# Chapter 5 Well Log Sequence Stratigraphy

5.1 Introduction

In 1960's private drill operator C.G Sulzberger drilled two oil prospecting wells at Bracknell (OP1) and Hagley (OP2) in the north of the Longford Sub-basin (Matthews 1983). These two wells provide the most complete stratigraphic section through the basin. Stratigraphic data and geophysical logs (OP1) are particularly useful in providing additional information to help interpret depositional environments and seismic sequences. Palynology on samples also allows age constraints on basin formation and sequence deposition. Abrupt changes in gamma-ray logs response are commonly related to sharp lithological breaks associated with unconformities and sequence boundaries (Krassay 1998). Sequence boundaries identified from OP1 closely tie to high amplitude reflections on seismic line TBO1-PM. Integrated analysis of well log and seismic data allows a higher resolution interpretation of sequences. Smaller 4th-order packages are identified.

The principle gamma-ray log shapes are frequently used for interpreting sedimentary cycles or depositional facies. The five log trends (figure 5.1) are bell shape (upwards increasing in gamma counts), funnel shape (upward decrease in gamma counts), box-car or cylindrical (relatively consistent gamma readings), bow shape (systematic increase and decrease of gamma counts) and irregular trend (no systematic change in gamma values).
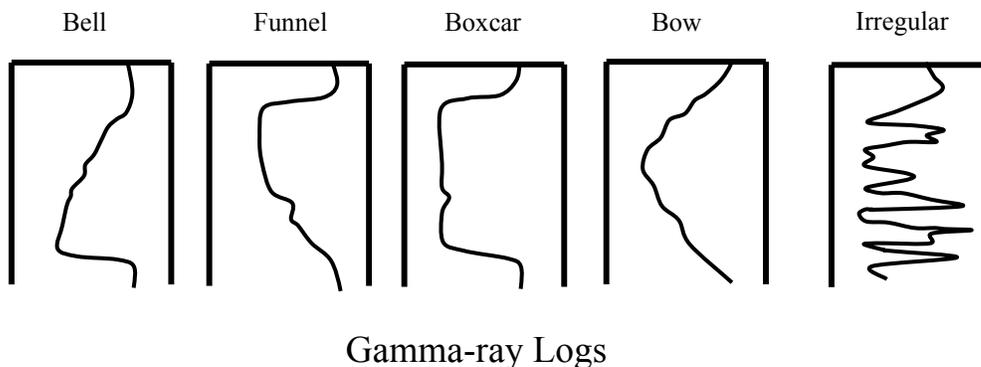
Gamma-ray Logs

Figure 5.1: Idealized gamma-ray log trends (modified after Rider 1993).

Gamma-ray logs measure the natural radioactivity of rocks and generally show a close relationship to grain size. The naturally radioactive elements are normally concentrated in shales (clay-size grains). Defining the word "clay" is important due to the uncertain use and ambiguity. Here, clay is used in a textural sense, meaning grain size less than 4 μm, whereas shale is used to describe lithologies, following the format of Rider (1993). The problem encountered by simplifying the relationship, that low gamma counts indicates clay are discussed in Chapter 5.2.1.

Samples from OP1 have not been archived, so the relationship between the rocks and geophysical readings cannot be established. Assuming that grain size of the lithology logs relates to gamma ray readings and these conditions are consistently met, the depositional facies can be quantitatively interpreted on the basis of gamma-log shapes.

5.2 Reinterpretation of OP1

OP1 and OP2 contain a complete record of the Tertiary deposition, over two thirds more than any other drill hole in the basin. Electric logs, consisting of gamma-ray, self-potential (SP) and single point resistivity were run on OP1 to depths ranging between 560 and 610m (Matthews 1983).

Since OP1 contains crucial geophysical information, the logs can be reinterpreted based upon these parameters to produce a more detailed lithological interpretation (figure 5.2). The reason for reinterpretation is due to the incomplete and ambiguous lithological descriptions of OP1 (Matthews 1983; Appendix 6). The OP1 lithological log is based upon a composite of sample description and driller's logs (figure 5.2).

Gamma-ray logs measure natural radioactivity in formations, therefore enabling qualitative identification of zones of shale (high gamma readings) from sand (low gamma readings). SP identifies areas of low or high permeability, and can be useful in supporting gamma-ray identification.
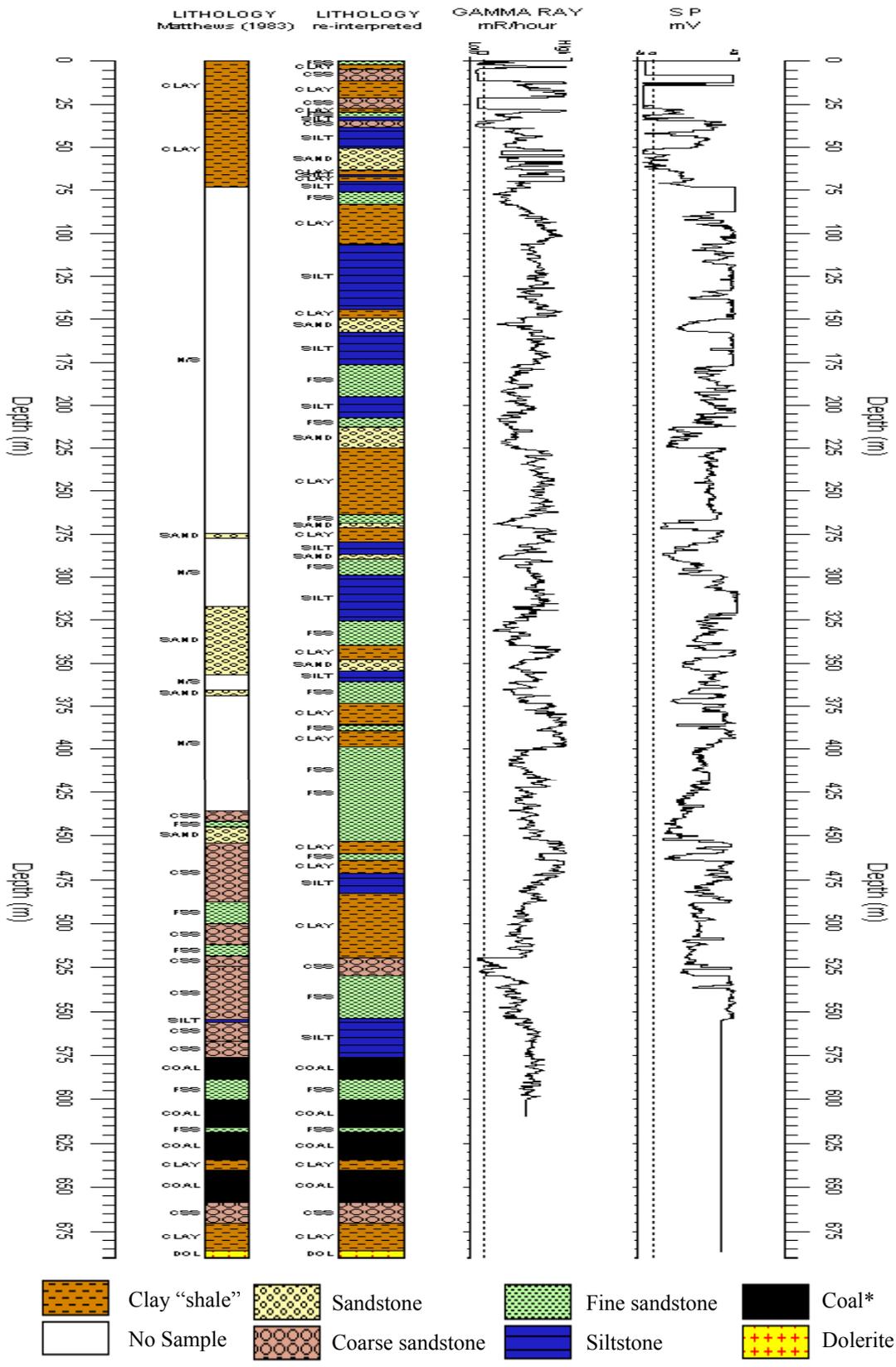
Figure 5.2: Lithological and geophysical logs of OP1. The second log is my reinterpretation based on the other three.

5.2.1 Results

The reinterpreted log was primarily based on the gamma-ray log readings, then revised based upon significant variations in self-potential. Inaccuracies are identifiable in figure 5.3 with high permeability (SP values <10mV) covering the entire range of gamma-ray values and therefore not always an indication of sand regions. Low permeability also has a wide variation in gamma-ray readings, but this may not be an inaccuracy rather an indication of non-radioactive pore filling cement, such as calcite or kaolinite (Moss 1993).

Cross Plot of Gamma Vs SP
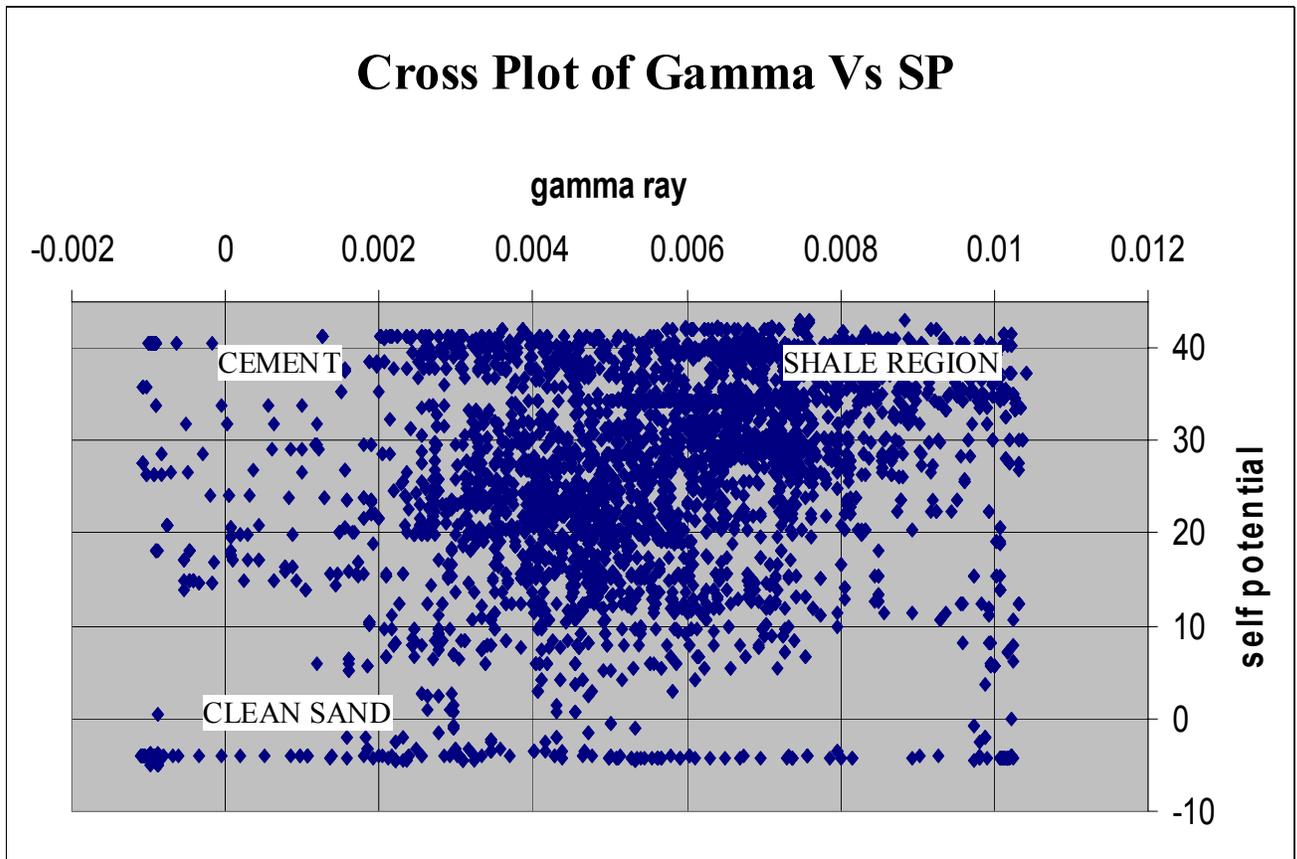
Figure 5.3: Cross plot of spontaneous potential data against natural gamma-ray data, tertiary sediments of well OP1. Low permeability (>30mV) shows a wide variation in gamma readings.

5.3 Sequence 6 and 7 (S6 & S7)

There are no geophysical logs to help interpret either of these sequences. OP2 reaches basement at 792 m, 6.5km northwest of the northern most seismic line. S6 has been interpreted as the stratigraphic section between 700 and 800m on the basis of projection. The lithology log for OP2 shows coal rich deposits at depth (Matthews 1983).

5.4 Sequence 5 (S5)

Geophysical logging of OP1 was not conducted to basement. S5 can not be identified on the basis of well log characteristics and is therefore characterized on its seismic reflection properties. Rock sample descriptions indicate an increase in coaly material and this unit has been broadly classed in an attempt to simplify my reinterpretation log (figure 5.3). The small interval of gamma-ray information for the upper proportion of S5 proves this broad classification to be a false representation of coal thickness. The gamma-ray response shows no dramatic decrease in reading, as one would expect when passing though a coal bed. Therefore the coal is likely to be finely bedded or interbedded with clastic material.

5.5 Sequence 4 (S4)

This 3rd order sequence can be separated into three 4th order members: S4.a, S4.b and S4.c based on well log identification (figure 5.4).
This sequence contains the greatest preserved thickness (Up to 240m) of all the Tertiary sediments.
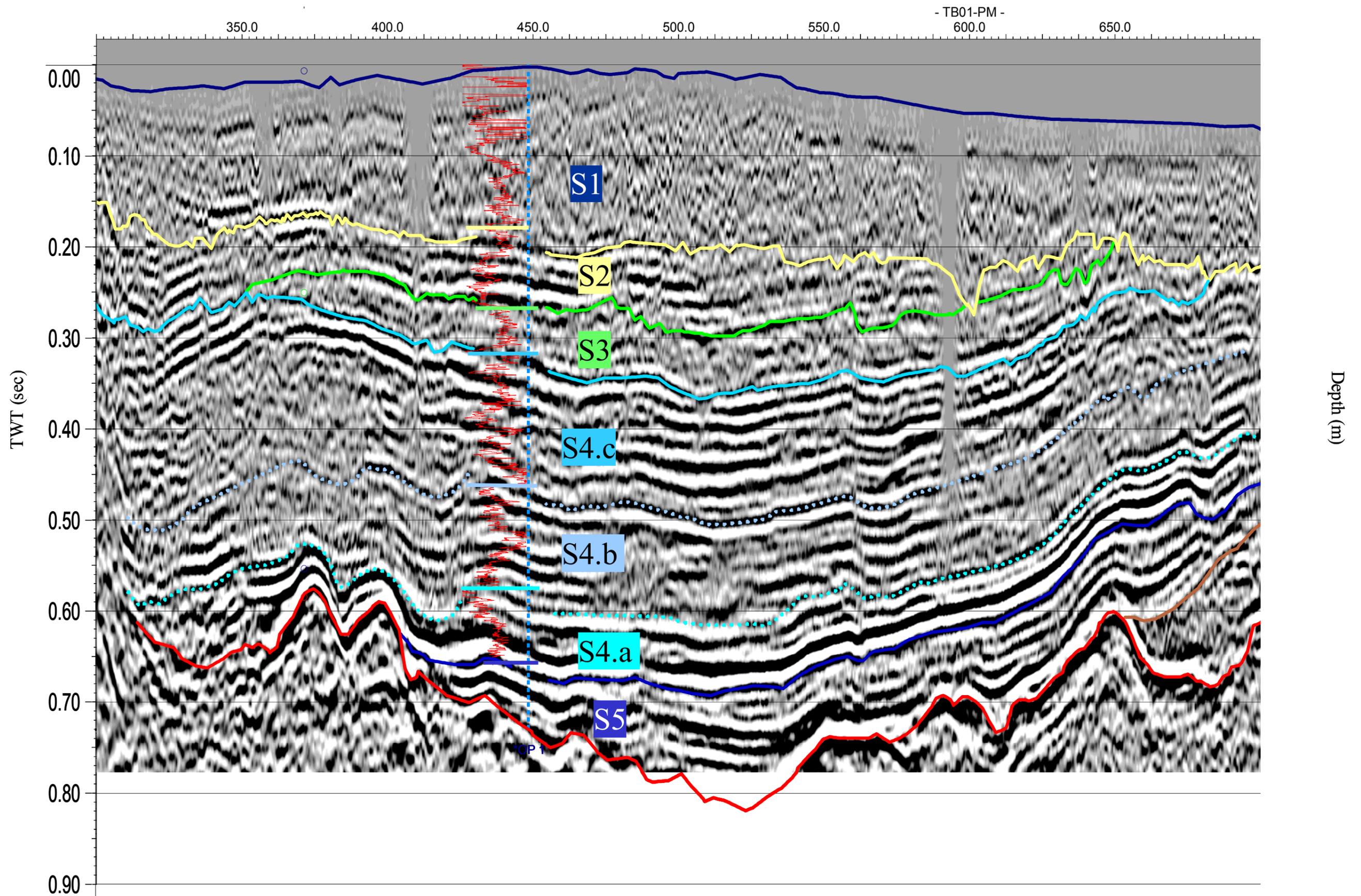
Figure 5.4: OP1 tied to seismic line TB01-PM. Sequence boundaries are identified from abrupt changes in the gamma-ray log. S4 has been separated into 'members' based on these sharp changes in gamma counts. There is an excellent correlation between the sequence boundaries and high amplitude seismic events.

5.5.1 Member S4.a

The lower boundary of the S4 or the S4.a member is represented by the disappearance of coal units in the sample description of OP1. Above the sequence boundary there is a coarsening upward log pattern reflecting the S4.a member. The log pattern indicates an upward increase in depositional energy.

5.5.2 Member S4.b

The lower boundary of S4.b is represented by a marked increase in gamma-ray values and SP shift (figure 5.5). Above the sequence boundary, gamma-ray values increase systematically then decrease in the same manner. The log characteristics of S4.b follow a bow trend. The sharp-based sequence represents a significant change in depositional environment.

5.5.3 Member S4.c

The sequence boundary S4.c is interpreted by a sharp increase in gamma-ray readings (figure 5.5). S4.c is represented by decreasing gamma ray values and shift in SP, corresponding to incoming sand in the lithology log. The overall log trend is very irregular. Spikiness of log motifs is due to rapidly alternating lithologies. This either reflects a multitude of discrete depositional events or a variable sediment supply (King; Scott & Robinson 1993).
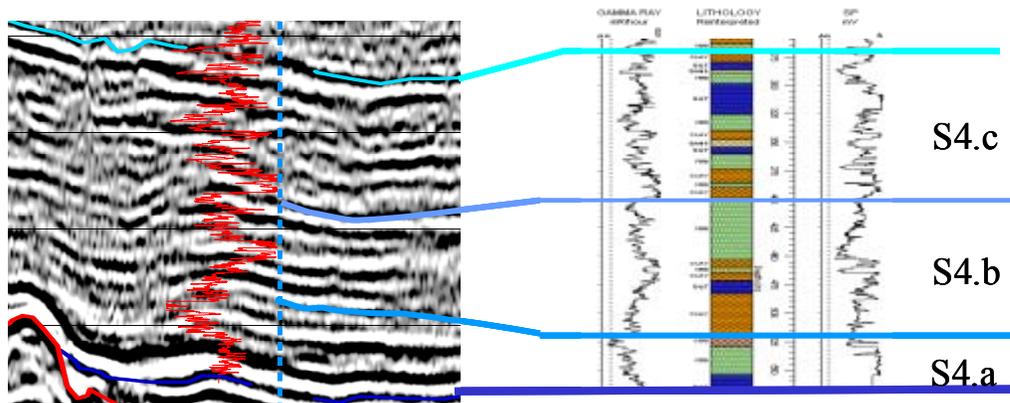
Figure 5.5: Major change in gamma-ray response. The changes correspond to the upper sequence boundary of S4 (top) and minor sequence boundaries of members within S4. The lower sequence boundary of S4 (bottom) is recognised from lithology descriptions. Refer to figure 5.2 for lithology legend.

5.6 Sequence 3 (S3)

The sequence boundary is picked at a sudden decrease in gamma-ray and SP values (figure 5.6). The S3 log trend clearly shows a blocky log pattern, with a discrete break from the underlying spiky log trend. The sharp boundaries with overlying and underlying sequences imply the existence of an abrupt change from a low gamma coarse-grained unit to a high gamma finer unit and back again.
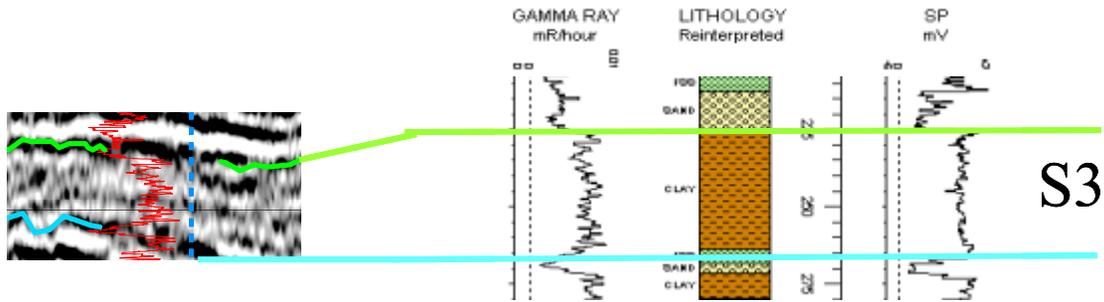
Figure 5.6: **Gamma-ray response for S3. The abrupt change to a homogeneous clay package quantifies the separation out of S4, S3 and S2 sequences. The fine grain nature of this package makes it an ideal seal.**

5.7 Sequence 2 (S2)

The base sequence boundary of S2 is represented by abrupt changes from high gamma-ray to lower gamma-ray values (figure 5.7). The log trend is boxcar with only minor gradations in texture. The top of the sequence contains a thin sand body with high permeability based on the gamma-ray and SP logs.
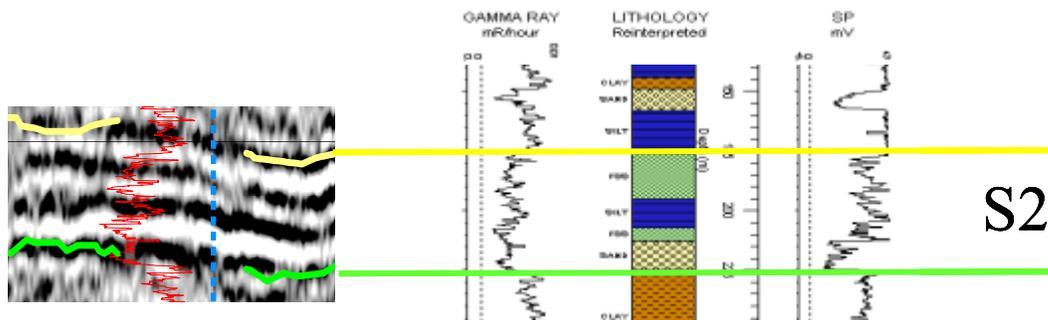
Figure 5.7: **Sequence boundaries of S2. The sand dominated package would be an excellent aquifer or reservoir rock, especially at the base where the sand is highly porous.**

5.8 Sequence 1 (S1)

Sequence boundary S1 is based on an abrupt decrease in gamma-ray and shift in SP values (figure 5.8). The basal part of this sequence is represented by three coarsening upward cycles. These cycles have not been classified as members on the basis of poor correlation to seismic reflectors and therefore well-log interpretations could not stand alone. Direen (1995) makes detailed interpretations of the S1 package stating difficulties in correlating lithofacies between drill holes. Above the cyclic packages the log character becomes irregular.
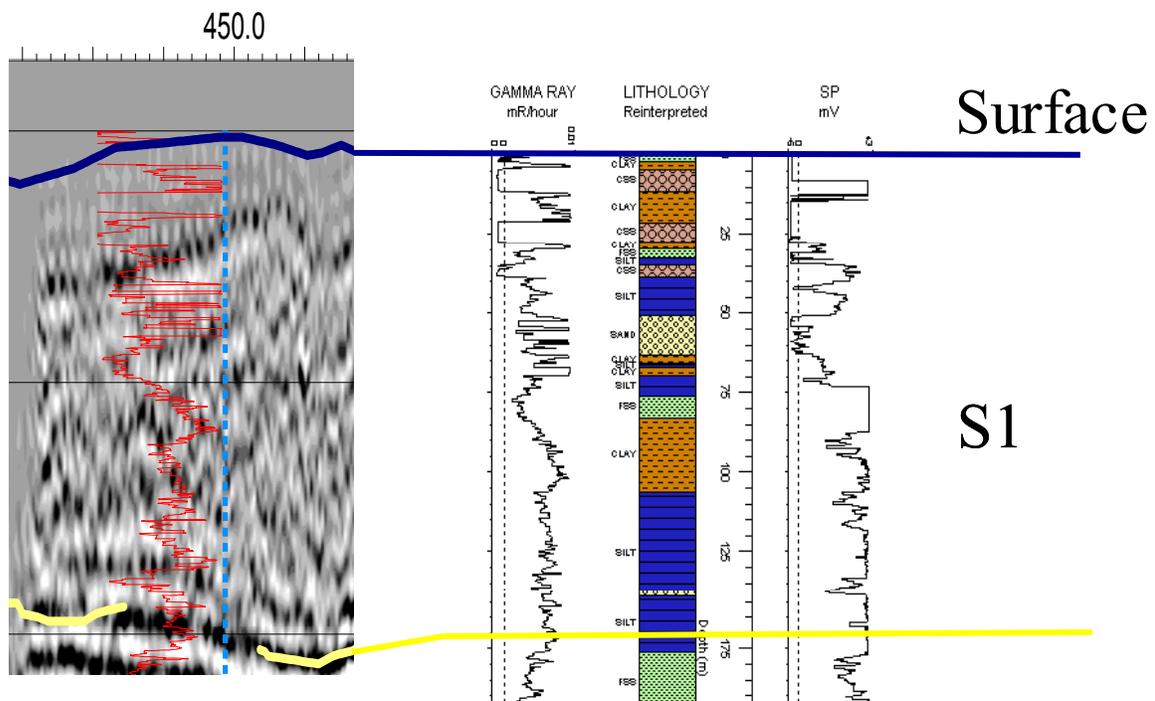

Figure 5.8:   **The lower sequence boundary of S1.**

5.9 Interpretation of Depositional Environments

The depositional environment of S7 can only be inferred based on seismic character. The package appears as a series of prograding reflectors on a marginal slope overlain by sub-parallel laterally continuous beds. The depositional environment is interpreted as channel or fan deposit.

Sample description indicates S6 and S5 are coal rich sequences. They both have very high amplitude and continuous sub-parallel reflectors, signaling a coal rich and low energy deposition respectively. Depositional environment of S6 and S5 is interpreted as lacustrine over remnant topography.

The S4.a member gamma-ray trend is a gradual coarsening up whereas the seismic sections show the highly continuous package to truncate underlying sequences. Both these patterns suggest a higher energy lacustrine environment due to a fall in base level. The S4.b member has similar seismic characteristics to the underlying S4.a and consists of both coarse and fine-grained deposits. The S4.b package resulted from waxing and waning of clastic sedimentation where sediments were unconstrained by base level (Bradshaw & Scott 1999). S4.c like the all members of S4 is dominantly lacustrine succession based on the laterally continuous reflectors and spiky log motif. The irregular gamma-ray log trend is interpreted to represent coal seams; the high amplitude reflectors support this. The overall trend appears to be a swallowing lake, becoming a depositional hiatus above S4.

The fine-grained S3 sequence has non-continuous low amplitude reflectors, not conforming to previous lake synthesis. S3 is interpreted as a crevasse splay deposit. S2 has similar characteristics to underlying S4, the depositional environment is interpreted to return to a lake, with low base level depositing sand into the system.

The upper S2 sequence boundary marks a regional depositional hiatus and end to dominant lacustrine environment.

The shallow depth of S1 makes determining the depositional environment extremely difficult from the seismic data (figure 5.8). A fluvio-lacustrine and extensive flood plain interpreted by Direen (1995) is agreed upon.