P31

Seals, Superseals and Faults

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SUMMARY

"Superseals" are qualitatively different from conventional hydrocarbon seals because they confine water and abnormal pressure, not merely fluids that are immiscible with water. In the normal course of dewatering, common shales are largely invisible to expelled water. In some basins, sediment can accumulate so fast that thick common shales can interfere with dewatering sufficiently to cause transient overpressure. Superseals, such as the Woodford Shale, are impermeable to water and can retain overpressure indefinitely. The identification of superseals may have an impact on both the sequestration of carbon dioxide and the isolation of certain waste materials. Common shales are able to trap hydrocarbons because the pore entry pressures for fluids other than water are very high (a capillary seal), but the shale remains transmissive to water and to some solutes. A common shale seal is unsuitable as a barrier to carbon dioxide. A shale superseal will retain CO2.

Horizontal pressure compartments are also very common and must also be accounted for in basin models. The sealing capacity of a fault is determined by the capillary entry pressure of the sealing rock unit (or fault gouge zone). The sealing capacity is increased where there is a pressure differential across the fault.

"Superseals" are qualitatively different from conventional hydrocarbon seals because they confine water and abnormal pressure, not merely fluids that are immiscible with water. They are quantitatively different from conventional pressure seals due to the higher rate of pressure change across them than conventional seals exhibit.

Shales often act as the top seal for commercial hydrocarbon accumulations and, therefore, they are of substantial economic importance. However, in the course of the de-watering of many, if not most basins, common shales are largely invisible to expelled water and possess a hydrostatic pressure gradient despite the presence of significant hydrocarbon accumulations. In many basins, sediment can accumulate so fast that common shales can interfere with dewatering sufficiently to cause transient (at geologic timescales) overpressure and, therefore, operate as "Dynamic" pressure seals. Superseals, such as the Woodford Shale in the Anadarko Basin are effectively impermeable to water and can retain overpressure essentially indefinitely. Such instances of overpressure belong in the "Static" overpressure category.

The differentiation between superseals and common shale seals is important in several areas. In environmental geology, the identification of superseals may have an impact in both the sequestration of carbon dioxide and in the isolation of radioactive materials. Common shales are able to trap hydrocarbons because the pore entry pressures for fluids other than water are very high (a capillary seal), the shale remains transmissive to water and to some solutes. A superseal effectively has lost all of its interconnected pore space (which was formerly occupied by free water) through the process of compaction and/or cementation. The difference in sealing style becomes critical when it is important to retain or isolate substances that, unlike hydrocarbons, are soluble or miscible in water. A common shale seal is unsuitable as a barrier to carbon dioxide. Since the vast majority of hydrocarbon reservoirs are top sealed by common shales, such reservoirs are not suitable as sequestration sites. One must choose instead, reservoirs that are sealed by salt or, better still, by a superseal. A shale superseal has the advantage over salt in two ways; it is not at all soluble in water, and it is of normal density and thus not capable of diapiric movement.

Superseals can be distinguished from common shales based on several characteristics (Figure 1). They consistently exhibit an abnormally low standard deviation, and they have a high degree of vertical symmetry in most LWD and MWD data streams (see Figure 1). In addition, superseals display a high positive slope in both NPhi and SPhi values but no similar slope in DPhi values.

Horizontal pressure compartments are also very common and must also be accounted for in basin geopressure models. Figure 2 shows a number of the most common forms of horizontal pressure compartmentalization. In Figure 2A, a normal fault with constant throw is shown, however, there is no pressure change across the fault. This indicates fluid flow across the fault and the pressures on either side have equilibrated over time. Suspicions should be raised in this case as to the sealing characteristics of the fault. If it cannot hold overpressure, it may not be an efficient seal for hydrocarbons. Figure 2B shows the case, sometimes seen on seismic data, where there is a pressure sink (or, conversely, a pressure bulge) around the fault. This indicates that the fault may be acting as a conduit for fluid flow and pressure release along its surface. In this case, there may be anomalously pressured sands above and below the pressure compartment boundary. The risk that the fault may not be an efficient hydrocarbon seal is obviously greater in this example than in others. Figure 2C shows the case where a normal fault has an offset in overpressure equal to, or greater than the throw on the fault. The fault is acting as a pressure barrier and as a compartment boundary in the interval of the pressure offset. The sealing capacity of a fault is determined by the capillary entry pressure of the sealing rock unit (or fault gouge zone). The sealing capacity is increased in cases where there is a pressure differential across the fault. A similar situation exists in Figure 2D where the sense of pressure offset is different than the sense of throw on the fault. Again, the fault can be demonstrated to be a sealing surface since it acts as a pressure compartment boundary and is a pressure seal over this interval.

The most common form of lateral variations in the magnitude of overpressure is illustrated by Figure 2E, where lateral changes in the lithology (facies change) of any unit directly effects the magnitude of overpressure in the unit below it. In this case, a facies change from sand to shale results in a change in the retained pressure, causing the pressure surface to cut across stratigraphic boundaries. This may be as subtle as a change from silty shale to less silty shale in the upper unit that has an attendant change in the permeability of the unit and its hydraulic connectivity. Pressure is more effectively bled-off in the higher permeability unit than in the lower permeability unit. Pressures in the underlying unit may only change by a small amount but the effect is cumulative from unit to unit with depth and across an area. In the case of the presence of a superseal, the gradient may be very high since the shale itself is an extremely effective seal and may separate compartments of very different pore pressures.

The conditions of pressure sealing fault compartment boundaries shown in Figure 2C and 2D are directly related to the conditions of Figure 2E, plus faulting, plus geologic time, to allow dynamic seals to bleed off pressure differentially on either side of the sealing fault.