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3D seismic attributes and well-log facies analysis for prospect identification and evaluation: Interpreted palaeoshoreline implications, Weirman Field, Kansas, USA

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ABSTRACT

We present a workflow integrating post-stack seismic attributes and well-log facies analysis in order to understand the development history and depositional setting of the Weirman Field in central Kansas, and to propose a fresh prospect-evaluation approach for our study area. This study successfully addresses compartmentalisation due to highly variable lithofacies by analysing geophysical well-logs, lithofacies modelling, and 3D seismic attributes including time thickness, amplitude, and structural time maps. In the light of some discouraging drilling results at Weirman Field, we recommend a revised approach to prospect evaluation, based upon a newly interpreted palaeodepositional setting, to predict the distribution of clean sand facies, using a combination of seismic attribute signatures and structural closure maps. In support of our interpretation, we compare the proposed palaeodepositional setting with a modern analogue of a transitional coastal to shallow marine depositional environment. The dimensions and spatial relationships of the interpreted geo-bodies are in conformity with the modern shoreline analogues of a barrier beach or strandplain adjacent to an estuary. The lithofacies clustering was calibrated to a lithostratigraphic column, which was constructed based on drilling-cuttings of Wanda Judeen No. 1. This calibration was upheld against correlation with well-logs for other wells.

1. Introduction

Seismic attributes analyses, in studying depositional sedimentary environments of potential reservoirs, have been successfully applied for hydrocarbon field exploration and development case studies, e.g. Verma et al. (2009). The use of key seismic attributes; such as amplitude, seismic primary-wave attenuation, curvature, and coherence in stratigraphic characterisation of hydrocarbon reservoirs has been reported by many authors, e.g. (Russell et al., 2003, 454–457; Chopra and Marfurt, 2007, 856–867; Chopra and Marfurt, 2008, 1590–1594; Lozano and Marfurt, 2008, 914–918). Attribute-assisted interpretation may help to distinguish shale-filled channels from sand-filled channels (Suarez et al., 2008). According to Suarez et al. (2008), the use of several seismic attributes may assist in defining sand facies zones in more detail than relying on single-attribute delineation. Integrating and calibrating seismic attributes analyses with other independent geoinformation from drilling results and well-logging enable cross-validated interpretation, in a geological sense, of seismic attributes variation patterns.

An understanding of the depositional setting of the Cherokee sand bodies, in our study area of the Weirman Field (Fig. 1a–c), based on coupling well-log facies analysis with stratigraphic and structural seismic attributes, seismic modelling, and comparison with modern analogues, is essential for prospect identification and evaluation and field development.

The study area is located on the southwestern flank of the Central Kansas Uplift, a noted structural high with a long history as a positive feature (Merriam, 1963). The study area also includes the northeastern margin of the Hugoton Embayment of the Anadarko Basin (Fig. 1a and b). Hydrocarbon fields in Ness County are shown in Fig. 1c. In 2003, Coral Coast Petroleum began drilling the wildcat well, Keith No. 1 located in section 18, T16S, R22W – State Plan Coordinate Projection. The target formation for this well was the Cherokee sandstone. Keith No. 1 produced 162 barrels before it was plugged as a dry well and abandoned. Prospect evaluation for drilling Keith No. 1 was based mainly on a doublet seismic anomaly, immediately below the uppermost Cherokee seismic horizon (Fig. 2), which was interpreted as a thicker section of Cherokee sandstone (personal communication from Coral Coast Petroleum staff). In our study, this interpretation is refuted following analysis

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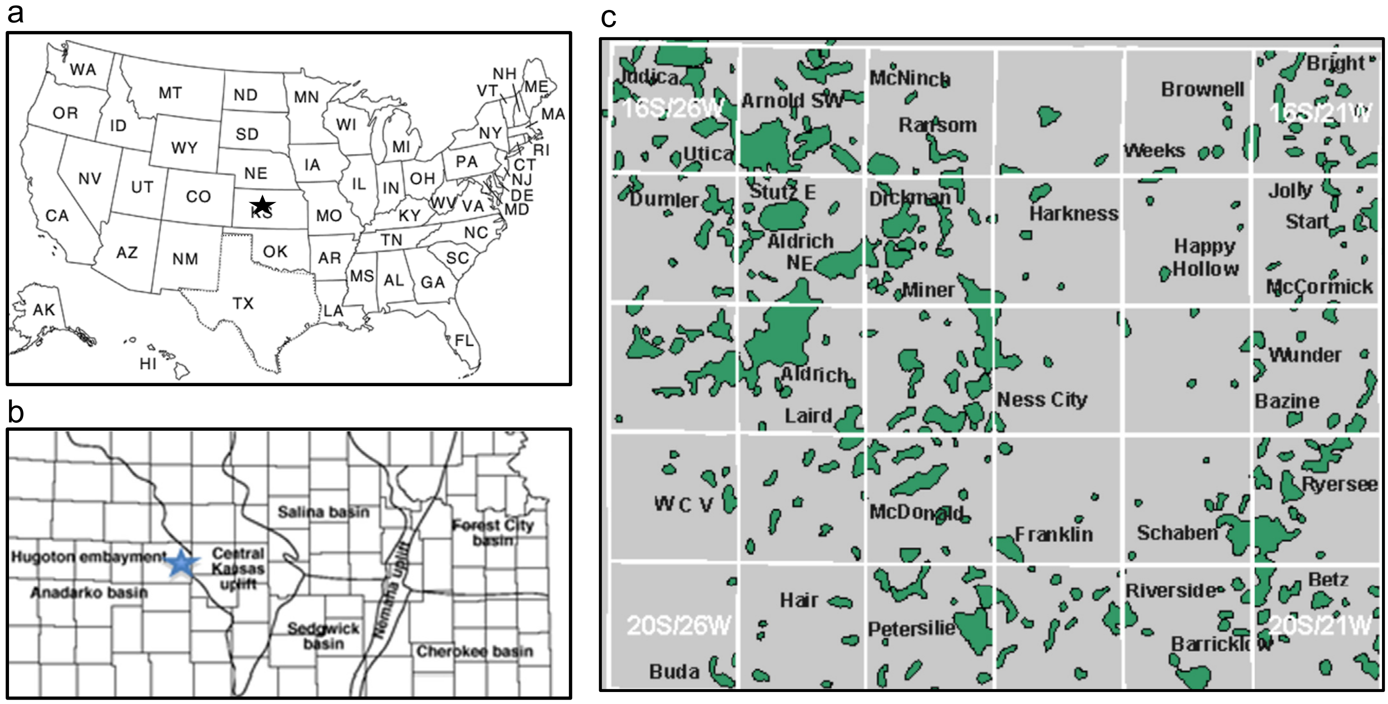

Fig. 1. Study area: (a) United States map; the star marks Kansas state and approximate location of study area, (b) State of Kansas County map with a star marking Ness county, and (c) Ness County oil-fields map with area of study marked with a rectangle.

of lithofacies clusters using cross-plots of gamma ray and sonic log data. The seismic doublet of Keith No. 1, though is also produced by synthetic modelling, is not correlating with significant thickness of sand nor with lower proportions of shale content.

Fig. 3a shows that the Central Kansas Uplift had existed during deposition of the basal Cherokee clastics. The basal Cherokee sandstones directly above the Mississippian unconformity (Fig. 3a and b) are prolific oil reservoirs in many parts of Kansas, but they are notoriously difficult to locate in the subsurface (Mazzullo, 2005). We use key seismic attributes, such as structural seismic-time anomalies, time thickness and amplitude anomalies, isochron maps, and gamma ray and sonic well-log facies analysis, to develop and evaluate indicators of high-potential hydrocarbon prospects of the Cherokee sands in the Weirman field. We seek to evaluate qualitative relationships, integrating geophysical well logs, a set of post-stack seismic attributes and production data, to establish a sound prospect evaluation approach in a highly heterogeneous sand lithofacies setting in Weirman Field.

Our approach, towards a more complete understanding of the controls on the distribution and the depositional setting of the Cherokee sands in Weirman Field, coupled well-log lithofacies modelling and seismic time and amplitude attributes analysis with comparison to a modern depositional analogue. We seek to identify palaeoshorelines, tidal channels, and sand beaches/sand-barriers as probable controls on the distribution of the Cherokee basal sands. Seismic time anomalies and seismic amplitude anomalies have been key attributes in this study for identifying different depositional environments.

2. Geological setting, lithofacies, and petroleum geology

The Cherokee Group has been classified on the basis of cyclothems and is dominated by both marine and non-marine rocks such as sandstone, shale and coal beds (Merriam, 1963). This group, in the subsurface of Ness County, comprises mixed siliciclastic and carbonate sequences. In Ness County, the Cherokee Group lacks the coals found in eastern Kansas and is primarily composed of limestone and shale with sparse sandstone (Ramaker, 2009). The thickness of the Cherokee Group ranges from 1.5 to 61 m (Stoneburner, 1982). The following geological description is mainly based on Ramaker (2009). His investigation is highly applicable locally and represents a very recent study of the area.

The Mississippi unconformity is a karstic surface of Mississippian limestones, from which dolines, as deep as 50 m and measuring 1.6 km across, have been described in the study area as well as an extensive network of palaeovalleys; most of these valleys display a north–south trend (Ramaker, 2009). In the easternmost part of Ness County NE-SW oriented valleys join into larger north–south oriented valleys towards the west, and whereas the palaeovalleys in easternmost Ness County are relatively narrow, ranging from 0.8 km to 2.4 km with a depths ranging from 3 m to 12 m, the approximately north–south oriented valleys in the west are 0.8–4 km wide and up to 28 m deep (Ramaker, 2009).

The Mississippian surface is overlain by cherty conglomeratic breccia, glauconitic sandstone and variegated silty mudstone, filling the palaeovalleys (Ramaker, 2009). This depositional interval did not result in a very thick clastic sequence, as indicated by the depths of the palaeovalleys. Thus, the thickest cherty conglomeratic breccia measures 7 m, and the thickest and most persistent sandstone accumulation 17.5 m (Ramaker, 2009).

The cherty material is poorly sorted, sub-rounded to angular, and is derived from the underlying carbonate successions. It is associated with limestone and dolomitic limestone clasts (Ramaker, 2009). The cherts are reworked residual karst deposits (Nodine-Zeller, 1981, 1985). The sand of the glauconite sand may have been shed from the Palaeozoic Reagan Sandstone of the Central Kansas Uplift, and the glauconite sandstone probably represents fluvial deposition in an upper estuarine environment (Ramaker, 2009).

This clastic sequence is capped by a palaeosoil, representing a sequence boundary, and followed by a thin (40–50 cm), laterally continuous, wackestone-packstone horizon reflecting an open, shallow-marine shelf environment within the photic zone as well as marine flooding (transgressive sequence, Ramaker, 2009). A grey