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QUANTITATIVE METHODS FOR RESERVOIR CHARACTERIZATION AND IMPROVED RECOVERY: APPLICATION TO HEAVY OIL SANDS

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Abstract

Improved prediction of interwell reservoir heterogeneity is needed to increase productivity and to reduce recovery cost for California's heavy oil sands, which contain approximately 2.3 billion barrels of remaining reserves in the Temblor Formation and in other formations of the San Joaquin Valley. This investigation involves application of advanced analytical property-distribution methods conditioned to continuous outcrop control for improved reservoir characterization and simulation. The proposed investigation is being performed in collaboration with Chevron Production Company U.S.A. as an industrial partner, and incorporates data from the Temblor Formation in Chevron's West Coalinga Field. The first part of the project has focused on collecting data for characterization and modeling. In addition, data from Coalinga Field have been analyzed for fractal structure present in the data set. The current work involves collecting and loading data to build property models and continuing to define fractal structure in the data sets.

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Results and Discussion

New depositional and sequence-stratigraphic interpretations of the Miocene Temblor Formation are based on detailed sedimentological study of outcrops and cores in the Coalinga area of the San Joaquin Basin, California. Approximately 2300 feet of section have been measured from twelve outcrop localities. In addition to the outcrop descriptions, approximately 4470 feet of cores from 13 wells in Coalinga Field have been described by Clemson University personnel. Two major transgressive-regressive cycles are recognized in the Temblor Formation. A thick lower interval of sandstone represents deposition on an erosional surface that was incised during lowstand of relative sea level. Incised valleys were filled during subsequent relative sea-level rise, which produced a succession of stacked fining-upward sequences. Marine influence in the valley-fill succession, which reaches a thickness of approximately 45 m, increases upward through estuarine deposits and into marine shale. This transgressive systems tract is overlain by regressive deposits of a tide-dominated shoreline. The regressive accumulation, which becomes coarser grained upward, consists of alternating tidal-channel and intertidal-flat deposits. Sandstone beds containing abundant shell debris separate depositional cycles and serve as useful marker horizons within this interval. The regressive tidal-shoreline deposits are capped by a diatomite, up to 9 m thick, that represents deposition in response to relative sea-level rise. In the upper part of the Temblor Formation, a regressive tidal and coastal-plain succession of sandstone and shale overlies the diatomite. Sediments of the Temblor Formation were deposited on the margin of a forearc basin associated with Miocene initiation of transform motion along an active continental margin. Consequently, Temblor depositional patterns represent the combined effects of sediment influx, tectonic subsidence, and global sea-level variations. A paper on the results from field investigation of the Temblor Formation was presented at the annual national meeting of the Geological Society of America (Bridges et al., 1999).

A new borehole minipermeameter will be used to make measurements of permeability on outcrops near Escalante, Utah during June/July 2000. This technology is being developed to be a truly reliable field method. Small boreholes are created in an outcrop with a masonry drill, followed by probe insertion, seal expansion and *in situ* calculation of the intrinsic permeability via measurement of the injection pressure, flow rate, and knowledge of the system geometry. Advantages of this approach are that it eliminates the use of questionable permeability measurements from weathered outcrop faces, provides a superior sealing mechanism around the air injection zone, and allows measurements to be made at multiple depths below the outcrop surface.

The theory for analyzing radial gas flow from a cylindrical hole has been developed. Use of the new probe prescribes a change in the system geometry from that of the more conventional exposed rock surface probe. It was necessary to derive the mathematical theory for this new type of probe in a way that is analogous to the derivation by Goggin et al. (1988) for the conventional probe. There is a geometric factor for our probe system, just as there was a geometric factor for the probe system of Goggin et al. (1988). This factor accounts for the geometry of the system and nonlinear flow through the system. In order to determine the geometric factor for the new probe, finite-difference computer simulations were developed to model the pressure-distribution throughout the system. We began by verifying finite-difference solutions by Goggin et al. (1988) for the probe that applies flow to an exposed rock surface. We proceeded by modifying the boundary conditions of the simulation to reflect the new borehole system geometry, and as a result obtained the geometric factors for our new system.

A paper on the development of the new borehole minipermeameter probe was presented at the fall meeting of the American Geophysical Union (Dinwiddie et al., 1999). As a result, contact was made with minipermeameter experimentalists involved in spatial weighting function concepts. This has led to our development of a theoretically-based analysis of spatial weighting functions and their intrinsic relation to the averaging volume of the measurement instrument. One immediate outcome of understanding our instrument's averaging volume is that a minimum borehole depth will be indicated in order to ensure that the averaging volume does not substantially overlap with weathered surface rock.

Laboratory work with the new borehole minipermeameter will commence soon. The experimental plan has been developed, and it will accomplish the following tasks: 1) thin section analysis of the rock zone in the immediate vicinity of the borehole for the purpose of appraising any damage due to drilling, 2) determination of the optimal normal force between the seal and the borehole wall, subsequently outfitting the probe with a torque limiter such that the optimal normal force can be consistently achieved in the field independent from the operator, 3) determination of the minimum distance needed between boreholes to eliminate the possibility of short circuiting gas flow through adjacent holes, 4) calibration of a Hassler-sleeve permeability dataset with a borehole permeability dataset obtained from identical bedding planes with the anticipation of observing correlating trends that will lend credence to the methodology. Additionally, the laboratory work will indicate other general guidelines for field use, such as appropriate pressure and flow rate ranges, expected life of seal material, and the efficacy of obtaining measurements at multiple depths per borehole. Other developments will include a seal-cutting device and a field-portable vacuum for clearing the boreholes of drilling dust. Several sandstone boulders from the field site in southern Utah have been transported to Clemson University for testing of the new prototype permeability probes. Laboratory testing of the prototypes in the field-site sandstone will facilitate the move to *in situ* measurements in southern Utah.

During the past quarter, a manuscript entitled, "Multifractal Scaling of the Hydraulic Conductivity" was revised and re-submitted for publication in *Water Resources Research.* In this manuscript we were able to show that data from the Coalinga Oil Field, as well as data obtained in the laboratory using the air permeameter, displayed multifractal scaling over a significant range of scales.

Conclusions

During the past six months, results from geologic field study in southern Utah have been compared and integrated with results from our fieldwork on Temblor exposures in California. The Temblor Formation contains reservoir zones from which heavy oil is produced at Coalinga Field and at other fields in California's San Joaquin Basin. This type of comparative analysis between Utah and California is yielding a better understanding of the distributions of subsurface geologic and hydraulic properties. In addition, data from Coalinga Field have been analyzed to define the fractal structure present in the data set. Natural heterogeneity appears to have aspects of both monofractals (fractional Brownian motion and fractional Levy motion) and multifractals, but is not a perfect match for any one type of fractal. Therefore, we have been considering the combination of facies modeling for macroscale structure and Gaussian fractal modeling for microstructure. Efforts during the next six months will include the following: collecting permeability data from outcrops in southern Utah using the new mini-permeameter being developed, continuing to generate property distributions using fractal structures, and conditioning the fractal function to the data sets.

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