6819

LBL/Industry Heterogeneous Reservoir Performance Definition Project: The BP Gypsy Site

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The goal of this work is to demonstrate the combined use of state-of-the-art technology in fluid flow modeling and geophysical imaging in an interdisciplinary approach for characterizing heterogeneous petroleum reservoirs. The product of this work will be improved interpretational and predictive methods, which the petroleum industry will use to enhance production from existing and new reservoirs. This project focuses on porous reservoirs and is being done in conjunction with British Petroleum (BP). A related project focusing on fractured reservoirs is being done in conjunction with Conoco (Daley et al., 1992).

The purpose of characterizing the behavior of a petroleum reservoir is to create a model that will be a useful tool for planning the development of the reservoir. In highly heterogeneous and fractured reservoirs, the characterization process is both difficult and critical to efficient recovery. Its success depends on the ability to successfully interpolate and extrapolate *in situ* point measurements made from the surface and wells to the volumetric properties affecting the production of the resource.

Fundamentally there are two ways to create a model of a heterogeneous system: the forward approach and the inverse approach. In the forward approach, one takes measurements of the relevant physical parameters (permeability, porosity, etc.) and develops a technique to assign these values to areas of the reservoir where the parameters have not been measured. Forward calculations of the reservoir behavior can then be made. The advantage of the forward approach is that it is based on physical laws relating parameters to behavior. The disadvantage is that there may not be enough data available to adequately specify the model. In the inverse approach, the behavior of the reservoir during some testing phase is used to infer the physical properties throughout the field. The advantage of the inverse approach is that the model focuses directly on the behavior of the system that we want to predict. The disadvantages are that the technique may be computationally intensive, as it essentially requires performing forward calculations repeatedly, and the results may be non-unique.

No matter which of these techniques is used, there is rarely enough fluid flow information to adequately characterize the reservoir flow parameters. One of the most promising approaches to this problem is to use geophysical imaging to infer the pattern of heterogeneities that exist between wells. For example, the propagation of seismic or electromagnetic waves may be studied to infer mechanical or electrical properties of the subsurface, using inverse techniques. Learning how to properly use this information in the development of a flow model (i.e., how to relate mechanical and electrical properties to flow properties) is a key factor in reservoir definition. In this first year of the project, independent hydrologic and seismic analyses are being carried out; in future work an integrated analysis will be done.

THE GYPSY SITE

The BP Gypsy site consists of two suites of boreholes and an outcrop in a mixed-load meander belt formation in northeast Oklahoma. The Gypsy outcrop is a 1000 ft long, 50 ft high road cut that reveals six fluvial sandstone channels, as well as lower-permeability formations (see Figure 1). Over 1100 permeability and porosity measurements have been obtained, along with detailed geologic mapping. Three-dimensional information has been obtained by coring 20 shallow boreholes near the outcrop. At the subsurface pilot site, located about 20 miles away, six wells have been drilled into the Gypsy formation (located at a depth of 1000 ft). The data collected by BP include an extensive set of well logs, core information, pressure transient well tests, and 3-D surface seismic and cross-well seismic tests.

HYDROLOGIC INVESTIGATIONS

The first order of business was to evaluate existing data and begin to develop an understanding of the Gypsy site. Efforts to date have concentrated on the subsurface pilot site and involve reviewing the well-test data and evaluating its potential for inclusion in a hydrologic inversion to characterize heterogeneities at the pilot site. Sixteen well tests were conducted, using multiple observation intervals in six wells. A matrix display of well-test results provides a concise way to assess the consistency, precision, and coverage of a large number of well tests. Each entry in the matrix describes the response between a pair of pumping and observation well intervals. Each of the wells has two or three screened intervals, making a total of 16 intervals altogether, leading to a matrix with 256 entries. According to the principle of reciprocity (Barker, 1991), the response at well A during a test in which well B is pumped should be the same as the response at well B during a test in which well A is pumped, if the same pumping rates are

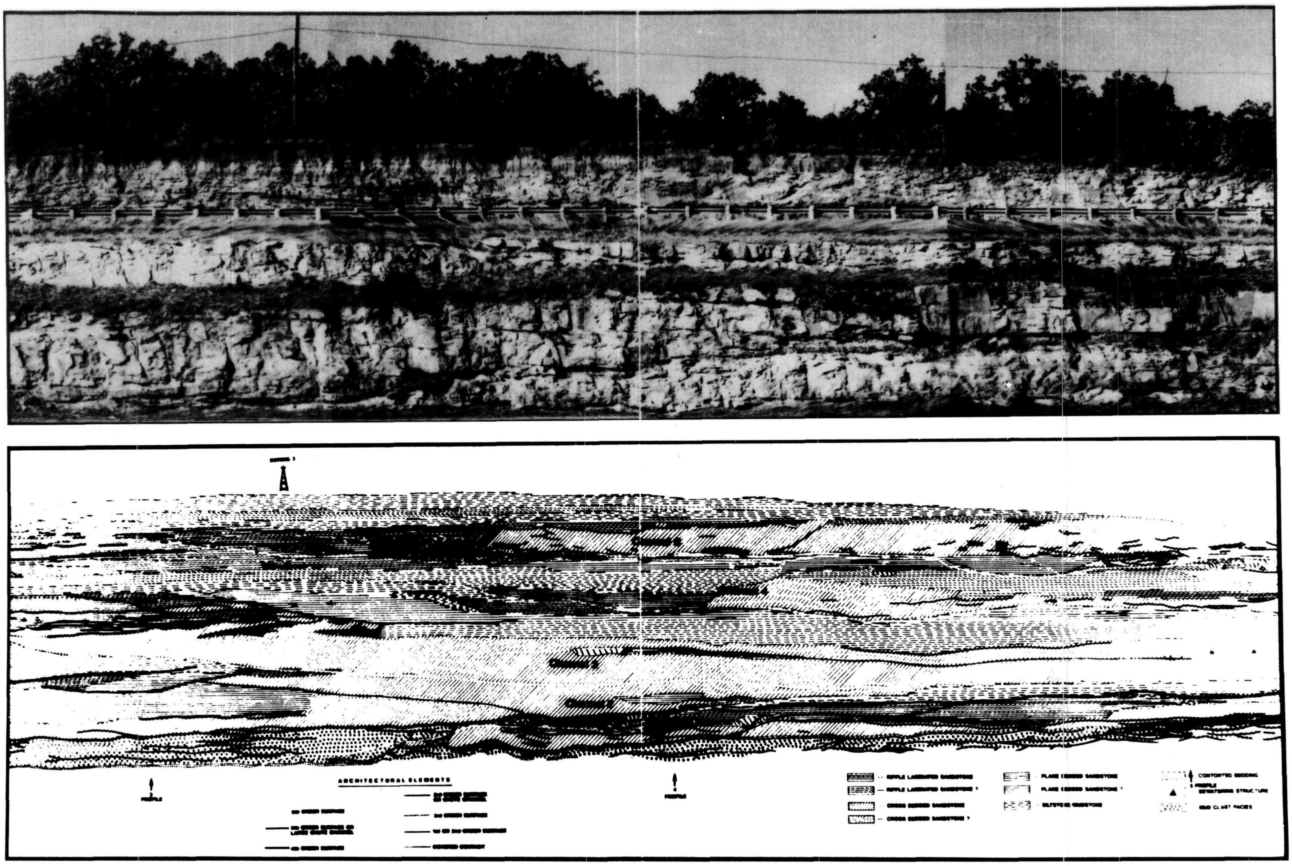

Figure 1. An orthophotograph of the central portion of the Gypsy outcrop and a geologic facies map inferred from geologic mapping. [CBB 927-5725]

used in both tests. This relationship even holds when different flow rates are used, if each drawdown response is normalized by the flow rate used. We have located several entries in the matrix that qualitatively contradict the reciprocity principle (i.e., no response at well A when well B is pumped but a large response at well B when well A is pumped). This is an indication of instrument or operational failure (e.g., packer failure, electrical power outage). We have also found reciprocal entries in the matrix that are qualitatively the same but differ quantitatively; these will be used to assess the precision of the pressure measurements and flow rate control. Finally, the matrix has been used to identify gaps in coverage; that is, combinations of wells that have not been tested together but which would be useful locations for future well tests.

Based on the internal BP reports describing the pilot-site well tests, we expected to have 130 pressure transients from 16 well tests to use for our hydrologic inversions. Our evaluation of the data has indicated that 90 pressure transients from a total of 13 tests will be directly usable in the inversion method. The remaining 40 pressure transients fall into one of five categories:

- 13 pressure transients that qualitatively satisfy the reciprocity principle or involve duplicate tests; these will be useful for checking the precision of the data.
- 6 pressure transients that qualitatively contradict the reciprocity principle; these have been used to identify three occurrences of instrument failure.
- 10 pressure transients that were measured during one of the tests with instrument failure; these are not usable.
- 8 pressure transients for which the data were missing or garbled; these are not usable.
- 3 pressure transients from tests that were designed in such a way as to make the results uninterpretable with our inverse method; these are not usable.

Overall, we will be able to use 103 out of 130 pressure transients, either directly in the inversions or indirectly to check the precision of the data.

Our evaluation of the data indicates that the well-test data as a whole support the conceptual geological model of the pilot site presented in the BP reports. This model consists of three sand channels (denoted the lower, middle, and upper channels) separated vertically by two clay layers. The lower clay layer (the dense red clay) is inferred to be continuous and the upper clay layer discontinuous. We have developed a tentative strategy for doing hydrological inversions, which will be carried out during fiscal 1993.

SEISMIC INVESTIGATIONS

The goal for seismic field work in fiscal 1992 was to do a set of mini cross-hole seismic surveys at the Gypsy outcrop site, using boreholes located near the outcrop. In this setting the results of the seismic survey can be related to the geology with some confidence because the outcrop reveals an extensive 2-D picture of the formation. The resulting relations can then be used to interpret seismic surveys done at other locations in the Gypsy formation, such as at the subsurface pilot site, where only 1-D geological observations are available via boreholes. These interpretations can then be used in conjunction with the hydrologic characterization of the subsurface pilot site.

Three wells were drilled to a depth of 75 ft around well 5, which is located about 10 ft from the outcrop. The new wells, identified as wells A, B, and C, are all 25 ft from well 5 (Figure 2). When we arrived at the outcrop site to perform the surveys, we found that the well A water level was 58 ft below the surface, the well B water level was 68 ft below the surface, and that well C was dry and blocked at a depth of 45 ft. We attempted to fill each well with water, but none would hold water for enough time to allow a reliable survey to be performed (the cross-hole source and receivers need to be in water to function properly). It is notable that well 5 maintained a water level of about 5 ft below the surface throughout our attempts to fill the other wells, supporting the notion that fluid flow paths are highly heterogeneous.

The limited data obtained indicate that good data could be collected if the wells were sealed. Further field work will be conducted in fiscal 1993 by first sealing the wells so that they will hold water and then conducting the cross-hole survey.

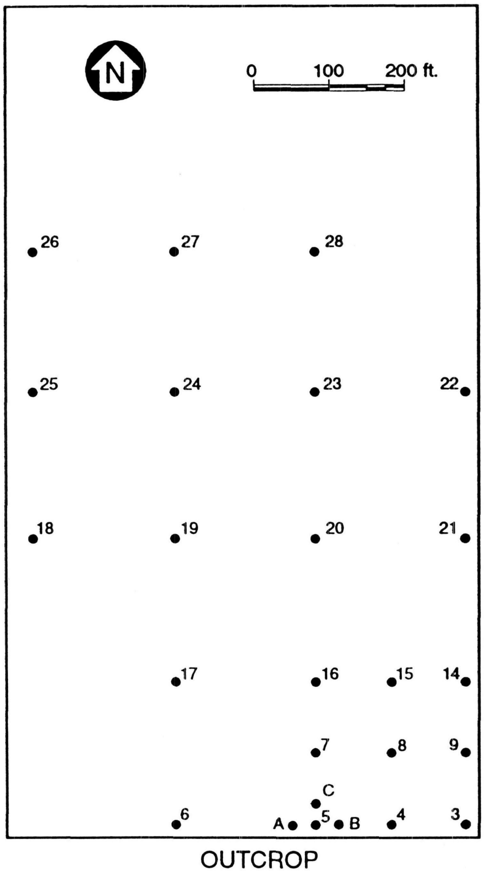

Figure 2. A plan view of the boreholes adjacent to the outcrop. The wells labeled A, B, and C were drilled for the mini cross-hole seismic survey. [XBL 935-809]

REFERENCES

Barker, J.A., 1991. The reciprocity principle and an analytical solution for Darcian flow in a network. Water Resour. Res., v. 27, no. 5, p. 743–746.

Daley, T.M., Majer, E.L., Long, J.C.S, Hestir, K., D'Onfro, P., Rizer, W., and Queen, J., 1992. LBL/Industry Heterogeneous Reservoir Performance Definition Project: The Conoco Site. *In this Annual Report.*