requirement low as the Danish dry drill. Problems with Kevlar cable are more related to cable construction type than Kevlar fiber itself. The weight, strength and wear properties change with each different construction type. The perceived problem with Kevlar cable use in shallow drills has been confused. PICO has successfully used Kevlar cables to drill many hundreds of meters without problems. Also, in connection with cable type Australian drilling group has considered a battery powered drill using radio for communication. This allows the cable to be a simple standard steel wire (yacht rigging wire) or a Kevlar string. This greatly simplifies the winch and cable formations.

ATED equipment was explained here. The total weight of the equipment (200 m depth) including power generator (2.5 kW) and fuel is about 180 kg. Without using of ethanol the ATED method (drill) can be utilized on glaciers with ice temperature of 0 to –5 °C. With limited quantity of ethanol (10% of the borehole volume) the shallow drilling with ATED can be done at ice temperature of –15°C.

Secondly, we discussed about the core quality. Many improvements have been made over the past 30 or 40 years in shallow drilling in ice. However, there is still great room for improvement with respect to core quality. The core quality depends on what measurement they are used. Here, how drilling should be performed without cracks was mainly discussed. Use of round cutter was proposed. The round cutter have producted fine chips because the bit geometry as currently used causes the cutter to have a near vertical face as it approaches the edge. Then, B. KOCI suggested that the rake angle is 15° and relief angle is 45° on edge of cutter. Other is addition of small amount of liquid to bottom of hole in shallow drilling to prevent crack formation or crack propagation. This is a danger for core contamination. We need to sort out eventually what types of tests need to be conducted to truly understand "how the system" works through international cooperation.

Above problems of (3) and (4) were not discussed because of not enough time.

(Chaired by S. JOHNSEN; Documented by H. NARITA)

Report 3. Status of Deep Drill

According to the summary given by N. GUNDESTRUP, there are several types of deep drills:

1. The thermal type, introduced by V. ZAGORODNOV

The core displaces a solution that dissolves the water produced by melting. This type has the best ratio between core length and drill length: the drill is hardly longer than the core. This means that this type of thermal drill can use a higher viscosity hole liquid than other drills. The problem with this type of drill is the hole liquid. It has only been tried with alcohol, and which has quite a high density. Thus, it is natural that this drill has only been tried to the depth of 900 m. It can possibly drill deeper, but the drilling has to be fast in order to avoid hole closure.

The hole will be lost after a few years due to the pressure difference between the ice and the hole, and creation of slush by constant interaction of alcohol with the ice hole wall. V. ZAGORODNOV reported on one such incident. If the hole is lost, it will not be possible to obtain information on ice flow with depth.

2. Thermal type with pump, modified CRREL version

This type of drill was first tried at Camp Century in 1961. The French and other groups have also tried this technique. Compared to the thermal type mentioned above, this type has the advantage that the hole liquid does not have to be miscible with water. This means that the same type of hole liquid as used with mechanical drills can be used.

A disadvantage is that the ratio between core length and drill length is about the same as for the mechanical drill, so why not go for a mechanical drill with better core quality?

3. Mechanical drill

This type gives ideal core quality outside of the brittle zone. There are potential problems with hole inclination. But until now, no drilling has been stopped prematurely on account of this. The drill is typically 4 times longer than the core, and thus requires a hole liquid with a viscosity not higher than 5 cSt. The design of this type of drill is more complicated than one introduced by V. ZAGORODNOV.

Two main versions are now in production: PICO sucks up the cuttings and filters them; ISTUK sucks up the cuttings, and stores the mixture.

Japan has done laboratory experiments that indicate that a shallow type mechanical drill can be used for deep drilling. The Japanese drill is simpler than both the PICO and the ISTUK drills. (N. GUNDESTRUP)

There are three important factors in selecting a drill: drill length, hole liquid and core quality. In deep drilling, moving the drill up and down in the hole liquid consumes most of the time and energy. This is boring for drillers. So, we want to design the core barrel as long as possible, so that the drill can take long cores to decrease the number of drilling runs. Unfortunately and naturally, the longer the drill, the stronger the friction between the drill and hole liquid. Design of the winch system including the cable essentially depends on this factor. To lower this friction, the total drill length cannot be too long. From this point of view, N. GUNDESTRUP stressed the importance of the ratio of core length to drill length.

L. AUGUSTIN suggests that the core length should be long enough to reduce operating time, but short enough for easy handling by hand. (L. AUGUSTIN)

As pointed out by S. J. JOHNSEN and L. AUGUSTIN, there is another important design factor to reduce friction: clearance between the drill and hole wall. ISTUK is designed to have channels to suck chips from cutters to the chip chamber, so that liquid can flow easily between channels. On the other hand, according to M. A. WUMKES, the PICO drill sucks up liquid by pump, while it is going down, producing a flow inside the core barrel in addition to the outside natural flow.

Cables were discussed by S. J. JOHNSEN, M. A. WUMKES, K. STANFORD, V. MORGAN, L. AUGUSTIN, H. RUFLI and Y. FUJII.

Steel cable is used in various countries, because of good storage on the winch drum with high winching speed (faster than 60 m/min). PICO, on the other hand, chose Kevlar cable for its light weight. Small cable diameter is preferable to make the winch system small and light.

The hole liquid is important problem in deep drilling. Chemically, it affects core quality, borehole lifetime, cable material, pressure chamber gaskets and other parts. Various tests have been carried out in several countries to check the chemical interaction between material of parts of the drill system and the liquid. Physically, the choice of liquid affects borehole lifetime and drill movement in a liquid-filled borehole. Below –55°C, there is limited choice of hole liquid with viscosity lower than 5 cSt and also with high cost performance.

As shown by B. L. HANSEN and N. GUNDESTRUP, liquid density is not a negligible factor at all. To maintain a borehole for long term logging, say 20 years, the greatest care must be taken in controlling liquid density.

This issue is discussed further in the report "Status of Borehole Liquid" in this edition.

Core quality is a very critical issue. As there is a separate report on "Status of Core Quality" in this edition, I only introduce here J. J. KELLEY's comments: The definition of "high quality ice core" is still somewhat elusive. It needs clarification in light of the fact that there are multidisciplinary needs for information from the core; and from the long term use of the hole. Presently, the analytical chemical technology is much better than in the past. Measurements of chemical constituents in the ice can be made in the parts-per-trillion or more. Does this imply that high quality cores mean "no cracks of any dimension" ?

Cracks within core (its shape, size and number) depend on drill type, ice hardness, cutter shape, cutting speed, cutting thickness and cutter load. But there are few data to discuss cracks in relation to these factors. So, let's keep them in mind until the next workshop.

The answer for K. KUSUNOKI's question whether there are specific problems on patent properties in the deep drilling business is obviously "No!". Information is open to anybody who is interested in drill systems. Concerning this, M. A. WUMKES comments: Many differences in methods of approach to deep drilling depend on the experiences of drill designers. It would be helpful if we could somehow share information, not necessarily in peering reviewed papers, but in a manner that would benefit all who design drills, preferably more frequently than every 4 years at ice core drilling workshops.

I would like to close this report introducing comments from H. T. UEDA one of the pioneers of deep drilling: A large part of deep drill system design is in the design philosophy of the designer or designers of the system. There is nothing wrong in approaching the problems in different ways. In fact it probably is desirable, at least for now. However, it would be beneficial for everyone to have easy access to objective and unbiased experimental results from the drilling community.

(Chaired by N. GUNDESTRUP; Documented by Y. TANAKA)

Report 4. Methods of Maintaining a Vertical Borehole

S. HANSEN: At present, the most successful method of maintaining a vertical borehole is to keep the contact pressure of the drill head to a minimum. It is therefore desirable to run an electromechanical drill using a head, and carefully control the descent rate of the drill. Also it is important to keep the center of gravity in the drill as close as spacers may be mounted onto the tube.

M. WUMKES: I agree with Sigfus' observations on the factors affecting borehole deviation, especially cable feed rates vs. cutter penetration rates. We have seen this at GISP on a number of occasions. We see accurate cable feed rate, stable drill head, stiff drill string and negative cutter loading as being desirable in minimizing borehole inclination.

K. STANFORD: (1) Penetration rate and bit weight control