INCISED VALLEY SYSTEMS AND REGIONAL SEQUENCE STRATIGRAPHY OF THE NOTOM DELTA, HENRY MOUNTAINS REGION, UTAH

by

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ABSTRACT

The Ferron Sandstone represents the east and northeast ward progradation of several fluvial-deltaic systems, including the Notom system, from the Sevier orogenic belt to the western margin of the Western Interior Cretaceous Seaway during the mid-late Cretaceous. This sandstone is well exposed in the Wasatch Plateau, the Henry Mountain region, and in the Kaiparowits Plateau in central-east, southeast, and south-central Utah respectively. Tremendous studies, including both detailed facies architecture and regional stratigraphy, have been done on the Last Chance Delta in the Wasatch Plateau. However, surprisingly, the Notom Delta, which is only 65 km away from the Last Chance Delta and is especially well exposed on the canyon cliffs in the Henry Mountains region, southeast Utah, has been largely ignored by previous workers.

Previous stratigraphic studies have recognized seven sequence boundaries in the Ferron sandstone, none of which are the same. This stratigraphic chaos has been partially induced by the heated debate on whether or not there are incised valley systems in the Ferron.

The current regional sequence stratigraphy study of the Notom Delta in the Henry Mountains region is the first effort to repackage this fluvial-deltaic system in a depositional sequence stratigraphic perspective. The first stage of fieldwork has measured 27 sections and recognized 9-10 parasequences and a clear incised valley system, the bottom of which is a candidate sequence boundary. It has been traced continuously over at least 4 km. Based on detailed field observation and mapping， the incised valley system will be further mapped， and the candidate sequence boundary and key surfaces will be further traced in the study area. All these will help to establish a depositional sequence stratigraphic framework in the Notom fluvial deltaic system. Petrographic studies will be performed to make a primary analysis of the reason for the dynamic change in sedimentation during the deposition of this system in this region.

The current sequence stratigraphic study of the Notom Delta could provide a framework for further sedimentology and more detail facies architectural analysis. More importantly, it will contribute to tie the stratigraphic studies of the Ferron sandstone in south-central Utah together to understand the controls of dynamic tectonic activities, relative sea level change, and change in sediment supply on the development of depositional sequences in foreland basins or even in the subbasins of a foreland area.

INTRODUCTION

Incised valleys are defined as “Elongate erosional features larger than a single channel” (Dalrymple et al., 1994, Willis, 1997). They are important for sequence stratigraphic studies because they typically mark regional unconformities of sedimentary basins and form sequence boundaries (Van Wagoner et al., 1988, 1990, Allen and Posamentier, 1993). Incised valley fills are also of particular interest because they represent an important class of petroleum reservoir (Van Wagnor et al., 1990, Zaitlin et al., 1994). Despite their importance, recognition of a single channel belt vs. incised valley systems can be a challenge, and there remain a relatively small number of convincing outcrop examples.

Channels, channel belts, and fluvial incised valleys are large scale fluvial forms that could be easily confused in the field. Channels are the building elements of channel belts and fluvial incised valleys. They usually have associated overbank deposits. Passive channel-fill elements represent filling of the channels during avulsion and abandonment (Bridge, 1993, 2003). The concept of a channel belt is well established (Allen, 1978, Bridge and Leeder, 1979, Miall, 1996). It represents a history of channel avulsion, abandonment, reoccupation, and/or changes in discharge. Channel belts are composed of channels and bars and could be highly amalgamated, multistory and multilateral. But channel and bar deposits within a channel belt could also interfinger with adjacent floodplain mud. Fluvial incised valleys are even larger fluvial form with channel belts and floodplains contained within it. Van Wagoner et al. (1990) documented the response of fluvial systems and the formation of incised valleys as a function of coastal plain and shelf gradient during a relative sea-level fall. Certain criteria for recognizing incised valleys include erosional relief, stratal truncation and onlapping, and interfluve paleosoil (Van Wagoner et al., 1988, 1990, Zaitlin et al., 1994). However, in many cases, recognizing incised valleys based on these criteria could be extremely difficult because of outcrop limitations and potential erosion during later shoreline transgression (Van Wagoner et al., 1988, 1990). Bhattacharya and Tye (2004) provided a more quantitative method to separate incised valleys and distributary channels based on comparison between total depth of incision and calculated bankfull water depth. However, to make more precise calculation, well preserved bed forms, bar forms, or channel forms are needed.

Recent studies of fluvial deposits in the Ferron sandstone have been variably interpreted as distributary channels and incised valleys (Bhattacharya and Tye, 2004, Garrison and van den Bergh, 2004, Moiola et al., 2004). The difficulties in separating incised valleys from channels and channel belts in outcrops have, to a large extent, led to chaos in sequence stratigraphic analysis of the Ferron sandstone (Ryer, 2004). The study area lies in the Henry mountains region, southeast Utah (Fig. 1). Outcrop reconnaissance shows well-developed incised valley systems, superbly exposed more or less in a strike direction along canyon cliffs of the Ferron sandstone in the Henry Mountains area of Utah. This research aims to tackle these difficulties and reconcile the current chaos in sequence stratigraphic studies of the Ferron.

PREVIOUS STRATIGRAPHIC STUDIES OF THE FERRON SANDSTONE

The Ferron sandstone is a fluvial-deltaic clastic wedge deposited in a rapidly subsiding retroarc foreland basin which rimmed the western margin of the Western Interior Cretaceous Seaway during the mid-late Cretaceous (Fig.2). It was first named by Lupton (1916) in his studies on the coal resources in the Castle Valley, Emery, Utah, and described it as a member of the Mancos Shale. The sandstone is bound above and below by the Blue Gate Shale Member and the Tununk Shale Member of the Mancos Shale Formation respectively (Fig.3). In Utah, USA, The sandstone outcrops mainly in the Wasatch Plateau, the Henry Mountain region, and in the Kaiparowits Plateau in central-east, southeast, and south-central part of the state respectively.

Stratigraphic studies on the Ferron sandstone started in the late 1800's and early 1900's and become accelerated during the 1950's after the discovery of natural gas at Clear Creek field on the Wasatch Plateau. More detailed and comprehensive stratigraphic studies of the Ferron sandstone are represented by Ryer (1981a, 1984), Ryer et al., (1980), Ryer and McPhillips (1983), Gardner (1995a, 1995b), Garrison et al. (1997), and Garrison and van den Bergh (2004). Ryer and his colleagues recognized seven coarsing upward "delta-front" cycles bounded by flooding surfaces and associated coals in the Last Chance Delta (Fig. 4). Gardner (1995a, 1995b) made a more comprehensive study of the nature of the cyclicity in the Ferron and showed a hierarchy of cycles related to base-level change. The Ferron represents a long term 3rd order cycle of Vail et al. (1977). Four intermediate term cycles named after characteristics fossils are recognized. The upper Ferron sandstone was subdivided into seven genetic sequences, bounded by the base-level fall and rise turnaround. An essential conclusion of Gardner's work (1993, 1995a) is that there are no unconformities in the Ferron. Garrison and van den Bergh (1997, 2004, inpress) conducted a detailed depositional sequence stratigraphic study of the Ferron sandstone and subdivided the fluvial-deltaic Last Chance Delta complex into at least 42 parasequences, 14 parasequence sets, and four unconformity bounded depositional sequences (Fig. 5). Three of the recognized sequence boundaries (SB2, SB3, and SB4) have associated incised valley systems (Garrison and van den Bergh, in press). Various papers in Chidsey and Morris (2004) detail the sedimentology, stratigraphic, and reservoir characteristics of the Last Chance Delta.

Compared with these extensive and detailed studies on the Last Chance Delta, the fluvial-deltaic system in the Henry Mountains region (informally named as the Notom Delta by Hill, 1982) has largely been ignored. The first important geological investigations of the study area dates back to Gilbert (1887). He documented the general stratigraphy of this region, and named the sandstone above the Tununk shale as the Tununk Sandstone. Hunt and Miller (1946) and Hunt et al. (1953) studied the Ferron sandstone in this region and noticed the interfingering of the Ferron sandstone with the Mancos shale. Peterson and Ryder (1975) documented the Cretaceous rocks in the western and southwestern part of this region, and made an attempt to correlate them with neighboring regions. Based on lithostratigraphy and molluscan paleontological analysis, they subdivided the Ferron sandstone into a nearshore marine dominated lower unit and a more fluvial dominated upper unit and assigned a late middle and earliest late Turonian age to the lower unit. The age of the upper unit is not clear. Considering the interfingering of the marine lower unit and the nonmarine upper unit, they inferred that the nonmarine upper unit is no younger than earliest late Turonian.

MAJOR PROBLEMS

- **Are there incised valley systems in the Ferron fluvial-deltaic systems?**

Answering this question is critical because the bottom of the incised valleys, across which there is usually a marked basin ward shift in facies, is a candidate sequence boundary. As of yet, there is no consensus on whether or not there are incised valleys in the Ferron fluvial-deltaic systems. Incisions up to 25 meters deep and hundreds of meters wide in the Ferron are interpreted to be distributary channels by Moiola et al. (2004), while others have interpreted them to be incised valleys

(Bhattacharya and Tye, 2004, Garrison and van den Bergh 2004). Dalrymple et al. (1994) and Willis (1997) define incised valleys as “Elongate erosional features larger than a single channel”. Based on this definition, many big incisions in the Ferron, previously interpreted as distributary channels, have now been reinterpreted to be incised valleys. A major incision recognized in the Notom fluvial-deltaic system is up to 25 meter deep and could be traced continuously at least 4 kilometers. There is a marked basin ward shift in facies from lower shoreface environment to fluvial environment across the bottom of the candidate valley system (Fig. 6).

- **Sequence boundary and the chaos in Ferron stratigraphy**

Five studies have recognized seven depositional vs. genetic sequence boundaries in the Ferron fluvial-deltaic complex, none of which are common (Barton and Tyer, 1995, Schwans, 1995, Shanley and McCabe, 1995, van den Bergh and Sprague, 1995, Garrison and van den Bergh, 1996). Several questions arise, do any of these boundaries have regional significance? If any one of them does, can we correlate it through different fluvial-deltaic system or are all of these boundaries higher order boundaries restricted to individual systems? Another candidate sequence boundary, at the bottom of the incised valley in the Notom fluvial-deltaic system, has been recognized during the first stage of field work in this study. Is this one the same as any one of the boundaries recognized above, or is it another higher order boundary that is restricted to the Notom fluvial-deltaic system itself? Any effort to the answers will help to decipher the development of depositional sequence in the dynamic foreland basin environments. The Notom fluvial-deltaic system lies in-between the Last Chance system and the Ferron sandstone in the Kaiparowits Plateau. To understand the nature of the candidate sequence boundary and establish a regional sequence stratigraphic framework will help to tie the various regional sequence stratigraphic hypotheses of the Ferron fluvial-deltaic systems together.

MAIN PURPOSE OF THIS STUDY AND METHODOLOGY

Depositional sequence stratigraphic studies overcome the disadvantage of lithostratigraphic units, which are commonly diachronous, in that it repackages rock bounded by unconformities and their correlative conformities into a chronostratigraphic framework (Van Wagoner et al., 1988, 1990). The main purpose of this study is to map the incised valley system and to establish a regional sequence stratigraphic framework in the Notom Delta for further detailed sedimentology and facies architecture analysis and to make a primary analysis of the factors controling the development of the delta in a comparative view.

Detailed field mapping is the essential method in this study. In the northeast and east of the Henry Mountains, the Notom Delta is well exposed in a dip direction along the north and south Caineville cliffs and in a more or less strike direction along Neilson Wash, Factory Bench, and the Blue Valley Bench cliffs. In the west and southwest of the Henry Mountains, the delta is also well exposed (Fig. 1). These outcrops are especially suitable for detailed field studies and regional mapping. Shoreline activities during the deposition of the Notom Delta could be easily observed in the dip direction, and mapping of the incised valley system could be easily conducted in the strike direction. The valley system exposed along the Neilson Wash cliffs have been continuously traced for 4 km. Ravinement surfaces with clear transgressive lags in the lower marine section of the delta have been traced 10 km from Neilson Wash to the Blue Valley Bench. Thin bentonite layers could also be traced a long distance. If these key surfaces and markers could be traced to the west and southwest of the Henry Mountains, it will become much easier to understand the regional stratigraphy. Next summer, measuring sections, tracing the incised valley systems and other key surfaces will be expanded to the west and southwest of the Henry Mountains. A 3D mapping of the valley floor using GPS equipment will be conducted next summer to better characterize the morphology of the bottom of the incised valley. Primary petrographic analysis will be used to get information about the tectonic and climatic background for the development of the incised valley systems.

Filed work equipments are fully loaded, including field vehicle, scintillometers digital cameras, rock hammers, hand lens, grain size card, a complete range of technical climbing gear, tape measure, as well as a new state-of-the-art Trimble RTK/GPS digital mapping system with a Laser Atlanta Reflectorless Rangefinder. All these equipments will be used in next summer's field work.

SCIENTIFIC RELEVANCE

Sequence stratigraphy of foreland basins is a complex topic since local thrusting, uplift and basinal downwarping largely govern the highly uneven lateral change in accommodation, sediment supply, and relative sea-level change, which in turn controls the development of depositional sequences and the wide variability in the stratal stacking patterns (Krystinik and Dejarnett, 1995, Schwans, 1995, Shanley and McCabe, 1995). Seven sequence boundaries have been recognized in the Ferron sandstone Last Chance Delta and in the Kaiparowits Plateau, but their regional extent and significance has not been addressed. Gardner (1995a) has documented progressively north-south migration of mid-Cretaceous depocenters across Utah and migration of his Ferronesis sequence from southern to central Utah. This rapid shift of depocenters in foreland basins is probably the dominant factor that controls the development of sequences, the occurrence of different scales of sequence boundaries and their regional significance. Primary field work in the study area has recognized a clear incised valley system and a candidate sequence boundary. A systematic regional mapping and sequence stratigraphic study in this area could not only establish a chronostratigraphic framework for future sedimentology and detail facies architectural analysis but also could provide an outcrop example of a superbly exposed incised valley system. More importantly, the study could contribute to tie the Ferron fluvial-deltaic systems in central-south Utah together to understand the complex variables that control the development of sequences in foreland basins.

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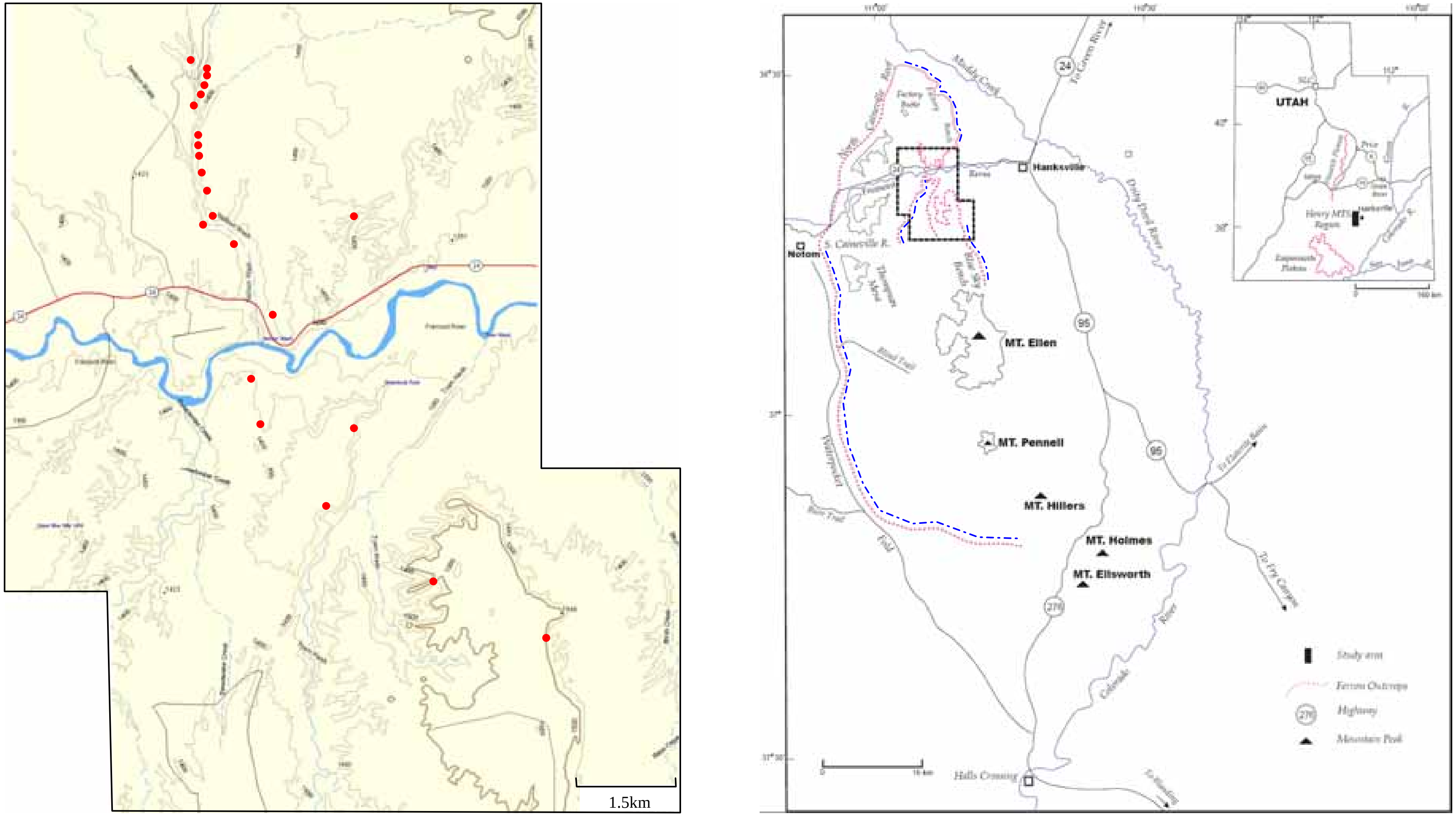

Fig. 1 map showing the location of the study area, the main Ferron outcrops in the central-south Utah and the Henry Mountains region. Measured sections are shown as red solid circles. Dashed blue lines show the intended working area next summer.

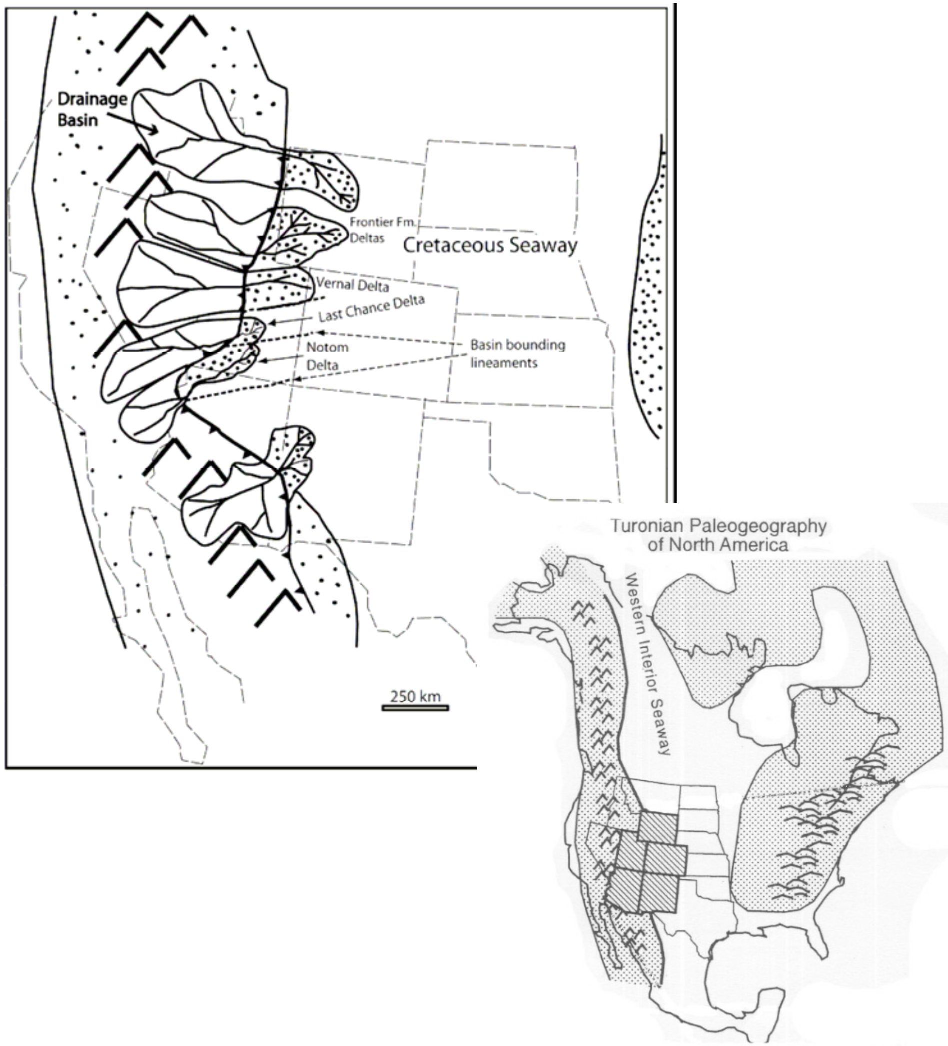

Fig. 2 Turonian paleogeography of North America and the location of the mid-Cretaceous clastic wedges (From Gardner, 1995a, Bhattacharya and Tye, 2004)

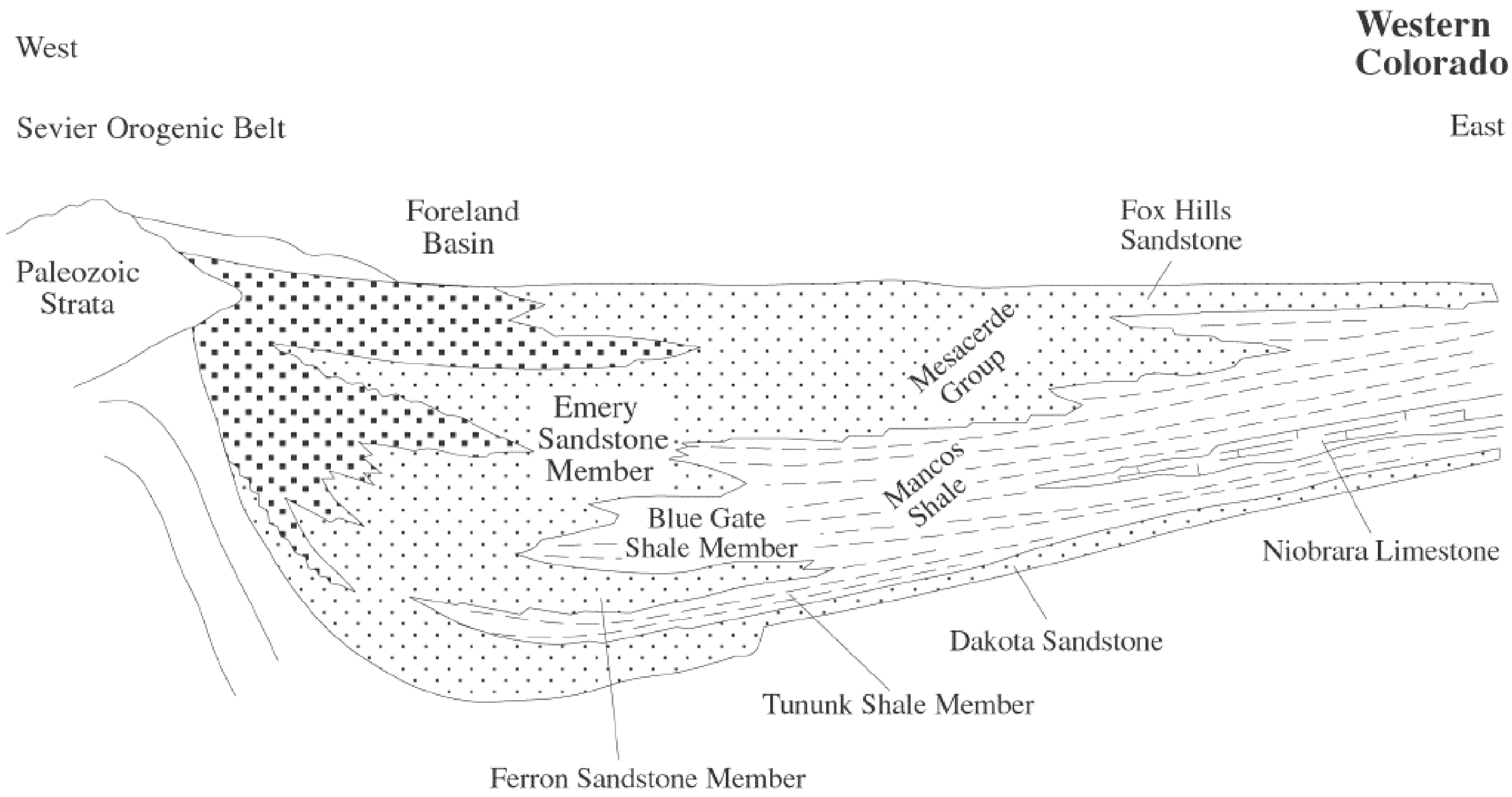

Fig. 3 Cross section showing the general stratigraphy of the Cretaceous strata in central Utah, the position of the Ferron fluvial-deltaic clastic wedge and its stratigraphic relation with the Mancos Shale Formation (From Barton et al., 2004)

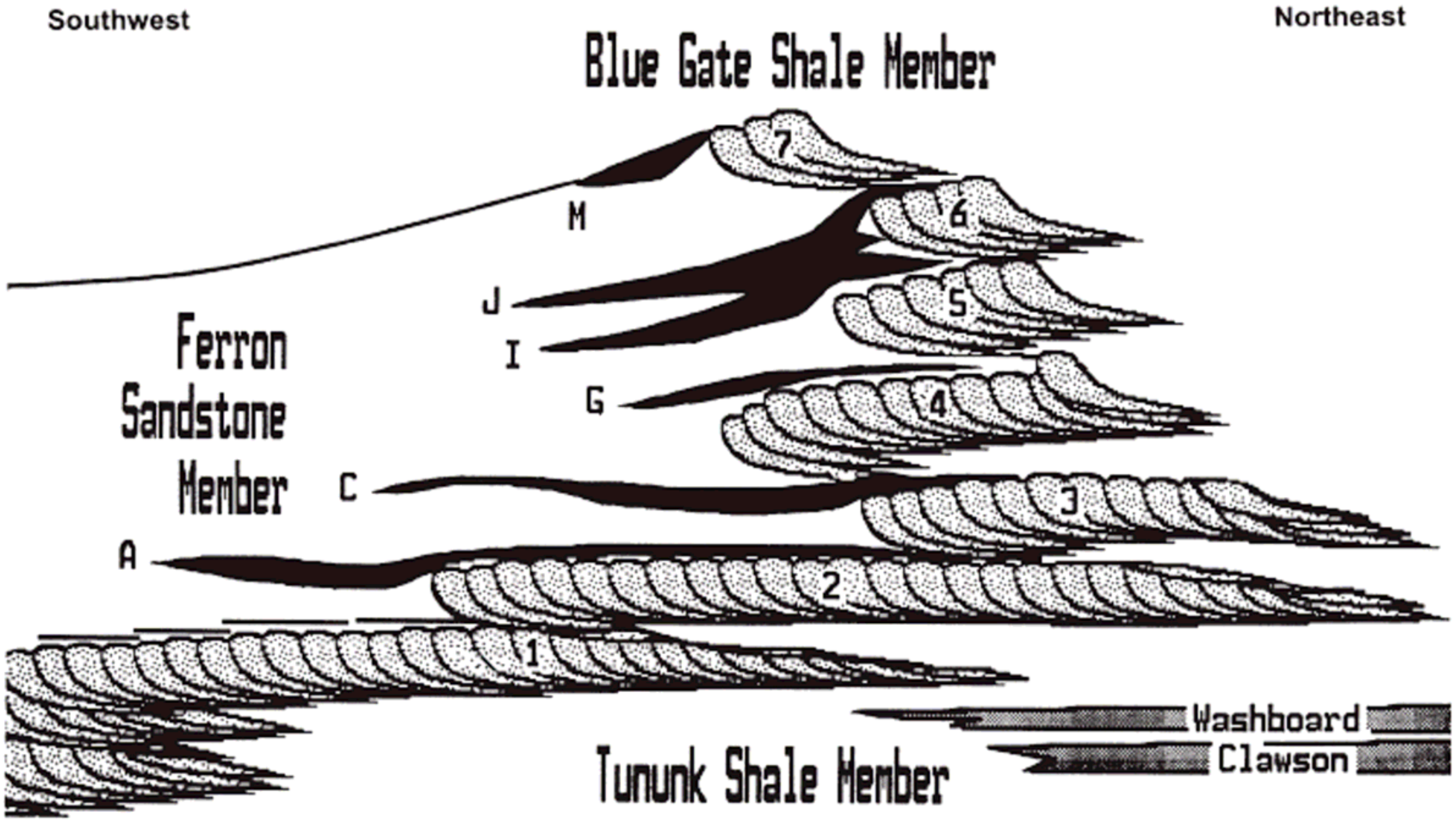

Fig. 4 Cross section of the Ferron in the southern part of Castle Valley showing delta-front units and their associated coal zones (From Ryer, 1984)

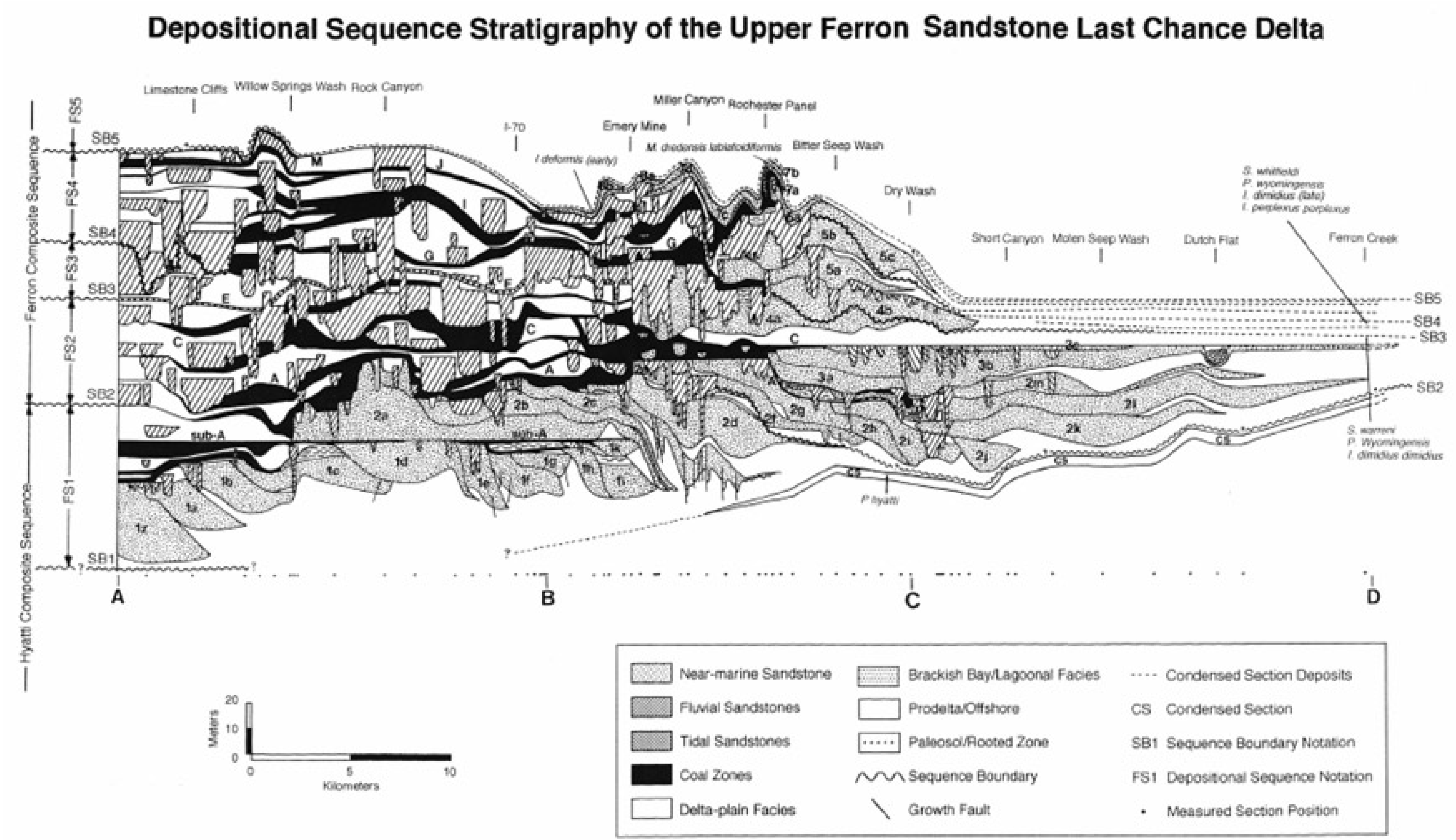

Fig.5 Ferron Sandstone stratigraphic framework from Garrison and van den Bergh (2004). Note that three subaerial, erosional unconformities and their associated incised valleys are recognized. They, coupled with two other undefined unconformities in the lower Tununk Shale and overlying Blue Gate Shale, are interpreted to be sequence boundaries that define three 4rd order and one composite sequences. The study recognized at least 42 parasequences and 14 parasequence sets.

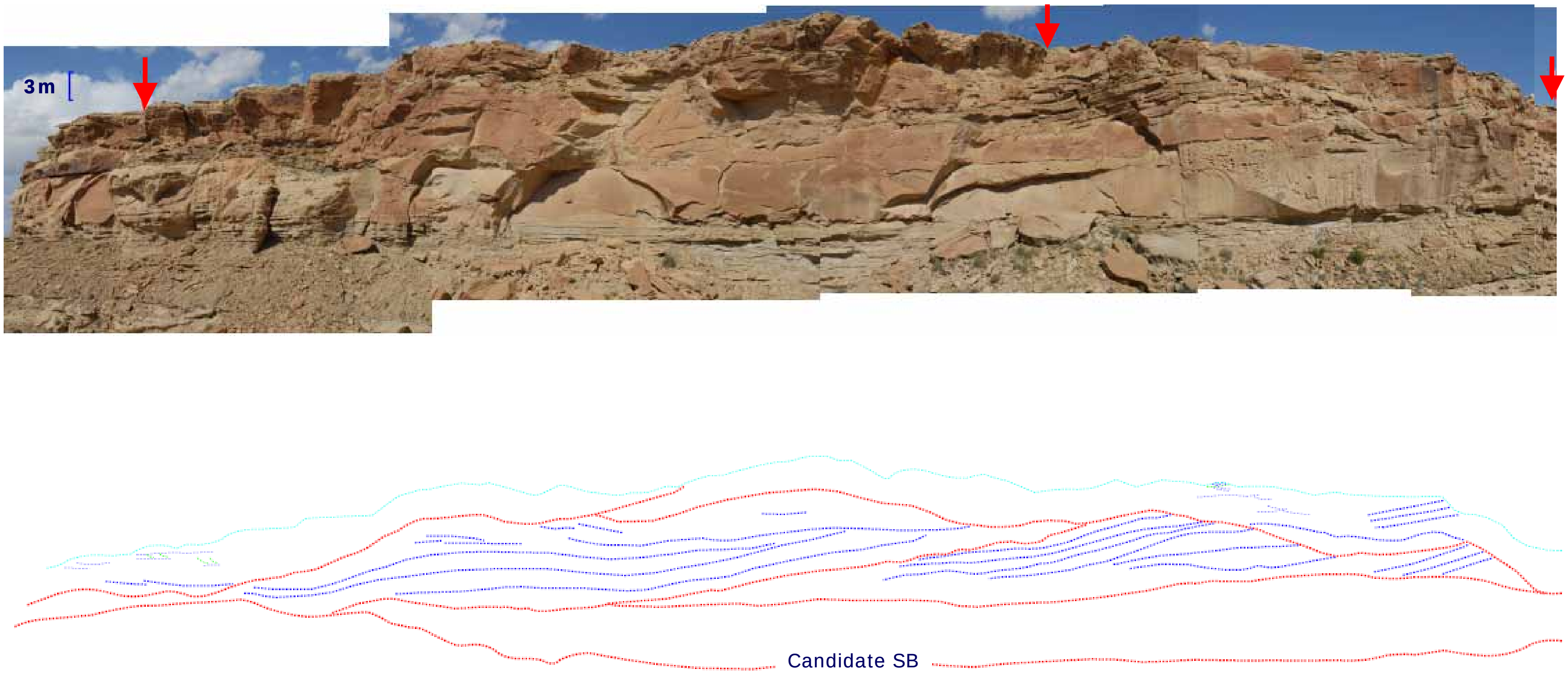

Fig.6 Incised valley systems have been recognized in the Ferron sandstone, Notom Delta. The valley cuts down into the underlying lower shoreface marine succession and is filled dominantly with multistory fluvial sandstone. Total thickness of valley fill is up to 25 m. The erosional surface at the bottom of the valley, the candidate sequence boundary, has been traced continuously over at least 4 km. Arrows show the location of measured sections.