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# Fracture Density and Permeability

## Fracture Density Relationships (continued from previous panel)

Siberia Ridge vertical fracture density ranges from one fracture every 5.5 feet to less than 1 fracture per foot. Fracture density increases with depth in each of the key Siberia Ridge wells below the Almond 300 interval (figure 1 and figures 6 and 7 on prior panel). The apparent increase in fracture density with depth may be explained several ways: increased sand penetration, changes in mechanical properties of the sandstones, and closer proximity to local increases in stress. Increased fracture density in the Siberia Ridge #5-2 and Siberia Ridge #27-4 wellbores corresponds to penetration of thicker, lower Main Almond and Ericson sandstones. The Siberia Ridge #5-2 is also less sandy than the SRU #27-4 (by a factor of two). The Siberia Ridge #5-2 was drilled to take advantage of a regional structural lineament, whereas the Siberia Ridge #27-4 was not. The difference in fracture density (normalized for lithology and wellbore deviation) between these wells, however, is only a factor of 1.4, suggesting lithology strongly influences the presence of natural fractures in these wellbores.

Figure 1 - Vertical and Deviated Well Comparison
Fracture occurrence increases with depth

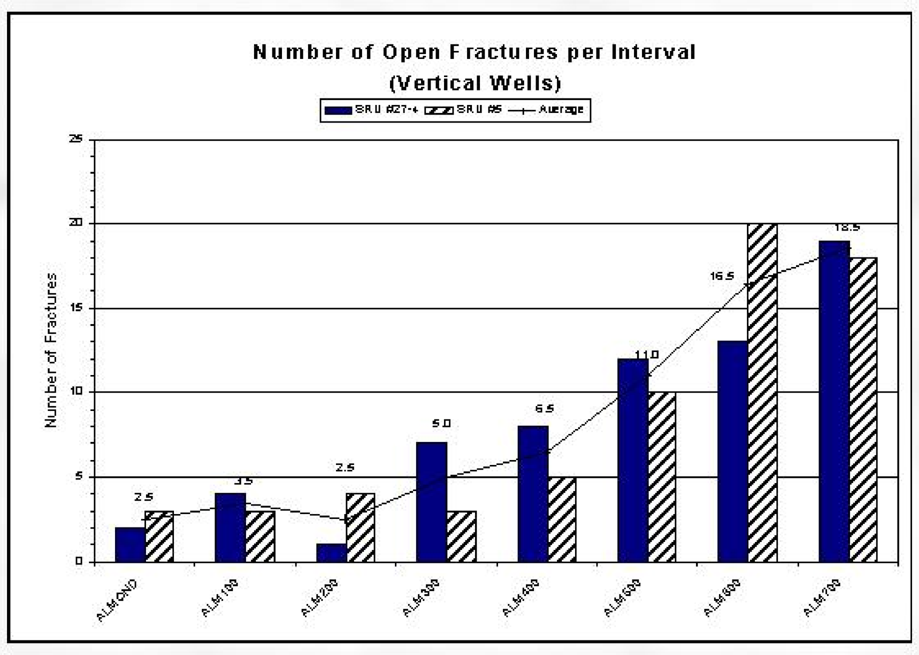



Figure 2 - Vertical and Deviated Well Comparison
Average fracture spacing decreases with depth

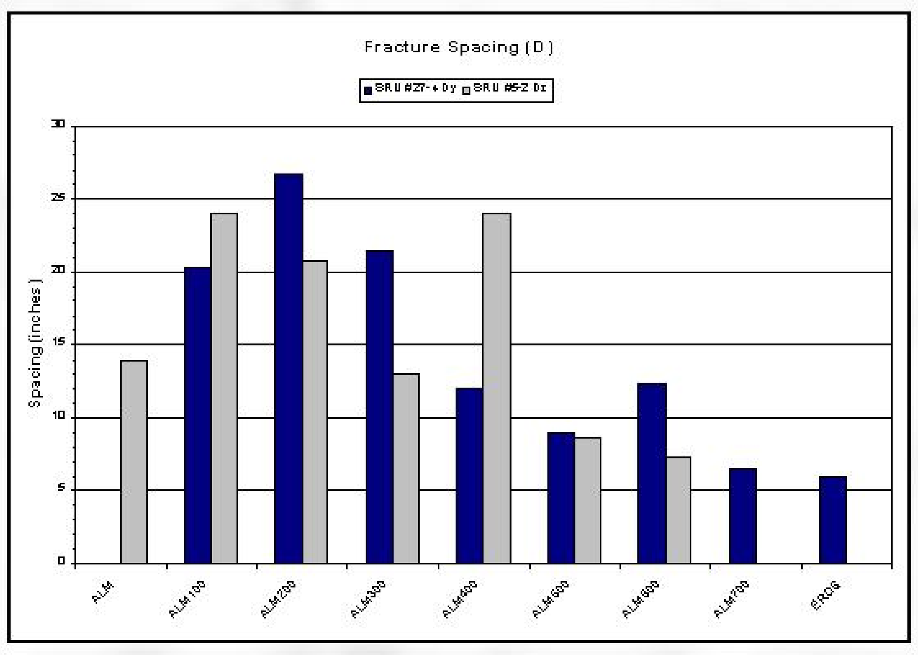



Figure 3 - Vertical and Deviated Well Comparison
Sandstone thickness increases with depth

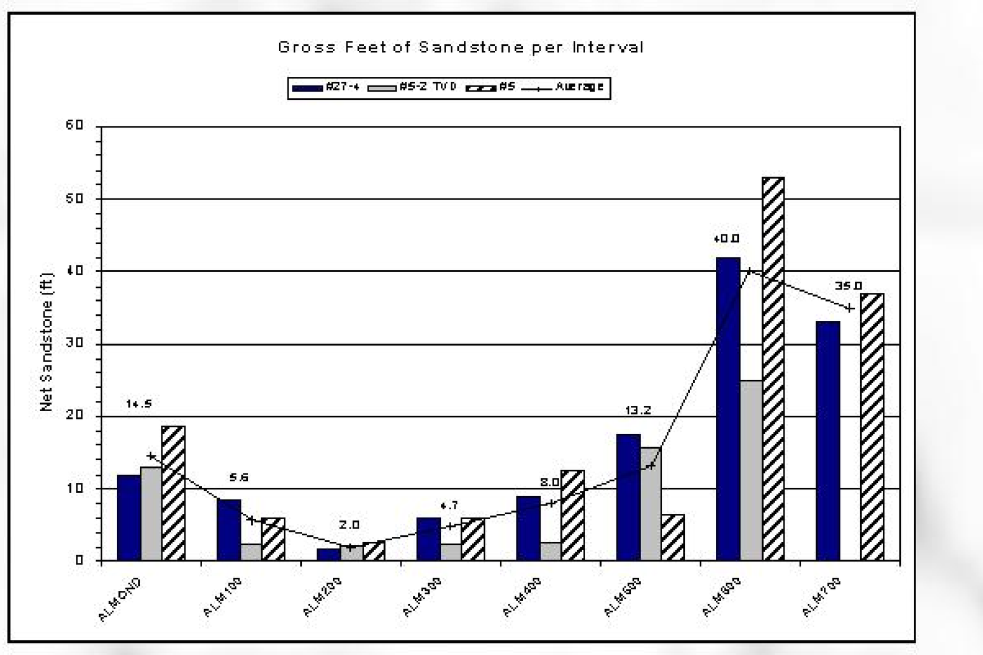
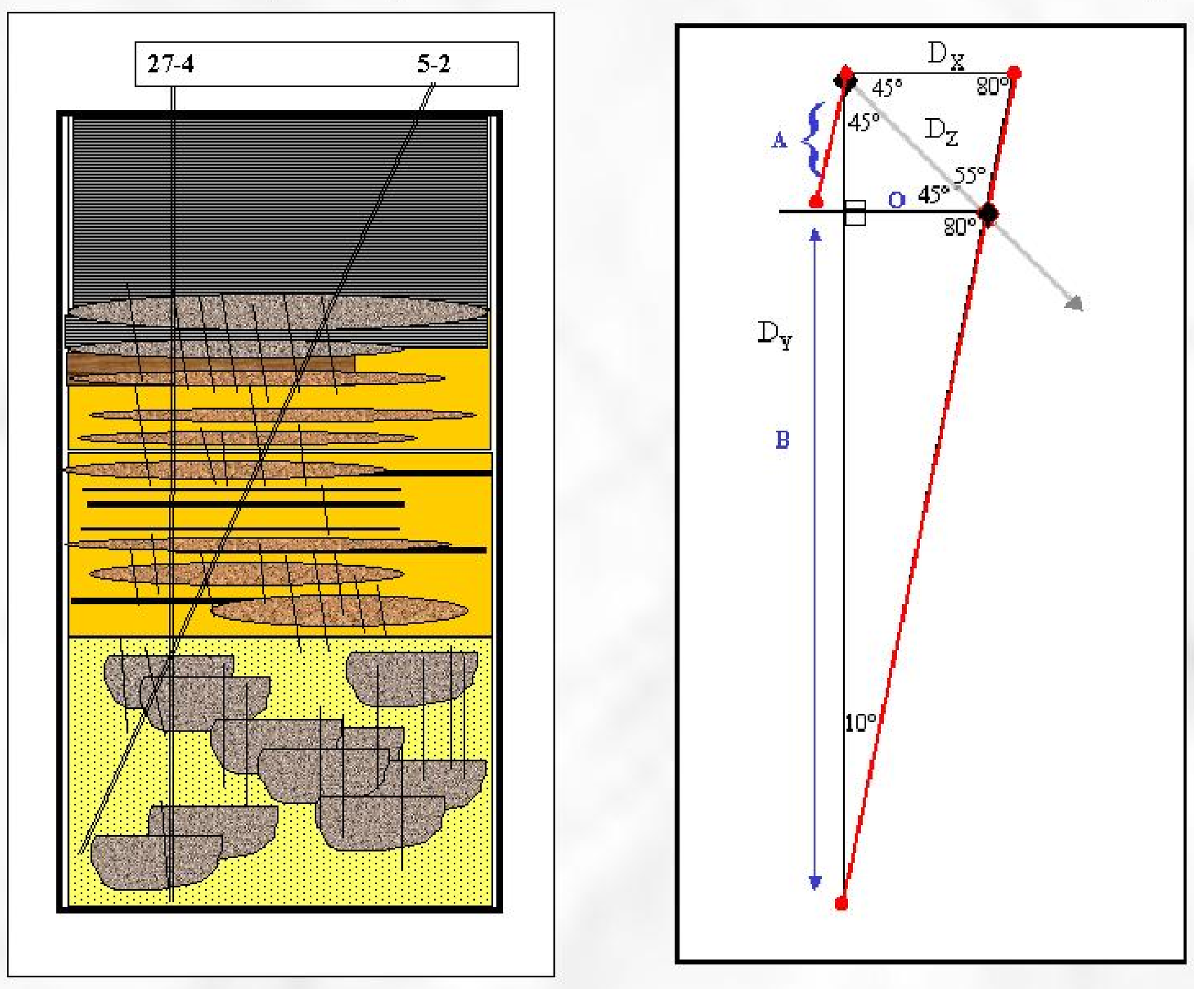



Figure 4
Fracture Frequency as a Function of Wellbore Geometry




Investigation of the wellbore geometry shows that the fracture spacing reported for the Siberia Ridge #5-2 are in the Z direction, whereas those reported for the Siberia Ridge #27-4 and Siberia Ridge #5 are in the Y direction (figure 4). Even though the Siberia Ridge #5-2 is deviated, the average fracture spacing, as determined from FMI, is similar to the Siberia Ridge #27-4 (figure 2).

**Table 1**

- SRU #5-2
  Dx = 3.3"
  Dy = 18.8'
  Dz = (4.0")
- SRU #27-4
  Dx = 4.7"
  Dy = (26.8")
  Dz = 5.7"
- Dy = 4.7•Dz

To understand the effect of drilling near and/or through the 5-2 Lineament, the fracture spacings are compared on the same plane. Siberia Ridge #5-2's fracture density converted to fracture spacing, $D_X$, equals 4 inches, whereas fracture density for the vertical wells converted to fracture spacing, $D_Y$, is 26.8 inches.

What is the effect of wellbore deviation? Utilizing the geometric relationships obtained from these figures and equations, the spacings in each plane are reported in Table 1 to the left.

The geometrical difference between $D_Z$ and $D_Y$ spacing is a factor of 4.7, and the fracture density difference between the wells normalized for lithological effects is 6.7. This leaves just a factor of 1.4 as the increase in natural fracturing possibly due to fault proximity. This result is surprising, since it suggests that wellbore deviation impacted fracture spacing more than lineament proximity in the Siberia Ridge #5-2.

**Wellbore deviation impacts fracture density by a factor of 4.7**
**Lineament proximity impacts fracture density by a factor of 1.4**

## Fracture Permeability

Fracture permeability is inversely proportional (both numerically and linearly) to the distance between fractures. Fracture permeability is also proportional to the cube of the fracture width. From a mathematical standpoint (Table 2), the fracture width effects fracture permeability more than fracture spacing (figures 5, 6, 7).

Figure 5 - Fracture Spacing

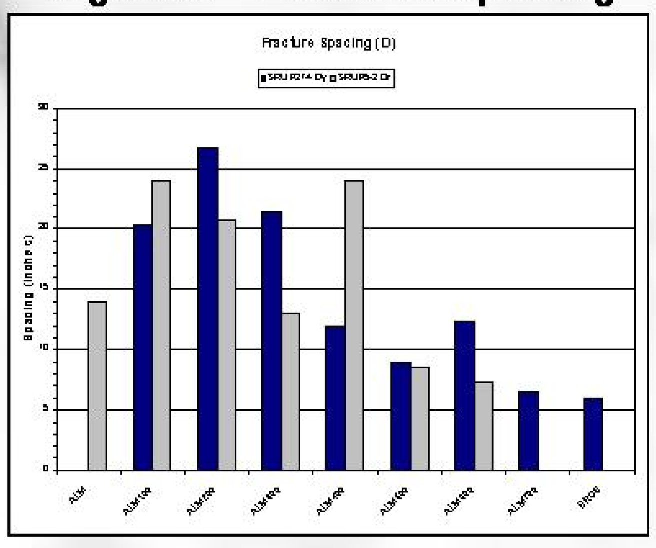



Figure 6 - Fracture Aperture

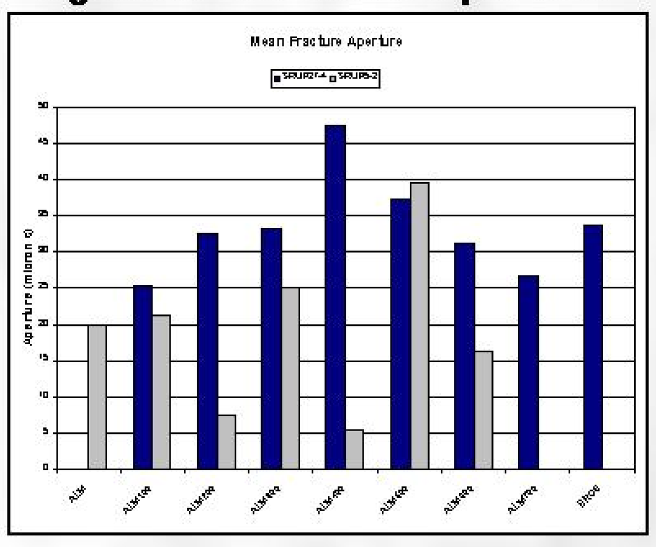



Figure 7
Hydraulic Fracture Aperture

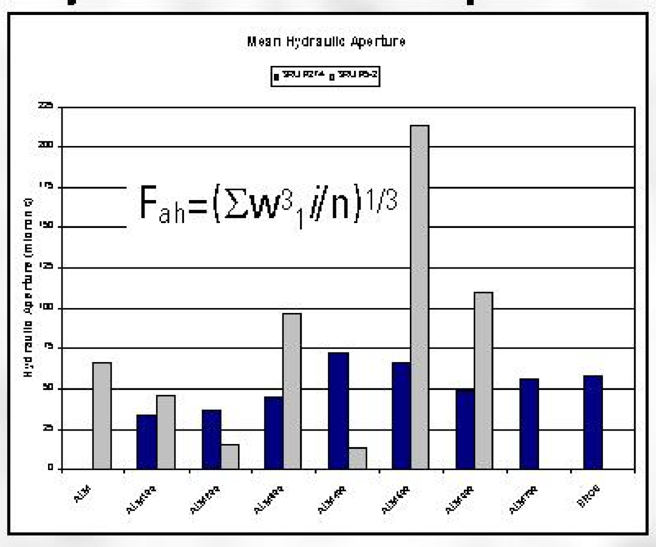



**Table 2**

**Absolute fracture permeability $k_f$:**

$k_f = 54*10^6 \cdot w_o^2$ (darcys) *$w_o$ in inches*

$k_f = 8.35*10^6 \cdot w_o^2$ (darcys) *$w_o$ in cm*

**Parallel Plane fracture permeability $k_2$:**

$k_2 = (k_f \cdot w_o)/D$

**Cubes $k_2$:**

$k_2 = 2/3(k_f \cdot w_o)/D$

**Matchsticks $k_2$:**

$k_2 = 1/2(k_f \cdot w_o)/D$

*Equations from Aguilera, 1995*

Figure 8 - Fracture Permeability

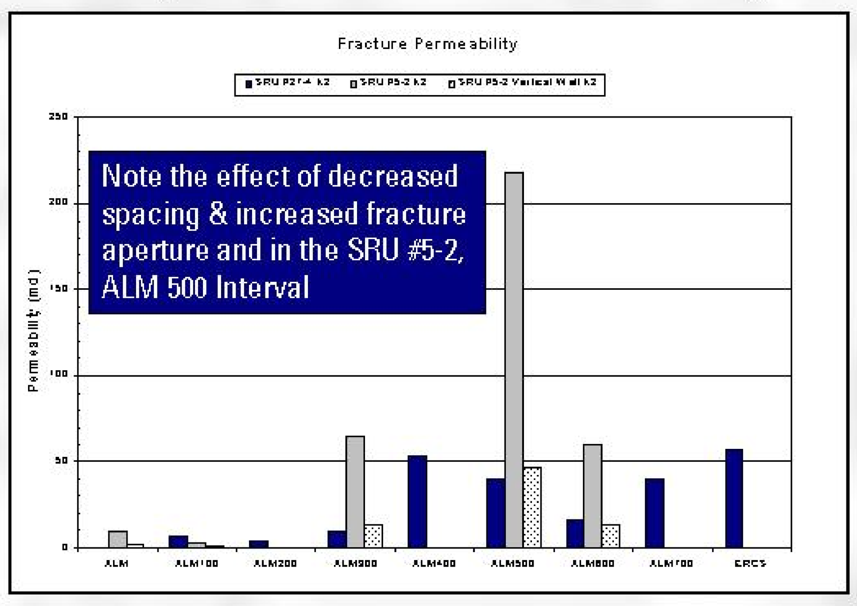
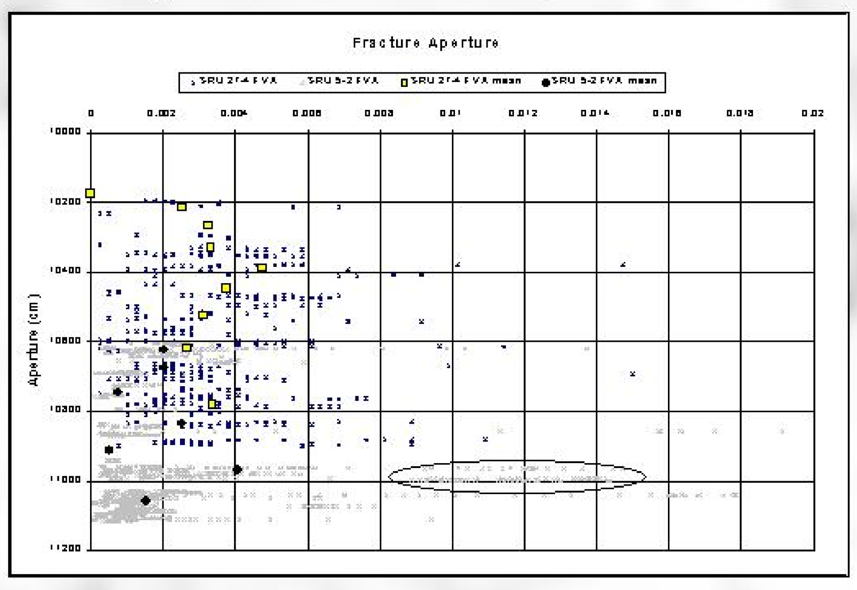



Figure 9 - Fracture Aperture




This bar graph (figure 8) of mean fracture permeability ($k_2$, parallel planes) shows mean $k_2$ permeabilities of 5 md to 225 md. Fracture permeability is lowest in both wells (less than 10 md) in the Almond Bar to Almond 200 intervals, where fracture spacing is also the greatest. Fracture permeability increases to more than 50 md in the Almond 300 interval in the Siberia Ridge #5-2, and the Almond 400 interval in the Siberia Ridge #27-4. This permeability increase corresponds to the increase in fracture density.

There is tremendous fracture permeability (225 md) in the Siberia Ridge #5-2, Almond 500 interval. Since fracture spacing is the same as the Siberia Ridge #27-4 in this interval, why is fracture permeability so high?

A glance at the distribution of fracture apertures (figure 9) answers this question. The very large apertures in this interval are masked by the interval mean. For this reason, fracture data needs to be manipulated and viewed a number of different ways. Averaged data allows for ease of comparison between wells or intervals, but point to point fracture data is necessary to compute discrete fracture permeability values.

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