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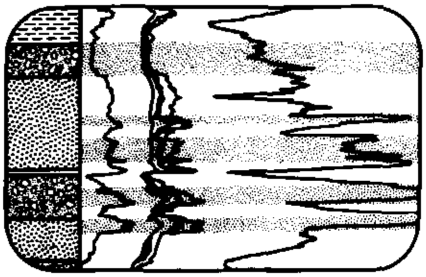

Use of Geophysical Wireline Logs for Interpreting Depositional Processes

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Summary
The recorded shapes of some geophysical wireline (well) logs are useful in subsurface studies for the interpretation of depositional processes, important to the understanding of petroleum and other reservoirs, and in the reconstruction of paleo-environments. By combining data from well logs, sample cuttings and cores with inferences obtained from conceptual facies models (Walker, 1976), reasonable and practically rewarding predictions of reservoir geometry and trend are possible. However, because of the character of the petrophysical measurements recorded, some interpretational pitfalls are present.

The proposed series of articles on facies models edited by Roger Walker (1976, p. 21-24) will be welcome reviews to those geologists/sedimentologists employed in the search for hydrocarbon reservoirs and certain mineral deposits, e.g., uranium. To the petroleum explorationist engaged in the specific recognition of processes, the use of facies analysis and facies modelling is not new.

Unlike the field geologist, who has the flexibility to search the outcrop for data and "distill away local variability," the subsurface stratigrapher-sedimentologist has limited access to a representative "sample" of the process to be unravelled. The subsurface geologist has available several "tools" to assist in the recognition of process and environment. Aside from regional syntheses compiled from high resolution reflection seismic data (Sangree and Widmier, 1974; Harms and Tackenberg, 1972) and regional lithofacies maps derived from computer files of cuttings data (Hay, 1976), geological information for solving local problems is obtained from three major sources; well cuttings, cores (both conventional and sidewall) and downhole geophysical logs.

The description and laboratory analysis of cores and cuttings for mineralogical, paleontological, paleoecological, petrophysical, and other information is almost routine in the petroleum industry. These data are integrated with correlations and regional syntheses of sedimentary associations derived from geophysical well logs and other sources. Data from well logs has been used for many years to provide information on lithology, structure, correlation, porosity and interstitial fluid content. Petroleum explorationists are concerned with both the relative merits of logs for stratigraphic correlation over broad areas and the use of logs in defining possible "genetic units" (Busch, 1974; Shelton, 1973) amenable to practical sedimentological interpretation. The development of suitable (albeit stochastic) models for facies prediction in the subsurface of both shelf-carbonates and siliciclastic rocks from geophysical wireline logs, cuttings, and core data, is a challenging one.

The identification of clastic depositional processes and environments from well logs relates basically to the identification of sand bodies of which the texture, fabric and geometry reflect their origin. However, no panacea for the identification of the process is to be found in well logs, because the character of a log is based on certain specific and limited petrophysical measurements made in a more-or-less vertical borehole and is *not* at all directly related to depositional conditions. Process may be inferred by analyzing log patterns and relating them to known sand body or facies association and sequential patterns (Allen, 1975; Pirson, 1970, p. 36-58).

A major parameter, but certainly not the only one, on which conclusions of depositional process are based is the characteristic of the vertical profile of the sand body (Visher, 1965). The most important geophysical logs which commonly offer an insight to the vertical motif are the Gamma-Ray log (G.R.), the Self Potential (S.P.) log and to a lesser extent, the several types of resistivity log. Several studies have made use of the log pattern as a clue to the changes in depositional processes (see Fisher, 1969; Shelton, 1973; Weber, 1971; Tizzard and Lerbekmo, 1975).

Several pitfalls need be borne in mind in all interpretations which are based on log character. These difficulties are caused by the basic petrophysical property to which the logging device responds (natural radioactivity, electrical potentials) and the vertical resolution (or spacing) of the instruments (particularly in the case of resistivity logs) versus the boundary character, thickness, and spacing of beds.

The S. P. log records natural electrical potentials that exist in the borehole generated by the electrochemical and electrokinetic potentials. These potentials are small and are easily influenced by the character of the fluids, both in the borehole and in the formations. They are also affected by the permeability of the formation and the size of the hole. S. P. values may be positive or negative depending upon the ratio of the resistivity of the filtrate from the drilling fluid to the resistivity of the formation water. Reduction in the negative S. P. deflection opposite a sand may be indicative of the presence of clay minerals either in a dispersed or laminated form. A reduction in the S. P. deflection is indicative of the cleanness of the sand, and, therefore, it can be used as a very rough measure of the degree or sorting or winnowing and can be used as a continuous grain-size profile through clastic formations. It may also indicate the existence of graded bedding.

"Flat" S. P.'s are not necessarily indicative of no "sand" or qualitative permeability, but may result from the use of a drilling mud of which the resistivity of the filtrate is nearly equal to the resistivity of the fluids in the formations penetrated. Similarly, variations in the resistivity of formation waters with depth can lead to erroneous conclusions about transgressive or regressive sequences. The S. P. log is also not a good indicator of lithology where sands are cemented and the S. P. curve shape may also be suppressed in zones containing hydrocarbons.

When S. P. measurements cannot be made as in wells drilled with oil-base fluids, the Gamma-Ray log is a natural substitute. Fortunately, where practical, the S. P. and G. R. logs are almost always run on exploratory wells. The Gamma-Ray logging tool measures the natural radioactivity of formations traversed. Potassium is the predominant radioactive element present in sediments, and generally is most abundant in clay minerals. As a general rule, the G. R. reads low in sands and high in clays and shales, but caution is required if other radioactive sources (e.g., glauconite, some micas, zircon) occur in the sand sections (see Selley, 1976). In addition to hole size, due to the electronics of the G. R. tool both logging speed and recording methods can alter the appearance of a log. Slow logging speeds give a more accurate measurement of the natural formation radioactivity (Allen, 1975; Jageler and Matuszak, 1972).

Useful ancillary data for subsurface stratigraphic and sedimentologic information is available from dipmeter logs. Dipmeter devices are basically instruments for simultaneously recording microresistivity with small electrodes oriented at three or more azimuths (nowadays typically four - hence the Four Arm Dipmeter), stationed around the wall of the borehole. Dips are determined by correlating boundaries of beds as recorded on each resistivity curve. Once corrections for hole deviation have been applied, and assuming that the chosen points lie on a plane, the dip and strike of that plane can be calculated.

Modern dipmeters make it possible to obtain better quality and a greater quantity of information concerning dips, some of which may be related to local sedimentary structures. In making facies and environmental analysis, all available sedimentologic data should be integrated with the interpretations from dip logs. Computed displays of dipmeter data and their interpretation are dependent on the "step-length" and "search angle" used in averaging the data.

The dipmeter is used to aid in establishing subsurface dip reversals (compaction dips or drape) over sand (e.g., offshore barrier) or carbonate (e.g., shelf edge or isolated reefs) bodies, interpreting structures (e.g., faults, salt dome tectonics), detecting unconformities and analyzing paleo-currents (Jageler and Matuszak, 1972, p. 125-134; see also Steinmetz, 1972).

The Gamma-Ray, Spontaneous Potential and Dipmeter devices can all achieve good resolution of bed thickness which is of the order of several centimetres in magnitude. Hence, sedimentologic and stratigraphic data of some detail can be obtained by competent analysis of well logs. Nevertheless, the practical (time consuming) and economic limitations (e.g., too thin to be of economic significance) frequently do not allow the identification of thin bedded units, containing, for example, small scale cross-lamination and, in the case of the dipmeter, it is questionalbe if such units would ever be distinguished from data referred to as "noise".

Notwithstanding, the use of sample cuttings, cores and geophysical wireline logs combined with Walker's (1976) reviewed and proposed facies models, should assist greatly in the successful prediction, location and enlightened exploitation of hydrocarbon and other reservoirs. However, the subsurface geologist should not work independently of the trained well log analyst and interpreter. Only by combining their respective talents will meaningful and practically rewarding solutions to subsurface sedimentological problems be found by using geophysical well logs.

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