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Recognition and Use of Induced Fractures, and Other Features in Core Produced by the Coring Process

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ABSTRACT

There are several distinctive types of coring-induced fractures that can be recognized in core on the basis of morphology, assisted by certain characteristics such as edge effects and surface ornamentation. The shape and orientation of many of these induced fractures offer information on the in situ stress conditions and the coring process. Petal, petal-centerline, scribe-knife, disc, and torque-related fractures may all be caused by coring in vertical wells. Saddle fractures, (related to petal fractures) are unique to horizontal core, as is the polishing of fracture surfaces during coring. Other features such as scribe-line rotation, hammer marks, and rotary-bit patterns are important in making correct interpretations of the in situ stress and reservoir permeability, and in making the maximum use of the evidence bearing on reservoir fracture-system permeability provided by both induced and natural fractures.

INTRODUCTION

Mineralized planes in core are easily recognized as natural fractures, but not all natural fractures are mineralized. Unmineralized natural fractures can be misinterpreted as fractures that resulted from the coring or handling processes. Examples of fractures, in core from vertical and deviated wells, are offered in the accompanying core display as illustrations of the different distinctive types of coring-induced fractures that have been recognized. Familiarity with these fracture types assists in their recognition in slightly different forms in other cores.

Examples of natural fractures are also displayed for comparison. In addition, the importance of using any or all coring-produced features in the interpretation of

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both natural and coring-induced fractures is illustrated. Cores containing different types of fractures and features (Table 1) are available at the display, and are briefly described below.

Because fractures are two-dimensional, they are more difficult to locate in core than are sedimentary structures, and fracture information is commonly destroyed or lost when core is slabbed. Whole, unsampled core, analyzed at the well site if possible, is essential in order to maximize the data obtainable from core (Lorenz and Hill, 1992). Each piece of core must be picked up individually and examined carefully on its entire surface when studying core for fractures.

CORE FRACTURES AND FEATURES

Petal and Petal-Centerline Fractures

These fractures form in the rock below the bit during the coring process and are subsequently cored. Typical petal fractures form short (4-10 cm) concave-downward parabolas where they intersect the core surface, and they terminate within the core. The fracture may be planar, or it may increase or decrease in dip downward. Although isolated petal fractures are common, these typically occur in groups of between 2 and 20 parallel fractures, spaced anywhere between 5-20 cm apart. Most if not all of the petals of a group may be on one side of the core, or they may occur as mirror-image petals on opposite sides of the core. Petals are more common in brittle strata (sandstones, limestones), and are rare in ductile shales. A petal may consist of one plane or a series of anastamosed fracture planes (Lorenz et al., 1990).

An individual petal fractures may extend downcore as a centerline fracture, becoming sub-parallel to the core axis for up to several meters. Other petal fractures may strike parallel and adjacent to the centerline fracture without intersecting it.

The morphology and grouping of petal fractures is distinctive, and they are rarely mistaken for natural fractures. However, where the originating petal fracture is missing (due to sampling, etc.,) centerline fractures may resemble unmineralized natural fractures. If the lithology is suitably fine grained such that plumose structures and arrest lines are created during petal and centerline fracture propagation, this can be resolved: plumes and arrest lines indicating vertical, downhole propagation suggest a centerline fracture, whereas horizontal propagation indicates natural fractures (Kulander et al., 1990).

The regular spacing of many groups of petal fractures records the periodicity of weight-on-bit variation during coring. The strike of petal and petal-centerline fractures indicates the orientation of the in situ maximum horizontal compressive stress (except at local anomalies and in ductile lithologies). This orientation relative to natural fracture strike is important in determining whether associated natural fractures will provide in situ permeability or whether they will be squeezed shut by an orthogonal maximum horizontal compressive stress (Lorenz et al., 1990).

Scribe-Knife Fractures

Scribe-knife fractures are relatively rare, and they are usually difficult to detect when present. They are best observed on the ends of the core, since they originate within scribe-knife grooves on oriented core, where marring of the core surface by the scribing process imparts a wedging action to the rock. Scribe-knife fractures commonly penetrate only part-way into the core.

Scribe-knife fractures can be distinguished from natural fractures by their lack of complete core penetration and by their origination at scribe lines, commonly the more deeply gouged lines.

As with petal fractures, the strikes of scribe-knife fractures commonly parallel the maximum in situ horizontal compressive stress in brittle lithologies and they may be used similarly in determining the probable effectiveness of associated natural fractures. In ductile lithologies, however, scribe-knife fractures may strike normal to the core surface, penetrating directly to the heart of the core since the in situ horizontal stresses are equal (Lorenz et al., 1990).

Disc Fractures

Disc fractures trend normal to the core axis, commonly parallel to bedding, and usually occur in shaley lithologies. They are dissimilar to most natural fractures, and a slightly raised lip common at the edge of the core indicates that they formed after the core was cut. These fractures commonly originate at a flaw in the rock and propagate horizontally: the direction of propagation, locally recorded by subtle plumose structure that is best visible in oblique lighting, is inferred to parallel the maximum in situ horizontal compressive stress (Kulander et al., 1990). Where this plume axis can be recognized, it can be used in the same way as inferences from petal and scribe-knife fractures in assessing probable natural fracture permeabilities.

The lip at the edge of the core is an edge effect between the propagating fracture and the stress-free surface of the core. Locally the lip records torsion from the rotating core barrel during formation of the disc fracture, in the form of a small tang with a curving surface.

Torque Fractures

Rotation of the bit causes a certain amount of torque on the core, as evidenced by a common clockwise-downhole drift of the scribe-line grooves on oriented core (see below). In some coring operations, however, the inner core barrel fails to rotate as designed. This can create enough torque between the core in the barrel and the intact rock being cored to break the core in a distinctive helical fracture pattern.

The helical surface rotates about the core axis about 180 degrees (rotating clockwise downhole), spanning a length along the core axis that is roughly equal to the core diameter. A rough, unoriented break connects the top and bottom of the helical surface. Continued coring often breaks up the core at this location, leaving the helical surface difficult to recognize. This torque and its effects on the core can be duplicated by twisting the ends of a length of chalk in opposite directions.

These fractures form in the more competent lithologies, where bedding-plane weaknesses are not pre-disposed to form the more common polished spin-off surfaces normal to the core axis. Torque fractures will not be confused with natural fractures and do not indicate anything of the in situ formation stresses, but they suggest that the coring equipment is not operating smoothly and that the bearings that allow the inner core barrel to rotate freely should be replaced.

Pine-Cone Fractures

A severe example of torque fractures occurs in combination with attempts to over-fill a core barrel. A result of trying to put 32 ft of core into a 30-ft barrel results in shattering of the the bottom 3 ft of the core in a specific pattern of numerous small, constant-orientation, helical-shaped shards. The resulting pattern on the core resembles an opening pine cone, thus the term for this type of fracture. (They may also be referred to as "blivit fractures"). They suggest that better depth control should be attempted with the next core.

Saddle Fractures

Coring-induced fractures are less frequent in horizontal core, due perhaps to the greater care that is commonly used in these coring operations, but also as a result of the different orientation of core relative to the in situ stresses. Because the variable bit-weight stresses that cause petal fractures no longer augment the maximum (vertical) in situ stress by paralleling it, stresses do not exceed the level required to form petal fractures as frequently as they do in vertical core.

When fractures do form, they follow bit stresses with a modified trajectory "below" the bit. Shallow petal fractures form, cutting across the core in a compound curve that resembles a saddle. Uphole curvature creates small tangs on opposite sides of the core that resemble the fore and aft ends of a saddle. Downhole curvature (the sides of the saddle draped over the horses flanks) creates tangs pointing downhole that are oriented 90 degrees to the uphole tangs.

Saddle fractures typically occur in groups, similar to petal fractures, but they cut entirely across the core rather than ending within the core as do the majority of petals. Surface ornamentation (plumose structure) suggests that these fractures originated near what is now the core surface, again similar to petal fractures.

In the one definative example available, the uphole lips of 25 saddle fractures always formed on the top-hole and bottom-hole sides of the core. If the analogy to petal fractures is correct, the fracture surfaces of the uphole tangs should strike parallel to the maximum compressive stress, suggesting that the maximum compressive stress is horizontal rather than vertical in this hole.

The spacing of saddle fractures is an indication of the frequency of high-stress contact of the bit with the bottom of the hole.

Polished Fracture Surfaces

Core from a horizontal borehole is not "stored" vertically in the barrel while the rest of the core is being cut, thus the weight of the core does not hold the core together across breaks normal to the core axis. Vertical or near-vertical partings in the core, such as natural or induced fractures, are free to vibrate against each other while the core is lying on its side on the bottom of the inner core barrel.

Continued vibration (without rotation), with minimal pressure across the plane of contact, polishes the contact surfaces. This obscures or obliterates most ornamentation on the fracture surfaces, and can even remove minor amounts of mineralization, making interpretations of the origin of the fractures difficult. Interpretation may rest on mineralization preserved within the hollows of the fracture surface, or on the preserved overall morphology of the fracture.

Scribe Rotation

Oriented cores are usually scribed with three reference grooves. The position of the principle scribe line relative to a straight line down the core surface is an important quality-control factor in making the most of the data provided by natural and induced fractures (Skopec et al., 1990; Lorenz and Hill, 1992).

The reference grooves commonly rotate clockwise downhole due to bit rotation and the incomplete isolation of the inner barrel from this rotation. A scribe rotation of 0-5 degrees per foot is common and acceptable; more than this leads to uncertainty in the correlations between core depths and orientation points, and thus to increasingly unreliable orientation results. In severe cases, the scribe knives rotate rapidly enough against the core to scrape sideways, locally or even completely resurfacing the core.

The amount of scribe-line rotation on the core should be measured per foot and then compared to the orientation data provided by the core orientation company. This provides a quality check on the orientation data, and often allows definitive correlation of core depths with orientation depths where uncertainty exist (as in cases where less core is recovered than was cut).

Spin-Offs and Connection Breaks

Notations of scribe offsets, in combination with scribe deviation surveys described above, allow the geologist to decide whether a fracture in the core correlates with orientation data above or below the core break. Even if the core is not oriented, such notations provide information on the alignment of different fractures with respect to each other and to the in situ stress as measured by other core features.

Spin-offs are the most common scribe-line offsets, often forming during brief periods of increased drill-string RPM. Drill-pipe connections made during coring also frequently re-set the scribe line orientation. These can be recognized by an overlapping dual set of scribe lines and local scarring of the core surface by the catcher.

Scribe lines may or may not have originally been continuous through rubblized core zones (often the core orientation data will help to determine this), and such zones should be noted in order to help in deciding whether fractures above and below rubble zones are co-planar or may in fact represent two different important fracture strikes.

Miscellaneous Patterns

Other patterns of wear and breakage on the core provide additional evidence as to the relative orientations and importance of different fracture patterns seen in core.

A tri-cone rotary bit leaves a distinctive pattern of dimples and a central, uphole protrusion on the rock at the bottom of the hole. The rock containing this pattern is often cored. If core is missing from a core run, recognition of this pattern at the top of the core suggests that the missing core is from the bottom of the core run rather than the top, and that therefore the upper sections of the core orientation survey data should be applied to the core that was recovered. (Otherwise, core lithology may sometimes be correlated with rate of penetration for the coring operation, or with a later downhole gamma ray log, to determine which section of the cored interval the partial core came from, and thus which part of the orientation survey it correlates with.)

Kulander et al (1990) report "barbs" that sometimes form on the bottom-hole sides of horizontal core, usually pointing in the downhole direction off of a break that is otherwise normal to the axis of the core. Similar barbs can be formed in chalk by bending it to break it: barbs always form in the inside of the bend due to local compression, whereas the outside of the bend, in extension, forms a break directly across the cylinder. Thus the barbs in the core are inferred to be related to bending of the core, probably as the horizontal core barrel sags on either side of a stabilizer during coring. Bending the core around a short-radius hole-deviation curve during recovery could also create barbs on the core at the inside of the bend. These barbs would be expected to be at the **top** of the core, **if** the core was retrieved by "chaining out" and the core barrel did not rotate during recovery.

Core is commonly hammered at the well site in order to break it into manageable lengths that can be carried or fit into core boxes. Characteristic marks of hammering include a small crush zone at the point of impact on the core surface (more than one where multiple blows were required to break the core), conchoidal fracture planes with a "bulb of percussion" at the point of impact (in homogeneous lithologies), and plumose structure radiating out from the point of impact (usually only in finer-grained lithologies).

In some cases, the core-catcher slip-dogs (wedges that jam against the core to grab and retrieve it when the core is pulled off the bottom of the hole) may not completely retract during coring. These will drag against the core as the core enters the barrel, much as do the scribe knives, leaving scratches on the core surface that superficially resemble scribe grooves. A protractor and the knowledge of scribe-knife pattern used (the patterns often change between companies) are useful in differentiating scribe grooves from marks made by a dragging core catcher. The core catcher should be reconditioned when these marks appear.

Where core cuts easily and rapidly and the bit is rotating slightly eccentrically, closely-spaced spiral ridges may be cut into the core surface. The low pitch of the spirals (on the order of 150-200 ridges per meter) makes them look like circular ridges, although they can in fact be traced up and down the core like threads on a screw. An eccentric bit coring at a rate of 3-4 minutes per meter, with kelley table rotation at 50 RPM, will rotate around the core 150-200 times in the course of cutting one meter of core and leave evidence of its rate of passage. This pattern has no direct use, but its recognition gives confidence in the reconstruction of other coring conditions.

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TABLE 1

Induced Fracture Types

<u>Vertical Core</u>

1. petal/petal centerline fractures
2. scribe-knife fractures
3. disc fractures
4. torque fractures
5. pine-cone fractures

<u>Deviated Core</u>

6. saddle fractures
7. polished fracture surfaces

Other Important Core Features

8. scribe rotation
9. spin-offs and connection breaks
10. miscellaneous patterns
    - rotary bit marks
    - barbs in horizontal core
    - hammer marks
    - core-catcher drag
    - bit spiral