Chemostratigraphy and stable isotope stratigraphy of the Triassic and Lower Jurassic within the well Spoonbill C-30; an intergrated stratgiraphic approch

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Summary

This study represents an integrated stratigraphic study on the stratigraphy of the Triassic and Lower Jurassic sequences of the well Spoonbill C-30, from the Jeanne d'Arc Basin. This basin formed as a result of a failed triple rift system that developed during the North Atlantic Mesozoic Rift. Overall, across the Grand Banks penetrations of the Lower Jurassic and Triassic are limited with the key sections occurring in the southern wells of the Jeanne d'Arc, Carson and Whale Basins. The deposition during the Tethys Phase of rifting (during the Late Triassic – Early Jurassic) sediments are predominantly deposited in continental and lacustrine settings. There were some marine incursions resulting in the deposition of salts and carbonates, which are contemporaneous with equivalent salt deposits across the Scotian Shelf (Enachescu, 2013).

The published stratigraphy of the Spoonbill C-30 well (CNLOPB, 2007) shows the occurrence of the Banquereau Formation to a measured depth of 469.5 metres, the base of which also corresponds to the Base Tertiary Unconformity. The Late Cretaceous Dawson Canyon Formation is recognised between 469.5 to 911 metre; the Fox Harbour and Otter Bay Members are both defined. The base of the Dawson Canyon Formation is also consistent with the Coniacian Unconformity. Below this is the Early Jurassic Iroquois Formation (911 to 1263 metres), the Late Triassic-Early Jurassic Argo Formation (1263 to 2534 metres) and the Triassic Eurydice Formation (2534 to 2632 metres). The Carnian Unconformity is recognised at 2632 metres MD, and below this the strata are tentatively assigned as Palaeozoic 'red beds' to TD. In addition, a thin basalt is recognised between 1514 to 1564m. Overall, the Lower Jurassic – Triassic biostratigraphy is sparse and the stratigraphy is largely based on E-log response and lithostratigraphy.

Method

This study focuses on the well Spoonbill C-30 which penetrates the Lower Jurassic, Triassic and Palaeozoic strata. A total of one hundred and twenty-six samples have been analysed for whole rock geochemistry, while one hundred and eighteen samples have been analysed for $^{\delta 13}$C and $^{\delta 18}$O stable isotope stratigraphy.

The technique of chemostratigraphy involves characterising and correlating sedimentary strata by using stratigraphic variations in their inorganic geochemistry (Pearce 1991; Pearce & Jarvis 1992a, 1992b and 1995; Pearce et al. 2005 and 2010). The technique is particularly sensitive to these variations and, in many instances, has proved successful in detecting and correlating strata, especially with regards to successions over which the lithology remains uniform.

The inorganic geochemical data acquired for the current study come from cuttings samples. To collect material for geochemical analysis, each sample has been sieved and checked for contamination under binocular microscope to prepare between two hundred and three hundred chips of the relevant lithology, as determined by reference to the gamma log for the study well. Each prepared sample weighs approximately one gram, this weight and volume being ideal for geochemical analysis. All prepared samples are then ground in agate prior for geochemical analysis. Sample preparation and analysis follow the procedures advocated by Jarvis & Jarvis (1992a and 1992b) and Pearce et al. (1999) - preparation involves using a lithium metaborate (alkali) fusion procedure, after which the samples have been analysed by accredited Inductively-Coupled Plasma - Optical Emission Spectrometry (ICP-OES) and Inductively-Coupled Plasma - Mass Spectrometry (ICP-MS) instruments. Quantitative data has been acquired for forty-nine elements, which include the ten major element oxides, trace elements and the rare earth elements. The precision of the ICP-acquired geochemical data has been assessed by replicate analysis of multiple preparations of certified rock standard reference materials (SRMs) along with duplicate preparations of unknown samples, which have all been analysed on a routine basis together with each of the samples.

Stable isotopes, particularly those of carbon, are now widely used in stratigraphic studies and have proved to be extremely useful in this context. Stable carbon isotope values vary systematically through marine sedimentary rocks, with laterally persistent intervals of exceptionally heavy or light values being recognized world-wide (Saltzman & Thomas 2012). These signals are regarded as being independent of facies (McLaughlin et al. 2012) and are particularly isochronous (Cramer et al. 2010). Furthermore, trends in isotope values can often be identified in coeval strata, regardless of whether the data came from carbonate minerals ($^{\delta 13}C_{carb}$) or organic matter ($^{\delta 13}C_{org}$), though some caution must be exercised when comparing these types of data directly (Kump & Arthur 1999).

The bulk material selected for isotope analysis from each cuttings sample is first washed and sieved, before being ground to form a homogeneous powder. Each sample powder is then weighed into a clean Exetainer™ tube and flushed with 99.995% helium (He), after which phosphoric acid is added to the sample, which can react in the acid overnight to allow complete conversion of carbonate to CO_2. Reference and control materials are prepared in the same way. The CO_2 gas liberated from the samples is analysed by Continuous Flow - Isotope Ratio Mass Spectrometry (CF-IRMS). CO_2 is sampled from the Exetainer™ tubes into a continuously flowing He stream using a double hold needle and is then resolved on a packed column gas chromatograph, with the resultant chromatographic peak being carried forward into the ion source of a Europa Scientific 20-20 IRMS, where it is ionised and accelerated. Gas species of different mass are separated in a magnetic field and then simultaneously measured using a Faraday cup collector array to measure the isotopes of CO_2 at m/z 44, 45 and 46.

Results

Figure 1 shows the isotope curve results from Spoonbill C-30, with inferred tops referenced of a global carbon isotope curve. With reference to Figure 1, the top of Chemostratigraphic Megasequence MS0 is characterised by high $^{\delta 13}C$ values, which then decrease into the lower part of Chemostratigraphic Sequence S8, the Eurydice Formation, the inferred age from the global isotope curve is that of a lower Carnian age, which is also characterised by low $^{\delta 13}C$ values. The strata assigned to the Chemo. Megasequence MS1, Sequences S8 to S10, and represent the Iroquois, Argo and Eurydice Formations, which are largely composed of carbonates, evaporites and a minor amount of clastics. The global isotope curve also shows that the Carnian Stage is characterised by initially low $^{\delta 13}C$ values that increase steadily upwards to the Carnian - Norian boundary, with a similar trend being recognised over Sequence S8. $^{\delta 13}C$ values remain high over the lower part of Sequence S9, then slowly decrease upwards to c. 2100m in the lower third of the Argo Formation, this trend being comparable to the global $^{\delta 13}C$ curve for the Norian. Values remain low increasing upwards slightly though the remainder of S9 (upper Argo Fm.) and this interval is attributed to the Rhaetian.

A basalt is present toward the top of Sequence S9 between 1514m and 1564m - sample 1575m (Argo Formation – within the Rhaetian section) and have an abnormally high $^{\delta 13}C$ values that could be due to the igneous rock being present in this sample. Notably, basalts have been observed in the Rhaetian succession across the Atlantic conjugate margin (Leleu & Hartley 2010).

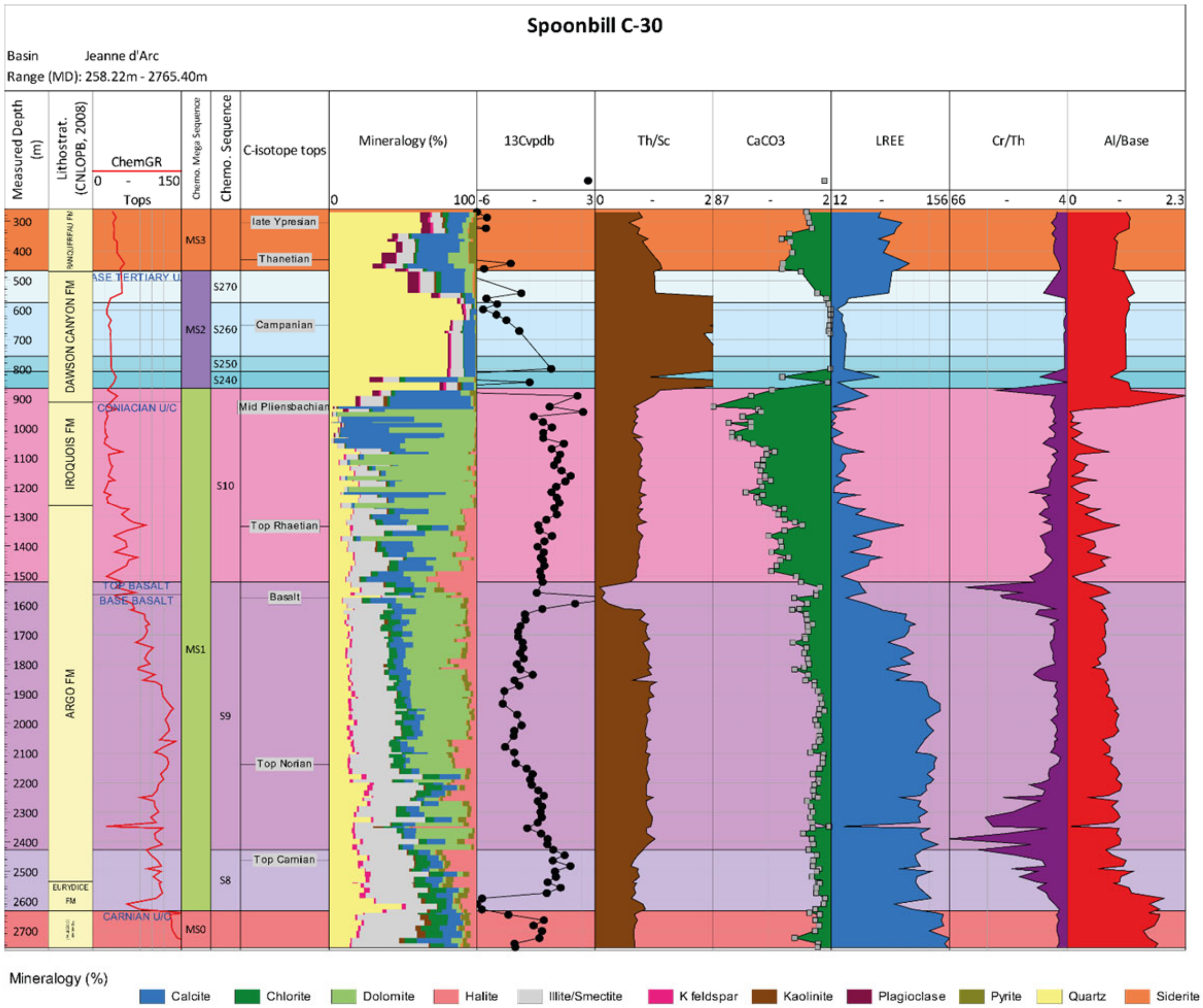

Figure 1. Carbon isotope curve, normative mineralogy and selcted key elements for Spoonbill C-30

The $\delta^{13}C$ values increase upwards through Sequence S10 attributed to the Lower Jurassic (Hettangian, Sinemurian to lower Pliensbachian) section and culminate in a pronounced positive excursion in the mid Pliensbachian. $\delta^{13}C$ values likewise increase steadily upwards above c.1300m and finish with a positive excursion in a thick limestone at the top of the Iroquois Formation, which has been allocated to Sequence S10. Based on the isotopic data, the Triassic - Jurassic boundary in well Spoonbill C-30 is placed at c.1300m, with the basal part of Sequence S10 (Iroquois Formation) with the remainder of the Iroquois being Hettangian to Sinemurian to mid Pliensbachian in age. The increasing trend in $\delta^{13}C$ values extends above the top of the Iroquois Formation and stops at 890m in the basal part of the Dawson Canyon Formation. The 890m sample could come from either a Pliensbachian or a Cenomanian limestone, as both typically exhibit high $\delta^{13}C$ values, but based on the chemostratigraphic zonation for well Spoonbill C-30, this limestone lies at the top of Sequence S10 (= Iroquois Formation) of Pliensbachian age. Consequently, the top of the Lower Jurassic in this well is put at c.880m and is overlain by Upper Cretaceous successions allocated to Sequences S240 to S270 (= Cenomanian to Maastrichtian). The Sequence S180 sample from 871m has a very low $\delta^{13}C$ value that is due to contamination of this sample by cement coming from the casing point at 853.45m, whereas the 826m sample has a very low $\delta^{13}C$ value (<10‰) that could be linked to diagenesis of the parent succession linked to the unconformity that marks the Lower - Upper Cretaceous boundary. High values have been recorded from Sequence S250 (Cenomanian - Turonian), which then decrease upwards through Sequences S260 and S270 (Santonian to Campanian). Moderately high $\delta^{13}C$ values occur at the base of Megasequence MS3 (Upper Thanetian), with the 405m sample (Lower Ypresian) having a much lower value and the 323m sample (Upper Ypresian) having a higher value.

Discussion

The Paleozoic 'red beds' are not assigned to a specific lithostratigraphic division. Furthermore, the $\delta^{13}C$ values acquired from that interval display no diagnostic excursions to identify the age of the sequence. The Eurydice and base of the Argo Formation are assigned to the Carnian based on the comparison to the global isotope curve. Furthermore, the top of the Carnian is broadly equivalent to the identification of the top of Sequence S8. Interestingly, the evaporites within Sequence S9 are Cr rich which implies the influx of some mafic volcanic material into the basin during the formation of the evaporites and which could be linked with the occurrence of basalts in the Rhaetian strata (such basalt presumably being associated with Late Triassic rifting - Leleu & Hartley 2010). Notably, some of the excursions within the carbon isotope are recognisable within Triassic sandstones from offshore west of Ireland (Schmid et al. 2006).

The positive excursions of the mid-Pliensbachian are clearly identified within the upper part of Sequence S10 (= Iroquois Formation), where it corresponds to a limestone that caps the dolomites. The thin Upper Cretaceous interval is assigned to the Dawson Canyon Formation and is geochemically sub-divided into the Sequences S240 to S270, representing a condensed Cenomanian to Campanian succession. Analyses of samples straddling the Lower Cretaceous - Upper Cretaceous unconformity have low $\delta^{13}C$ values and show the parent successions have suffered significant diagenesis and alteration. $\delta^{13}C$ values over the basal Tertiary section have been affected by the analysed samples being contaminated by casing cement, but low $\delta^{13}C$ values characteristic of the Danian Stage have been encountered above the casing point.

Conclusions

This integrated stratigraphic study demonstrates how the application of a chemostratigraphy and a stable isotope stratigraphy workflow can provide an enhanced well stratigraphy. The stable isotopes provide an absolute age comparison, while the chemostratigraphy provides a high resolution stratigraphic scheme. In addition, the carbon isotopes have correlation potential to the offshore west of Ireland and potentially provide correlation across the conjugate margin.

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