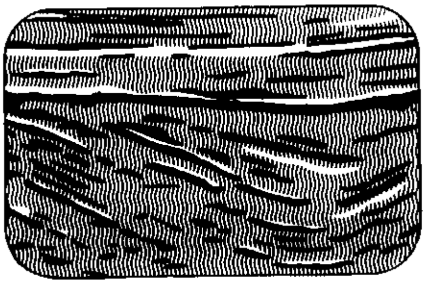
Articles



Subsurface Sedimentology

Douglas J. Cant
Alberta Geological Survey
Alberta Research Council
4445 Calgary Trail S.
Edmonton, Alberta T6H 5R7

Introduction

This article will attempt to bridge the gap between "academic" sedimentology based largely on outcrop and modern sediment studies, and the techniques of resource geologists who investigate sedimentary rocks in the subsurface. It is intended to be an introduction to subsurface data and procedures, particularly 1) geophysical logs; 2) cores and cuttings; 3) correlation; 4) facies analysis. The article is written for an audience of students and/or researchers who have a sedimentologic background, but are unfamiliar with subsurface techniques. Seismic methods will not be reviewed because this form of data is not usually available outside of private companies. Readers interested in these methods are referred to Payton (1977), a collection of papers which summarizes a great deal of information about seismic stratigraphic analysis.

Differences from Surface Work

In many ways, subsurface data differs from the kinds of data collected from outcrops and modern sediments. Most fundamentally, subsurface data provide a differently biased sample of the characteristics of a rock unit than do outcrop data. Drill holes and cores are concentrated in localities and zones of economic interest while outcrops preferentially expose harder, more resistent rocks occurring near the margin of a basin. Drill holes "sample" a complete section while outcrops rarely do. Some common sedimentological techniques such as paleocurrent analysis are much less applicable in the subsurface because of difficulties in obtaining data. No matter how closely spaced wells may be, data from 3 to 20 cm diameter holes cannot provide as much local information as an outcrop. However, because outcrops are in most cases two-dimensional and restricted in size, subsurface data from an extensively drilled unit may be superior for larger scale or regional studies. For example, the sizes and shapes of offshore bars are known entirely from subsurface studies. This variation in the most appropriate scale of investigation may be the most important difference between the two situations.

Geological Uses of Well Logs

Well logs are extensively used in the petroleum industry for the evaluation of fluids in rocks, but this aspect will not be covered here. The interested reader is referred to the numerous logging company manuals or other manuals such as Merkel (1979). In most subsurface studies, geophysical logs are the fundamental source of data because virtually every oil and gas well is logged from near the top to the bottom. Coal and mineral exploration drill holes may provide well log data on shallow rock units.

Types of logs. 1) Spontaneous potential (SP)—This log measures the electric potential between an electrode pulled up the hole in contact with the rocks and a reference (zero) electrode on the surface. The log is measured in millivolts on a relative scale only (Fig. 1) because the absolute value of the potential depends not only on the properties of the rock and interstitial fluid, but also on the properties of the drilling mud. The log delineates zones of permeable rock with interstitial fluid which has a salinity contrast with the drilling mud.

The SP log is run in most wells, and while it is not a good lithologic indicator in many areas, in others it provides the only available data which can be used (Table I). In areas of low-permeability rock, such as the Deep Basin of Alberta or the bitumen-saturated Athabasca Oil Sand, it is useless for lithologic interpretation. In freshwater-bearing units such as many Upper Cretaceous formations in Alberta, SP deflection is suppressed where low salinity drilling mud is used. However, in other areas such as the Ventura basin in California, the sandstones are all permeable and saturated with salt water (or hydrocarbons), with the result that the SP log delineates them very well (Hsu, 1977). Experience in an area, and calibra-

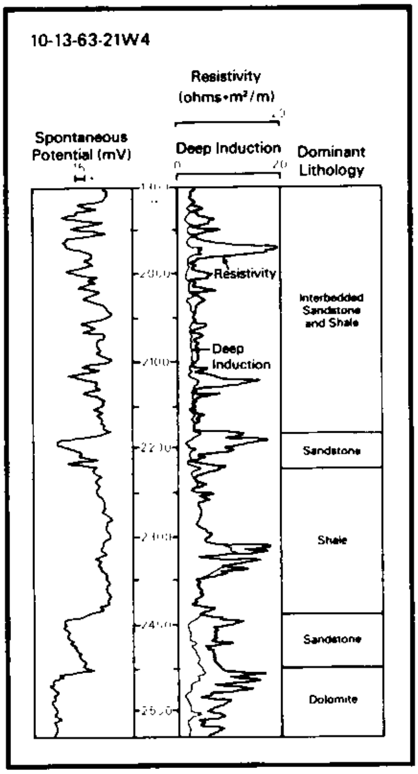


Figure 1 *Example of SP and resistivity logs. The deep induction tool reads lower resistivity, probably indicating salt water in the sandstone.*

TABLE I *Log types and their uses*

LOG	PROPERTY MEASURED	UNITS	GEOLOGIC USES
Spontaneous potential	Natural electric potential (comto drilling mud)	Millivolts	Lithology (in some cases), correlation, curve shape analysis, identify porous zones
Resistivity	Resistance to electric current flow	Ohm-metres	Identification of coals, bentonites, fluid evaluation
Gamma-ray	Natural radio-activity-related to K, Th, U	API units	Lithology (shaliness), correlation, curve shape analysis
Sonic	Velocity of compressional sound wave	Microseconds/ metre	Identification of porous zones, coal, tightly cemented zones
Caliper	Size of hole	Centimetres	Evaluate hole conditions and reliability of other logs
Neutron	Concentrations of hydrogen (water and hydrocarbons in pores	Percent porosity	Identification of porous zones, crossplots with sonic, density logs for empirical separation of lithologies
Density	Bulk density (electron density) includes pore fluid in measurement	Kilograms per cubic metre (gm/cm^3)	Identification of some lithologies such as anhydrite, halite, non-porous carbonates
Dipmeter	Orientation of dipping surfaces by resistivity changes		Structural analysis, stratigraphic analysis

tion against cores and cuttings, are the best criteria for the reliability of the SP log as a lithologic indicator.

2) Resistivity log—A great variety of logs of this type are used. They all measure resistance of the rock and interstitial fluid to flow of electric current, but because of differences in the length of the tool and in focussing of the current, they do so at different depths into the formation. Several resistivity measurements are commonly shown on the same track (Fig. 1) with the scale in ohm-metres. Resistivity logs are used mainly for evaluation of the fluid content of the rocks, but are also useful for identifying coals, thin limestones in shaly sequences, and impure bentonites (Table II). In areas where only SP and resistivity logs are available, resistivity logs are used for "picking" or identifying formations and correlation.

3) Gamma-ray log—This is probably the single most useful log for geological purposes. It measures the natural gamma emissions of the rock, a property which is closely related to the content of potassium, thorium and uranium. Because these elements (particularly potassium) are most common in clay minerals, the log reflects the "cleanness" or, conversely, the "shaliness" of the rock. This property is very useful because gamma-ray patterns in many cases mimic vertical grain-size trends of sedimentary sequences. Gamma-ray logs are calibrated in API units, increasing to the right. It should be emphasized, however, that a gamma-ray reading is *not* a function of grain size, i.e., a clean, well sorted, fine sandstone composed of quartz grains will give a similar gamma-ray reading as will a coarse sandstone of the same mineralogy.

The log can be affected by diagenetic clay minerals which can be precipitated in the pores of rocks. Different clay types can affect the log by different amounts because of their composition. Shales rich in illite (higher K) are more radioactive, on average, than those rich in montmorillonite or chlorite (low K).

4) Sonic log—This log is run with the gamma-ray log and measures the travel time of compressional sound waves through the formation. The velocity of the sound depends on 1) the lithology of the rock; 2) the amount of interconnected pore space; 3) type of fluid in the pores. This log is useful for delineating beds of low-velocity material such as coal or very porous rock, or high velocity material such as tightly cemented carbonate or sandstone, or igneous basement. The interval travel time is measured in time per unit length (sec/m) with longer travel times to the left (Fig. 2).

5) Density log—This log is again run with a gamma-ray log. The density tool emits gamma radiation which is scattered back to a detector in amounts proportional to the electron density of the formation. Electron density is directly related to density of the rock (except in evaporites) and the amount and density of pore- filling fluids. The log is plotted in gm/cm^3 or kg/m^3 (Fig. 3). Because the major classes of sedimentary rocks have somewhat different densities, this log is useful for lithologic identification where porosities are known.

6) Neutron log—This log is used primarily to estimate porosities because it responds to the concentration of hydrogen (in water or hydrocarbons) in the rock. It is useful in many cases in conjunction with other logs for empirical calibration of rock type against log response. Neutron porosity is commonly shown in the same track as a porosity calculated from the density log by assuming a density of the rock material

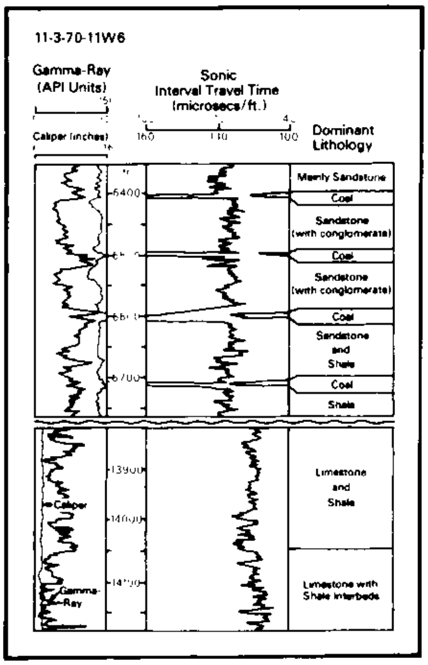


Figure 2 *Example of gamma-ray and sonic logs. Siliciclastic and carbonate-dominated sections are shown.*

TABLE II *Recognition of lithologies in the subsurface*

LITHOLOGY	PRIMARY LOG(S) USED	IMPORTANT PROPERTY	NOTES
Limestone	Gamma-ray	Low radioactive K-content	Porous limestone best distinguished from sandstone in cores or cuttings
Dolomite	Gamma-ray density	Low radioactivity density of 2.87	Best distinguished from limestone in cores or cuttings
Sandstone	Gamma-ray (SP)	Low radioactivity K-content	Arkosic sandstone may not be identified
Shale	Gamma-ray	High radioactivity	
Conglomerate	Gamma-ray	Low radioactivity	Best distinguished from sandstone in cores or cuttings
Anhydrite	Density	Density of 2.96	
Halite	Density	Density of 2.03	
Sylvite (and other K-bearing evaporites)	Gamma-ray	Very high radioactivity	
Coal	Gamma-ray and sonic or density	Low radioactivity, long sonic travel time, low density	Argillaceous material in coal may raise radioactivity
Bentonite	Resistivity	Low resistivity	Impure ones may have high radioactivity

(2650 kg/m^3 for limestone) and fluid (1000 kg/m^3 for water; Fig. 4).

7) Caliper log—This log records the diameter of the well bore measured with a caliper device. It gives an indication of the conditions of the borehole. A very large hole indicates that a great deal of caving or falling in of the rock has occurred. While most logging tools are designed to compensate for the size of the hole, anomalous or unreliable readings can occur where a very much enlarged hole has developed. A hole size smaller than the drill bit results because the fluid fraction of the drilling mud invades very permeable zones leaving the solid fraction (mud or filter cake) plastered to the inside of the well bore. The caliper log is usually plotted on the same track as the gamma-ray log (Fig. 2), with hole size increasing from left to right.

8) Dipmeter log—This log is made by a resistivity tool with 3 or 4 electrodes, each capable of detecting changes in lithology, mounted on separate arms with a common centre point. The orientation of the tool in the hole also is continuously recorded. Where a dipping bed is encountered, the response to the lithologic change occurs at slightly different elevations for each electrode. Because the orientation of the electrodes is known, correlation of the resistivity records yields the magnitude and direction of the dip.

The tool can measure structural dip or fractures in the rock, but can also detect various types of sedimentary dips, such as compaction drape over a reef, a mud drape on a point bar surface, and even some cross-laminations. In many cases it is difficult to determine the nature of a dipping surface unless a core has been taken of the interval. Dipmeter results are shown in "tadpole plots" which indicate the magnitude (0-90 degrees) laterally, and the direction of dip by the small tail (Fig. 5).

Interpretation of Lithology from Logs

Interpretation of lithologies in the subsurface from logs without any other data is very difficult. In sections where lithologies are known in general, lithologic interpretation can be made with much more confidence, based on the properties measured by each log. It should be emphasized, however, that the interpretation procedure is somewhat subjective because of 1) unusual minerals in the rock; 2) anomalously high or low porosity; 3) thinly inter-bedded lithologies; 4) poor hole condition; 5) poor log quality. A few specific problems will be discussed.

1. Sandstone versus carbonate—Many sedimentary units contain one or the other, so discrimination is not a problem in these cases. However, where they are mixed, distinguishing them solely on the basis of logs can be difficult. Because carbonates have higher densities, the density log can be successful; however, it should be noted that this log records bulk density, and so will read values less than pure carbonate where porosity is present. The density log should be checked against other data.
2. Sandstone versus shale—The gamma-ray discriminates clearly in most cases. The log can be calibrated by establishing minimum and maximum readings corresponding to sandstone and shale end members, and scaled between. Where a thick section is being considered, several estimates of the position of the maximum "shale" end member should be obtained over the entire depth range under study. As shales compact, the amount of radioactive material per unit volume increases, so the shale line will drift to the right on the gamma-ray log with increasing depth. The tool response is nonlinear (Fig. 6). A cutoff can be established

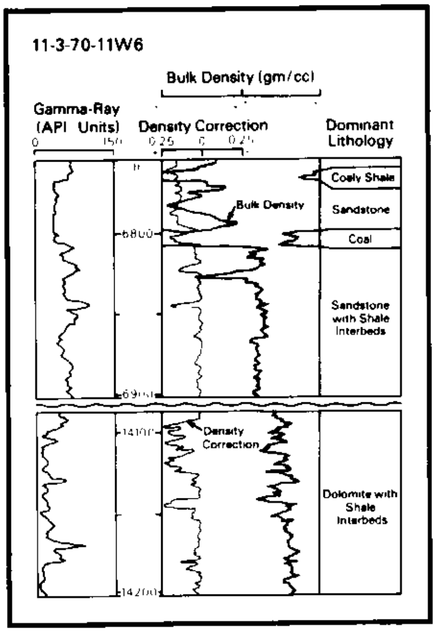


Figure 3 *Example of density (along with gamma-ray) log. The bulk density and density correction curves are shown. The density correction is calculated from the caliper log and is designed to compensate for mud cake buildup on the side of the hole. It has already been applied to the density value, and gives an indication of its reliability. Where density corrections are greater than .1gm/cm^3, the density values are suspect.*

by drawing a line at some appropriate value. This calibration works well for thick beds, but log response in thin beds (less than 2 m) is affected by surrounding lithologies and registers an intermediate value. It is extremely difficult to distinguish thinly interbedded sandstone and shale from shaly sandstone or siltstone. The gamma-ray log run with the density log may provide slightly better resolution of thin beds because it is run at a slower logging speed. Another problem is that the gamma-ray log does not satisfactorily separate sandstone and shale where the sandstone contains much K-bearing feldspar or granite fragments. If this is known from cores or cuttings, the SP log can be used in some cases to discriminate between sandstone and shale. This has proved successful in evaluating lithologies in the so-called "Granite Wash", a wedge of porous Devonian arkoses and conglomerates shed from the Peace River Arch in northwestern Alberta. In this case, checking against cores showed that SP logs are more reliable for lithologic interpretation than are gamma-ray logs.

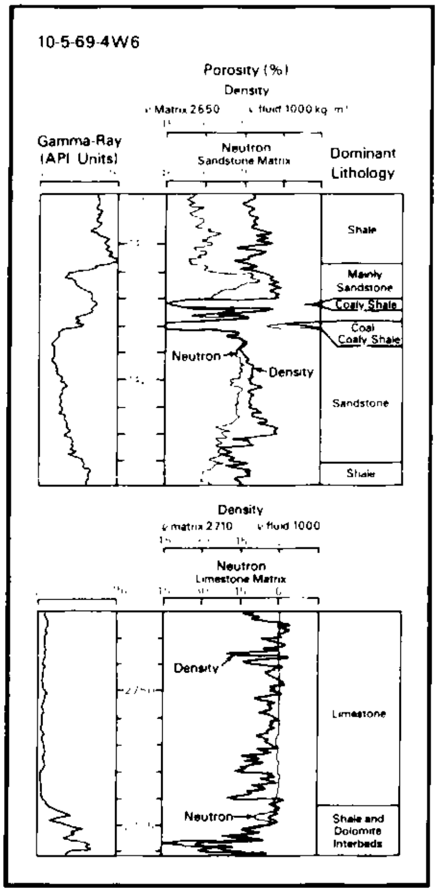


Figure 4 *Example of neutron porosity and density porosity logs. In shales, the neutron porosity log reads anomalously high because of water bound into the clay minerals. In the limestone, the density log records higher porosity because of light natural gas in the pores, and the neutron log low porosity because of low concentrations of hydrogen in the gas (compared to water or oil).*

3. Sandstone versus conglomerate—No general method is available to discriminate between these two rock types, especially for conglomerates with a sandy matrix. In local areas, by calibration from cores or cuttings, some differences in log response can be found. An empirical solution can be applied to the same unit in the local area where it was developed.

4. Dolomite versus limestone—The greater density of dolomite (2.85 vs. 2.71) in some cases allows a distinction to be made by the density log. However, porous dolomites have a lower bulk density than the rock material itself, making distinction difficult. The best solution is calibration of logs against cores and cuttings.

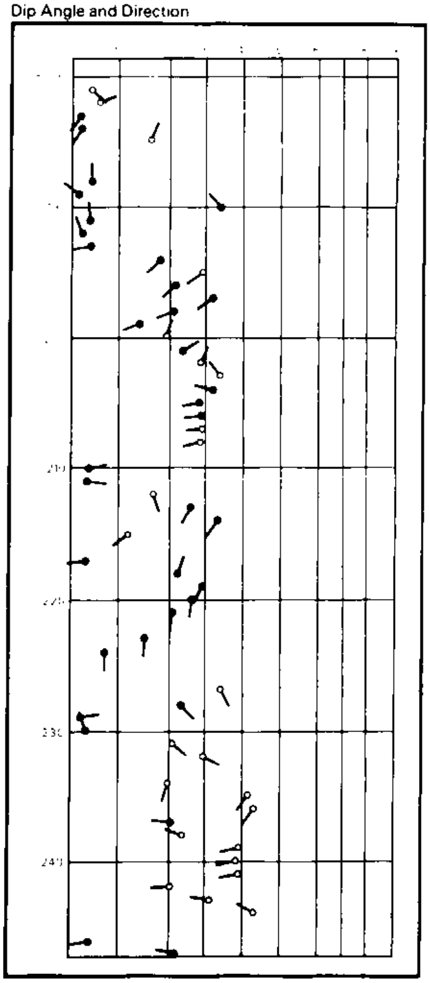


Figure 5 *Example of a dipmeter log indicating direction and magnitude of dip. The section from 205-209 m shows uniform dip, and the section 225-219 m shows an upward steepening of dip.*

One general problem of interpretation of lithologies occurs where two or more rock types are interbedded on a small scale. Where the beds are less than about 2 m in thickness, log measurements are influenced by each of the rock types, and an intermediate response results. In this case, logs cannot be used effectively, and cores are necessary to identify lithology.

In many cases, empirical calibration of logs against cores or cuttings depends not on any intrinsic property of the rock, but on the observation that in some areas each rock type present has a range of porosity and permeability values which do not overlap with others. This causes different responses on logs which then can be interpreted by means of the empirical calibration. This approach is commonly very effective, but constant re-calibration should be done to check the results. In conclusion, it must be emphasized that lithologic interpretation from logs depends on understanding the properties measured by the logs. In some cases, a unique solution cannot be found, and empirical calibration can be used effectively.

Core Description

In general, core description is much like measuring an outcrop section, and all the usual methods and procedures should be followed. This section will deal with some problems specific to core studies.

The most obvious limitation of cores is their width. Not only are large features such as channels or bioherms undetectable in them, but also much smaller sedimentary structures such as hummocky crossbeds are difficult to recognize. In many cases, trough and planar crossbeds cannot be distinguished, especially in unslabbed core. Another general problem with core is its less

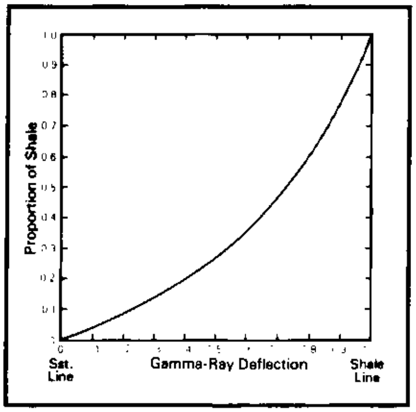


Figure 6 *The relationship between gamma-ray reading and the proportion of shale. A reading half-way between maximum and minimum log values corresponds to about 30 percent shale. Modified from Schlumberger basic manual.*

than perfect recovery. Because of stresses on the rock during drilling and later handling, soft or very brittle lithologies may be poorly represented, or even totally absent from the core. Lines of weakness such as contacts commonly are broken for the same reason. Bedding surfaces are rarely exposed, with the result that sole markings are difficult to detect in core.

To minimize the possibilities of error, before a core is logged the order of the boxes should be checked. Oil industry cores and boxes are numbered from the top downwards, and notations are usually recorded on the tops of core segments. Cores should be described with the geophysical logs present to check for completeness of core recovery, thicknesses, core-log correlations, and log response.

Relating Cores and Cutting to Logs

In many cases, recorded core depths do not correspond precisely to depths on the well logs. Where a core-gamma log (made by passing a detector down the core) is available, this can be compared to the gamma-ray log of the well to establish a correlation. When this kind of record cannot be obtained, a sedimentological log of the core relating grain size or "cleanness" of the rock can be used. This can be inspected and compared to patterns in any of the logs, but particularly the gamma-ray log from the well. In many cases, distinctive patterns, commonly fining- or coarsening-upward, are present (Fig. 7), which allow the cored interval to be located precisely on the log. Distinctive lithologic units such as coals, bentonites, or any isolated bed different from other lithologies in the core can also provide a good correlation point to the log. When a core analysis (porosity and permeability measurements) is available, it can be used to check core depths.

After a core-log correlation has been established, lithologic data from the core can be used to check or recalibrate the lithologic interpretations made from the logs. For example, sandstone-shale cutoffs can be adjusted to match the core data more closely.

Well cuttings are fragments of rock from 1-5 mm diameter ground out by the drill. Two main difficulties are associated with their study: (1) the time lag required for the cuttings to reach the surface, (2) caving of rock from higher in the hole. The first problem can be overcome by carefully logging the proportions of lithologies present, working down the hole. The first occurrence of a new lithology, or increase in proportion of a lithology, can be correlated to the logs. The problem of caving is alleviated because the cavings are larger and more angular in many cases. Where casing is set in a well (noted on logs) caving from higher up is prevented. By careful work, cuttings can provide valuable data on lithologies where no cores are present. However, cuttings should be used with caution because of the possibilities of error in the original collection of the sample.

Correlation of Logs

To conduct regional facies analysis, to map, and make cross-sections, logs must be correlated. Biostratigraphic and mineralogic procedures will not be discussed here, only those methods which are applicable with well logs alone. Three major methods will be discussed: correlation by (1) marker beds, (2) sequence analysis, (3) slice techniques.

Marker beds. Any bed or series of beds with a distinctive response on any log, and which can be recognized over the area of interest, can be used as a marker for correlation (Figs. 8 and 9).

In cases where the section is simple and laterally unvarying, the major units themselves may be distinctive enough to use as markers, i.e., a simple laterally extensive carbonate unit within a dominantly shale section. In other cases, unusual lithologies must be used. Bentonites, where present, are commonly used (Fig. 9). Other examples are shales rich in organic debris, such as the Fish Scales Horizon of the Alberta plains. This unit is present over thousands of square kilometres, and is recognizable by its characteristic very high gamma ray reading, slightly high resistivity response and high density-porosity and neutron-porosity values. Other possible markers are tightly cemented zones, with high sonic velocities and density values, or shale beds with anomalously high radioactivity.

Many markers have the further advantage of approximating time lines. The Fish Scales Horizon has been dated paleontologically as occurring very close to the Upper-Lower Cretaceous boundary, and is taken to approximate this wherever it is found. Bentonite beds originate as ash falls, and so are essentially isochronous.

Marker beds are most useful in sediment laid down in relatively low-energy environments such as lacustrine or some marine settings. In high energy fluvial and near-shore sediments, distinctive sediment types are likely to be dispersed by depositional processes.

Sequence analysis. Sequence analysis involves the recognition and matching of fining-upward or coarsening-upward sequences (Fig.7). In many cases, these sequences are prominent on logs and can be traced over wide areas. Sequences defined in this fashion may cut across lithologic and facies boundaries as shown in Figure 8. In this case several of the sequences (FA to WA) pass laterally from shoreline deposits capped by coal into marine coarsening-upward deposits.

The major strength of this method of correlation is that well-chosen sequences are natural sedimentary units. Data collected from within a unit may be very meaningful because any patterns observed can be fitted into the overall depositional framework established by the sequence. Correlation of sequences is an example of "event" correlation as defined by Ager (1973). It has been suggested by Dixon *et al.* (1981) that time-significant correlations can be established by this method, and this has been partly verified paleontologically. Whether or not the correlations established by sequence analysis are precisely time-makers is difficult to judge, but these correlations appear to be closer to true time lines than those defined by any other method.

The weakness of sequence analysis is that it cannot be applied in many sections. In nonmarine sediments, the method commonly breaks down because of channelling and laterally-restricted sediment bodies.

Slice techniques. Where no other method can be applied, an interval can be subdivided by establishing arbitrary slices, either of constant thicknesses, or of thicknesses proportional to the thickness of the entire interval. This method is not precise in that slices may cut through natural units, but it may be the only possible means to subdivide an interval. Slices should be chosen with some knowledge of the geology. For example, if most sand bodies are 30 m or more thick, to choose slices less than 30 m thick would complicate the results unnecessarily. Another way of establishing slices is to arbitrarily extend naturally-occurring

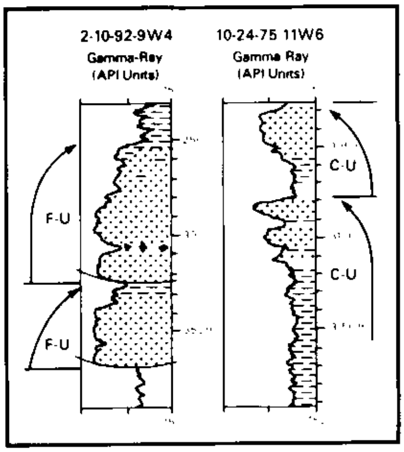


Figure 7 *Good examples of coarsening- and fining-upward sequences (actually upwardly decreasing shaliness and increasing shaliness) on gamma-ray logs.*

sequences of marker bed correlations laterally into zones lacking them.

Slice techniques are most useful in nonmarine sediments where other techniques do not work well because of channelling and differential compaction. In the Upper Cretaceous Horseshoe Canyon Formation the distribution of sandstones and coals has been documented by Nurkowksi and Rahmani (in preparation) by slicing an interval between a bentonitic marker and a persistent shaly marker (Fig. 9). In the Athabasca Oil Sand deposit, Flach (in preparation) also has used a slice technique to subdivide the McMurray Formation. By noting the stratigraphic position below a marker horizon and thickness of each lithology, the data is in a form of maximum utility when computerized. The thicknesses of slices can be varied easily, and lithologic maps produced rapidly until patterns emerge.

Subsurface Facies Analysis

Subsurface facies analysis depends heavily upon the availability of cores. Without sufficient core material, interpretations must be generalized and imprecise. However, subsurface facies analysis is more than simply core examination. The interpretation made from cores can be extended further than core coverage allows by use of log interpretation and can be put into a larger context by cross-sections and maps prepared from log data.

Log curve shapes. A great deal has been written about the interpretation of log curve shape in terms of depositional environment (e.g., Pirson, 1970; Selley, 1978). Much of the published literature is extremely simplistic, using a naive "pigeon-hole" approach to depositional environments. The best procedure is to calibrate the log curve shape against core so that the specific response can be interpreted. Where no core is available, the curve shape can be interpreted by means of general facies models (see *Geoscience Canada Reprint Series #1*). This should be done only with a great deal of caution because many factors, such as amalgamation of units, erosional effects and deviations from the idealized facies models may cause errors. Because log patterns (i.e., trends in shaliness of the sediment) are not uniquely associated with particular depositional environments, other data must be included in many cases to discriminate between possibilities.

Other methods. This section will mention briefly other specialized methods of facies interpretation commonly used in the subsurface. Palynology and micropaleontology can be applied to cuttings. Mineralogic or

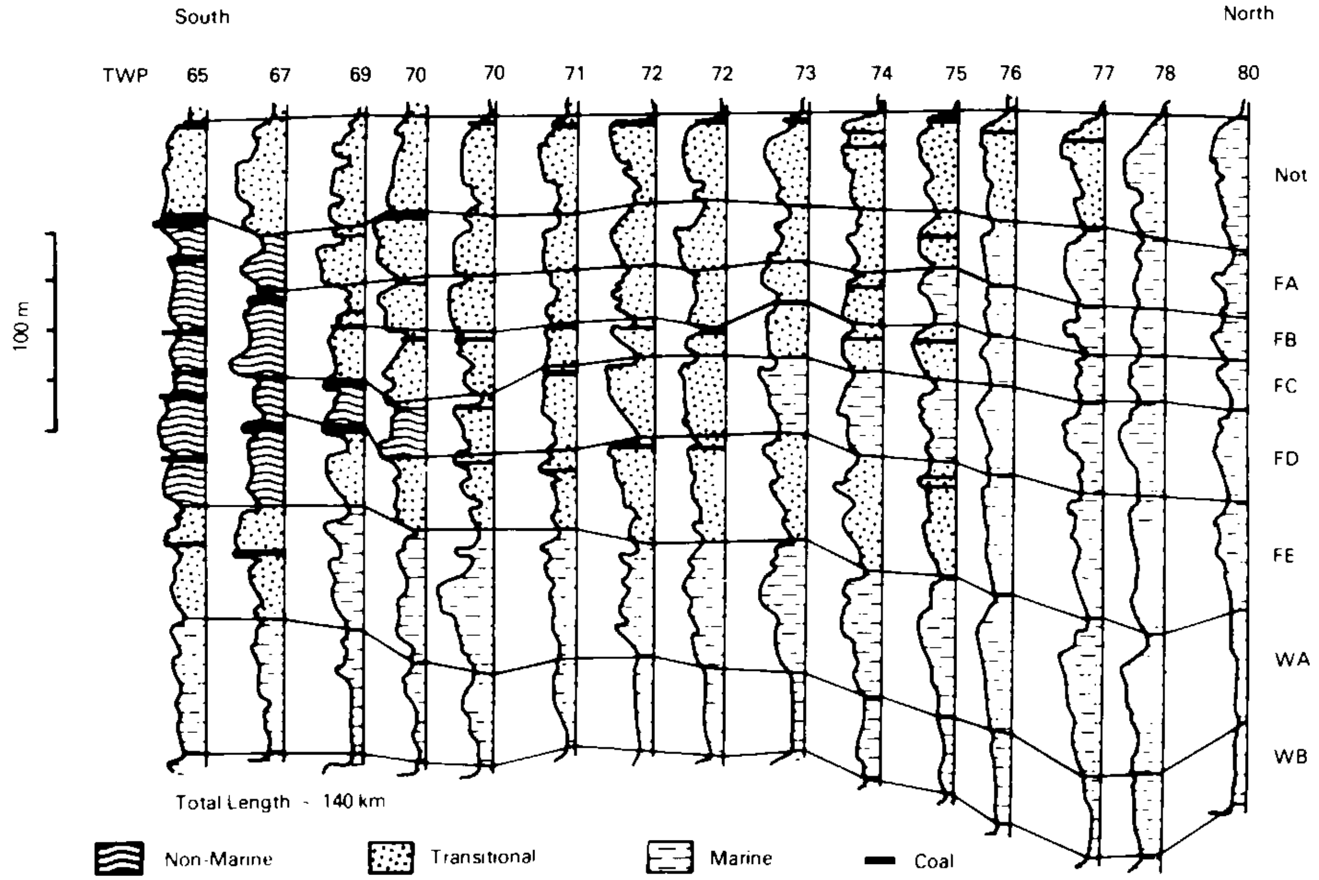


Figure 8 *A north-south, equi-spaced, gamma-ray cross-section from the Lower Cretaceous Spirit River Formation near the Alberta-British Columbia border. Sequence analysis has allowed correlation of 8 genetic units in marine and transitional areas. Each sequence boundary represents a transgression which occurred over a short time interval compared to the regressive deposition of the sediment. The sequence boundaries, therefore, are taken to approximate time lines. The interpretation of depositional environments was made from cores, log curve shape analysis, palynology, and comparison to outcrop. From Cant (in press).*

lithologic criteria such as the presence of glauconite or coal also have this advantage. Ichnology is a very useful tool in many clastic units where microfossils and body fossils are lacking, but requires core.

Dipmeter logs are not very common, but can provide useful data where available. They may show dips increasing or decreasing upward, patterns which can aid interpretation if other data are available. In the McMurray Formation of Alberta, epsilon crossbeds can be detected by dipmeters, and their directions mapped.

In general, it should be emphasized that all available lines of data should be integrated to form a complete interpretation. While core logging is undoubtedly the most powerful method of analysis, integration into a larger scale picture is necessary. This can be accomplished by use of correlation techniques discussed previously to enable construction of cross-sections and maps. No single technique is adequate to uniquely define and interpret sedimentary facies in the subsurface.

Conclusions

Sedimentology in the subsurface depends on the same body of knowledge as does surface work, but the type of data collected differs substantially. Subsurface work can contribute a great deal to modern sedimentology, particularly in developing an understanding of large-scale facies relationships, geometries of lithologic units and sedimentary basin development.

References

Ager, D.V., 1973, The nature of the stratigraphic record: Macmillan Publishing Company, London, 114 p.

Cant, D.J., in press, Development of shoreline-shelf sand bodies in a Cretaceous epeiric sea deposit: Journal of Sedimentary Petrology.

Dixon, O.A., G.A. Narbonne and B. Jones, 1981, Event correlation in Upper Silurian rocks of Somerset Island, Canadian Arctic: American Association of Petroleum Geologists Bulletin, v. 65, p. 303-311.

Flach, P.D., in preparation, Regional subsurface geology of the Athabasca Oil Sands deposit—north sheet: Alberta Research Council Bulletin.

Hsu, K.J., 1977, Studies of Ventura Field, California, 1: Facies geometry and genesis of Lower Pliocene turbidities: American Association of Petroleum Geologists Bulletin, v. 61, p. 137-168.

Merkel, R.H., 1979, Well log formation evaluation: American Association of Petroleum Geologists Continuing Education Course Note Series, number 14, 82 p.

Nurkowski, J.R. and R.A. Rahmani, in preparation, Paleoenvironments of sediment deposition and coal accumulation of the Upper Horseshoe Canyon Formation, central Alberta, Canada: Alberta Research Council Bulletin.

Payton, C.E., 1977, Seismic stratigraphy—applications to hydrocarbon exploration: American Association of Petroleum Geologists Memoir 26, 516 p.

Pirson, S.J., 1970, Geological well log analysis: Gulf Publishing Company, Houston, 377 p.

Selley, R.C., 1978, Concepts and methods of subsurface facies analysis: American Association of Petroleum Geologists Continuing Education Course Note Series, number 9, 82 p.

MS received February 23, 1983.

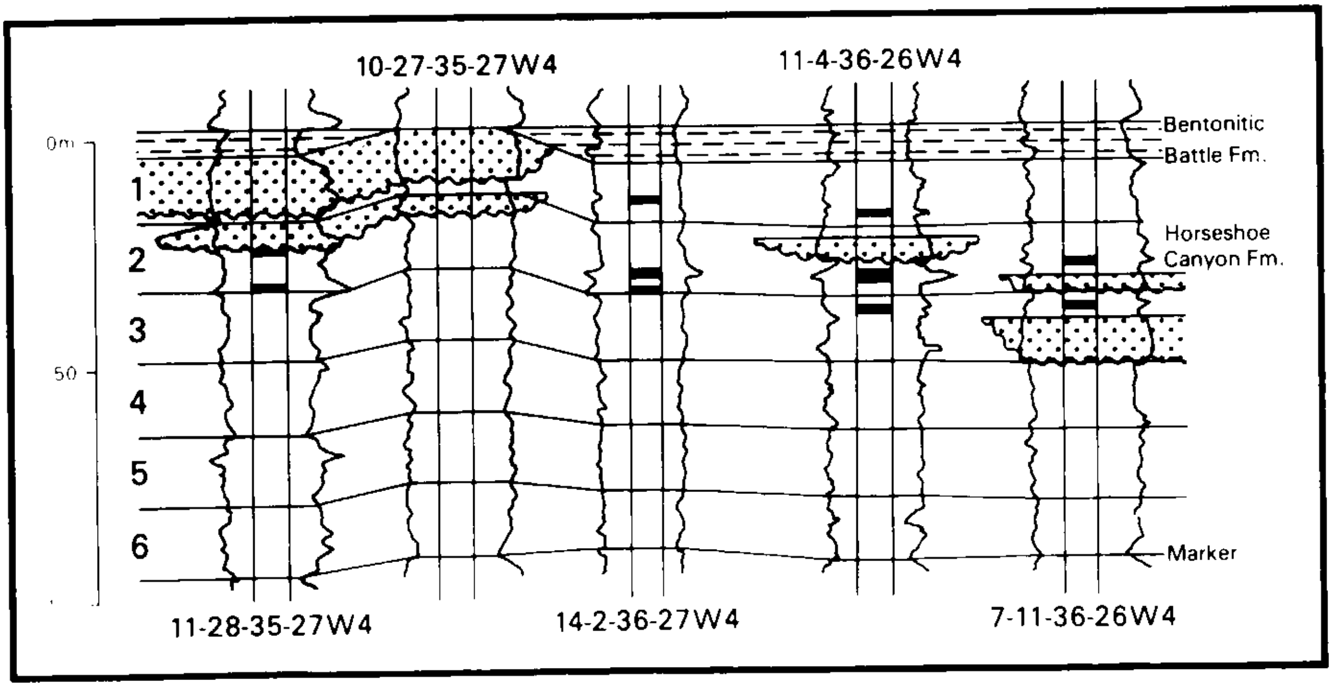


Figure 9 *A cross-section (gamma-ray logs on left, resistivity logs on right) from the Upper Cretaceous Horseshoe Canyon Formation in central Alberta. The section between the bentonitic Battle Formation and the basal marker was subdivided into 6 equal slices. The slices were chosen to include but not subdivide the major channels (stippled) in this non-marine section. From Nurkowski and Rahmani (in preparation).*