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Seismic Detection of Fractured Reservoirs: Progress and Challenges

L.A. Thomsen* (BP America Inc.)

SUMMARY

Seismic anisotropy provides an indirect measure of fracture distributions. The interpretation of that seismic observation is a matter of rock physics, and requires an adequate accounting of rock-fluid interaction, and of fracture size and shape.

It is now commonly accepted that many hydrocarbon reservoirs are fractured, *i.e.* that significant contributions to their permeability come from one or more populations of fractures. Sometimes a population consists of open fractures, leading to an enhancement of permeability in the direction of those fractures. Sometimes, a population consists of closed fractures, leading to a reduction in permeability in the direction of those fractures. We should not forget that both classes of fractures may exist (and sometimes in the same reservoir!); but I will discuss here only the former.

Fractures usually have a wide distribution of sizes and shapes. This deceptively simple remark has deep implications for the appropriate means to detect fractures, remotely and indirectly, since each technique is sensitive to fractures in a limited range of sizes. (Of course, those distributions are not *fractal* in the strict sense (although they may be “multi-fractal”), so what one learns in a limited range of sizes is not obviously generalized to other sizes.) Further, each remote technique delivers a measure of fracture presence that is a surrogate for what we really want to know (the fracture permeability), rather than that quantity itself.

It is clear that the larger open fractures offer the greater positive contributions to permeability. The largest individual fractures are visible using advanced seismic techniques, through signal processing algorithms such as spectral decomposition and coherency technology. Smaller fractures can produce equivalent fracture permeability, in aggregate, if there are enough of them, and with a preferential alignment. This alignment leads to anisotropy in any measurement (eg seismic, electromagnetic, etc) of the properties of the rock mass.

In measurements of this seismic anisotropy, what one obtains is a lumped measure of fracture properties, often called the (non-dimensional) fracture density (not to be confused with the geological quantity with a similar name, but with the dimensions of #/meter normal to the fracture strike), *c.f. e.g.* Crampin 1978, and many subsequent contributions. Subject to a number of assumptions, the fracture density depends upon the cube of the (crack diameter/crack separation) ratio.

This fracture density affects the measured anisotropy in a way which depends upon the isotropic hydraulic connectivity of the fracture with the surrounding rock formation. This counter-intuitive result is well-documented by physical measurement, in the laboratory, where the population of cracks was *engineered* into a sandstone, with known crack properties Rathore (1994), and not subject to empirical fitting. This is shown by Figure 1 (from Thomsen, 1994), which also shows the result (Hudson, 1980) from the theory assuming an impermeable host rock.

The larger fractures in a population differ from the smaller fractures, in more than just size. The small fractures, which are normally of complicated shape, may be appropriately idealized, in many circumstances, as flat ellipsoids (“penny-shaped”). However, the larger fractures are limited in their vertical extent by bedding boundaries, but unlimited in their horizontal extent. Therefore, they are best idealized as “ribbon-shaped”, rather than “penny-shaped”. This leads to a fracture density (better described in this context as a “joint density”), controlling the seismic anisotropy, which depends upon the (joint height/joint separation) to the first power, rather than to the third power (Thomsen, 2002).

This linear dependence of seismic anisotropy upon joint density raises vexing issues for any argument deducing fracture permeability from seismic anisotropy, since the seismic anisotropy will always be small, but the permeability anisotropy may be large. We may conclude that the study of fractured reservoirs will have a long future, in its theoretical aspects, as well as its practical aspects.

Figure 1.

References

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