Wellbore to Outcrop Correlation and Sequence Stratigraphic Evaluation of the Late Cretaceous Lower Ferron Sandstone in East Central Utah, U.S.A.*

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Abstract

Deposition of the Ferron Sandstone Member occurred during a widespread regression of the Western Interior Seaway during the Turonian. The Ferron is informally subdivided into two units. The Upper Ferron, ferronensis sequence is well exposed as a shallow marine and coastal plain clastic wedge along the edge of the Wasatch Plateau in central Utah. In contrast the Lower Ferron, hyatti sequence, has previously only been documented in thin, northern outcrops and as basal sandstone in the subsurface Drunkards Wash, Buzzard Bench and Helper fields around the town of Price, where the Upper Ferron is interpreted to form a major coal bed methane accumulation in non-marine deposits overlying the Lower Ferron sandstone.

The aim of this study is to improve the current understanding of the stratigraphy and sedimentology of the Lower Ferron unit. Correlation of 55 borehole logs coupled with outcrop studies have resulted in a new depositional model for the system. The correlations suggest that the Lower Ferron is comprised of a series of progradational to aggradational shoreface parasequences which prograded in an east to south-easterly direction. Modelling also suggests that a series of outcrops, previously interpreted as long shore bars, are in fact the downdip expression of these shorefaces. This model is supported by extrapolation of the facies tracts mapped in the subsurface, geometric reconstruction of the large scale structures and correlation of bentonite horizons. The final model suggests a more prominent Lower Ferron depositional system than previous studies and paleogeographic reconstructions suggests a dynamic transition between the informally named Lower and Upper Ferron Sandstone.

Introduction

The Late Cretaceous Ferron Sandstone Member of the Mancos Shale is a well exposed, shallow marine to paralic, clastic wedge that crops out along the western edge of the San Rafael Swell in eastern Utah. Outcrops of the unit have been extensively studied as analogues for sub-surface reservoirs (Corbeanu et al., 2001; Li and White, 2003; Bhattacharya and Tye, 2004; Forster et al., 2004; Garrison and van den Bergh, 2004). There has been a long tradition of coal mining from the unit, and more recently it has become commercially important as a Coalbed Methane (CBM) play. The Ferron clastic wedge represents a highstand system tract (Ryer, 2004) within the Mancos Shale of the Mesaverde Group, deposited in a period of regression during peak Cretaceous flooding of the Western Interior Seaway in North America. The Ferron is informally subdivided into upper and lower units, of which the Upper Ferron comprises the majority of the outcrops and has been extensively studied over the past century (e.g. Lupton, 1916; Katich, 1953; Davis, 1954; Hale and Van De Graaff, 1964; Hale, 1972; Cotter, 1976; Ryer, 1980, 1981, 1984, 1994; Ryer and McPhillips, 1983; Gardner, 1993, 1995a, 1995b; Garrison and van den Bergh, 1997), and culminated with the publication of an AAPG memoir (Chidsey et al., 2004) that captures the current understanding. In contrast, the Lower Ferron, which is said to underlie the recent CBM fields, has been largely ignored.

The lower part of the Ferron Sandstone Member crops out in Castle Valley along the northwestern rim of the San Rafael Swell (SRS), southeast of Price, Utah. Castle Valley is bordered by the escarpment of the Wasatch Plateau to the east and the Book Cliffs to the north. The Ferron Sandstone Member outcrop stretches as a near-continuous ridge, cut by rivers and small canyons, south-southwest from the Book Cliffs for about 120 km to Indian Canyon in the south, and includes up to 180 m of Turonian to Cenomanian strata.

Data for the study include 55 geophysical well logs and 12 outcrops. Similar outcrop studies in this area include Katich (1953), Hale (1972), Cotter (1975), whereas Lyons (2001) and Henry and Finn (2003) studied the subsurface coal distribution in Castle Valley. The present model focuses on the Drunkards Wash CBM field, which is the largest field in Castle Valley and one of the most productive of its kind in North America (Montgomery et al., 2001). The coal-bearing deposits from which the methane gas is extracted are related to a large coal fairway in Castle Valley that stretches from beneath the Book Cliffs in the north to the Upper Ferron outcrops 100 km south.

In the Cretaceous, compressional plate movement and subsidence along the western coast of North America formed the Sevier Thrust fault (DeCelles, 2004), and in response to these thin-skinned tectonic forces, a foreland basin developed. Sediment shed from the Sevier Mountain belt were deposited along the western margin of the foreland basin, called the Western Interior Seaway.

During the Turonian, the foci of deposition were governed by the flexural subsidence of the foreland basin (Pang and Nummedal, 1995; DeCelles, 2004). Laramide tectonics later affected the Turonian deposits by uplifting their distal parts and tilting the strata in an opposite direction to that of deposition, away from the SRS monocline and underneath the Wasatch Plateau.

Two depositional sequences have been identified in the Late Cretaceous Turonian Ferron Sandstone Member (Fisher et al., 1993). The thin Lower Ferron Sandstone of the Vernal deltaic complex (Cotter, 1976; Ryer and Lovekin, 1986; Bhattacharya and MacEachern, 2009), which is the focus of the present study, crops out in the north of Castle Valley, while the Upper Ferron Sandstone of the Last Chance Delta (Hale, 1972) outcrops in the south around the I-70 highway and was initially defined by Lupton (1916) as paralic deposits in the coal fields near the towns of Ferron and Emery.

The Lower Ferron deposits were originally described by Cotter (1975) as a series of units that represent the earliest sandstone deposits within the Mancos Shale. The units are capped by a regional transgressive surface (Garrison and van den Bergh, 2004) that marks the end of the Lower Ferron Sandstone deposition, the hyatti sequence of Gardner (1995a), and the onset of the Upper Ferron Sandstone further south.

Lower Ferron Model

The motivation for building a model were threefold: 1) to understand and visualise the sequence stratigraphy and facies architecture within the Drunkards Wash CBM field; 2) to facilitate detailed correlation between the outcrops and the subsurface; 3) to visualise a largely unstudied clastic wedge in 3D, in order to further understand the detail of sediment transport and stacking patterns. The data used for building the model were the extensive well and outcrop log database and the surfaces mapped at outcrop. Given the high density of well data within the proximal part of the model, it can be considered highly deterministic and the extrapolated facies associations did not extend far from each given input data.

The geocellular model covers an area of 28 x 31 km and the Lower Ferron interval is 90 m thick on average. The maximum depth of the Ferron succession, seen where the model diverges the most from the Digital Elevation Model (DEM), is 1,843 m.

The model (Figure 1) shows a westward dipping package of strata which dives into the subsurface at a tectonic dip of 1-6 degrees and then flattens underneath the Wasatch Plateau away from the SRS. Minor bulges in the model are most probably related to small scale reverse faults documented by Burns and Lamarre (1997). No apparent repeated sections have been observed in the well data, although some of the wells show a relative thickening when compared to neighbouring well logs.

Individual parasequences (van Wagoner et al., 1990) are up to 60 m thick and the facies belts within them are up to 4 km wide (Figure 2a) The shorelines follows a relatively straight, north-northeast to south-southwest trend, in accordance with the conceptual model. Lateral variations along the strike of the shoreline are highlighted in the areas where the model is conditioned to a lot of well data: in spatial interval between the well logs and the outcrops, where surfaces are extrapolated, the facies boundaries are subject to the modelling algorithm rather than input data.

Various cross sections through the model show the facies stacking patterns and stratal architecture. Some of the cross sections are displayed with a simbox-grid. The simbox option is a way to simplify the 3D-model so that it is uniformly flattened, faults (if present) are neglected and the depth of the model is averaged. The result is a rectangular cube that does not correspond with the well log depth (Figure 2b), but offer a unique way to view and evaluate the cross sections. For the current model this results in the removal of the post-sedimentary deformation and tilt of the Lower Ferron, which enables a view into how the sedimentary package could have looked like at the time of deposition. It is important to bear in mind that this view of the model is flattened.

The model includes data that have been taken from both the subsurface and the adjacent outcrops. Using the model it is possible to visualize and QC the proposed relationships. The model illustrates that there is good conformity between the geocellular model, the field observations, and the conceptual understanding of shoreface architecture.

Extrapolating dipping strata, flooding surface and bentonite horizons all contribute to a reasonable basis for tying the subsurface correlation panels to the surface outcrops. 3D modelling serves as a powerful tool for such.

Discussion

Cross sections and maps highlight the progradational stacking patterns for PS1-PS3. The models also show the back-stepping to aggradtionally stacked PS4 at the top of the Lower Ferron. Note that PS4 contains a high proportion of channel bodies. This model differs from that proposed by Henry and Finn (2003), which suggested that sandstone in PS4 was all comprised of a transgressive shoreface deposit.

The model highlights the distribution of coal within the model. The major coal intervals are associated with PS2 and PS3. Coal layers are almost completely absent in the upper part of the model, where the channel sands dominate. This suggests that the rate of accommodation may have been too great for coal formation (Diessel et al., 2000).

Visualising the strata in 3D has implications for understanding the spatial relationships of the different stratigraphic elements. The present model suggests that the subsurface Drunkards Wash CBM-field is readily correlated to the outcrops in the northern part of Castle Valley. The lowermost parasequences pinches out within the CBM field and does not extend to the surface, while the three uppermost parasequences all extend to the Lower Ferron (Clawson and Washboard units) outcrops which is a new correlation, not previously proposed by former work (e.g. Cotter 1975; Ryer 1986; Henry and Finn, 2003).

The correlation panel below (Figure 3) summarises the interpretation for the parasequences in the outcrops; in the north the Clawson is equivalent to PS2 and the overlying Washboard is equivalent to PS3. The Farnham unit which includes the tidal channel complex within the Washboard is a possible expression of the sequence boundary at the stratigraphic turn-around between progradation and retrogradation (c.f. Edwards et al., 2005).

To the south, the main escarpment east of Castle Dale and the town of Clawson is the distal expression of PS4 rather than PS3. In that case the lithostratigraphic Clawson unit is now assigned to PS3 and the Washboard is PS4. PS2 does not extend this far south. This revised correlation has implications for understanding the stratigraphic evolution of the area.

The lower parasequence of the present outcrop study is thought to coincide with the Clawson unit of Cotter (1975). The sandstones are overlain by an interval of finer grained material related to the overlying parasequences which corresponds to the Washboard unit of Cotter (1975). However, the proposed relationship between the units Clawson and Washboard in northern Castle Valley does not fit with the conceptual model for the Lower and Upper Ferron units towards the south. The Washboard and Clawson both thin and become more distal south toward Jackass Flat and then disappear. A unit also called the Washboard reappears south of Castle Dale and thickens and becomes more sand rich towards the south before eventually thinning and pinching out underneath the Upper Ferron to the south. As it stands, the Washboard unit alters between proximal to distal deposits over short distances although there is an overall proximal to distal trend towards the south for both the Clawson and Washboard. This trend is then reversed in the Washboard south of the town of Clawson where the Washboard unit becomes more proximal and extends southward as far as I-70. The lower Clawson unit pinches out in the Tununk shale near the town of Emery.

Further, following the terminology of Cotter (1975), the units are named after type localities along the Lower Ferron escarpment instead of being descriptive of parasequences. For example, the unit named the Clawson unit is the most inconspicuous feature east of Clawson according to the present study. The terminology of Ryer (1994), Kf-Washboard, is the best fit with the correlation panel presented above, as it describes the unit of Cotter (1975) as a parasequence, and also notes that it is the most basinward expression of the Lower Ferron.

The model constructed in this study, based on outcrop and well logs, show a progradational through aggradational to backstepping, ascending shoreline (Helland-Hansen and Martinsen, 1996) divided into four distinct parasequences (Figure 4). The lowermost parasequence pinches out in the subsurface, while the three uppermost, prograding to backstepping shorelines are visible at outcrop-level, where they manifest themselves as the Clawson and Washboard units defined by Cotter (1975) and one additional parasequence (PS4). Katich (1953) suggested that the subsurface coal bearing strata is time equivalent to the lower shoreface deposits in outcrop and argued further that the lower Ferron shoreline was embayed. This was later contested by Ryer and McPhillips (1983). Other studies such as Thompson et al. (1986) have suggested that the Clawson and Washboard units represent the southern extent of longshore transported plumes derived from the north. Based on the model built, this study has shown that the subsurface interval in the Drunkards Wash CBM-field has its down-dip marine equivalent exposed along the western escarpment of San Rafael Swell in Castle Valley.

Conclusion

The relationship between the various outcrop units of the Lower Ferron, and its subsurface deposits, and the Upper Ferron cropping out around Ivie Creek is ambiguous. Visualizing the succession in 3D is a useful way to investigate some of the facies trends spatially and to relate the various data sets.

The study of distal deposits in outcrop correlated to subsurface deposits tectonically down dip of the outcrops resulted in a geocellular model for the younger, northern interval of the Ferron Sandstone Member, informally named the Lower Ferron Sandstone/hyatti sequence. This model yielded four distinct parasequences comprising the Lower Ferron. Three of which extends to the surface of northern Castle Valley, where they crop out along the San Rafael Swell. A full cycle of shoreline advance and retreat was recorded in this parasequence set, representing the transition from a highstand to a transgressive system tract with an ascending shoreline trajectory.

Correlations presented herein differ a great deal from the USGS study (Henry and Finn, 2003), which underestimates the importance of the lowermost progradation of the Ferron Sandstone Member. The apparent discrepancy between the studies stems from the dispute over the nature of this initial depositional cycle of the Turonian clastic wedge. The present study highlights that the Lower Ferron must have been a more pronounced depositional feature at its time of deposition. In fact, the model shows that the coal seams in the northern part of the Castle Valley CBM play belong to the paralic deposits of the Lower Ferron shoreline, rather than to the Upper Ferron. Instead of attributing the coal bearing strata to the Upper Ferron directly on top of Lower Ferron sandstones, this study found a more dynamic evolution from the northern Vernal deltaic complex to the southern Last Chance Delta. Additionally, it offers a different explanation for the southward extent of the Lower Ferron sandstone as a dynamic and gradually transitional shoreline deposit.

Although not directly stated, such a model would suggest that further coal deposits lie beneath the Wasatch Plateau in the south west.

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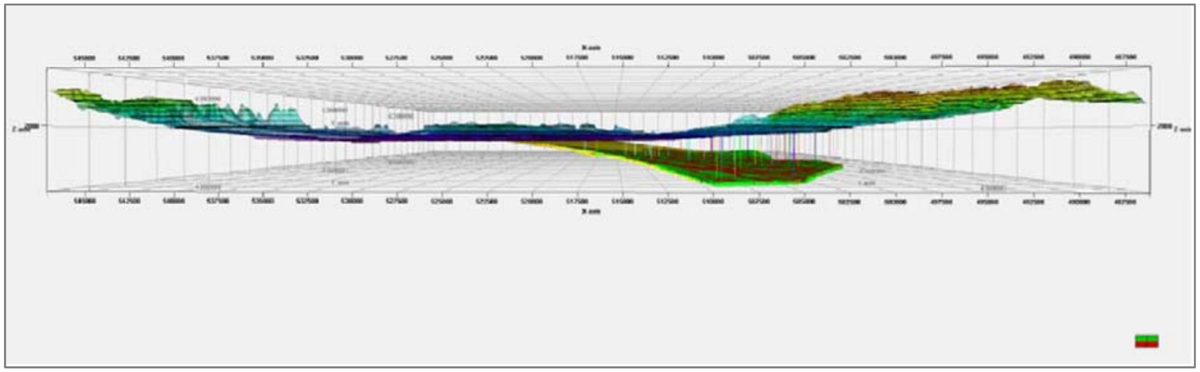

Figure 1. 3D model of the subsurface Lower Ferron Sandstone beneath the Castle Dale topography. Vertical exaggeration is x3, and view to the south.

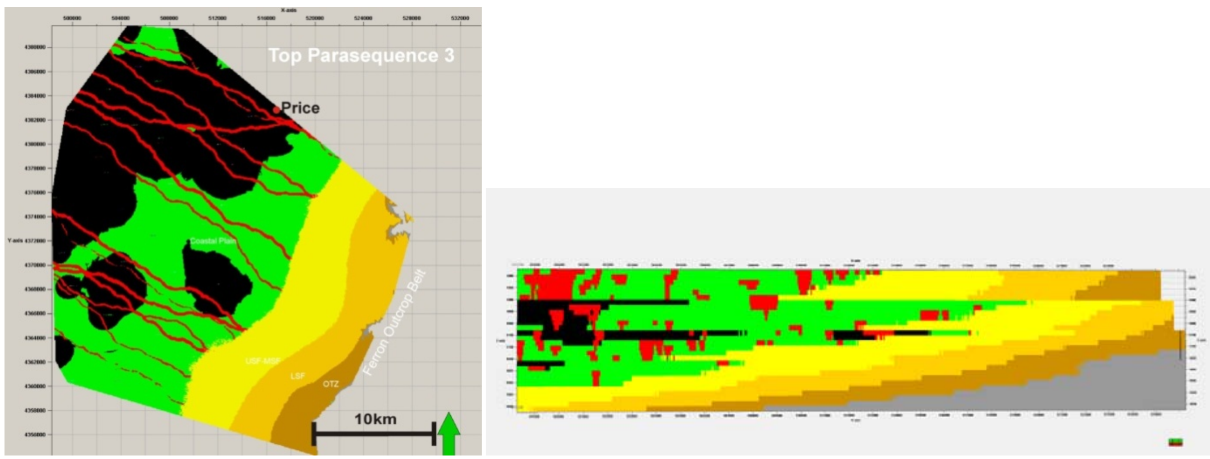

Figure 2. a) Plan view of the third parasequence interpreted in the Lower Ferron Sandstone. Colour code refers to facies associations, as follows -red: channel sandstone; black: coal; green: coastal plain; yellow: upper shoreface; deep yellow: lower shoreface; brown: offshore transition zone; grey: offshore. b) Simbox profile through the model.

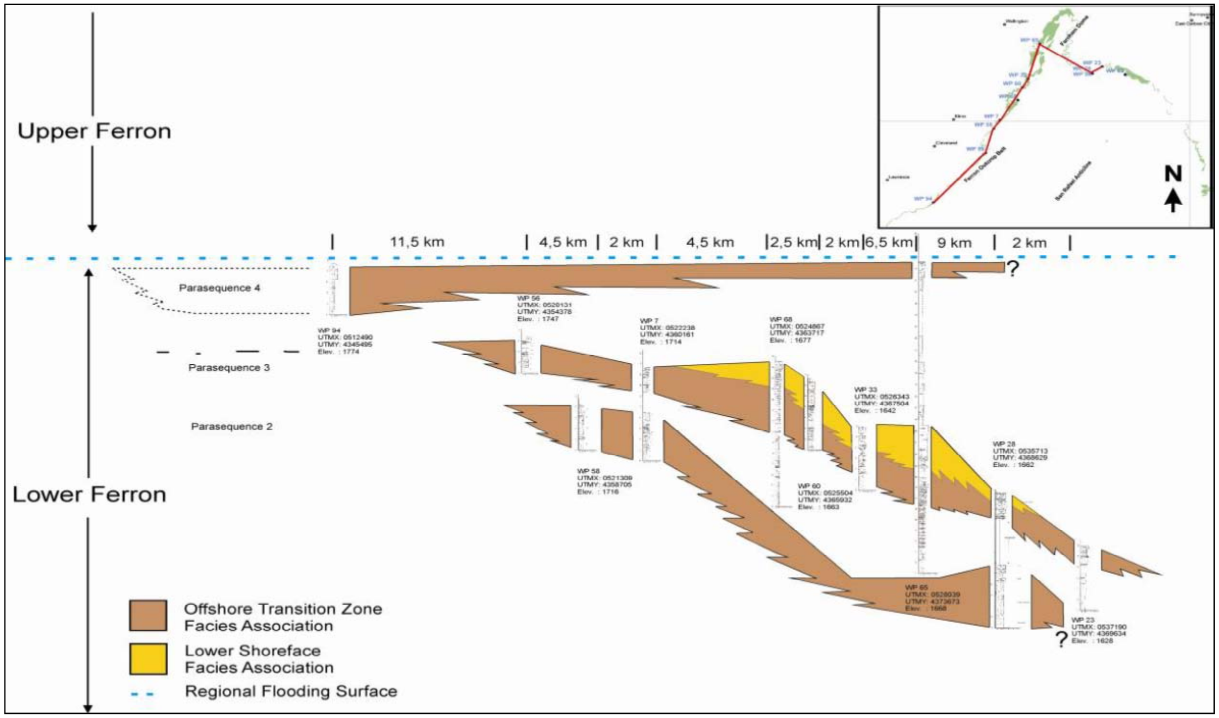

Figure 3. Correlation panel that illustrate the proposed relationship for the parasequences as they appear in outcrops along the northeastern part of Castle Valley, Utah.

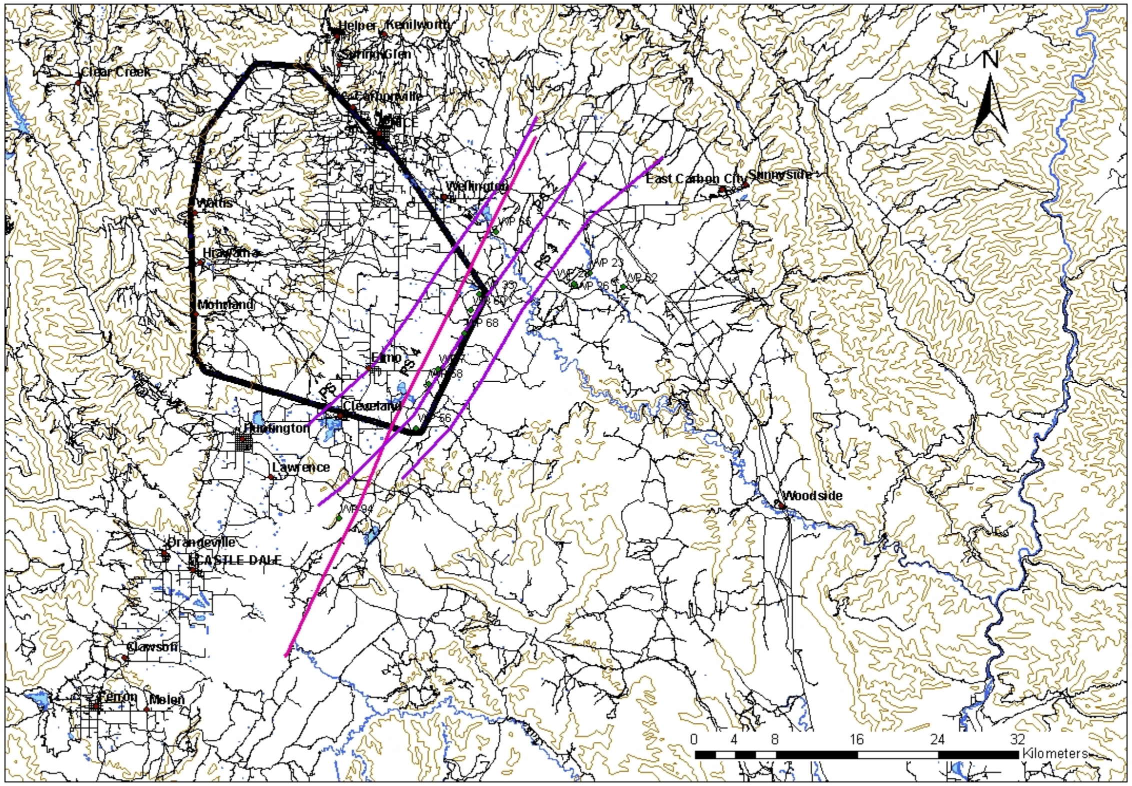

Figure 4. Map of the northern Castle Valley. Purple lines indicate the successively more basinward position of the Lower Ferron shoreline as the system prograded to the southeast, whereas the pink line indicate the position of the fourth, final and backstepping parasequence of the Lower Ferron. Heavy black line is the outline of the 3D model, which boundary is given by the Drunkards Wash CBM well log data and, in the most southeast position, logs from outcrop.