Lecture on Sunday 5-4-2020

High Resolution Sequence Stratigraphy

(Outcrop (core) and Well logging Data)

From the book of Sequence stratigraphy

(Emery and Mayer, 1996)

Outcrop OR/ Core

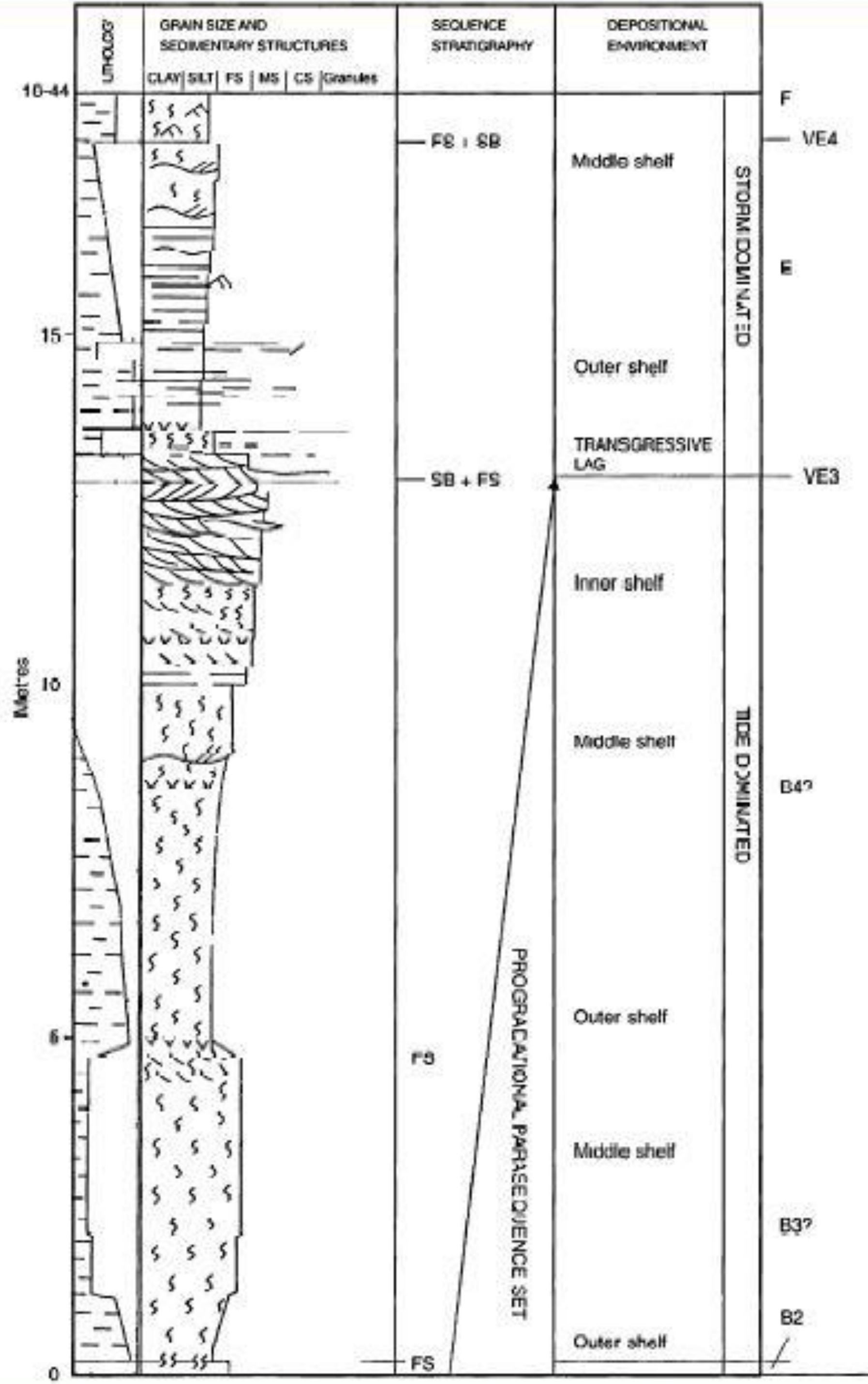
The most common is the coarsening-up signature (Fig. 4.1), widely recognized in parasequences from marine settings. Here, the shale content decreases upwards, but sand content and bed thickness may increase upwards. The marine flooding surfaces can be recognized by abrupt deepening, for example marine shales lying erosively on sandstones with rootlets. In addition, a number of non-diagnostic features characterize the outcrop and core expression of parasequence boundaries:

Positions of parasequence boundaries (FS)

1 marine carbonate, phosphate or glauconite may be present, suggesting low siliciclastic sedimentation rates;
2 lags, which may record the transgression of the shoreface, are common, but are generally thin (< 10 cm thick) and contain only sediment reworked from below;
3 where flooding surfaces pass into amalgamated marine sandstones they sometimes can be traced as zones of preferential marine sedimentation;
4 if outcrop exposure is good enough, or cores are spaced sufficiently closely, parasequence boundaries may be recognized as essentially flat, with only a few centimetres (but rarely up to a metre or two) of sediment eroded at the boundary.

4.3.2 Parasequence stacking patterns and systems tracts

The stacking patterns (or 'architecture') of parasequences are discussed in section 2.5.3. The three patterns observed are progradational, in which the facies at the top of each parasequence becomes progressively more proximal, aggradational, in which the facies at the top of each parasequence is essentially the same, and retrogradational, where the facies become progressively more distal. These stacking patterns can be recognized both in outcrop and in core, and the position of the parasequences with respect to a major stratigraphic surface can help to constrain the systems tract represented by the parasequence architecture.



LITHOLOGY
GRAIN SIZE AND SEDIMENTARY STRUCTURES
CLAY SILT FS MS CS Granules
SEQUENCE STRATIGRAPHY
DEPOSITIONAL ENVIRONMENT
Metres
0
5
10
15
FS + SB
SB + FS
FS
FS
PROGRADATIONAL PARASEQUENCE SET
Middle shelf
Outer shelf
TRANSGRESSIVE LAG
Inner shelf
Middle shelf
Outer shelf
Middle shelf
Outer shelf
STORM DOMINATED
TIDE DOMINATED
F
VE4
E
VE3
B4?
B3?
B2

4.3.3 Key stratigraphic surfaces in outcrops and cores

As described above, parasequence architecture can help to indicate the status of a stratigraphic surface. However, it may be difficult to distinguish a flooding surface separating parasequences from a more significant flooding surface in the absence of continuous core coverage in the subsurface, or from limited exposure. In the absence of interpretable wireline-log evidence or a regional geological context, such surfaces should not be overinterpreted beyond naming them flooding surfaces. Such caveats also apply to sequence boundaries, where lack of exposure or core coverage can give rise to the overinterpretation of boundaries. Sharp-based channel sandstones cutting into flood-plain deposits may simply represent a river meandering across its flood-plain, a normal sedimentary process, rather than abrupt fluvial incision caused by sea-level fall. In cases where a sequence boundary is suspected but not proven, it can be referred to as a candidate sequence boundary.

The recognition of a sequence boundary from outcrop or core requires the recognition of a facies dislocation; the superposition of a relatively proximal on a significantly more distal facies without the preservation of the intermediate facies (Fig. 4.4). This is not likely to be obvious in all locations; in the core example described above, the sequence boundary was represented by a lag deposit that could be correlated regionally into an incised-valley fill. However, if an incised-valley fill is cored or exposed, the rapid jump from fully marine to fluvial or estuarine valley-

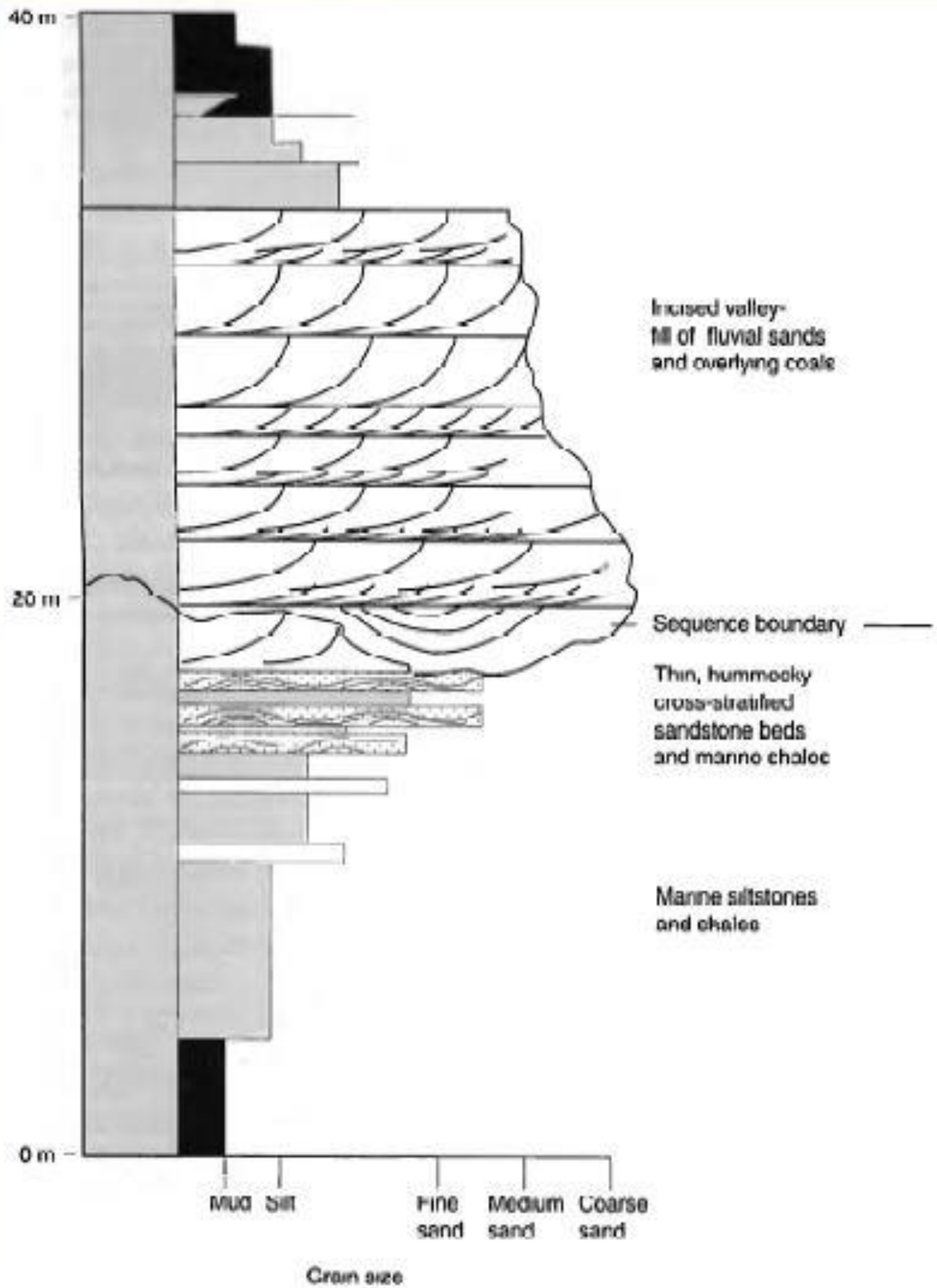


Fig. 4.4 Schematic log of a sequence boundary showing a major facies dislocation between marine and fluvial sediments

Sequence stratigraphy from Wireline ligs

Sequence stratigraphic analysis of wireline log data is neither easy nor unambiguous. Some systems tract boundaries may have a subtle expression on logs, and may even be hard to recognize in core (section 4.3). Correlation between individual wells is often ambiguous. Where wells are closely spaced and core control is good, for example in a data set of production wells from an oil or gas field, the data coverage may be sufficient to resolve the sequence stratigraphy. However, a more sparse well-data-set may not allow a single stratigraphic model to be derived.

Gamma-ray logs

The gamma log is one of the most useful logs for sequence stratigraphic analysis, and is run in most wells. The radio-activity of the rock, measured by the gamma tool, is generally a direct function of the clay-mineral content, and thus grain size and depositional energy. Gamma-ray logs are often used to infer changes in depositional energy, with (for example) increasing radioactivity reflecting increasing clay content with decreasing depositional energy. Although this usually is the case, there are exceptions where this rule breaks down.

Uranium in organic-rich anoxic shales, or precipitated post-depositionally in sandstone aquifers, may give anomalously high gamma readings. The radioactivity from feldspar in arkosic sandstones may give a high gamma reading, as may concentrations of heavy minerals in lags, particularly monazite and thorite. Some of these effects can be distinguished by using a spectral gamma log.

Most of the variations on the gamma log shown on Fig. 4.6 are related to depositional parameters, and to the sand : shale ratio. Exceptions are the cemented zones and coals, which have low gamma readings without being necessarily more sand rich.

Sonic

Sonic logs measure the sonic transit time through the formation. Transit time is related to porosity and lithology. Shales will have a higher transit time (lower velocity) than sandstones of a similar porosity, which sometimes allows the sonic log to be used as a grain size indicator. High concentrations of organic matter in coals and black shales will result in very long travel times, and these 'troughs' on the sonic log are often indicators of organic-rich condensed sections. The log is also affected by post-depositional cementation and compaction, and by the presence of fractures. The sonic log in Fig. 4.6 does not differentiate very well between sandstones and mudstones, but clearly indicates the cemented zones and coals.

SP log

SP (spontaneous potential) logs measure the difference in electrical potential between the formation and the surface. They are sensitive to changes in permeability, and are good at distinguishing trends between permeable sands and impermeable shales. The SP log works best where there is a good resistivity contrast between the mud filtrate and the formation water. Opposite impermeable shales the SP curve usually shows a more-or-less straight line on the log, known as the shale base line, and any differentiation within the shales is best done on the gamma or resistivity logs. Spontaneous potential is affected by hydrocarbons, cementation and changes in formation water salinity. The SP log in Fig. 4.6 differentiates between the sandstone–mudstone interbeds in the lower part of the section, but is of little use for determining trends in the upper mudstone.

Density–neutron suite

The density–neutron suite (the Schlumberger FDC–CNL suite, and other similar curves) is the best indicator of lithology and thus can be used to link lithology and depositional trends. It is one of the best log suites for sequence stratigraphic analysis, but is not as commonly run as a gamma tool. The density (FDC) log measures the electron density of the formation via the backscatter of gamma rays, which is related to the true bulk density. The neutron log (CNL) attempts a measurement of formation porosity by using the interaction between neutrons emitted from the tool and hydrogen within the formation.

The logs are scaled to approximately overlie in clean carbonate lithologies. In clean sandstones there will be a small separation (larger if the sand is feldspathic). An increase in shale content will result in an increasing neutron reading (from hydrogen in bound water within the clays) with no apparent change in density. The resulting cross-over and separation between the curves can be a sensitive and useful grain-size indicator. In addition, coals are easily identified on the density–neutron suite. The density log is affected by caved hole (oversized borehole due to erosion or collapse of the walls), and by heavy minerals such as pyrite and siderite. The presence of gas increases the neutron response, owing to the high proportion of hydrogen atoms within methane.

The density–neutron suite in Fig. 4.6 is as good as the gamma log for determining depositional trends, with the added bonus that the coals and cemented zones are differentiated clearly. The density log in particular is a good indicator in this well of small scale upward cleaning cycles (e.g. in the water-bearing sandstone).

Resistivity suite

Resistivity logs measure the bulk resistivity of the rock, which is a function of porosity and pore fluid. A highly porous rock with a conductive (saline) pore fluid will have a low resistivity, whereas a non-porous rock, or a hydrocarbon-bearing formation, will have a high resistivity. Resistivity trends may be excellent indicators of lithology trends, *provided the fluid content is constant* (i.e. in the oil leg or in the water leg). Resistivity logs often are excellent for correlating within shale successions, or within clean sandstones with uniform gamma response. Different resistivity logs give different scales of bed resolution, and the raw resistivity traces from dip-meter logs, measured every 2.5 or 5 mm, provide geological information on a bed-scale. In Fig. 4.6, the effect of the oil leg in the upward-cleaning sandstone masks any depositional trends.

Thanks