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Evolution of overpressured and underpressured oil and gas reservoirs, Anadarko Basin of Oklahoma, Texas, and Kansas—Underpressure

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10. Underpressure developed recently

Rapid deposition during Pennsylvanian and Permian time buried the Devonian Woodford Shale and Pennsylvanian source rocks (not shown) into the hydrocarbon generation window. We surmise that most of the overpressure in the deep basin developed at that time, although additional hydrocarbon generation may have occurred during Cretaceous time. The Permian cap, of Leonardian and Guadalupian age, covered the area until it was progressively eroded from east-central Oklahoma and Kansas.

11. What’s wrong with pressure?

In oil and gas exploration, formation pressure P is routinely measured and plotted as a primary parameter of interest. However, in hydrological work, hydraulic head H (also referred to as potentiometric elevation) is the primary parameter of interest. In order to map potentiometric surfaces within a geologic formation, we need to convert measurements of P to H. The sketch below shows why we need to use H to indicate the propensity for flow between two wells. The pressure-depth ratio of 0.35 psi/ft is the same in the two wells but H is 2,000 ft higher in well A than in well B. Water flows laterally within the formation from well A to well B at a rate governed by the hydraulic conductivity and the hydraulic gradient. Thus, to understand the reason for regional pressure variations, we need to map H over the basin.

The graph in section 12 shows that examination of either pressure or pressure-depth ratio along a transect yields a rather puzzling picture, a dilemma which is readily explained from a plot of H.

12. To reveal the control on underpressure, we convert pressure to hydraulic head

13. The separation between surface elevation and potentiometric surface decreases from west to east in Desmoinesian transects

Separation between the surface elevation and the potentiometric surface shown below translates to underpressure. Separation (or underpressure) is greatest on westernmost swath H and least (or nonexistent) on easternmost swath N. Some separation (underpressure) persists on the north end of swath N, an indication that the pressure reference (leak point) lies in central Oklahoma, not Kansas.

Note that only a fraction of the hydraulic head data is used to define the potentiometric surface. Points falling below the potentiometric surface are caused by low pressure measurements—these points are not used. Points above the potentiometric surface are pockets of overpressure.

14. Potentiometric surfaces

Potentiometric surfaces were constructed for seven geologic horizons; two are shown here. The broad green area between 1,250 and 1,500 ft on the Permian potentiometric map shows the low hydraulic gradient over much of the mapped area. Similarly, the broad blue area between 750 and 1,000 ft on the Desmoinesian map shows a large low - gradient area.

Separation surfaces

Subtracting the potentiometric surface from the elevation surface gives the separation between the two surfaces. The greater the separation, the greater the apparent underpressure. Because the elevation surface varies more than the potentiometric surface, these maps tend to reflect the elevation surface. Separation is greatest in the western part of the study area.

15. The Nemaha fault zone and outcrops of Upper Pennsylvanian strata establish the pressure reference

It is unlikely that a single discharge point exists. Rather, the atmospheric pressure reference for Lower Permian, Pennsylvanian and older strata lies in east central Oklahoma and Kansas where fault offsets and relatively permeable strata provide fluid pathways to the surface.

16. Why is the Panhandle-Hugoton gas field underpressured? (Sorenson revisited)

Initial reservoir pressure in the giant Panhandle-Hugoton field is 435 psi at a depth range of 2,500-3,000 ft, for a pressure-depth ratio of approximately 0.16 psi/ft (Sorenson, 2005). To explain this degree of underpressure, Sorenson (2005) advanced the concepts that the pressure of the Panhandle-Hugoton field is controlled by Permian outcrops in eastern Kansas and that the reservoir was normally pressured prior to Tertiary uplift and erosion. We agree with these concepts, with slight modifications based on the accompanying figure, which shows that the outline of the Panhandle-Hugoton field coincides with the area of maximum separation of the potentiometric surface and land surface. We suggest that the gas expansion occurred as Permian strata were exposed in the general area of the Nemaha ridge (areas of 0 to +300 ft and -300 to 0 ft). As hydraulic potential was reduced, pressure fell, and gas expanded with gas pressure regulated by pressure of the underlying Permian aquifer.

Summary

A Permian sequence of shales, siltstones, and evaporites form a hydraulic seal isolating deep strata from the surface in the Anadarko Basin. Much of the area is structurally benign, reducing the chance of leakage through faults and fractures. Oil and gas are ubiquitous beneath the regional seal but are not present above it, indicating that the low-permeability seal has been effective over a very long time.

Resistivity logs reveal reversals from a normal compaction gradient. These reversals are attributed to the existence of a broad area of original overpressure (paleopressure). Overpressure in the deep basin remains today as a substantial remnant of the larger paleopressured area, even though a great deal of time has elapsed since subsidence and hydrocarbon generation. The mechanism for preservation of overpressure has been studied but not resolved.

Outside the overpressured area in the deep basin, hydraulic potentials of Lower Permian and older strata are controlled by outcrops at elevations of 1,200 ft and less. Land surface rises to the west, so separation between land surface and potentiometric surface increases westward, and consequently, so does the degree of underpressuring. Underpressured reservoirs, including that of the Hugoton field, are the result of exposure to atmospheric pressure in the vicinity of and east of the Nemaha fault zone.

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