Use and Abuse of Oriented Drill Core

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ABSTRACT

Considerable valuable structural geological information can be gained from oriented drill core. This data can be used to enhance geological models and provide reliable parameters for Mineral Resource estimation. All too often, however, structural data gathered from oriented drill core is inaccurate, not taken in correct geological context or not used at all.

Many of the problems are a function of inexperience in dealing with core orientation methods at the front-end, lack of care and knowledge during the mark-up process and deficient geological manipulation and interrogation of data at the collection and interpretation stages. These problems are commonly amplified by a lack of dialogue between geologists and drillers, followed by a less than professional approach to managing the whole process.

This paper documents core orientation systems currently in use in the mineral exploration and mining industry. Problems and solutions to issues associated with initial orientation of diamond core at the rig are addressed, followed by issues pertaining to the mark-up of oriented core. Collection of structural geological data from oriented drill core remains an area of concern in the minerals industry and some discussion pertaining to inherent problems is given. The paper concludes with a number of general considerations.

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INTRODUCTION

From a geological perspective, the use of diamond drill core is paramount in hard-rock exploration and mining. It provides invaluable information for prospect evaluation, Mineral Resource and Ore Reserve estimation and general geological understanding. With few exceptions, the mineral occurrences drilled have an architecture dictated by structure. Oriented diamond drill core is therefore critical to providing information on the structural controls to mineralisation, which in turn adds confidence to geological and Resource/Reserve models.

The process of oriented core collection should not take value from the project through unnecessary expense or loss of productivity. To this end, oriented diamond core should fulfil the following objectives:

- there should be no interruption of the drilling cycle and productivity should not be compromised
- the orientation method must be cost-effective
- drillers and geologists should possess a full understanding of the desired objectives and meet them through regular and accurate orientations
- core orientation methods may need changing due to ground conditions (and possibly driller experience)
- back-up systems have to be in place if a particular method or orientation tool fails
- a permanent record of the method used needs to be kept
- if not sampled, oriented core should be available for future interrogation and half-core should preserve the orientation mark and line.

This paper does not purport to be a 'how to' document that dictates the cradle-to-grave process of diamond core orientation through to geological interpretation. Rather, it looks at problems associated with oriented diamond core that can occur from the initial orientation stage at the rig through to interpretation of structural data at the end of the process. Details of procedures for oriented core are only discussed in detail sufficient for understanding the process; however, if readers require more information, they are directed towards other published sources or to contact people skilled in the necessary procedures.

Several orientation methods and tools are briefly described. However, in the interests of objectivity, the author does not advocate any preferred method.

METHODS OF DRILL CORE ORIENTATION

Downhole survey data provides the plunge and plunge-direction (azimuth) of the axis of the core; however, additional equipment, including mechanical/digital devices (Figure 1), is required to fully orientate the cylinder of core. These methods determine the orientation of the face of core at the drilling break between core runs and include the use of the following:

- downhole spear – no moving parts or electronics are involved
- Ezy-Mark™ – a mechanical system
- Verti-Ori™ – a mechanical system for orienting core from vertical holes
- Ballmark® – a mechanical system that is becoming less common
- Reflex™ – the latest in an evolution of electronic systems that has evolved from the electronic Ace core orientation tool
- ORIshot™ – an electronic system similar to the precursor of the Reflex ™ system.

The above list is by no means exhaustive and variations on methods exist. Still, in the hard-rock exploration and

FIG 1 - Examples of various diamond core orienting tools. (A) The downhole spear. (B) The Ezy-Mark™ tool. The orange section has pins that conform to the shape of the core stub, as seen in (C) below. The orange section can be left in the core tray as a proxy for a core block, thereby preserving the orientation with the core. (C) Ezy-Mark™ tool with permanent pins and crayon. Note the three aligned balls on the right-hand side of the instrument. (D) The Verti-Ori™ tool. (E) Ballmark® soft metal washer (left) with reference mark (hole) and orientation indentation (near finger). The right-hand picture shows the ceramic ball in the track where it freely rotates until the orientation is made. (F) The Reflex™ tool. (G) The Ace™ tool (left) and stopwatch (right). (H) The ORIshot™ tool showing orientation instruments and handset.

mining industry, the list contains the most common methods encountered.

In recent years, electronic methods, such as the Reflex™ system and ORIshot™, appear to be taking increasingly larger portions of the market. The industry appears to be progressing towards using Ezy-Mark™ and other electronic systems as the standard. The use of the spear, though, is still the most common because implementation is the simplest and cheapest, despite generally being considered less accurate than the newer and relatively more sophisticated methods. To be fair, the downhole spear can produce very good results and many of the problems encountered are not a product of the orientation method. Rather, poor results are commonly the product of poor techniques at some, or all, stages from orientation to mark-up. The following sections detail the causes of problems associated with various methods.

Details of the methods and potential associated problems

The downhole spear

The spear orientation method is the simplest for orienting core and, when done properly, can yield accurate and consistent data. It consists of lowering a heavy steel spear with a sharp point (eg a tungsten tip) or a wax-pencil tip on a wireline inside the drill rods after the inner tube is removed (Figure 1a). The influence of gravity causes the spear to travel down the lower edge of the hole and produce a mark or chip on the lowest edge of the next piece of rock to be cored. Good quality spear orientation marks will occur as discrete marks near the edge of the core.

Although the spear orientation device is very simple, several problems can arise (Figure 2), including:

FIG 2 - (A) to (E) show various marks made using a downhole spear that has had either a hardened metal tip or a crayon tip. (A) Smeared crayon mark defining a poor quality orientation mark, which is too wide to confidently locate the bottom-of-core position. (B) Unusable mark produced by a metal-tipped spear in the centre of a core interval. (C) Several metal-tipped spear impact marks at various positions across a core break. The impact marks define a line and are a result of dropping the spear from too far up the hole. (D) Elongated metal-tipped spear impact mark defining an unusable orientation mark in the centre of the core break. (E) Smudged crayon impact mark. Although the inclination would be to use the point at which the mark intersects the edge of the core, this is not correct and the mark should be treated as unusable. (F) Example of a poorly designed spear comprising an impact tip of a blunt crayon loosely attached to the spear with gaffer tape.

- The drill-bit may not be on the bottom of the hole.
- Smaller core sizes (eg BQ) will be more prone to error and produce marks relatively closer to the centre of the core than for larger core sizes.
- A bent spear tip will produce inaccurate results; therefore, the tip must be firmly screwed into the spear to prevent it from bending or breaking.
- A thick nut or some other holder for the tungsten tip or crayon will result in the mark being too far in from the edge of the core. To avoid this, the spear should be a tapered cylinder and the tip of the spear should be a sharp taper terminating in the tungsten tip or the wax pencil.
- If the spear is lowered too slowly it will fail to produce a mark and if it is lowered too fast the spear may bounce, producing multiple marks or streaked lines. The spear should be lowered so that it produces a single punch or crayon mark. The correct speed will be dependent on the angle of the hole and the hardness of the rock, and can only be determined by trial and error.
- The angle of the hole may be too great or too low. The best results are obtained in drill holes with plunges between 35° and 75°. The depth of the hole should not significantly affect the quality of the marks.

Ballmark®

The Ballmark® system (Figure 1e) uses the action of the inner tube back-end during core breaking, which transfers load to the outer tube via compression of a spring. The system indents a previously aligned soft metal disc using a non-magnetic ceramic ball. In angled holes, gravity causes this free-running metal ball to be positioned at the lowest point in its track, which is the bottom side of the hole and consequently the bottom of the core. By breaking the core after the drill-string has stopped rotating, an indentation is created on the soft metal disc. This mark is then transposed onto the core, resulting in relatively accurate core orientation.

One good aspect of the Ballmark® method is that the orientation mark on the metal disk relies on pulling the tube down against the disk when breaking the core. There will be no mark if core is from broken ground where drilling-induced breakage has not occurred. This means that there are no false marks associated with broken core.

A problem with core orientation using the Ballmark® method is that the aluminium washer can be punched too soon, ie before the ball has stopped revolving in the hole. In some cases, two indents can be produced on the same disc. This can be due to lowering the rods too quickly, causing compression of the spring when the rods hit the bottom of the hole. One way to check which mark is due to the tube landing and which is due to core breakage (ie the orientation process) is to join the lines from the two marks back up the hole. The correct one will align with the previously established orientation mark. More often than not, the deeper indentation is the one associated with breaking the core.

Ezy-Mark™

The Ezy-Mark™ system is one of a number of proprietary core-stub template tools. The tools are leased to the exploration/mining company, precluding any on-site maintenance of the tools if something goes wrong.

The Ezy-mark™ tool fits inside a standard inner core tube and is lowered down with the core tube. Three freely rotating non-magnetic balls are located at different intervals along the tool (Figures 1b and 1c) and are designed to roll to a position at the bottom side of the tool due to gravity. When the tool reaches the core stub at the bottom of the hole, a number of spring-loaded steel pins take an impression of the core stub shape. One of the pins is substituted for a wax pencil, which makes an independent mark on the core. The action of pulling the tool from the hole locks the steel pins in the shape of the core stub and locks the three balls, which record the bottom of the hole.

The Ezy-Mark™ tool comes out with the core at the end of each run. When the run of core is drilled and pulled from the ground, the template pins and pencil mark are matched to the core end. The tool has a shroud around it that is taken off and replaced with an orienting gauge, which has a window through which the balls, in their locked position, can be viewed (Figure 3). If a good quality orientation has been achieved, all three balls will be aligned and visible through the window.

FIG 3 - Orientation shroud for the Ezy-Mark™ tool showing viewing window where a high-confidence orientation mark is indicated by the alignment of the three balls.

Finally, the marker gauge is aligned with the orientation balls and the core is marked. Then a line is drawn along the core that matches the alignment of the three locked balls. This tool is very effective and generally quite accurate because it has three independent indicators that combine to give the bottom of the hole. It is common for failed orientations to be quickly identified.

Problems that can arise include:

- If the tool is lowered too quickly, the impact against water in the hole can cause the device to 'fire' prematurely before contacting the broken face on which the orientation mark needs to be made. Hence, the presence of a water table must be considered in holes when using the Ezy-Mark™.
- Because the position of the balls is directly influenced by gravity, the angle of the hole can cause induce problems if the holes are steep (eg of the order of 75° or greater). The three freely rotating balls are located at successive intervals along the tool, which means the balls are at progressively different depths when the tool is lowered into the hole. The balls roll to the lower side of the tool (and hence the lower side of the hole) due to the influence

of gravity and these positions are locked in when the Ezy-Mark tool fires.
- If the core breaks are perpendicular to the core axis, the profile will be circular and the pins will not show a marked asymmetry. The number of orientation techniques is consequently reduced and the orientation of the core is then dependent on the crayon mark and the successful alignment of the balls.

Verti-Ori™

Verti-Ori™ (Figure 1d) is a relatively new system designed by the same company that produces the Ezy-Mark™ instruments. Core is oriented relative to magnetic north and utilises a hybrid digital/mechanical orientation system. The author has not used this system yet and initial usage has been primarily for geotechnical purposes (eg drilling of vertical holes to assess foundations for dams).

Reflex™ (including Ace™)

The Reflex™ tool (Figure 1f) represents an evolution from Ace™ (Figure 1g), which was an electronic orientation tool. The Reflex™ tool is the most sophisticated of all core orientation tools in terms of its inner working, comprising digital read-outs, internal silicon accelerometers and electronics. In the past, instruments such as the Ace™ tool were returned to surface on completion of the drilling run and the user entered the time at which the core was broken based on the read-out on a stopwatch. The tool recalled the associated accelerometer information for the same time period from its memory and then guided the user to position the tool and core barrel so that the same low side position was reproduced on the surface.

Apparently random orientation errors from the Ace™ tool could be checked by placing the tool on a bench or jig and leaving it while recording the time period. The tool could then be rotated before inputting the time and reorienting the tool. If the tool consistently/accurately returned to its marked position, the error was most likely due to problems induced by drillers not following the correct orientation procedure.

The marking of the orientation obtained from the Ace™ tool was originally prone to error because it relied on an accurate measurement of the amount of time from when the reading was taken relative to when the rods were lowered. This potential area for error has been rectified in the Reflex™ instruments and stopwatches are no longer required as the instrument automatically records time and date. LED lights and an audible signal now compliment the LCD screen to direct the operator towards the correct orientation alignment.

When a drilling run is completed, the core is laid out and assembled such that all breaks are tight. The oriented mark is placed on the uphole face of the last piece of core. To do this, a coherent core interval without breaks or core rotation must link the uphole end of the interval, which is 'connected' to the Reflex™ tool, with the last piece of core. If there is obvious discontinuity, such as a fault zone in the middle of the interval, the entire run is effectively condemned. If the run has intersected a zone where orientation data is critical, the core can be separated at the zone where loss of continuity has occurred and the orientation mark can be placed on the last piece of core in the coherent interval. To date, the author has not seen any companies employing this technique, meaning much more core is condemned as poorly oriented than is necessary.

Potential errors that can arise when using the Reflex tool include:

- A jig provided with the Reflex™ tool is used to guide the marking up process at the lifter case end of the sample. Although the mark should be made on the end of the core it is common for drillers to put the orientation mark on the outside of the core, which can then be removed when the core is slid out of the barrel. Significant errors can be induced when the drillers attempt to determine where the original mark was.
- Unlike the downhole spear and Ezy-Mark™ tools, the orientation mark on core using the Reflex™ system is made on the uphole face of core at the core break. That is, it is made on the last piece of core drilled during the run, rather than on the first piece of the next run. Once again, if the method of orientation is not noted in the database, the tendency can be for the geologist to flip the core around such that the orientation mark is visible on a face that can be seen when viewing downhole. It is imperative that an arrow marking the downhole direction be placed on the piece of oriented core as soon as the core is laid out at the rig.
- A failure to reproduce continuous measurements on earlier versions due to extreme cold. The author worked on projects in northern Canada where the Ace™ instruments simply could not reproduce consecutive measurements.

ORIshot™

The ORIshot™ system (Figure 1h) comprises an electronic downhole probe and a synchronised handset. Use of the system is essentially the same as for the Ace™ core orientation tool, which was the precursor to the Reflex™ system. The probe is fitted to the back end of the core barrel and lowered down the hole. At the end of the core run the instrument has to be stabilised, which requires stopping the rod rotation and waiting for about a minute. The instrument is then returned to surface along with the completed core run.

Once the orientation assembly and inner tube have been returned to surface, they are placed on a stand – typically a core rack – and a request to get data is entered into the handset. The handset indicates which way to rotate the inner tube and probe so that their orientations match. A match in orientation between the handset and probe is indicated when two values, termed the roll and the downhole roll, match on the handset display. A match is also indicated by two vertical bar symbols on the handset display. When the match occurs the core is in its original position.

The core orientation line is marked using the V-block jig provided. The unit is purportedly accurate for holes that plunge up to 88.75°, which gives the ORIshot™ system an advantage over some other tools for steep holes.

A problem that can arise with the ORIshot™ is when extreme conditions, especially at the lower end of the range, may cause the equipment to give erroneous measurements. The downhole probe has an operational temperature range from -10°C to +70°C and the handset has a range from 0°C to +60°C.

Comments on orientation mark convention

In the case of the downhole spear, a good crayon mark will occur at the bottom of the core break and there is usually little confusion. If the crayon mark has not been made at the bottom of the broken surface, the geologist can usually resolve this when checking the quality of the marks during the reorientation process (see later).

The crayon mark associated with the Ezy-Mark™ method is used in conjunction with the array of pins that conform to the surface of the broken core combined with the locked alignment of three balls. As such, there should be little confusion with where the bottom of the broken face is located. Disposable Ezy-Mark™ core orientation blocks (Figure 1) containing the pin profile are commonly used in lieu of core blocks and the quality of the crayon mark can be assessed by comparison with the pin profile. However, in the unlikely situation where the blocks are missing, the marks may be incorrectly interpreted as bottom-of-hole marks made by a spear if the Ezy-Mark™ method has not been recorded in the database. All of these issues can be compounded by a geologist who is unfamiliar with the method being used, which is more common than people would think. The variation in orientation location makes it imperative that the method of core orientation is recorded in the database.

A final point worth noting is that good marks can be interpreted as unreliable if there is no indication of the method of core orientation used. Drillers using the Reflex™ tool commonly put an elongate mark on the end of the core that projects to the core margin. These elongate marks associated with orientation of core via the Reflex™ tool can look like badly smeared spear marks. This is another reason why it is imperative that the method of core orientation be recorded in the database.

General problems at the rig

Experience of personnel

A general problem inherent in many drilling campaigns is the inexperience of the geologist, driller or both, which can result in poor results. Generally, the capture of an orientation by the driller is factored into the contract, typically within the metre rate. The author has seen examples where an orientation charge has been agreed upon and was contingent on orientations being taken every 6 m (the drillers were using a 6 m barrel). Despite this, the drillers proceeded to take orientations every 40 m or more. Situations such as this are unacceptable and, in the cited example, were the result of the geologist not checking the frequency of orientation marks and the drilling supervisor not adhering to the agreement.

Case study

The author worked on a job at a major gold deposit in Ghana where the core recovery and integrity was great. Unfortunately, a short time in the core yard revealed numerous problems with the orientation process. The drillers were being paid to produce oriented core but were taking advantage of the lack of vigilance. In some cases, there were intervals of up to 60 m between orientation marks because the maximum amount of metres were being drilled without the stoppages associated with the orientation process. However, the long inter-orientation distances meant that there was no easy way to check the integrity of the marks in detail. If three marks were to line up, 120 m of core would need to be checked. Furthermore, the company was not getting the product (the orientation mark) it was paying for. Such situations are unacceptable and avoidable when the process is properly monitored.

Frequency of core orientation marks

The frequency of orientation marks will usually be every 6 m if the drill rig is completing 6 m core runs. If the drill-rig is completing 3 m core runs and very accurate structural data is required, orientation marks could be taken every 3 m. The onus is on the geologist to check the frequency of the marks and the quality of each one of them. A change to greater intervals between orientation marks should only occur in instances of very good ground and proven consistency of the orientations; however, the author does not recommend this.

Implementation of orientation method

There needs to be a dialogue between the driller and the geologist to establish if the drillers are confident in the application of the chosen method. For example, if the Reflex™ tool method is introduced, a Reflex™ tool representative should cover every shift with all drillers and the drilling supervisor until everyone is familiar with the method.

The geologist managing the project has to become familiar with the orientation method at the start of the drilling program. Drillers can be a wealth of knowledge and time spent at the rig is never wasted. At the very least, the geologist may pick up errors by the driller, which will mean early elimination of bad orientation marks.

Both geologists and drillers should be comfortable that the method being used is working well. In some cases, it will be necessary to do a comparison of methods to see if similar results are achieved (eg using both the Ezy-Mark™ and a spear). Note that different coloured crayons should be used if comparing methods so that the distinction can be easily made; eg red crayon for a spear orientation, yellow crayon for an Ezy-Mark™ orientation.

Contingency plans for the failure of an orientation tool, in particular the mechanical or electronic ones, need to be made. Some manufacturers forbid on-site maintenance by personnel who do not work for their company and request that orientation tools be sent back to the recognised dealer. Consequently, one instrument failing can be costly in terms of downtime while waiting for the instrument to be fixed or replaced. The presence of a spare tool on-site can avoid this but can also be costly and the merits of cost versus importance of the orientation data will need to be assessed. At the very least, a simple downhole spear should be available as a stand-in instrument if a decision to keep drilling is made while the other tool is being repaired.

Case study

The author was based in an exploration camp in northern Eritrea where an extensive drilling campaign was being undertaken. The government was very restrictive in terms of travel and the use of a helicopter to travel to and from the capital, Asmara, was likewise quite limited. Consequently, supplies were driven in along a route that took ten to 12 hours for a one-way trip. The travel time, combined with the paperwork associated with general travel as well as the import of goods into the country, imposed restrictions on how quickly equipment could be sent out for maintenance and the time taken for a replacement to arrive. An orientation instrument failing in cases such as this could have been costly in terms of productivity, time and money if an alternative was not available.

Ongoing surveillance of the orientation process

A simple problem that commonly occurs when using instruments such as the Reflex™ tool is that the driller transfers the orientation mark incorrectly from the face of the core to the outside of the core, or vice versa. Both marks need to be checked in the core yard during the next marking-up phase.

For the spear method, the geologist should always check the correct shape and tolerances of spears, especially those that have been manufactured 'on the spot'. Alarm bells should ring if a driller says 'no worries, we'll just whip up a spear and use that'. The author has seen some remarkably bad spears that have been 'whipped up' and in all cases the orientations were unusable.

Poorly made spears will produce marks like the one shown in Figure 4. Note that the orientation mark was a yellow crayon mark but this has been overwritten by drillers trying to be helpful through painting around and over the mark. Both the state of the spear and the mark should have been identified by the geologist in charge and rectified.

FIG 4 - The poorly designed spear in Figure 2F has produced the mark shown here. The orientation mark was originally a yellow spot but the mark has been overwritten by drillers trying to be helpful through painting around the mark. Both the state of the spear and the mark should have been identified by the geologist in charge and rectified.

Keeping track of the culprits

Bad orientations are commonly a product of one driller or one drill crew only. As such, it is important to identify any such problems early in the drilling program. Spot inspections of the rig and an assessment of the orientation process need to be made regularly; however, geologists should never announce that they are going to visit the rig to inspect the orientation process and equipment. Otherwise, drillers who are less than scrupulous are given time to cover up things that they do not want the geologist to see.

Case study

The author was working on a job where a spear was used for orientations but the marks lacked consistency. When asked if the spear was bent, the drillers emphatically denied that it was. On hearing this, the author told them he would go up to the rig that day to check the equipment; however, once there everything was in order with no apparent explanation for the bad orientations: the spear was fine, the rock was competent with few breaks and the hole plunged at a moderate angle (-60°). It was only when walking away and glancing over the side of the drill pad that something could be seen hidden in the bushes. The bent spear that the drillers had been using had hastily been hidden and replaced with a new one because they were expecting a visit.

To allow a bit of detective work and to deter unscrupulous behaviour, the driller responsible for the orientation mark on the core should put his initials on the block at the same core break (Figure 5). Although drillers should be identified from the drill plods, their initials on the block make the task easier, and highlights the driller's responsibility in the core orientation process. In other words, drillers will tend to use a bit more caution if they know that they can be identified.

The identification of drillers and their corresponding marks can circumvent a couple of potential problems. It is rare, but sometimes the marks will be fabricated. It may be that the driller is paid for each orientation in the program, which may lead to drillers putting a mark with no integrity on the core if the orientation process/tool hasn't worked. This can happen, especially so on night shift, when it is harder to see if a mark has been made or not by the tool. If geologists see a mark like the one in Figure 6, they should be cautious because the mark

FIG 5 - Examples of driller identification on core blocks at the break where the orientation was taken. RK has produced an unusable mark whereas Henry has produced a good mark.

FIG 6 - Example of a very discrete orientation mark near the edge of the core. This mark was allegedly made by a spear but is more likely to have been fabricated.

is a little too perfect. Needless to say, alarm bells should ring if there are a series of perfect marks.

Any qualified geologist should be able to interrogate the data and see if it makes sense. For example, consider good quality core that has a structure that consistently intersects it at the same angle over large intervals (say 100 m). If the measurements for oriented core vary wildly and show no pattern on a stereonet, there is obviously something amiss. Conversely, if a strongly folded fabric shows the same orientation from all measurements, the geologist should identify this early on in the program.

Case study

The author spoke to a colleague recently who had examined the structural data for a company working in SE Asia. When the orientation data failed to make sense, the colleague delved further and discovered that the geologist responsible for the data had fabricated the readings.

Identifying drillers also serves to determine who is competent enough to use the orientation method. If a driller consistently produces bad marks or no marks at all, consider moving them to a role not involving orienting the core.

Final comments on the surveillance of the orientation process

It is imperative that the core be marked up and the confidence of the orientation lines be examined while the drilling program is underway. If the mark-up process in the core yard lags too far behind the drilling and orientation process, several holes (or more) may get drilled before errors are found.

In cases where more than one instrument in each of the non-spear methods is being used on the same hole, the blocks need to be marked with the instrument number. In addition, a number of continuous orientations need to be taken with each instrument in order to check the repeatability of the measurements.

Ultimately, the onus is on the drillers and geologists to monitor the orientation process and results in order to ensure quality orientation marks. Essential to this is a good rapport and two-way respect between the drillers and the geologists.

Case study

Sometimes the sophisticated methods, such as the electronic tools, just don't seem to work. The author has seen occasions where both the geologists and the Ace™ tool (precursor to the Reflex tool) representatives couldn't resolve why the instrument was giving variable orientations across shifts and using different drillers. This has been in cases in the Arctic, where the problem could be attributed to the effects of cold on the instrument, through to cases where good drilling conditions were present and the problem was attributable to the tool. The instrument at the time was rated to -30°C and conditions in the Arctic are commonly colder than this.

Problems at the marking up stage – the orientation line

Potential problems associated with obtaining a good quality orientation mark represent only a portion of the issues that can arise prior to taking a structural data reading. This section reviews some of the relatively more common problems, although it is by no means exhaustive.

What does the orientation line represent?

By drawing a line along the bottom of the core, joining the individual bottom-of-hole marks, we are able to provide an 'orientation line' from which the true orientation of the planar and linear structures in the drill core can be determined. The accuracy of the orientation line is critical to the quality of the measurements. If the orientation line is not correct, all measurements made relative to the line are inaccurate and the data collected will be wrong and misleading.

Core reassembly

Prior to marking the orientation line the core must be carefully reassembled. This needs to be done diligently as it highlights factors such as core loss and whether or not orientation marks can be accepted.

Core reassembly may require gluing together core fragments in critical areas. Every break has to be assessed for continuity by firmly placing the core fragments back together. Core breaks should be assessed individually as some apparently good contacts can be the result of grinding induced during drilling. Failure to diligently check each break can result in unsatisfactory situations as shown in Figure 7. The result of failure to accurately join core back together will be misaligned core and an imperfect orientation line.

Note that the industry convention is to draw the orientation line on the bottom surface of the core so that it sits adjacent to bottom-of-hole orientation marks. In rare cases the geologist may encounter orientation lines on top of the core. In such situations there should be a clear indication that the line is not on the bottom side of the core. Unfortunately, a minority of geologists are somewhat reckless in defining the location of the line, or even worse may switch from a bottom-of-core line to a top-of-core line during a single drill program. This can result in whole data sets that are unable to be used. The problems created are twofold. Firstly, error in the line position is induced during the process of transferring from the bottom

FIG 7 - The core either side of the angled break (circled) fits together tightly. There is a lack of quality control associated with the red orientation line, however, as it shows misalignment across the break. The core across the breaks had not been pushed together to check the joins prior to marking. As an aside, this mistake was noted while the geologist concerned was claiming that there were no core orientation issues.

of core to the top of core. Secondly, if geologists are not made aware of the non-industry procedure of swapping the line from bottom of core to the top, they will place the core in an orienting frame in a position that is rotated 180 degrees from its true orientation. Similarly, Kenometer™ and alpha-beta strips typically measure alpha (apparent dip) and beta (apparent dip-direction) values relative to a bottom-of-core line, not top-of-core.

The situation of orientation lines on the top of the core may seem uncommon but the author has seen this on several occasions.

Case study

The author experienced an even more incredible situation when working on the initial holes in a major orogenic gold deposit in the Eastern Goldfields of Western Australia. After spending a day or so in the balmy 40°+ degree summer heat in the core yard, the data was not making sense. When querying the resident exploration manager about the core orientations, the author was told that the geologist wanted to view the orientation line when he was looking at the core so he changed it from bottom-of-core to top-of-core after the first seven holes. Clearly, this is an inappropriate practice.

The marking-up process briefly described below follows industry convention and pertains to bottom-of-core orientation marks and lines.

Marking the orientation line

The orientation line should represent the result of joining up confidently made orientation marks. Since each orientation mark has an unknown accuracy, it can only be accepted if it correlates with at least one but preferably two or more of the other adjacent orientation marks; that is, a straight line must connect the orientation marks when a coherent core between the marks is confidently reassembled.

To make an orientation line, the core should be reconstructed between the orientation marks. The best method for this is to use a continuous length of angle iron that can accommodate several runs. For example, if using a 6 m core barrel, at least 20 m of angle iron should be available to lay the core out on (Figure 8). This allows four marks (three internal marks plus one from the end of the interval above or below) to be assessed for consistent bottom-of-hole positions. Alternatives to angle iron include the use of a sheet of corrugated or ribbed metal that allow successive runs to be aligned adjacent to each other (Figure 9).

FIG 8 - Core laid out in a piece of angle iron to the left of the trays from which it was taken. The oriented marks are then lined up and the edge of the angle iron used as a guide to draw the orientation line.

FIG 9 - Core laid out on a sheet of iron with angular corrugations. The orientation marks are aligned on the top side of the core (still bottom-of-hole but the core is rotated around). A piece of iron is then rubbed against the core and produces a non-temporary line on pieces of adjacent core. This line can then be checked against the marks for consistency and over-written in ink if the marks are of good quality.

The procedure for marking orientation lines should incorporate the following:

- Placing a small pencil mark on the side of the core where the interpreted bottom of the hole is. This is done by taking the estimated bottom-of-hole and lining it up in a straight line with the centre of the core. Do not use permanent marker – human nature will invariably decide that the permanent mark represents a high-confidence reference mark later on in the orientation process.

- The core should be laid out in the V-rail with 'down-the-hole' to the right, and from top to bottom. Maintain and enforce this convention, otherwise mistakes will invariably occur.
- Core blocks should be left in the tray and a small mark made on the core where the block belongs; thus, any confusion as to where the core should go back in the tray can be avoided. This method also allows all breaks to be assessed and adjacent pieces of core to be meshed because there is no break in continuity by core blocks.
- When a V-rail is filled, carefully mark the reference line onto the end of the last piece (making sure the pen is horizontal). Transfer this mark to the next V-rail interval, ensuring the mark is horizontal to the pen.
- Continue until two or three runs are laid out. If three runs are laid out, four orientation marks can be compared.
- Check the correlation between the orientation marks. Generally, you will find by playing with any loose connections that good quality orientation marks can be made to match (within ±15°).
- To start an orientation line, two or preferably three orientation marks must be aligned within 15°. These aligned marks may straddle a poor quality mark, which may not be aligned if the core can be confidently reconstructed through the substandard orientation mark.
- When it is determined that the orientation marks are reliably aligned a reference line can be drawn on the core joining the marks. Always draw the line from the known to the unknown. A common occurrence in drill holes that traverse markedly different rock types or contain thin ductile shear zones is core-spin. If an interval of core becomes free spinning, it may show a tight join across one or both ends of the interval. This is because the core is ground into the next interval across the break. Consequently, many apparently tight joins are the result of drill-induced grinding and the orientation line cannot and should not be carried across these. This is easily identifiable when all the breaks are examined because the core will have concentric rings on the broken face (Figure 10) and the join will be at right angles to the core. Taking measurements from rotated core will give small circle data distributions when plotted on a stereographic projection.

As a general point of interest, the rotation of drill rods during coring is typically clockwise. Consequently, rotation about the drill hole axis will likewise be clockwise, but there is no way of determining how many times the core has been rotated or how far (ie a rotation of 20° will be the same as a rotation of 380°). Note that evidence for core-spin and the grinding together of adjacent pieces of core commonly occur across the break in core runs, which will be designated by a core metreage block; however, that evidence for core-spin does not necessarily mean that both pieces of core are rotated. More likely, the piece of core from the greatest depth (ie the first piece of core for the next run) was stationary, and can show an acceptable orientation mark (Figure 11) due to orienting the core after the run with the upper rotated core piece has been removed. Still, it is advisable that the

FIG 10 - Example of core spin that has induced circular marks on the core either side of the break.

FIG 11 - Example of a portion of core showing evidence for core-spin. The spin marks were due to the rotation of core from the previously drilled interval. The piece of core in this figure represented the start of a new core run and did not undergo rotation.

orientation mark on the lower piece of core, which will be the first piece in the next run, be checked for consistency with marks from further down the hole before it is accepted.

It is important to check for continuity or otherwise of geological markers (eg veins) across core breaks. If the marker is displaced across the join, the orientation line should not be carried across the break. Likewise, if the marker is continuous across the break but the orientation line is displaced, there is a problem. Unacceptable situations like that in Figures 12 and 13 result from a lack of diligence on the part of the geologist.

The orientation line may be extended up to several metres past the last orientation mark, provided the core can be confidently reconstructed. The points at which an orientation line is stopped and the reason for the termination should be recorded on the orientation record form. In extreme situations where orientations are critical, a single reference line may be extended for many tens of metres in competent, well-oriented core, although this is not advisable. The author has also encountered the opposing situation where the lack of training of geologist and technicians resulted in orientation

FIG 12 - Poor geological practice exemplified by misalignment of a core orientation line across a core break. Note that the core fits together well, and when it does the pyritic vein under the thumb is continuous.

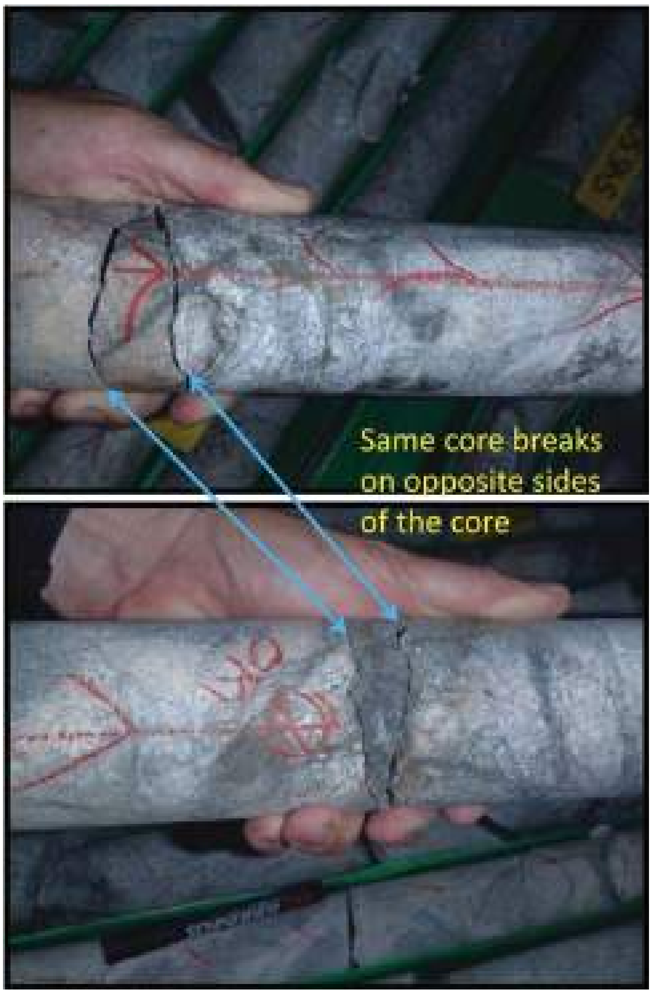

FIG 13 - An example of a dislocated orientation line that is hard to explain. Either the core had not been diligently reassembled, or the orientation line had been drawn from two different directions and did not match. In both cases the orientation lines are of no confidence.

lines terminating at the ends of core runs despite continuity of good core with that of the successive run. Even more perplexing is the uncommon occurrence of orientation lines that terminate across coherent core breaks (Figure 14).

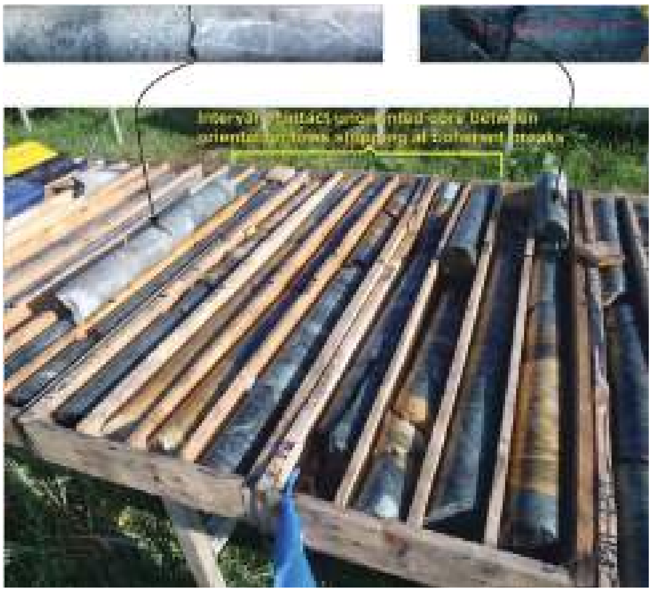

FIG 14 - Example of high-confidence orientation lines terminating at core breaks that could be confidently reassembled. The breaks are shown in the oriented core with the orientation lines at the top of the figure. Terminating the lines has meant that a large interval of coherent core has not been oriented. In this case, the lack of orientation line was a concern because the unmarked interval contained a number of important structures needing to be measured.

The correct way to position core in the V-rail is with the orientation mark parallel to the edge with a pen held horizontal to the edge of the V-rail. The pen must be kept horizontal when drawing the reference line. It cannot be stressed how important it is that the pen be kept horizontal. The tendency is to roll the wrist as the mark is put on the core but this can cause a progressive deflection of the orientation line from what it should be. The ultimate result will be an orientation line that spirals around the core! Unfortunately, the spiralling line may only be evident if a substantial portion of the hole is laid out. Data from this situation will appear rotated because a consistently changing line orientation is used as the reference when taking alpha-beta measurements or measuring directly from dill core.

Designating the quality of the orientation line

Different line types or colours should be used to delineate between lines of high confidence and those where there is some uncertainty as to the quality of the line. Another line type or colour should be used to mark a 'cut' line along which the core is sectioned for sampling. It might seem obvious but the geologists, technicians and people cutting the core should all be familiar with the different line types. It is quite surprising to have geologists who supposedly know about a deposit be unable to tell you which is the orientation line and which is the 'cut' line – and even more so when the worker cutting the core doesn't know which line is which and has removed the orientation line. There is little hope of rectifying this as the line has either been lost when it was sawed or is somewhere in a sample bag.

When marking the lines, it is preferable to use the bottom edge of the V-rail to guide the pen when marking the orientation line rather than a ruler, regardless of type or style. If the collection of orientation data is critical, the geologist may decide to be strict with the designation of the orientation line and choose only solid lines of high confidence and dashed lines of low or no confidence.

A record should be kept on the orientation sheet that indicates which orientation marks were used (good) and which ones did not line up and were not used. In this way, a record of the orientation marks is kept for future reference.

Comments on the convention of line-marking direction

Line marking on core should always show the downhole direction of the hole as an arrow (Figure 15). This convention applies to cut lines as well as orientation lines and helps avoid core being placed back into the trays the wrong way round. The tendency of geologists is to place core back into the tray such that the arrow points downhole. Consequently, if the arrows are absent or point the wrong way, the continuity of geological features – significantly mineralisation – can be dislocated and this may even result in changes to the economics of a project. The author has seen holes with the arrows pointing uphole and, in a several cases, intervals of core where the arrows at either end of the intervals pointed both uphole and downhole.

FIG 15 - 'Oriented' core showing a red downhole spear orientation mark on the core break. The core break represents the start of a new core run and progressively deeper portions of core are located in a direction away from the mark. Consequently, the orientation line on the outside of the core that points towards the orientation mark is incorrect because it indicates an uphole direction.

Collection of structural data from oriented core

Methods of data collection/measurement and comments on interpretation

Collection of data is principally done directly via measurement in core orienting frames, or indirectly by taking alpha, beta and gamma readings and then calculating true orientations via a spreadsheet or some form of canned software.

Numerous forms of core orientation frames are available, from commercially produced ones to those that have been manufactured on site. The professionally produced frames can be very expensive and are typically only purchased by mid-tier to major companies. Some of the less expensive models are very useful because they are relatively compact, allowing easy transport and use across any number of exploration and/or mining properties. All of the core orienting frames will work well although care has to be taken that they are made entirely of non-magnetic material. Failure to do so can produce some interesting and potentially erroneous results. In this respect, the professionally produced frames are trouble-free in terms of magnetic material. Figure 16 shows the impact of magnetic material in a locally produced core orienting frame at a property in West Africa.

In the case of alpha and beta measurements, the introduction of the Kenometer™ (Figure 17) has been extremely useful. Regardless of the method used for taking alpha and beta measurements, it is recommended that a core frame/rocket launcher is used for the measurement of structures in oriented core at the start of each project. The use of a core orienting frame permits direct visualisation of the structures in their original orientations. In some cases, this can help avoid some embarrassing and more expensive errors.

Case study

The author worked on a job in West Africa where a deposit was proceeding to the resource evaluation stage. All the measurements of the structures, including the planar mineralised zones, had been taken using the alpha-beta method. Interpreted drill sections showed beautiful subvertical gold-bearing zones. When checking the orientations using a core frame, it turned out that the mineralised zones were actually subhorizontal. A lot of the problem centred on geologists being reluctant to leave their air-conditioned offices to spend time in the humid core yard.

If a considerable amount of data is required quickly, the alpha-beta-gamma method can be used. If using this method, the author will reiterate what was said above and emphasise the use of a core orienting frame so that structures can be visualised. Core orienting frames allow measuring non-penetrative linear features and checks on the alpha-beta-gamma measurements taken from the same intervals.

The author has seen examples where a lot of alpha and beta data has been collected but the geologist never used a core orienting frame to double-check measurements or to visually assess the structural relationships. It's amazing when populations of widely varying alpha and beta structural data are presented but the core in the trays shows a consistent core-to-structure angle.

Figure 18 is from a project where a client was firm in their belief that their bedding orientation data was impeccable. However, the data distribution for poles to bedding should have rung some alarm bells. The plots also highlight some of the pitfalls of letting software deal with the data. The individual data is plotted and forms a distribution that defines a broad circle with an area of minimal data in the core of the distribution. This is a typical distribution for data that has been rotated and is referred to as a small circle data distribution. The axis of rotation is the drill hole orientation. From this plot alone it is possible to predict that the drill hole orientation was approximately 60°→200°.

Final pleas

Geologists should never wait until a drilling program is over before they start orienting the core, taking measurements or performing checks. It may be too late, especially if all the critical data is of low confidence. It is entirely feasible that the company may lack the money, logistical support or backing of management to redrill the holes and re-collect

FIG 16 - Examples of problems arising from a core frame that contains magnetic material (left). The yellow item is a pen magnet. The upper-right photo shows the compass several centimetres away from the core frame, whereas the lower one shows the compass resting against the core frame. The two photos show that the needle orientation in the compass can be out by as much as 30°, depending on proximity to the core frame.

FIG 17 - Oriented core inside a Kenometer™. This device allows for easy measurement of alpha and beta angles.

the data, even if the geologist goes cap-in-hand and admits to making an error. Such situations are sure-fire ways to damage a reputation, guarantee a poor performance review and restrict the geologist's contribution to future exploration programs.

CONCLUSIONS

Geologists must take ownership of core orientation and data collection, performing checks down the line to ensure everything is on track and correct. Geologists need to get out of their climate-controlled offices and look at the rocks.

Never assume the core is correctly oriented. Perform some checks; eg measure a feature that has a consistent orientation regionally and check that it conforms.

A core orienting frame should be used initially for oriented core at the start of each project and regularly throughout the logging process. This permits direct visualisation of the structures. The frame should always be on hand for checking

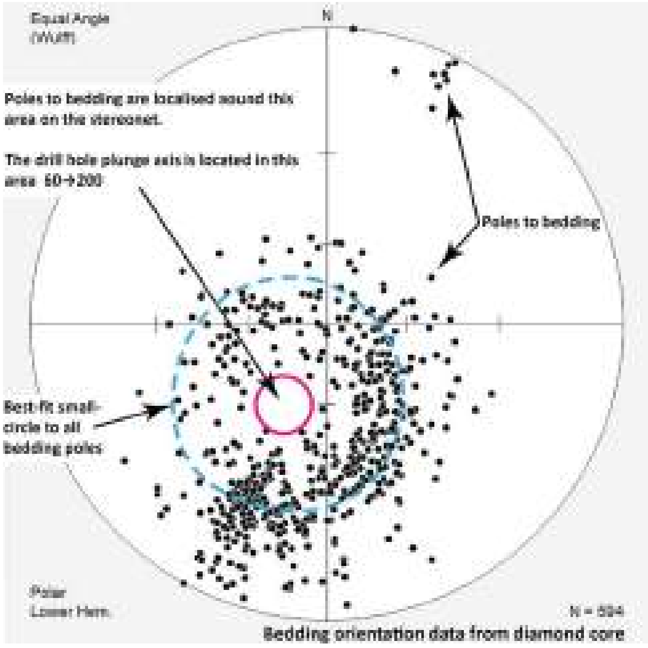

FIG 18 - Example of a small circle distribution of data due to measurements being taken from core that has been rotated. The centre of this distribution is the rotation axis, which is the orientation of the drill hole axis.

measurements and for measuring non-penetrative linear features (eg fold hinges).

If a large amount of data is required, the alpha-beta-gamma method should be used. Use of equipment such as the Kenometer™ can facilitate this; however, regular checks should be made using a core orienting frame.

A number of core orientation methods are available and the industry is still establishing a broadly accepted standard, which will likely be either the Reflex™ tool method or the Ezy-Mark™ method. Those methods with more than one independent check on orientation and those with the least number of moving/mechanical parts will become most widely used.

Modest amounts of good-quality data (from well-oriented drill core) are much better than large amounts of poor-quality data.

Although not covered in this paper, it will be obvious that a geological history that combines paragenetic and deformation histories is an essential framework to help constrain geometric relationships gathered from oriented core. The geological history allows the structures to be broken into different populations that can be measured and interrogated separately.

Finally, if in doubt about the process of getting good oriented core and about what structures to measure, seek help. Find someone in the organisation with experience in oriented core, or get an external source such as a consultant. Never let the program carry on without addressing the issue.

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