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CLIMATE STRATIGRAPHY – A NEW APPROACH IN NEAR-SYNCHRONOUS SUBSURFACE CORRELATION

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As oil and gas E&P is moving towards more mature phases, innovative new approaches are needed in petroleum geology. To find additional reserves in mature exploration areas and to improve production in existing fields, a better understanding of the spatial distribution and time-stratigraphic framework of the potential reservoirs and seals is needed. To meet these challenges, existing conventional stratigraphic methods have been improved and new stratigraphic concepts have been developed during the last decade. Amongst one of the most important concepts which have been proposed by the Exxon school a decade ago was sequence stratigraphy. Nowadays, sequence stratigraphy is widely applied in subsurface correlations and is becoming a routine practice. Sequence stratigraphy can best be seen as the delineation and correlation of changes in depositional trends that are generated during a base level cycle (see Embry, 2002). Despite the constant modification and improvement of the sequence stratigraphic concept, it did not reach an important objective – the construction of a near- synchronous stratigraphic correlation framework. One of the main reasons is the strongly model-driven approach of sequence stratigraphy which is preventing to construct an objective and reproducible correlation framework.

To resolve this, Climate Stratigraphy and a specially-designed tool have been developed recently and some of its principles and application to the subsurface is presented here. Briefly, the approach comprises two key elements:

1. The Global Cyclostratigraphy model of Perlmutter et al (1990, 1998) – i.e. the theory that climate change is a fundamental control on lithofacies succession – is then applied to the interpretation of this otherwise unexploited information.
2. A facies-sensitive log – normally the GR – is transformed to a spectral trend (or INPEFA™) curve, which shows uphole changes in the waveform properties of the data. The software used for this is CycloLog®, developed by ENRES.

Climate Stratigraphy is basically the science of climate change through geological time and it takes Global Cyclostratigraphy as developed by Perlmutter et al (1990, 1998) as its basic principle. The Global Cyclostratigraphy model was developed as a tool for the prediction of vertical lithofacies succession. The model accepts the control of global climate by changes in the Earth's orbital parameters, through their influence on insolation: this is the Milankovitch model of orbitally-forced climate change. Because climate change is an influence over stratigraphy that is external to the basin, we predict that the pattern of vertical lithofacies change (including any hiatuses and erosion surfaces) will be similar, at least within any latitude-related climatic belt. The vertical stratigraphic succession in a basin is strongly related to climatic change (albeit in the form of a filtered and incomplete record); see Figure 1.

Global Cyclostratigraphy is mainly dealing with basin fill patterns, while Climate Stratigraphy deals with reservoir-scale subsurface correlations. The climate record or more specifically the climate change record is stored in the sedimentary rock record, which again are the "building stones" of the stratigraphic record. This vertical succession is exactly what is sampled by wireline logs. Therefore, an analytical tool that looks at the pattern of vertical lithofacies change (and is also sensitive to breaks in the succession) can potentially reveal the pattern imposed on the depositional system by the succession of climate change. The INPEFA™ curve, with its emphasis on changes in the frequency content, is just such a tool (Nio et al, 2005).

In summary, the method of Climate Stratigraphy allows the development of a framework of near-synchronous well-to-well correlations by identification of (time-)equivalent, primarily climate-controlled, vertical lithofacies changes and trends in wireline log data.

Given our emphasis on climate as the key driver of stratigraphic succession, it might be assumed that we ignore the effects of tectonics. Tectonic processes are, however, not discounted in our approach. The effects of climate change on the lithofacies succession (and hence on wireline logs) are in the order of 10,000s to 100,000s years. The processes of basin subsidence act on a longer time-scale than insolation-driven climatic changes. In terms of their effect on stratigraphy, climate-driven patterns can be considered as superimposed on tectonically controlled patterns that are of longer duration. For instance, an overall increase in sediment-calibre in a given area (as the area becomes more sand-rich) may well be the result of increased tectonic activity, but the shorter term vertical lithofacies variations (as expressed in the changes and patterns of the INPEFA™ curves) are primarily controlled by climatic variations; see Figure 1. In our experience, any effect caused by shorter-term tectonic processes (such as fault movements) do not impact on our ability to interpret and correlate the INPEFA™ patterns.

Although the analysis and correlation of the spectral trend curves of GR logs (INPEFA™_GR curves) is largely a matter of experience, some general principles can be stated. A brief outline will be given here. More detail is available elsewhere (De Jong et al, 2006; Nio et al, 2006).

It is important to realize that the waveform properties can only be analyzed for sections that have been preserved. The INPEFA curves of GR will be identical for different wells only if and when the preserved sections are identical. Practically speaking, this does not occur. The interpretation of INPEFA curves, therefore, focuses on identifying equivalent breaks and trends rather than on finding identical patterns.

Intervals of positive (left-to-right) and negative (right-to-left) trend in the INPEFA™ curve are separated by turning-points

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(Figure 2). A positive turning-point is a point at which the trend (in an upward direction) changes from negative to positive (clockwise). A negative turning-point is a point at which the trend (in an upward direction) changes from positive to negative (anti-clockwise). After identification, the turning-points and intervening trends are, firstly, calibrated in lithological terms and, secondly, interpreted in stratigraphic terms. Turning-points that (a) signify changes in depositional trends (Embry, 2002) and (b) are correlatable between wells, are called bounding surfaces. Negative turning-points thus become negative bounding surfaces (NBS), positive turning-points become positive bounding surfaces (PBS). These are our (time-)equivalent, primarily climate-controlled, vertical lithofacies changes. Usually, an NBS marks the base of a trend with a progradational or related component, whereas a PBS represents the beginning of a period of retrogradation or related process.

A hierarchy of change is commonly observable in the INPEFA™_GR curve, indicating a hierarchy of vertical lithofacies trends and changes. StratPacs (stratigraphic packages) are bounded by adjacent negative bounding surfaces of the same hierarchical rank. StratPacs represent systematic changes in (litho)-facies controlled by climatic variations. They are stratigraphically time-synchronous. The lithofacies units within a package are genetically linked: usually, a progradational or related trend is overlain by a retrogradational or related trend.

An example of a time-synchronous correlation is shown in Figure 3.

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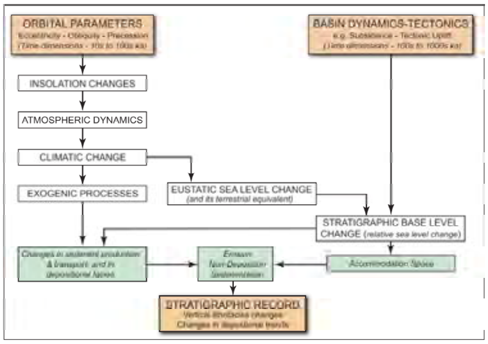

Figure 1: Connection between the orbital parameters and their record in strata.

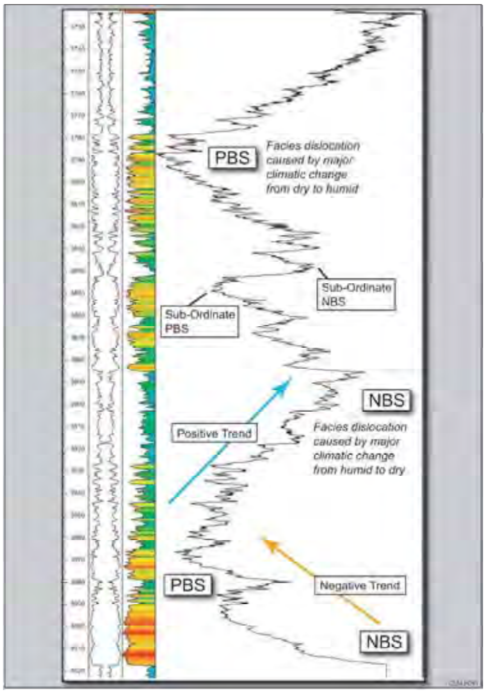

Figure 2: Nomenclature of the INPEFA™ trends and bounding surfaces

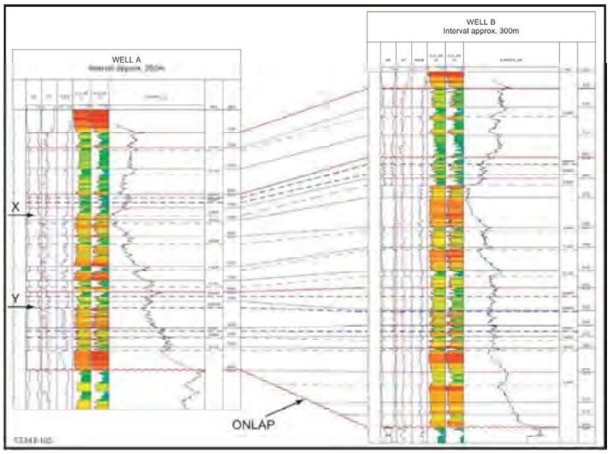

Figure 3: Time-synchronous stratigraphic correlation of two wells within a continental basin setting.