4
Caliper Logs

Caliper tools measure hole size and shape. The simple mechanical caliper measures a vertical profile of hole diameter (Figure 4.1). The more sophisticated borehole geometry tools record two simultaneous calipers and give an accurate borehole shape and orientation.

4.1 Mechanical calipers – the tools

The mechanical caliper measures variations in borehole diameter with depth. The measurements are made by two articulated arms pushed against the borehole wall. The arms are linked to the cursor of a variable resistance (Figure 4.2). Lateral movement of the arms is translated into movements of the cursor along the resistance, and hence variations in electrical output. The variations in output are translated into diameter variations after a simple calibration. Frequently logging tools are automatically equipped with a caliper, such as the micrologs (Chapter 6) and the density-neutron tools (Chapters 9, 10) where the caliper arm is used to apply the measuring head of the tool to the borehole wall. Sophisticated, dual caliper tools, such as the Borehole Geometry Tool of Schlumberger, also exist specifically for measuring hole size and volume. However, today, such information is generally taken from dipmeter tools, which acquire geometry data in order to derive dip (Chapter 12). These tools have four pads fixed at right angles, opposite pairs being linked but independent of the perpendicular set. This, in terms of geometry, gives two independent calipers at 90°. The tool also contains gyroscopic orientation equipment so that the azimuth (bearing) of the two calipers is permanently defined.

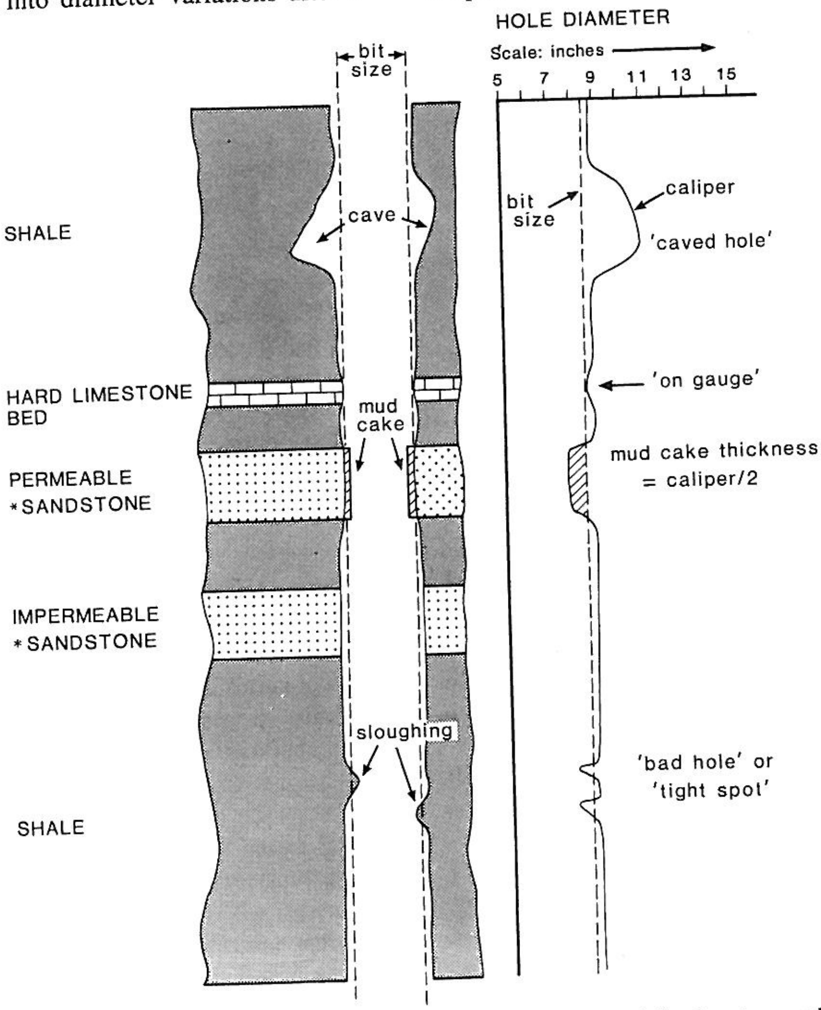

Figure 4.1 The caliper log showing hole diameter: some typical responses. *Limestone, dolomite, etc. equally applicable.

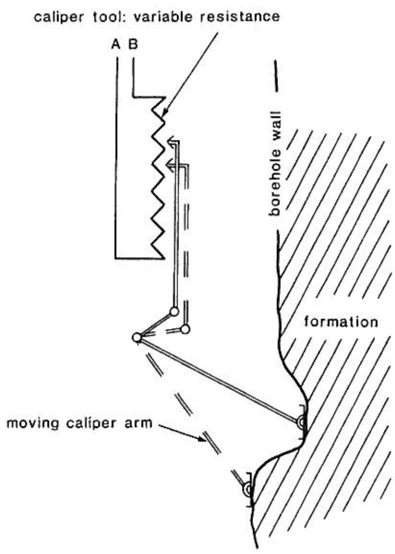

Figure 4.2 Schematic caliper tool showing the conversion of a mechanical movement to an electrical signal using a variable resistance. (Adapted from Serra, 1979).

4.2. Log presentations

The caliper log is printed out simply as a continuous value of hole diameter with depth (Figure 4.3). The curve is traditionally a dashed line and usually plotted in track 1. The horizontal scale may be inches of diameter or, in the differential caliper, expressed as increase or decrease in hole diameter about a zero defined by the bit size (Figure 4.3). The ordinary caliper log is accompanied by a reference line indicating bit size.

The geometrical data from four-arm, dual-caliper tools such as the dipmeter are presented in various formats, only one of which is shown (Figure 4.4). The two hole diameters measured by the two calipers are combined with the directional elements of tool orientation (pad 1 azimuth), hole deviation and azimuth of the deviation. An integrated hole volume may be added as horizontal ticks on the depth column giving a continuous record of hole volume (not on the example).

The calipers of the example presented (Figure 4.4), show the geometry tool turning slowly as it moves upwards in a persistently oval hole with a small diameter of approximately 9" and a large diameter of approximately 11". The larger diameter is oriented nearly north to south as indicated by the pad 1 azimuth over the depth 0–15 m (calipers 1–3 in larger diameter). At depth 30 m, calipers 2–4 show the larger radius (approx. 11"), calipers 1–3 the smaller (approx. 9"). The rotation of the tool is indicated by the persistent change in the pad 1 azimuth and explains the caliper cross-over at depth 17 m (where both calipers show the same diameter but the hole is still oval). Above this, calipers 1–3 follow the larger diameter (approx. 11"), while calipers 2–4 follow the smaller (approx. 9").

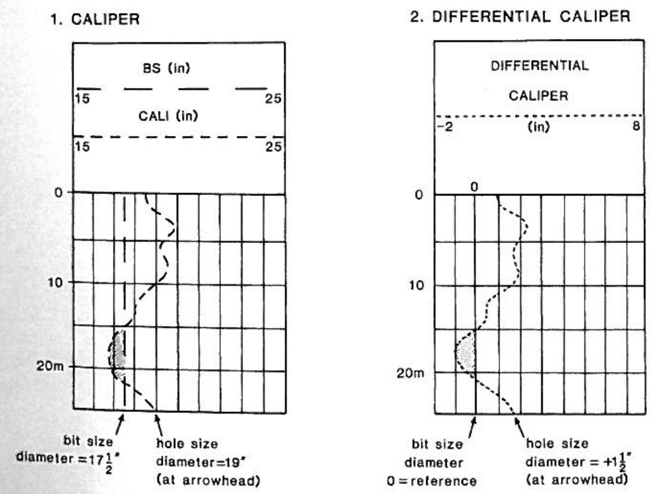

Figure 4.3 Presentation of the caliper log: (1), in ordinary format; (2), in differential format.
BS = bit size

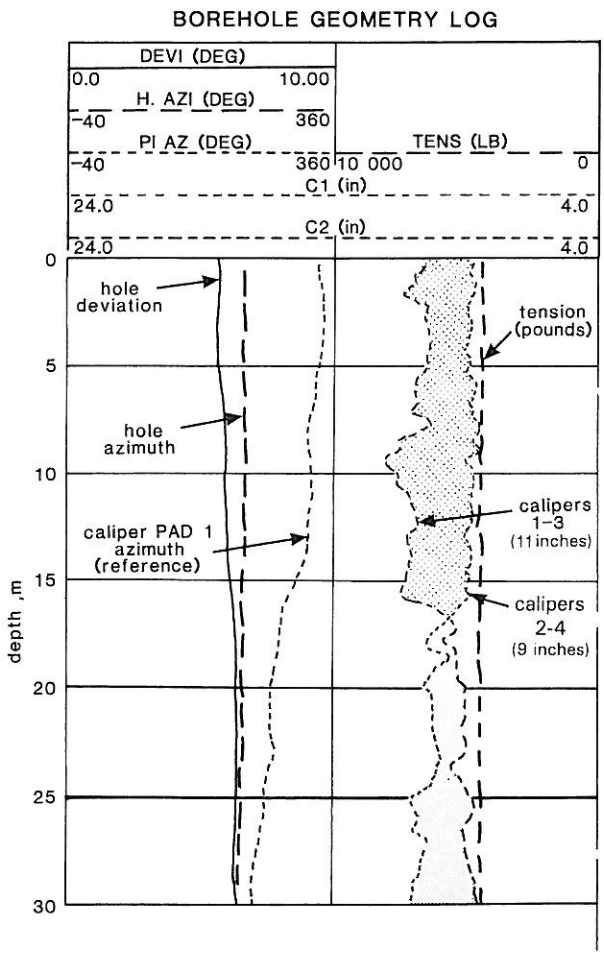

Figure 4.4 Borehole geometry log presentation (*see* text for explanation).

4.3 Simple, two-arm, caliper interpretation

Increase in borehole diameter

The simple caliper log records the mechanical response of formations to drilling. A hole that has the same size (diameter) as the bit which drilled it, is called *on gauge* (Figure 4.1). On gauge holes are the target for all drilling and essentially indicate good drilling technique. Holes with a much larger diameter than the bit size are '*caved*' or '*washed out*'. That is, during deepening of the hole, the borehole walls cave in, are broken by the turning drill pipe, or are eroded away by the circulating borehole mud. This is typical of shales, especially when geologically young and unconsolidated, so that caving can have a general lithological significance (Figure 4.1).

However, caving is also typical of certain specific lithologies such as coals or even organic shales. In some fields, even with varied drilling fluids and drilling techniques, it is found that certain stratigraphic levels habitually cave – generally for mechanical (textural) reasons. The example (Figure 4.5) shows a section of Carboniferous shale from the UK East Midlands in which moderate caving occurs in the same organic rich interval, over a wide area. The shale is either very laminated or locally fractured.

Decrease in borehole diameter

Calipers may show a hole diameter smaller than the bit size (diameter). If the log has a smooth profile, a mud-cake build-up is indicated (Figure 4.6*a*). This is an extremely useful indicator of permeability: only permeable beds allow mud cake to form. The limits of mud-cake indicate clearly the limits of the potential reservoir. Mud cake thickness can be estimated from the caliper by dividing the decrease in hole size by two (the caliper giving the hole diameter), i.e.

$$\frac{\text{bit size (diam) - caliper reading (diam)}}{2} = \text{mud cake thickness}$$

It should be remembered that this thickness may vary between tools. The caliper of a density tool is applied harder to the formation than the caliper of a micro-log: the former probably causes a groove in the mud cake and therefore gives a thinner, log derived mud-cake thickness.

Boreholes with a smaller diameter than the bit size but rugose, are probably sloughed (Figure 4.6*b*). The zones of small holes will be the 'tight spots' encountered during drilling, trips or logging. That is, it will be at these points that tools stick or the bit gets stuck while being pulled out of the hole. A frequent cause of tight spots is abundant smectite in the clay mineral mixture. Smectite is a swelling clay which takes water from the drilling mud, expands, breaks from the formation and sloughs or collapses into the hole. The Gulf Coast 'gumbo', which often causes hole problems, is smectite rich.

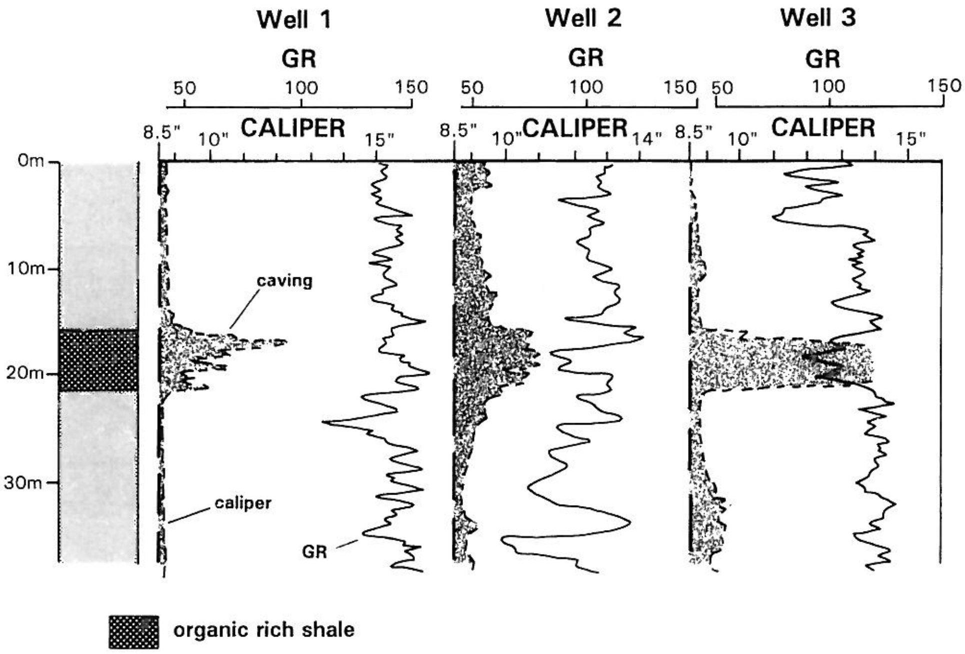

Figure 4.5 Consistent caving, indicated on the caliper log, over the same, organic rich, stratigraphic level in three different wells. Upper Carboniferous, East Midlands, U.K.

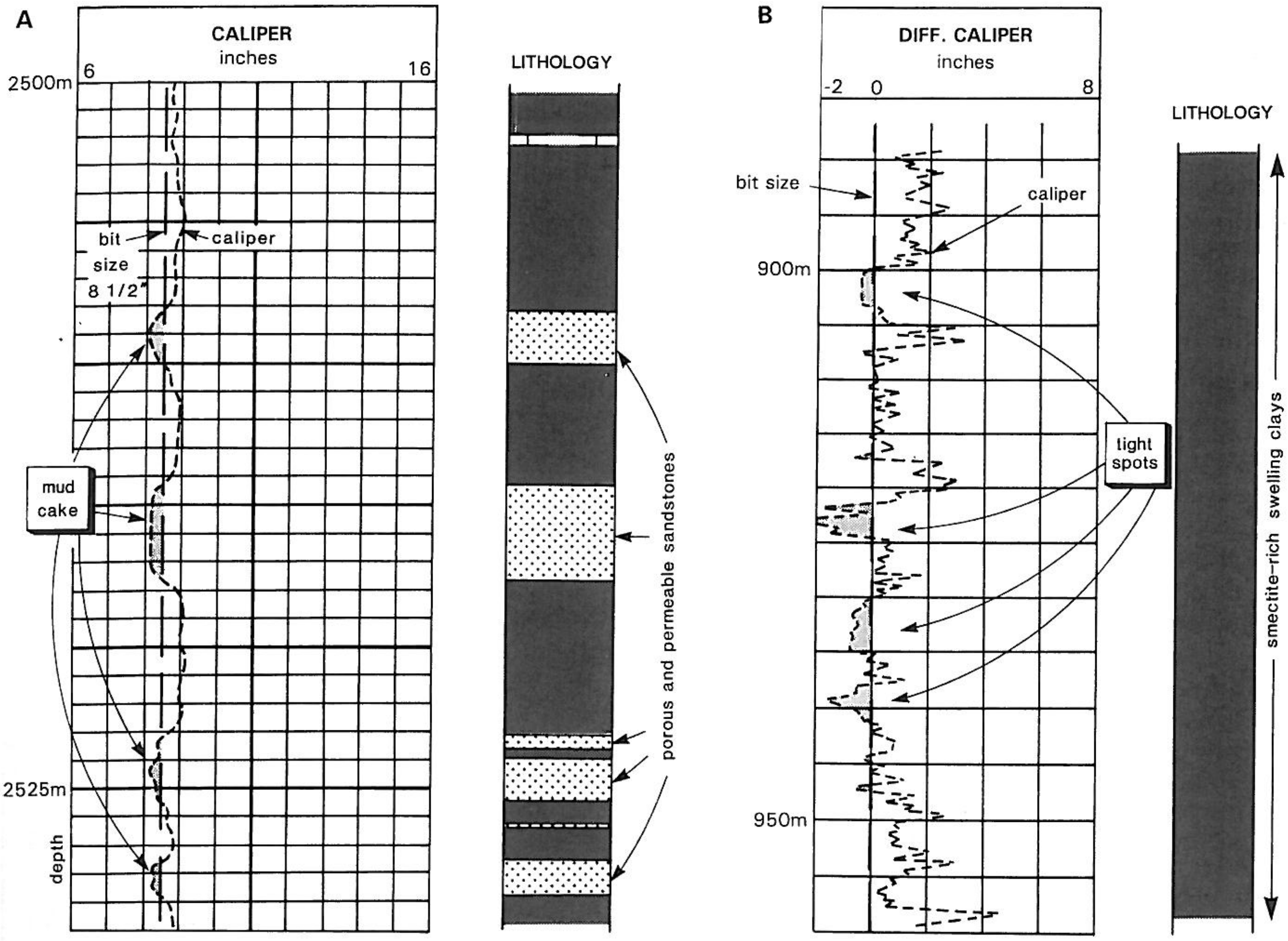

Figure 4.6 Hole size diminution seen on the simple caliper. (A) Mud-cake build-up opposite porous and permeable sandstones. (B) Tight spots in a shale sequence caused by hole sloughing due to swelling clays.

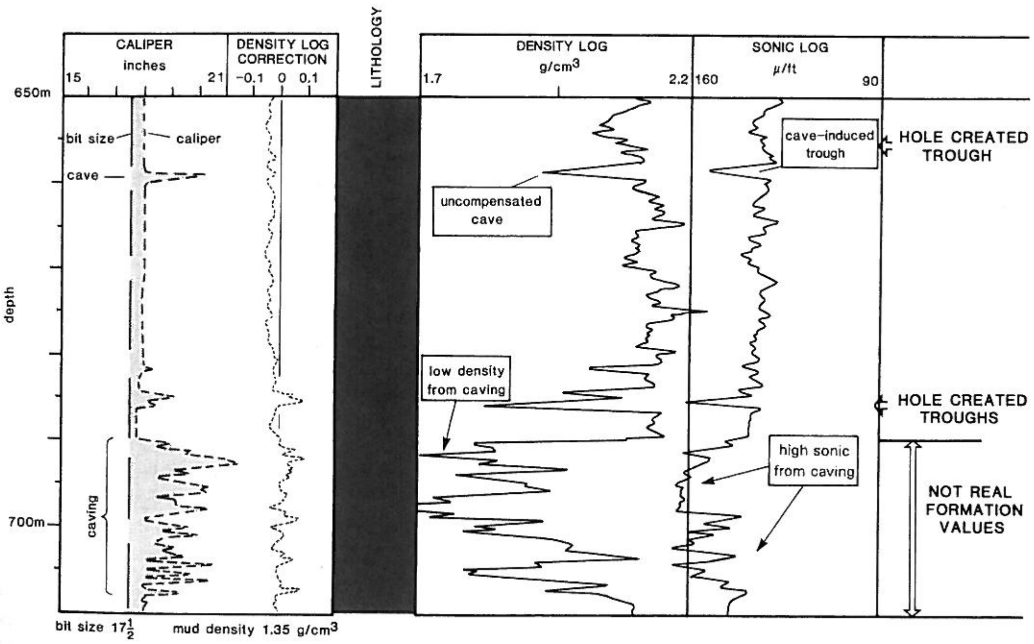

Figure 4.7 Poor hole conditions and caving creating zones of poor data quality where log readings do not represent real formation values. The automatic density correction derived from the caliper is insufficient to compensate for the large caves at around 700m. The density and sonic logs suggest a formation change at 690m, but the interval is homogeneous from top to bottom, being poorly consolidated clay/shales.

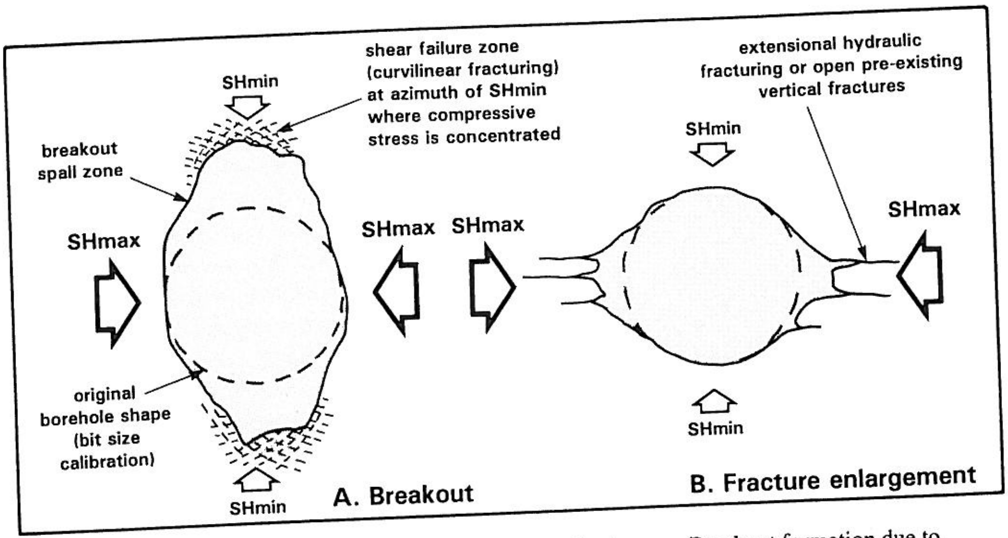

Figure 4.12 Horizontal stress field relationship to borehole shape. a. Breakout formation due to spalling during drilling, in the direction of minimum horizontal stress (Sh_{min}). *b.* Hole enlargement along drilling induced extensional fractures oriented in the direction of maximum horizontal stress (Sh_{max}) (modified from Dart and Zoback, 1989 and Hillis and Williams, 1992).

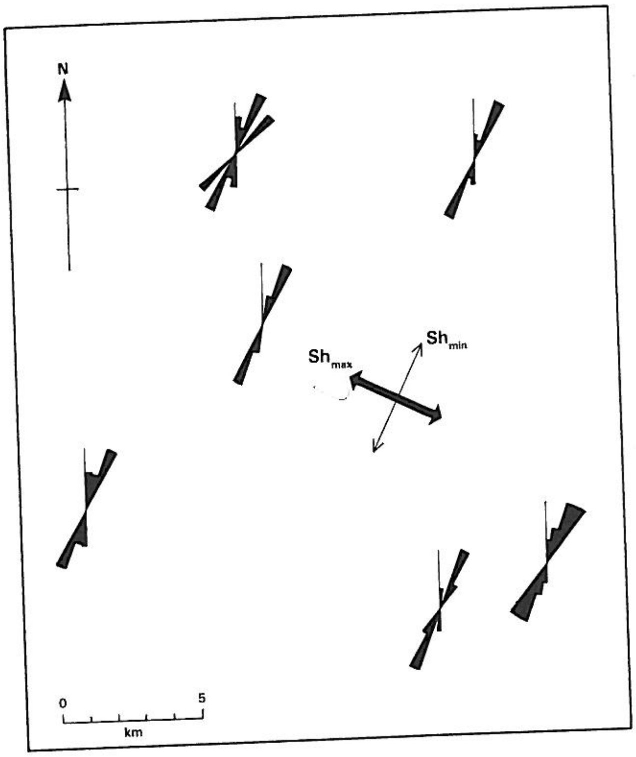

Figure 4.13 Consistently oriented breakouts, identified from dipmeter caliper data in an offshore field, indicating the present day, horizontal stress field. Depth of analysed interval from 2.5 to 3.5 kilometres. Sh_{min} = minimum horizontal stress, Sh_{max} = maximum horizontal stress.