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Research paper

Chemostratigraphy and biostratigraphy of Devonian, Carboniferous and Permian sediments encountered in eastern Saudi Arabia: An integrated approach to reservoir correlation

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A R T I C L E I N F O

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A B S T R A C T

The following study was completed on inorganic geochemical data acquired from 850 core and cuttings samples taken from Devonian, Carboniferous and Permian sediments encountered in six wells in the arabian gulf, eastern saudi arabia. The principal objective of the study was to employ chemostratigraphy to produce a 'robust' high resolution correlation scheme. A secondary aim was to integrate this with existing biostratigraphic data as part of a multidisciplinary approach to reservoir correlation.

Data were derived for 50 elements using ICP-OES (Inductively Coupled Plasma – Optical Emission Spectrometry) and ICP-MS (Inductively Coupled Plasma – Mass Spectrometry), but definition of chemostratigraphic boundaries are based on changes in the following key element ratios: Cr/P, Th/Nb, Th/Ta, Zr/Th, Zr/P, Nb/Ti and Nb/P. Variations in these parameters are largely dependent on changes in source/provenance, which affects the relative concentrations of detrital heavy minerals.

To avoid geochemical variations relating to changes in grain size/lithology, separate frameworks were constructed for data derived from sandstone and mudrock lithologies. Both comprise a hierarchical order of zones, subzones and divisions, with subdivisions also being identified in the sandstone dataset. The schemes are considered to be 'robust' as chemozones (general term used to refer to any zone, subzone, division or subdivision) are clearly defined using geochemical profiles and binary diagrams and most are correlative between three or more wells. Given the similarities in definitions of zones, subzones and divisions in the two schemes, and the fact that these chemozones are considered to be roughly time equivalent, both were combined to produce a 'final' chemostratigraphy scheme. In a further stage of interpretation, the correlation was refined by integrating the interpretations of this chemostratigraphy study with lithostratigraphic markers (identified by significant trends in GR that exist in two or more wells) and an existing correlation based on biostratigraphy.

In the Tawil and Jauf formations there are obvious inconsistencies between the placement of chemostratigraphic and biostratigraphic boundaries, with some subzones occurring within different palynozones in adjacent wells. Such disparities may be explained by the existence of separate fluvio-deltaic/shallow marine sandstones having a similar source/provenance but being deposited in different parts of the study area at different times. This interpretation is supported by the available seismic data showing that the Jauf, and to a lesser extent the Tawil, formations take the form of laterally discontinuous sandstones. By contrast, the chemozones associated with the overlying Jubah Formation, Berwath Formation, Unayzah Group (Juwayl and Nuayyim formations) and Base Khuff Clastics Member show a very close match with the placement of palynozones in each well and were probably deposited at a similar time on both field and subregional scales.

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1. Introduction and geological setting

The following study was completed on 6 wells located in the Gulf of Arabia, Saudi Arabia and penetrating clastic sediments ranging in age from Devonian to Permian (Fig. 1). The specific

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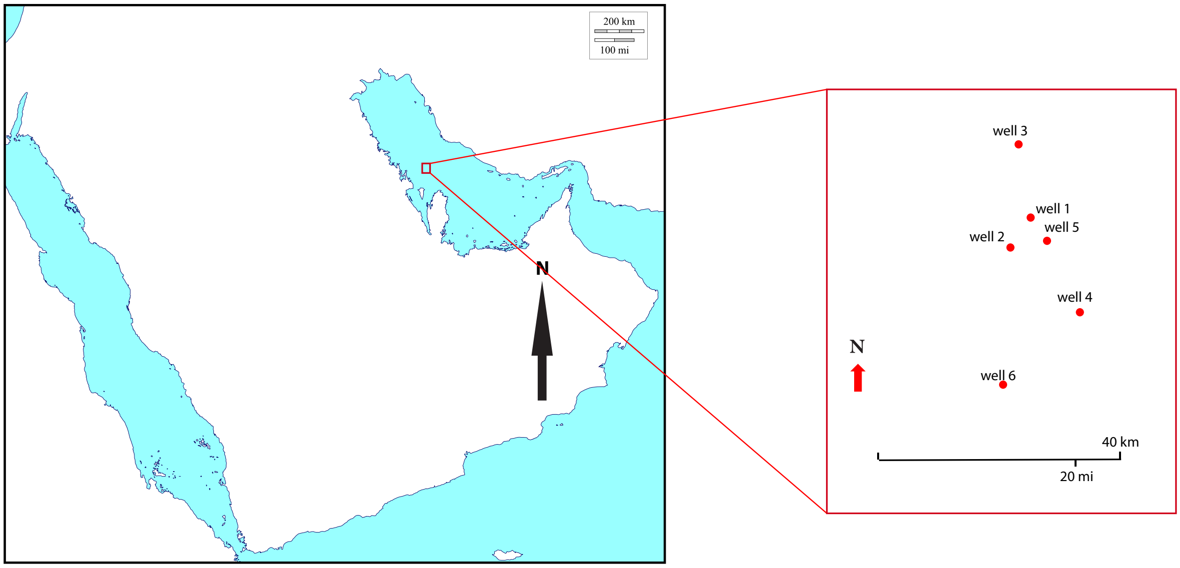

Fig. 1. Map showing the location of study wells.

objectives of the study were as follows:

1. To produce a chemostratigraphic correlation scheme for Devonian, Carboniferous and Permian sediments encountered in six study wells.
2. To compare the proposed chemostratigraphic correlation scheme with an existing scheme based on biostratigraphy and to integrate the result of the chemostratigraphic and biostratigraphic studies as part of a multidisciplinary approach to reservoir correlation.

The study intervals of most wells comprise the Tawil, Jauf, Jubah, Berwath formations and the Unayzah Group. These are dominated by sandstones and occasional mudrocks deposited in fluvial, fluvio-deltaic and shallow marine environments. A stratigraphic column is shown in Fig. 2.

The Devonian sedimentary rocks of the Middle East generally consist of an overall coarsening upwards, progradational sequence along the passive margin of northeastern Gondwana that commenced in the Silurian and culminated in the Upper Devonian times (Al-Hajri et al., 1999). The Tawil Formation occurs at the base of each study section, though this has not been sampled in full in any of the wells. An unconformity occurs at the boundary between the Tawil Formation and the overlying Jauf Formation, with the latter being associated with the Emsian Stage of the Lower Devonian. A major marine transgression, recognized by Palynosubzone D3B is identified in the upper part of this formation. The Jauf Formation is succeeded by the Jubah Formation, extending in age from the Emsian to the middle of the Tournaisian (Lower Carboniferous). The Berwath Formation overlies the Jubah and is dated as Tournaisian to Serpukhovian (Al-Hajri and Owens, 2000). A major unconformity is associated with the Jubah/Berwath boundary which was associated with a period of erosion, as Al-Hajri and Owens (2000) recorded reworking of Late Devonian and Carboniferous sediments into the Berwath Formation. An increase in sea level occurred at the base of the Berwath Formation but the top of this interval is marked by tectonic uplift and the Hercynian Unconformity, also known as the pre-Unayzah Unconformity, at the base of the Unayzah Group (Al-Laboun, 1990; Ferguson and Chalmers, 1991; McGillivray and Husseini, 1992; Stump et al., 1995; Evans et al., 1997; Al-Hajri and Owens, 2000; Sharland et al., 2001). This unconformity resulted from a major period of structuring and inversion following the collision of Gondwana with Eurasia to form Pangea (Sharland et al., 2001). The Unayzah Group is dominated by continental sediments deposited in a range of fluvial aeolian and glaciogenic environments, with the boundary between the Unayzah Group and Khuff Formation marked by a pronounced increase in sea level and deposition. The Khuff Formation is dominated by carbonates deposited in shallow marine environments but the Basal Khuff Clastics Member is often recorded at the base of this formation by an 'erosive lag', dominated by sandstones, conglomerates and breccias.

Chemostratigraphy has been utilised as a correlation technique since the early 1980's and is often used to characterize/correlate intervals where biostratigraphic recovery and resolution are limited (for example, Craigie, 2015a). Some studies of the 1990's involved an integrated chemostratigraphy:biostratigraphy:lithostratigraphy to correlation but, according to Ramkumar (2015) these generally related variations of selective elemental abundances and isotopic compositions to known geological events and/or chrono, litho and biostratigraphic boundaries (for example, Kaminski and Malgren, 1989; Nandy et al., 1995). More recently, the technique has been applied to a range of geological studies (for example, Hurst and Morton, 2001; Jarvis et al., 2006; Nedelec et al., 2007; Cramwe et al., 2008; Gouldey et al., 2010; Gotzinger et al., 2011; Hildred et al., 2010; Wright et al., 2010; Salzman and Sedlacek, 2013; Uramoto et al., 2013; Craigie, 2015a, b; Holmes et al., 2015).

Owing to the aforementioned geological and structural complexities occurring during the deposition of Palaeozoic sediments in the Middle East region, it was decided to employ a fully integrated chemostratigraphy:biostratigraphy:lithostratigraphy approach to reservoir correlation. Utilising chemostratigraphy in isolation may result in erroneous correlations if observed changes in geochemistry, usually related to changes in source/provenance or depositional environment, do not occur at the same time in study wells. Conversely, biostratigraphy also has its limitations as sediments of similar age can be identified in adjacent wells but individual beds are not always correlative and may be of different lithologies in adjacent wells. In the absence of biostratigraphic and chemostratigraphic datasets, lithostratigraphy is often used to correlate sections showing similar trends in GR and other logs

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