis indicated that the type of drill and the location of the radiotracer core had a significant effect on gold recovery. Further analysis indicated that the three auger drills had significantly higher gold recovery than the two reverse circulation drills even when the test results were limited to holes where the radiotracer core dropped to the bottom of the hole.

8.5 SAMPLE PROCESSING

All of the drill samples were processed on one of a variety of small sluice runs known as Long Toms (Photo 4). The concentrates from the Long Toms were upgraded by gold panning to a heavy mineral or black sand concentrate. The magnetic minerals were removed with a magnet. The tracers were picked out of this concentrate using a hand held scintillometer and counted to determine their recovery. The remaining concentrate was wetted and treated with mercury and nitric acid to remove the remaining natural gold particles.

To prevent accidental salting, Long Toms or other drill sample processing equipment were not used for upgrading concentrates from any other process for the duration of the testing program. To be secure from contamination they were never located in the same room or even within 100 m (330 ft) of a concentrate upgrading, weighing or storage area. Placer gold particles were often among the only particles remaining in a receptacle which had not been thoroughly cleaned and would have contaminated subsequent drill samples. Mechanical screens and testing sieves usually contain several pockets which can hold gold and contaminate subsequent samples.

8.5.1 Long Toms

Long Toms are easy to build, simple to operate and with proper operation will also provide consistent high recoveries (97 to 100%) of gold particles at least as small as 0.15 mm (100 mesh) in size. Long Toms also provide a relatively high concentration ratio resulting in a small volume of concentrate for upgrading by panning. If a large proportion of the gold particles are expected to be smaller than 150 microns in size, other gold recovery methods such as centrifuges or mercury amalgamation may be required.

The recovery device must be easy to clean thoroughly between samples. Jigs are not suitable for sample analysis due to the many gold traps in the screens, hutches and ragging which are extremely difficult to clean. Many commercially available vibrating and trommel screens are not suitable because they contain many gold traps, especially at the edges of screens and at retainers.

Long Toms must be constructed with steel, aluminium or fibreglass so that they can be cleaned quickly and thoroughly. Wooden, porous or rusty Long Toms were extremely difficult to clean and would carry over gold values between samples. The Long Tom must include a hopper large enough to minimise spillage losses. Hoppers which were too small to adequately contain the sample had excessive spillage losses (a common source of gold loss). The hopper should have wash bars and an adjustable slope to allow holding and washing the sample to break up any lumps of clay prior to releasing the the slurry into the sluice run (Photo 4). A stationary screen should be used to remove any coarse gravels, but may not be necessary for drill samples.

The width of the Long Tom's sluice run will vary depending on the size of the samples processed, but for drill samples, a width of from 150 to 250 mm (6 to 10 in) is adequate. Wider runs produce too much concentrate, narrower runs must be fed too slowly. The runs should be at least 1.5 m (5 ft) long (including a 300 mm or 1 ft section of slick plate) and sloped at 7 to 10 degrees (1.5 to 2 in/ft). They should be fitted with medium to light-weight expanded metal riffles, held down tightly on top of a porous, easily cleaned matting.

Thin, unbacked Nomad matting had the highest gold recovery but was also more difficult to clean than the next best matting, paper box conveyer belting (a rubber belt with spherical pockets). Both cocoa matting and Montsanto Astro-Turf matting are not recommended because of lower gold recovery. Cocoa matting was also extremely difficult to clean and would contribute to a carry-over of values.

A steady supply of clean water was provided to a depth of 10 to 20 mm (0.4 to 0.8 in) above the expanded metal riffles. Greater water flows washed larger radiotracers particles away, while lower flows often resulted in riffle packing and subsequent high gold losses. A bucket was placed at the discharge of the Long Tom to check for gold losses. Once the sample was run, the Long Tom's concentrate was removed by thoroughly washing all parts, including the hopper, the expanded metal and the matting into a pan or bucket. The matting had to be cleaned vigorously by beating in a tray with water and inspected carefully to ensure that all the gold was removed.

8.5.2 Gold Panning

Once the sample was processed and removed from a Long Tom, it was upgraded by gold panning in a tub. Even experienced panners had to exercise extreme care to prevent gold losses during panning. The highest and most unpredictable gold losses (0 to 10%) occurred due to careless or rapid gold panning. Pre-screening the drill sample before panning with an easily cleanable sieve helped reduce losses. The oversize gravels were checked for gold nuggets before discarding. Another receptacle or gold pan was placed in the bottom of the tub to recover the gravels so that they could be panned again (by another person) to check for gold losses.

Gold panning was stopped once the gold was detected by swirling water in the pan. Fine gold losses occurred whenever the concentrate was panned down with only gold remaining in the pan. Once the gold pan concentrate consisted entirely of high density minerals such as black sands, a magnet was used to remove the magnetic minerals.

Gold particles were often trapped between magnetic particles and dropped with the magnetics into water filled containers. A magnet was then used to pick up and release the magnetic particles several more times in various containers to ensure that gold particles were not rejected. The larger particles of gold were picked out of the pan. If any smaller particles remained, they were amalgamated with mercury.

8.5.3 Mercury Amalgamation

WARNING

Always use extreme caution when handling mercury and nitric acid. Both are very poisonous and nitric acid is extremely corrosive. Work in a well ventilated place and use a fume hood. Never breathe the fumes. When stored, keep mercury and nitric acid in sealed identified containers, out of reach of children in a locked cabinet. Do not store mercury or nitric acid or any of the containers which contact them in your kitchen. Mercury can stick to metal pans and end up in your food. When handling these compounds, always wear sealed latex gloves to prevent absorption into skin and safety glasses to protect your eyes. Don't eat or smoke when handling these chemicals. When handling mercury in samples, keep it under water to help keep its vapours from getting into the air. Never add water to acid, always add acid to water using a dropper. When you are finished working with mercury and nitric acid always seal and store containers and wash your hands thoroughly. If you are unsure of proper handling procedures for these compounds do not use them.

The gold pan concentrates were placed with water in a plastic gold pan and a small droplet of mercury was added. While using rubber gloves, the mercury and the high density concentrates were ground together in the gold pan. The ball of mercury was swirled around the pan until it had adsorbed all of the gold particles.

The ball of amalgamated gold and mercury was rolled out of the pan and into a clean Petri dish. First water and then concentrated nitric acid was added to the dish to dissolve the mercury while it was warmed in a ventilated fume hood. (nitric acid is extremely corrosive and its vapours are poisonous). Once the mercury was completely dissolved, the nitric acid and any white salts were rinsed using a wash bottle into a sealable container for disposal. The remaining gold particles were allowed to dry in the dish and then were weighed on an accurate scale with a sensitivity of at least 1 mg, although a sensitivity of 0.1 mg is preferred.

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