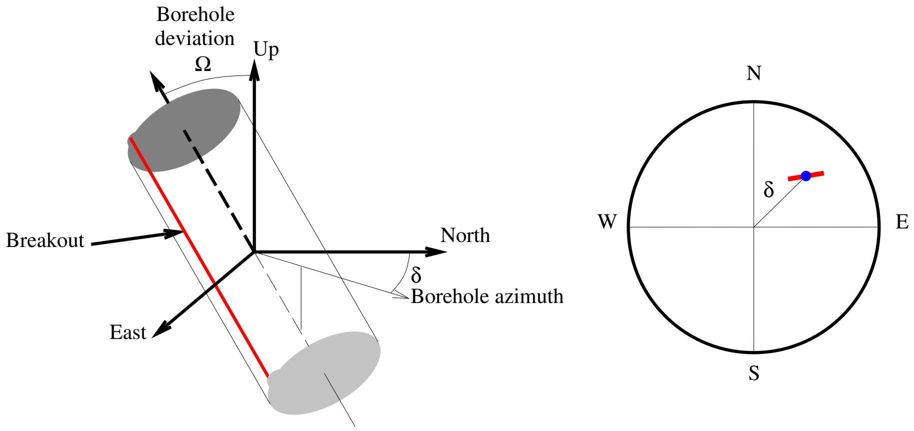

Figure 1. Relationship between an arbitrarily oriented borehole containing a breakout and how this borehole and its breakout orientation would be plotted on a lower hemisphere stereograph of borehole azimuth and deviation.

and the stress ratio

$$\phi = \frac{S_2 - S_3}{S_1 - S_3}, \tag{1}$$

where S_1 is the maximum stress, S_2 is the intermediate stress, and S_3 is the minimum stress.

Note that, given enough variation in borehole orientations, the stress state can be reasonably constrained, since the patterns vary continuously from an entirely radial distribution of breakout azimuths (for degenerate thrust faulting, $S_H = S_h > S_v$) to an entirely circumferential distribution of breakout azimuths (for degenerate normal faulting, $S_v > S_H = S_h$). Here a "degenerate case" is defined when two of the principal stresses are equal in magnitude. The nodal points represent borehole orientations where circumferential stress on the borehole wall is uniform, and there is no preferred direction of breakouts; at these orientations the maximum stress at the borehole wall is relatively low and less likely to exceed rock strength, so that breakouts may be absent altogether. Note that the nodal point for degenerate thrust faulting is in the center of the projection; as the ratio of S_H to S_h increases, two nodal points appear and move radially away from the center along the S_H direction. The nodal points reach horizontal at the degenerate case when $S_h = S_v$ (combined thrust and strike-slip faulting): as S_h continues to decrease, the nodal points split again and move along the circumference of the plot. For the degenerate case of $S_H = S_v > S_h$ (combined strike-slip and normal faulting) the two nodal points are horizontal again and aligned along the direction of S_h; as the stress ratios progress through the normal faulting stress regime, the nodal points again approach the center of the plot.

Although in theory these patterns will vary continuously as a function of the stress regime, our ability to resolve them depends on the distribution and quality of the data, particularly on the available borehole orientations. Since few drill holes approach the horizontal, data near the nodal points for some patterns may be hard to obtain. If the boreholes within a study region are all within 30° of vertical, then our ability to resolve the stress ratios will depend on the stress regime; stress ratios in normal faulting or thrust faulting stress regimes will be better resolved than those in strike-slip faulting stress regimes [*Mastin*, 1988]. However, in recent industry drilling programs it is common for boreholes to be deviated more than 30°. Our ability to resolve the stress state will also depend on the consistency of the data, since we assume that all data plotted or inverted together correspond to the same stress tensor, including both the orientations of the principal axes and the stress ratio, ϕ.

Reference Frames

Throughout this work we use two reference frames: the geographic reference frame and the borehole reference frame (Figure 3). The geographic reference frame is an orthonormal reference frame with its **X** axis horizontal and pointing due east. The **Y** axis is also horizontal and points due north. The **Z** axis is perpendicular to both the **X** and **Y** axis and points up. This geographic reference frame will often be referred to as the **XYZ** reference frame for short.

The borehole reference frame stays aligned with the borehole axis as the borehole orientation changes with