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Shoreline Architecture and Sequence Stratigraphy of Campanian Iles Clastic Wedge, Piceance Basin, CO: Influence of Laramide Movements in Western Interior Seaway

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Shoreline Architecture and Sequence Stratigraphy of Campanian Iles Clastic Wedge, Piceance Basin, CO: Influence of Laramide Movements in Western Interior Seaway

by

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Dedication

To my mother Songül Karaman, my father Selçuk Karaman and my brother Eren Karaman

Acknowledgements

I am indebted to many people for their help and support during my study, but first and above all, I would like to thank to my supervisor Professor Ronald J. Steel for his invaluable guidance, encouragement and patient; without his guidance and teaching, this research would not have been finished. I would like to acknowledge committee members, Dr. William Fisher and Dr. Cornel Olariu for their reviews and suggestions. This research was funded by Turkish Petroleum Corporation (TPAO in Turkish) and could not have been possible without financial support by TPAO.I especially thank Safiya Hassan for her friendship, encouragement and her great help during the fieldwork. I would also like to thank to Timothy H. Prather for fieldwork assistance. I am also thankful to Dr. Mariana lulia Olariu and Joseph Sung-Ling Yeh for their comments and technical support with *Petra software*. I thank everyone in Dynamic Stratigraphy Workgroup and all my other friends in University of Texas.

Finally, I want to thank to my parents and my brother for always encouraging me and trusting in me to succeed my aims.

Abstract

Shoreline Architecture and Sequence Stratigraphy of Campanian Iles Clastic Wedge, Piceance Basin, CO: Influence of Laramide Movements in Western Interior Seaway

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The University of Texas at Austin, 2012

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The Campanian Iles Formation of the Mesaverde Group in northwestern Colorado contains a stacked series of some 11 shoreline sequences that form clastic wedges extending east and southeastwards from the Sevier orogenic belt to the Western Interior Seaway. Iles Formation shorelines and their alluvial and coastal plain equivalents (Neslen Formation, Trail and Rusty members of the Ericson Formation) are well exposed from Utah and from southern Wyoming into northwestern Colorado. The Iles Clastic Wedge was examined in the subsurface Piceance Basin and at outcrops in Meeker and south of Rangely, NW Colorado. The clastic wedge contains low-accommodation regressive-transgressive sequences (8-39 m thick) of Loyd Sandstones, Sego Sandstone, Corcoran Member, and Cozzette Member and their updip-equivalent Neslen Formation strata.

Facies associations of the sandstone succession indicate storm-wave dominated coasts that transition seaward into offshore/prodelta mudstones with thin-bedded sandstones and extend landward into tidal/fluvial channels and coal-bearing strata; facies associations also indicate interdeltaic coastal embayments with moderate tidal influence. 14, 75-km-long Piceance Basin transects (dip and strike oriented) makes it possible to evaluate coastline variability, and the progressive southeasterly pinchout of the 11 coastline tongues within the larger Iles Clastic Wedge. The thickness and great updip-downdip extent of the Iles stratigraphic sequences (compared to the underlying Blackhawk or overlying Rollins sequences) support previous observations of a low accommodation setting during this time. It has been suggested that this low accommodation was caused by combined effects of embryonic Laramide uplifts and Sevier subsidence across the region. Uplift or greatly reduced subsidence across the Western Interior Seaway would have caused an increase in coastal embayments as well as generally accelerated coastal regressions and transgressions in this 3.3 My interval.

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CHAPTER 1: INTRODUCTION & GEOLOGIC SETTING

The Iles Formation of the Mesaverde Group in northwestern Colorado contains a stacked series of some 11 shoreline tongues that together form the Iles Clastic Wedge. Masters (1966) divided the Iles Formation into lower and upper parts. The lower part includes from Loyd Sandstone of Mancos Shale to Rollins Shale base and represents most of the Iles Formation. The upper part of Masters (1966) Iles Formation consists of Rollins Sandstone (or Trout Creek Sandstone) and these are the last regressive deposits of the region. Crabaugh (2001) included only the lower part of this succession as his Iles Wedge (Wedge 3 of Crabaugh) and this convention (also used by Gomez and Steel, 2010) is followed here. The same stratigraphic interval in the Book Cliffs area was named Wedge B by Aschoff and Steel (2011).

The Iles Clastic Wedge in the northern Piceance Basin (Rio Blanco County) (Fig. 1.1) contains low-accommodation regressive-transgressive tongues of Loyd, Sego, Corcoran and Cozzette Sandstones and occurred over a period of some 3.3 My based on the excellent published ammonite biostratigraphy for this succession (Fig. 1.2). In the study area (Meeker to Rangely) two major shoreline types are identified: deltaic and interdeltaic embayed shorelines. In deltaic shorelines, facies successions vary from marine shale at the base to prodelta siltstone mudstone and then delta-front sandstone. The delta-plain facies includes sandy fluvial and tidal-fluvial distributary channels and coals. However, interdeltaic embayed shorelines contain barrier-island systems associated with flood-tidal deltas, tidal flats and tidal sand bars, fluvial channels and flood plain deposit. The deltaic shorelines are observed commonly in the Meeker outcrops, whereas embayed shorelines are observed especially near Rangely (Noe, 1984; Stancliffe, 1984). The present study shows along-strike variation of the Iles Clastic Wedge in the Piceance

Basin and incorporates both well-log correlations and detailed analysis of outcrops around Meeker and Rangely (Fig. 1.3).

PREVIOUS WORKS

The deposits of the Iles Clastic Wedge and its temporal equivalents are well exposed in the Sand Wash Basin and the Piceance Basin in Colorado (Masters, 1966; Noe, 1984). Previous work has been completed on depositional systems and sequence stratigraphy of the deposits of Iles Formation in the wave-dominated Sand Wash Basin (Crabaugh 2001; Gomez 2009) and tide-dominated neighboring areas of the Book Cliffs as far east as Grand Junction (Kirschbaum and Hettinger 2004; Aschoff 2008). However, not much has been published on the Iles depositional systems or on the sequence stratigraphy in the main central and northern parts of the Piceance Basin, and in the Meeker-Rangely areas of Colorado.

Wave dominated deposits of the Iles Clastic Wedge in the Sand Wash Basin were first well defined by Crabaugh (2001). He documented the geometry, architecture, and the shoreline trajectory of low-accommodation, regressive sandstone tongues of the lower Iles Formation (Iles 1-9 tongues) based on detailed outcrop data. Gomez (2009) extended Crabaugh's work to the upper portion of the Iles Formation; she also studied the landward reaches of the wedge in the Rock Springs region of Wyoming by integrating subsurface well-log data and outcrop data. Gomez suggested that the lower regressive shorelines of the Iles were wave dominated and the upper transgressive shorelines were tide influenced.

In the Book Cliffs of Utah and the southernmost Piceance Basin, Kirchbaum and Hettinger (2004) analyzed the sequence stratigraphy of the Upper Campanian strata. They defined six sequences incorporating the sandstone units of the Sego Sandstone, Neslen

Formation, Corcoran, Cozzette and Rollins Members of the Mount Garfield Formation. These sequences, which are bounded by erosional surfaces, were formed by mild incision on the shoreface deposits by large channels (incised valleys); the incised valleys later were filled by tidally influenced strata during transgression (Willis and Gabel, 2001).

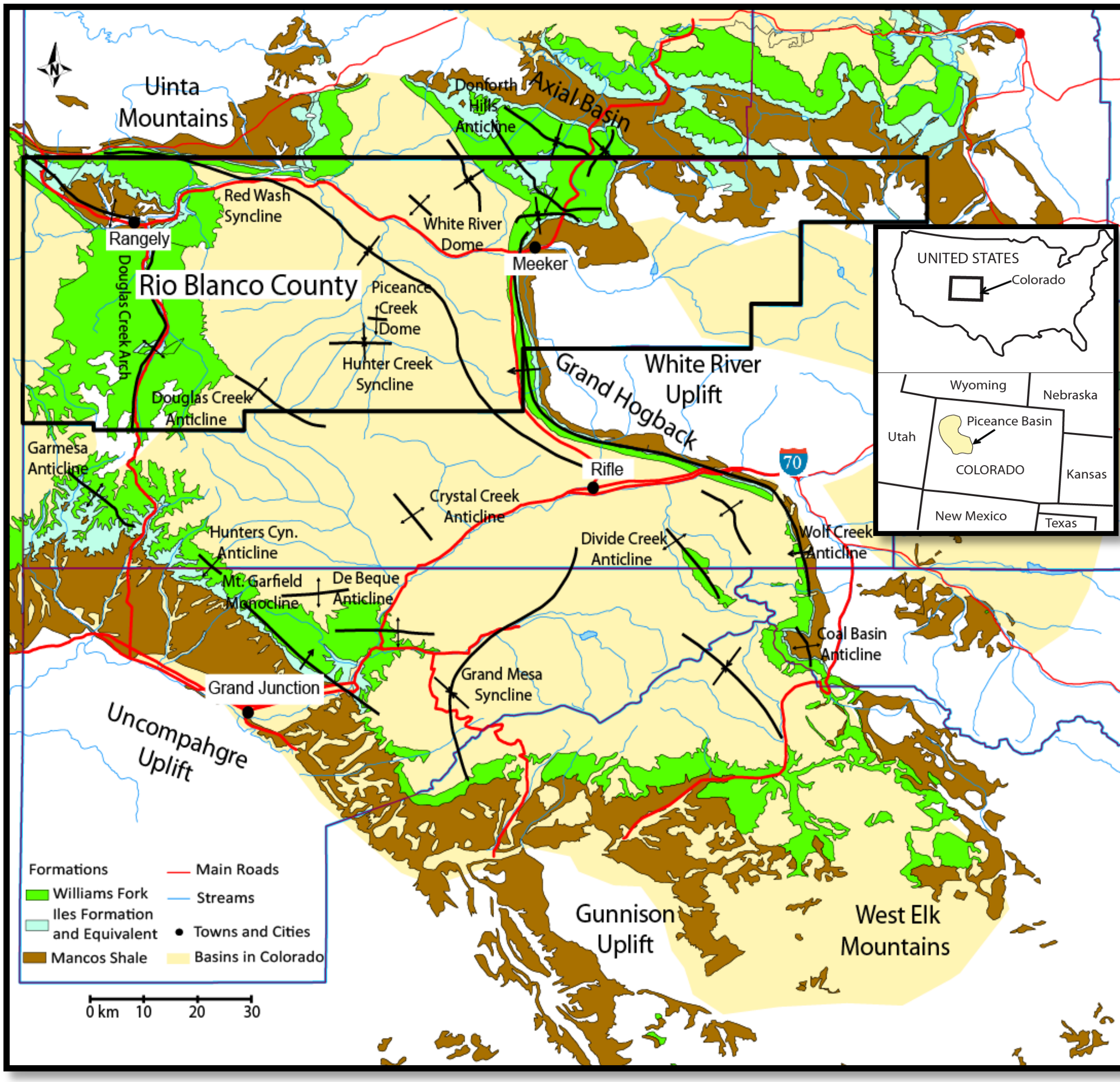


Figure 1.1: Location of the Piceance Basin and neighboring formations. Rio Blanco County (black box) is within the northern part of the Piceance Basin (Modified from a map compiled by Julio Leva).

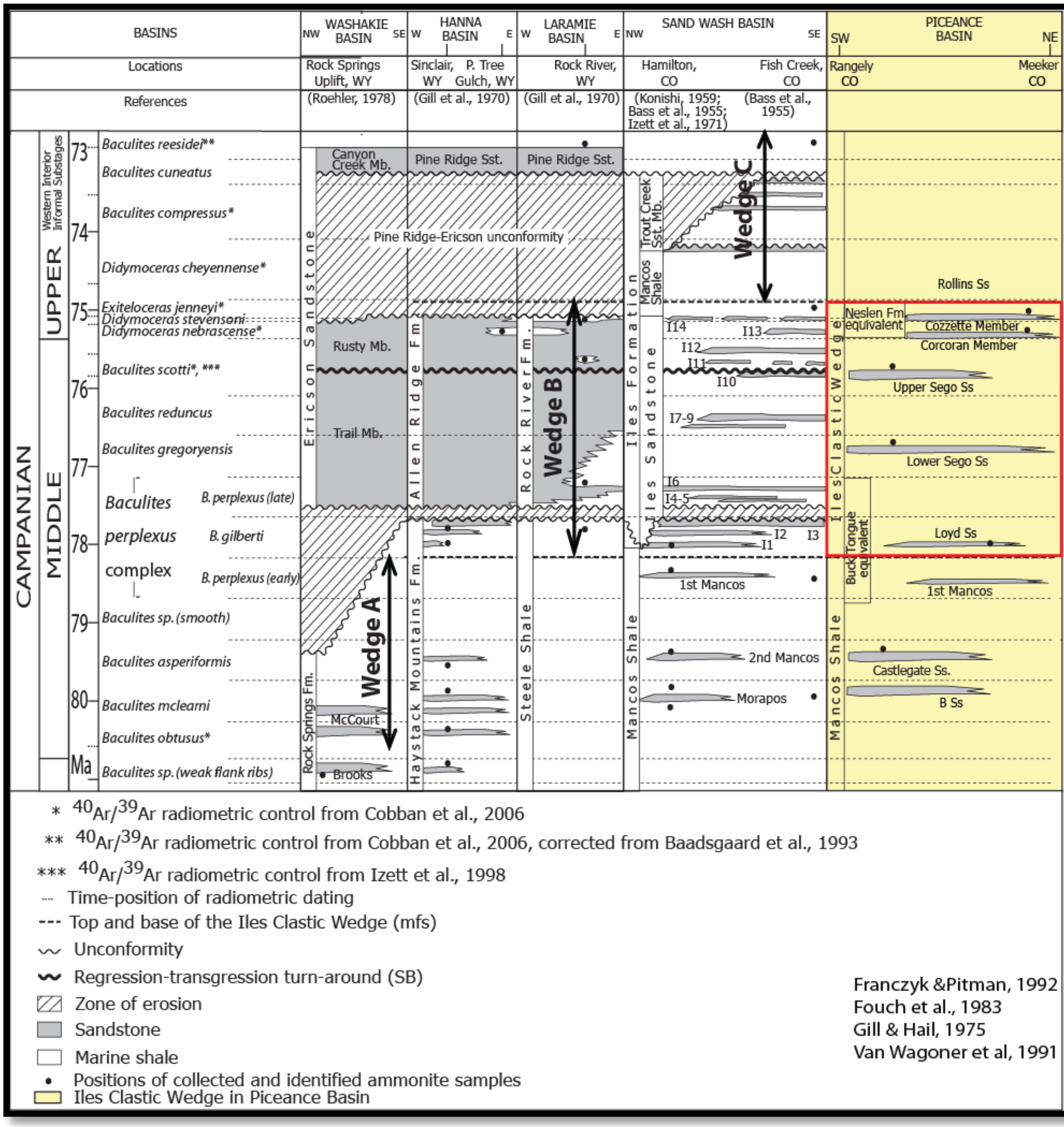


Figure 1.2: Stratigraphy of the study area (Iles Clastic Wedge (red box) in Piceance Basin, yellow colored) and adjacent basins. The ammonite zone column shows the excellent dating control of this succession and is taken from Cobban et al. (2006).The black dots represent positions of collected and identified ammonite samples (modified from Gomez, 2009).

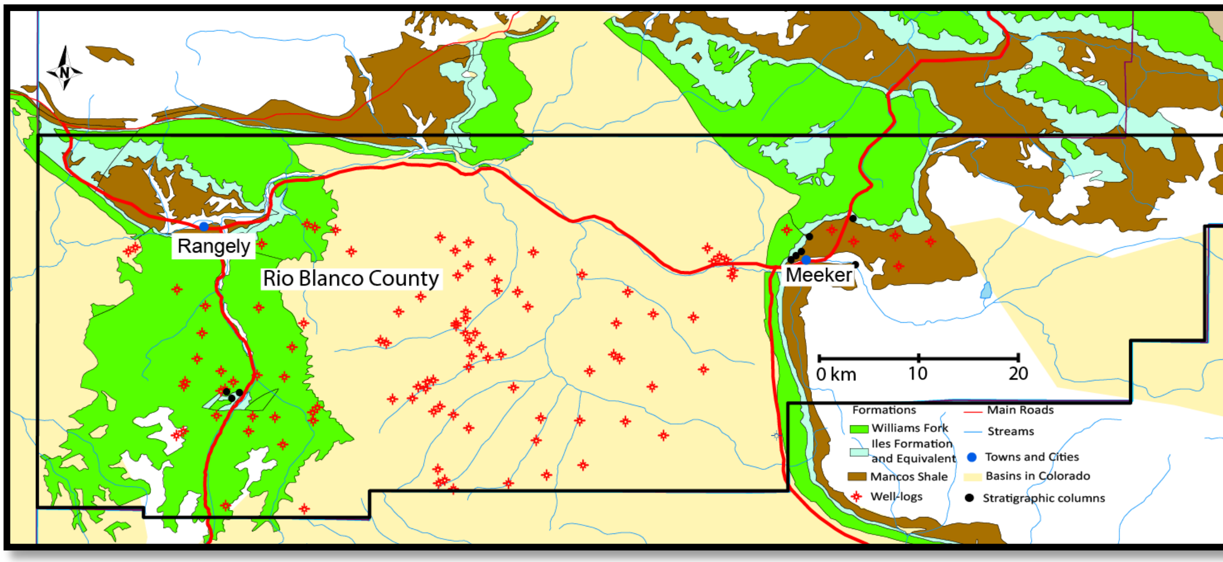


Figure 1.3: Location map of wells and measured sections in the study area (Modified from a map compiled by Julio Leva).

Aschoff (2008) also described a similar Iles Clastic Wedge (but she referred to it as the Sego-Corcoran-Cozzette Wedge) within a transect from Thistle, Utah to east of Redstone Colorado; she calls it Wedge B (Fig. 1.2). Wedge B contains the successions of Buck Tongue of Mancos Shale, Sego Sandstone, Castlegate Sandstone, Neslen Formation, and Corcoran and Cozzette Members. Aschoff (2008) pointed out that the stacking pattern within Wedge B (in contrast to the younger A and older C wedges) suggests rapid progradation of embayed, wave and tide influenced shorelines. On the western part of the Piceance Basin (south of Rangely, Colorado), Noe (1984) documented an embayment in the interdeltaic areas between progradational shorefaces. He described the Mesaverde Group and Mancos Shale deposits as barrier island system deposits that contain two offshore marine, three marginal marine, and one nonmarine facies association.

STRUCTURAL SETTING AND PALEOENVIRONMENTS

The Piceance Basin contains many economically important stratigraphic units with large reserves of coal, oil shale and gas. The basin area was located in the

Cordilleran foreland basin during the Late Cretaceous along the western margin of the Western Interior Seaway that stretched from the Gulf of Mexico north to Canada and the Arctic basins. The paleoshoreline in the study area was oriented approximately northeast to southwest (Roehler, 1990) and sediments were derived from periodically rising Sevier Orogenic belt and volcanic highs in central Utah and southwestern Wyoming (Lorenz, 1982) (Figure 1.4). During the Campanian period many clastic wedges which interfinger with the mud-prone Mancos Shale and some limestones were recorded (Krystinik and DeJarnett, 1995).

During the Laramide Orogeny (latest Cretaceous-Early Tertiary), the Piceance Basin became a separate structural depression as the Cordilleran foreland basin was broken up by Laramide uplifts (Fig. 1.5). The Piceance Basin is an asymmetric northwest-southeast oriented basin and it is surrounded by the White River Uplift and Grand Hogback monocline on the east, the Axial Basin anticline on the northeast, the Uinta Mountains on the northwest, Douglas Creek Arch on the west and the Uncompahgre Uplift on the southwest, and Gunnison and the West Elk Mountains on the southeast (Fig. 1.1 and 1.5).The basin is deepest along the Red Wash Anticline and it has several high-angle small displacement faults and elongate anticlines and synclines (Cole and Cumella, 2003) (Fig. 1.1).

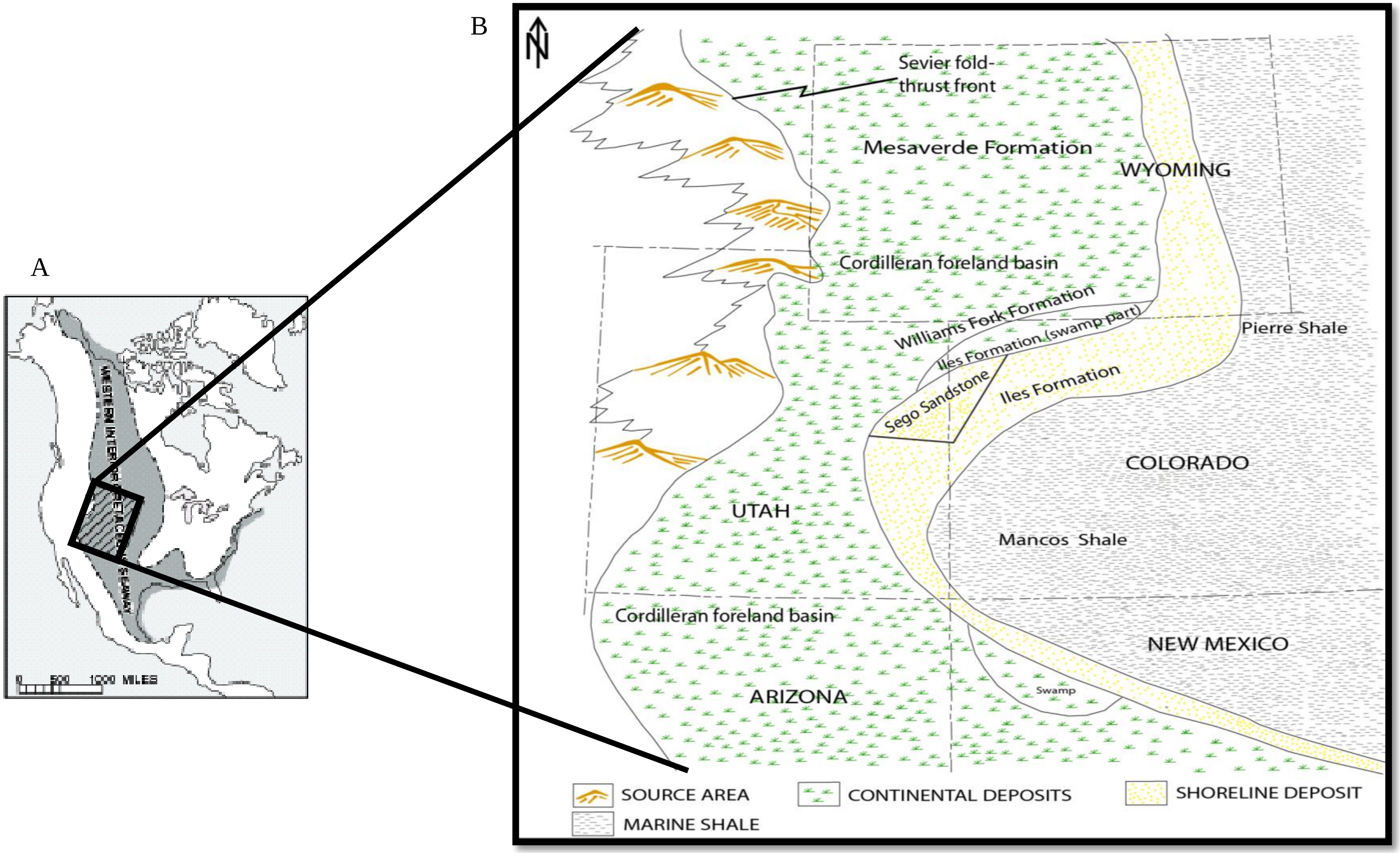


Figure 1.4: (A) Map of the Western Interior Seaway (modified from Patterson et al., 2003) (B) Late Cretaceous paleogeographic setting during the deposition of the Iles Clastic Wedge (modified from Boyles, 1983).

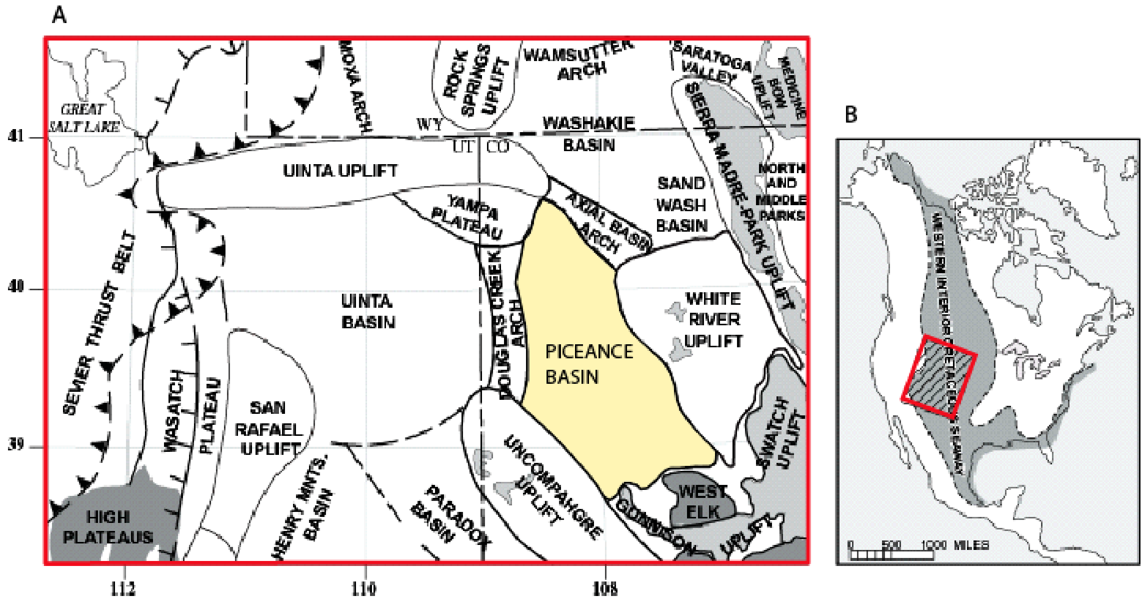


Figure 1.5: (A) Map of the Laramide tectonic elements in western Colorado and eastern Utah (B) Map of the Western Interior Seaway (modified from, Patterson et al., 2003).

STATIGRAPHY

The Iles Clastic Wedge contains the low-accommodation regressive-transgressive tongues of the Loyd Sandstone, the Sego Sandstone, the Corcoran Member, and the Cozzette Member of the Iles Formation and non-marine equivalent of Corcoran and Cozzette Member strata (Neslen Formation). It is bounded by the *Baculites gilbert* zone at the bottom of the Loyd Sandstone and *Exiteloceras jenneyi* zone at the base of the Rollins Sandstone. Based on the dating on the identified ammonite zones within the Iles Clastic Wedge (Gomez, 2009), the deposition had a duration of some 3.3 My and the thickness of the wedge is approximately 380 m.

The details of the deposits in the Iles Clastic Wedge are given in the Meeker and Rangely stratigraphic successions (Chapter 3). In general, the sandstone tongues in the study area indicate storm-wave dominated coasts that transition seaward into offshore/prodelta mudstones with thin-bedded sandstones and landward to tidal/fluvial coal-bearing facies that indicate interdeltaic coastal embayment with moderate tidal influence. The regressive-transgressive sequences of Iles Formation are overlain by fluvial sequences of the Williams Fork Formation.

OBJECTIVE

This study describes the characteristics of the facies and facies associations of progradational shorefaces and associated paralic deposits, the stratigraphic variability of deposits, and the sequence stratigraphic framework of the Iles Clastic Wedge in the northern Piceance Basin.

This research builds upon previous studies in the Sand Wash and Piceance basins (Masters, 1966; Noe, 1984; Crabaugh, 2001; Kirschbaum and Hettinger, 2004; Aschoff, 2008; Gomez, 2009) to examine the Iles paralic and shoreline sedimentology both in dip and strike directions and to explain the outcrop facies, well-log patterns, and sequence stratigraphy of the Iles Clastic Wedge in an area of approximately 3,900 km^2 in the northern Piceance Basin in Rio Blanco County. The change in shoreline sedimentology from northeast to southwest is also investigated in an attempt to evaluate how wave domination in the Sand Wash Basin changed to a mixed tide and wave influence in the northern Piceance Basin.

METHOD

The methodology used in this project combine outcrop and subsurface datasets. The analysis involves description and interpretation of sedimentary structures, trace fossils, paleocurrents, bed thicknesses and grain sizes in 7 long outcropping sedimentary profiles. The outcrop measured sections are near Anderson Gulch, Sulphur Creek and on the outcrops of Highway 13 (approximately 10 km away from the Anderson Gulch) in

Meeker (6 long sections) (Fig. 1.6) and near Little Horse Draw some 35 km south of Rangely (1 long section) (Fig. 1.7). In Meeker, the nearest studied oil and gas well is located 7.5 km west of the outcrop measured sections whereas in Rangely the well-logs are closer (250 m) to the measured sections along the long section. A number of 110 well logs have been used for subsurface mapping of the shoreline units. The datum used for the well-log correlation is the surface at the top of the Rollins Sandstone. However since Rollins Sandstone pinches out towards Rangely, the correlation is also checked by choosing the maximum flooding surface at the top of the Castlegate Sandstone as a datum. In Meeker, sometimes strata between Corcoran Member and Rollins Sandstone were poorly exposed. The sequences between these sandstones were correlated by the equivalent sand body in the well-logs. The facies and facies associations were defined first and were compared and calibrated with well logs to establish a relationship between the outcrop facies and well-log patterns. Correlated cross sections and isopach maps were created based on 110 digitized well-logs from Rio Blanco County. The well-log information was gathered from the Colorado Oil & Gas Conservation Commissions (http://ogccweblink.state.co.us/Search.aspx) and MJ Systems. Sedimentary successions were correlated using facies stacking patterns, grain size trends and a previously published biostratigraphy of ammonite zones.

The well spacing in the study area ranges from 0.54 km to 18 km. This variation led to some correlation challenges. Subtle changes in vertical and lateral variability of the log character were not always easily interpreted. However, examination of the cross sections both in dip and strike directions together with the outcrop observations made it possible to reasonably define the stratigraphy of the Iles Clastic Wedge in this region. Available well-logs were correlated based on the gamma ray logs, and conductivity logs. Gamma ray and conductivity logs were used to define the sandstone and shale content.

Cut-off API values have been used to identify coal (<10 API), sandstone (≤ 87 API), and shale (87-150 API).

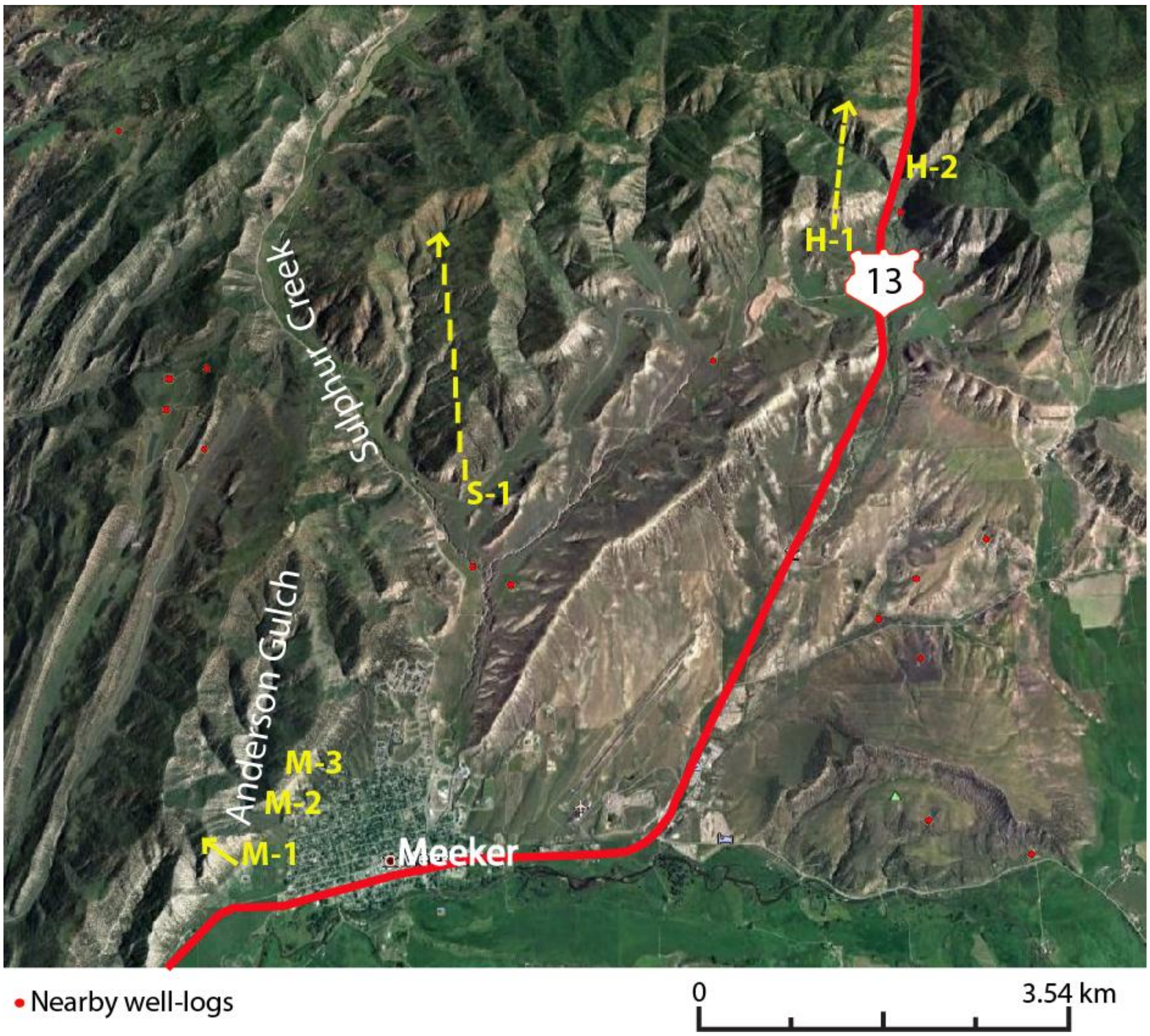


Figure 1.6: Outcrop measured section locations in Meeker area (yellow arrows indicate the direction of the measurements).

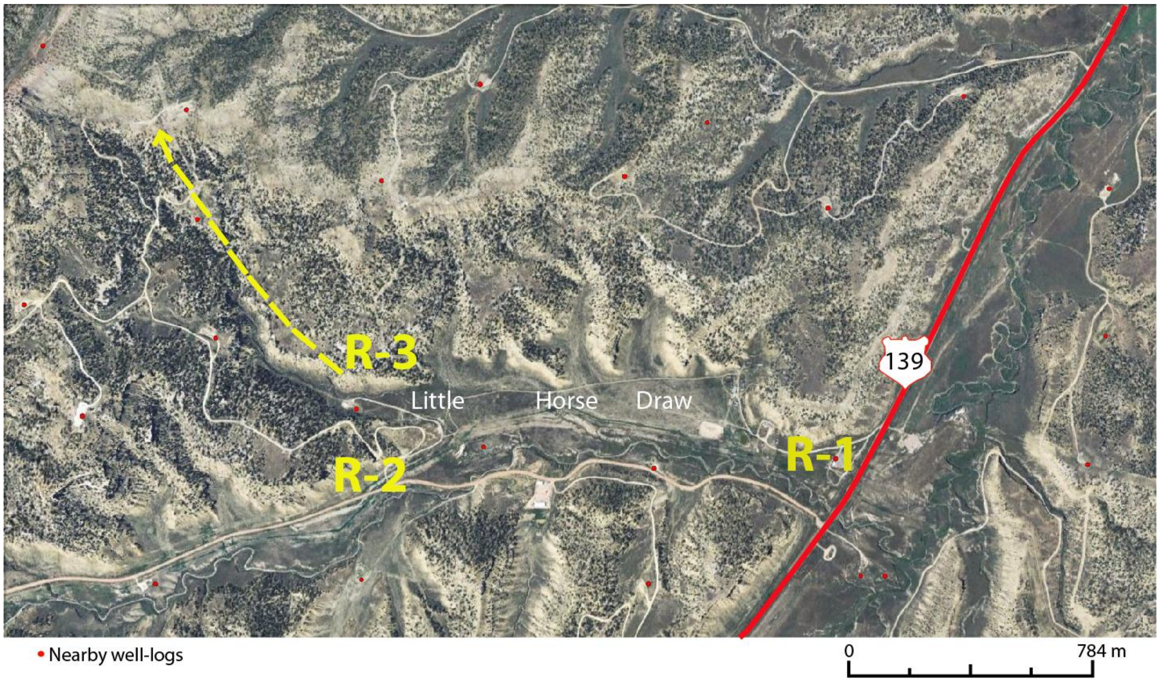


Figure 1.7: Outcrop measured section locations south of Rangely (yellow arrows indicate the direction of the measurements).

CHAPTER 2: DESCRIPTION OF THE SUCCESSIONS

FACIES ASSOCIATION 1: OFFSHORE/PRODELTA MUDSTONES WITH THIN BEDDED SANDSTONES

Although it is poorly exposed in general (Fig. 2.2), it consists of mudstones and locally interbedded, thin, very fine grained sandstones in units up to 30 m thick. The thickness of the individual thin sandstones varies from 5-35 cm and thin beds are wave, current ripple laminated though also flat laminated or structureless with very thin mud drapes. The grain size of the sandstones varies from lower very fine to upper very fine. In some outcrops bioturbation is very common in this muddy succession and it destroys the stratification (Fig 2.4C). Ammonites (*Baculites species*) occur in these mudstones and a few fragments of *Inoceramus sp* were found. This heterolithic succession is mostly muddy but becomes sandier upwards just below first thick sandstone units of the Iles shoreline tongues. This association is especially common below the wave dominated shoreline deposits, though it also occurs in the thin basal parts of each of the Iles shoreline tongues too.

This facies association is represented by generally high gamma ray (GR) values, indicative of high mudstone content throughout (Fig. 2.3C). There are subtle decreasing upward GR patterns which indicate slight coarsening upward in grain size, either throughout the succession or in smaller scale units (parasequences).

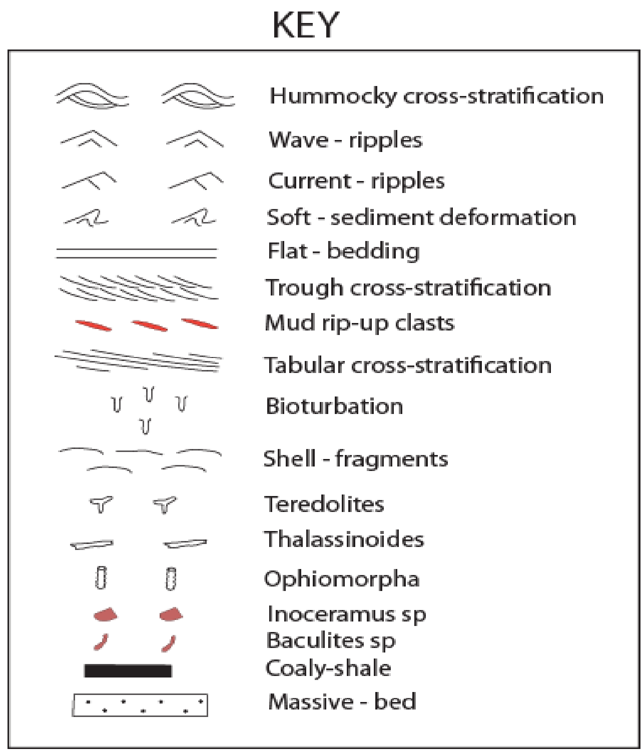


Figure 2.1: Legend for Figures which have outcrop measured sections.

Figure 2.2: Muddy facies association 1 is often only intermittently exposed (Photo is from Anderson Gulch area).The deposits in the view are about 50 m thick.

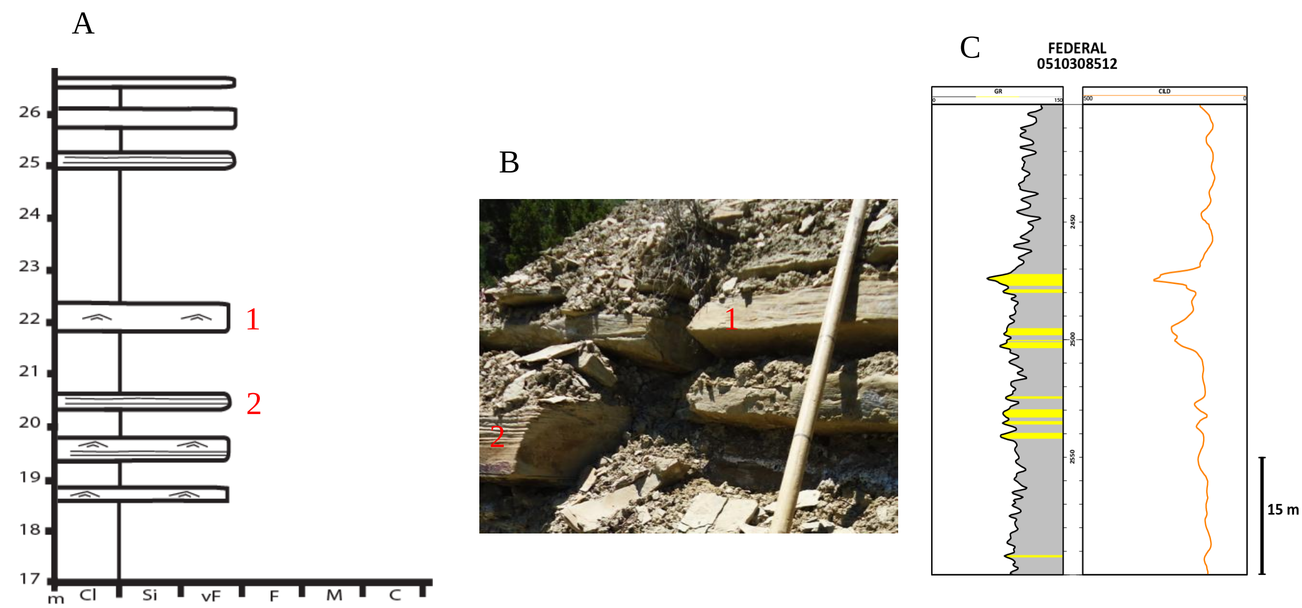


Figure 2.3: Offshore/prodelta mudstones with thin bedded sandstones in Meeker succession (M-1 section (Fig. 1.6)). (A) Profile showing thin sands with ripple lamination and flat-to-ripple-laminated sandstones.(B) Photo shows 60 cm thick muddy interval with ripple lamination(1) and flat-to-ripple lamination (2) at the bottom of the M1 section in Meeker.(C) Well-log example for the Facies association 1.

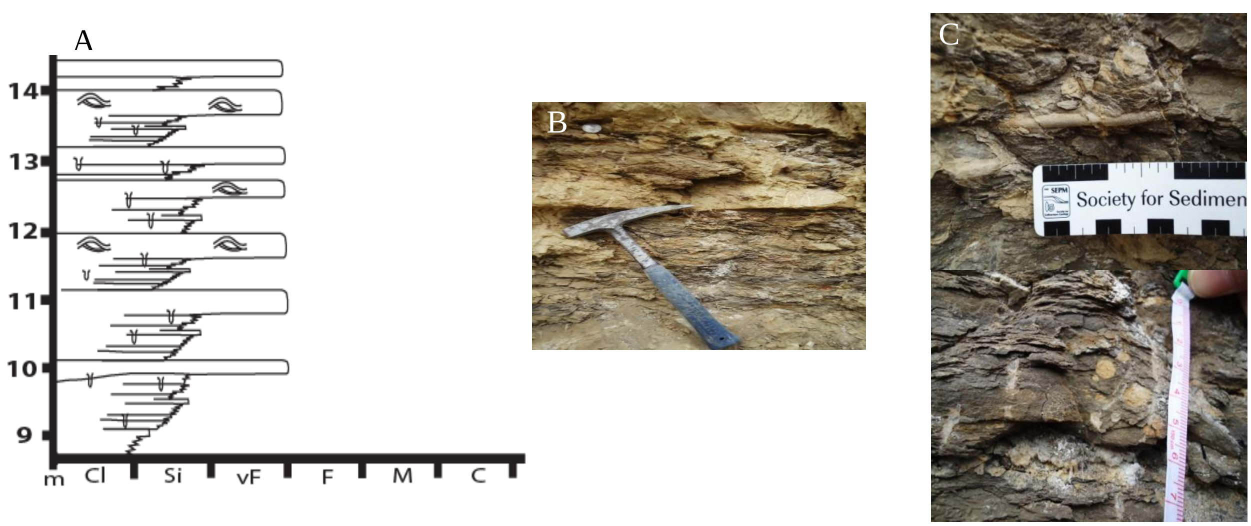


Figure 2.4: (A) Offshore transition deposit in Rangely (R-2 section (Fig. 1.7)). (B) Thin sandstone bed with hummocky bedding and structureless sandstone, (C) Bioturbation destroyed sedimentary stratification.

Interpretation

The abundant mudstone deposits with marine fossils (bivalves, ammonites) suggest offshore deposition on a shallow-water shelf. The thin sandstone beds with wave and current ripples indicate emplacement of the sand by shelf currents, fair weather wave and storm. The heterolithic and increasingly sandy character of the succession towards the top is interpreted in terms of overall shoreline progradation with the offshore transition approaching the lower shoreface.

FACIES ASSOCIATION 2: INTERDELTAIC AND DELTAIC PROGRADATIONAL SHOREFACE DEPOSITS

This association in Meeker is characterized by up to 23 m thick, upward coarsening and thickening successions. At the base of the Facies Association 2, muddy heterolithics of Facies Association 1 are found.

The lower heterolithic part consists of sandstone beds interbedded with silty gray mudstones in intervals of thickness ranging from 3-6 m. The grain size of the sandstone beds changes from lower very fine to upper very fine grained and beds usually have a sharp contact with the underlying silty mudstone layers. Bed thickness of the sandstones is 20-60 cm and beds are characteristically ripple laminated, hummocky cross stratified, swaley cross stratified, flat laminated and sometimes structureless. This part of the association shows intense to moderate bioturbation, though this decreases upwards toward the fist thick sandstone. The trace fossils identified are *Ophiomorpha, Thalassinoides*, and *Planolites*. This heterolithic interval exemplifies the transition from mud dominated strata to sand-rich deposits. Both bed thickness and sand/mud ratios increase upward within this succession.

The first thick sandstone beds above the heterolithic succession have sharp contact with the succession below. These sandstones are hummocky cross-stratified

(HCS) and amalgamated with very little intervening mudstone. The thickness of the HCS sandstone unit is 0.5 - 6m. Locally, mud rip-up clasts are found within the hummocky cross-stratified sandstones. Bioturbation is moderate at the base of the amalgamated sandstone beds and mainly *Ophiomorpha* and *Planolites* are seen, which imply *Skolithos* ichnofacies. Bioturbation decreases towards the top of the succession. Soft-sediment deformation also occurs and this affects the underlying swaley strata. Within the hummocky and swaley cross-stratified strata 2-6 cm red mud rip-up clasts were found.

South of Rangely, this facies association has somewhat different characteristics than the Meeker succession. Sedimentary structures within the Facies Association 2 are similar but there is thickness difference between sharp based hummocky cross-stratified sandstone beds. Although shoreface sands are up to 23 m thick in Meeker, they are 1-5 m thick, cliff-forming trough cross-stratified and planar laminated sandstone near Rangely (Fig 2.5A and 2.6A). Paleocurrents readings from trough cross-stratification indicate flow to the north and northwest direction. Gutter cast observed in Rangely was also used to determine the paleocurrent direction.

GR pattern of Facies Association 2 shows a generally sharp base, decreasing upward to blocky and lower heterolithic part shows alternation of high and low gamma ray values which indicate interbedded mudstones with sandstones (Fig. 2.5F).

Interpretation

The coarsening upward character of the succession in Meeker is interpreted as delta front deposits with underlying prodelta deposits. The presence of the hummocky and swaley cross stratification indicates influence of the storm wave activity. The occurrence of mud rip-up clasts within the hummocky and swaley cross-stratification indicates the erosion of previous mudstones (offshore or lagoon environment).

Symmetrical ripples (wave rippled units) may indicate deposition below fair-weather wave base.

Heterolithic intervals exemplify the transition from mud dominated strata to sandy deposits. Both bed thickness and sand/mud ratios increase upward within this facies association.

Within the Iles sequences, Facies Association 2 extends from the proximal shoreline pinchout into coastal plain deposits to the distal pinchout into prodelta deposits.

Facies Association 2 near Rangely is indicating interdelatic embayed progradational shoreface deposits. The thickness of the shoreface deposits near Rangely is thinner than the similar facies association of the Meeker succession. This can be because of the differences in wave, storm and tide activity, and sediment supply and subsidence rate (Noe, 1984) between the deltaic and interdeltaic coasts. Generally, in open-coast deltaic environment, subsidence rates are much greater than along embayed coasts and wave activity is dominant. However, in interdeltaic environments sediment can be capped by estuarine deposit.

Figure 2.5: (A) Upward coarsening very fine grained wave-dominated delta front facies association (M-1 section). (B) Hummocky-cross stratified sandstone. (C) Wave ripples, (D) *Ophiomorpha* in highly bioturbated sandstone. (E) *Ophiomorpha* in rippled sandstone (F) Well-log example for the Facies association 2.

Figure 2.6: (A) Interdeltaic progradational shoreface deposits (R-2 section). (B) Outcrop view of the succession. (C) Hummocky cross-stratified sandstone bed with interbeded siltstone. (D) Trough cross-stratified sandstone.

FACIES ASSOCIATION 3: TIDAL-FLUVIAL CHANNELS

Facies Association 3 consists of erosively based, upward-fining, lower medium to fine-grained sandstones in channelized units 4-14 m thick, which cut into muddier coastal plain deposits. The sandstone in this facies occurs as lenticular bodies and these, in turn, stack to form amalgamated large sandstone bodies up to 39 m thick. They extend over a minimum of several hundred meters laterally. The sandbodies are characterized by tabular and trough cross-bedded sandstones with mud clasts. The sandstones also show some bidirectional cross-bedding sets with organic-rich mud drapes on planar cross-bedded foresets of planar cross-bedded set as well as ripple-laminated sandstones. Trough cross-bed set thickness is between 15-30 cm and the tabular cross bed thickness is between 10-50 cm. In the basal part of the sandbodies mudstone rip-up clasts, wood fragments, *Teredolites* burrows and lots of shell fragments are found. Throughout the units, soft sediment deformation is also observed. Paleocurrent measurements from tabular cross-beds show clear variation by area. Some of them indicate SE (basinward) direction and some of them show NW-N (landward) direction.

GR patterns of Facies association 3 in wells are generally sharp based and blocky. However, sandstones are often interbedded with mudstone (high GR values) and capped by thick mudstones (e.g. ~30 m) (Fig. 2.7H).

Interpretation

This facies association is generally seen above the Facies Association 2 (delta front) on the delta topset. The sandstone units with erosional bases show general upward fining trend of grain size, bidirectional cross-strata, organic rich double mud drapes and the stratigraphic position within the vertical succession close to the shorefaces all suggest tidally influenced distributary channels. Bidirectional cross-strata indicate the landward (flood) and seaward (ebb) movement of the tidal currents. Double mud drapes developed during high tide and low tide slack water periods when suspended sediments concentration is high enough. The *Teredolites* burrows indicate brackish water influence. Current ripples which are formed to the top of the succession indicate lower current velocities on the margins of bars or transitional to overbank areas.

In some locations, lag deposits are observed near the top of the tidal fluvial channels. Laterally extensive and amalgamated channel belts up to 39 m thick indicate multistory, multilateral channel complexes.

Figure 2.7: (A) Representative measured section from tidal-fluvial deposits (H-1).(B) *Teredolites* burrow, (C) Highly bioturbated sandstone, (D) Shell fragments at the base of the channel, (E) Bidirectional large cross-bedding, (F) Mud rip-up clasts, (G) Ripples with mud-drapes (H) Well-log example for the facies association 3.

FACIES ASSOCIATION 4: FLUVIAL CHANNELS

This association is composed of lenticular units with medium to fine grained sandstones with dominantly tabular and trough cross-bedding. The set thickness of the tabular beds is 10-35 cm and the set thickness of the trough cross bedding is 10-30 cm. Paleocurrent readings indicate unidirectional basinward flow mainly in a NE to E direction. Mud rip-up clasts are found within the cross stratified sandstones. Besides cross-stratification, massive beds and soft sediment deformation (Fig. 2.8B) are also observed. Below the base of the channelized units, coal deposit is present. Towards the top of the cross-stratified units current and climbing ripples were observed.

This facies association shows sharp based, increasing upward GR pattern with some overlying and underlying high GR shifts (Fig. 2.8D).

Interpretation

The unidirectional cross-stratification, structureless sandstone beds, absence of marine or brackish bioturbation and association with coal deposits suggests fluvial distributary channels. These distributary channels intertongue with coastal plain deposits. Distributary channel fill sandstones show sharp-based succession of low or increasing upward GR values which indicates uniform or fining upwards of grain size.

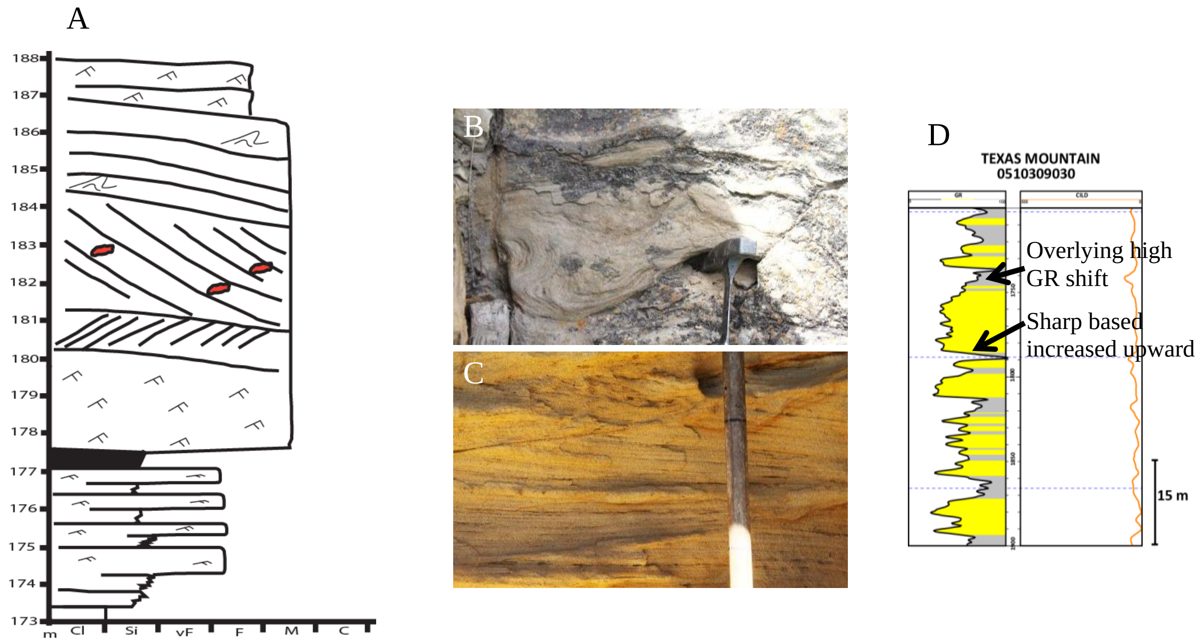


Figure 2.8: (A) Fluvial distributary channel facies without any tidal influence (S-2 section). (B) Soft-sediment deformation. (C) Cross-stratified. (D) Well-log example for the facies association 4.

FACIES ASSOCIATION 5: COASTAL PLAIN/LAGOON

Facies Association 5 consists mainly of structureless, organic-rich, carbonaceous mudstones and some thin laminated heterolithic siltstones/sandstone and plane parallel laminated, rippled, or structureless sandstone beds. The massive mudstone also occurs up to 7 m thick which contains yellowish to orange color discontinuous layers. The organic rich part consists of 20-50 cm thick coaly-shale layers. These muddy successions interbeded with fluvial channels and crevasse splay deposits (Fig. 2.9)

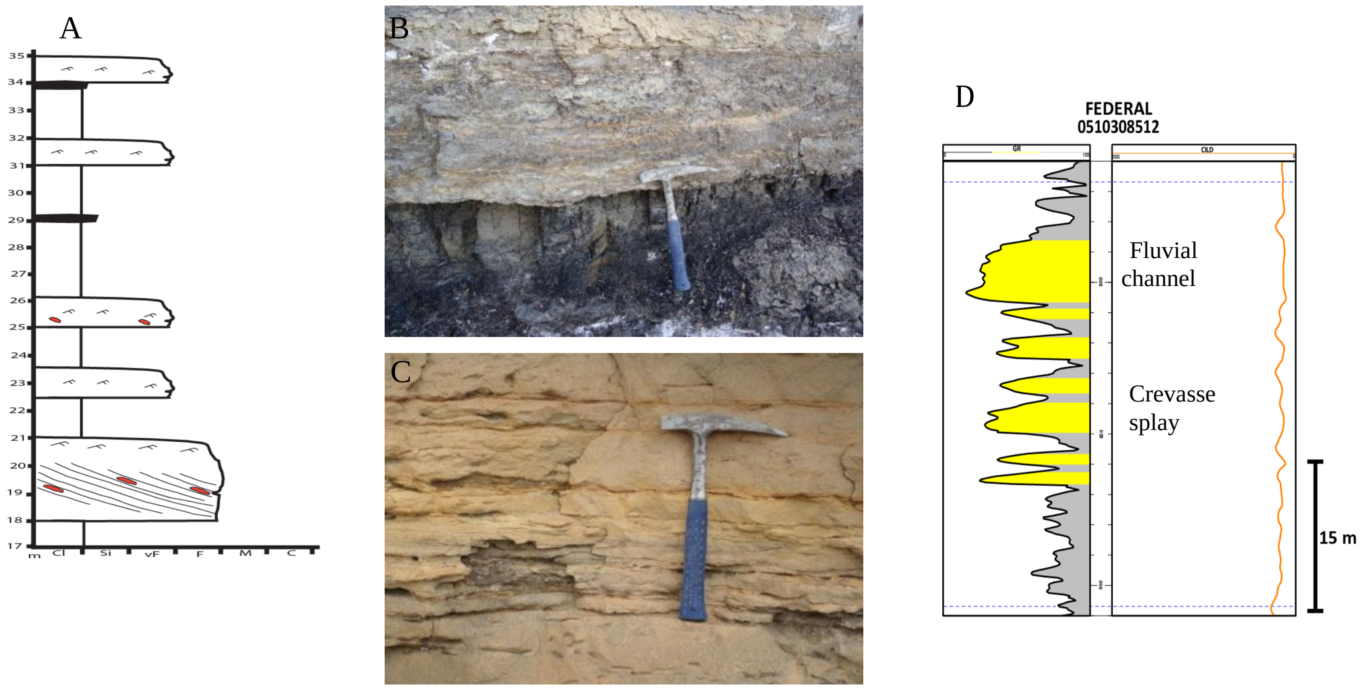


Figure 2.9: (A) Coastal plain deposit with coaly-shale (H-2 section). (B) Mudstone deposit with carbonaceous matters, (C) Ripple laminated sandstone. (D) Example well-log pattern for the Facies association 5.

Interpretation

The presence of the coaly shale and interbedded organic-rich mudrock and upward transition from coaly shale to heterolithic siltstone/sandstone represent the deposits of coastal plains/lagoon. This facies association has a heterolithic GR character where low GR values represent thin sandstone beds (crevasse splay) and coal beds. The general trend for GR pattern is decreasing-upward and this trend is interpreted as lagoon-fill deposits that show upward shallowing.

FACIES ASSOCIATION 6: INTER TIDAL FLATS

This facies association was found only near Rangely and is composed of organic rich, blocky, structureless grayish and sometimes brownish color mudstone, massive heterolithic siltstone and sandstone, coal layers, 2-5 m thick lenticular tabular cross-bedded and rarely trough cross-bedded sandstone bodies, soft sediment deformation is common. Organic-rich mud drapes are found on the foreset of the cross bedding. Paleocurrent direction shows variations.

Interpretation

Organic rich massive mudstone with blocky structures indicates muddy tidal flat deposits. Massive up to 1 m thick sandbodies which alternates by fine grained and coal bearing facies indicates sandy intertidal flat deposits. 2-5 m tabular and trough cross bedded sandstones indicates high current velocity conditions. Bi-directional current direction also indicates tidal flat conditions (Fig. 2.10).

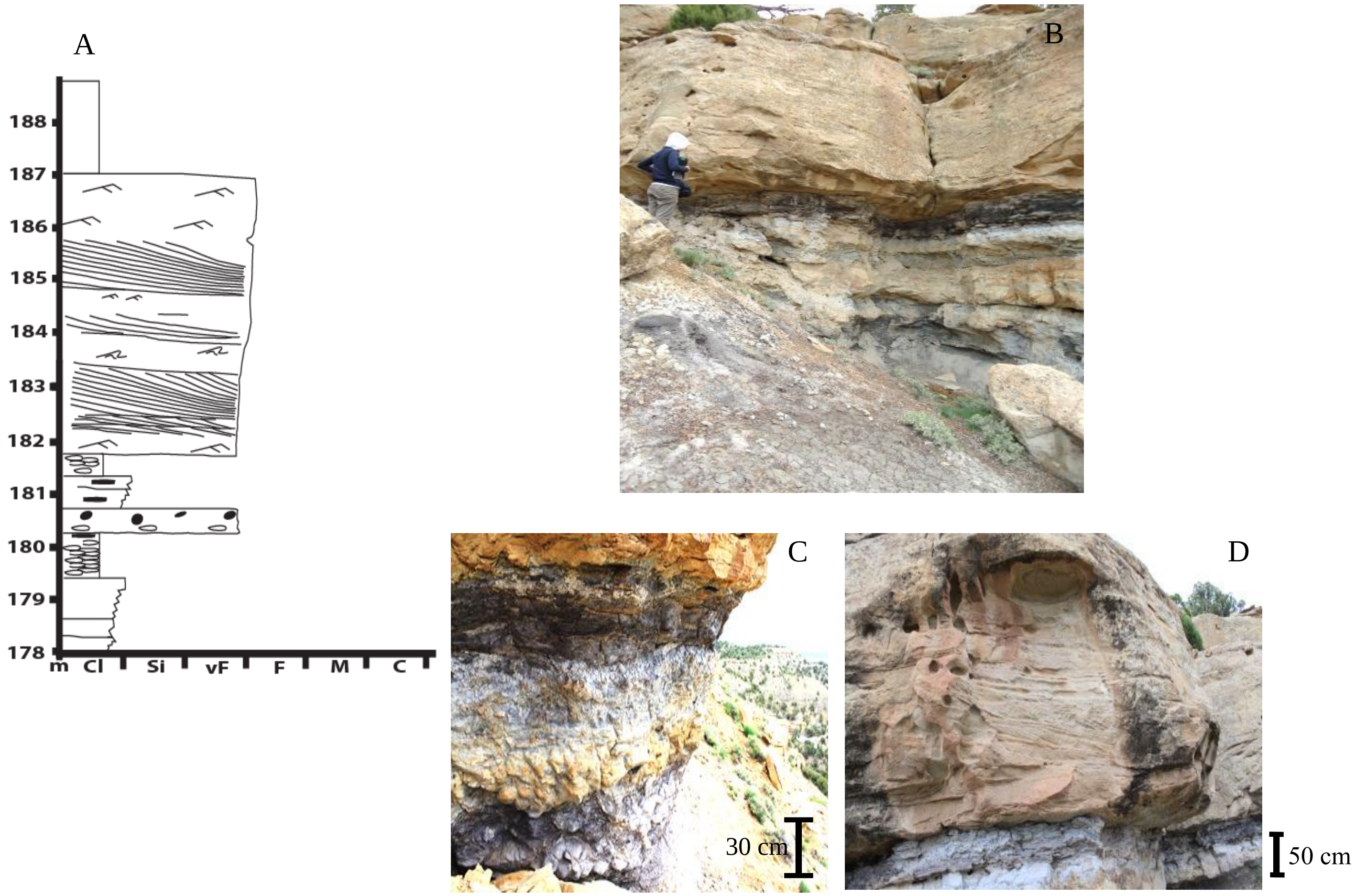


Figure 2.10: (A) Inter tidal flat succession, (B) Outcrop view of the succession, (C) Organic rich massive mudstone, (D) Lenticular sandbody with trough and tabular cross-bedding.

FACIES ASSOCIATION 7: TIDAL SAND BAR

This facies association was only found near Rangely. It is composed of cross-bedded sandstone with some siltstone. The sandstone shows upward-coarsening and upward-thickening. In the lower part of this upward-coarsening units coaly shale and siltstone with wavy and lenticular bedding is present. The upper part of this unit is overlain by cross-bedding with mud drapes on the foresets, reactivation surfaces with intense bioturbation (Fig. 2.11).

Interpretation

Mud drapes on cross bedding, wavy, flaser and lenticular bedding, reactivation surfaces indicate tidal influence on the deposits (Nio and Yang, 1991). Current ripples and flaser bedded with trace fossils and mudstone lamina are characteristic of the middle part of the tidal sand bars.

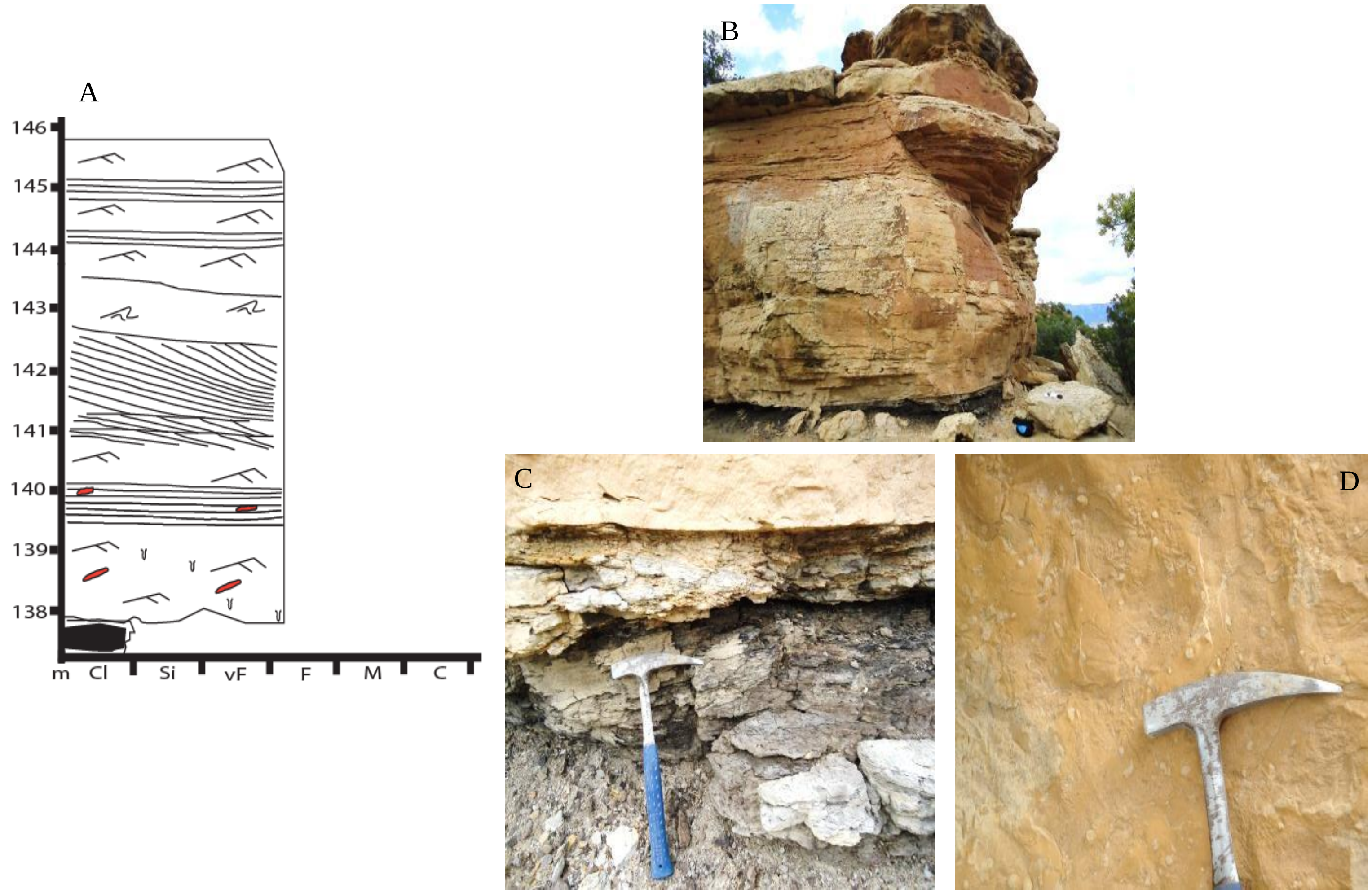


Figure 2.11: (A) Tidal sand bar succession and photo shows this succession (B) Meters thick cross-stratified and flat laminated sandstone. (C) Coaly-shale at the base, (D) Intense bioturbation at the base of sand body.

CHAPTER 3: SUBSURFACE MAPPING OF SEQUENCES IN MEEKER AND RANGELY SUCCESSIONS

In this study, initially the maximum flooding surfaces were identified on the subsurface well-logs. Since these surfaces are relatively continuous and have uniform distribution laterally, they are fairly easy to recognize on the well-logs. Sequences defined in this way, bounding by maximum flooding surfaces, are the 'genetic sequences' of Galloway, 1989. On well-logs the maximum flooding surfaces generally occur in high radioactive shales and in outcrop they occur in the organic-rich shale interval. After maximum flooding surfaces were picked and sequences defined in this way conventional (Exxonian) sequence boundaries were also identified within the Galloway-type sequences. These conventional sequence boundaries were usually recorded at the base of incised valleys or channel complexes on top of upward coarsening and thickening packages and at the sharp-base of shoreface deposits. These unconformity surfaces were noted on most of the measured logs and they commonly indicate important basinward shifts of facies. The unconformity surfaces may represent a significant break in deposition.

The thickness of the mapped sequences ranges from 21 to 112 m. In general, from bottom to top a sequences consists of a mudstone-rich interval (based by the sequence bounding maximum flooding surface) of offshore/prodelta mudstones (Facies Association 1) followed by an upward coarsening regressive interval of lower shoreface to upper shoreface deposits (Facies Association 2). This is then overlain by erosively-based (Exxonian or conventional sequence boundary) fluvial or tidal fluvial channelized deposits (Facies Association 4) with overlying brackish to marine mudstones (Facies Association 5) capped by the next maximum flooding surface. In the more distal reaches of a sequence the maximum flooding surface was picked near the base of the marine shales at the top of the underlying bioturbated, transgressive sandstone. In the more proximal reaches of the sequences the maximum flooding surface or its landward equivalent overlies erosively-based fluvial channels and brackish water mudstones.

THE MEEKER SUCCESSION

The Iles Clastic Wedge succession exposed in the Meeker area (Fig. 3.1) has a thickness of 380 m (defined here from the base of Loyd Sandstone to the marine shale at the base of Rollins Sandstone) and shows a wide variation of storm-wave, tide and fluvial facies associations that were deposited along different segments of a generally a wave-dominated coastline. Storm-wave domination is indicated by the occurrence of hummocky cross-stratified sandstones in the repeated regressive shoreface deposits. However, tidal influence is especially seen in the tidal-fluvial channel deposits of the transgressive stratigraphic intervals. In general, the stratigraphic sequences deposited within this clastic wedge at Meeker contain coarsening-upward successions of offshore to prograding shoreface deposits, and these are increasingly (up through the cyclic succession) overlain by coal, carbonaceous mudstone and tidal-fluvial channel deposits.

Iles Clastic Wedge in this area includes Loyd Sandstone, Sego Sandstone, Corcoran Member and Cozzette Member of the Iles Formation. The Iles Clastic Wedge succession was subdivided into 11 regressive-transgressive stratigraphic sequences as mapped on both the outcrop and well-log succession. From bottom to top, these sequences include one sequence in Loyd Sandstone (Sequence-1), two sequences in Sego Sandstone (Sequence-2, Sequence-3), four sequences in Corcoran Member (Sequence-4, Sequence-5, Sequence-6, and Sequence-7) and four sequences in Cozzette Member (Sequence-8, Sequence-9, Sequence-10, Sequence-11).

The Meeker outcrop descriptions are important because the outcrops are relatively poorly known and the methodology for picking sequences is defined in these outcrops. This methodology is then further applied to the subdivision of the adjacent well-logs and for well-log transects where the lithology data is inferred from gamma ray measurements.

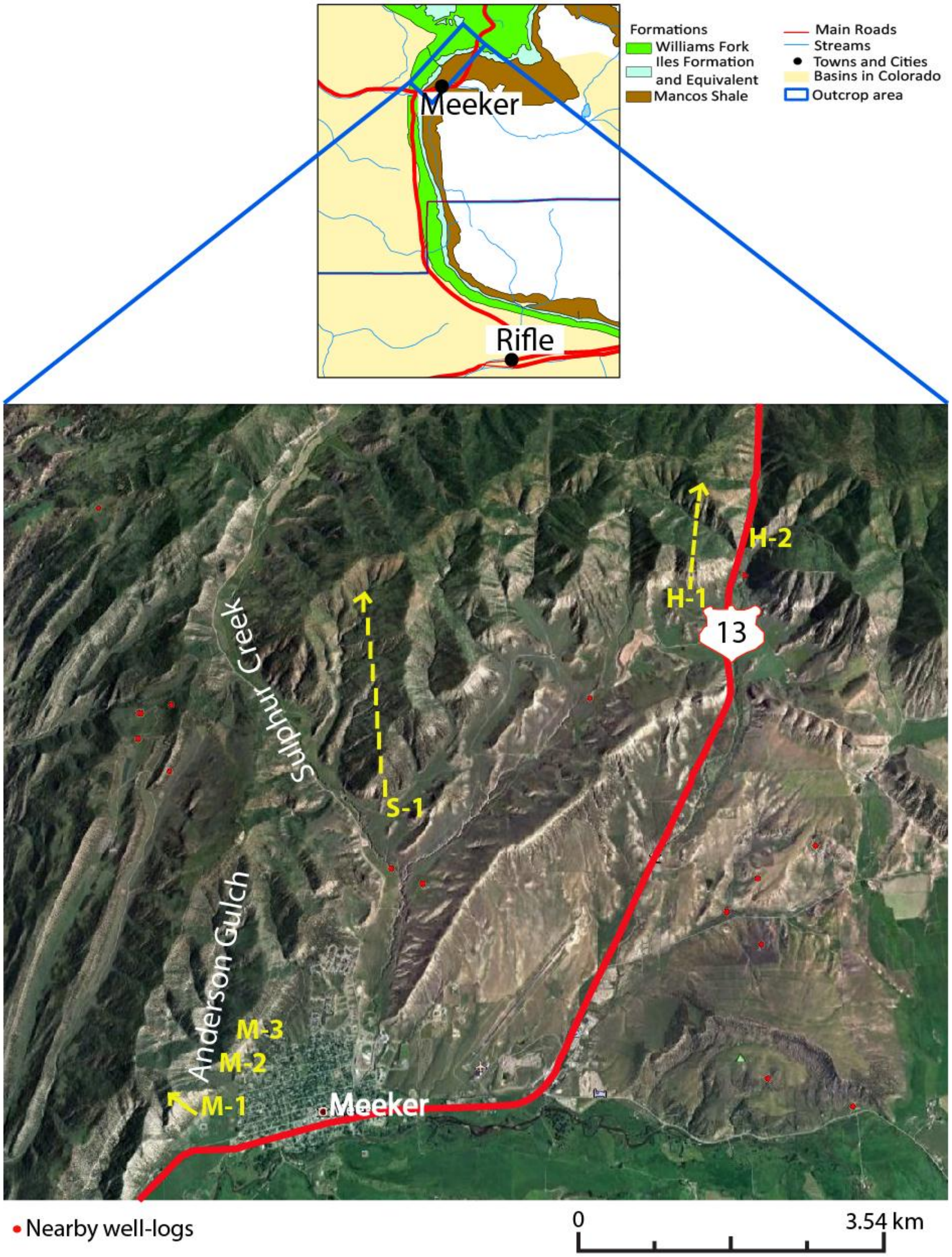


Figure 3.1: Yellow letters show location of the measured sections in Meeker area (yellow arrows indicate the direction of measurements).

Loyd Sandstone (Sequence-1)

Loyd Sandstone in the Meeker area was measured in the outcrops of Highway 13 (H-1 section in Fig. 3.1). A representative vertical section of the Loyd Sandstone is shown on Fig. 3.2, along with a photo of the outcrop (Fig. 3.2B). The Loyd Sandstone is cliff forming, massive; greenish-gray colored sandstone and contains ammonite fossils. It was deposited between *Baculites perplexus* (early) and *Baculites perplexus* (late) (Gill and Hail, 1975) in the north-northwestern area of Meeker. Since the Loyd Sandstone is fossiliferous (Fig. 3.2C) and highly bioturbated (Fig. 3.2D), almost no primary sedimentary structures were observed. The thickness of the Loyd Sandstone is measured as 9 m (Fig. 3.2A). However, based on the nearby well-log cross-sections the thickness of the Loyd Sandstone varies from 6-24 m around Meeker area (Fig. 3.3). The Loyd Sandstone is both underlain and overlain by thick marine shales where maximum flooding surfaces were picked. The base of the bioturbated top of the Loyd Sandstone indicates the transgressive surface of the sequence.

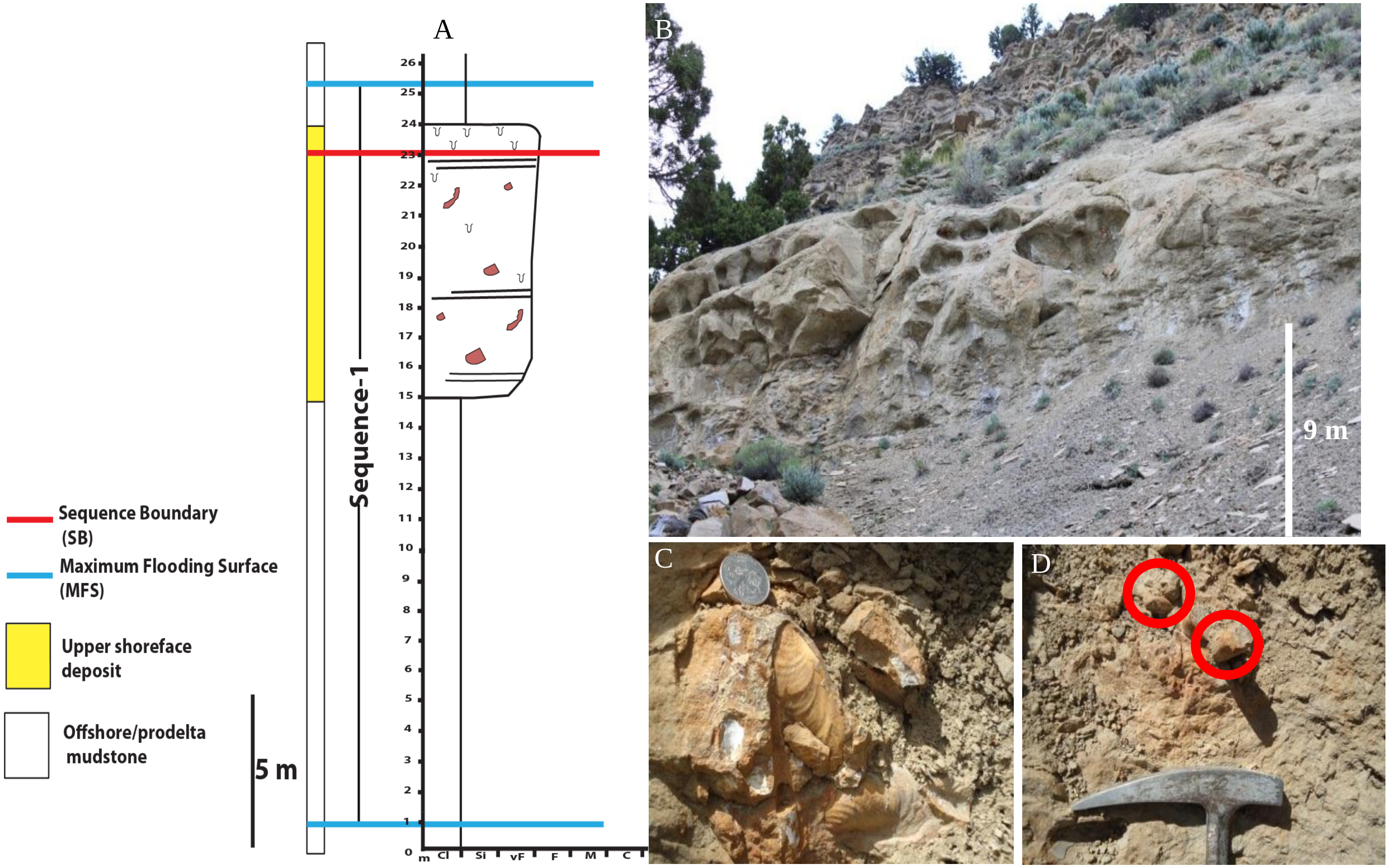


Figure 3.2: (A) Measured representative section of the Loyd Sandstone (section H-1). At level 23 m in the log there is a combined SB/TS (sequence boundary/transgressive surface) whereas at about level 1 m or below there is a maximum flooding surface.(B) Field photo of the Loyd Sandstone. (C) *Inoceramus* fossils. (D) *Baculites* fossils.

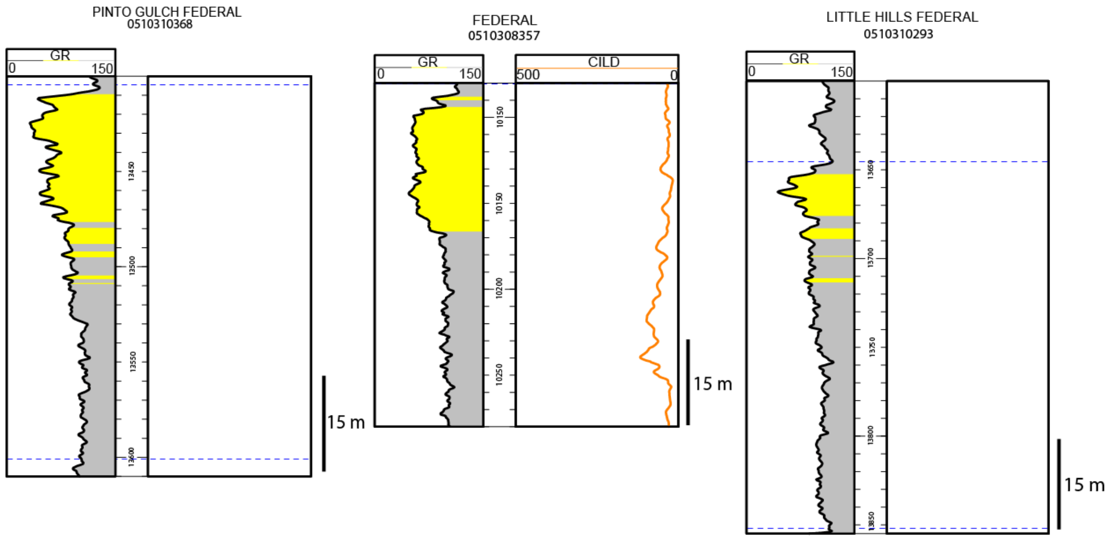


Figure 3.3: Thickness variation and changing character of the Loyd Sandstone as shown by the varied log response in nearby wells.

Sego Sandstone (Sequence-2 and Sequence-3)

The total thickness of the Sego Sandstone succession in the Meeker area is approximately 100 m. It consists of two stratigraphic sequences and these are usually referred to as lower and upper Sego Sandstone. Lower Sego Sandstone is represented by Sequence-2 and Upper Sego Sandstone is represented by the Sequence-3. The Sego Sandstone in Meeker area is well exposed and can be seen across 10 km in the outcrops.

Lower Sego (Sequence-2)

Lower Sego is some 60 m thick and begins with offshore/prodelta mudstone (Facies Association 1) of Mancos Shale. There is a maximum flooding surface near the base of this mudstone (Fig. 3.4). This muddy section becomes locally interbedded with thin, very fine-grained sandstones and in general it coarsens upwards in grain size and the sandstone/mudstone ratio increases. These fine-grained deposits pass upwards to offshore transitional heterolithics and to lower shoreface sandstones with marine trace fossils, moderate bioturbation and thin sets of hummocky cross-stratified sandstones. These heterolithic and thin-bedded deposits eventually pass upwards to more amalgamated hummocky and swaley cross-stratified sandstones of middle shoreface origin (Facies association 2). At the base of the thick amalgamated sandstones *Ophiomorpha* trace fossils were observed (Fig. 3.4). Capping the sandy succession of Lower Sego are trough cross-stratified sandstones in places, interpreted as upper shoreface deposits.

Lower Sego Sandstone has an Exxonian sequence boundary at the top of the shoreface sandstone and maximum flooding surface is a little above (Fig. 3.4). Sequence-3 in some areas truncates down into the highstand deposits of the Sequence-2.

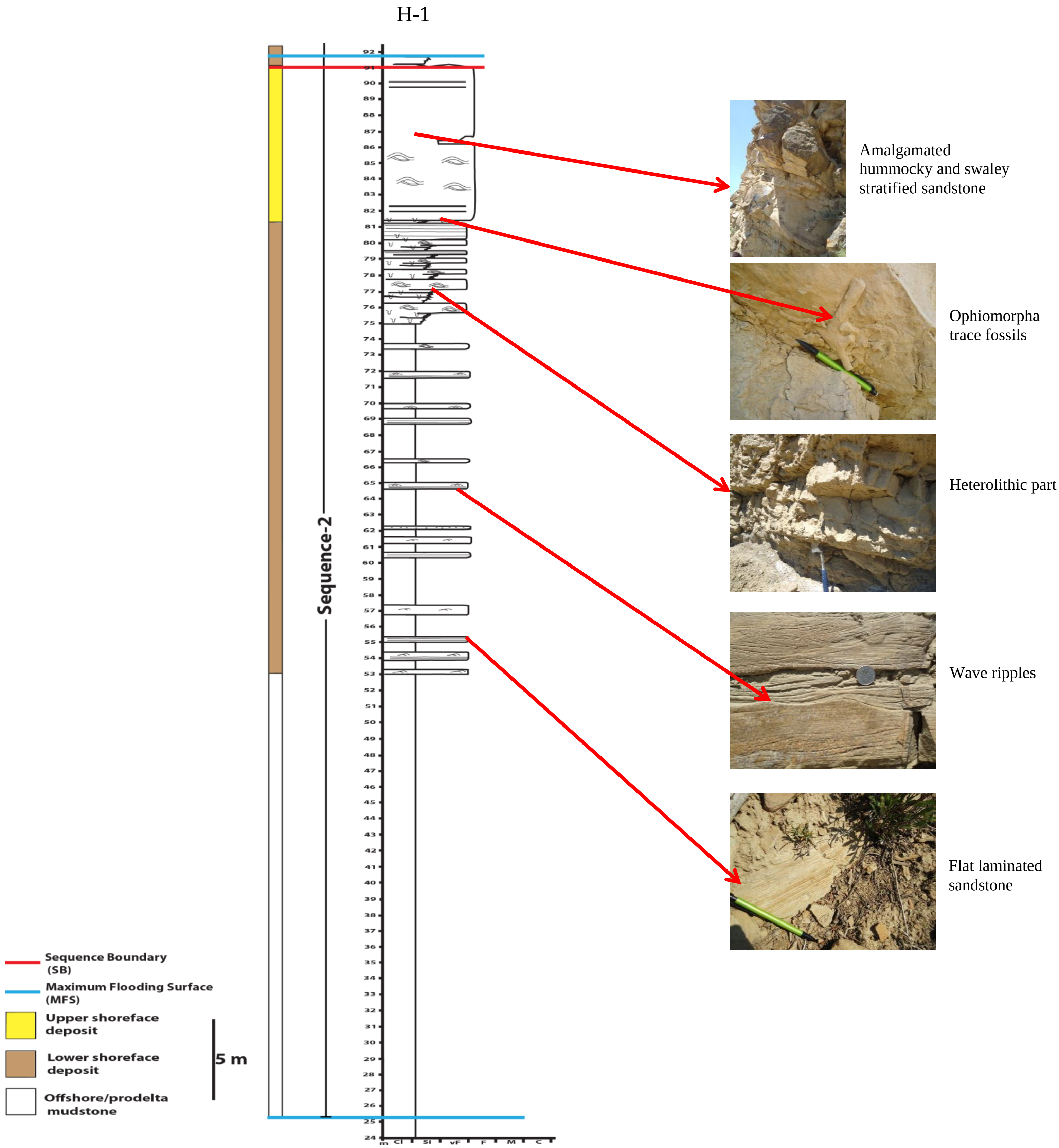


Figure 3.4: Sedimentary structures and key surfaces (MFS and SB) in a representative Lower Sego Sandstone sequence (Section H-1 in Fig. 3.1).

Upper Sego (Sequence-3)

Upper Sego Sandstone is some 30 m thick and begins with offshore mudstone. This offshore mudstone separates the Upper Sego from Lower Sego and contains the maximum flooding surfaces of Sequence-3. The Upper Sego has sheet like geometry and is similar to the Lower Sego in facies but has a lesser thickness. It coarsens upwards from marine shale to hummocky cross-stratified sandstone. The hummocky stratified shoreface deposits here are thicker (0.7 – 3 m) than the lower shoreface deposits of Lower Sego (0.5-1 m). Upper shoreface strata are also thicker in Upper Sego (~15 m) than the Lower Sego (~10 m). In the Upper Sego the whitish-greenish upper shoreface deposits are capped by coal deposits and ripple lamination is common in sandstones at the top of the coal bed. The contact between the coal and underlying sandstone is sharp and is interpreted as the Exxonian sequence boundary (Fig. 3.5) because of the implied basinward shift of facies. At the top of the coarsening-upward whitish greenish sandstone there are coals, fine-grained coastal plain deposits and then marine mudstones (Fig. 3.5). A maximum flooding surface is picked within the marine shale which is located above the coal deposits and the sequence boundary is at the coal-shoreface contact. Between the Exxonian sequence boundary and the maximum flooding surface the coal and the coastal plain deposits represent the transgressive systems tract.

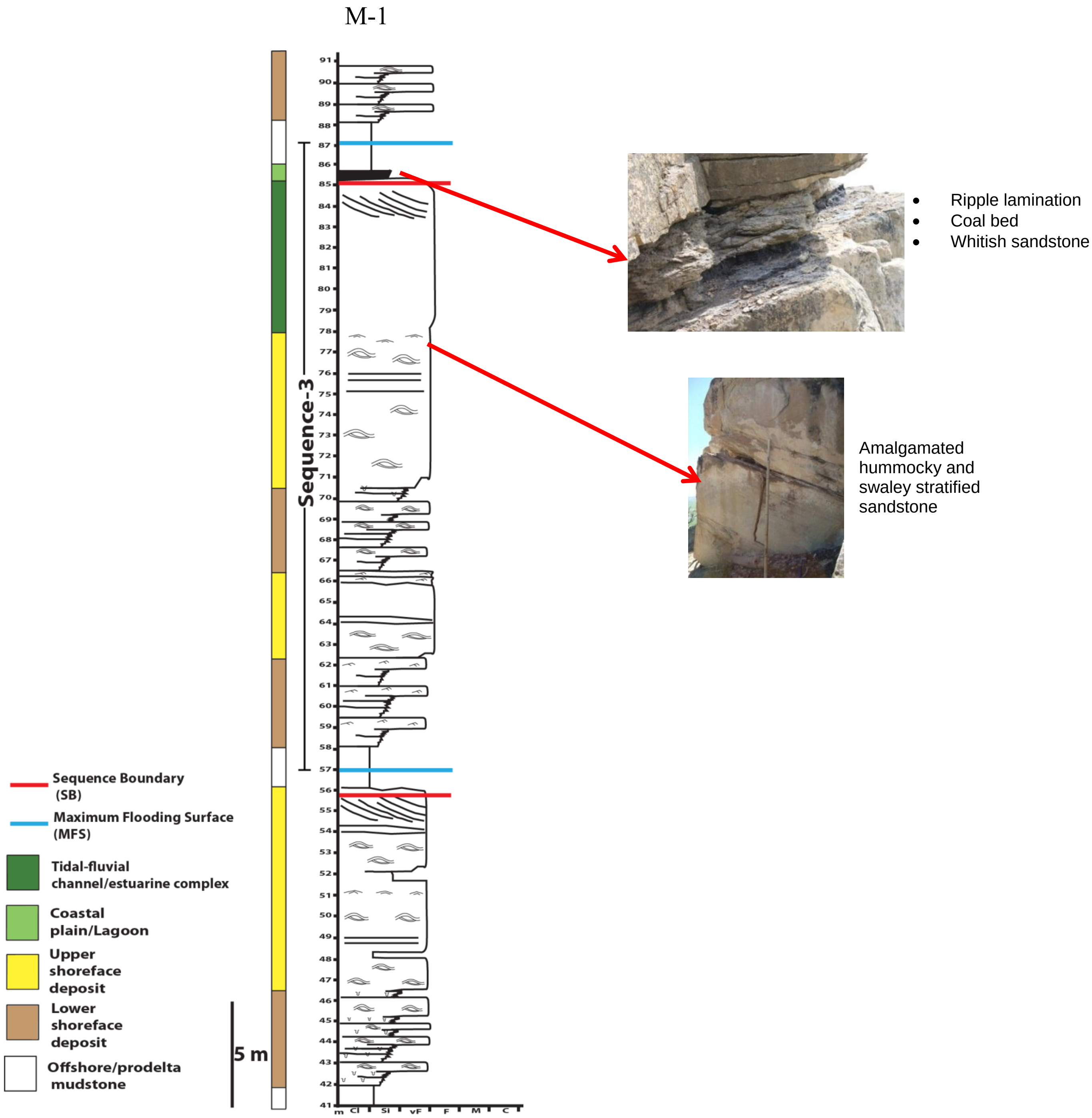


Figure 3.5: Measured section of a representative Upper Sego sequence at Meeker with characteristics facies (Section M-1 in Fig. 3.1).

The Corcoran Member (Sequence 4 to Sequence 7)

The total thickness of the Corcoran Member in the study area is 126 m. By the well-log and outcrop integration 4 sequences (sequence 4 to sequence 7) were interpreted in the Corcoran Member. Mancos Shale separates the Corcoran Member from underlying Sego Sandstone. In the Meeker area some of the progradational shoreface deposits of Corcoran Member were eroded locally and replaced by tidal/fluvial channels and estuarine deposits.

The thickness of individual sequences ranges between 26 to 60 m. In outcrop measured sections, the thickest sequence within the Corcoran Member is Sequence-4 and is approximately 52 m. The character of the sequences in the Corcoran Member changes from M-1 section to H-2 section (Fig. 3.1). In the M-1 section, Sequence-4 starts with offshore/prodelta mudrock and is overlain by lower shoreface and upper shoreface deposits and then by coal-rich coastal plain/lagoonal deposits. On top of these deposits amalgamated, hummocky cross-stratified upper shoreface deposits were deposited. The top of the upper shoreface deposit is trough cross-bedded and it is whitish- greenish. This sequence is overlain by fine grained, marine mudstone deposits (Fig. 3.6).

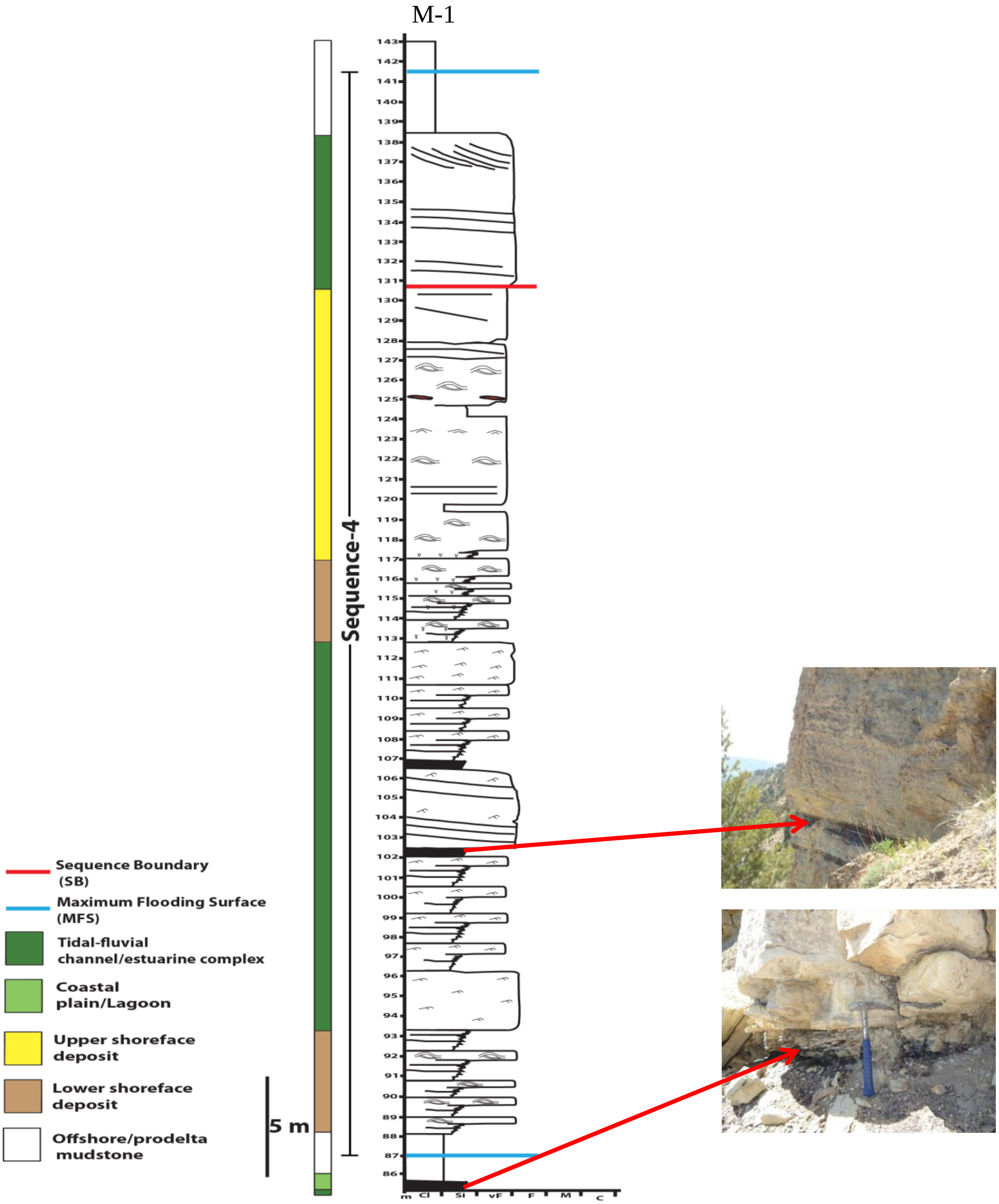


Figure 3.6: Representative measured section of the Corcoran Member (Sequence-4) succession with characteristics features (Section M-1 in Fig.3.1).

However at H-1, the Corcoran Sequence-4 starts with the coastal plain/lagoonal deposits (transgressive part of Sequence-4) and these are overlain by a maximum flooding surface in offshore deposits and then overlain by shoreface deposits. This shoreface section is cut by erosively based (SB) tidal-fluvial channels (Fig. 3.7) which are in the basal transgressive part of Sequence-5. At the base of the tidal-fluvial channel, massive very fine to fine grained sandstone with thin and deformed coal beds were seen as well as mudstone rip-up clasts. Within the tidal/fluvial channel thick piles of shell fragments were also observed (in Fig. 3.7 between 159-160 m levels). Bidirectional cross bedding (paleocurrent directions show both NW (310^0) and SE (110^0) directions, and double mud drapes are present (Facies Association 3). Towards the top of the tidal-fluvial channel finer grained sandstones occur with ripple-laminated sandstone at the top.

Sequence-5 at other locations is very similar to Sequence-4 (Fig. 3.8).Sequence-6 and Sequence-7 are not well exposed in the H-1 and H-2 sections though deposits of coastal plain, crevasse splay and distributary fluvial channels can be seen. Especially, in the Sulphur Creek outcrops fluvial and coastal plain deposits within Sequence-6 and Sequence-7 are well developed. In this same location of fluvial distributary channel occurs and consists of medium to fine grained sandstones with both tabular and trough cross-bedding. The set thickness of the tabular beds is 10-35 cm and the set thickness of the trough cross-bedding is 10-30 cm. Paleocurrent readings indicate unidirectional basinward flow mainly in a NE to E direction. Mud rip-up clasts are found within the cross-stratified sandstone. Besides cross-stratification, massive beds and soft sediment deformation are also observed. No evidence of marine fossils or trace fossils was found in the channel fill. Below the base of the channelized units, a coal deposit is present. Towards the top of the cross-stratified units current ripples were also observed (Fig. 3.9 and 3.10).

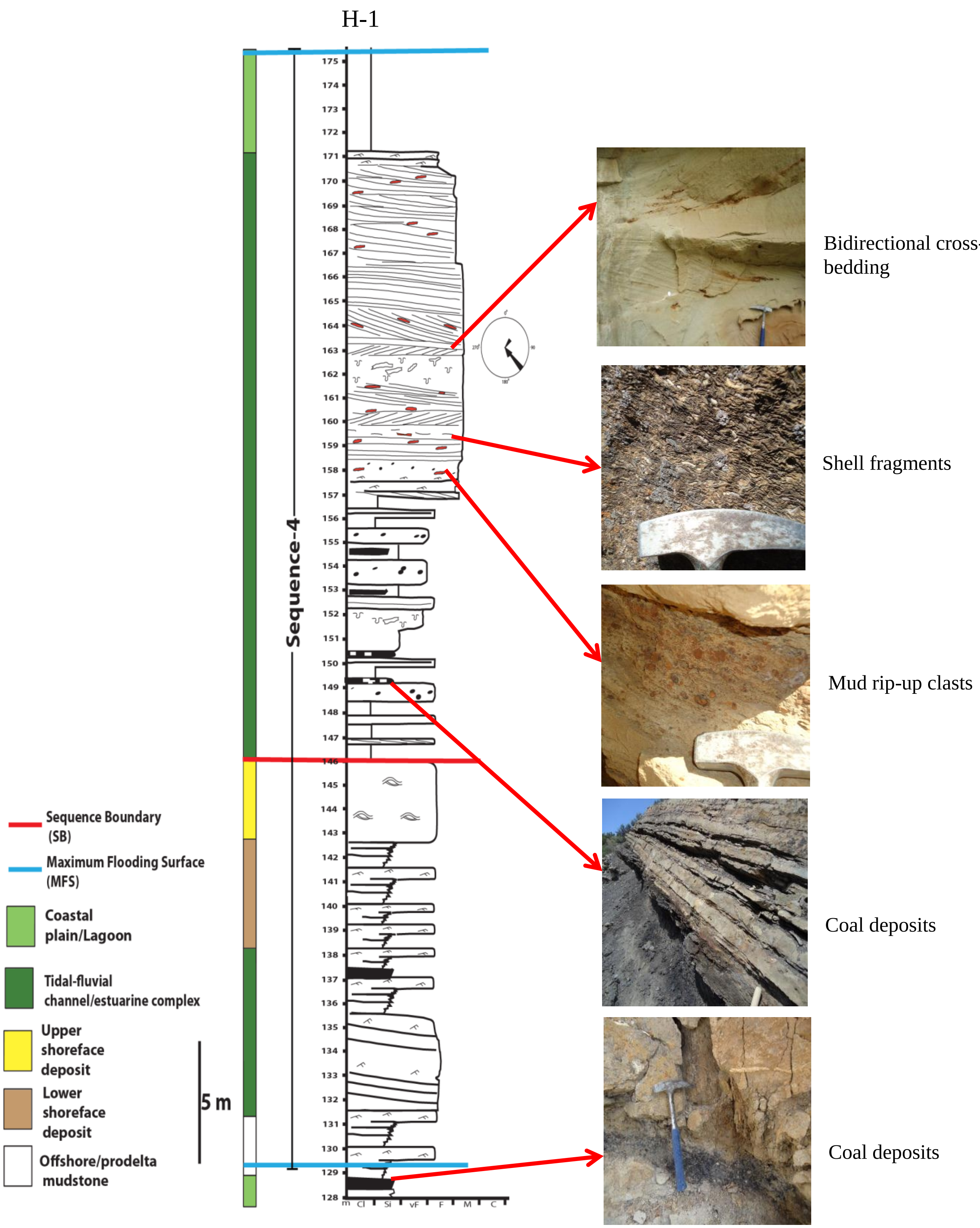


Figure 3.7: Representative measured section of the tidal-fluvial channel in Corcoran Member (Sequence-4) with characteristics features (Section H-1).

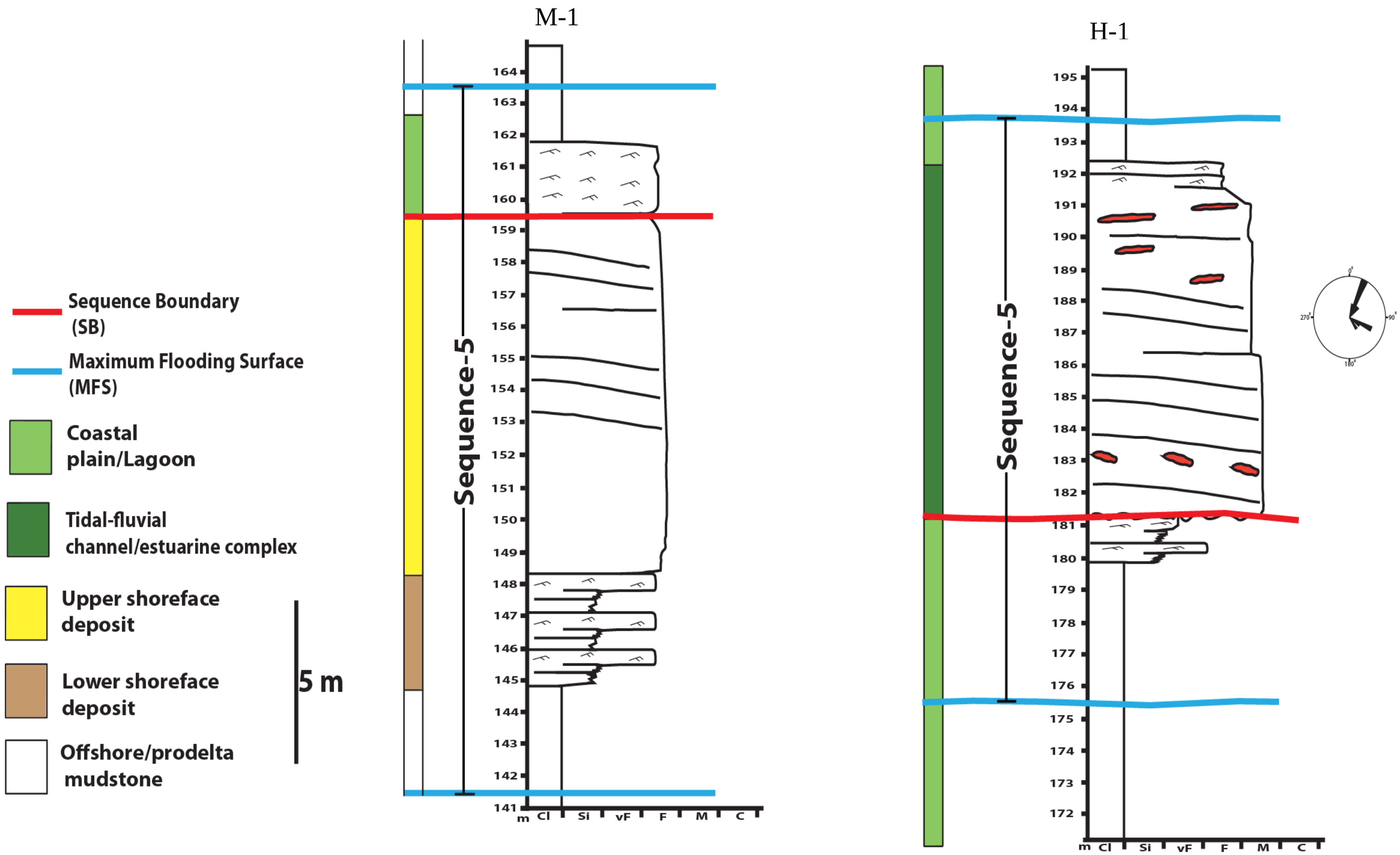


Figure 3.8: Representative measured sections of the Sequence-5 from M-1 and H-1 sections.

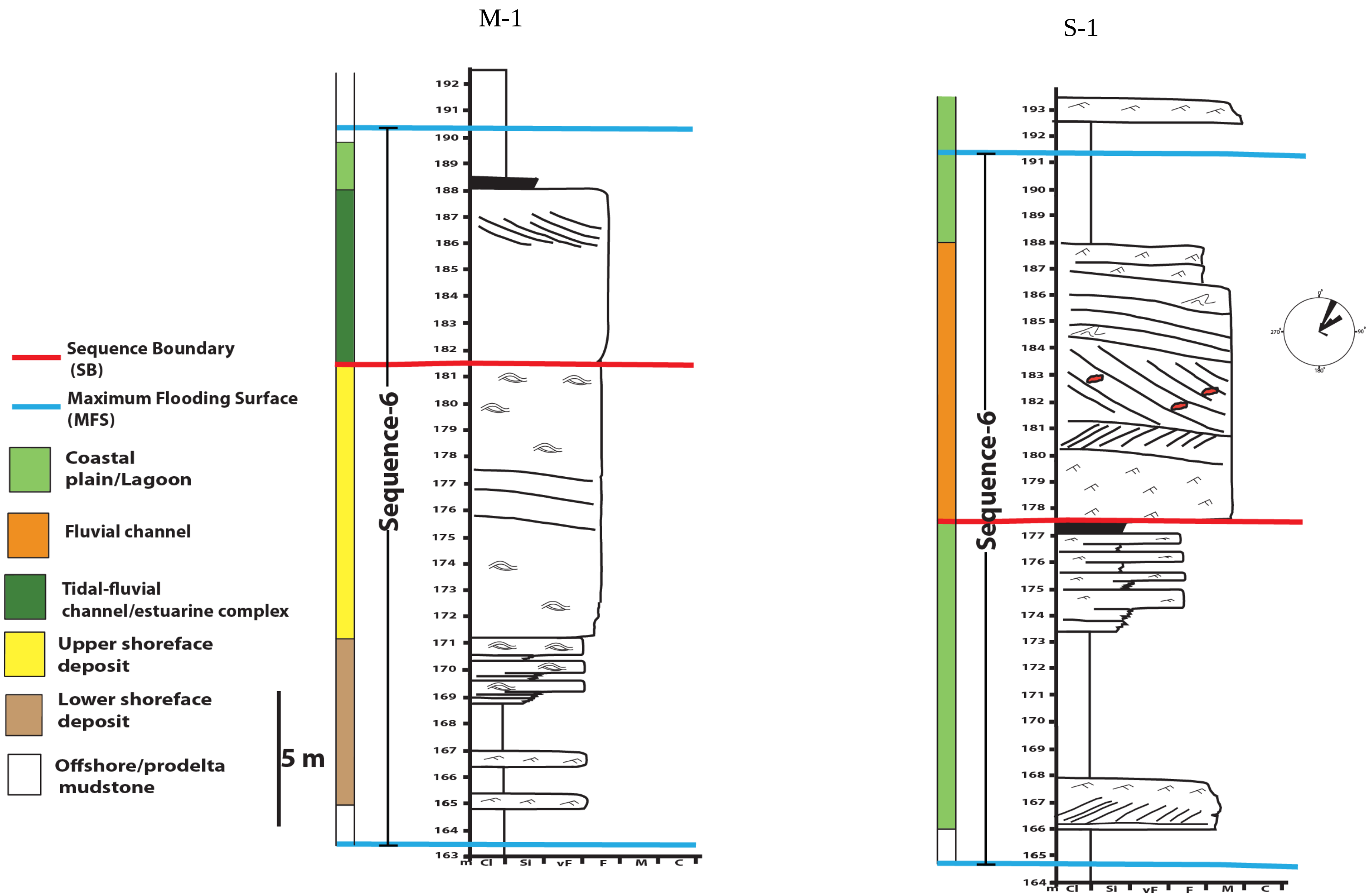


Figure 3.9: Representative measured sections of Corcoran Sequence-6 from M-1 and S-1 sections.

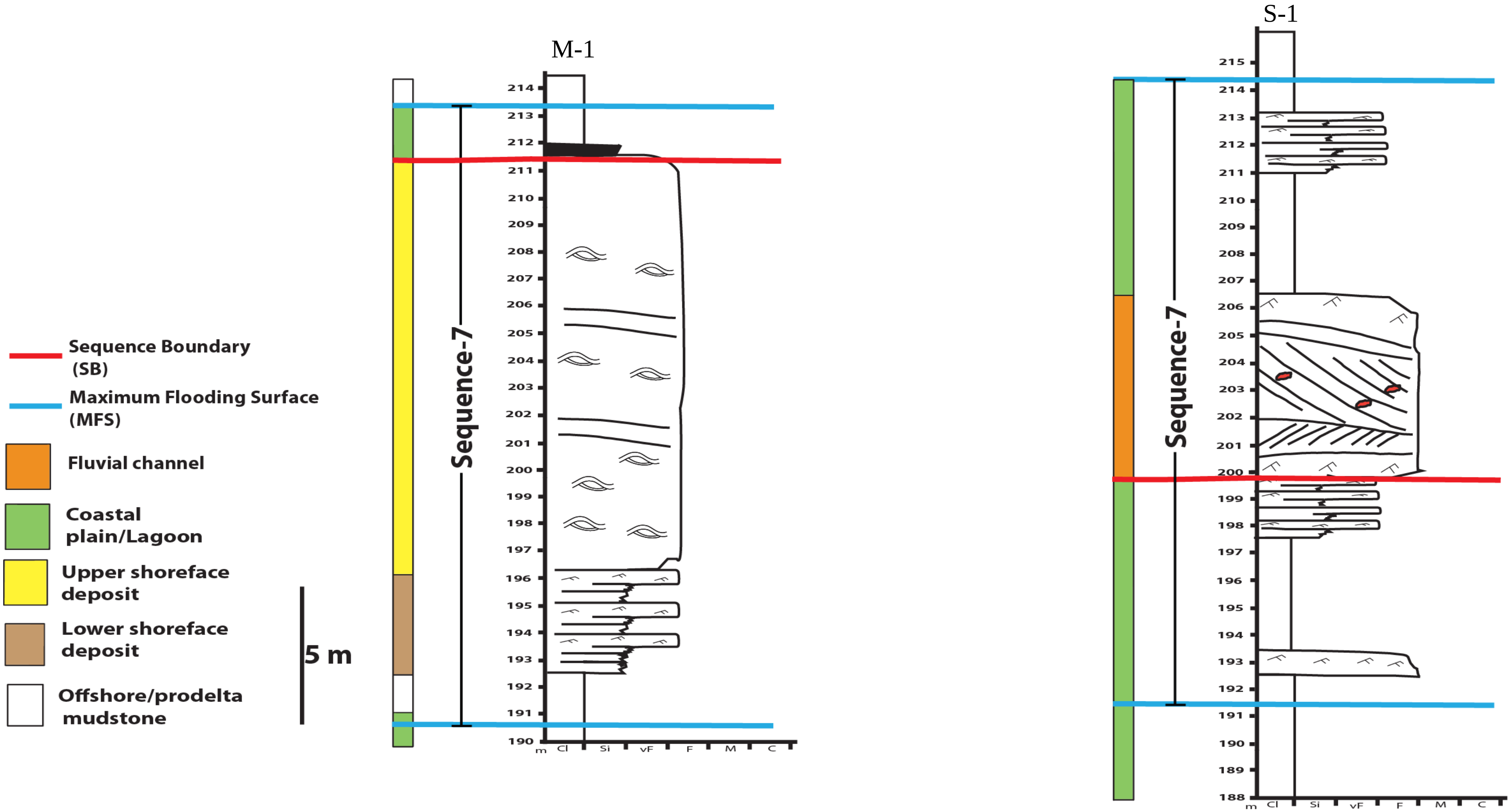


Figure 3.10: Representative measured sections of Corcoran Sequence-7 from M-1 and S-1 sections.

The Cozzette Member (Sequence 8 to Sequence 11)

Above the Corcoran Member is the Cozzette Member of the Iles Formation and it also appears to consist of 4 sequences. The exposures around Meeker are relatively poor but the logs of nearby wells are used to describe the Cozzette Member sequences. The total thickness of the Cozzette Member is ~120 m and the thickness of the individual sequences ranges from 21 to 60 m. The sequence measured in the outcrop for the Cozzette Member is Sequence-8 and it has a thickness of some 60 m. In M-1 section (Fig. 3.11) the transgressive coastal plain/ fluvial deposits are overlain by regressive shoreface deposits. In the H-2 (Fig. 3.11) section the sequence starts with coastal plain deposits overlain by a thick (39 m) tidal-fluvial channel. In the basal part of the channels wood fragments, *Teredolites* burrows, highly bioturbated sandstones were found (Facies Association 3).This tidal-fluvial channel is then overlain by coal beds and reddish ripple laminated ~1.5 m thick sandstone.

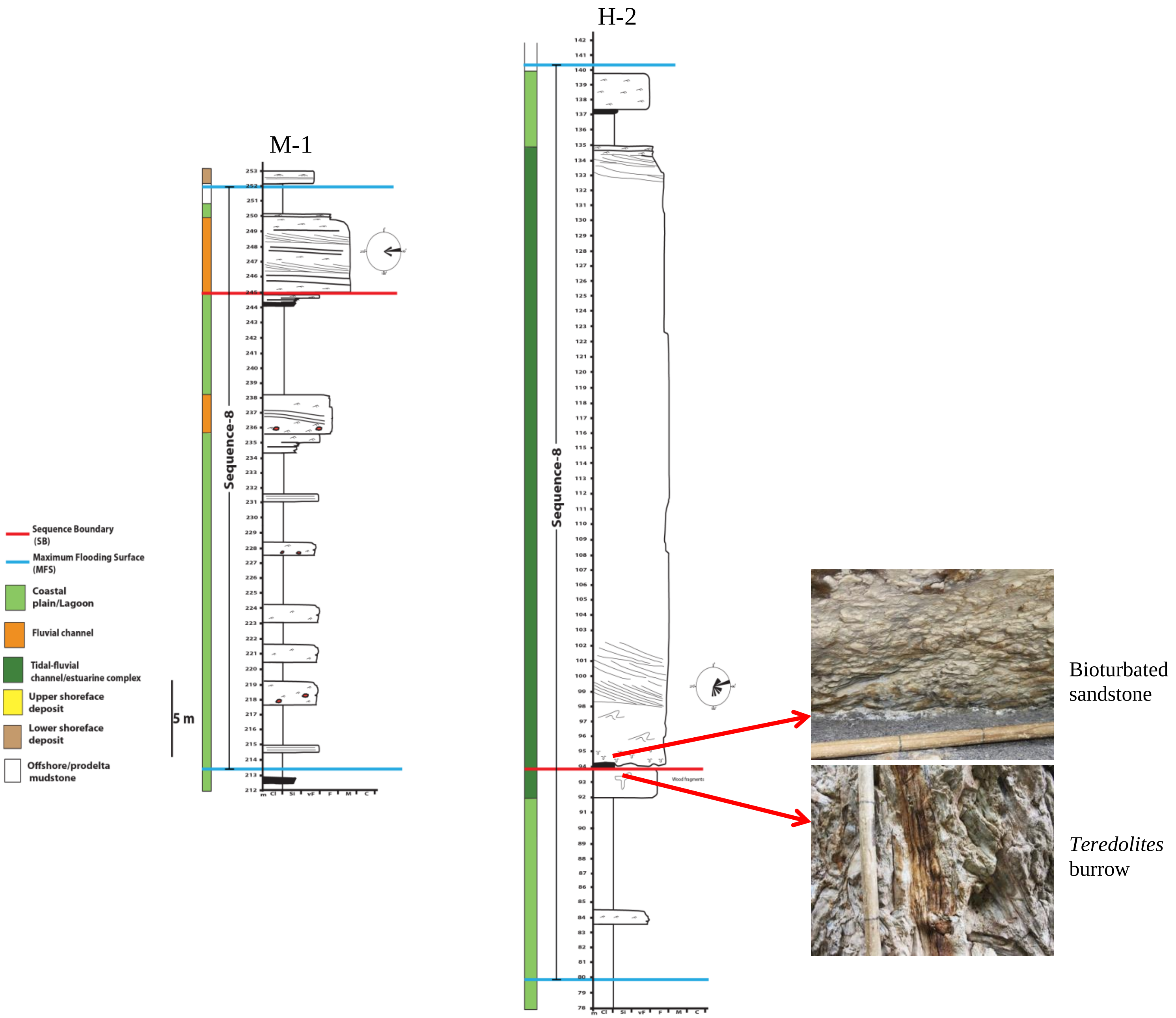


Figure 3.11: Representative measured sections of the Cozzette Sequence-8 from M-1 and H-2 sections.

DEPOSITIONAL HISTORY

An Iles strike section across the Meeker area is shown in Figure 3.12. The distribution of the facies in Figure 3.12 indicates the variation in paleoenvironments as they laterally and vertically shifted through time and space. Each sequence in the Meeker area consists of sand bodies as much as 39 m thick and associated coal bearing beds. The regressive shoreface deposits interfinger with marine shale and the top of the shoreface is sharp. Tidal influence is observed in the aggradational to transgressive (back-stepping) deposits of the overlying tidal-fluvial channels. Fluvial distributary channels indicate coastal regression. The progradational deposits were deposited as wave dominated deltas or sand-rich strandplains. Delta plain environments include deposits of crevasse splays and fluvial distributary channels. Most of the fourth order sequences (150-400 ky) in the Iles wedge are separated from each other by marine shale flooding intervals and the superposition of these can be indication of repeated regression and transgression on the Western Interior Seaway, possibly caused by eustatic or subsidence rate changes or periodic changes of supply of sediment, which would have allowed the marine environment to migrate inland without time for significant transgressive sandstones to form (Warner, 1964). A possible modern analog to the system in the Meeker area would be wave-dominated modern Danube Delta (Bhattacharya and Giosan, 2003) or the tidal to wave influenced modern Niger Delta (Allen, 1965)

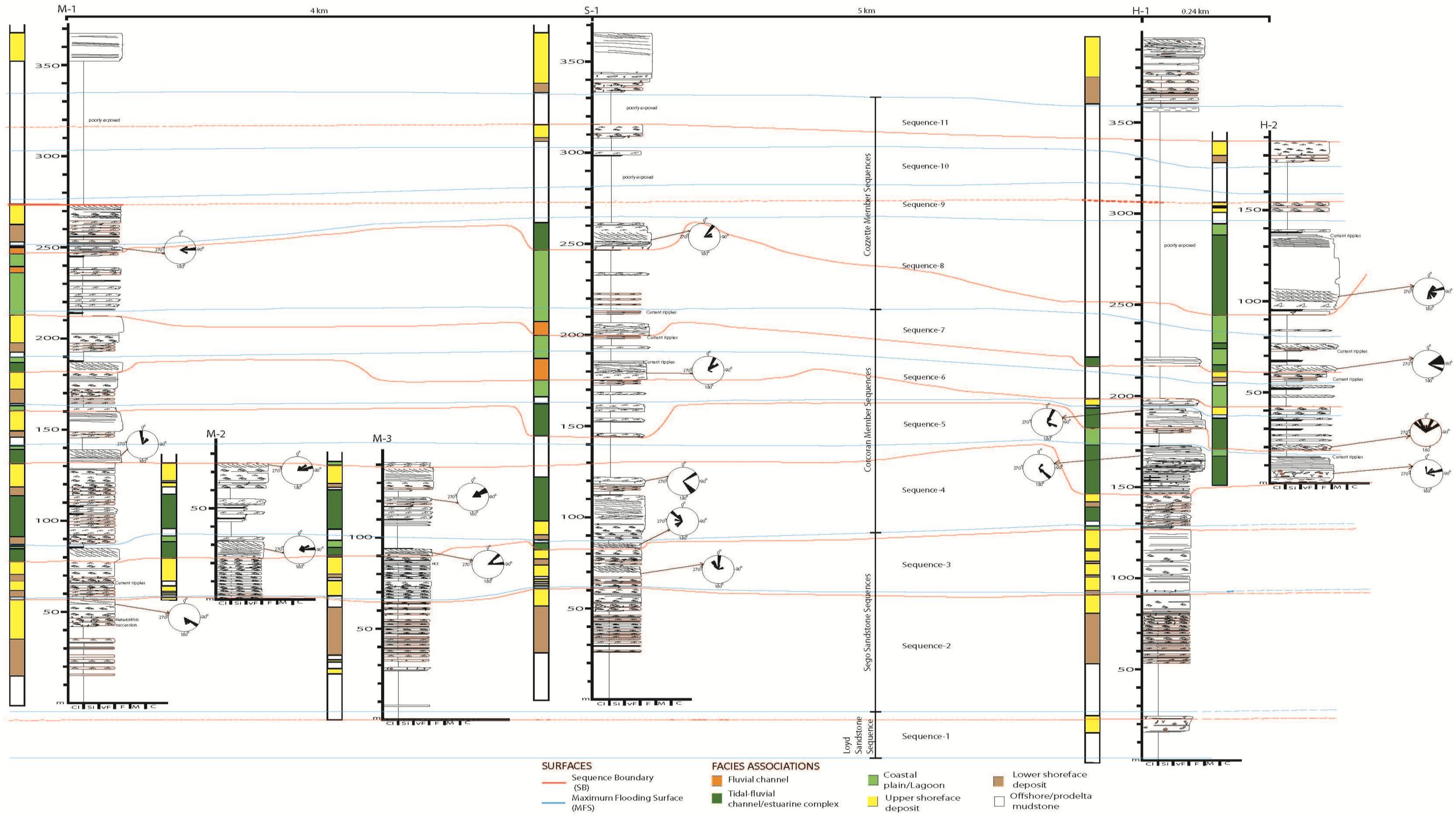


Figure 3.12: Outcrop correlation panel of measured sections in Meeker area.

THE RANGELY SUCCESSION

The Iles Clastic Wedge succession exposed just south of Rangely (Fig. 3.13) was measured up to the Cozzette Member equivalent and the measured thickness for the long section is 262 m. The formations measured consist of Buck Tongue of Mancos Shale, Lower Sego Sandstone, Upper Sego Sandstone, and Neslen Formation. However Iles Clastic Wedge in the Rangely area is defined from base Loyd Sandstone equivalent to top Neslen Formation (Corcoran and Cozzette Member equivalent). According to Erdmann (1934) the Sego Sandstones are equivalent of Mt. Garfield Formation and the overlying formations are equivalent of Hunter Canyon Formation in west-central Colorado.

Offshore marine, marginal marine and nonmarine facies are recognized in the study area. Based on the outcrop measured sections 8 sequences were identified from the Buck Tongue of the Mancos Shale and to the Neslen Formation top.

From bottom to top, there are two sequences in Buck Tongue of Mancos Shale, one sequence in Lower Sego Sandstone (Sequence-2) one sequences in Upper Sego Sandstone (Sequence-3), and four sequences in Neslen Formation (Sequence-4, Sequence-5, Sequence-6, Sequence-7).

Many studies have been conducted around the Rangely outcrops which describe the Sego Sandstone (Stancliffe 1984; Noe 1984, York et al., 2011) and coal bearing Mesaverde successions and fluvial deposits (Nelson, 1984). However, there are few publications dealing with Iles Formation in the Rangely subsurface. In this study both previous published works and new outcrop measured section and subsurface data were integrated to understand the variability of the Iles Clastic Wedge between Meeker and Rangely.

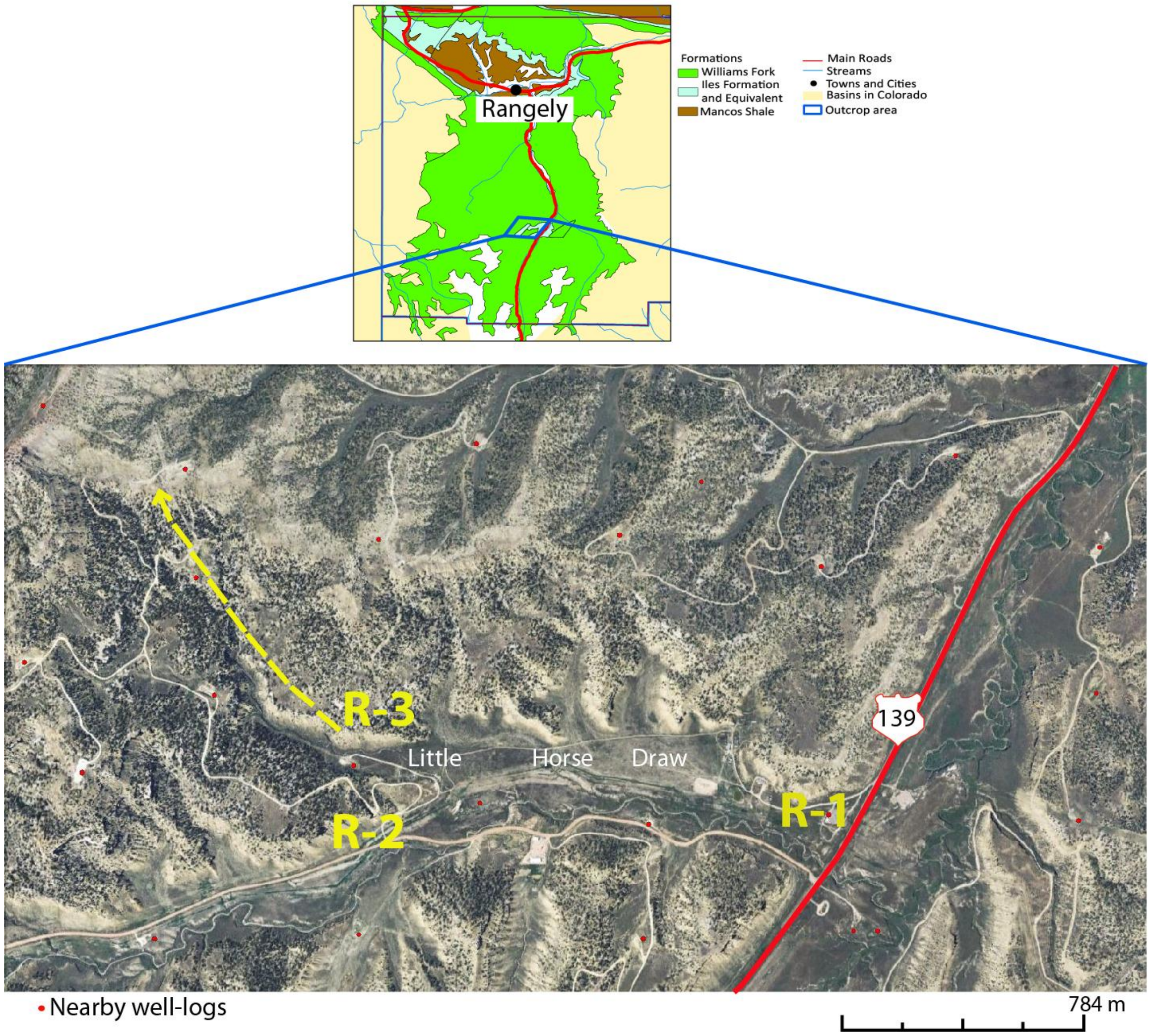


Figure 3.13: Yellow letters show location of the measured sections in south of Rangely area (yellow arrows indicate the direction of measurements).

Buck Tongue of Mancos Shale

The Buck Tongue is a mostly muddy succession with lens shape sandier successions near the top. The Buck Tongue mudstones are gray to light brown and grain size is ranging from clay to silt. Bioturbation is very common in this muddy succession and it has destroyed the stratification. Thin sandstone beds within the heterolithic section are 10-35 cm thick, very fine grained, sharp based, hummocky-stratified, flat-laminated, sometimes structureless and moderately bioturbated. Sandstone beds are not continuous. Rarely, reddish-brownish *Baculites* fossils were observed in the succession. Sand-mud ratio and grain size increase upwards as the Buck Tongue grades upward into Lower Sego Sandstone. The mudstone indicates low energy conditions; however, sand was deposited during exceptional current or storm events. The Buck Tongue indicates offshore/shelf transition conditions based on interbedded mudstone-sandstone, increase in sand thickness in the upward direction and gradation into thicker and bioturbated shoreface deposits. The Buck Tongue of Mancos Shale was deposited in the period between the early and late forms of *Baculites perplexus* (Gill and Hail, 1975). The Buck Tongue is thinning in a landward (towards Rangely) direction and contains Loyd Sandstone equivalent and 1st Mancos Sandstone.

A representative outcrop measured section of the Loyd Sandstone equivalent in the south of Rangely is shown in Figure 3.14. It has interbedded mudstone at the base overlying thin hummocky bedded heterolithic succession and 3 m thick massive sandstone at the top. This sandbody is interpreted as distal shelf deposits in this area. The basal maximum flooding surfaces for the Buck Tongue sequence lies just above the top of the Castlegate Sandstone with another possibly at the base of Lower Sego Sandstone.

An extensive regression overlying the Buck Tongue is represented by the progradation of the Sego Formation in eastern Utah, and the lower half of the prograding Iles wedge in northwest Colorado (I-1 to I-9) (Crabaugh, 2001).

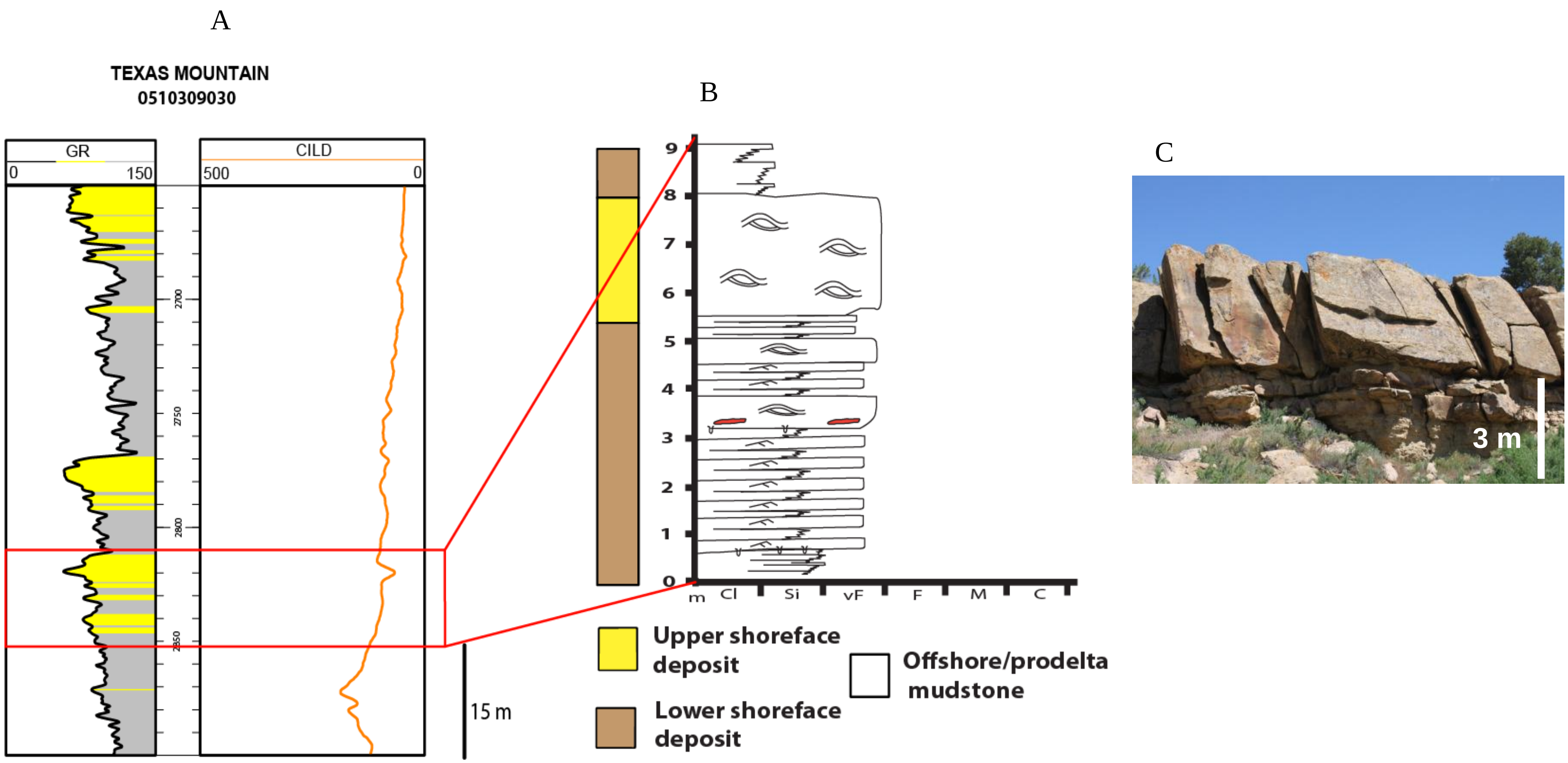


Figure 3.14: Representative well-log example (A) and representative measured section (B) for the possible Loyd Sandstone equivalent. (C) Outcrop photo of the measured section (R-1 section in Fig. 3.13).

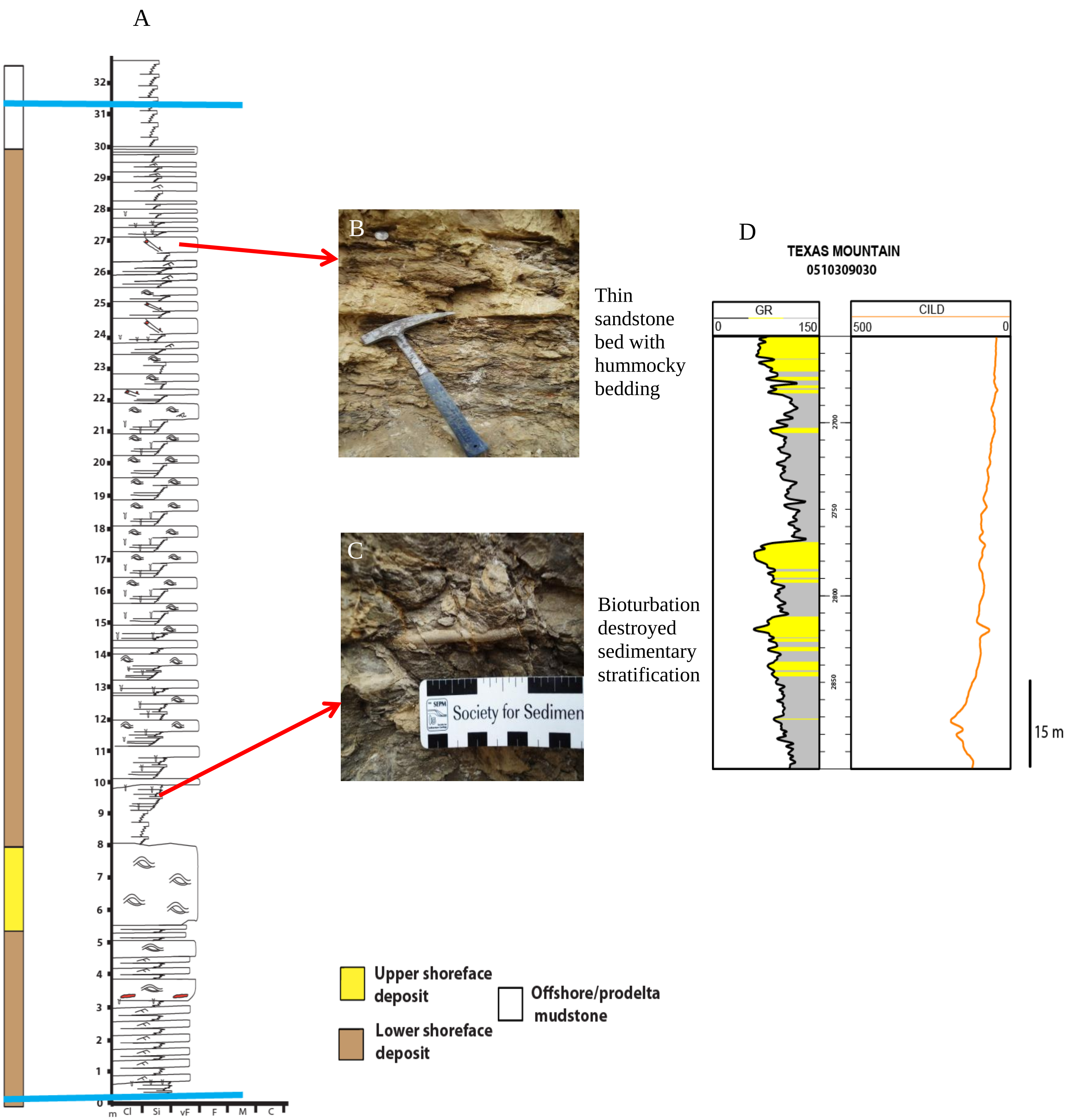


Figure 3.15: (A) Representative measured section of the Buck Tongue of the Mancos shale sequence (R-1 and R-2 section in Fig. 3.13) and well-log response of the Buck Tongue near Little Horse Draw (D). (B) Thin sandstone beds in the Buck Tongue. (C) Highly bioturbated mudstone (R-2 section in Fig. 3.13).

The Lower Sego Sandstone (Sequence-2)

The total thickness of the Lower Sego Sandstone sequence near Rangley (R-2 section in Fig. 3.13) is approximately 45 m. Similar to the Lower Sego Sandstone in Meeker, the measured section of the Lower Sego Sandstone in near Rangely (Fig. 3.16) contains offshore, lower shoreface and upper shoreface deposits. Shoreface deposits are sharp based hummocky cross-stratified sandstone beds with thin, wavy laminated siltstone interbeds and overlying 1-5 m thick, cliff-forming trough cross-stratified and planar laminated sandstone. The trough cross-stratified sandstone interval generally has an erosional base. Paleocurrents readings from trough cross-stratification indicate a north direction of sediment transport. The general trend in the grain size is upward coarsening and it is changing from very fine to fine sandstone. *Ophiomorpha, Thalassinoides* and *Skolitos* traces are found. Structureless beds, mud rip-up clast are also observed in the outcrop. However, the thickness of the shoreface deposits of the Lower Sego Sandstone near Rangely is thinner than the similar facies association of the Meeker succession. This can be because of the differences in sediment supply or subsidence rate in the more updip Rangely area. Generally, in deltaic fairways, subsidence and compaction rates are greater than in embayed coasts and wave activity is more effective. The basal maximum flooding surface is at the base of the Buck Tongue of Mancos Shale and upper maximum flooding surface is above the coal deposits which Noe, 1984 interprets as the Anchor Mine Tongue of Mancos Shale.

An Exxonian sequence boundary can be located at the contact between shoreface and tidal deposits (at level 73 m in Fig. 3.16A) which indicates the basinward shift in facies.

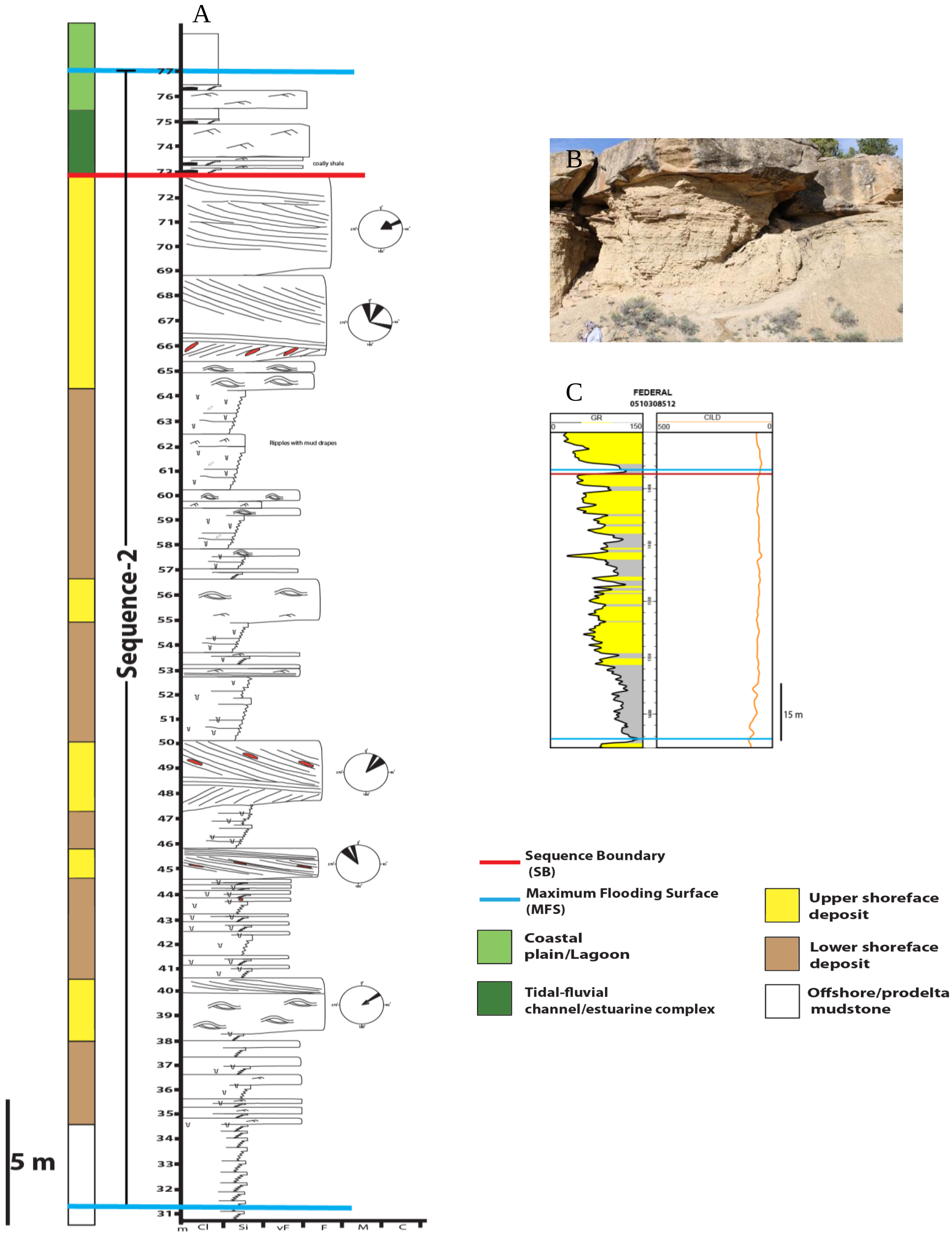


Figure 3.16: (A) Representative measured section of the Lower Sego Sandstone sequence (R-2 section). (B) Photo of a part of a Lower Sego Sandstone. (C) Well-log response of the Lower Sego Sandstone.

Upper Sego Sandstone (Sequence-3)

The total thickness of the Upper Sego succession is approximately 87 m. It consists of tidal sand bar, tidal-fluvial channel (Sequence-3) deposits (Fig. 3.17). Sand bodies in the Upper Sego Sequences have two main characteristics: trough cross-bedding and ripple stratification. The bases of the sand bodies have a sharp contact with underlying lagoonal carbonaceous mudstone and coals.

Tidal sand bars consist of trough cross-stratified sandstones with some siltstone content (Facies Association 7). At the base of this sand bar coaly shale and siltstone with wavy and lenticular bedding were observed. The tidal sand bar deposits are overlain by tidal fluvial channels (Facies Association 3). Paleocurrent readings from these sandstone bodies indicate bidirectional current (mostly 320^0 (NW) and 125^0 (SE)) activity. In the lower part of these sand bodies mudstone rip-up clasts were found along the foresets of the trough. Bioturbation is also intense in the lower part of these deposits. The bioturbated sandstone lithofacies is intercalated with the silty mudstones. Accumulations of the siltstone, mudstones with organic materials indicate lagoonal environment. In lagoonal environment, these sands can be ripple-modified by wind and tide generated currents (Fenies and Fauge`res, 1998). The shale and organic material content increases in Sequence-3 (Fig. 3.17). At the base of the tidal flat deposits, rippled stratified lateral accretion surfaces were observed. These lateral accretion surfaces can be interpreted as part of tidal creek point-bar deposits. Modern example of these deposits can be Arcachon Lagoon, SW France (Fenies, H. and Fauge`res, J. 1998) or Willapa Bay, Wsahington (Clifron, 1983).

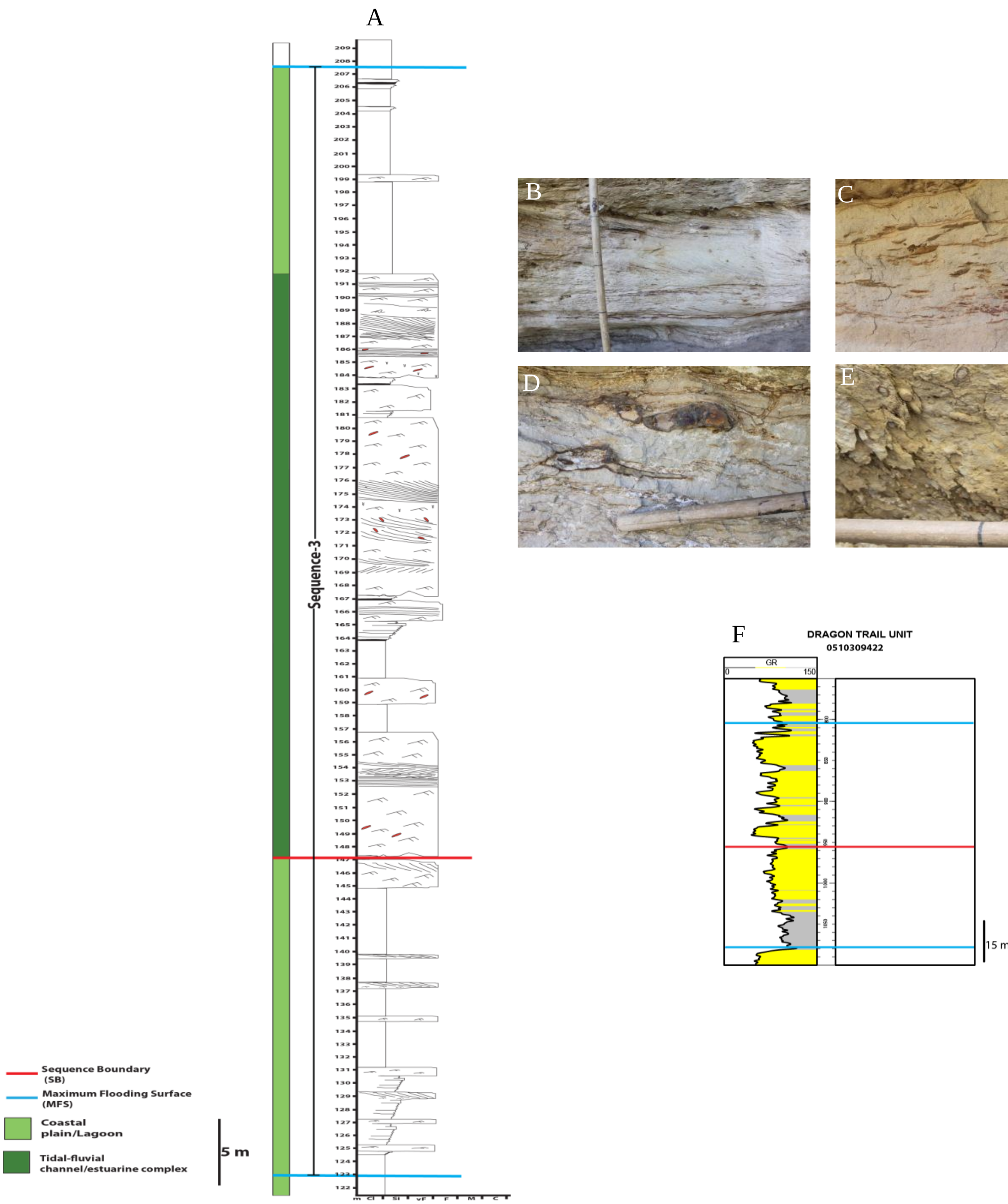


Figure 3.17: (A) Sequence-3 succession (R-3 section). (B) Cross-bedding with mud drapes on the foreset. (C, D) Double mud drapes and rip-up clasts. (D) Highly bioturbated mudstone. (F) Well-log response of the Upper Sego sequence.

The Neslen Formation (Sequence-4, Sequence-5, Sequence-6, Sequence-7)

The measured total thickness of Sequence-4, Sequence-5, Sequence-6, and Sequence-7 is 100 m. These are Neslen Formation (Corcoran member equivalent) sequences and are separated from the underlying Sego Sandstone deposits by coastal plain/lagoonal mudstone and coal zones. The sequences in this interval consist of tidal flat, fluvial channel and associated flood plain deposits.

Tidal flat deposits in Sequence-4 and 5 are similar to the same deposit in the Sequence-3.Fluvial channel deposits (Facies Association 4) occur stratigraphically above estuarine/tidal flat deposits and are covered with the floodplain material. Contacts with the underlying deposits are erosional. Sedimentary structures include trough cross-bedding at the base changing to ripple cross-stratification at the top.

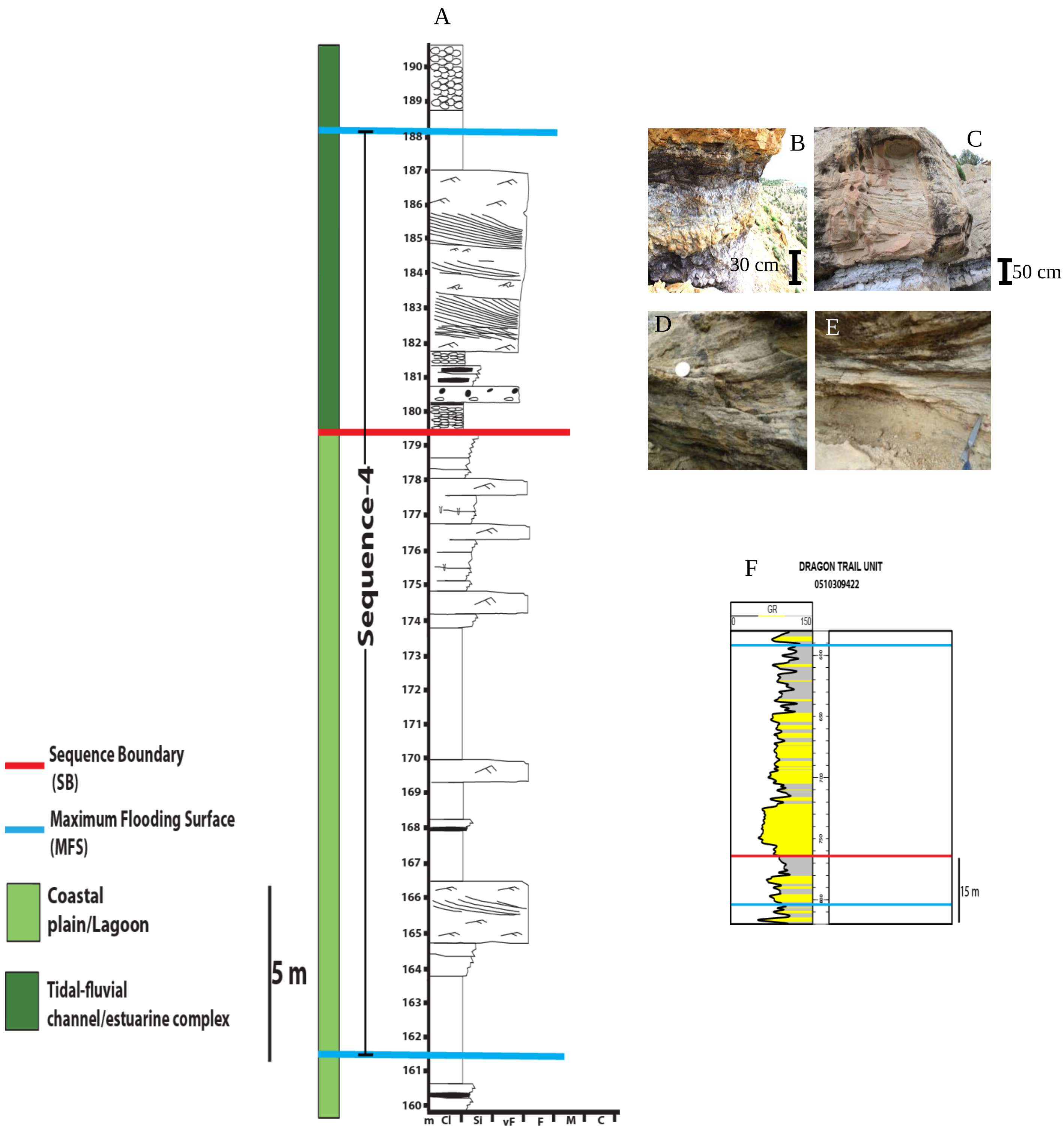


Figure 3.18: (A) Sequence-4 succession (R-3 section). (B) Organic rich massive mudstone (C) Lenticular sand body with trough and tabular cross-bedding (D) Trough cross bedding in fluvial channel deposit. (E) Rip-up clasts at the base of a channel. (F) Well-log response of the Neslen Formation sequence.

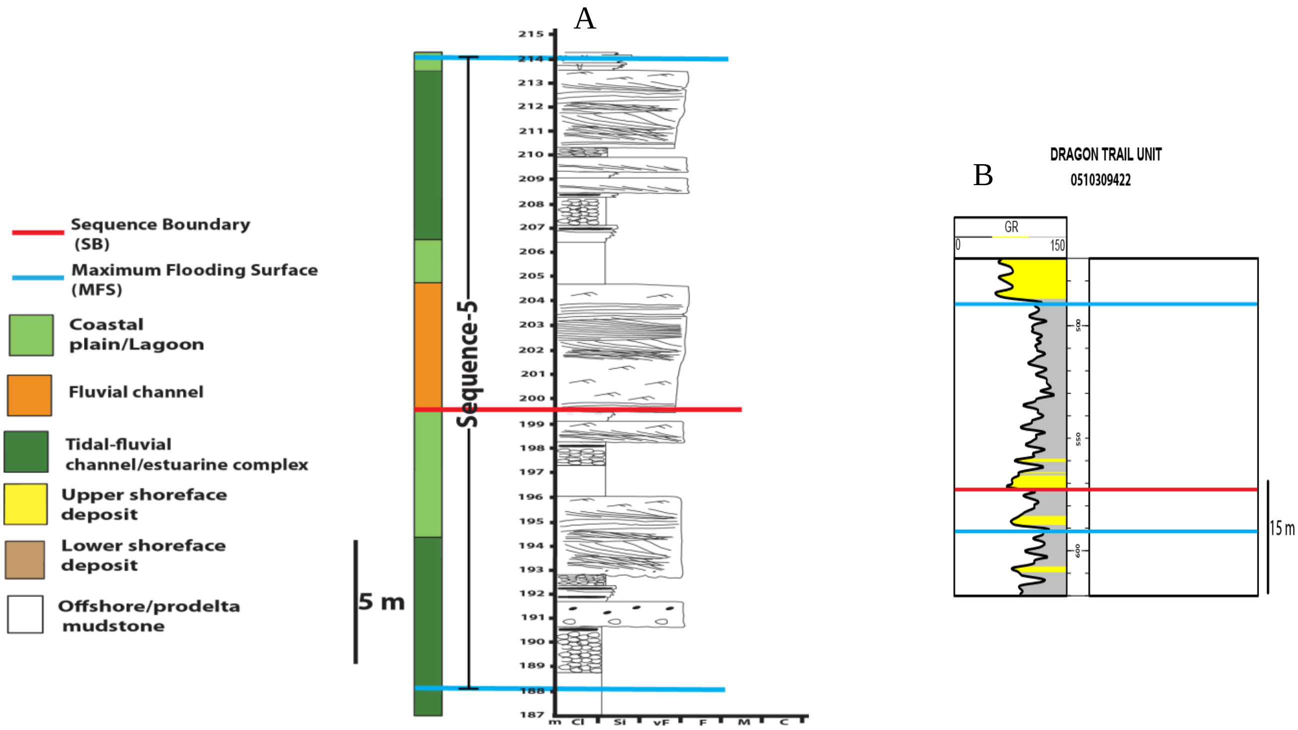


Figure 3.19: Characteristics of Sequence-5 in Neslen Formation (R-3 section).

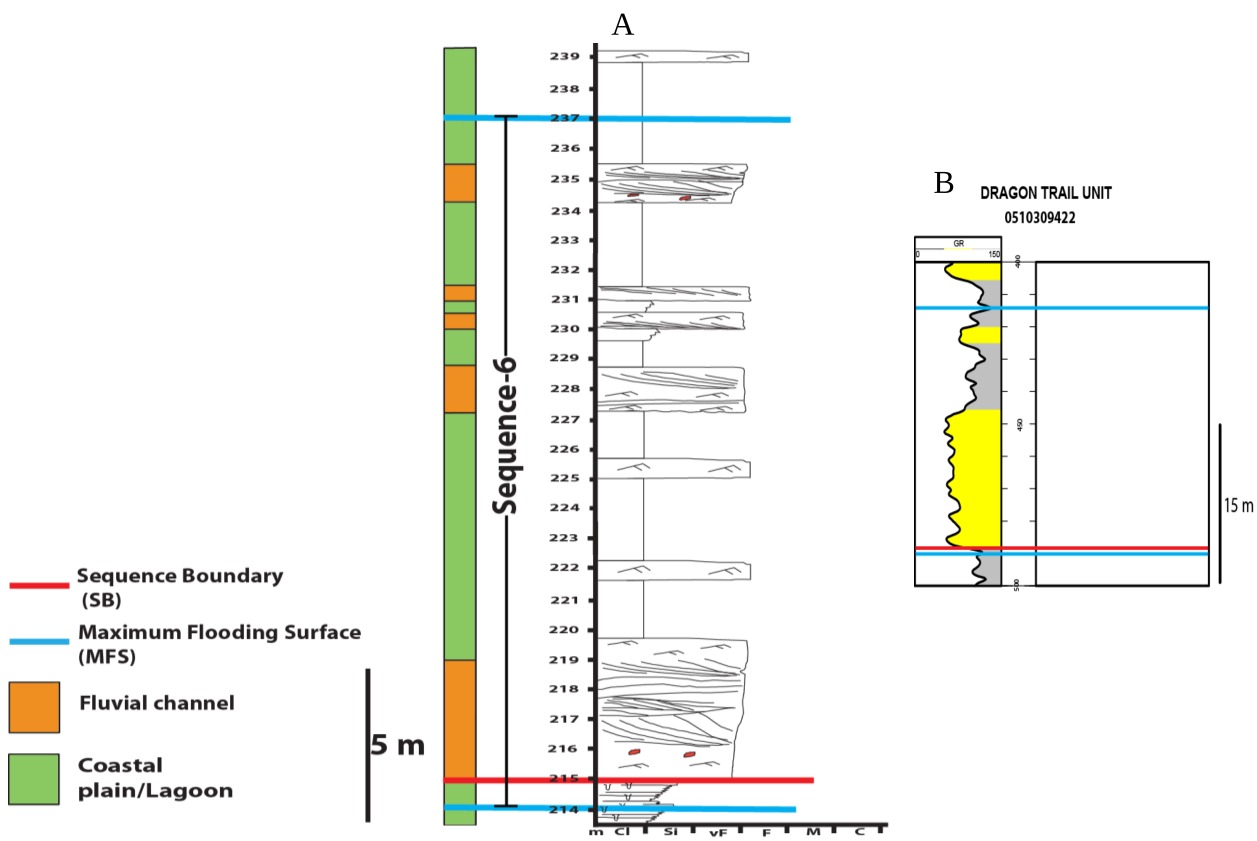


Figure 3.20: Characteristics of Sequence-6 in Neslen Formation (R-3 section).

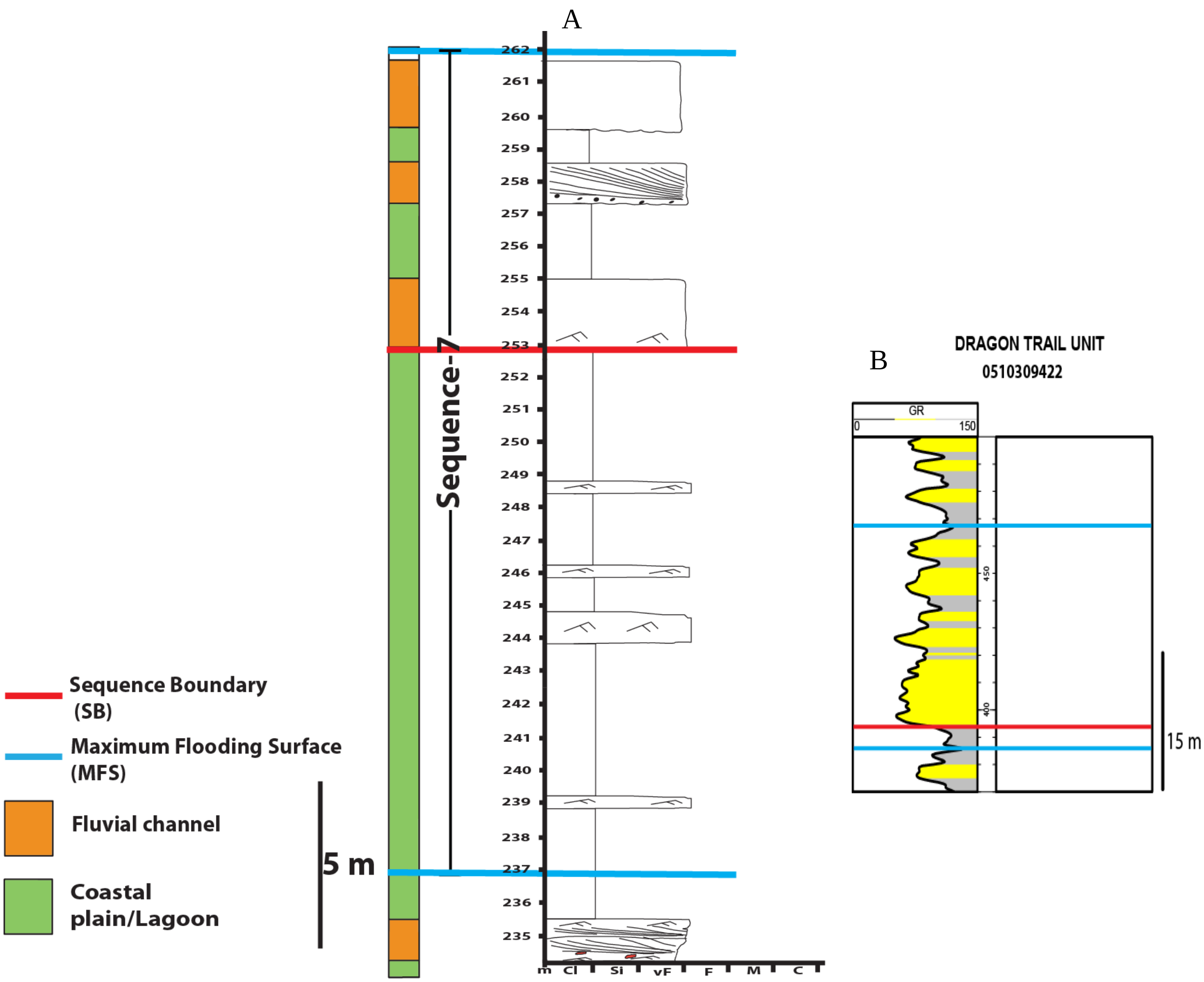


Figure 3.21: Characteristics of Sequence-7 in Neslen Formation (R-3 section in Fig. 3.13).

DEPOSITIONAL HISTORY

The main facies observed just south of Rangely are forming strike elongate (NE-SW) shoreface units in the lower part of the succession and dip-oriented tidal flat, tidal fluvial channels, lagoonal and fluvial channel facies in the upper parts (Neslen Fm) of the succession. Shoreface deposits can be interpreted as barrier island, strandplain and delta front (Fisher and Brown, 1972). However, the sandy and muddy tidal flats, fluvial and tidal-fluvial channels, and marsh deposits indicate deposition in the coastal plain and back barrier environment. Therefore, the facies associations in this area indicate barrier island, back barrier environment and coastal plain environments which occur in irregular embayed coastlines.

The occurrence of strandplains barrier islands in modern coastlines is due to moderate to low tidal range, a low gradient continental shelf adjacent to a low-relief coastal plain, and an abundant sediment supply (Stancliffe, 1984). The variation in tide and wave regime determines the coastal geomorphology in an area.

Based on both outcrop and well-log correlation, it is seen that wave dominated deltaic deposits in Meeker area change to mixed coastal plain, back-barrier and some strandplain deposits in Rangely. The Lower Sego Sandstone in Rangely is more bioturbated and thinner than the Lower Sego Sandstone in Meeker, and represents a more landward development of Sego Sandstone. Also the Upper Sego Sandstone is more tidally influenced in Rangely than in Meeker and so also represents a more landward development. The Neslen Formation consists mostly of fluvial, fluvial-tidal and embayment deposits and indicates a more proximal position compared to the downdip Corcoran Member coastlines at Meeker. This Neslen upper fluvial system above the Sego Sandstone is the evidence of continued progradation of coastal plain above the Sego shorelines. The Neslen coastal plain and tidal system at Rangely is clearly the feeder system to the downdip Corcoran and Cozzette Member shorelines at Meeker.

CHAPTER 4: VARIABILITY OF ILES CLASTIC WEDGE ACROSS PICEANCE BASIN

To understand the strike and dip variability across the northern Piceance Basin between Rangely and Meeker, 110 well logs and 7 measured stratigraphic sections were used to construct 14 cross-sections (Fig. 4.1) and to create 9 isopach maps. From these cross-sections one dip-oriented (Fig. 4.3) and one strike-oriented (Fig. 4.4) cross section were chosen to illustrate some of the main time and space changes in the sand/shale ratio and sedimentary environments within this sector of the Iles Clastic Wedge.

The main depositional environments or groups of environments in the study succession can be seen by the coloring in the cross sections of Figures 4.3 and 4.4. These are primarily (1) deltaic/strandplain/barrier shoreline (yellow), (2) behind-shoreline coastal plain (light green), muddy embayments, tidal flats and distributary or tidal channels (darker green) and (3) offshore and shelf areas (white). A key part of the study is that the outcrop succession allowed the picking of 11 stratigraphic sequences, and these sequences can be extended and picked also on the well data. This is illustrated in Figure 4.2 and is used in the stratigraphic cross sections covering this part of the Piceance Basin (Fig. 4.1). How the 11 sequences are distributed between the Loyd, Sego, Corcoran, Cozzette and Neslen lithostratigraphic units has already been shown in earlier chapters.

In well-log cross sections the maximum flooding surfaces are most easily placed near the base of offshore/shelf mudstone successions, but also can be extended into marine or brackish-water incursions associated with lagoonal and/or coastal plain deposits behind the shorelines. Sequence boundaries were picked at the base of fluvial and tidal-fluvial/estuarine deposits which cut into underlying delta/shoreface deposits or on erosional surfaces near the top of the delta/shoreface deposits, sometimes created by wave and storm activity during transgression.

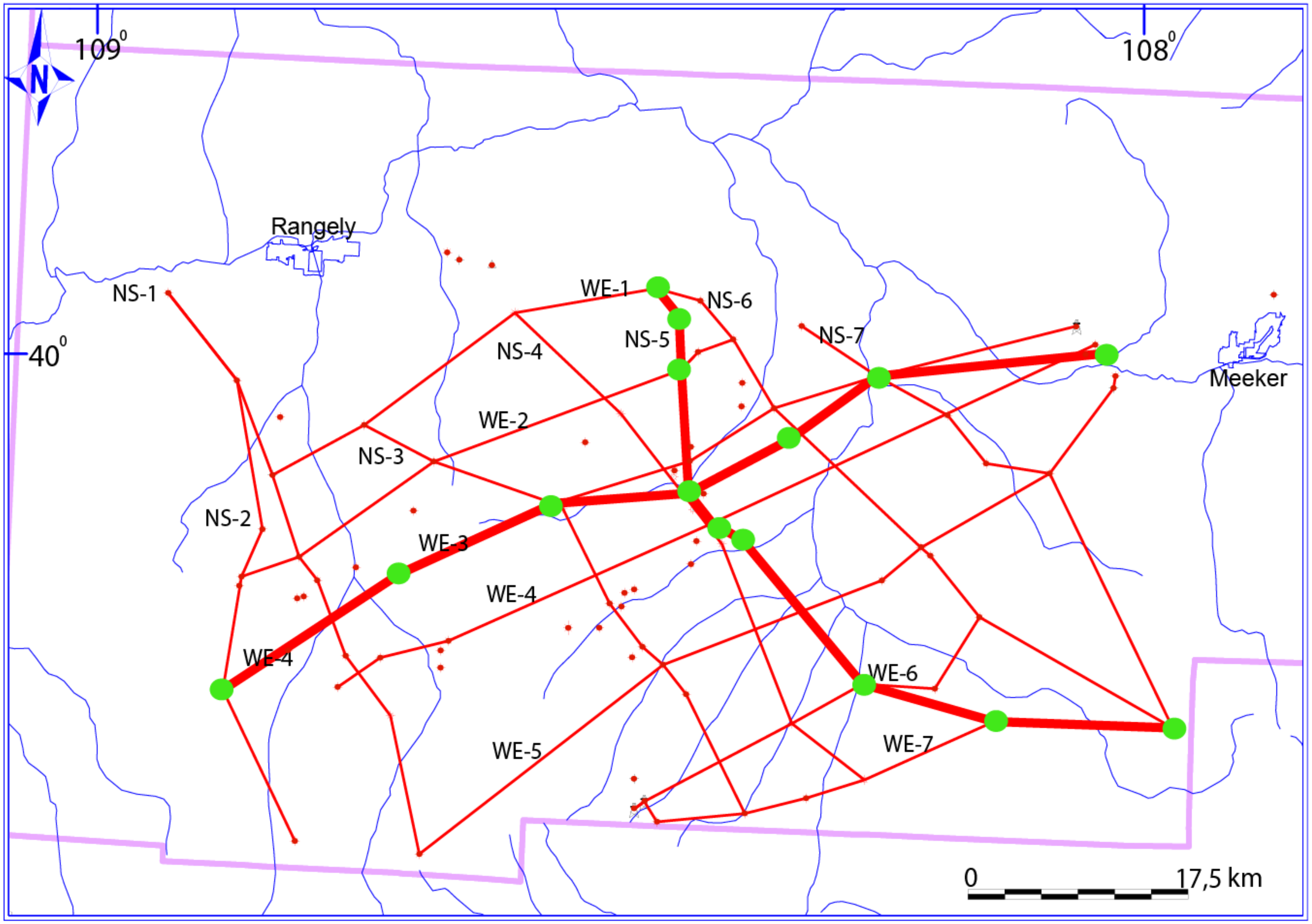


Figure 4.1: Dip and strike cross-sections' location map. Well at ENE end of WE-4 is used in Figure 4.2.

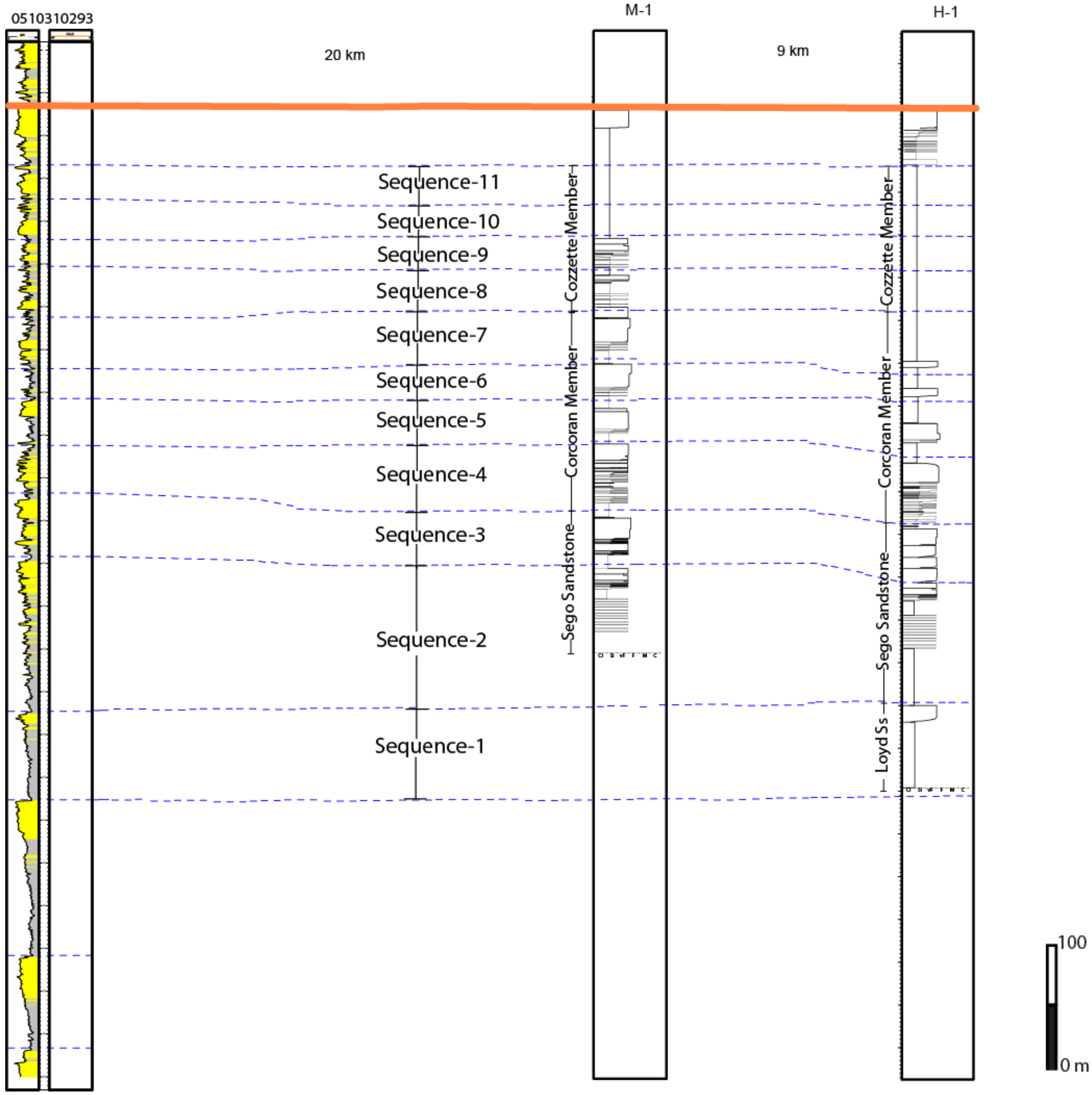


Figure 4.2: Eleven sequences based on well-log and outcrop correlation near Meeker.

NS-5 NEAR-DIP ORIENTED CROSS- SECTION

Figure 4.3 is a dip-oriented basinal cross section that illustrates how the 11 sequences relate to the Loyd, Sego, Corcoran and Cozzette lithostratigraphic units.

The following futures and trends emerge from the coloring in Figure 4.3:

1. There is a clear and overall progradation of the succession, shown by the upward change from white and yellow to yellow and green colors, as is expected from this being an overall, broadly southeast-oriented, regressive clastic wedge, probably of 3rd order status (ca 3.3. My).
2. The 11 sequences within the clastic wedge are higher-frequency regressive-transgressive sandstone tongues or wedges of likely 4th-order duration (few 100 ky).
3. The tendency to backstepping or retrogradation of the larger 3rd-order clastic wedge can be clearly seen by the increasing concentration of shoreline deposits (yellow colors) in the Cozzette levels of the uppermost part of the succession, as well as a corresponding decrease in the coastal plain deposits (green color) at this same upper level.
4. Keeping with the above, the lowermost sandstone benches of Castlegate Mancos Sandstone and Loyd Sandstone appear to be pinching out on the Western Interior shelf to the southeast. The Sego Sandstone bodies are also close to pinching out towards the southeast.

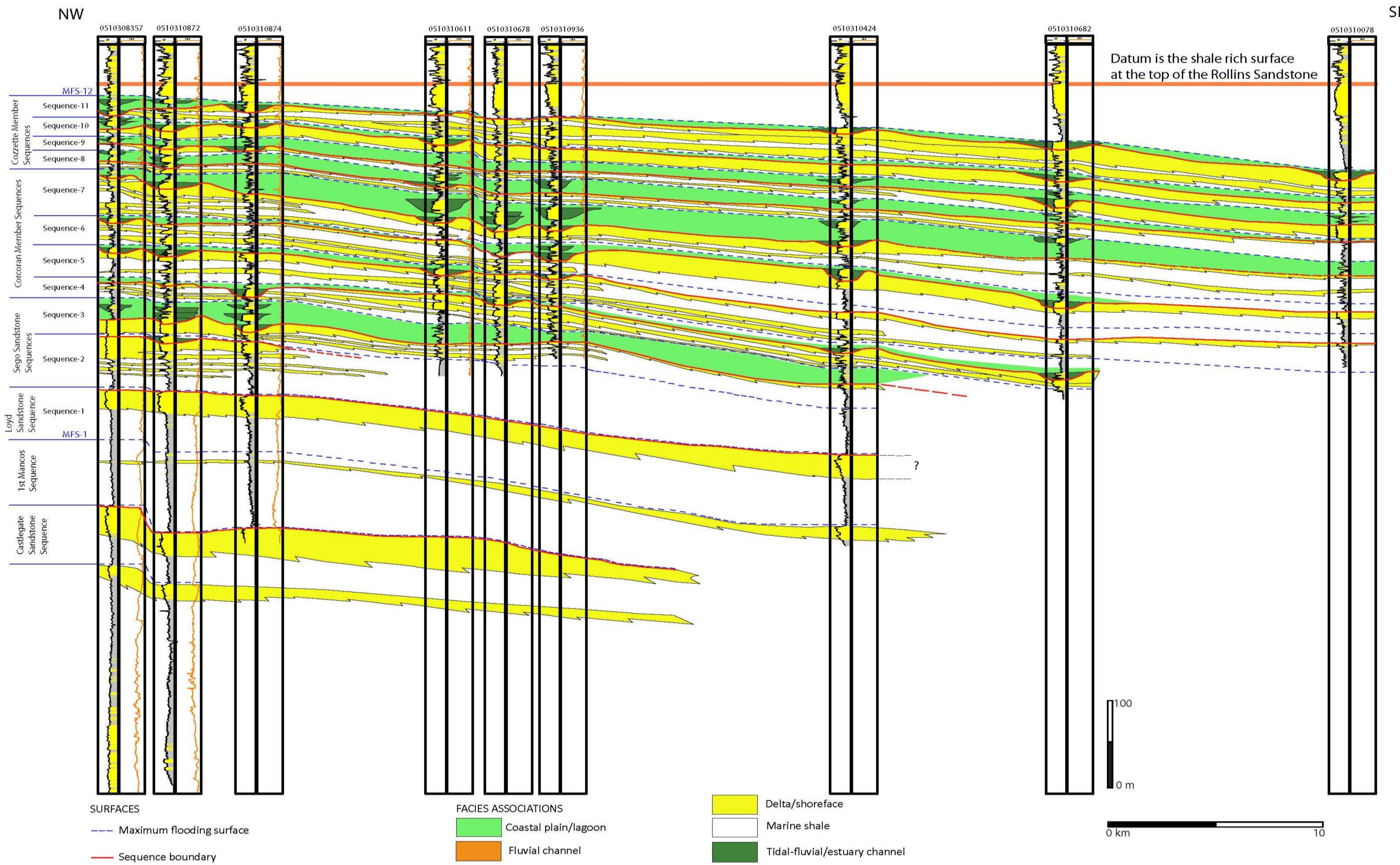


Figure 4.3: NS-5 near-dip oriented cross-section.

WE-4 NEAR-STRIKE ORIENTED CROSS SECTION

Figure 4.4 shows a cross section which is nearly strike oriented, NE-SW. The main features to be added to the comments on the dip-oriented observations from Figure 4.3 are:

1. The lower half of the clastic wedge shows some clear expansion towards Meeker area, suggesting that we are moving obliquely away from depositional strike and towards depositional dip in the ENE direction. At this time it appears that the depositional strike runs rather NNE.
2. The upper half of the clastic wedge also behaves like it is slightly dip oriented in the NE direction because there is a clear northeasterly change from mainly behind-the-coastline deposits (green) to increased shoreline presence. It is likely that here too the shorelines have a NNE strike orientation, though there is much less subsidence expansion in the upper level compared to the lower.

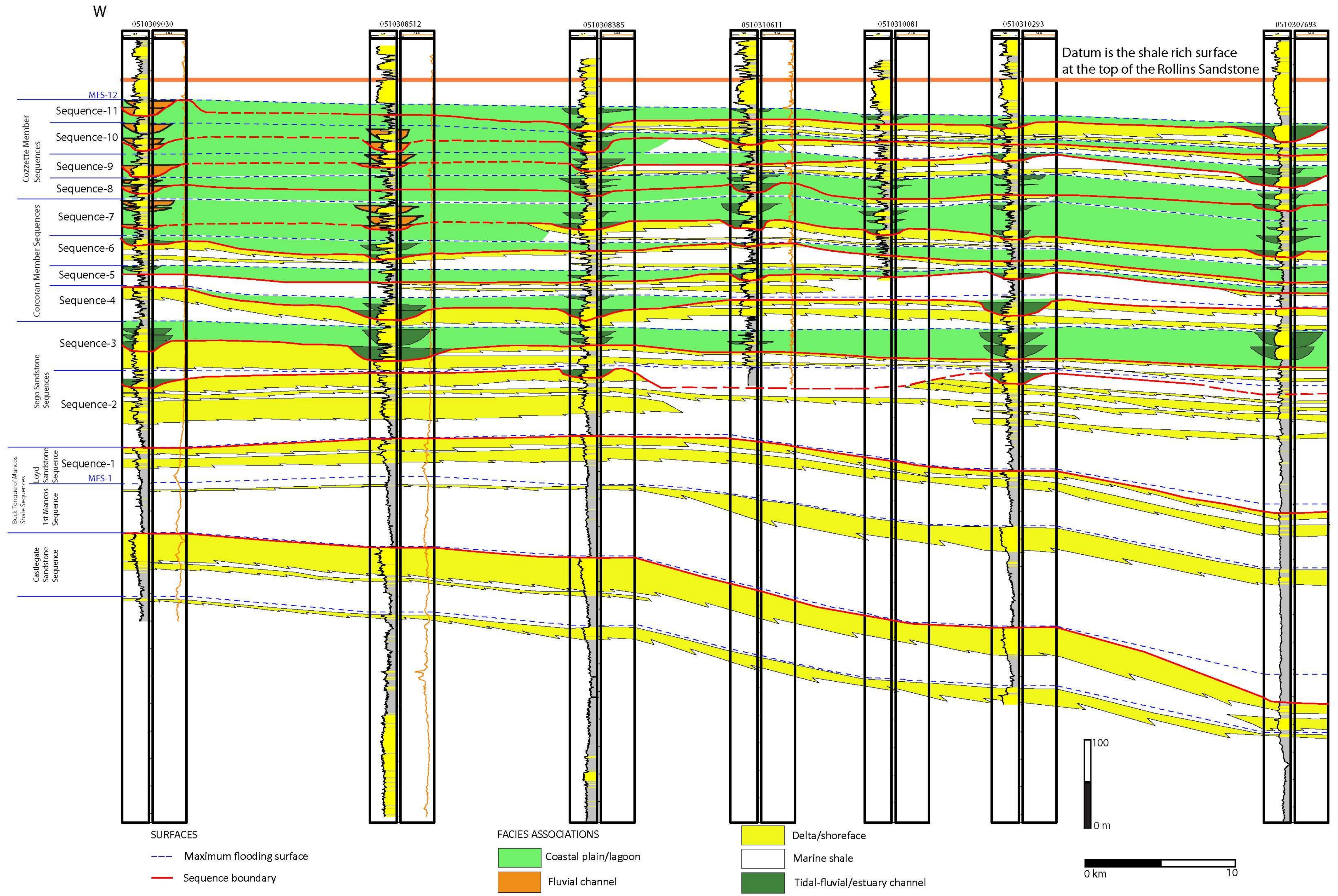


Figure 4.4: WE-4 near- strike oriented cross-section.

ISOPACH MAPS

14 interpreted cross-sections through the study area led to the creation of gross-sand isopach maps for the intervals of the high-frequency sequences between flooding surfaces (Castlegate Sandstone, Loyd Sandstone, Sego Sandstone, Corcoran Member, Cozzette Member and Rollins Sandstone Member) (Fig. 4.3 and 4.4). The thickness of the Castlegate Sandstone was calculated from base to top maximum flooding surface of the Castlegate Sandstone Sequence. The thickness of the 1st Mancos Sandstone was calculated from base to top maximum flooding surfaces of the 1st Mancos Sequence. The Loyd Sandstone was calculated between MFS-1 and MFS-2. Lower Sego Sandstone was calculated from MFS-2 to MFS-3. The Upper Sego was calculated from MFS-3 to MFS-4. The Corcoran Member thickness calculated from MFS-4 to MFS- 8 and the Cozzette Member thickness calculated from MFS- 8 to MFS- 11. The Rollins Sandstone Member thickness calculated between MFS-12 and datum line at the top of the Rollins Sandstone.

Castlegate Isopach Map

The Castlegate Sandstone that vertically passes up into the Buck Tongue of the Mancos Shale, was deposited during a major coastal regression in the Western Interior Seaway. The Castlegate Sandstone is reported between the *Baculites asperiformis* and *Baculites perplexus* (Gill and Hail, 1975, Sections 1,3 and 4, Jensen, Utah to Axial Colorado). Thickness of the Castlegate Sandstone ranges from 54 to 214 ft from E to W in the study area (Fig. 4.5) .The Castlegate Sandstone is a single, extensive sheet-like sandstone unit probably representing a shoreline with NE-SW trend, though in the study area it likely exists partly as a shelf sand body (Fig. 4.5).The unit is thinning from NW to

SE as the sand supply dwindled out onto the shelf. As is seen from the isopach map (Fig. 4.5) the Castlegate Sandstone is likely near its seaward limit in the Piceance Basin.

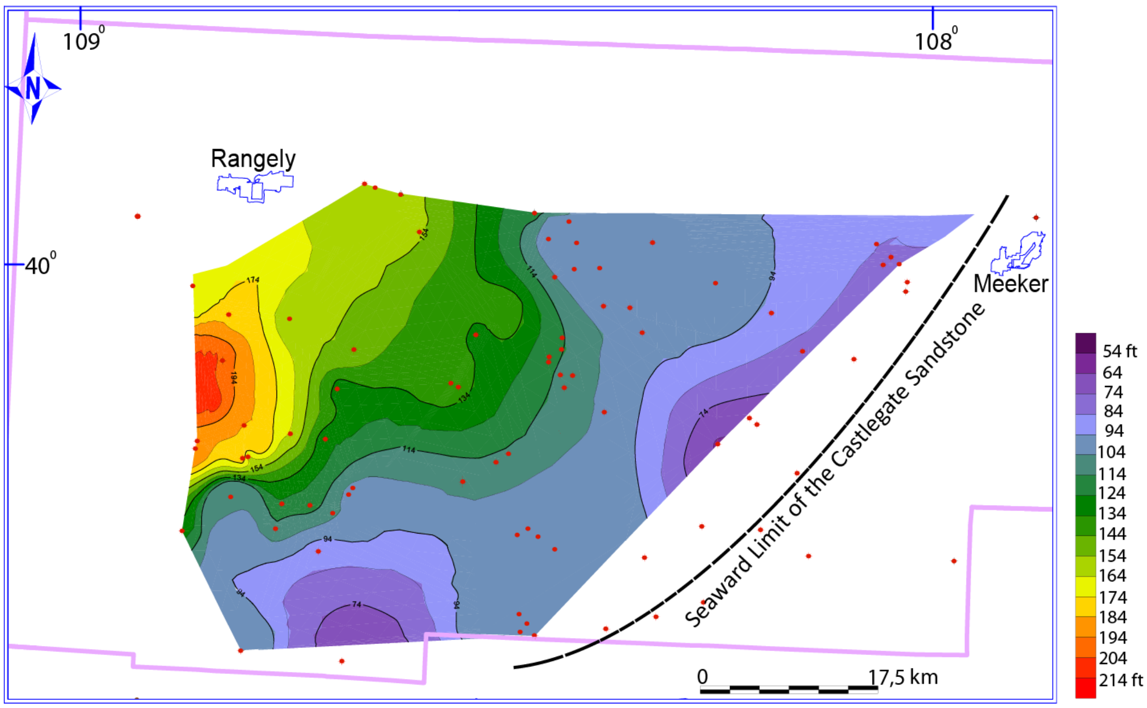


Figure 4.5: Isopach map of the Castlegate Sandstone. Dashed black line indicates the seaward limit of the Castlegate Sandstone.

Loyd and 1st Mancos Isopach Maps (Buck Tongue of Mancos Shale intervals)

The Loyd Sandstone and 1st Mancos Sandstone occur within the Buck Tongue of Mancos Shale. The 1st Mancos Sandstone is thick near Meeker and it thins toward the west, i.e., it (Fig. 4.6) shows a landward pinchout again suggesting that it represents a shelf sand body.

Konish (1959) defined the Loyd Sandstone as a marker bed in the exposures of the Iles Mountain, northeast Piceance Basin. As seen from the isopach map the thickness of the Loyd Sandstone changes throughout the study area over short distances. It thins both to NE and SW (Fig. 4.7); therefore, the geometry of the Loyd Sandstone is difficult to determine. In the areas where there is no thick blocky sandstone, the sandbody is interbedded with mudstone and siltstone and probably on the fringe area of the sand sheet. The Loyd is also probably a patchy shelf sand sheet.

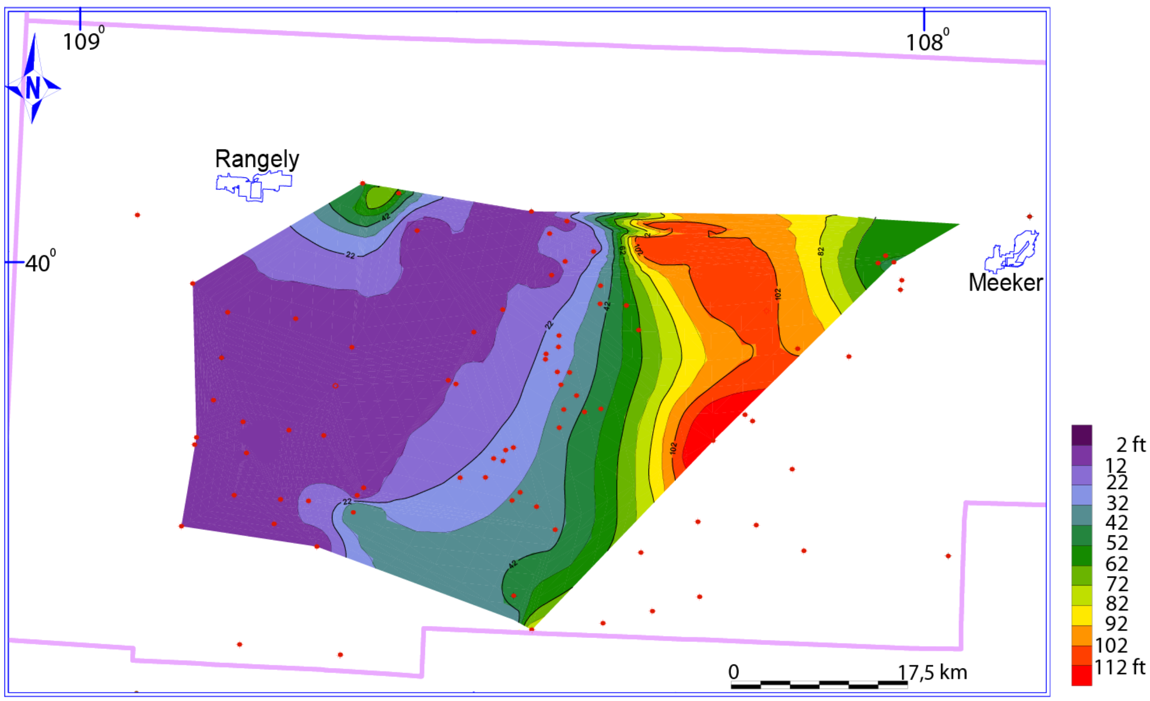


Figure 4.6: Isopach map of the 1st Mancos. It thins to the west and dark purple color indicates the landward pinchout of the 1st Mancos in this region.

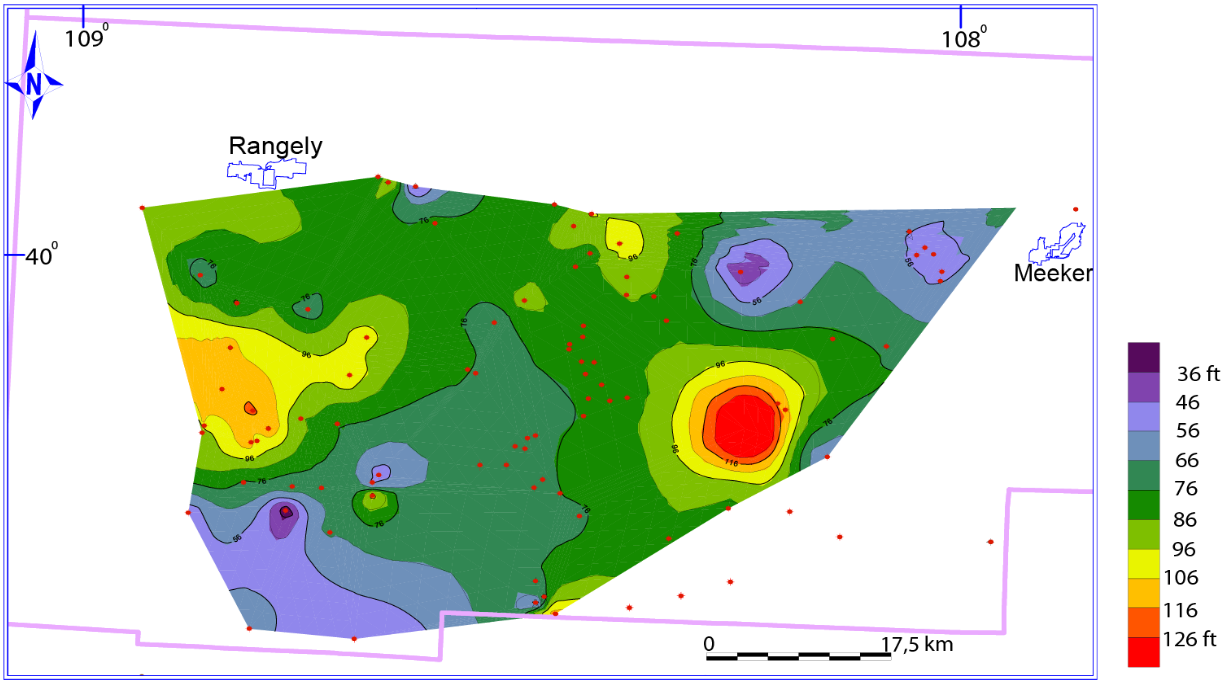


Figure 4.7: The isopach map of the Loyd Sandstone.

Sego Sandstone Isopach Map

The Sego Sandstone intervals were defined between MFS-2 and MFS-4 (Fig. 4.3 and 4.4). The Lower Sego Sandstone originated from progradational shorefaces. The isopach map of the Sego Sandstone shows the configuration of the shoreline with an embayed NE-SW orientation. The thickness of this succession decreases from NW to SE and ranges from 10 ft to 195 ft. The isopach map (Fig. 4.8) suggests that the Lower Sego is close to its seaward limit in the eastern and southern Piceance Basin.

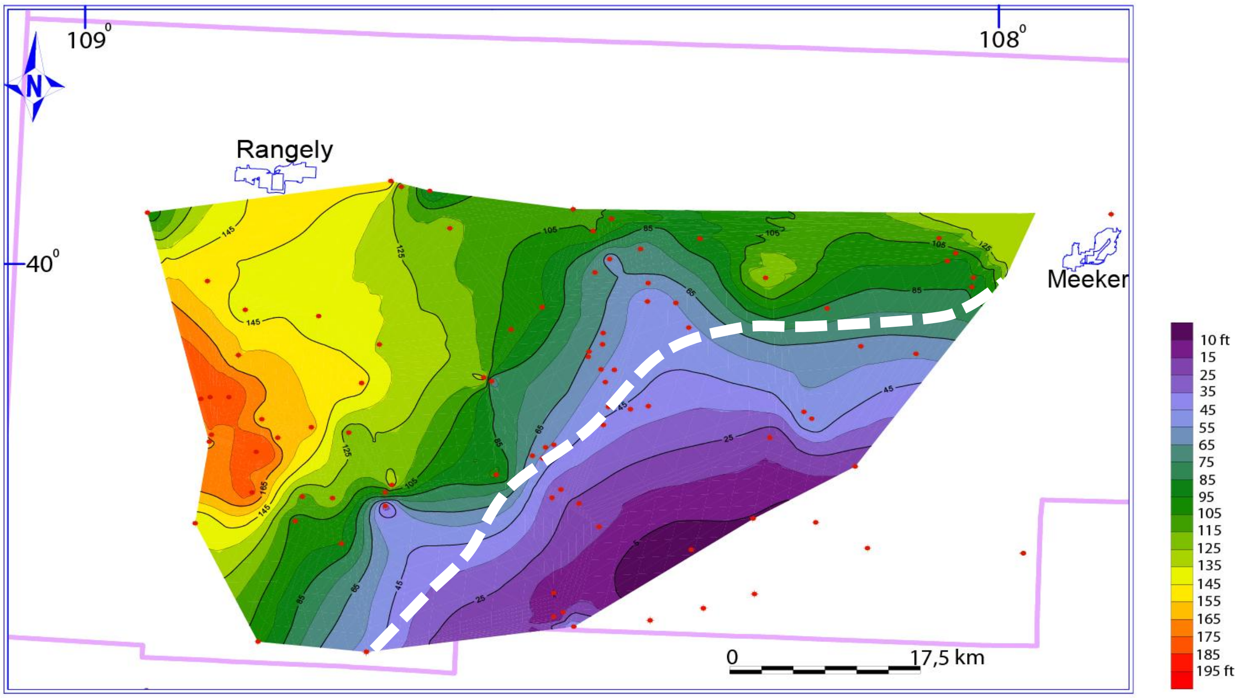


Figure 4.8: Isopach Map of the Lower Sego Sandstone. The shoreline (white dashed-line) is extensive and it is almost pitchout to the SE.

The Upper Sego Sandstone is the next regressive-transgressive cycle. The isopach map of the Upper Sego Sandstone again suggests an embayed coast in this region of the WIS shoreline (Fig. 4.9). The thicker sand-bodies in the isopach map with reddish color in Fig. 4.9 likely formed by wave-dominated mouth bars or shorefaces and the light green colors in Fig. 4.9 probably represent by tidally influenced sandstones. Changes in the interaction between storm and tidal processes as well as river supply and longshore sediment supply caused embayments in the shoreline configuration. Interruption of longshore current derived sediments in the Upper Sego Sandstone shoreline caused tidal inlet and flood-tidal deltas in places (Stancliffe, 1984).

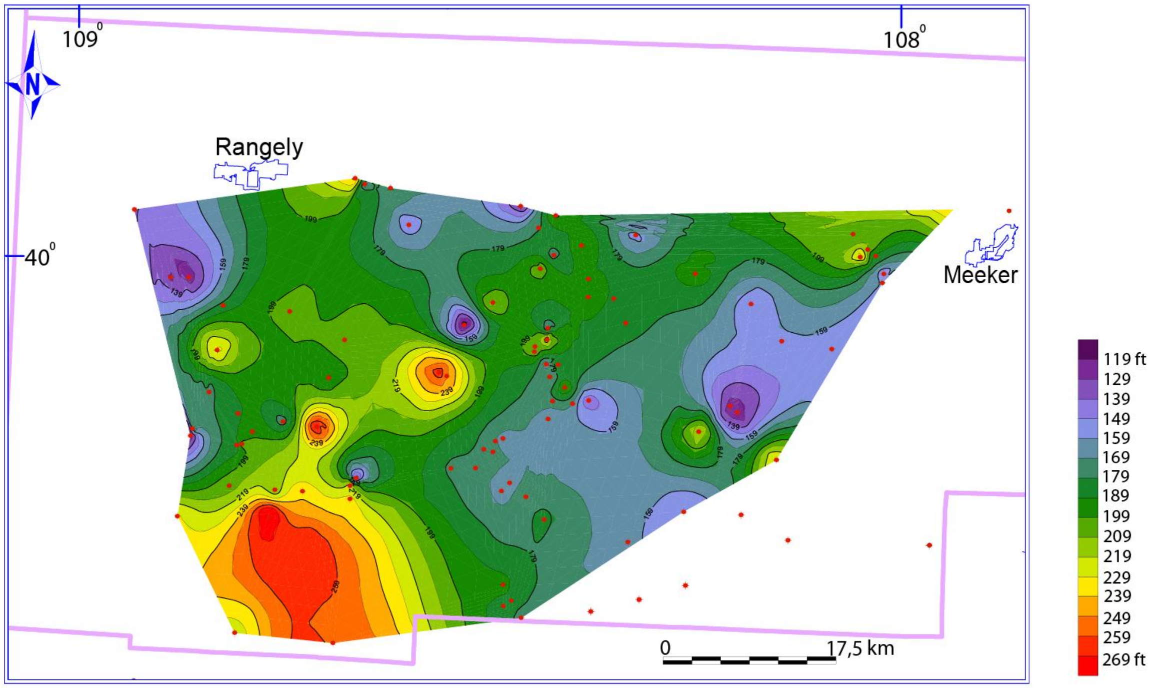


Figure 4.9: The isopach map of the Upper Sego Sandstone. The map indicates a very embayed coastal setting, caused by variable river-mouth bar strength interacting with tidal processes and longshore wave drift of sediment.

Corcoran Member Isopach Map

The Corcoran Member contains several thin progradational shoreface sandstones but generally represents a more landward coastal setting compared to the Sego because of the increased preservation of coastal plain and tidal deposits. The shoreface deposits were eroded locally and replaced by tidal-fluvial channels and thick coal, organic rich coastal plain deposits accumulated. The thickness of the distributary channels ranges from 29 to 127 ft. The outcrop evidence suggests that tidal-fluvial channels in the south east of the area change updip to the northwest to increased fluvial deposits and floodplain deposits towards the Rangely. The channels near Rangely are mostly fluvial dominated and the channels near Meeker are more strongly tidally influenced. Therefore, the deposits of

Corcoran Member pass into non-marine Neslen strata to the west and northwest and to marine shelfal Mancos shale to the east and southeast.

The isopach map of the Corcoran Member (Fig. 4.10) shows a possible incised valley zone which is indicated by the thick sandstone zone (reddish and yellowish colors in Fig. 4.10) with a NW-SE direction and the gamma-ray log patterns also strongly suggest fluvial and tidal-fluvial channel deposits within this valley. The valley may pass shorewards into increasingly wave-reworked mouth-bar systems in the southeastern reaches of the map in Fig. 4.10.

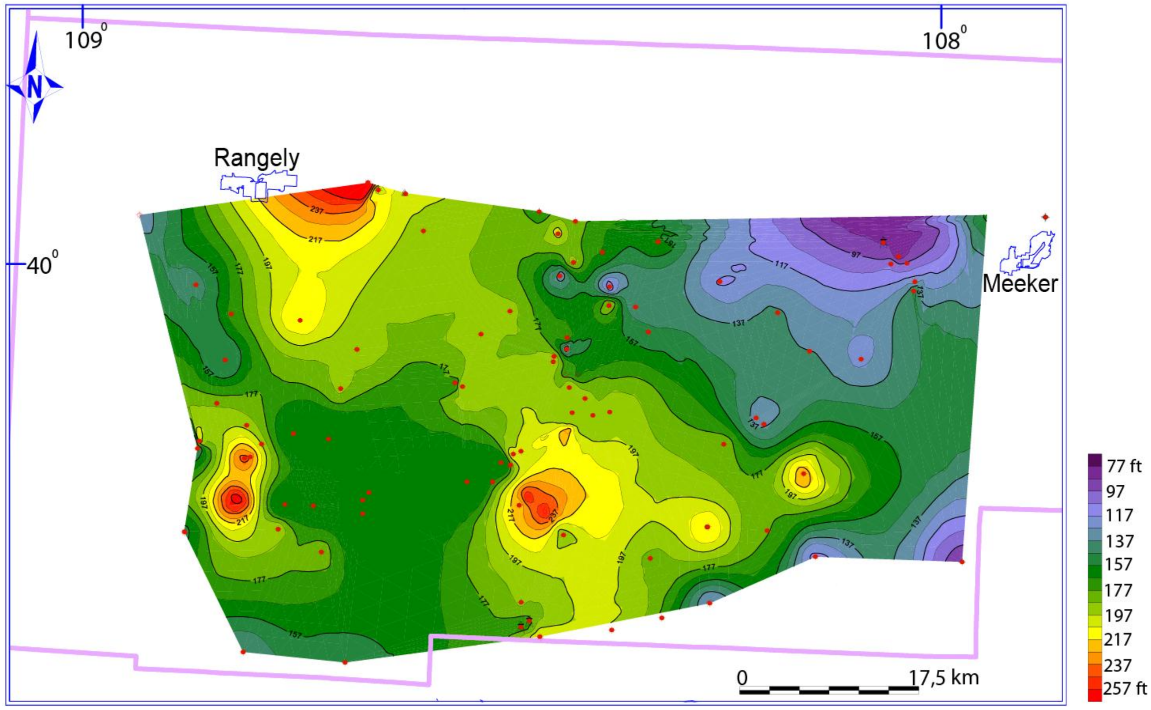


Figure 4.10: Isopach Map of the Corcoran Member.

Cozzette Member Isopach Map

The facies association distribution across the Cozzette Member isopach map suggests that there is a marine embayment (Fig. 4.11) with coastal plain and tidal-fluvial channels dominating most of the study area at a late stage, though this coastal plain came to overlie earlier shoreface segments. The Cozzette member contains 10-70 ft thick sandstone bodies that were deposited as estuarine complexes and as shorefaces in front of the earlier prograding coastal plain. The top of the Cozzette member is not well defined in the north-northwest direction and in this direction Cozzette interfingers with non-marine fluvial deposits of the Neslen Formation. Overall the Cozzette system represents a significant backstepping of the Iles Clastic Wedge with respect to the underlying Corcoran system, as discussed earlier and this is the likely reason for an increase in estuarine transgressive deposits compared to Corcoran.

The major thickening of sandstone to the SW in Figure 4.11 suggests a fluvial channel and estuary-supply fairway in this part of the map. The path of the rivers show a slightly different direction than that observed in the Corcoran Member.

Estuarine and some shoreface deposits merge with coastal plain and fluvial channel deposits near Rangely whereas offshore marine deposits are more common near Meeker. The Cozzette estuarine complex extends back across the earlier shoreface deposits.

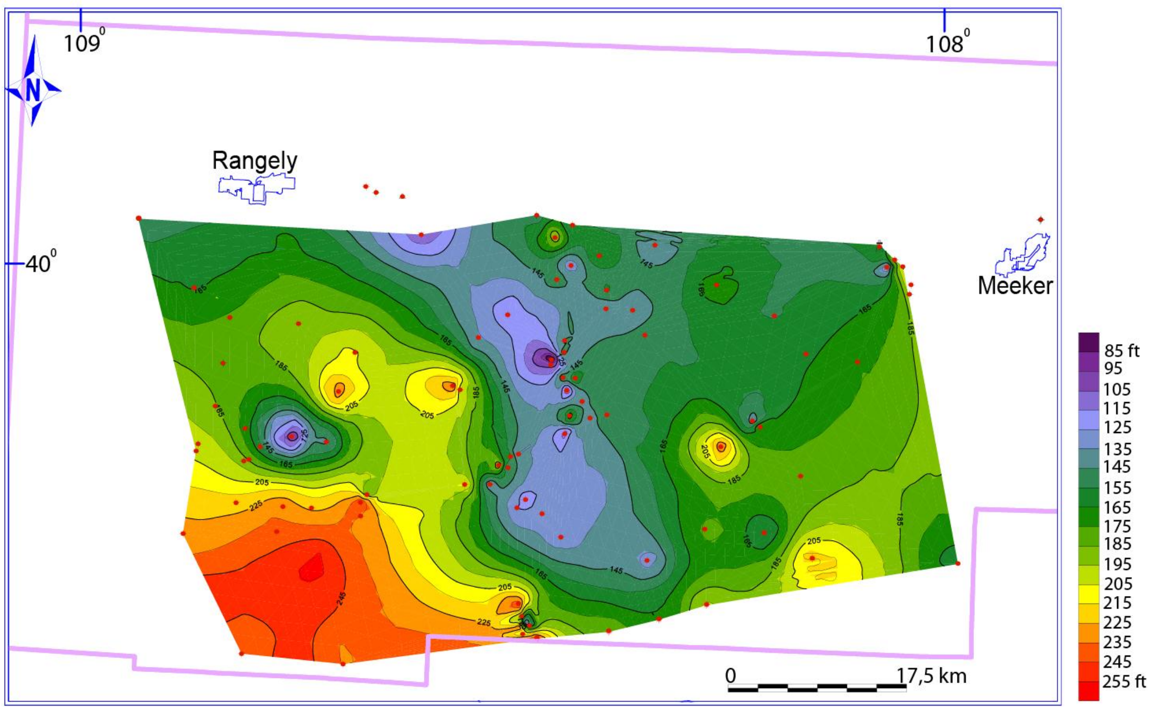


Figure 4.11: Isopach map of the Cozzette Member. Thicker parts indicate fluvial-estuarine channel deposits.

Rollins Sandstone Isopach Map

The Rollins Sandstone member is the youngest marine sandstone deposits in the Sevier foreland Basin in Colorado. It has repeated progradational units and the coastlines seem to have been N-S oriented (Fig. 4.12). Isopach map of the Rollins Member shows that it is thick in an eastward direction and it thins to the west, probably merging westwards with Neslen or Bluecastle fluvial systems. The Rollins Sandstone Member is extensive sheet-like sandstone, but at any point in time was a narrow, straight wave dominated shoreline in considerable contrast to the earlier Cozzette and Corcoran embayed coasts.

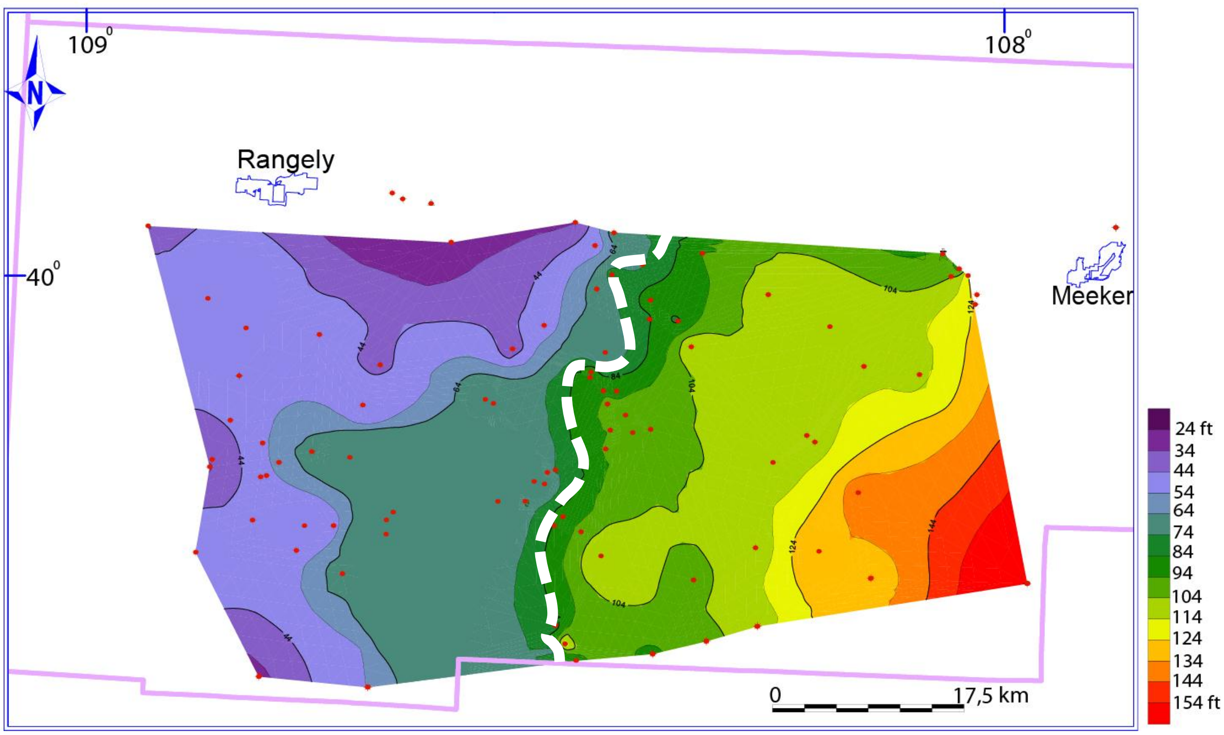


Figure 4.12: Isopach map of the Rollins Sandstone Member. The shoreline of the Rollins Sandstone is in N-S direction (white dashed-line), and is pinching out to the east and northeast.

CHAPTER 5: DISCUSSION OF ILES CLASTIC WEDGE IN NORTHERN PICEANCE BASIN AND CONCLUSIONS

DISCUSSION

The main factors that affect the formation of a clastic wedge are sediment supply, eustasy and tectonics. Tectonics affects both sediment yield and accommodation for the wedge; eustasy also creates accommodation while sediment supply fills the space made available. During the Campanian time interval, Aschoff and Steel (2011) defined three major clastic wedges that built out from the active Sevier fold belt as Wedge A, Wedge B (Iles Clastic Wedge) and Wedge C across the Utah-Colorado part of the Cordilleran foreland basin. Wedge A consists of Blackhawk Formation and Lower Castlegate Sandstone, Wedge C of Bluecastle Tongue and Rollins Sandstone, whereas, Wedge B contains Buck Tongue of Mancos Shale, Sego Sandstone, Neslen Formation, Corcoran and Cozzette Members of the Iles Formation. Wedges A and C prograded relatively slowly (200-250 km in more than 3 my) and are made up of thick, but narrow (10-20 km wide) wave dominated straight shorelines; however, Wedge B prograded more rapidly (340-400 km in 2 My), and is made up of much thinner but wider (60-80 km wide) and more embayed and irregular, mixed-energy (wave and tide influenced) shorelines. According to Aschoff and Steel (2011), the main reason for this differences between Wedge A, and Wedge B is the added effect of the initial Laramide movements during development of the Iles Clastic Wedge (Wedge B). Aschoff and Steel (2011) suggested that during the deposition of these three Campanian clastic wedges, due to greenhouse conditions, active uplift of the fold-and-thrust belt and the transverse depositional systems, the sediment supply was high and fairly constant and also the amplitude variations in sea level were modest, probably only 10-20 m. They concluded therefore that the sediment supply or eustatic variations did not cause the main stratigraphic difference between the clastic wedges. Through the use of isopach maps and biostratigraphic data they explained that the thinner and embayed, low accommodation successions of Wedge B developed during embryonic Laramide deformation from ca. 77 Ma in central Utah. Laramide deformation resulted in slight uplift or reduced subsidence on the foreland flexural profile, resulting in the thin, valleyed and amalgamated, low accommodation successions of Wedge B.

Sequence architecture differences between Iles Clastic Wedge (Wedge B) and Wedges A and C were also observed in the present study. The facies distributions in the Piceance Basin, Iles Clastic Wedge sequences are characterized by incised and amalgamated sand bodies, deposited within mixed-energy shorelines (Fig. 5.2A and 5.2B) and they are different from the underlying and overlying (The Castlegate Sandstone and Rollins Sandstone, respectively (Fig. 5.1A and 5.1B)) sequences. As seen from the isopach maps (Fig. 5.1) the Iles shorelines were more irregular and more strongly tidally influenced than the underlying Blackhawk shorelines (include Castlegate Sandstone) and overlying Rollins Sandstone shorelines. The thinness and the degree of shoreline irregularity suggested by the isopach map below (Fig. 5.2A and 5.2B) within the Iles Clastic Wedge as well as the tidal influence seen in the outcrops, confirm that these unique features of Wedge B in Piceance Basin may indeed have been driven by reduced subsidence rates and the combined impact of Sevier and Laramide movements at this time.

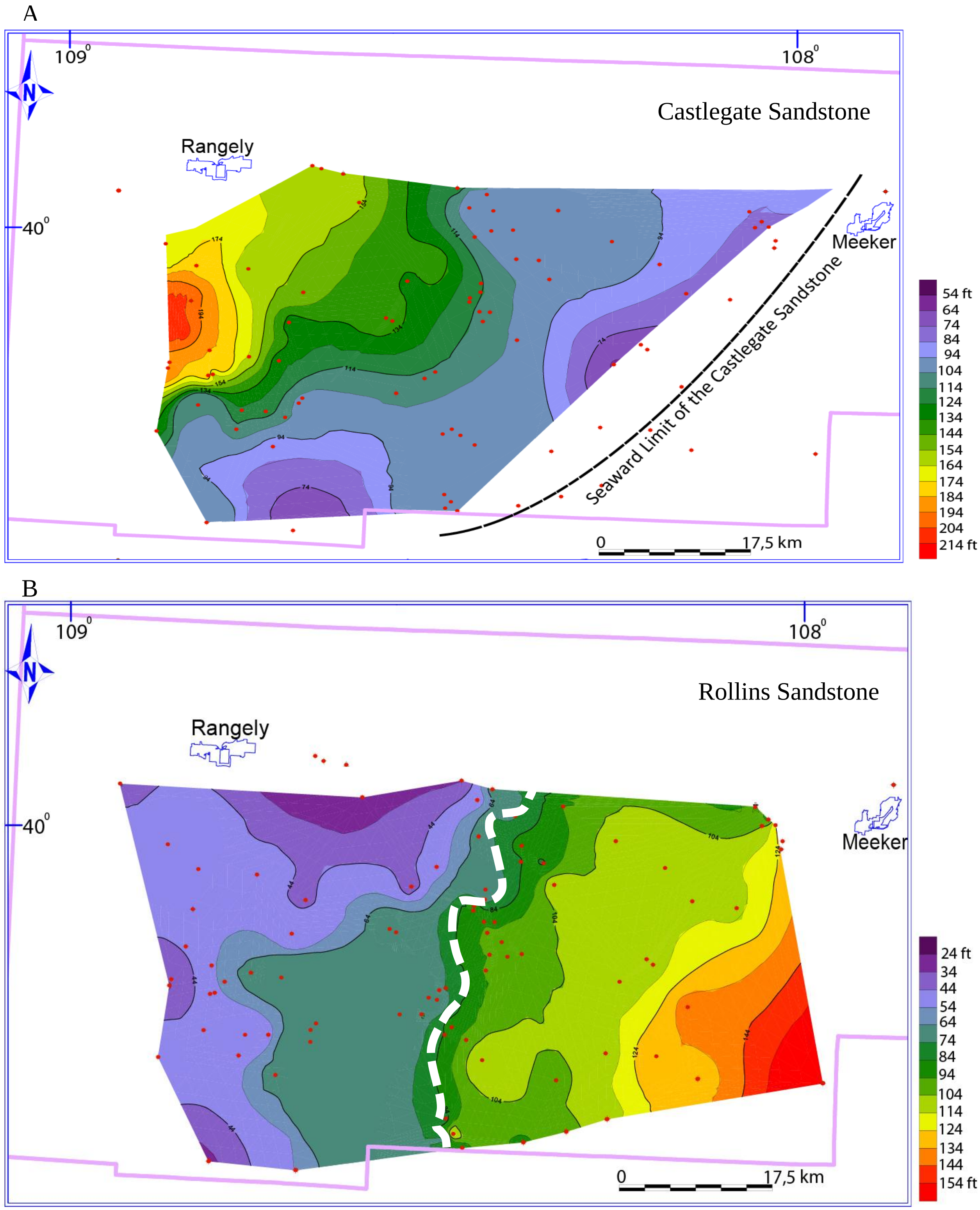
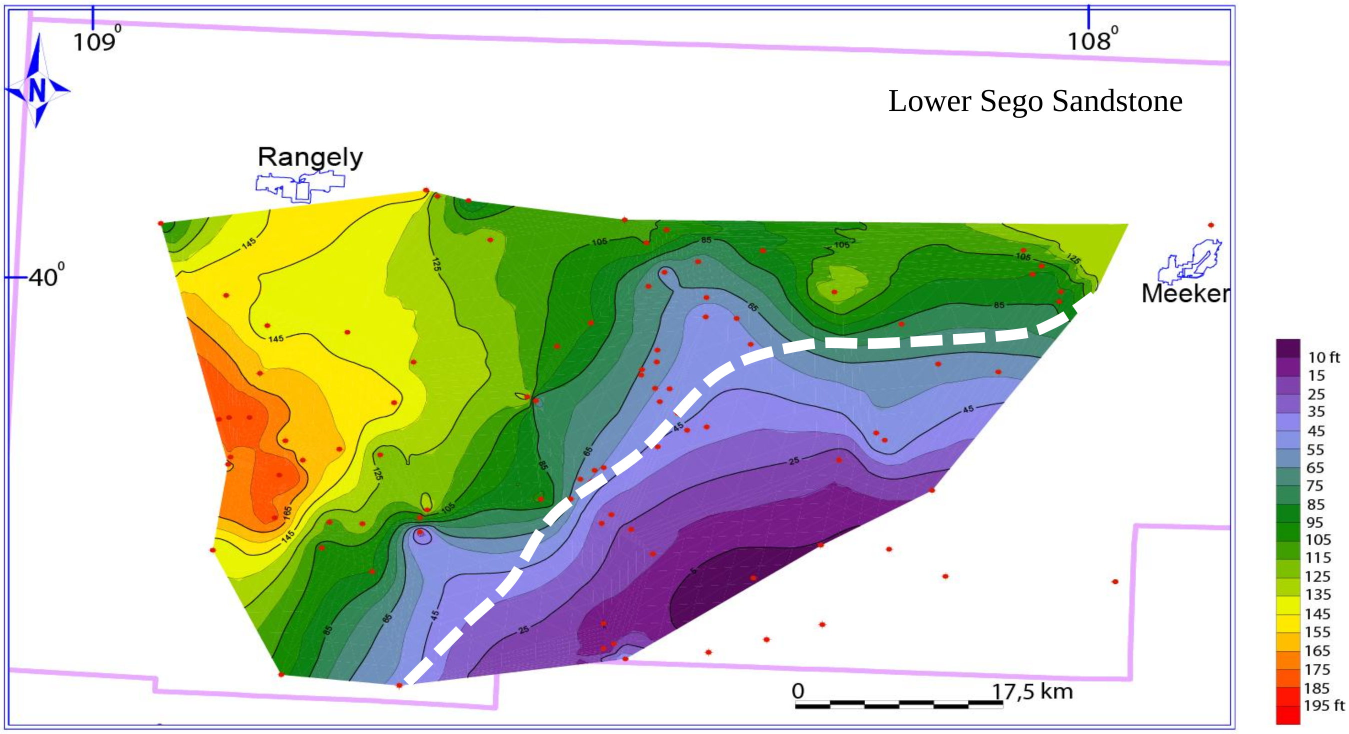


Figure 5.1: Isopach maps of the Castlegate Sandstone (A) and Rollins Sandstone (B) suggest narrower, mostly wave-dominated shorelines and have NE-SW trend.

A



B

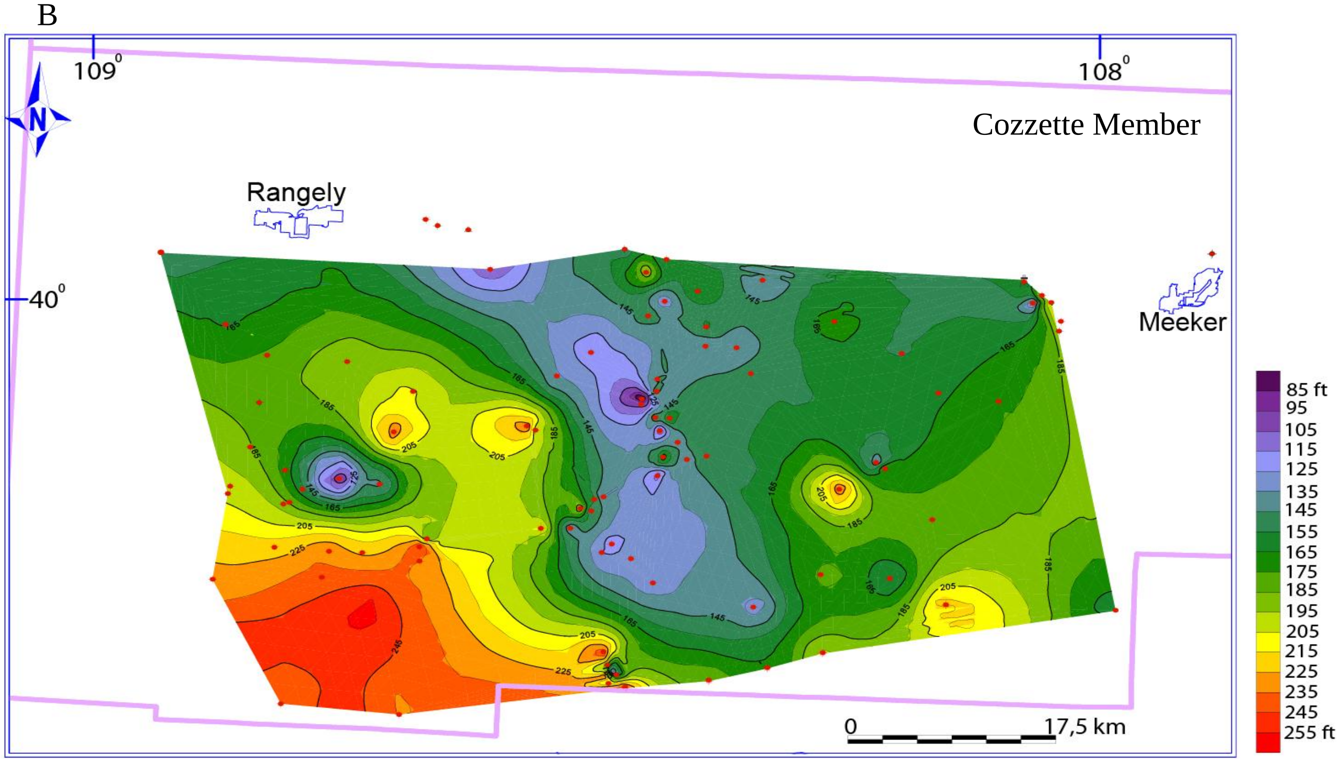


Figure 5.2: Isopach maps from Iles Clastic Wedge sequences (Lower Sego Sandstone (A) and Cozzette Member (B)). Examples of embayed and extensive, mixed-energy shorelines.

Besides isopach maps, the result of the comparison of average shoreline, the maximum stratal thickness of Clastic Wedge A and Iles Clastic Wedge (Wedge B) suggest the similar results. The maximum stratal thickness of the Wedge A is 700 m, duration of deposition was 5 my, maximum average accumulation rate was 140 m/My (Aschoff and Steel, 2011) and average shoreline thickness is 28 m (Hampson and Storms, 2003) (Fig. 5.3). However, the maximum stratal thickness of Iles Clastic Wedge is 380 m, duration of the deposition is 3.3 My, maximum average accumulation rate is 115 m/My and average shoreline thickness is 15 m (Fig. 5.4). Both the low average sediment accumulation rate and low average shoreline thickness for the shorelines of Wedge B strongly suggest relatively low accommodation during their deposition.

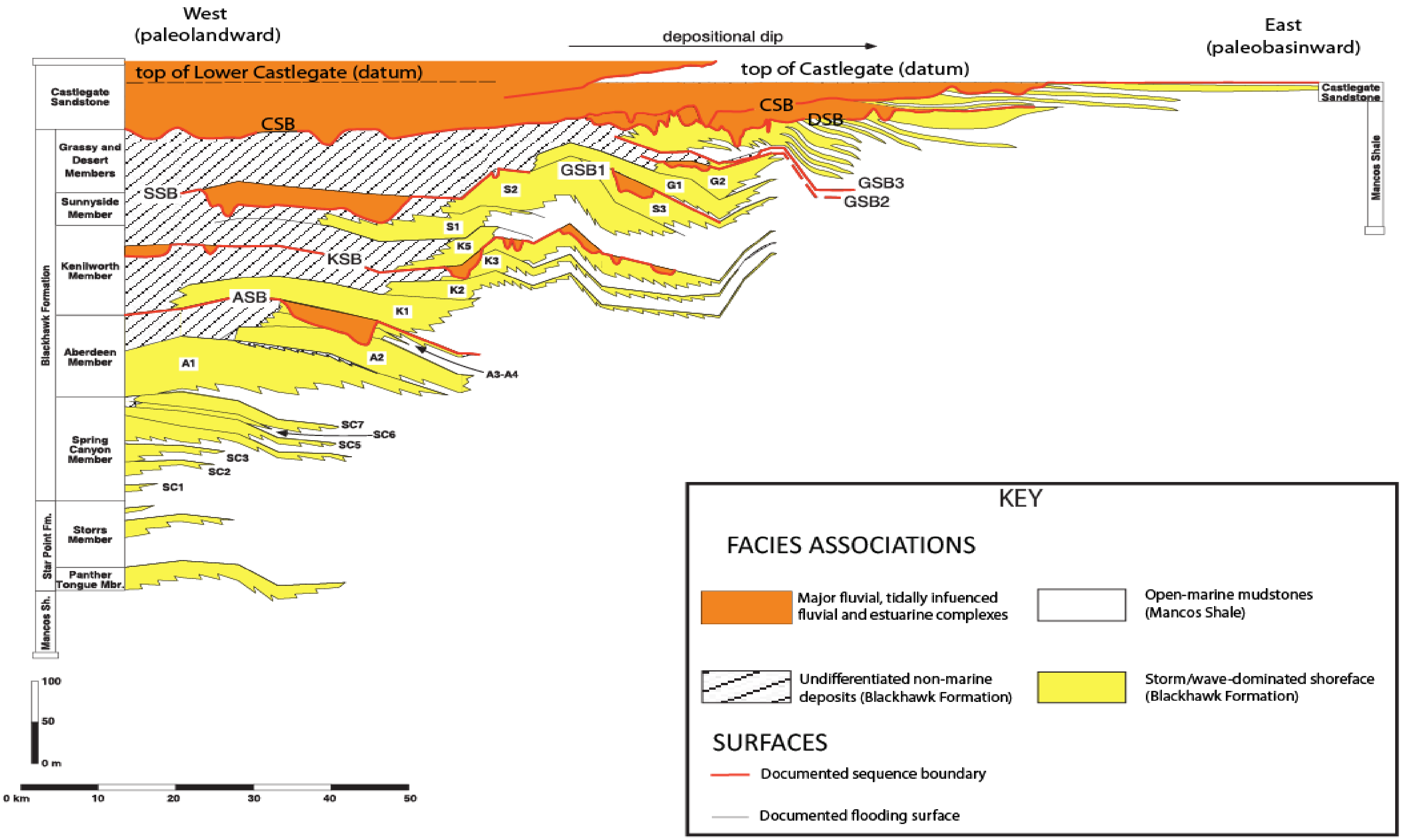


Figure 5.3: Stratigraphic cross-section through the Wedge A (modified from Hampson and Storms, 2003).

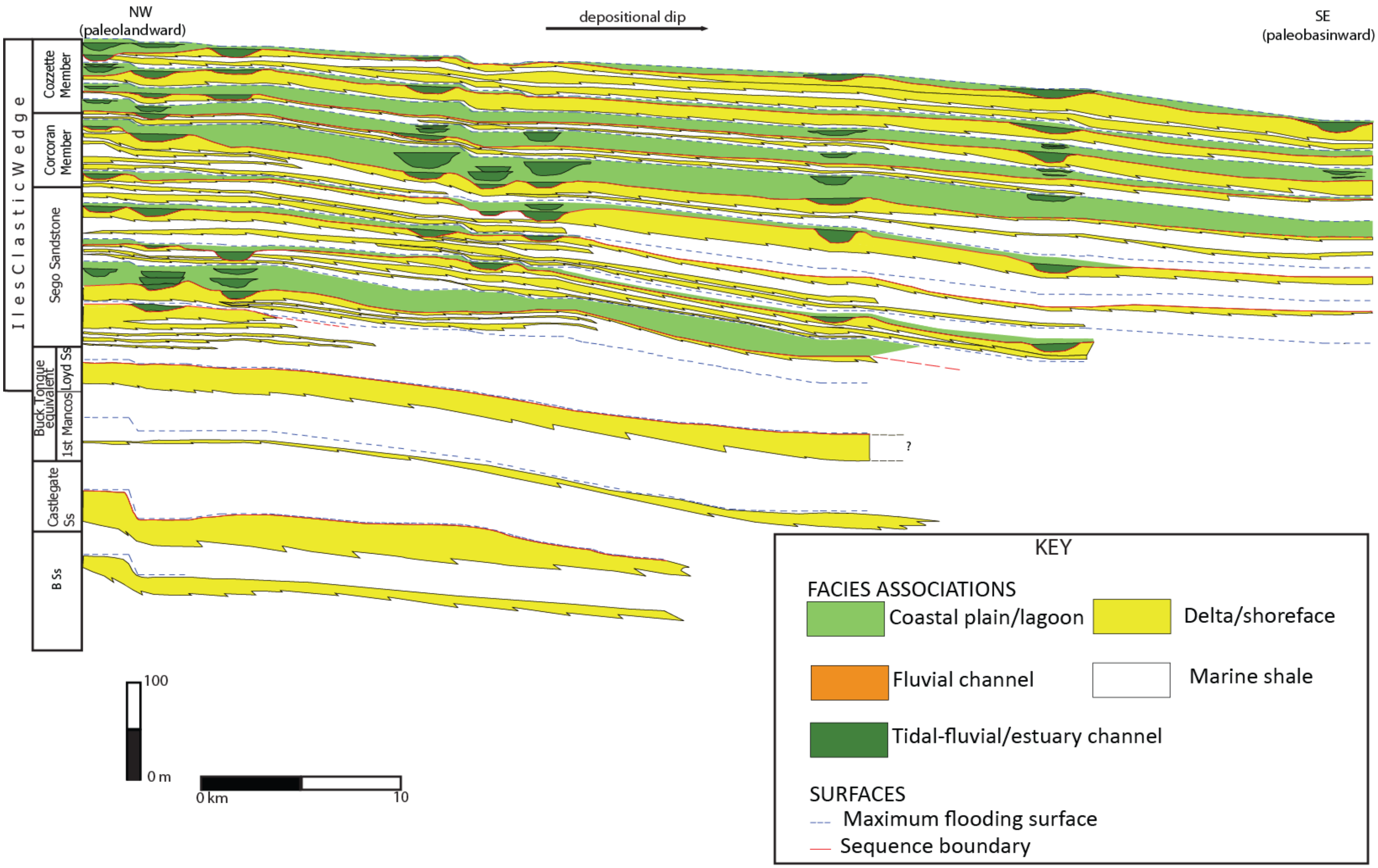


Figure 5.4: Stratigraphic dip cross-section through the Iles Clastic Wedge.

CONCLUSIONS

1. Based on outcrop succession correlation and the integration of this correlation with well-log data, 3.3 my duration Iles Clastic Wedge can be divided into 11 regressive-transgressive sequences (4^{th} order sequences).
2. Lateral and vertical facies relationship observed in outcrop data and well-log data and the geometry of the sequences seen in the isopach maps suggest two major shoreline types. Deltaic and interdeltaic embayments coasts developed in front of the prograding Iles Clastic Wedge.
3. Wave dominated succession in Meeker change to mixed coastal plain, back-barrier and some strandplain deposits in Rangely. The outcrop measurements in the Meeker succession indicates variation of storm-wave and fluvial facies associations that were generally deposited in the wave-dominated coast whereas the Rangely succession shows strike elongate barrier island shoreface deposits and dip-oriented tidal flat, tidal-fluvial channels and fluvial channel association that were deposited in the irregular, embayed coast.
4. Paleogeographic reconstruction (isopach maps and paleocurrent readings) show that shoreline orientation is in N-S or NE-SW direction and the sediment came from east of the Sevier fold and thrust belt and directed to south.
5. Progradational parasequences are characterized by wave-dominated shoreface deposits; retrogradational parasequences are characterized by tidal-fluvial/estuary

channel deposits (tidal deposits are generally more abundant in transgressive part).

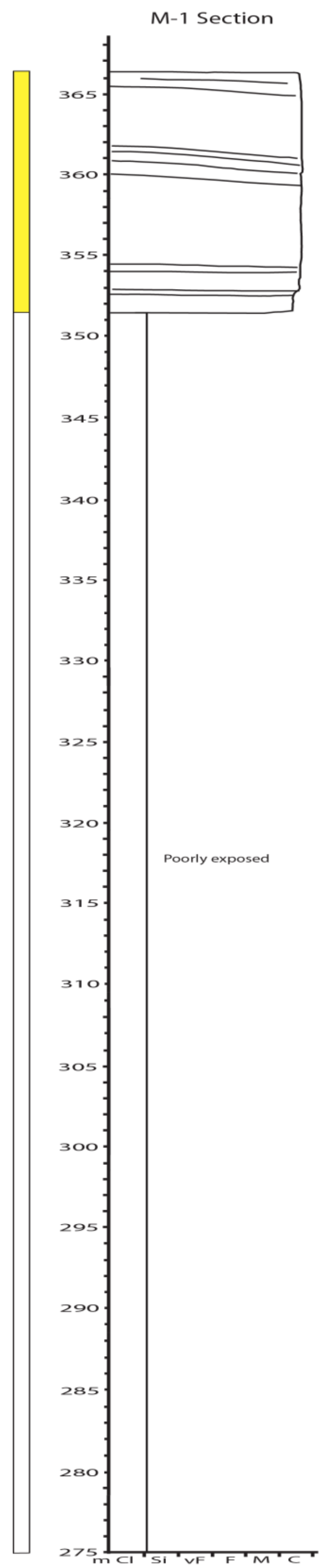
6. The upward facies change in the dip and strike cross-section point out overall progradation in the Iles Clastic Wedge; however especially in the upper most sequences of the Cozzette Member of the Iles Formation, the wedge indicate retrogradation by the increasing concentration of shoreline deposits and decreasing concentration of the coastal plain deposits.
7. The average accumulation rate and the average shoreline thickness of the Iles Clastic Wedge indicate relatively thin, amalgamated and low accommodation succession, than the underlying and overlying clastic wedges (Wedge A and Wedge C). This is likely due to reduced subsidence during transition from Sevier to Laramide-style deformation.

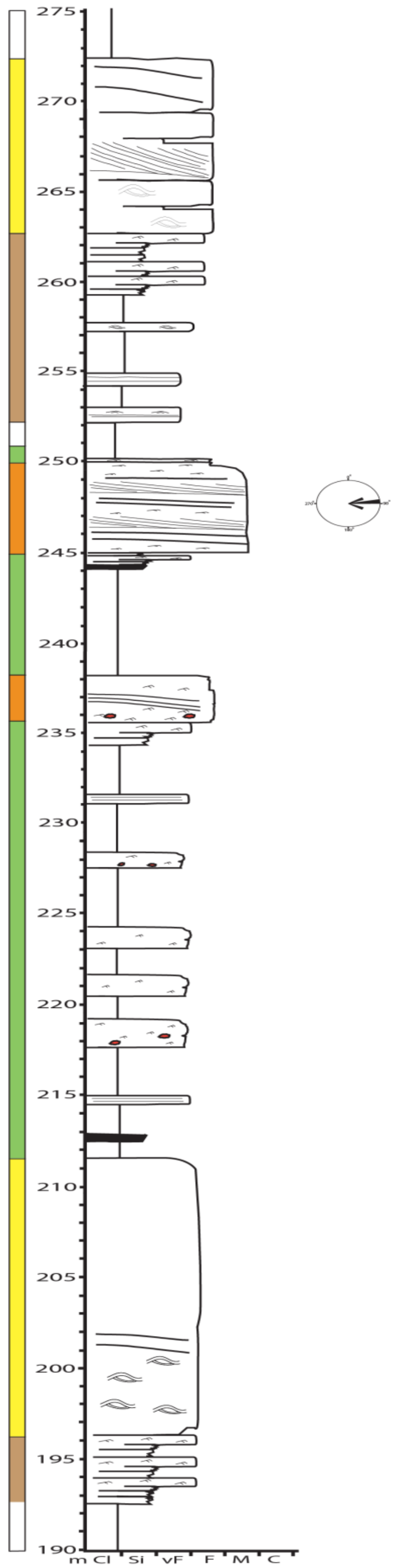
APPENDIX

The main measured stratigraphic sections are reproduced here in larger format.

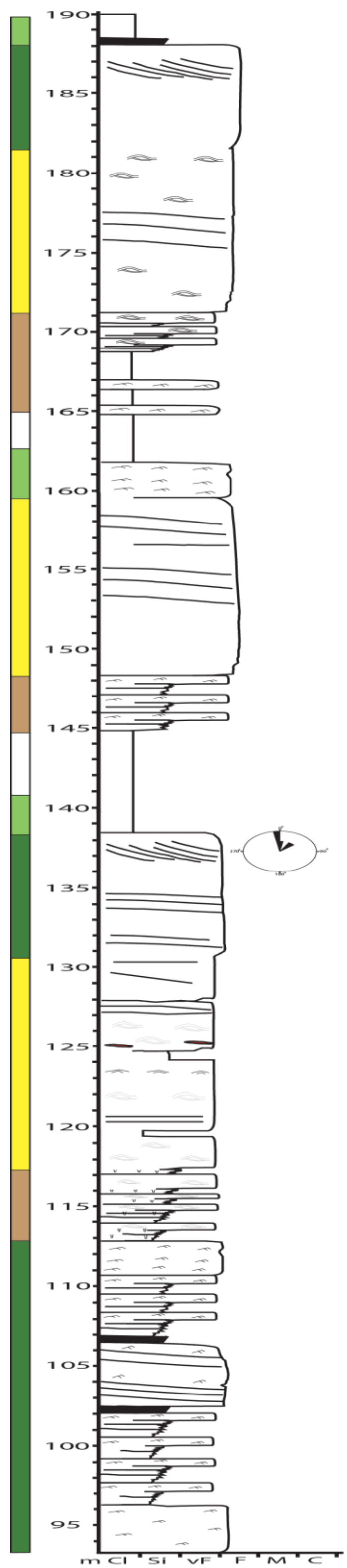
Meeker successions: M-1, M-2, M-3, S-1, H-1, H-2

Rangely succession

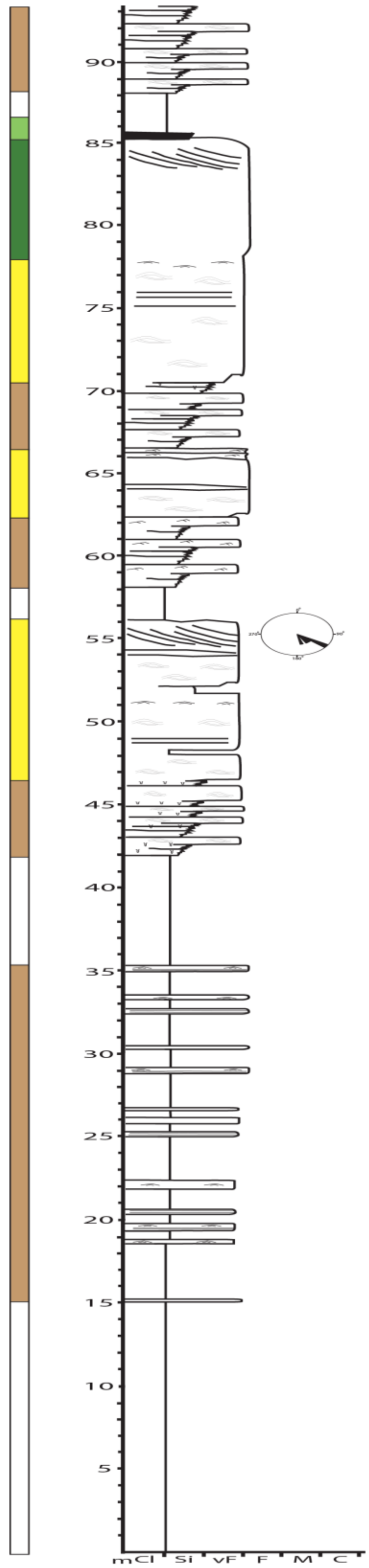

M-1 Section
365
360
355
350
345
340
335
330
325
320
315
310
305
300
295
290
285
280
275
Poorly exposed
m Cl Si vF F M C

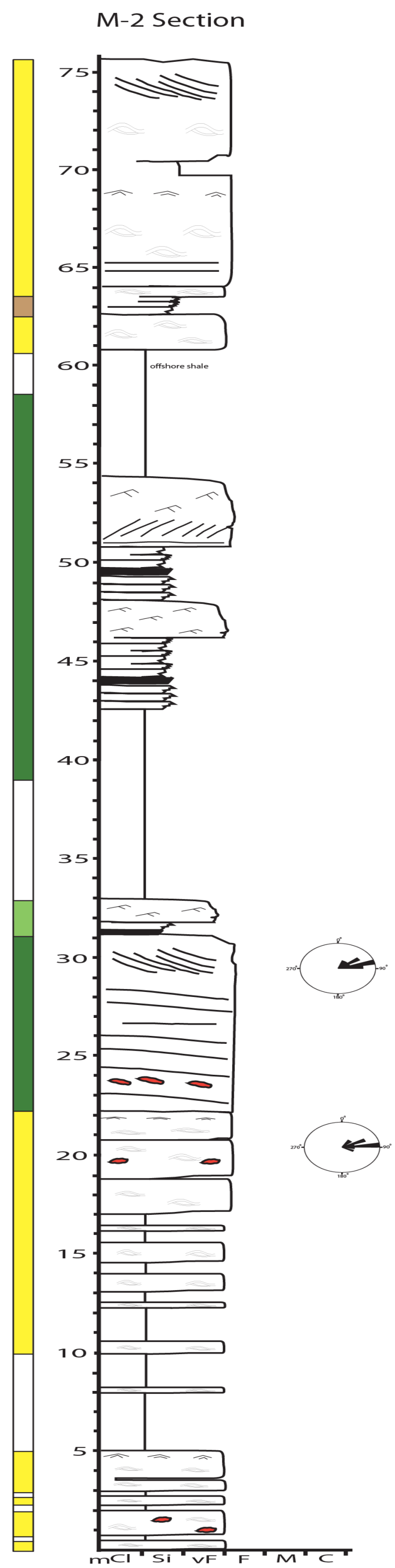


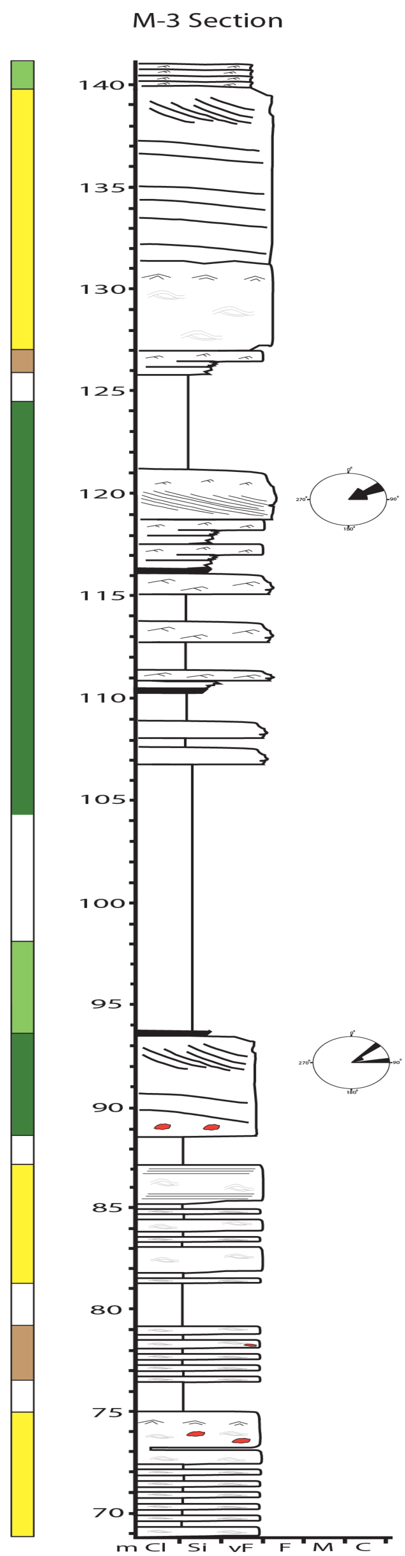
275
270
265
260
255
250
245
240
235
230
225
220
215
210
205
200
195
190
m
Cl
Si
vF
F
M
C

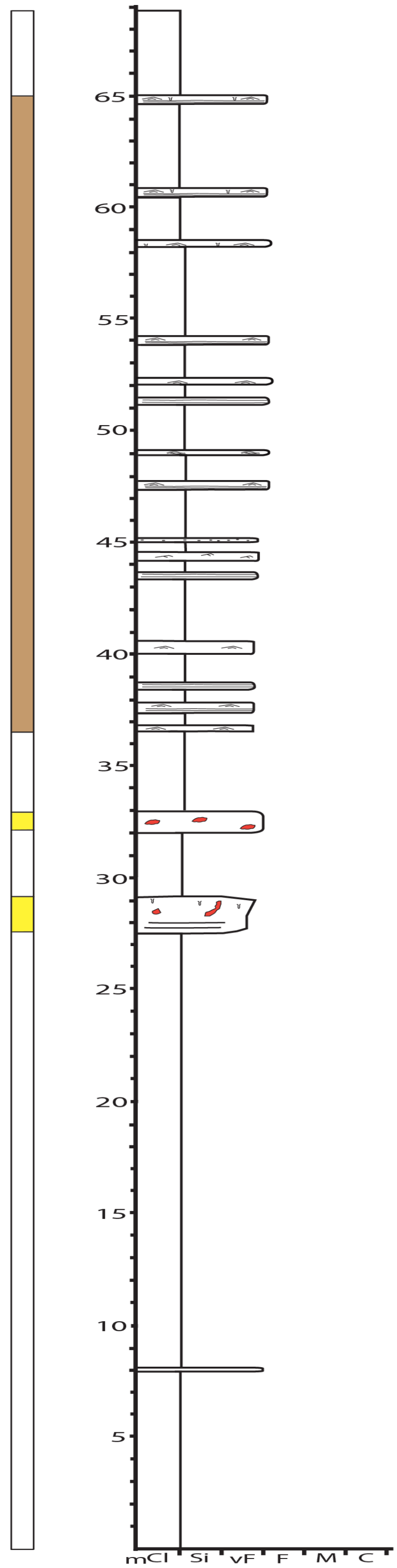


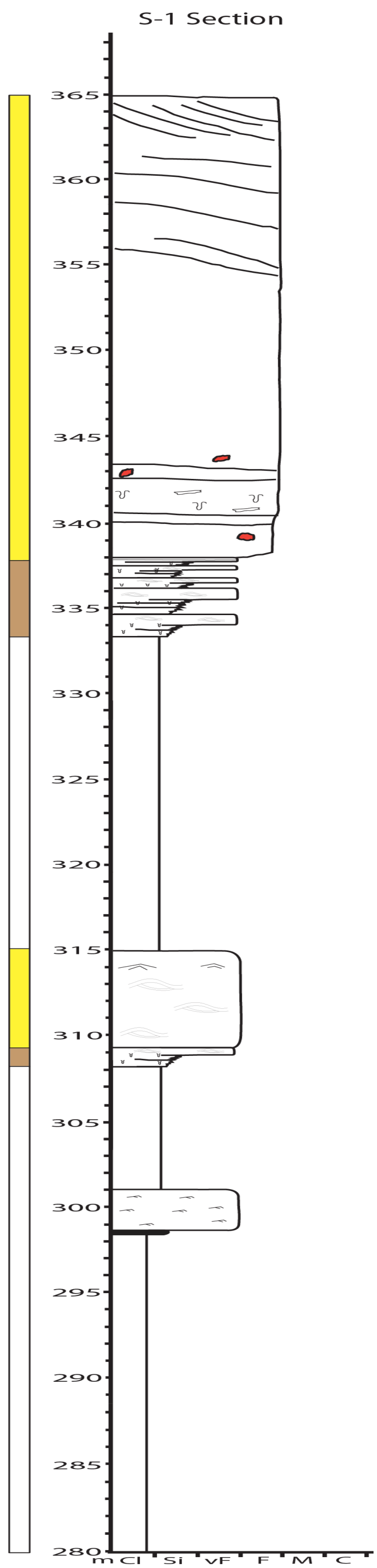
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
m Cl Si vF F M C

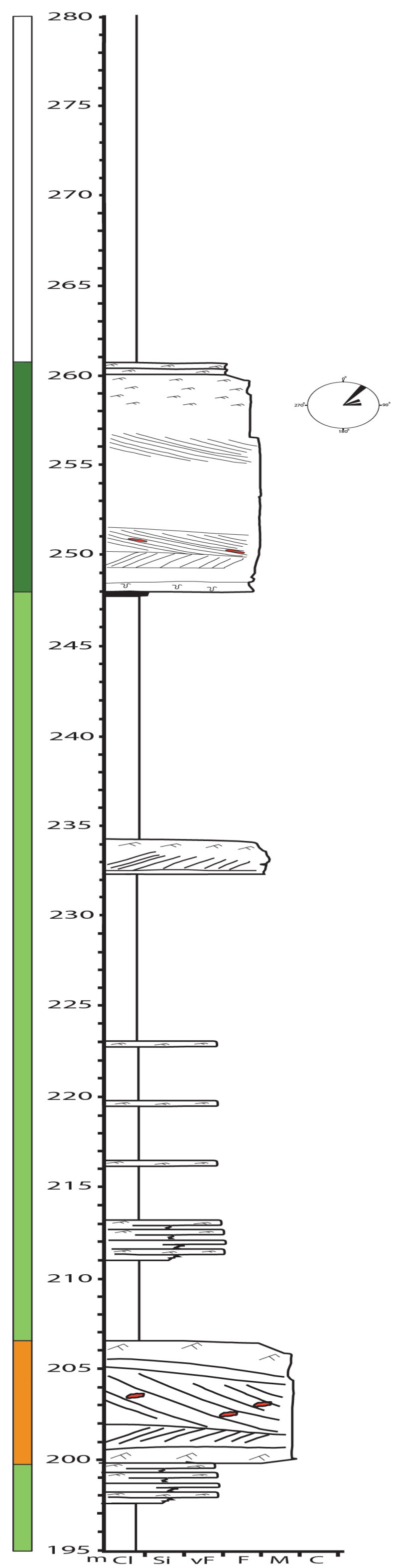

90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
mCl Si vF F M C

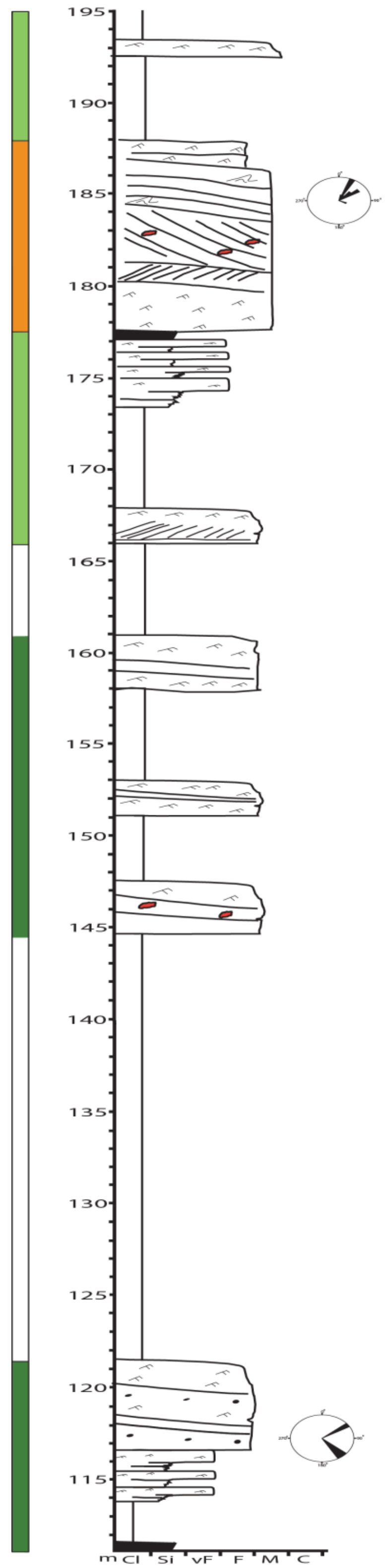

M-2 Section
offshore shale
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
mCl
Si
vF
F
M
C

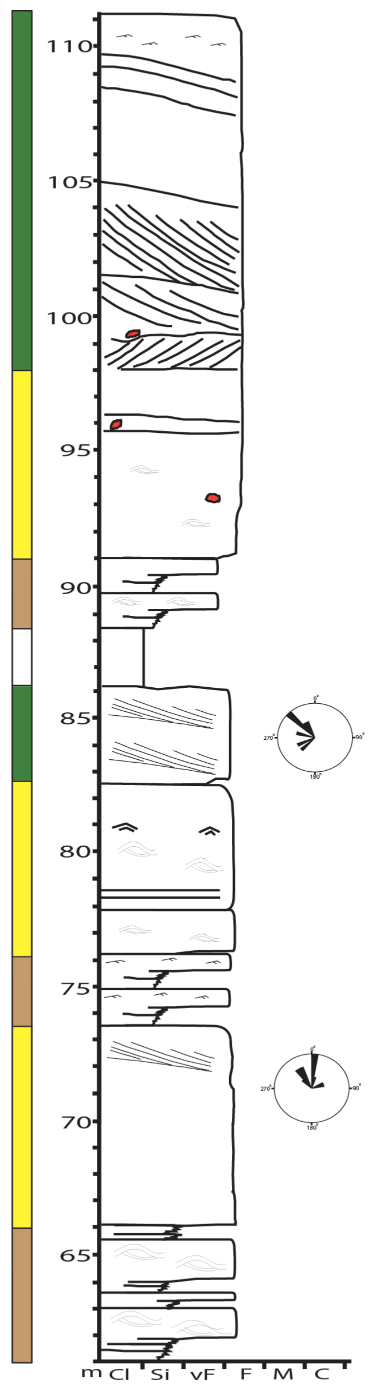

M-3 Section
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
m Cl Si vF F M C


65
60
55
50
45
40
35
30
25
20
15
10
5
mCl
Si
vF
F
M
C

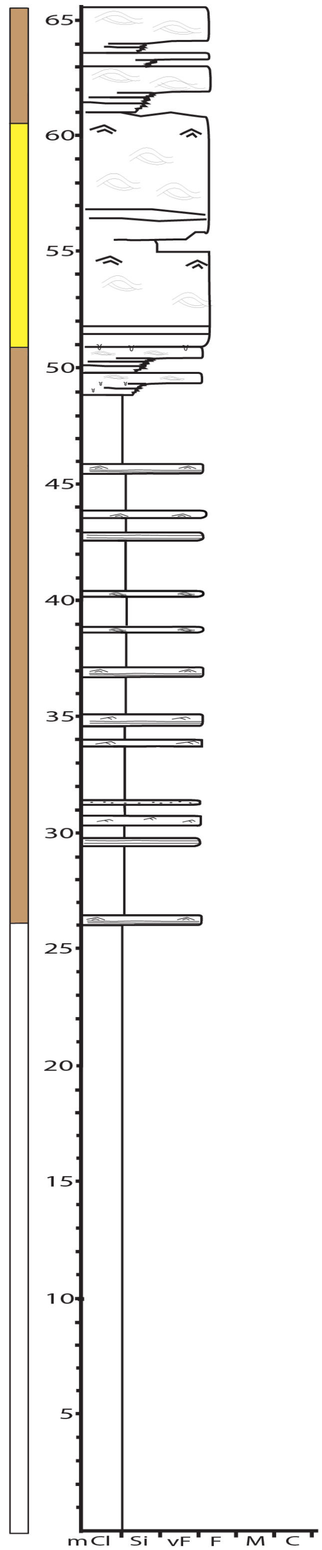

S-1 Section
365
360
355
350
345
340
335
330
325
320
315
310
305
300
295
290
285
280
m Cl Si vF F M C


280
275
270
265
260
255
250
245
240
235
230
225
220
215
210
205
200
195
m
Cl
Si
vF
F
M
C


195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
m Cl Si vF F M C



110
105
100
95
90
85
80
75
70
65
m
Cl
Si
vF
F
M
C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60
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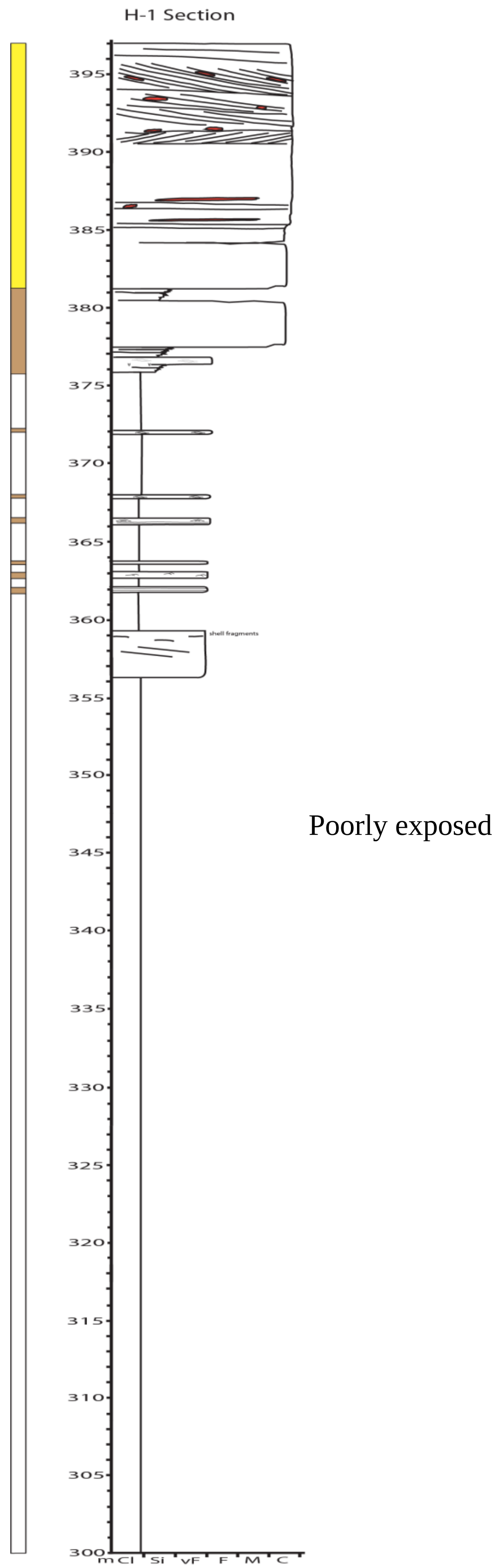
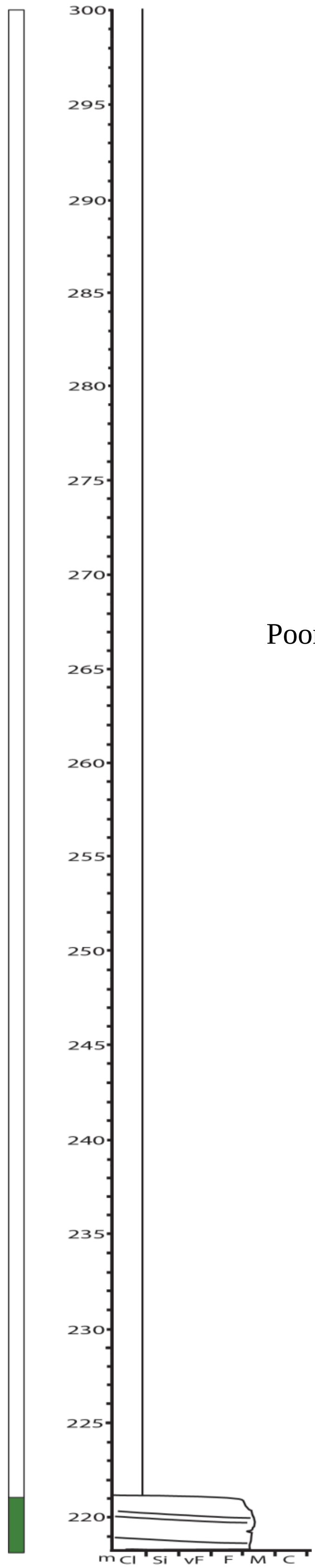
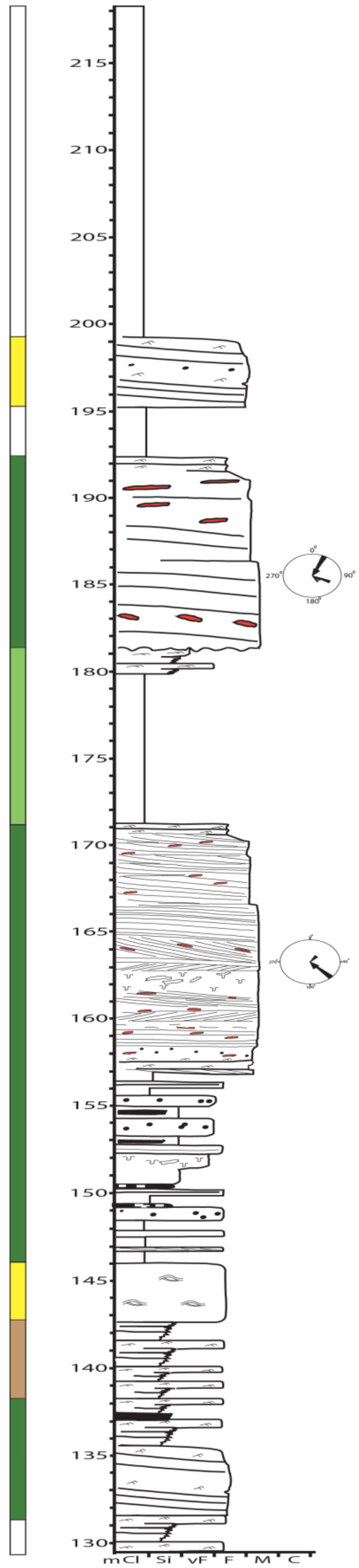
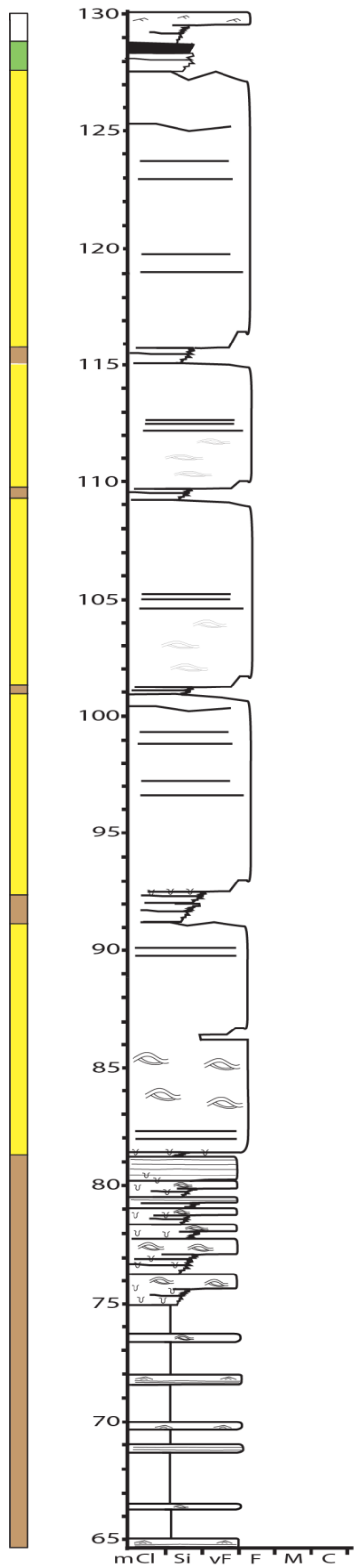
30
25
20
15
10
5
m Cl Si vF F M C

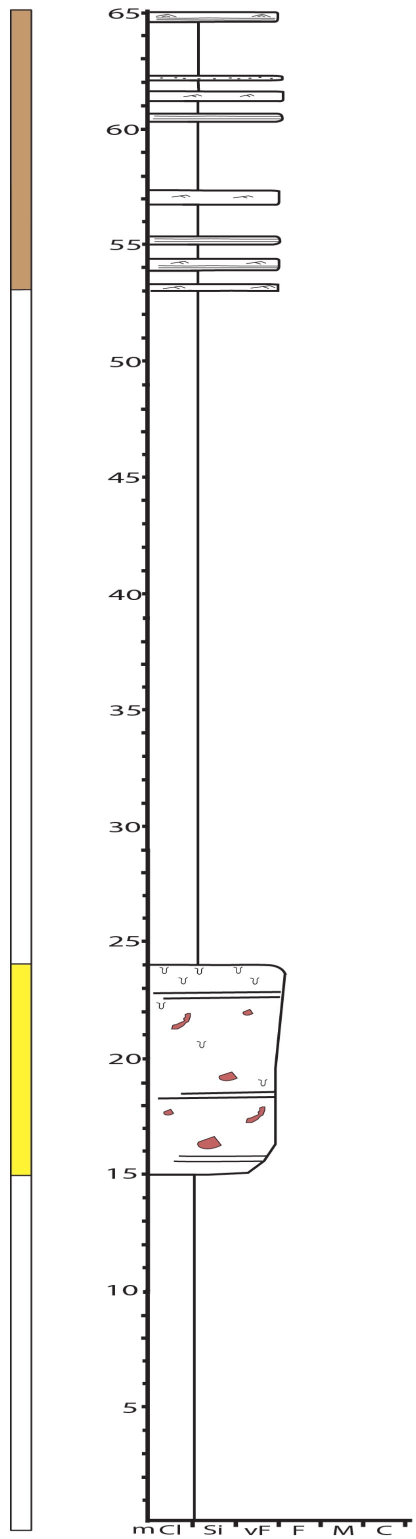

H-1 Section
395
390
385
380
375
370
365
360
shell fragments
355
350
Poorly exposed
345
340
335
330
325
320
315
310
305
300
m Cl Si vF F M C

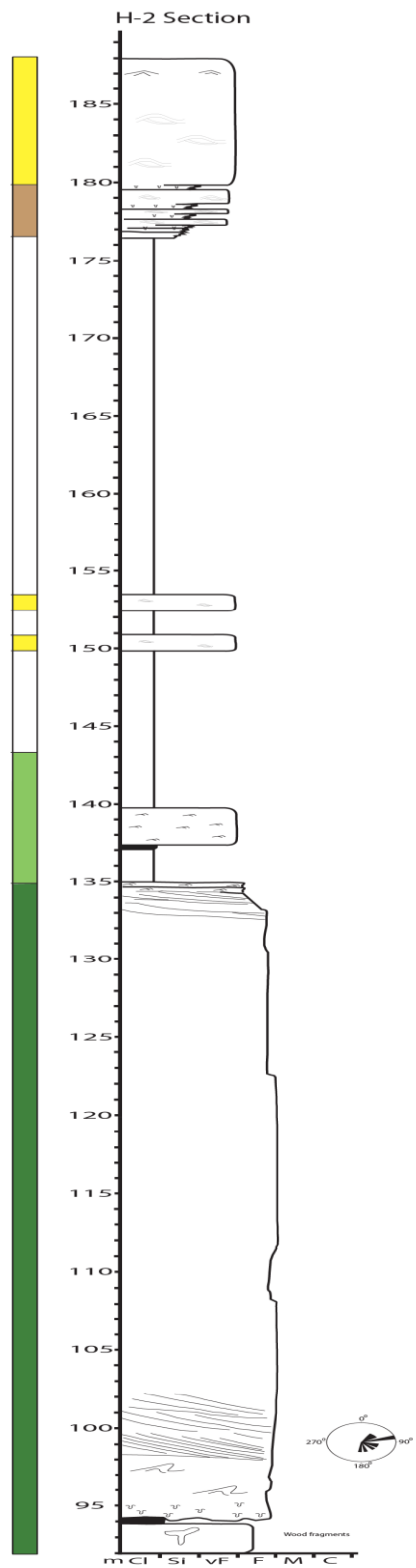


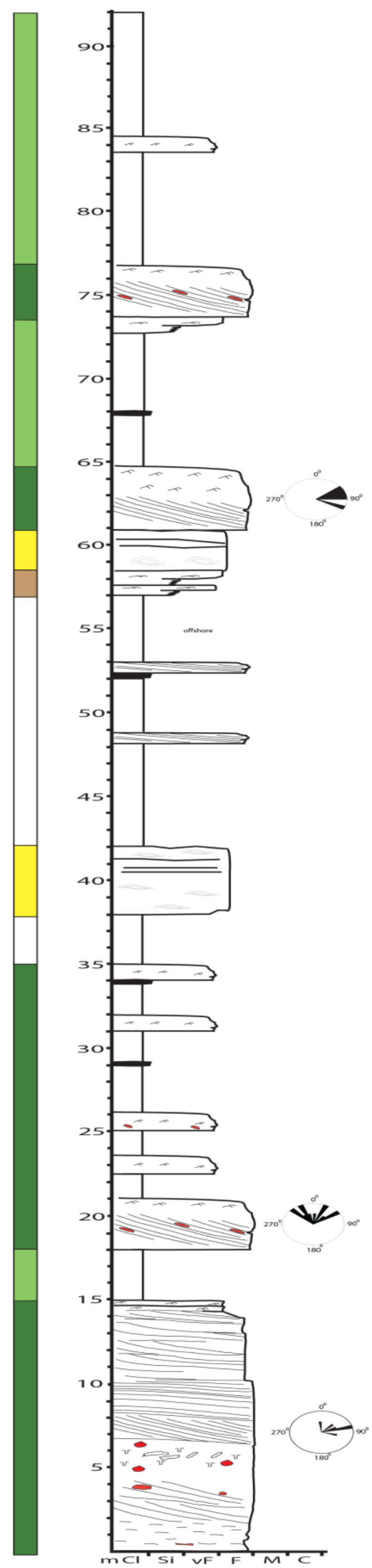
Poorly exposed


215
210
205
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
m Cl Si vF F M C
0°
270°
90°
180°


130
125
120
115
110
105
100
95
90
85
80
75
70
65
m Cl Si vF F M C

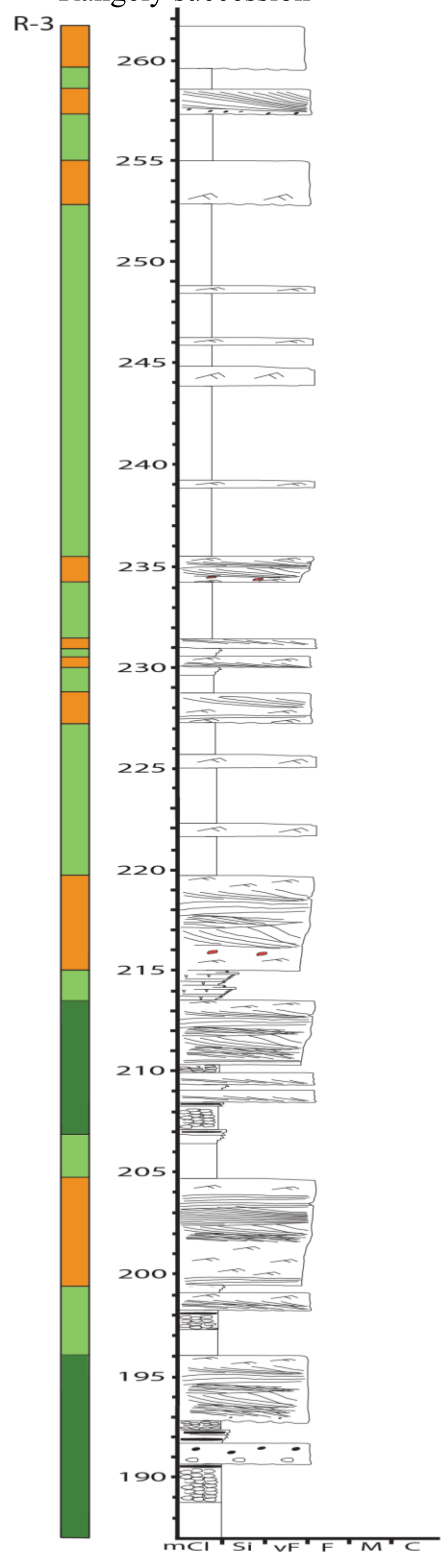

65
60
55
50
45
40
35
30
25
20
15
10
5
m Cl Si vF F M C

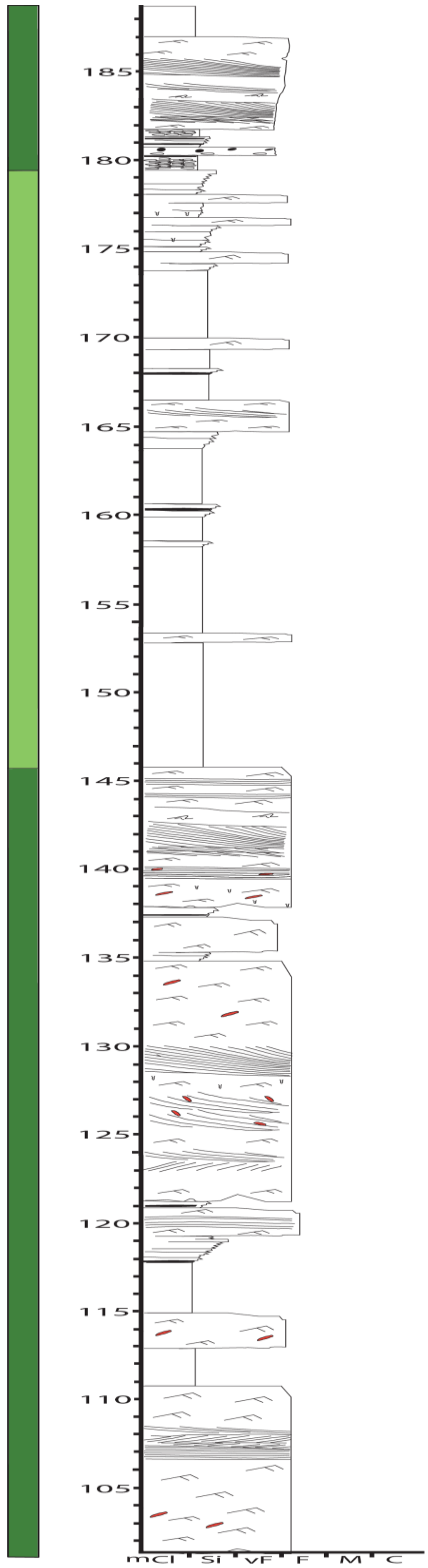

H-2 Section
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
0°
90°
180°
270°
Wood fragments
m Cl Si vF F M C



90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
offshore
0°
90°
180°
270°
mCl Si vF F M C

Rangely succession




185
180
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155
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135
130
125
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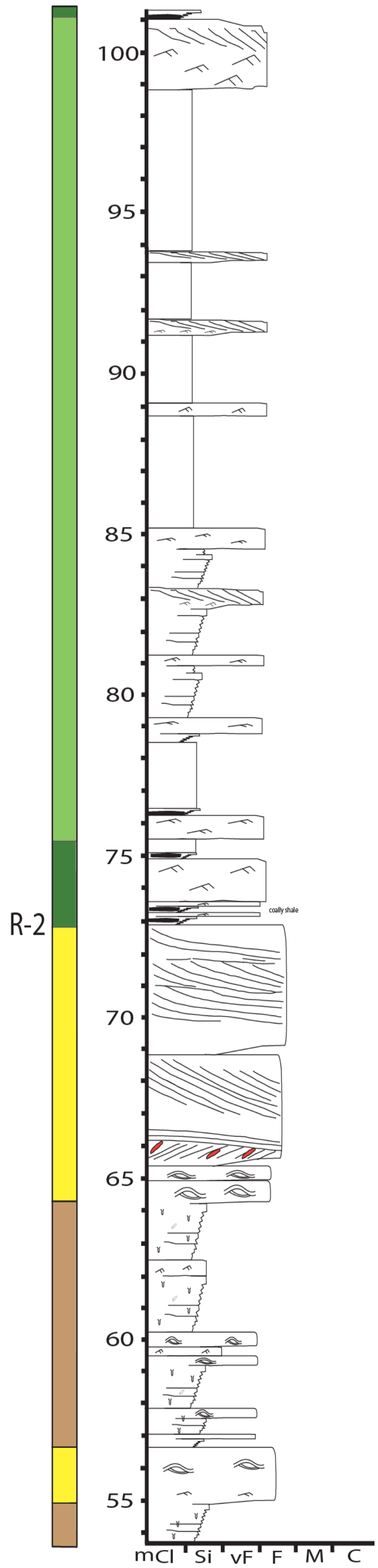
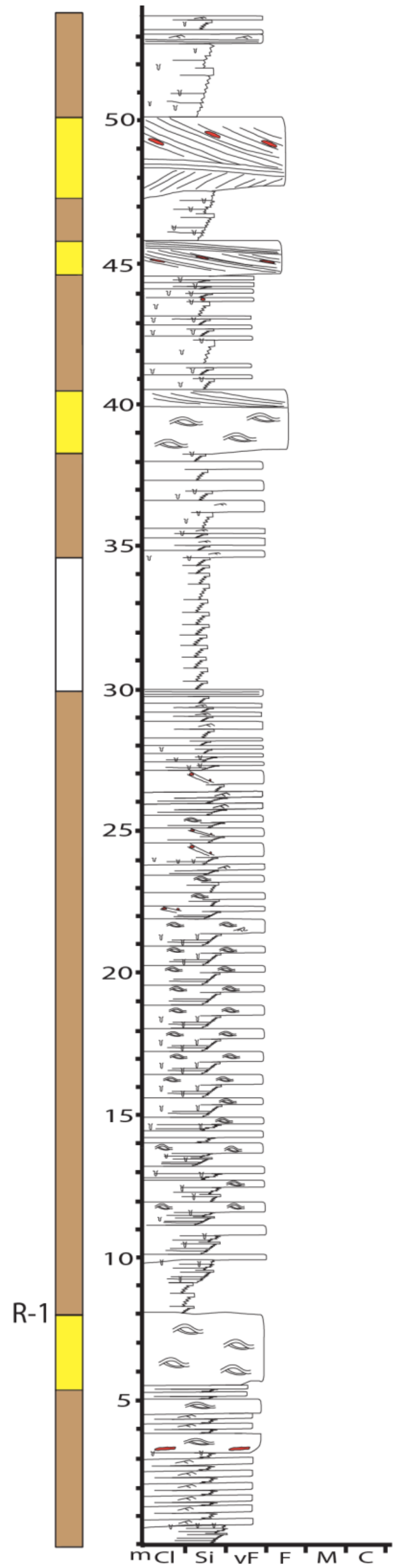
110
105
mCl Si vF F M C


R-2
100
95
90
85
80
75
coally shale
70
65
60
55
mCl
Si
vF
F
M
C


R-1
50
45
40
35
30
25
20
15
10
5
m Cl Si vF F M C

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VITA

Ozge Karaman was born in Zonguldak, in northern Turkey. Upon graduation from Bahcelievler Deneme High School, she attended Middle East Technical University (ODTU, in Turkish), Ankara, Turkey. She graduated from ODTU with a BS degree in geological engineering. Because of her interest in the energy industry she participated in two internship programs during her underground education. Ozge did her first internship with Turkish Petroleum Corporation (TPAO) - Research Center and her second internship with Guris Construction and Engineering Co. Inc. - Aydin-Germencik-Omerbeyli Geothermal Power Plant. After graduation the Turkish Petroleum Corporation (TPAO) and the Ministry of national Education (MEB) awarded Ozge to pursue a MS degree in the USA. She aimed to pursue her master study in the fields of sequence stratigraphy to play a role in the petroleum industry. After graduation from the Jackson School of Geosciences, University of Texas at Austin. She will be employed as an exploration geologist with TPAO in Ankara, Turkey.

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