Subsurface Correlation of the Triassic of the UK Southern Central Graben: New Look at an Old Problem

ENRES Technical Paper Series

Published in
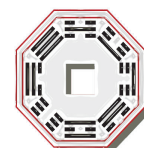*First Break*

Special Topic
Multi-Disciplinary Issue

Volume 24 - June 2006

solutions in petroleum geoscience

Subsurface correlation of the Triassic of the UK southern Central Graben: new look at an old problem

Mat De Jong,[1] David Smith,[2] S. Djin Nio,[1] and Nick Hardy[3] discuss climate change as a primary driver of vertical lithofacies change allowing a time-significant stratigraphic classification to be derived from a standard facies-sensitive wireline log such as the GR.

Knowledge of Triassic stratigraphy in the Central Graben is impeded by lack of regional seismic markers, poor recovery of microfossils, and regional structural complexity. Of the various sources of data available (seismic, logs, cuttings, core/sidewall core), the most reliable and continuous must surely be the wireline log. With the exception of occasional short intervals of bad data, logs are more or less universally available for all North Sea wells, providing an unparalleled source of objective and closely spaced samples of various physical quantities. An ideal stratigraphic method would extract time-significant information from the logs, allowing correlation at a resolution approaching that of the logs themselves.

We here describe the experimental application of just such an approach to 16 wells in the southern part of the UK Central Graben, quads 22 and 30 (Figure 1). Our method relies on (a) a new method of extracting trends in spectral (wavelength, frequency and phase) content of a wireline log, and (b) the interpretation of this information in terms of orbital-forcing of climate change in the 10^4 to 10^5 year waveband.

We first outline the regional background to the need for a unifying scheme for Triassic correlation that is readily applicable to all significant Triassic well-penetrations in the area. We next describe the key principles underlying the method. Finally, we describe the stratigraphic scheme that emerges from this initial study, and we discuss its implications.

Regional background

The Triassic of the UK Central Graben forms part of the regional high-temperature/high-pressure play, and our study area includes some of the fields developed under the Eastern Trough Area Project (ETAP – Pooler and Amory, 1999; McKie and Audretsch, 2005). While much of the succession is fine-grained, reservoir sand facies are developed in the mid to late Triassic, collectively referred to as the Skagerrak

Formation. These sands host economic reserves of oil, gas and condensate, and understanding their stratigraphy in detail is crucial to their development as well as to further exploration in this play.
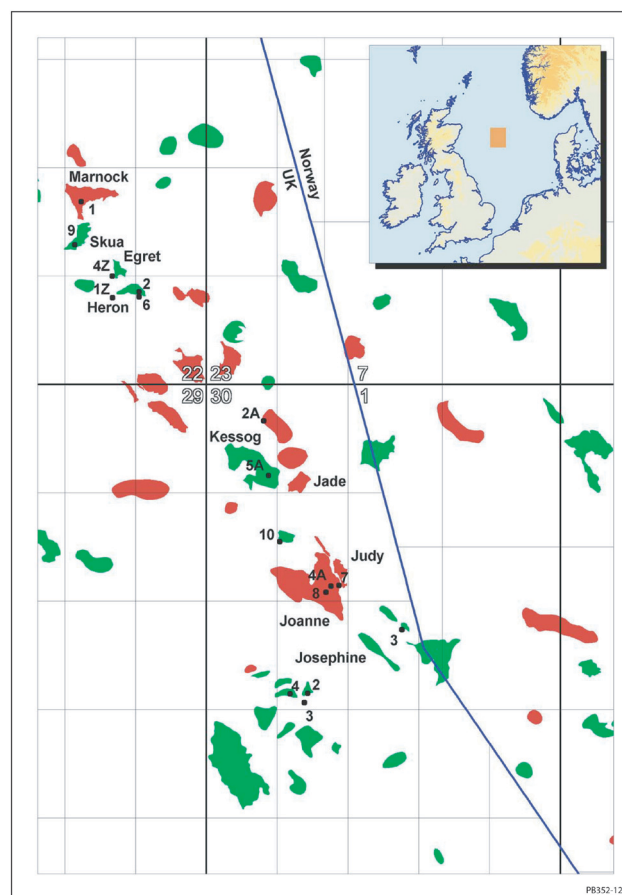
Figure 1 *Location map showing the 16 wells of this study. Oil fields are shown in green and gas fields in red. Wells are numbered by their drilling sequence number within each block (e.g., the well shown in the Marnock field is 22/24a-1).*

[1] *ENRES International, Ruysdaellaan 3, 3712 AP Huis ter Heide, The Netherlands.*
[2] *ENRES UK, 15 Stratton Terrace, Truro, Cornwall, TR1 3EW, UK.*
[3] *IHS Energy, Tetbury, Gloucestershire GL8 8RX, UK (Merlin Energy, Ledbury, Herefordshire, HR8 2EK, UK).*

Multi-disciplinary issue

A complicating factor specific to this area is the compartmentalization of the Triassic strata by a network of faults, many of which clearly involve salt movement. The mechanism and timing of these movements is variously considered to be syn-depositional or post-depositional with respect to the Triassic. Stewart and Clark (1999), for example, supported the syn-depositional model, with its direct consequences for depositional topography in the Triassic. Penge et al. (1999) have instead proposed a 'rift-raft' model, which involves post-depositional deformation and compartmentalization of the Triassic. Although the salt walls pose considerable problems for correlations based on seismic data, this debate is less crucial to our results, as we invoke an external driving force as the main control on vertical lithofacies variations.

Previous stratigraphic schemes and methods

Lithostratigraphically, the Triassic of the study area comprises the sand-prone Skagerrak Formation and the underlying (mainly fine-grained, biostratigraphically barren) Smith Bank Formation. The two formations are probably laterally equivalent in places, though the general absence of fossils made this very difficult to prove.

Improved recovery of palynomorphs in the southern part of the Central Graben (UK quads 29 and 30) allowed better dating of part of the succession by Goldsmith et al. (1995). The Lower Triassic remained undated, but good Middle Triassic and some Late Triassic assemblages were found in a few wells. Despite this improved means of correlating between wells, the new lithostratigraphic units proposed by Goldsmith et al. depended primarily on log correlation; the biostratigraphic data were used to confirm the log picks. They proposed a subdivision of the Skagerrak Formation into six members, alternately sand- and shale-dominated. Importantly, this implied laterally extensive deposition of shales around the Anisian-Ladinian boundary, and again

in the late Carnian: these events were interpreted as being eustatically driven. A significant problem with these units is the difficulty of tracing them to the north, to the Marnock area and beyond: this is addressed in part by the methods used in this paper.

Goldsmith et al. (2002) proposed a tentative sequence stratigraphic scheme for the Triassic of the Central North Sea, based on conventional log interpretation backed up by very limited palynostratigraphic data where available. Relying on wireline log character and lithostratigraphic methods of correlation was acknowledged to be problematical. An attempt was made to correlate interpreted flooding events with those recognized in the better understood successions offshore mid-Norway and the Barents Sea, but such long-distance correlations, largely unsupported by sound evidence of age, must be regarded as highly speculative. We are not convinced that it is possible to attempt a sequence stratigraphic breakdown from the kinds of information available, and the descriptions of Goldsmith et al.'s sequences Tr00 to Tr50, together with their facies distribution maps based on this classification, must be read with these limitations in mind.

Principles of climate-stratigraphy

Our approach to stratigraphic correlation depends on the importance of orbitally-forced climate change as a major control on vertical lithofacies succession. Climate is a major influence on every stage in the cycle of weathering, erosion, transport, and deposition of sediments. Orbitally-driven (Milankovitch) climate change takes place at timescales that are long enough (10^4 - 10^5 years) to ensure that successive climatic phases are likely to be represented in the long-term record. This part of the stratigraphic time-spectrum - long enough to stand a fair chance of representation in the 'final' record – is short enough to be of direct economic relevance in terms of reservoir stratigraphy, being typically represented at a vertical scale of metres to tens of metres. We envisage that the stratigraphic record comprises short intervals of net sediment accumulation - sediment that is 'permanently' added to the record - separated by hiatuses of widely ranging duration. Each interval of net sediment accumulation is typical of the environmental – and hence climatic – conditions prevailing at its time of deposition. Further, it will preserve a record, however distorted, of any climate change that took place during the time interval that it represents.

Orbitally-forced climatic change is driven by changes in insolation, the flux of solar energy at the Earth's surface and its distribution with latitude and through the seasons. Translation of variable insolation into climate is complex, involving the linked circulation systems of the atmosphere and ocean, mediated by the changing distribution of land and sea. However, Perlmutter and Matthews (1990) were

Stage	Sequence	Lithostratigraphic Units	
Rhaetian	Tr 50	Joshua Mudstone Member	
Norian	Tr 40	Josephine Sandstone Member	
		Jonathan Mudstone Member	
Carnian	Tr 30	Joanne Sandstone Member	Skagerrak Formation
Ladinian	Tr 20		
Anisian	Tr 10	Julius Mudstone Member	
		Judy Sandstone Member	
Scythian	Tr 00	Smith Bank Formation	

PB352-127

Table 1 *Lithostratigraphic and sequence stratigraphic schemes of Goldsmith et al. (1995 and 2002).*

able to derive some general principles, with predictive value, about the nature of climate change at Milankovitch timescales. From present-day climatic patterns, they recognized 11 roughly latitude-parallel belts from the Equator to each of the poles, each with a distinctive succession of climatic phases through a typical insolation cycle. By analogy, a location at latitudes typical of the southern Central Graben in the Triassic (25-35ºN) would have experienced temperature changes from tropical to temperate, and humidity that varied from arid to sub-humid. Furthermore, the succession of climatic phases may well have changed as the study area drifted north, from about 25ºN at the beginning of the Triassic to about 35ºN at the end of the period.
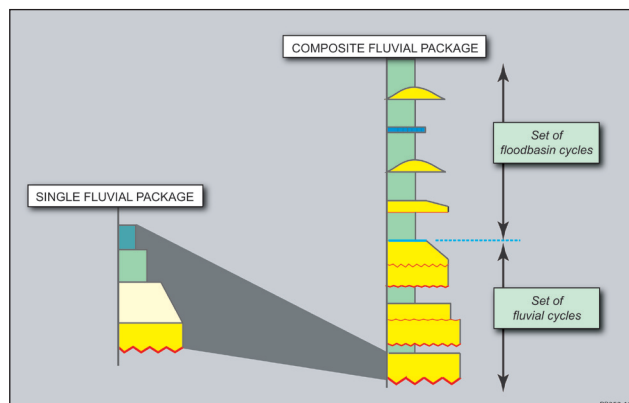
Climate change will have a significant influence on accommodation in a continental basin/terrestrial setting, through secular variations in base-level, brought about by changes in humidity and hence precipitation. The arid to sub-humid climatic succession predicted for the Central Graben in the Triassic is thought to have had a significant effect on accommodation as base-levels rise and fall. Similarly, climate change will affect the type of discharge and drainage systems (e.g., high-sinuousity versus low-sinuousity). The combined effect of these and other parameters controls the nature of the deposits formed. In a fluvial-alluvial depositional environment, low base-level at a humidity minimum is likely to be represented by non-deposition or even erosion, while high base-levels at a humidity maximum may be represented by floodbasin or lacustrine deposition if groundwater levels rise sufficiently high. A simple model of the changes predicted is presented in Table 2.

Thus, in a simple cycle from low humidity to high humidity and back again, we can predict a sedimentary package with (1) a non-depositional or even erosional base, (2) a lower part characterized by sand-prone, channelized fluvial deposits, (3) a flooding event where baselevel rise reaches some critical level, then (4) an interval of shale-prone deposits representing a floodbasin or lake.

In response to the composite nature of the input insolation function, the above succession will be repeated at several overlapping scales. The longer-term main or 'master' climatic cycles will have shorter-term sub-ordinate 'slave' cycles superimposed on them; the sub-ordinate cycles will be similar in character, but their exact expression will

Figure 2 *Predicted fluvial-alluvial succession resulting from a compound humidity cycle.*

depend on their position on the main cycle. Figure 2 suggests how slave cycles, each with a sand-prone lower part and a shale-prone upper part, can be predicted to stack up within a longer-term main cycle. Note how both main and sub-ordinate are predicted to have (a) a sharp, possibly erosional base, and (b) a distinct 'flooding' surface. Such a model can become more complex if aeolian activity occurs at a climatic minimum and evaporitic deposits are formed during wet stages (Yang and Nio, 1993).

Extracting and exploiting the climate-change signal

The model succession explored above will not apply equally to all parts of the basin: the actual *succession* will vary according to local conditions of sediment supply and other factors. The succession of climatic changes will, however, be the same for all areas within the same climatic belt. Because climatic change is ultimately driven by the compound waveform of the insolation function, it is the waveform properties (wavelength, amplitude, phase) of the stratigraphic response that we seek to use. Wireline logs happen to have an ideal combination of properties for this approach, particularly those that respond primarily to depositional facies, such as the natural gamma-ray (GR) log:

(1) They 'represent' the geology as a series of measurements of a completely objective physical quantity - no observer-bias is possible as it is at outcrop or with core or cuttings data.

(2) They conform to the requirements of 'time-series' analysis in being equally spaced with respect to the measurement axis (which in this case is downhole depth).

These properties open wireline log data to the methods of spectral analysis (Nio et al., 2006). Spectral analytical methods such as the Fast Fourier Transform seek to represent a composite wave as the sum of a number of simple (sine, cosine) waves. Given that we expect significant dis-

	Humidity	Baselevel	Fluvial Response
1	Minimum	Low	Non-deposition / erosion / no permanent record
2	Increasing	Rising	Channelized fluvial deposits (sand-prone)
3	Increasing	Near ground level	"Flooding"
4	Maximum	High	Unconfined floodplain or lacustrine deposits (shale-prone)
	Decreasing	Falling	Temporary deposition / removed by erosion

Table 2 *Response of the fluvial-alluvial system to cyclic change in humidity, as predicted for the study area in the Triassic.*

continuity in stratigraphy, the power spectrum of the log of a large stratigraphic interval is unlikely to be useful. What is more interesting is to look for the *changes* in the spectral composition of the data, because it is change that is predicted by the climate-stratigraphic model. We have developed (1) a method that transforms a typical log such as the GR into a curve of spectral change, and (2) a set of principles for interpreting these curves to generate a stratigraphic analysis of the succession.

Many studies have shown that the changes revealed by waveform analysis of wireline logs are always:

- Meaningful in terms of vertical lithofacies variation (i.e. they are linked to distinct changes in the shape of the wireline logs)
- Typically on a time-scale of 10^4 to 10^5 year (i.e. they are in the Milankovitch waveband)

They are hence understood to be controlled primarily by climate, which is external to the depositional system. Parallel changes revealed in different wells in the same region are, therefore, predicted to represent near-synchronous events and intervals. Because the underlying climatic changes are functioning at timescales of 10^4 to 10^5 years, the resulting stratigraphic breakdown has the potential to resolve correspondingly fine intervals of the stratigraphic succession.

The derivation of the spectral trend attribute curve is described in more detail elsewhere (see Nio et al., 2005 and 2006). Rather than the Fast Fourier approach, it uses spectral estimation as in Maximum Entropy Spectral Analysis (MESA). A prediction error filter is used to characterize the log data. Then the error is scored between the predicted and actual values of the log in each of a series of short (~10m) overlapping windows of the data. The prediction errors are then integrated over the analyzed interval, yielding a curve that represents trends in the spectral properties of the data. We call this curve the spectral trend attribute curve, or INPEFA (for Integrated Prediction Error Filter Analysis). Figure 3 ('Long term INPEFA') shows the spectral trend curve computed for the Triassic in 30/13-3.

Typically, a spectral trend curve reproduces the short-wavelengths variations of the original GR curve, but these are now superimposed on longer and shorter trends in the data: these trends are best shown by plotting the INPEFA transform in a wider track than normal (Figure 3). The trends can be objectively interpreted in mathematical terms as intervals over which the actual GR value is either persistently over-estimated or persistently under-estimated. The geological and climate-stratigraphic interpretation of the trends is more dependent on context; the summary in Table 3 is for the fluvial-alluvial setting of the Triassic in the study area, and might be expressed differently for different depositional environments.

Note the particular importance in well correlation of the turning-points, where the trend of the INPEFA curve is reversed:

- The base of a positive trend represents a change from sand-prone deposition to a relatively sand-starved setting, and may, in appropriate settings, be interpreted as a flooding surface. If identifiable in other wells, such a trend change can be regarded as a marking a correlatable surface, which we call a Positive Bounding Surface (PBS).
- The base of a negative trend represents a more or less abrupt input of sand, possibly (if particularly sharp, suggesting a major discontinuity) resting on an erosion surface. If identifiable in other wells, such a trend change is recognized as a Negative Bounding Surface (NBS).

Correlatable trend changes can be used to define the limits of stratigraphic packages. Note that the trend of the INPEFA curves of equivalent stratigraphic packages may vary between wells, due to lateral facies variations. Having identified the main correlatable turning-points of the INPEFA curve, we can refine the resulting classification by re-running the INPEFA calculation for shorter intervals of the data, and specifically for the intervals between the first-order turning-points. An example of a well subdivided in this way is shown in Figure 3. The INPEFA function has first been calculated for the entire Triassic interval and, through iterative correlation with the other wells in the study, a first-order classification has been made (black INPEFA curve).

Re-running INPEFA for each of the resulting packages (coloured INPEFA curves) helps to confirm the first-order breakdown by enhancing the features of each package, and it can also be used to suggest higher-order subdivisions because of the typically enhanced amplitude of the short-term INPEFA curve compared with the long-term INPEFA curve. In the example of well 30/13-3 an important NBS occurs at a depth of about 4740 m. The equivalent surfaces in other wells are of secondary importance only: as a consequence, the event in 30/13-3 has become a secondary bounding surface.

INPEFA Feature		Mathematical Interpretation	Geological Interpretation
Positive Trend	/	Persistent under-estimation of log properties (e.g. values)	Shale-prone or "transgressive" trend
Positive Turning-Point	<		Baselevel rise - "flooding" surface
Negative Trend	\	Persistent over-estimation of log properties (e.g. values)	Sand-prone or "regressive" trend
Negative Turning-Point	>		Low baselevel - possible erosion surface - new influx of coarser clastic
			P8352-131

Table 3 *Interpretation of INPEFA trends and turning-points in a alluvial-fluvial setting.*

As in other forms of stratigraphic classification, it is typically possible to recognize packages at two or more hierarchical levels. We use a simple numerical system of nomenclature to label packages and their subdivisions: in this paper we recognise only first-order packages Tr1000 to Tr7000. Further subdivisions of Tr1000 would be labelled Tr1100, Tr1200 …, and subdivisions of Tr1100 would be Tr1110, Tr1120, and so on. Two higher-order levels of subdivision have been identified in the study: these are, however, not presented in this paper.
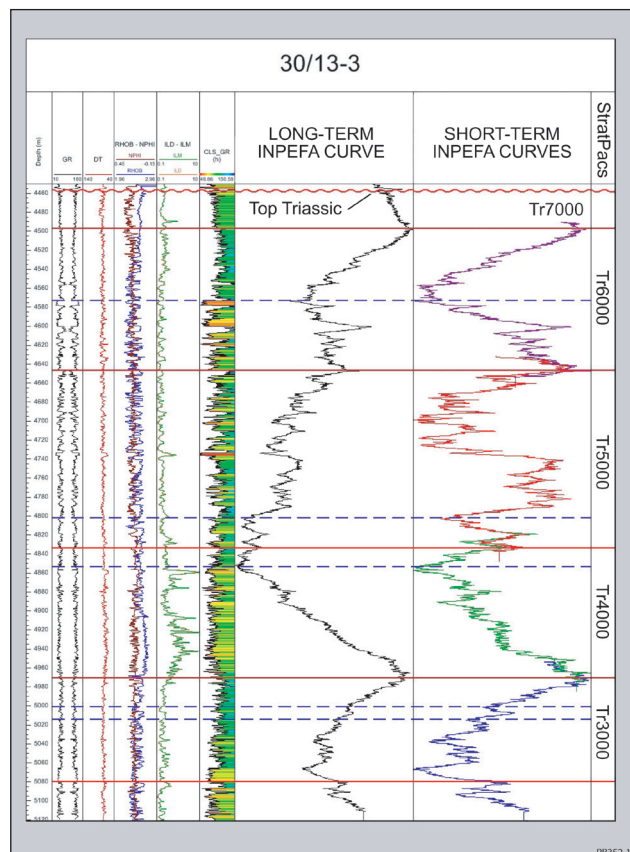
Stratigraphic packages

CycloLog analysis allows us to subdivide the Triassic succession of the study area into seven major packages, designated Tr1000 to Tr7000 from base to top. Two higher-order levels of subdivision have been identified in the study: these are, however, not presented in this paper. Each of the major packages is defined by the bounding surface at its base and the basal bounding surface of the next package above. These master packages are interpreted to be near-synchronous over the study area. Note that the new stratigraphic scheme is provisional and (to date) applies to the study wells only.

None of the study wells shows a full penetration of all major packages. The Zechstein (Permian) has been reached in two wells only, 30/12b-3 and 22/24b-4Z. Well 30/13-3 (Figure 3) shows a good penetration of packages Tr3000 through Tr7000, with a fairly typical INPEFA-GR pattern for all packages. Well 30/7a-7 (Figure 4) has good, almost complete, penetrations of packages Tr1000 and Tr2000.

Discussion

The seven first-order packages of the new scheme provide a framework for understanding the stratigraphic relationships and lateral facies variations of the Triassic of the study area. Comparison with previous schemes is not straightforward, and there is no simple relationship between our packages and previously defined lithostratigraphic and sequence stratigraphic units. An example of the significant differences involved is shown in Figure 5, in which our correlation of two wells is compared with the published lithostratigraphic correlation. The generally good fit of the long INPEFA curves is reinforced by inspection of the short INPEFAs computed for each of the interpreted first-order packages. The character of the individual packages, as well as the similarity of their succession, leaves us in little doubt that this is the correct correlation. The lithostratigraphic correlation, implying virtually no overlap between the Triassic strata in the two wells, was supported by the biostratigraphic data of Goldsmith et al. (1995). In Goldsmith's analysis, an apparent conflict was resolved as follows: the depths of sidewall core samples giving Middle Triassic dates from 30/7a-9 (close to 30/7a-4A) were interpreted as having been incorrect, in a section


Figure 3 *Well 30/13-3, with INPEFAs computed for the entire (penetrated) Triassic ('Long term INPEFA') and individually for the interpreted first-order stratigraphic packages ('Short INPEFAs'). Red wavy line = Top Triassic. Straight red lines show package bases; blue dashed lines are correlatable flooding surfaces. Lithofacies variation is represented by a GR log coloured from red (low values) to blue (high values). Refer also to the text.*

which was then interpreted as Upper Triassic. If the Middle Triassic dates in 30/7a-9 are in fact correctly located, there is substantially less conflict with our results. In other wells, the top of the Julius Mudstone Member has been variously picked at the base of our Tr3000 package (22/30a-2), base Tr4000 (22/24a-1), mid-Tr4000 (30/12b-2), and low Tr5000 (30/7a-8), suggesting very substantial diachroneity of this lithostratigraphic boundary.

In the Marnock area, a shale-dominated package informally called the Marnock Shale has been widely used as a marker horizon. In 22/24a-1 and 22/24b-4Z, this interval equates with our Tr3000 package (Figure 4). A few kilometres to the southwest, in 22/30a-6, McKie and Audretsch (2005) have identified the top of the Marnock Shale at the base of our Tr2000, two packages below the equivalent horizon in 22/24b-4Z. Although they believe they can trace the Marnock Shale on seismic (T. McKie, pers. comm.), the
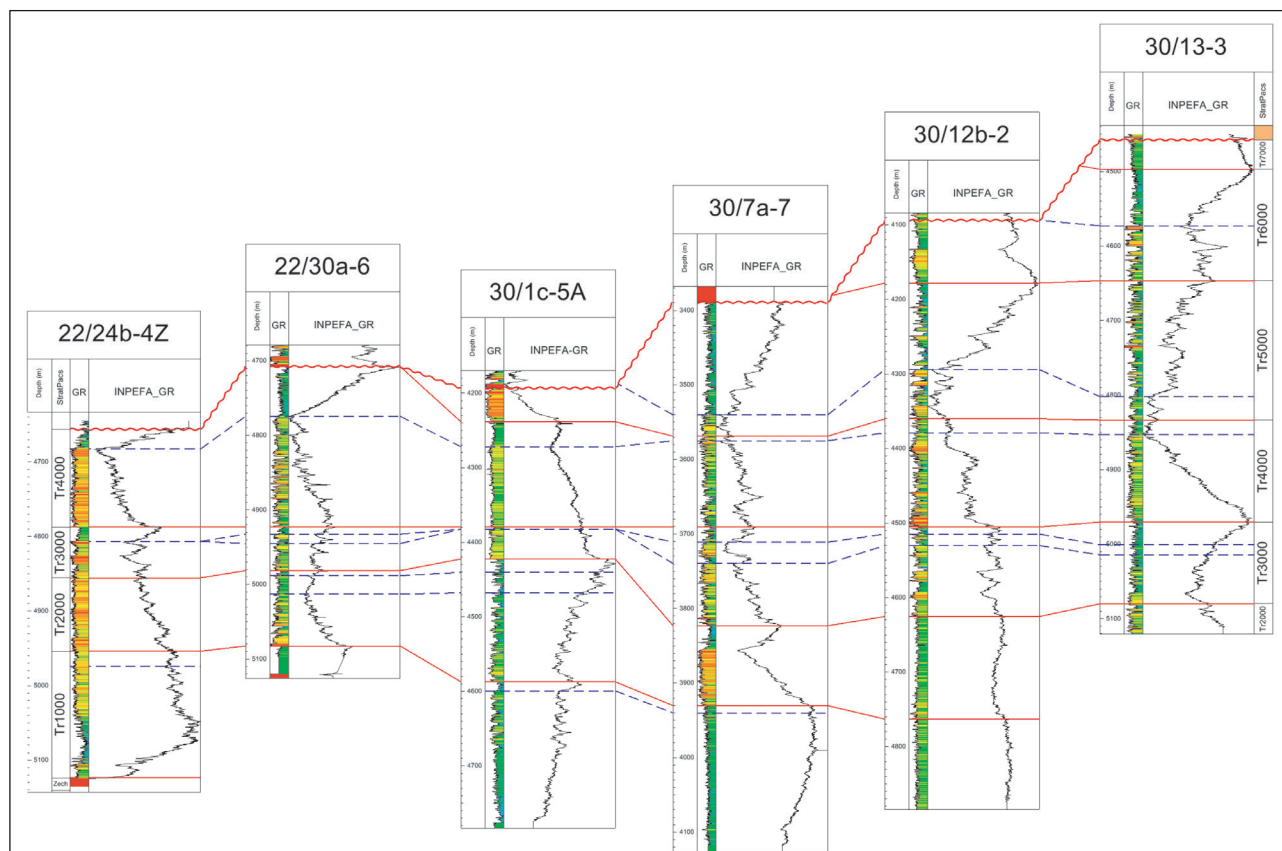
Figure 4 *Six-well correlation panel, from northwest (Egret, 22/24) to southeast (Josephine, 30/13). Lithofacies variation is represented by a GR log coloured from red (low values) to blue (high values). The broad track for each well shows the INPEFA curve derived from the GR and calculated for the whole of the (penetrated) Triassic interval. Red wavy line = Top Triassic. Straight red lines show package bases; blue dashed lines are correlatable flooding surfaces. The stratigraphic packages defined in this study are Tr1000 (base) to Tr7000 (top). The wells are arbitrarily hung on base-Tr4000.*

character of the INPEFAs strongly supports our correlation (see Figure 4). Further differences need to be addressed with reference to detailed biostratigraphic and seismic correlations.

It has been noted by various authors that GR curves for the Triassic of the Central North Sea may include anomalous values, because of the feldspar content of some of the sandstones, and because of anhydritic cements in some of the shales. This can result in higher-than-average GR values for sands, and lower-than-average values for shales. Having access to spectral GR logs for some (but not all) of the wells in this study, we were able to experiment with INPEFA curves derived separately from the K, Th and U logs, and ratios between them. While these INPEFAs are necessarily different from those derived from the total GR data, we were able to satisfy ourselves that we could identify correlatable trends and turning points without recourse to the spectral logs. It is important to be aware that the GR log is not being used simply as a lithology (sand versus shale)

indicator, because the information that the INPEFA transform reveals is contained in the spectral (i.e. wavelength/amplitude/phase) properties of the original log.

The reader should be aware that (given the long time-span covered by the study section) we do not discount tectonic processes in our analysis. Tectonic processes 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. 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. It is quite possible that some of the important changes we see on the long-term INPEFA curves have a tectonic component; the evidently synchronous nature of the important changes, however, we ascribe to orbitally-forced processes.
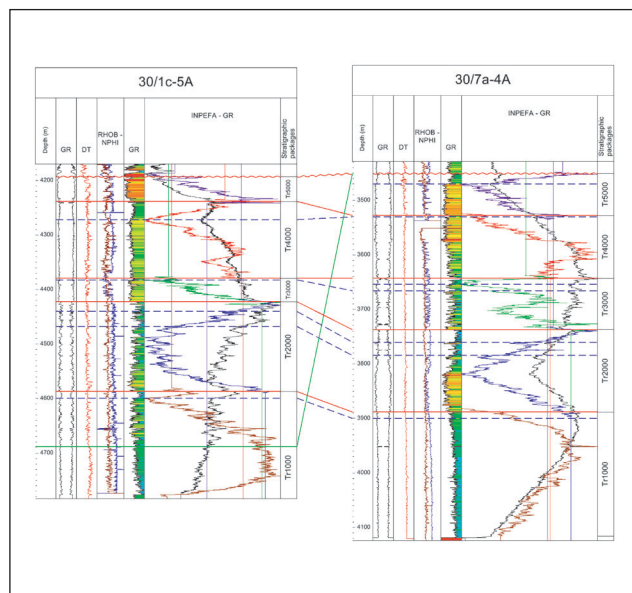
Figure 5 *Correlation of 30/1c-5A and 30/7a-4A. Red wavy line = Top Triassic. Straight red lines show package bases; blue dashed lines are correlatable flooding surfaces. Long INPEFAs (black) and short INPEFAs (coloured) are shown together in the same track. Green line connects the top Julius Mudstone Member as picked by Goldsmith et al. (1995, 2002) in the two wells.*

Conclusions

The acceptance of climate change as a primary driver of vertical lithofacies change allows a time-significant stratigraphic classification to be derived from a standard facies-sensitive wireline log such as the GR. The INPEFA (spectral-trend) transform is the key to the recognition of climate-driven changes in the stratigraphy. We have used this approach to erect an entirely new stratigraphic scheme for the study wells in the Triassic succession of the southern UK Central Graben. Although we have illustrated only our first-order stratigraphic packages, higher-order subdivision and correlation is readily achievable, and extension of our scheme to the reservoir-scale and beyond the study area is the logical next step. Used with care, we believe that the new scheme can provide insight where other methods are hampered by ambiguity of results or lack of resolution.

Acknowledgement

References

Goldsmith, P.J., Hudson, G., and Van Veen, P. [2002] Triassic. *In* Eds. D. Evans, D., Graham, C., Armour, A., and P. Bathurst, P. *The Millennium Atlas: Petroleum Geology of the Central and Northern North Sea.* Geological Society, London, 105-127.

Goldsmith, P.J., Rich, B., and Standring, J. [1995] Triassic correlation and stratigraphy in the South Central Graben, UK North Sea. *In* Boldy, S. (Ed.) *Permian and Triassic Rifting in Northwest Europe,* S. Special Publication, Geological Society, London, 123-143.

McKie, T. and Audretsch, P. [2005] Depositional and structural controls on Triassic reservoir performance in the Heron Cluster, ETAP, Central North Sea. *In* Doré, A.G. and Vining, B.A. (Eds.) Petroleum Geology: North-West Europe and Global Perspectives. *Proceedings of the Sixth Petroleum Geology Conference.* Geological Society, London, 285-297.

Nio, S. Djin, Brouwer, J., Smith, D.G., De Jong, M., and Böhm, A. [2005] Spectral trend attribute analysis: applications in the stratigraphic analysis of wireline logs. *First Break*, **23**, 4, 71-75.

Nio, S. D., Böhm, A.R, Brouwer, J.H., De Jong, M.G.G., and Smith, D.G. [2006] *Climate stratigraphy, principles and applications in subsurface correlation.* EAGE Short Course Series 1, 130 pp.

Penge, J., Munns, J.W., Taylow, B. and Windle, T.M.F. [1999] Rift-raft tectonics: examples of gravitational tectonics from the Zechstein basins of northwest Europe. *In* Fleet, A.J. and Boldy, S.R. (Eds.) The Petroleum Geology of NW Europe: Proceedings of the Fifth Conference. Geological Society, London, 201-213.

Perlmutter, M.A. and Matthews, M.D. [1990] Global cyclostratigraphy - a model. *In* Cross, T.A. (Ed.) *Quantitative Dynamic Stratigraphy.* Prentice Hall, 233-260

Pooler, J. and Amory, M. [1999] A subsurface perspective on ETAP – an integrated development of seven Central North Sea fields. *In* Fleet, A.J. and Boldy, S.R. (Eds.) The Petroleum Geology of NW Europe: Proceedings of the Fifth Conference. Geological Society, London, 993-1006.

Stewart, S.A. and Clark, J.A. [1999] Impact of salt on the structure of the Central North Sea hydrocarbon fairways. *In* Fleet, A.J. and Boldy, S.R. (Eds.) The Petroleum Geology of NW Europe: Proceedings of the Fifth Conference. Geological Society, London, 179-200.

Yang, C.S. and Nio, S.D. [1993] Application of high-resolution sequence stratigraphy to the Upper Rotliegend in The Netherlands offshore. *In* Weimer, P., and Posamentier, H. (Eds.) Siliciclastic Sequence Stratigraphy - Recent Developments and Applications. *American Association of Petroleum Geologists Memoir 58*, 285-316.