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DIAMOND DRILLING OF RIGID SOILS AND ALTERED ROCK MATERIALS

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DIAMOND-DRILLING OF RIGID SOILS AND ALTERED ROCK MATERIALS

by

Marc Bétournay*

ABSTRACT

Diamond drilling techniques have not been useful in providing representative, undisturbed samples of geotechnical material. Often, core recovery is very low and the core and in-situ mass are damaged by the process.

New techniques have been established that permit a high degree of recovery of undisturbed geotechnical material. In the case of rigid soils and altered rock, changing the nature and viscosity of the drilling fluid and using particular but available drilling equipment has resulted in successful, non-disturbing sampling campaigns.

KEYWORDS: diamond drilling, altered rock, rigid soil, drilling fluid, drill bit, core recovery.

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LE FORAGE AU DIAMANT DE SOLS RIGIDES ET DE ROC ALTÉRÉ

par

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RÉSUMÉ

Les techniques de forage au diamant ont eu peu de succès à fournir des échantillons intacts et représentatifs de matériau géotechnique. Souvent, la récupération de carotte est très faible et la carotte et la masse forée sont endommagées par le processus de forage.

De nouvelles techniques ont été établies qui permettent un haut niveau de récupération de matériau géotechnique non-perturbé. Pour des sols rigides et du roc altéré, un changement dans le genre et la viscosité du fluide de forage et une utilisation d'équipement de forage particulier (mais disponible) ont permis des campagnes d'échantillonages non-perturbantes.

MOTS CLÉS: forage au diamant, sol rigide, fluide de forage, taillant de forage, récupération de carotte.

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INTRODUCTION

Excavations in weak material is commonplace in civil works, but is only now becoming prevalent in hard rock mining because of profitable ore grade levels and improved excavation and ground control technology.

CANMET is active in the settings where such material is most detrimental, figure 1. In the case of surface crown pillars, where excavations are larger and have a smaller activity period than most civil projects near surface, ground control is not of permanent nature. But, there is always the danger that surface elements such as soil and water can cave with an underground failure thereby endangering worker safety, and reducing the profitability of the mining operation. It also stands to reason to find out what soils have self-supporting capabilities, and over what spans.

For these reasons it is imperative to extract all geomechanical data with a potential effect on stability.

This presentation relates to diamond-drilling and how it can be applied to new settings. Past experience with these methods for altered rock and soils is given. Details of the variations incorporated in successful campaigns in these materials are presented. Finally, the expansion of the method to other weak rock masses, and backfill is discussed.

DIAMOND DRILLING

Diamond drilling is a technique universally applied to sampling and instrumentation of rock masses (1)(2).

The method consists of abrading material in a circular fashion and collecting/retrieving a sample inside the rotating cylinder. The following parts form the basic components of a diamond drilling system (see figure 2):

- engine (for power to rotate and feed downward thrust);
- drilling head;
- pump (to inject cooling and flushing fluid);
- drill rods;
- drill bit;
- casing;
- hoist.

DIAMOND DRILLING AS A SAMPLING TOOL

Sampling is not the only purpose for diamond drilling. Location and variation of properties (geological, geomechanical) can be identified. Furthermore, the holes lend themselves to in-situ tests or installation of monitoring instrumentation which require smooth walls (e.g. borehole jacks, extensometers).

In rock, diamond drilling offers distinct advantages:

1. continuous sampling, in a definite volume, at depth;
2. small sampling time;
3. relatively undisturbed* sampling;
4. provides test ready sample shape;

(* care must be taken in the case of joint infillings and weak rock)

and some obvious disadvantages:

1. expensive, even for long core runs;
2. long set-up time before coring.

The past experience in soil-like material has not established diamond drilling as a viable sampling tool (2)(3). Some of the more important problems associated with such diamond drill sampling are:

1. disturbance of surrounding soil from the coring process;
2. disturbance of the core from the drilling technique;
3. reduction in the water content of the soil;
4. expansion because of unloading of in-situ overburden;
5. transport and sample preparation effects.

The system components that could be changed to improve core quality and quantity are:

- bit type;
- barrel type;
- rotation speed, advance speed;
- fluid type;
- fluid pressure.

The core barrel type used will dictate the quality of samples obtained.

Single barrel drilling, figure 3, is used when geotechnical information is not a priority. Several negative aspects relate to the single barrel. Samples, because they are in contact with the rotating barrel, are worn down but worse still, core segments rotate on top of one another. In rocks these disturbances erase joint infilling and roughness figure 4; in soil-like material the results are much more damaging, even with reduced r.p.m.

Double or triple barrel coring, figure 3, supports the core in a sampler, out of contact of the rotating barrel. In the case of soils, the sampler also prevents the soil from disintegrating.

The barrel size also plays a role in core quality. An example of this was provided by Les Mines Selbaie where core recovery of altered rock showed higher quality with larger core barrel size, figure 5.

The drill bit is the second most important element of diamond drill sampling. For joint infillings and soil-like material the right arrangement for fluid discharge location is crucial to maximize recovery. For standard bits, the drilling fluid passes between the inner wall of the bit and the core barrel. Such a flow at the bit end will wash away any loose or soft material; a lateral or face discharge (shuts off the bottom of the bit/core from fluid flow) is thus preferred since cuttings are washed up the exterior of the core barrel without affecting the core, figure 6.

Water is the standard fluid used for diamond drilling rock. When drilling in weak ground, the viscosity should be increased. The end purpose of this change is to reduce the ability to wash away the fine components of any material sample, to stabilize the drilled mass by forming a filter cake on the formation thus preventing fluid loss and damage, figure 7.

Drill speed is also important. Core recovery is usually greater for weak material using low rotation, but this must be balanced with drilling advance and cutting efficiency. Unfortunately non-geotechnical drilling contractors get paid for advance rates rather than for recovery, a detrimental situation for geotechnical studies.

Finally, drilling fluid pressure must be carefully set. It must be greater than the groundwater pressure and high enough to remove cuttings. But it must also be low enough not to hamper core recovery (eroding the material) and prevent hydrofracturing damage to the medium.

Ordinarily, soils are highly disturbed by the drilling system: erosion of the soil by the drilling fluid, damage from fluid pressure, coring vibration, barrel friction and particle movement. In the worst case, cohesionless soils induce hight bit wear, overheating and jamming between core barrel and casing.

By virtue of their inherent rigid nature, soils with cohesion have a potential to yield samples for testing of representative mechanical properties. This feature is also common to rock and therefore indicates possible diamond drilling application to these soils.

The questions remain then, has diamond drilling been used as an effective, essentially non-disturbing technique? Can it provide representative samples for stress-strain relationships?

The following section describes the experience encountered when attempting to apply diamond drilling to rigid geotechnical sampling.

CASE STUDIES OF DIAMOND DRILLING IN ALTERED ROCK AND RIGID SOILS

a) Altered Rock

In a project that started in 1985, CANMET sponsored research to study the stability of near surface underground openings in highly altered rock masses. For this reason, characterization of the rock mass was essential (4,5). This included small scale mechanical testing (hence the need for core), in-situ testing (natural stresses, modulus of elasticity), empirical rock mass classification and inherent failure mode mechanisms. Three-dimensional (3-D) numerical modelling was performed. Monitoring with roof instrumentation is now in progress.

The altered rock mass studied is found at the Selbaie minesite, some 280 km north west of Val d'Or, figure 8. A major fault has fractured volcanic rocks permitting meteoric waters to enrich the copper mineralization but also alter the rock to various degrees of kaolinization. The worst alteration can be described as soft, soil-like with small irregularly spaced remnants of rock. The richest ore values/kaolinization are found nearest the surface, immediately below the overburden. The overlying soil at the mine site is thick and averages 45 m, consisting primarily of fine grained very dense tills and till-like sediments, figure 9.

Drilling and sampling (4) were required in the lower overburden and upper rock mass. The geographical remoteness of the site made it necessary to use on-site, resident, production type rock drilling contractors, rather than experienced geotechnical drilling contractors.

The drilling was performed from surface with a skid-mounted Inspiration III drill rig, figures 10-11; 165 m of soil and rock sampling was performed over 34 days, late in 1985. The weather was extremely cold and daily production rates varied dramatically due to frozen lines, pump and rig starting problems, and the like.

Table 1 outlines the drilling methods used for altered rock and rigid soils at Selbaie, and the results obtained.

Conventional geotechnical sampling and diamond drilling were applied to sample the soil unit in contact with the rock. Previous reports had described it as a "till" but split spoon sampling retrieved samples of dense silty sand.

In this unit, the problems encountered using N-size triple barrel coring assembly were many. In the first of 3 boreholes, with only standing water at the end of the borehole, the bit quickly jammed. When applying circulated water, bits wore out very quickly. On occasion, sand would collect between drill rod and casing until the assembly stuck requiring removing casing and all. The diamond drilling was then resumed in the rock material, illustrated in figures 12-13.

The core recoveries there, using standard drilling techniques, were poor, <30%. The core size, NQ (4.76 cm Ø), was selected following the mine's better recoveries with larger diameter coring. HQ (6.35 cm Ø) size was not used because of prohibitive costs. Circulated water, high drill speeds and fluid pressure were used, as well as, the following drilling components:

- triple tube assembly;
- double tube core barrel on triple tube bit;
- double tube bit on triple tube core barrel;
- face discharge vs standard discharge bit.

None of these variations had any significant influence on core recoveries. The harder rock pieces, few softer portions and no very weak samples were recovered.

The second hole, started in the altered material, used the same drilling methods. The same lack of success was encountered at first. Subsequently, a small amount of "Polydrill R", a polymer mud, was added which improved core recoveries from 30 to 60%. In order to improve the recoveries even further, a variant of a technique first reportedly used in England for very soft, friable, rock was tried. The techniques of creating a foam at the bit are well-known in the water-well industry. An air compressor was connected by a T-joint to the drill stem water swivel, and both air pumped under pressure and water flow from the water supply pump were reduced. Immediate success was noted, not only for the coring operation but also in core recoveries. Average core recoveries increased to over 90% in the weakest rock zones. Large cores of kaolinitic materials, finely disintegrated siliceous dacite tuff breccia in a clayey silt matrix, highly fractured ore and sounder rocks were all recovered intact from the triple tube core barrel, figures 14-17.

The huge success with the second borehole prompted the initiation of an extra borehole, beyond the terms of reference for this research program. Verification of the validity of the compressed air injection technique was attempted in the third borehole.

At first an attempt was made to try the air-water mixture technique for coring of the overburden materials. Unfortunately, the compressor broke down and the validity of the technique for coring dense almost cohesionless finer grained soils, could not be verified. When the borehole drilling reached the bedrock contact area, the compressor had been repaired, and excellent core recoveries were obtained until the compressor broke down once again at which time core recoveries immediately dropped to values equivalent to those obtained earlier at the first drill hole.

Adding air to the drilling fluid permitted a reduction of water pressure, which in effect also helped restrict the erosion of the altered rock, while keeping wear on the diamond bits to a minimum. Best results were obtained with a bit advance rate of about 3 cm/min and a water/air pressure ratio of between 10 and 15. A fluid pressure of 1.7 to 2.0 MPa was found to satisfy the requirements of removing the cuttings and low enough not to hamper core recovery.

It thus appears that the fluid type alone is not sufficient to extract core successfully. A change of all drilling components seems to be required to maximize (close to 100%) core recovery and quality. A viscous fluid, under reduced pressure must accompany double/triple barrel coring using face centered bit.

b) Rigid Soil

Experience in this domain has been established by Hydro-Québec, mainly with the intent of developing a new drilling method that prevents hydro fracturing in the till cores of dams. These soils, containing 10 to 40% gravel, form close to 90% of Hydro-Québec's dam cores.

In a diamond drilling test program (6) a variety of fluids were used. These were: water, air, air activated water, bentonitic-froth (30-35s on the "Marsh Funnel Scale") mixture, polymer mud, high viscosity bentonitic mud (100s on the scale; comparable to the viscosity of the grout used in sealing dam foundations). Drilling was performed with a JKS Boyle BBS15 drill, PQ size (8.43 cm Ø) core barrel and face discharge bit.

Furthermore, the following drilling parameters were also modified:

- drilling speed (reduced);
- penetration rate (reduced);
- fluid pressure/flow (reduced);
- fluid types.

The coring was done as tests in soil compacted in a 1.5 m high 0.5 m ϕ steel cylinder. The soil, a till (table 1) was reconstituted from till samples. Drilling fluid pressure was monitored at several points along the drilling system: pump exit, tubing and soil cylinder side wall. Discharge was measured with an ultrasonic flow gauge. The information was relayed to a data logger and a recorder.

The tests using air, water or foam as drilling fluid, showed that the necessary pressure (900 to 1,100 kPa) and flow 30 to 35 l/min for the system to function were too high and caused extensive hydraulic fracturing (up to 1,000 kPa existed in the soil). As well, recovery was low, 0 to 30% and the core samples disturbed (the fine matrix washed out leaving behind the larger fraction). The final borehole size was 20 to 40% larger than the core barrel.

The addition of the bentonitic mud or polymer mud to the foam required only 200 to 700 kPa of fluid pressure. However, there were still numerous incidents of hydro fracturing (500 to 600 kPa existed in the soil) and recovery was 50 - 90% with disturbed samples. With the high viscosity bentonitic mud, only 200 to 250 kPa fluid pressure was necessary to make the system work. On the cylinder walls, fluid pressures were only 0 to 50 kPa. No hydraulic fracturing occurred, the hole diameter was smooth and the size of the barrel. The core, 100% recovery and not disturbed, had all stone and gravel pieces cut by the bit, figure 18.

These tests show that for short drill lengths fluid pressures can be reduced to very low levels and still make the system work, while high recovery and no hydro-fracturing are encountered, figure 19. In actual situations the fluid pressure will no doubt need to be increased for drilling tens or hundreds of feet down, to compensate for pressure loss. Indication of pressure at the coring interface might be necessary to prevent sample damage.

Other drilling components must also be chosen carefully: fluid type, rotation speed, etc.

APPLICATION TO OTHER MATERIALS

Further trials with such techniques have not yet been attempted, however, the potential for expanding this sampling technique to other types of weak rock masses and soils difficult to sample is certainly a possibility. To name a few, weak rocks such as highly micaceous schists, shale and partly disagregated igneous rock have been extremely difficult to sample. But whether or not the recovered core would be useable in mechanical tests is also unknown. Soil types such as very stiff clay could be sampled with these techniques. Geologic materials which present no rigidity will prove a challenge to sample undisturbed. But the usefulness of such samples for lab testing is limited.

Even mine backfill, if hydraulically emplaced, presents a stiff nature with sampling possibilities. Of course, a high degree of cement concentration could only help the sampling of the material.

The range of materials that could be sampled undisturbed for laboratory mechanical properties ranges from sound rock to weak rock and stiff soils.

CONCLUSIONS

The tests outlined in this report, pertaining to rigid soils and altered rock, have shown that:

1) conventional diamond drilling methods are not applicable to soil-like materials for sampling purposes;

2) good, undisturbed core recovery of these materials depends on the drilling method used;

3) an improvement in core recovery, reduction in material damage, requires that several drilling elements be varied: fluid type, drill rotation, fluid pressure as well as coring bit and barrel;

4) more viscous fluids behave differently under these conditions by penetrating less and causing less damage in the surrounding material mass than Newtonian fluids;

5) other weak geological materials could be sampled undisturbed with these methods as long as they present some rigidity;

6) the drill crew should not be allowed to drill at the rate they choose. Close control of the drilling techniques is required. An explanation of the purpose of the drilling campaign will help them understand the requirements of the drilling technique. If the drill crew is usually paid on a penetration basis, they should be compensated for the slower progression of these drilling methods.

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BOREHOLE DESIGNATION	MATERIAL TYPE	BARREL	BIT	ADVANCE	FLUID TYPE	FLUID PRESSURE	FLUID FLOW	RECOVERY	SAMPLE CONDITION
SELBAIE MT-11	DECOMPOSED AND KAOLINIZED VOLCANIC TUFF BRECCIA W_c=10-20%	DOUBLE, TRIPLE	FACE DISCHARGE, STANDARD	5cm/MIN	WATER	4.2 MPa	?	<30%	HARD PIECES RECOVERED, VERY FEW SOFT PIECES
SELBAIE MT-10		TRIPLE	FACE DISCHARGE	5cm/MIN	WATER	1.7-2.0 MPa	?	<30%	HARD PIECES RECOVERED, VERY FEW SOFT PIECES
		TRIPLE	FACE DISCHARGE	3cm/MIN	POLYMER MUD + WATER	3.5 MPa	?	<60%	HARD PIECES AND SOME SOFTER PIECES
		TRIPLE	FACE DISCHARGE	3-5 cm/MIN	AIR +) F POLYMER) O MUD +) A WATER) M	1.7-2.0 MPa	7.5l/MIN	>90%	HARD PIECES, KAOLINITIC MATERIAL, DISINTEGRATED FINE ROCK IN CLAYEY SILT
SELBAIE MT-12		TRIPLE	FACE DISCHARGE	3-5 cm/MIN	AIR +) F POLYMER) O MUD +) A WATER) M	1.7-2.0 MPa	7.5l/MIN	>90%	HARD PIECES, KAOLINITIC MATERIAL, DISINTEGRATED FINE GRAINED ROCK IN CLAYEY SILT
HYDRO-QUEBEC	TILL 40% COBLE STONES + 10-40% SAND, GRAVEL, SILT + 1-12% CLAY	TRIPLE	FACE DISCHARGE	1.3-3 cm/MIN	AIR OR WATER OR FOAM	0.9-1.1	30-35 l/MIN	0-30%	ONLY LARGE PIECES RECOVERED, HIGHLY DISTURBED DAMAGE TO SOIL MASS, HYDROFRACTURING
		TRIPLE	FACE DISCHARGE	1.3-3 cm/MIN	FOAM INCLUDING LOW VISCOSITY BENTONITIC/POLYMER MUD	0.2-0.6 MPa	18-40 l/MIN	50-90%	SAMPLES DISTURBED; HYDROFRACTURING OF THE MASS
		TRIPLE	FACE DISCHARGE	1.3-3 cm/MIN	FOAM INCLUDING HIGH VISCOSITY BENTONITIC MUD	0.2-0.25 MPa	?	100%	CORE UNDISTURBED; SOIL MASS UNDISTURBED

Table I. Diamond drilling methods used to recover altered rock (Selbaie) and rigid soil (Hydro-Quebec) (4)(6).

Figure 1. Special ground setting where conventional diam drilling techniques would be inappropriate: decaying vertical syenite dykes seperated by intact gabbro. Mount Royal road cut, Montreal (7).

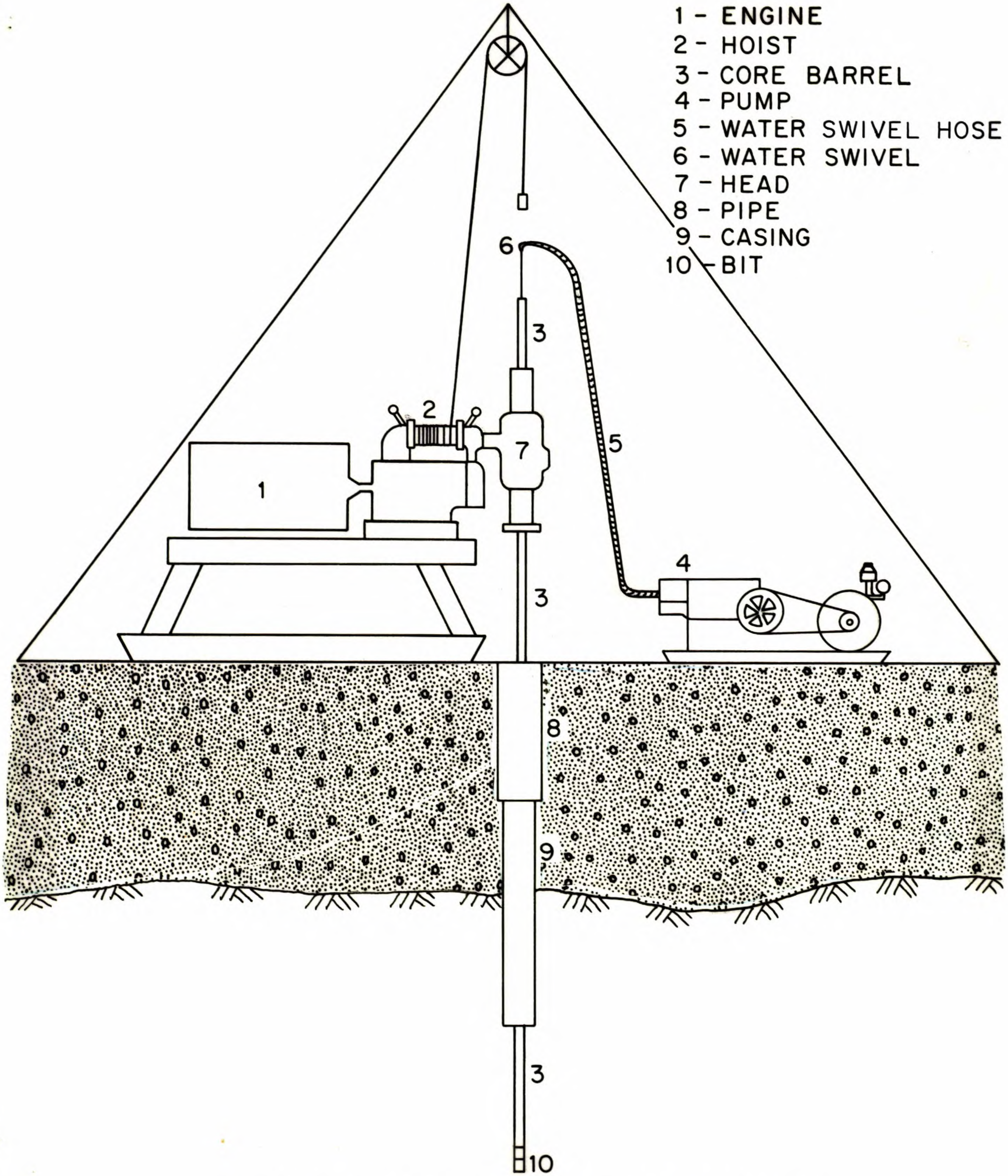


Figure 2. Basic components of a diamond drilling system.

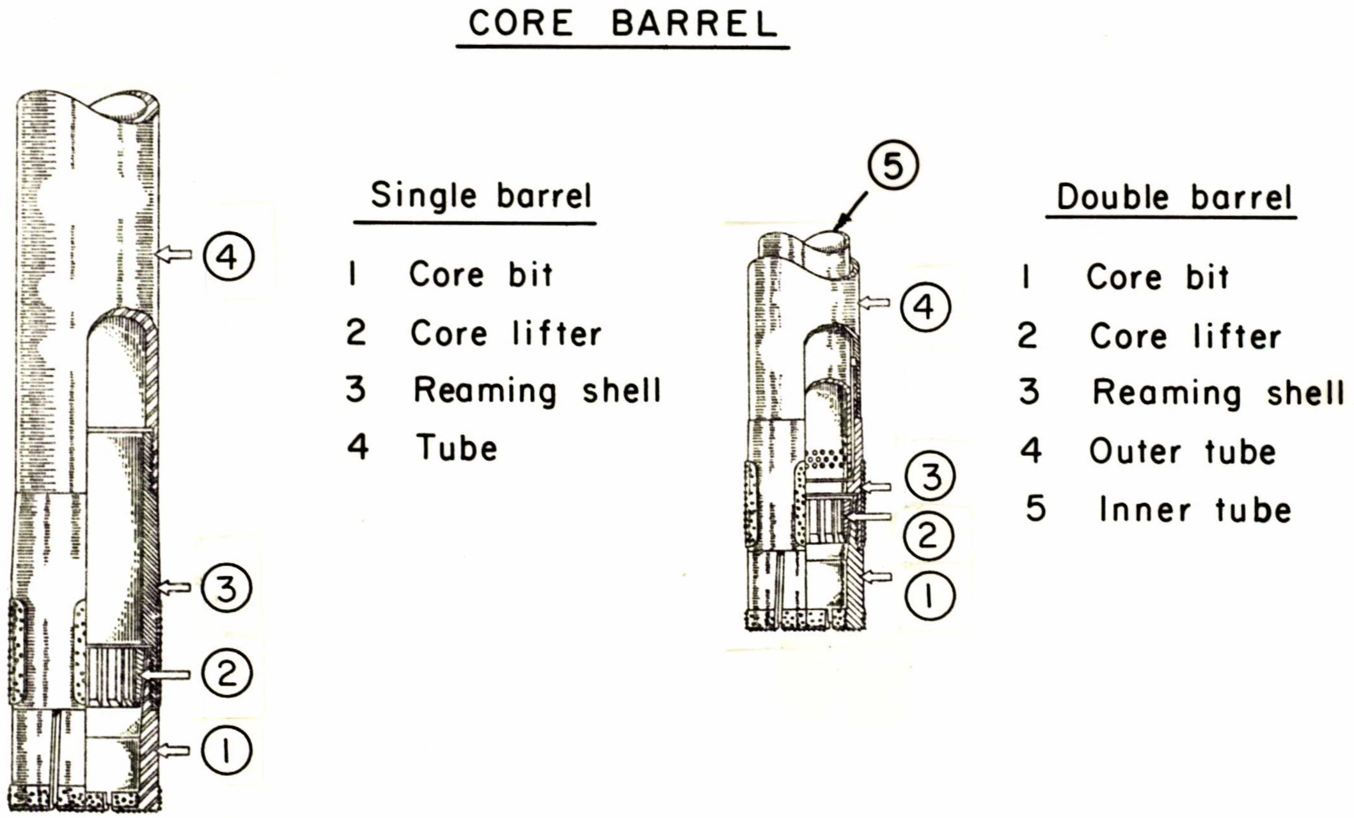


Figure 3. Change in system components to improve core quality and quantity: adopting double barrel (or triple) instead of single barrel.

Figure 4. Single barrel drilling damage: erasure of joint roughness.

Fig 4. Single barrel drilling
damage: nature of
joint roughness

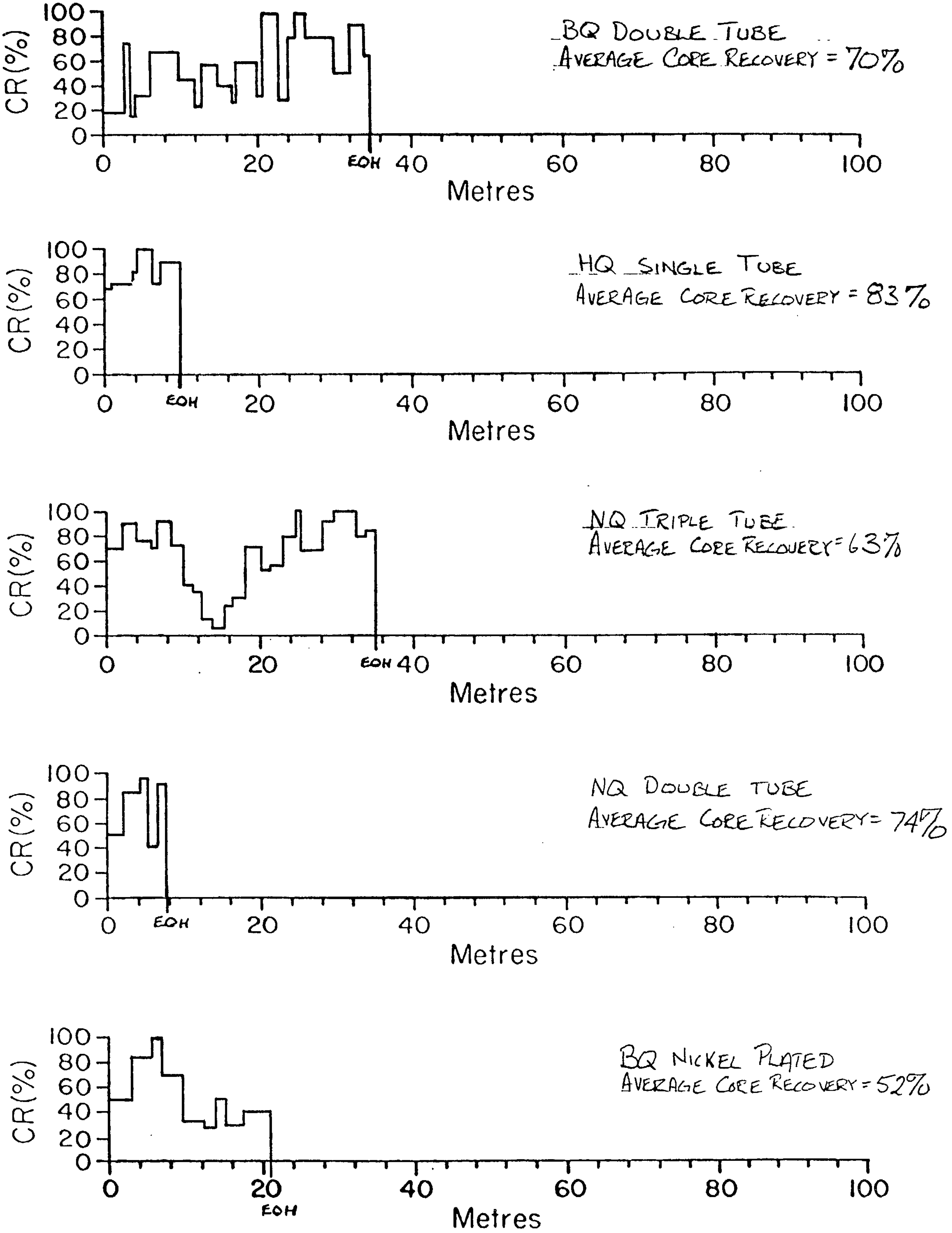
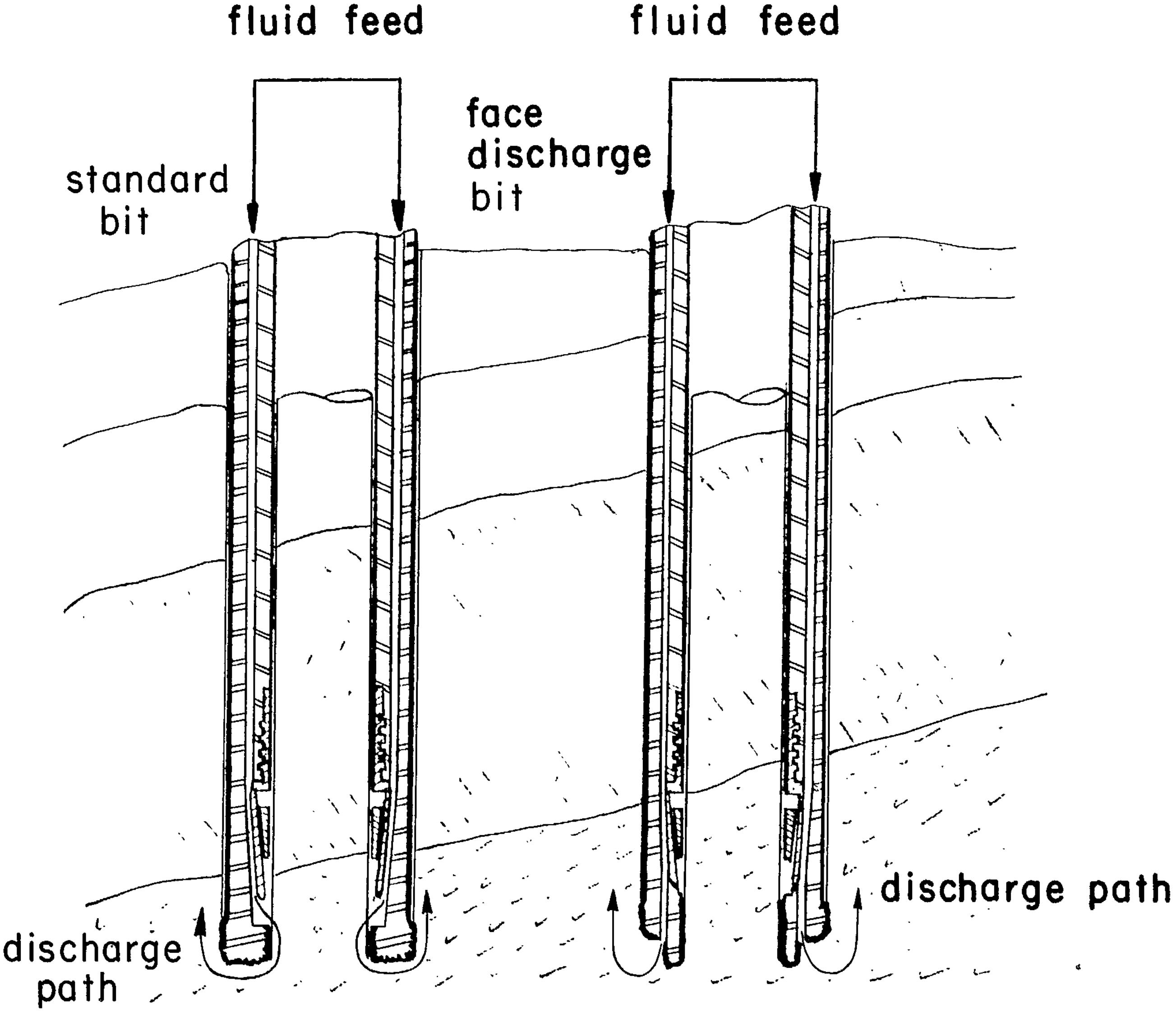


Figure 5. Improvement in core recovery with barrel size, four drill holes, Les Mines Selbaie. BQ, NQ and HQ sizes are respectively 3.65 cm, 4.76 cm, 6.35 cm.



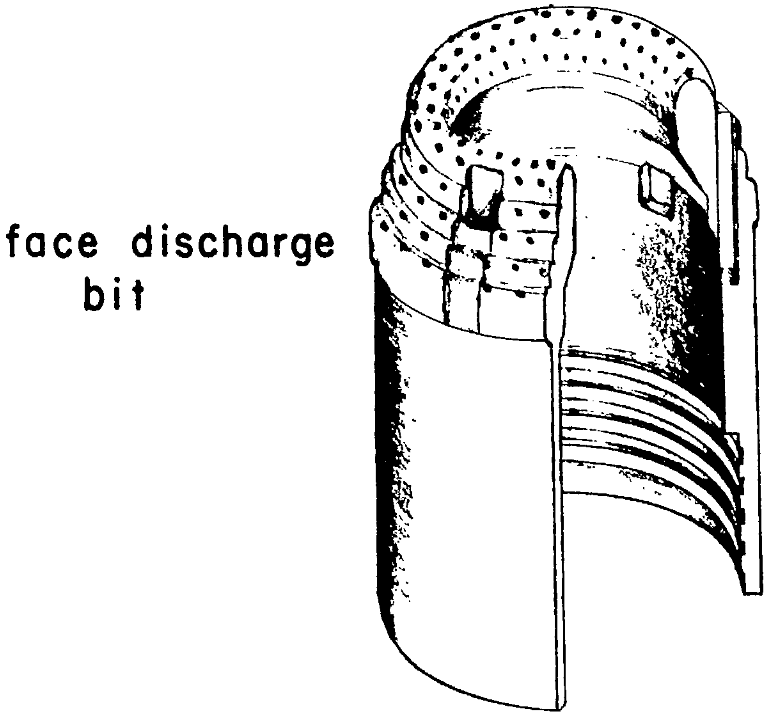


Figure 6. Change in system components to improve core quality and quantity: preventing sample damage by fluid washing, using face discharge bit.

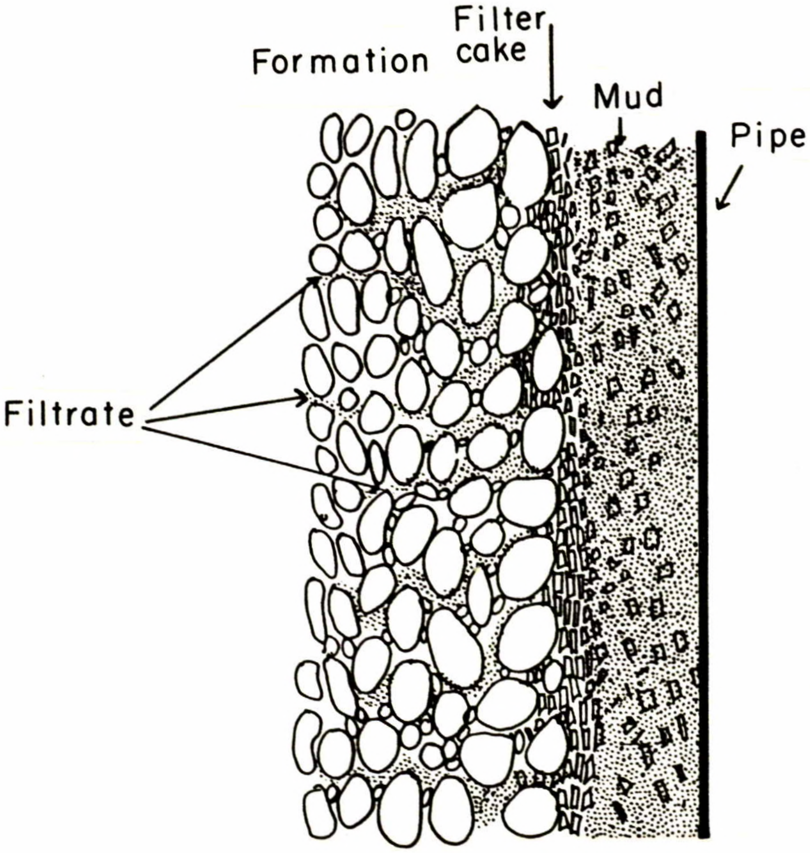


Figure 7. Stabilzation of weak ground and prevention of fluid loss and damage by using a higher viscosity drilling fluid.

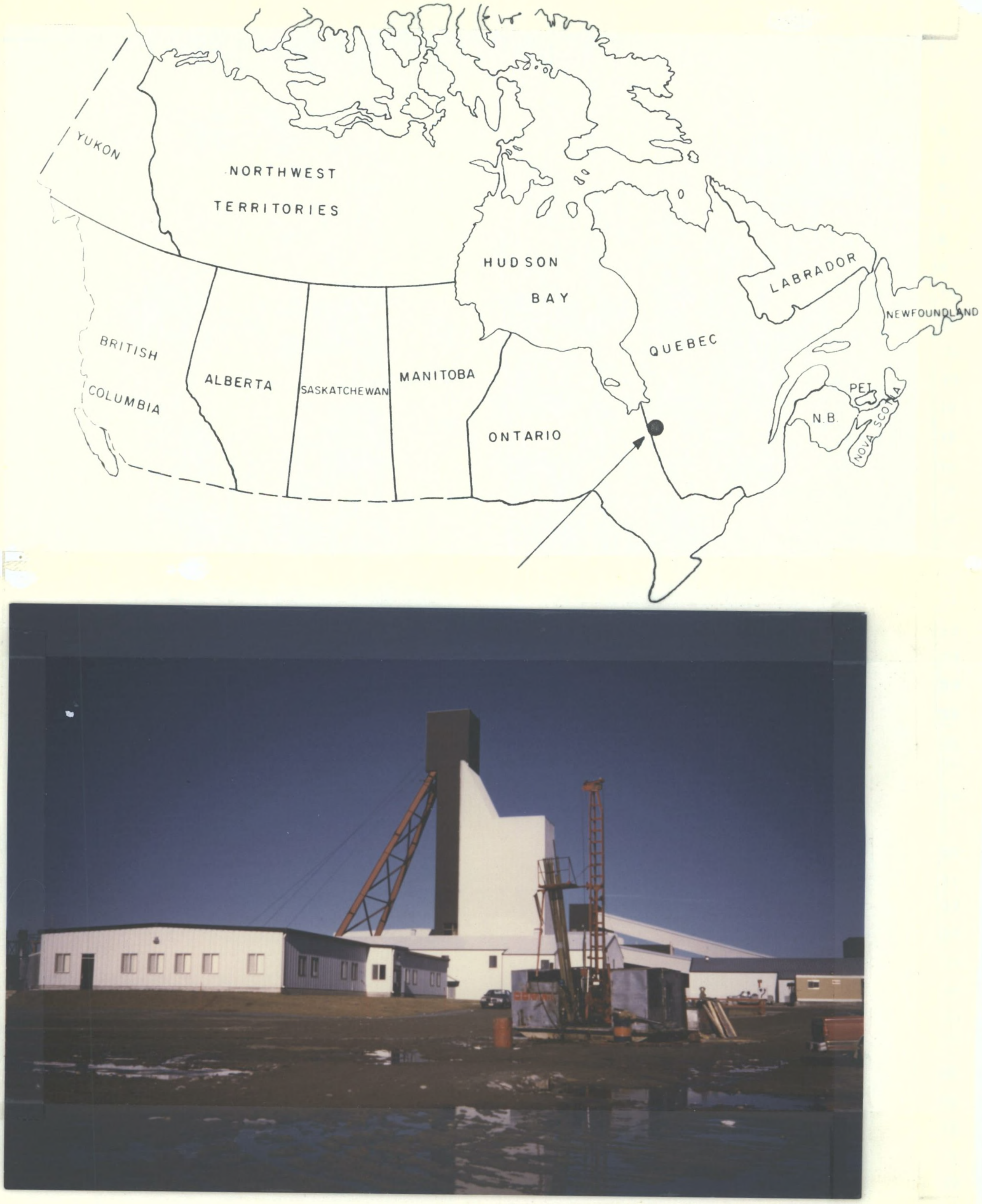


Figure 8. Minesite, Les Mines Selbaie.

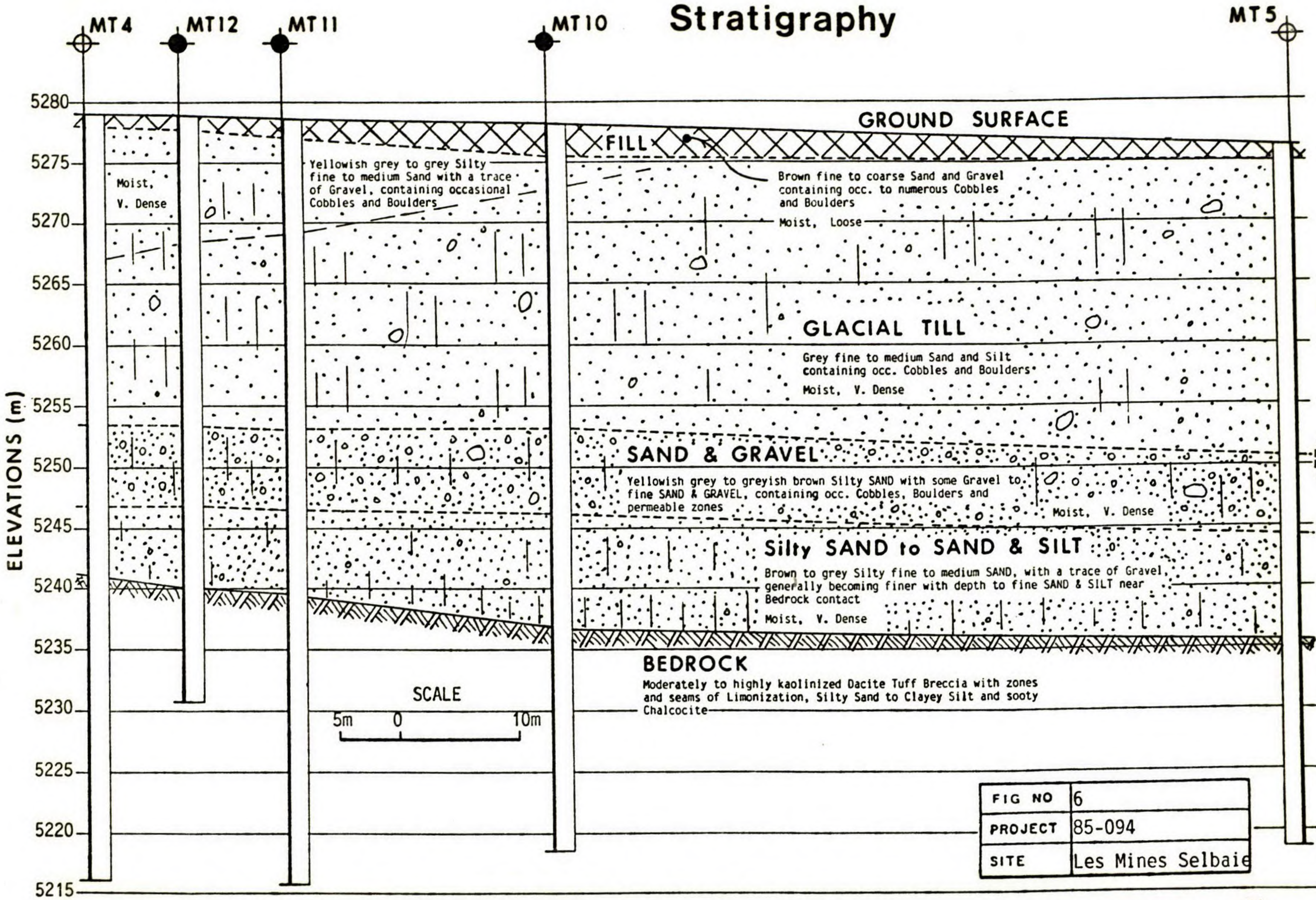


Figure 9. Overburden stratigraphy, Les Mines Selbaie, and location of project diamond drill holes.(4).

Figure 10. Inspiration III drill rig

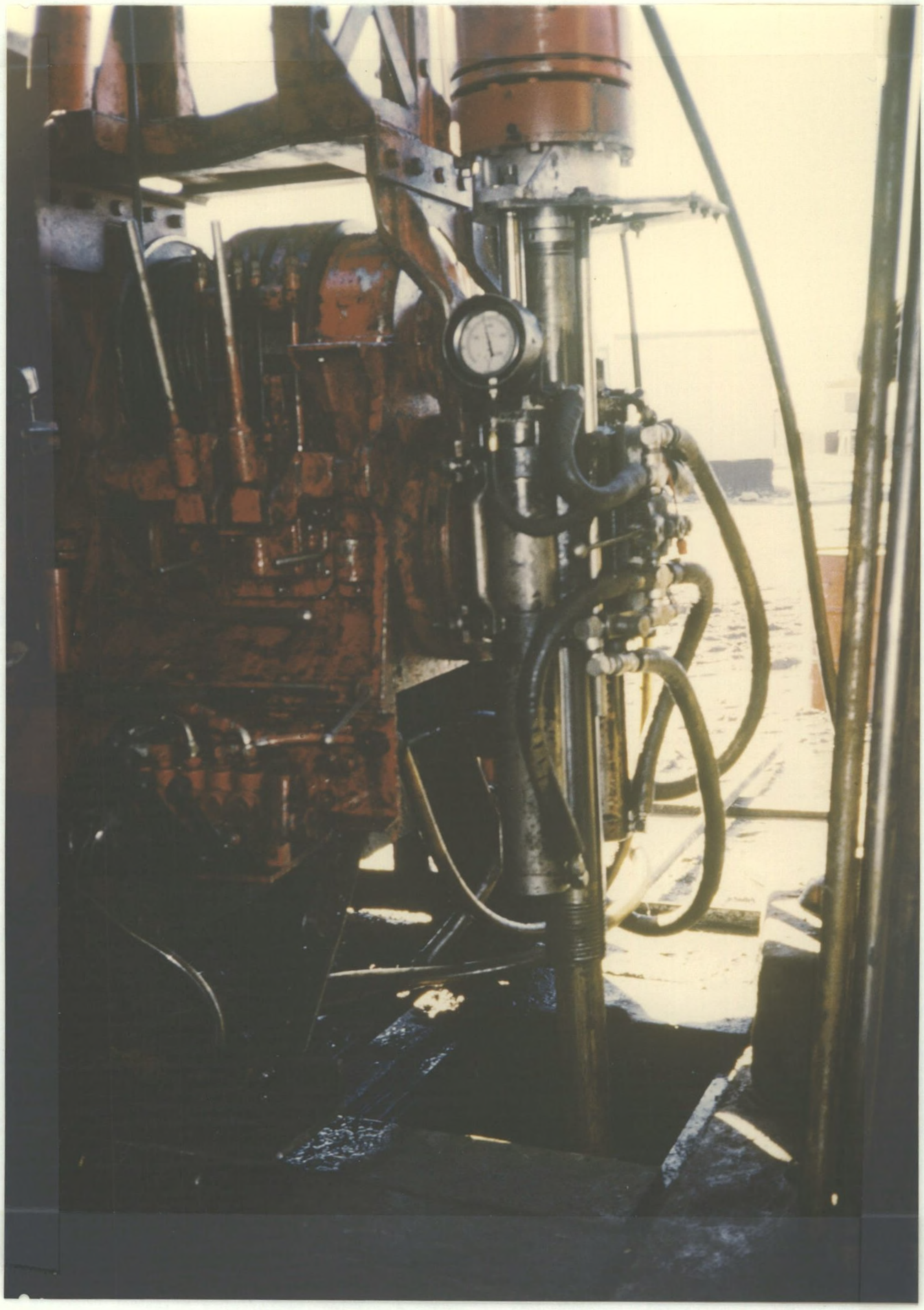


Figure 11. Inspiration III drill rig components.

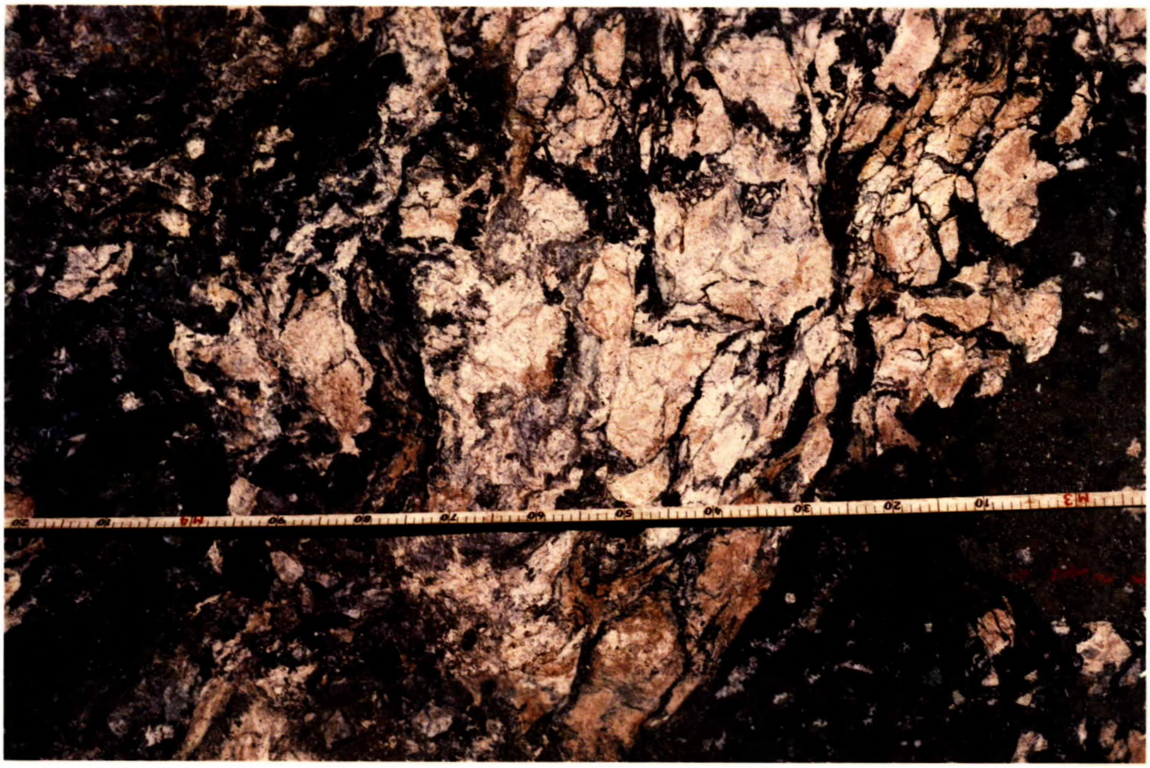


Figure 12. Example of altered rock mass, Les Mines Selbaie: Weak to very weak, moderately to highly kaolinized dacitic tuff breccia containing stringers of black sooty chalcocite (orebody material) (4).

Figure 13. Example of altered rock mass, Les Mines Selbaie: Weak to very weak, moderately to highly kaolinized and limonitized dacitic tuff breccia in a silty clay to clayey silt matrix - so called "cherry cheesecake". (orebody material) (4).

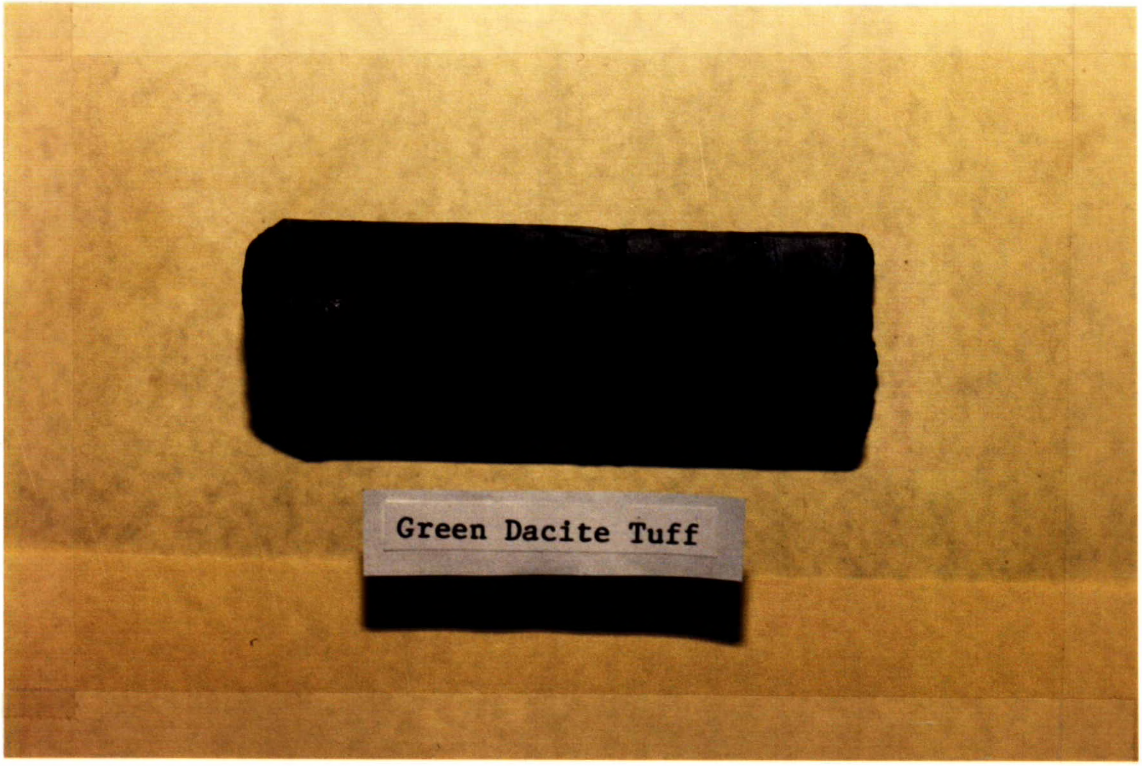


Figure 14. Core recovery using improved techniques: strong, dacite tuff (4).

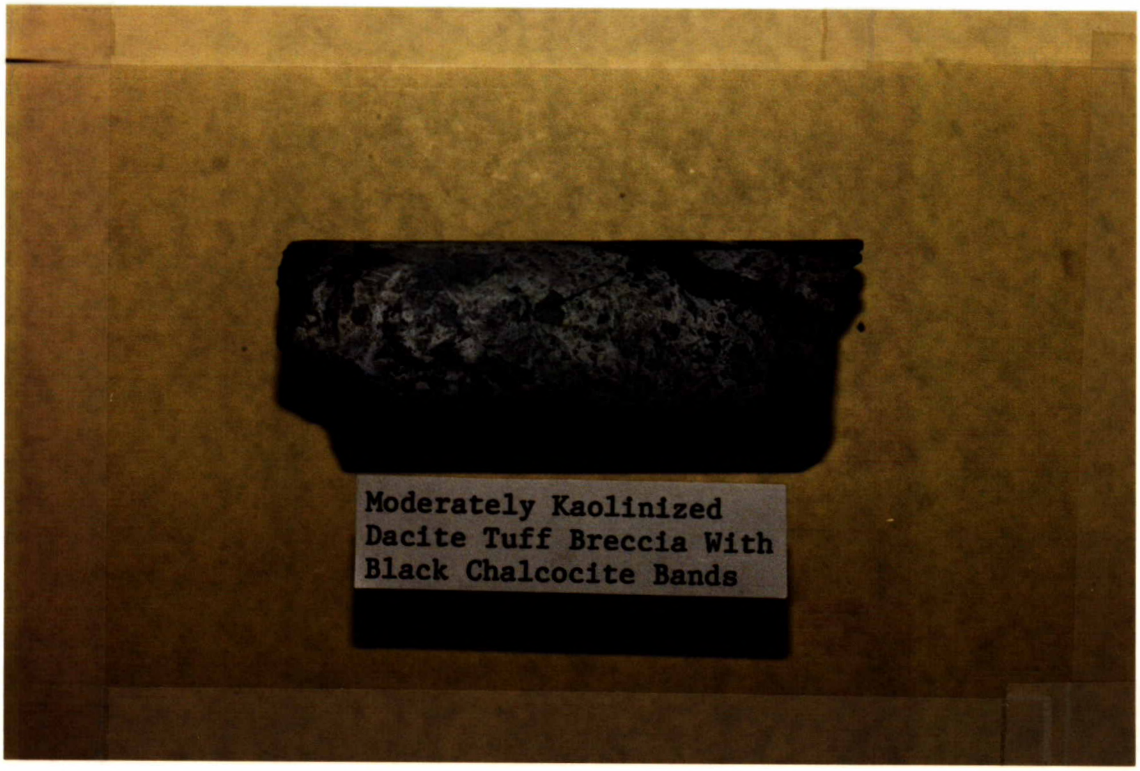


Figure 15. Core recovery using improved techniques: weak to very weak, kaolinized dacitic tuff breccia with black sooty chalcocite bands (4).

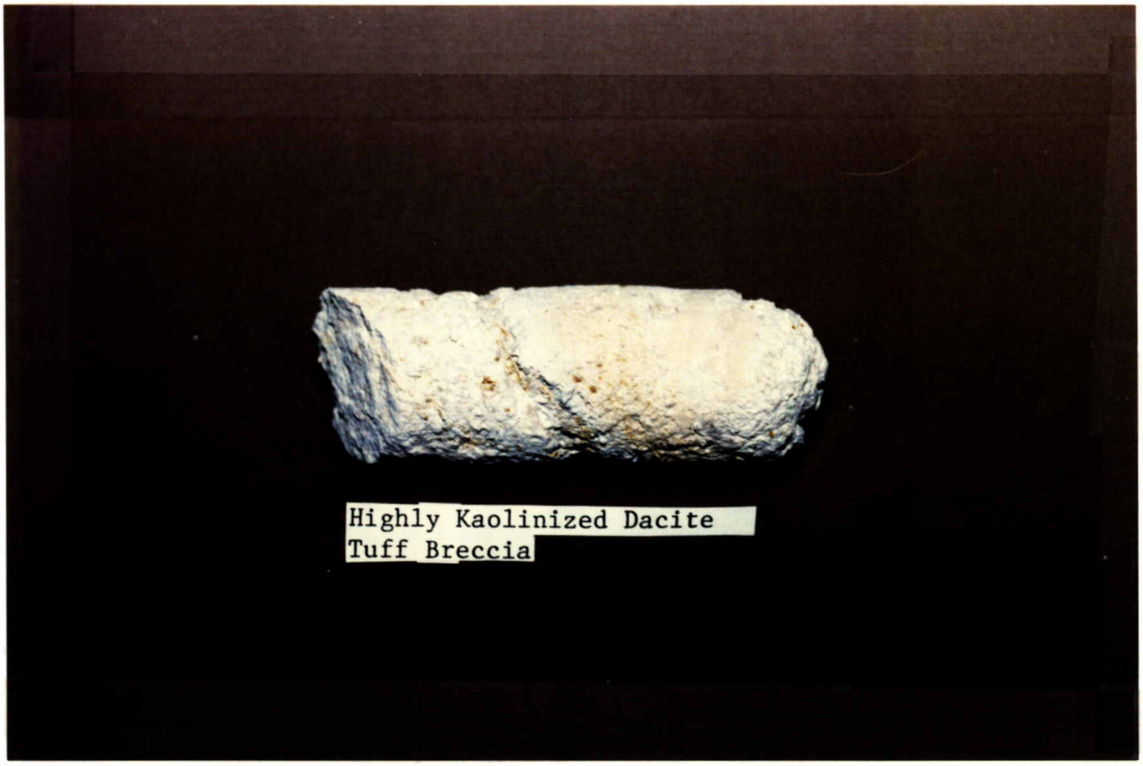


Figure 16. Core recovery using improved techniques: very weak, hihgly kaolinized dacitic tuff breccia (4).

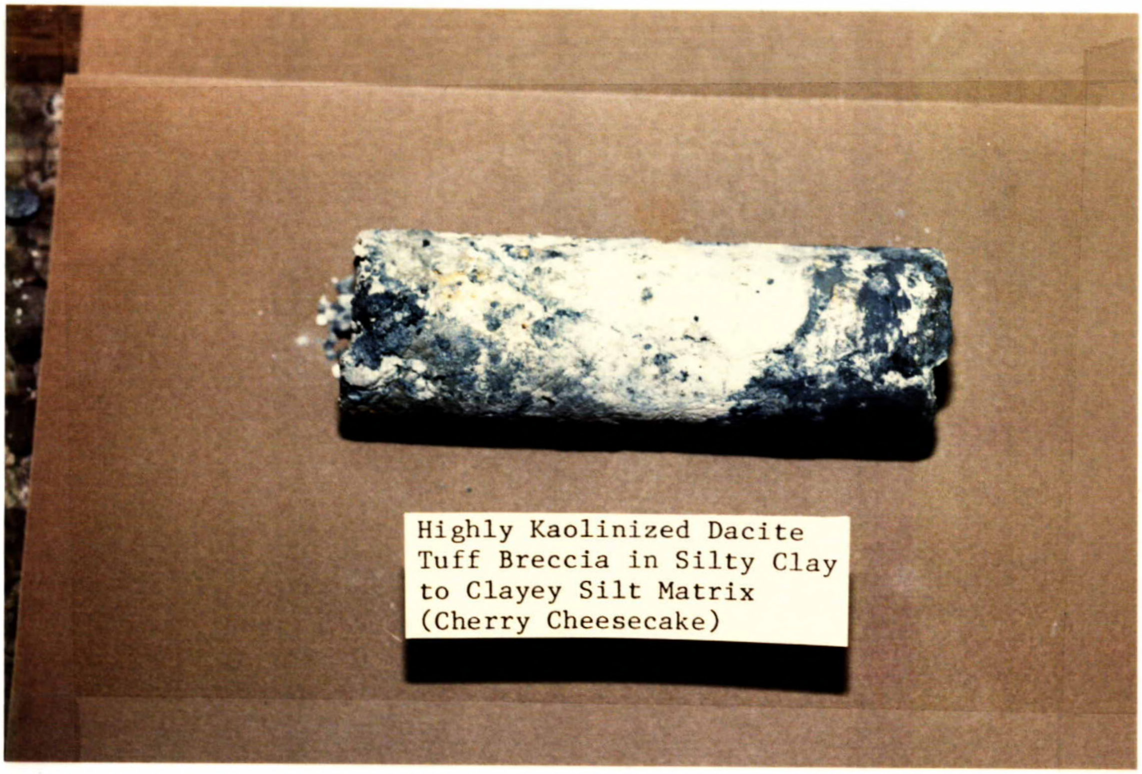
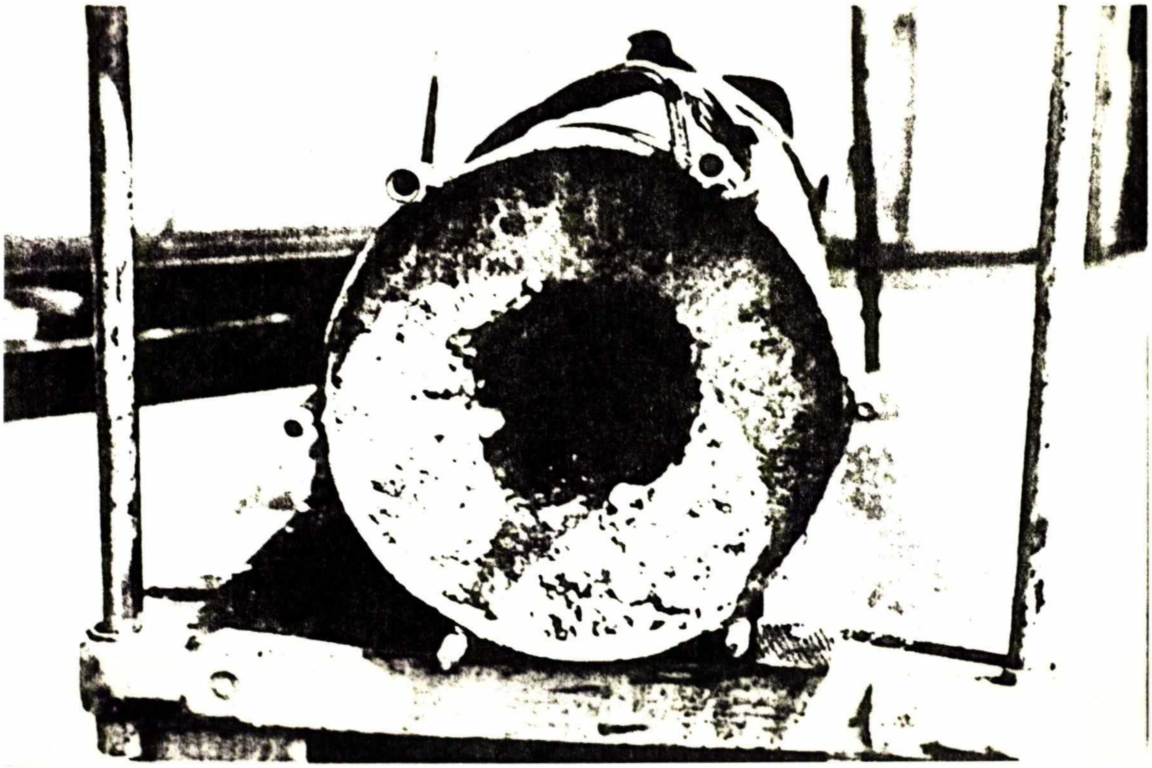
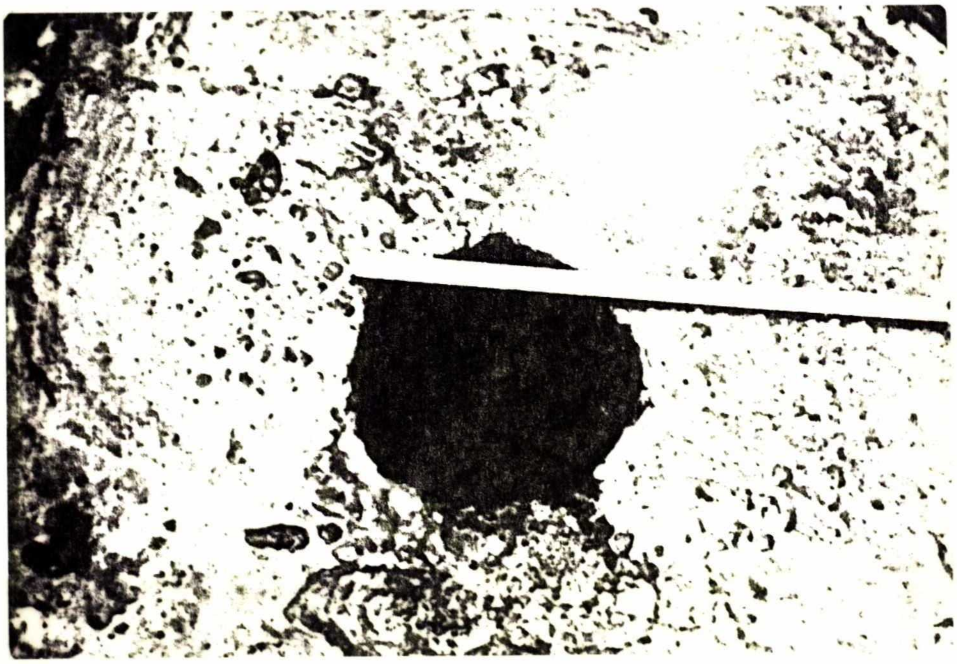


Figure 17. Core recovery using improved techniques: very weak, highly kaolonized dacitic tuff breccia in a silty clay to clayey silt matrix "cherry cheesecake" (4).

Figure 18. 100% recovery of gravel till by Hydro-Quebec; note the cut gravel pieces and undisturbed nature of the core (6).



(a)



(b)

Figure 19. Hydraulic damage to the drilled till mass (a) using conventional drilling techniques; intact till mass after using improved techniques. Hydro-Quebec study (6).