Paleosol Evolution in a Fluvial Sequence-stratigraphic Framework

Cretaceous Ferron 'Notom' Delta, Central Utah, USA

By

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ABSTRACT

The floodplain is an important part of the fluvial system that is often ignored in studies that focus on fluvial architecture. However, it holds subtle, but important clues that can answer significant questions about cyclicity and controls on cyclicity in the fluvial system. Floodplain paleosols and coals can improve our understanding of change in accommodation relative to sediment supply in the fluvial system, and can also allow proper identification and detection of surfaces that have chronostratigraphic significance.

The Turonian Ferron Sandstone Member of the Mancos Shale Formation was deposited in the Western Cordilleran foreland basin as a series of fluvial-deltaic wedges that prograded onto the Cretaceous epeiric seaway, one of which is the Notom Delta. The upper fluvial and lower deltaic/marine deposits of the Notom Delta are well exposed in the Henry Mountain and Caineville areas of South Central Utah. The focus of this study will be on the floodplain deposits of the Upper fluvial units that have been described extensively in the literature.

This study will attempt to place floodplain deposits and their associated paleosols and coals in a fluvial sequence-stratigraphic framework. It will attempt to link cyclicity observed in the floodplain to high-frequency cyclicity observed in adjacent incised valleys that have been previously identified and mapped. This study will also test some of the existing fluvial sequence-stratigraphic models.

Preliminary work shows that floodplain facies in parts of the study area consists of poorly to well-laminated and carbonaceous mudstones that are often capped by coals; indicating deposition in ephemeral floodplain lakes or swamps. These mudstones and coals often enclose or are interstratified with crevasse-splay and floodplain-lacustrine mini-mouthbar deposits. These paleosols are generally hydromorphic with the exception of some that are well-drained.

1. Introduction

There is increasing awareness of the relevance of floodplain deposits in understanding the intrinsic and extrinsic factors that control fluvial sedimentation and overall architecture (Legaretta et al. 1993, Wright and Marriot, 1993; Plint et al., 2001). The floodplain is an area of land adjacent to the fluvial channel that grows by vertical accretion during seasonal storm events, floods, which result in crevassing and avulsion (Perez-Arlucea and Smith, 1999, Wright and Marriot, 1993; Bridge, 2006; Karssenberg and Bridge, 2008). The floodplain contains a large percentage of fine-grained sediments relative to sediments deposited in the channel, which consists of a higher percentage of coarse-grained sediments.

Vertical accretion in the floodplain is enhanced by storage of fine-grained sediments that occur during periods of high accommodation in the fluvial system (Wright and Marriot, 1993). The space available for sediment storage (accommodation) is controlled by channel elevation and bankfull depth, and it is in turn controlled by rise and fall in local base-level (Wright and Marriot, 1993; Perez-Arlucea and Smith, 1999). Therefore, sediment accumulation on the floodplain scales to the rate of sediment accumulation in the channel; hence, the floodplain has a certain limit to which it can vertically accrete or store sediments (Wright and Marriot, 1993).

The exposed or partially exposed surface of a floodplain favors the development of paleosols. Paleosols are fossil soils that develop on ancient landscapes and are a product of physical, chemical and biological alteration of sediments or rocks that were exposed at one time on the surface of the earth (Kraus, 1999, Retallack, 2001). Paleosols develop in both the aggradational (Kraus, 1987; Bown and Kraus, 1987; Kraus, 1999; Plint et al., 2001) and the degradational (McCarthy and Plint, 1998, 2003) phase of a fluvial system.

In the degradational phase, paleosols (interfluve paleosols) represent a lengthy episode of landscape stability, such as an unconformity (or a sequence boundary), and will exhibit more extensive vertical and lateral variations that are influenced by relief and the prevailing drainage conditions in the fluvial system (McCarthy and Plint, 1998, 2003). However, in the aggradational phase, paleosols exhibit less extensive vertical and lateral floodplain-scale variations and are influenced by sedimentation rate and distance from the active channel.

The realization that the factors (e.g. fluvial aggradation, avulsion frequency, and channel migration) controlling deposition in fluvial channels (Bristow and Best, 1993) also control deposition on their associated floodplains, forms the basis for this proposed research. Understanding the allocyclic and autocyclic factors that influence sediment deposition in the floodplain is as important as understanding those that influence sediment deposition in the channel (Wright and Marriot, 1993; Karssenberg and Bridge, 2008). These factors also control pedogenic development; hence, studying paleosol evolution in an ancient system will provide a record of alternating episodes of fluvial aggradation and degradation (incised-valley formation) and will be crucial to understanding cyclicity in fluvial systems.

2. Geologic Setting of the Study Area

The Upper Cretaceous (Turonian) Ferron Sandstone Member of the Mancos Shale Formation was deposited as part of a series of fluvial-deltaic wedges that prograded into the Western Interior Seaway in the Western Cordilleran foreland basin (Cotter, 1974; Uresk, 1978; Decelles and

Giles1996; Bhattacharya and Tye, 2004). The Western Interior Seaway was an epeiric sea (fig. 1) that extended from the Northern Boreal Sea to the Gulf of Mexico in the South during the Cretaceous (Uresk, 1978). The Ferron Sandstone was first described as a member of the Mancos Shale Formation in 1916 during a comprehensive coal study carried out by Charles T. Lupton near the town of Ferron, Utah (Peterson and Ryder, 1975; Ryer, 1981; Hill, 1982; Ryer, 2004). It is bounded below by the Tununk Shale Member and unconformably above by the Blue Gate Shale Member, both members of the Mancos Shale Formation (Peterson and Ryder, 1975).

The Ferron Sandstone Member represents three clastic (deltaic) wedges, namely the Last Chance, the Vernal and the Notom (Cotter, 1974; Hill, 1982). The Ferron in the proposed study area (fig. 2) represents the fluvial-deltaic wedge of the Notom that outcrops in the Henry Mountain and Caineville areas of South Central Utah. The Ferron in the Notom Delta represents an interval of about 0.5 - 0 .6 my as shown by biostratigraphic data (Peterson and Ryder, 1975; Cobban et al. 2006) and isotopic dating (Zhu et al. 2010).

The Ferron Sandstone in the proposed area of study has been divided informally into an upper and lower unit (Peterson and Ryder, 1975; Uresk, 1978; Hill, 1982). The lower unit consists of shoreface and delta-front sandstones and marine shales, while the upper unit consists of coarse fluvial deposits and associated overbank mudstones, carbonaceous mudstones and coals that represent deposition in a waterlogged floodplain environment (Peterson and Ryder, 1975; Hill, 1982; Li et al., 2010; Zhu et al., 2010). The upper unit will be the focus of this study.

Recently, Zhu et al. (2010) conducted a regional study of the Ferron Sandstone (Notom delta) and correlated units in a sequence stratigraphic framework (fig. 3). His work showed two major incised valleys one of which has been mapped in detail by Li et al. (2010). These two most recent studies serve as the framework for this study.

3. Previous Work

3.1 Fluvial Sequence Stratigraphy

Wright and Marriot (1993) presented a conceptual and yet important fluvial sequence-stratigraphic model that links base-level change, accommodation, fluvial architecture, and pedogenesis (Fig. 4). It is a simple model that explains the evolution of the fluvial system through varying stages of accommodation or depositional systems tracts. The important point in this model is that the transgressive systems tract (TST) represents a time of high accommodation, high fluvial aggradation, and weak and/or hydromorphic paleosol development. The model also recognizes the development of mature, well-drained paleosols on interfluves and terraces due to valley incision at the falling stage (FSST) or lowstand systems tract (LST), and also well-developed paleosols in the highstand systems tract (HST). However, they recognized the effect of other high-frequency cyclic controls (e.g. climate) that may complicate this simple base-level controlled model. This proposed study is concerned with this higher- frequency cyclic controls.

Shanley and McCabe (1993, 1994) presented a similar stratigraphic model based on their study of Turonian to Campanian fluvial sequences in the Kaiparowits Plateau in Southern Utah, USA (Fig. 4). Although, there was no emphasis on floodplains and paleosols in their study, the stratigraphic framework recognized the role of accommodation in controlling overall fluvial architecture. High accommodation led to high fluvial aggradation, increased tidal influence, increased floodplain deposition, isolated sand bodies, and low sand-shale ratios, while low accommodation led to increased sand body interconnectedness (or stacking) and high sand-shale ratios.

Changes in accommodation in their study were also related to base-level rise and fall. However, in contrast to the conceptual model of Wright and Marriot (1993), high floodplain deposition and sand body isolation increases and persists in the highstand systems tract, which is supposed to be a phase of low accommodation, but they mentioned that this might only represent the early highstand. An unconformity beneath the overlying Drip Tank Member may have eroded the late highstand deposits. It is also important to mention that their interpretation has followed Posamentier and Vail's (1998) model, which differs from that of Wright and Marriot (1993) in terms of the direction of shift in the equilibrium profile and high rates of aggradation in the highstand systems tract (HST) relative to the transgressive systems tract (TST).

Plint et al. (2001) have also interpreted fluvial strata of the Cretaceous Dunvegan Formation in the Alberta foreland basin, in a sequence stratigraphic framework (Fig. 5). They recognized three systems tract that were interpreted based on their accommodation profile and paleosol maturity. The first systems tract is a low-accommodation systems tract that consists of multi-storey channels deposited within an incised valley, and it is equivalent to lowstand - early transgressive systems tract. This systems tract exhibits very little preservation of floodplain sediments and it is tidally influenced at the top, similar to Shanley and McCabe (1993).

However, the maximum flooding surface is not directly at the top of this systems tract, as it only represents an episode of initial marine influence. The second systems tract is a lacustrine-dominated, high-accommodation systems tract that is dominated by poorly laminated mudstones, carbonaceous mudstones, and coals that enclose or are interstratified with crevasse splays, ribbon sand bodies and lacustrine mouth bars. These represent deposition in a wet or lacustrine flood-plain environment with poorly-developed and hydromorphic paleosols. This systems tract is equivalent to late transgressive to early highstand systems tract and it said to be the dominant systems tract in the sequence. The time of maximum flooding (MFS equivalent) is interpreted to lie within and not on top of this systems tract.

The third systems tract in the sequence is a paleosol-dominated, low-accommodation systems tract which is dominated by well-drained, welded, moderately to well-developed paleosols with blocky ped structures. These floodplain mudstones are interstratified with crevasse-splay sand-stones and other floodplain facies. The top of this systems tract is marked by a sequence boun-dary that is marked by well developed interfluve paleosols that represent a significant period of non-deposition, weathering and overall landscape stability.

Li et al. (2010) conducted a detailed study and mapping of some incised valleys in the Creta-ceous Ferron “Notom Delta” in the Henry Mountains region in Utah. In one of the valleys de-scribed, coarse and amalgamated fluvial deposits represent deposition in the early lowstand sys-tems tract, while upper, finer, less amalgamated sand bodies represent late lowstand and trans-gressive systems tracts with an observed tidal influence, which is thought to represent the land-ward limit of marine influence (maximum flooding surface). The highstand systems tract is marked by single-storey sheet-like sandstones that are enclosed in fluvial floodplain and over-bank deposits. This interpretation is very similar to that of Shanley and McCabe (1993).

They also discussed the likely role of Milankovitch-induced eustasy in controlling deposition in these valleys, especially in valley incision and given that the location of these valleys is within 100 – 150km of the paleo-shoreline. However, higher frequency erosional surfaces within the valleys might be related to climate induced high-frequency cycles related to changes in the ratio of discharge and sediment supply in the system.

Holbrook et al. (2006) have discussed the importance of buffer (upstream) versus buttress (downstream) controls on base-level and their influence on cyclicity in fluvial systems. Karssenberg and Bridge (2008) have also highlighted the difficulty of separating the combined effects of autocyclic and allocyclic controls on deposition in a fluvial system. The issue of control on deposition in the fluvial system in the Ferron is still unclear and this proposed study will attempt to answer some of the questions by studying cyclicity in floodplain deposits and interfluve paleosols.

3.2 Floodplain Paleosols and Coals

A detailed study of lateral variations in channel and floodplain paleosols was carried out by Bown and Kraus (1987) in the Lower Eocene Willwood Formation of the Bighorn Basin, Wyoming, USA. They observed that lateral variation in paleosol maturity was a function of distance from the channel margin and sedimentation rates in the floodplain and were able to group paleosols into different stages of development (Fig. 6). Areas close to the channel margins receive more sediment than areas farther away from the channel margin. Moreover, areas close to the channel margins are frequently disturbed or eroded by processes like channel migration and overbank flooding, while areas farther away in the distal floodplain are more or less undisturbed. As a result, paleosols in areas close to channel margins are composite paleosols (Fig. 7) and are less mature than cumulative paleosols that develop in areas on the floodplain that are farther away from the channel margin.

Kraus (1987) studied vertical variations in paleosol maturity in the same area and observed the relationship of paleosols with interstratified crevasse-splay and channel deposits. Kraus (1987) observed progressive upward increase in paleosol maturity and then a decrease in response to episodes of crevasse splaying or river avulsion. On this basis, she grouped them into simple and compound pedofacies sequences. Simple pedofacies sequences are smaller and they extend from the top of paleosol-underlying crevasse-splay deposits to the base of the next overlying crevasse-splay sandstone in a vertical section (Fig. 8). Compound pedofacies sequences are larger and they extend from the top of paleosol-underlying channel sandstone to the base of the next overlying channel sandstone in a vertical section (Fig.8).

McCarthy and Plint (1998, 2003) conducted an extensive study on the vertical and lateral changes in interfluve paleosols associated with sequence boundaries in the Cretaceous Dunvegan Formation, Alberta foreland basin (Fig. 9). They identified interfluve paleosols by using stratigraphic position, field observation and detailed micromorphology of recovered paleosol samples. With varying base-level, interfluve paleosols show a record of initial aggradation on a coastal floodplain followed by a static or degradational phase associated with valley incision, non-deposition and soil thickening, and a renewed aggradational phase related to valley filling and sedimentation in the coastal plain. They also emphasized the role of micromorphology in recognizing this three phases.

Sequence boundaries in interfluve paleosols were recognized as clear but undulating contacts with some residual enrichment of Titanium and Zirconium (resistate elements) and increased soil Kaolinite - Chlorite or Smectite ratios suggesting a weathering surface of prolonged stability. Study of lateral variability in interfluve paleosols showed increased maturity towards the valley margins (Fig. 10). Interfluves closer to the valley margins were thicker, mature and contained more argillic horizons, thus indicating better-drainage conditions in comparison to those far from the valley margin that are less well developed and capped by coals, thus suggesting poor drainage conditions.

With renewed sedimentation (Fig. 11), interfluve paleosols that develop close the valley margin are cummulic (composite paleosols of Kraus (1987)) due to high rates of sedimentation (Kraus 1987) and show influence of brackish or saline groundwater (due to the presence of barite) while those that develop far away from the valley margins are thin and may be capped by coals, which suggests low sedimentation rates and influence of fresh groundwater away from the valley margin. In, general, these interfluve paleosols are said to be equivalent to modern Alfisols or Ultisols due to evidence of kaolinite, clay illuviation and formation of argillic horizons and intense bioturbation. Alfisols and Ultisols require a period of not less than 16 – 30 k.y. to form (Federoff and Eswarran, 1985). When compared to the period it took the whole Dunvegan interval (an interval of about 150 k.y.) to develop, the five interfluve paleosols described will represent long periods of landscape stability that are probably greater than the period it took for their corresponding incised-valleys to fill.

Driese and Ober (2005) studied paleosols in the fluvio-deltaic strata of the Pennsylvanian Crooked Fork Group in Eastern Tennessee. These paleosols are said to be associated with fourth-order depositional sequences, but record higher-frequency changes in paleohydrologic conditions during their formation, which probably suggests smaller-scale (probably Milankovitch-driven) cyclicity superimposed on larger- scale cycles of eustatic change. Paleosol features associated with good and poor drainage conditions suggest small-scale alternation of wet and dry cycles as controlled by rise and fall in base level. They suggested a sequence of seasonally wet conditions with well drained and moderately developed paleosols followed by ever wet conditions characterized by gley-overprinted and sideritic paleosols and coals and eventual drowning by marine sediments characterized by marine shale deposition (Fig. 12). This study also showed the importance of micromorphology in identifying subtle features in paleosol that would aid proper classification and interpretation of the rock record.

Davies et al. (2006) did a high resolution sequence stratigraphic study of the Sunnyside Member of the Castlegate Formation in Utah (Fig. 13, 14). The focus of their study was to correlate non-marine and marine strata using coals. Their work was based on recognizing base-level change expressions in non-marine strata, especially coal seams and linking them with base-level change expressions in marine strata. This method allowed them to identify significant and non-significant chronostratigraphic surfaces and high-frequency cycles that may have not been observed in marine strata.

The underlying assumption in their study is that for peat to accumulate in wet floodplains or mires, the rate of peat production has to balance the rate at which accommodation is being created (Cross, 1988; Bohacs and Suter, 1997). Accommodation itself is controlled by base-level and to a lesser extent by peat compaction. On this basis, increase in the inorganic mineral and shale content of coals would indicate higher accommodation rates (associated with flooding surfaces) that could eventually lead to drowning and inundation, while a lower mineral content and formation of limnotelmatic and ombrotrophic coals would indicate low accommodation (Fig. 13). On the extreme, very low accommodation rates (associated with sequence boundaries) is accompanied by inertinite-rich coals indicating exposure, oxidation and surface reworking.

4. Objectives

The goal of this research activity is to study the level of cyclicity in fluvial systems as expressed in floodplain and interfluve paleosols. It would attempt to link this level of cyclicity to higher-frequency erosional surfaces found in the compound incised valleys documented and mapped by Li et al. (2010, 2011) and Zhu et al. (2010). Cyclicity in these compound incised valleys are said to be controlled by sea-level, however, higher-frequency erosional surfaces within the valleys may suggest climate-controlled cyclicity (Li et al. 2010). The influence and importance of climate control will be evaluated by observing changes in groundwater levels, soil or coal types. This study will also evaluate valley to interfluve and floodplain variability (lateral and vertical) in paleosol development and place it in a fluvial sequence-stratigraphic framework. It will also serve as a test of earlier published fluvial sequence stratigraphic (Wright and Marriot, 1993; Shanley and McCabe, 1993, 1994; Plint et al., 2001) models.

5. Proposed Method of Study

This work will entail detailed measurement and construction of stratigraphic sections through the muddy and coal-prone floodplain facies adjacent to previously mapped channel-belts and valley systems. An estimated total of 30 to 40 paleosol (interfluve and floodplain) sections will be measured in outcrops that span a distance of approximately 30 km. An attempt will be made to correlate across the study area using distinct pedogenic intervals rather than using whole pedostratigraphic units because of variability. Detailed sampling of paleosol horizons and coals will be carried out for appropriate petrographic analysis (micromorphology) and geochemical evaluation. Paleosol sampling in interfluves will be as detailed as possible in order to capture the subtle variations (vertical and lateral) that may exist on such surfaces. Paleosols will be air-dried and impregnated with epoxy resin before they are cut into standard or larger (2” x 3”) petrographic thin section sizes. Geochemical evaluation will likely entail bulk chemistry analysis of powdered whole-rock samples (for major, minor and trace elements) using X-ray fluorescence spectroscopy.

Preliminary study and description of paleosols in the Ferron fluvial sequence show simple and compound pedostratigraphic units (Kraus, 1987). Each simple pedostratigraphic unit as shown in figure 15 consists of gleyed or hydromorphic (probably poorly developed) and rooted paleosols that are capped by a coaly (O) horizon. These pedostratigraphic units enclose, or are interstratified, with crevasse-splay deposits that likely represent a period of channel bifurcation (crevassing) or avulsion (Karssenberg and Bridge, 2008) that caps the underlying paleosols and results in renewed floodplain sedimentation and paleosol development. Directly overlying the coaly-O horizons are temporarily interpreted ‘Bssg’ horizons that consists of highly carbonaceous and almost coaly mudstones, and are likely to represent increased shale content in coals due to high accommodation as per Davies et al. (2006).

High accommodation will result in high fluvial aggradation that will promote crevassing and avulsion, hence explaining the occurrence and position of the overlying crevasse splay sandstone. The O horizons tend to mark the end of a floodplain episode, with renewed sedimentation above the coals or crevasse splays. Therefore each simple pedostratigraphic unit represents a cycle of floodplain aggradation or vertical accretion. There are a total of four cycles in this section (with a total height of 5.5m) between two large sand bodies. A combination of simple pedostratigraphic units is called a compound pedostratigraphic unit. This is very similar to the simple and compound pedofacies sequence of Kraus (1987). This is a general trend in this area except for places that have better-drained paleosols with blocky peds. On the sequence stratigraphic framework provided by Zhu et al. (2010), this section (Fig. 13) is in a transgressive systems tract and its characteristics are consistent with those described in earlier reviewed literature.

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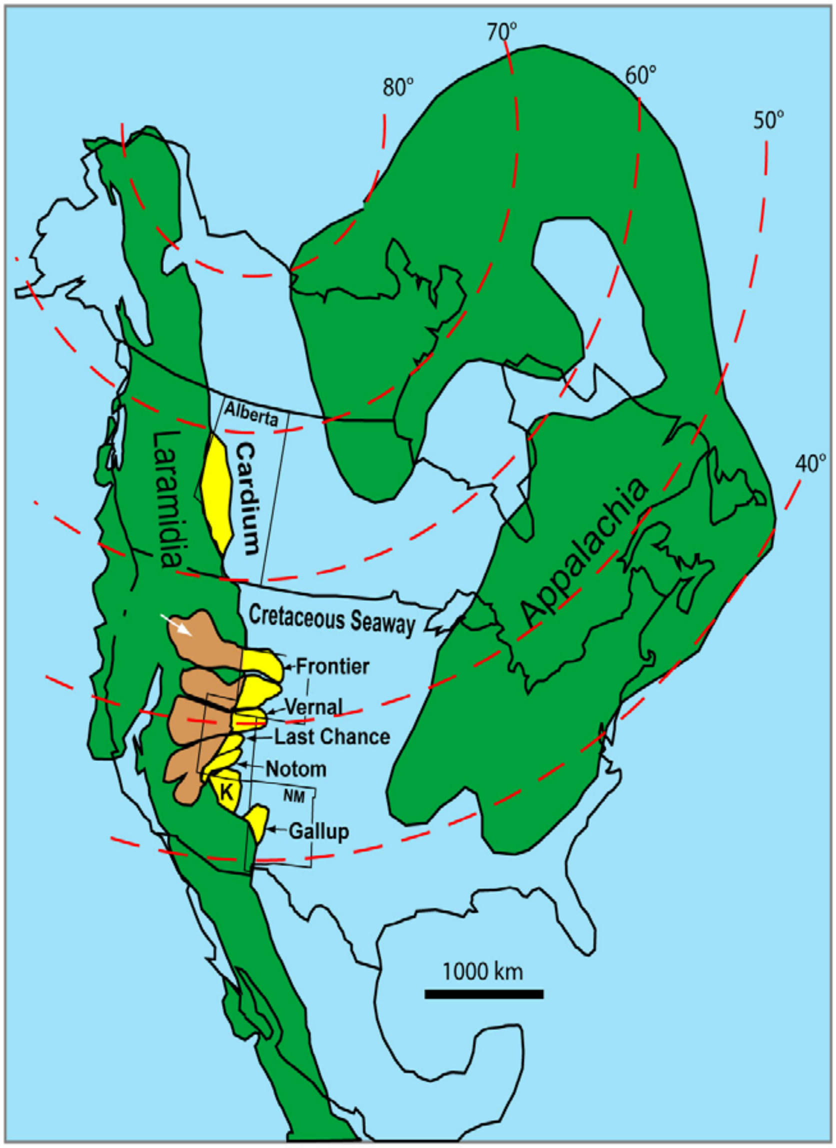


Fig. 1. Paleogeographic reconstruction of the Late Cretaceous showing the Western Interior Seaway and prograding deltas along the shoreline (after Bhattacharya and Tye, 2004)

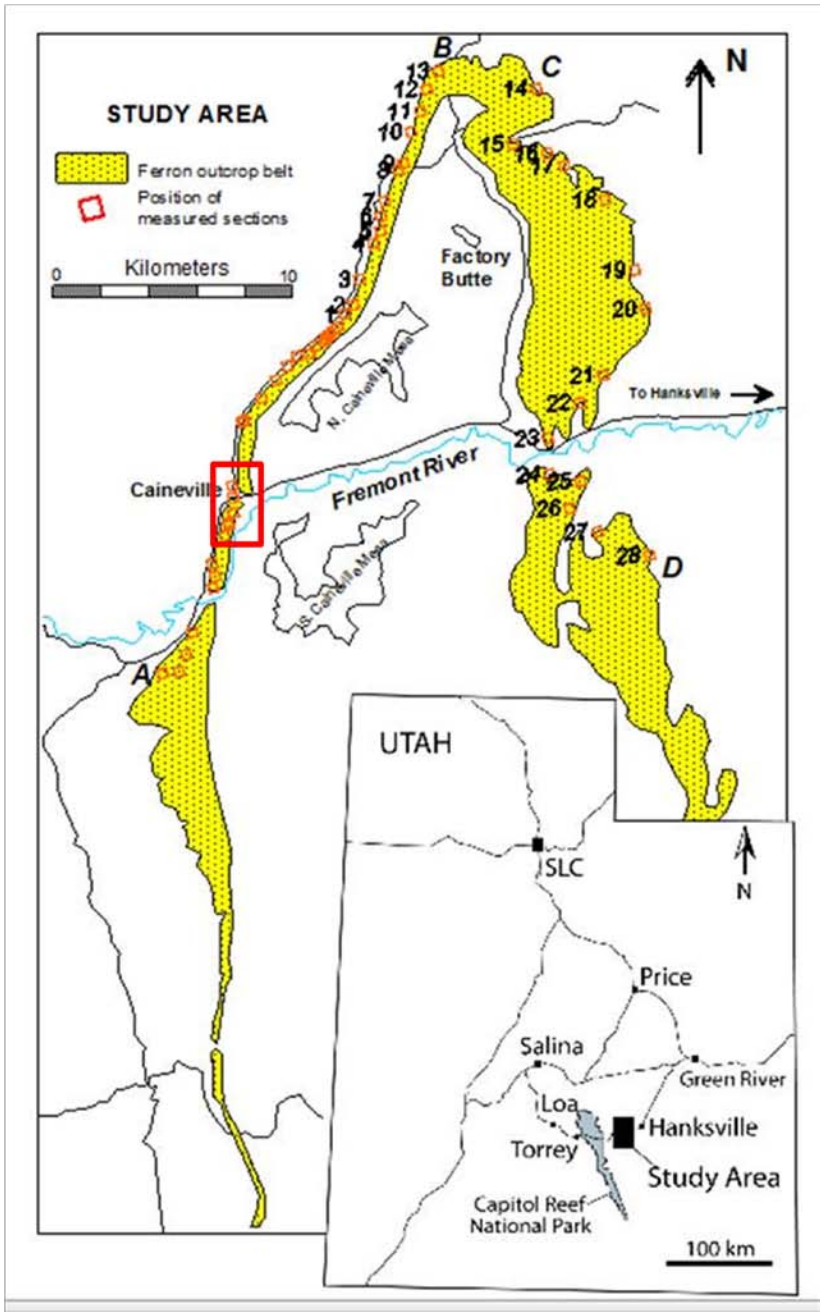


Fig. 2. Map of the study area and location of measured sections by Zhu et al. 2010 and Li et al. 2010. The study will involve re-measuring floodplain sections in their sections. Red box indicates area of initial measured sections for this study.

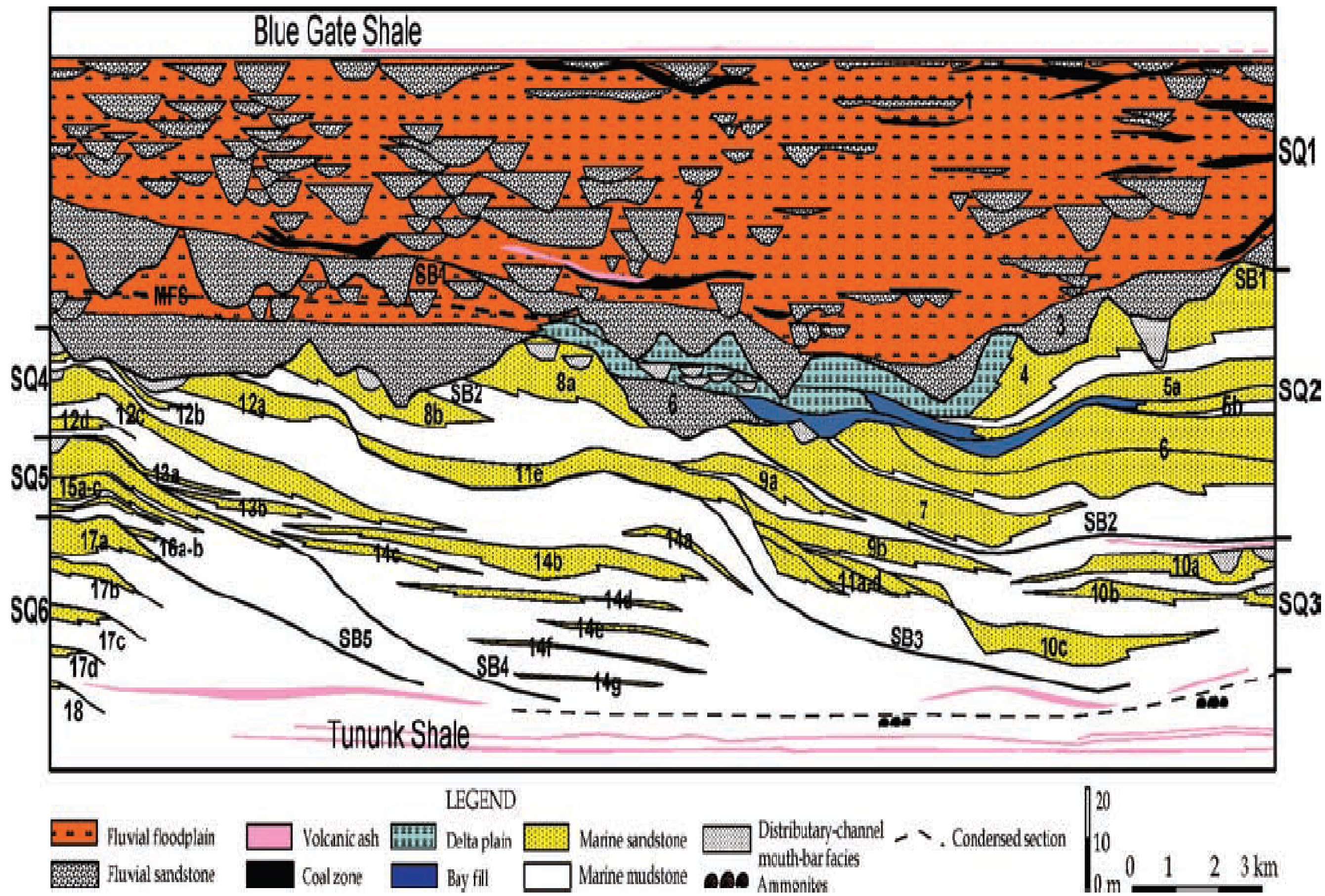


Fig. 3. Regional sequence-stratigraphic cross-section of the Ferron 'Notom' Sandstone showing the upper fluvial channel and floodplain deposits (Li et al. 2010 and Zhu et al., 2010).

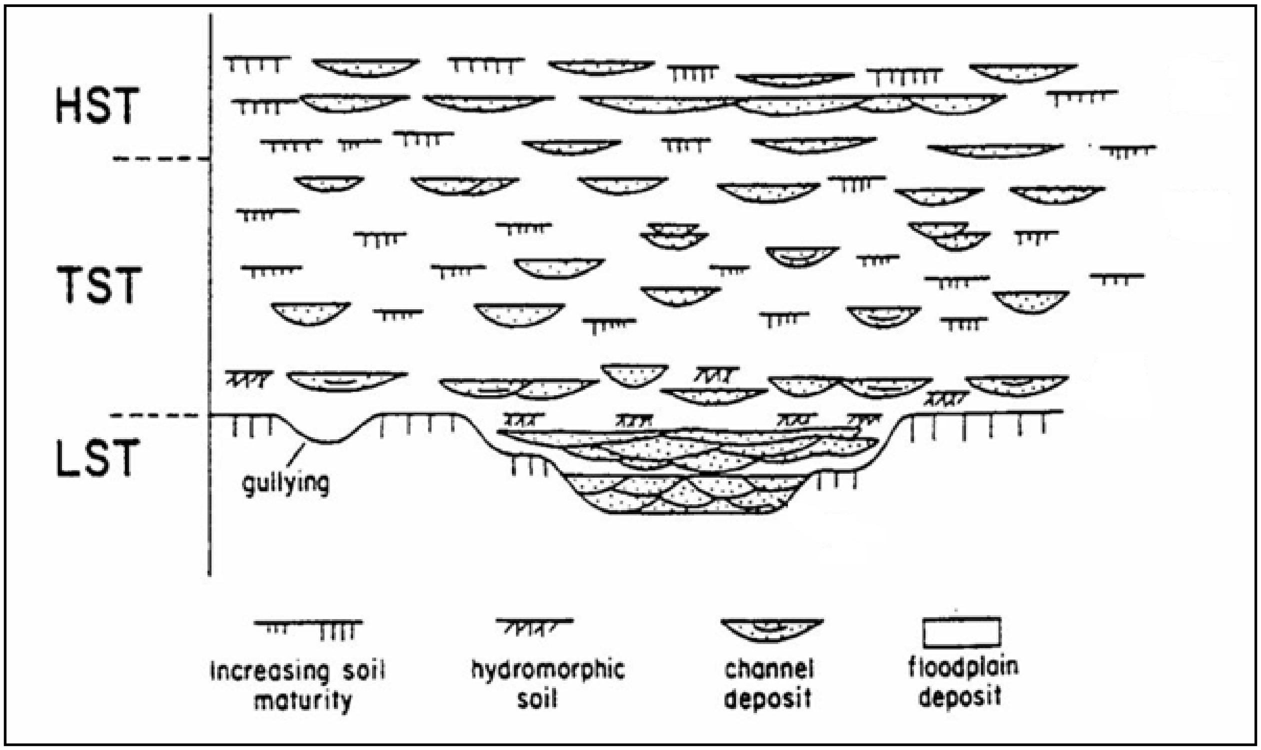


Fig. 4. A conceptual sequence-stratigraphic model showing increased floodplain sedimentation and channel isolation in the transgressive systems tract (TST). Paleosols are depicted as hydromorphic in the TST. Interfluve paleosols associated with incised-valleys in the LST are well developed (Wright and Marriot, 1993).

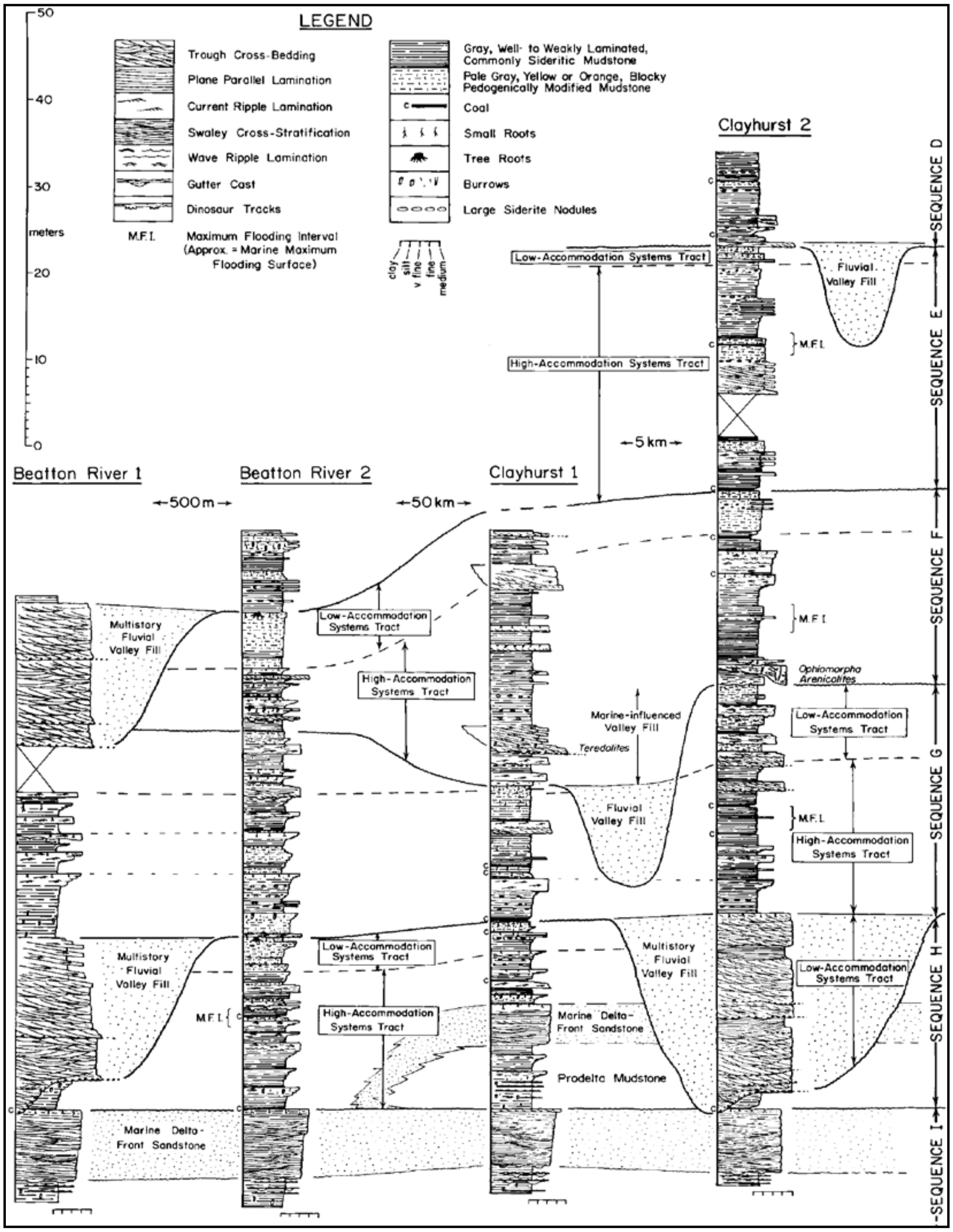


Fig. 5. Sequence-stratigraphic correlation in the Cenomanian Dunvegan Formation, Alberta foreland basin showing incised valleys and interfluves. Division of strata into systems is tract based on change in accommodation and associated paleosol maturity (Plint et al. 2001).

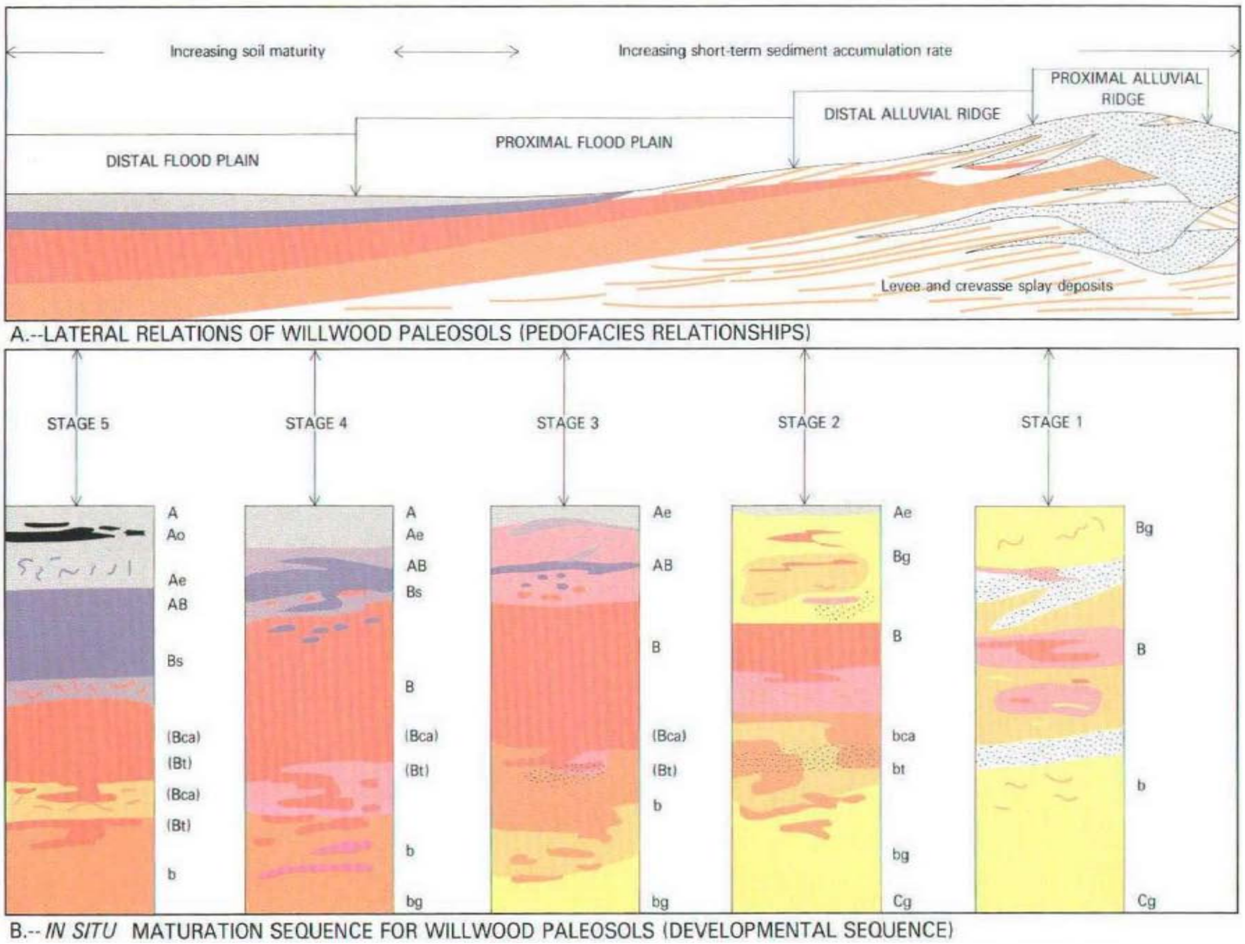


Fig. 6. Channel to floodplain-scale variation in paleosol maturity, Lower Eocene Willwood Formation. Increase in stage number indicates increasing paleosol maturity, which is based on distance from channel margin and rate of sedimentation (Bown and Kraus, 1987).

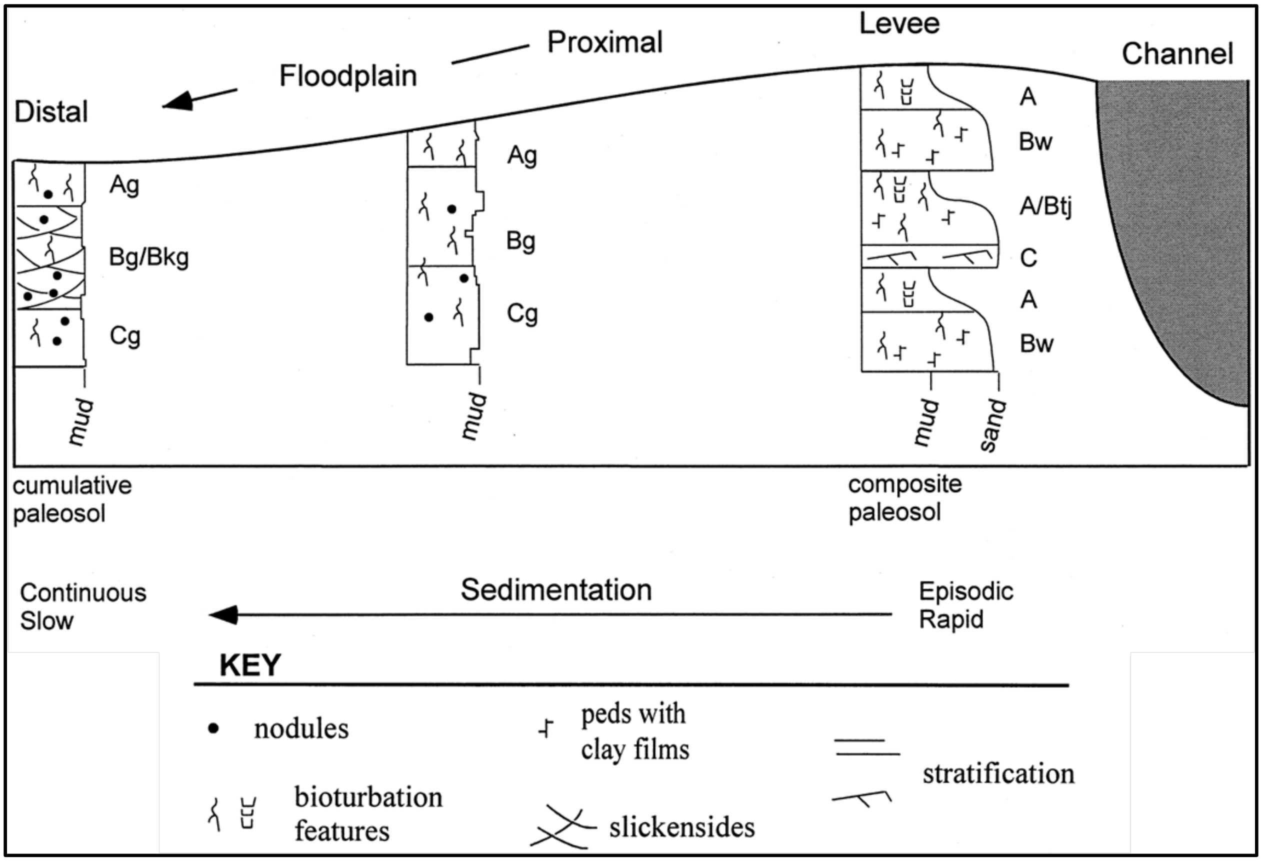


Fig. 7. A schematic diagram showing floodplain-scale variation in paleosols based on varying sedimentation rate, erosion and distance from channel margin. Composite paleosols develop close to the channel margins while cumulative paleosols develop farther away (Kraus, 1999).

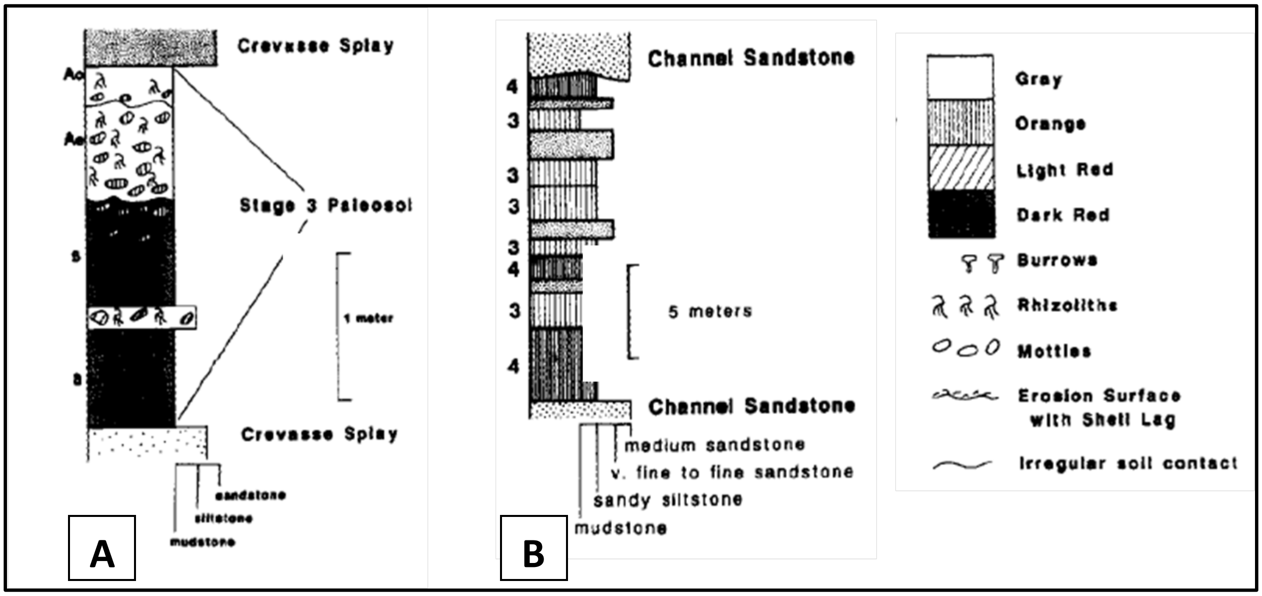


Fig. 8. Simple (A) and compound (B) pedofacies sequences in the Lower Eocene Willwood Formation (modified after Kraus, 1987).

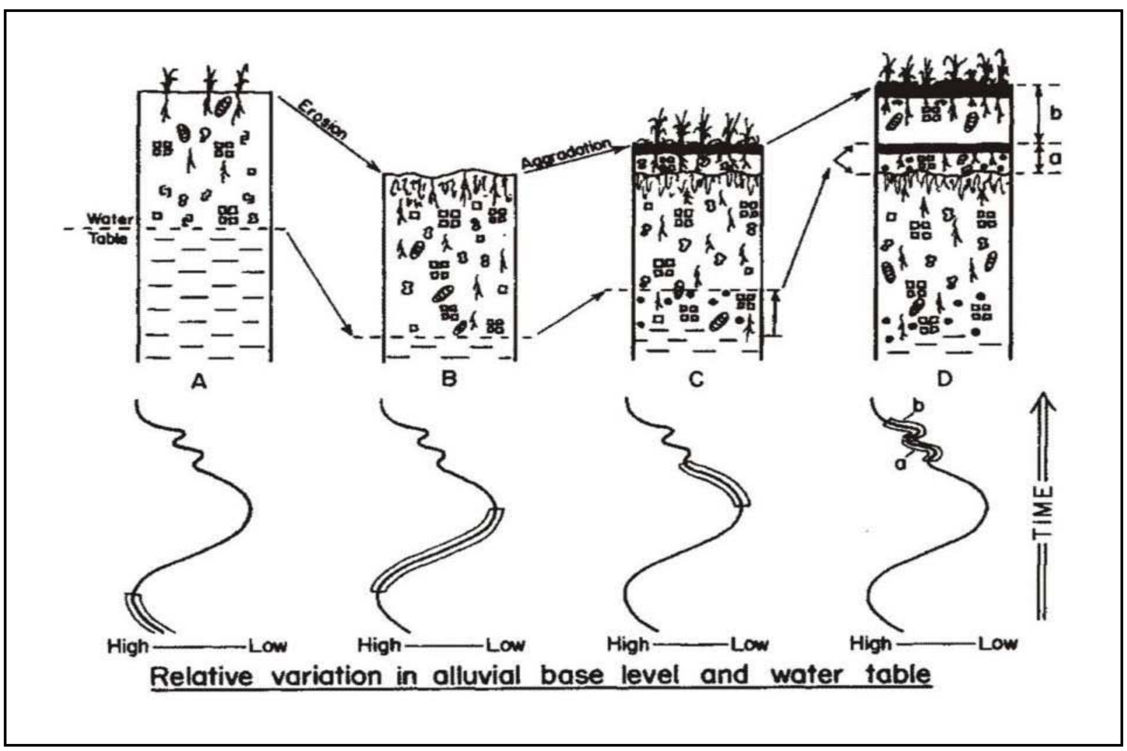


Fig. 9. Sequence of pedogenic development on interfluves depicted as a function of base-level change (McCarthy and Plint, 1998).

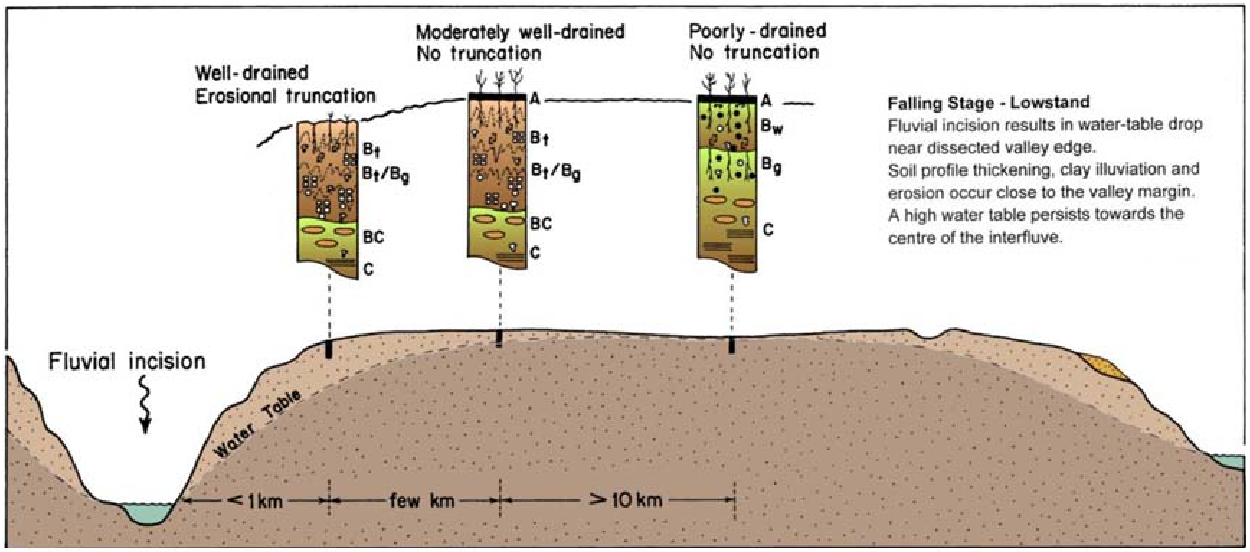


Fig. 10 Lateral variability in interfluve paleosols (after valley incision) depicted as a function of relief and drainage (McCarthy and Plint, 2003).

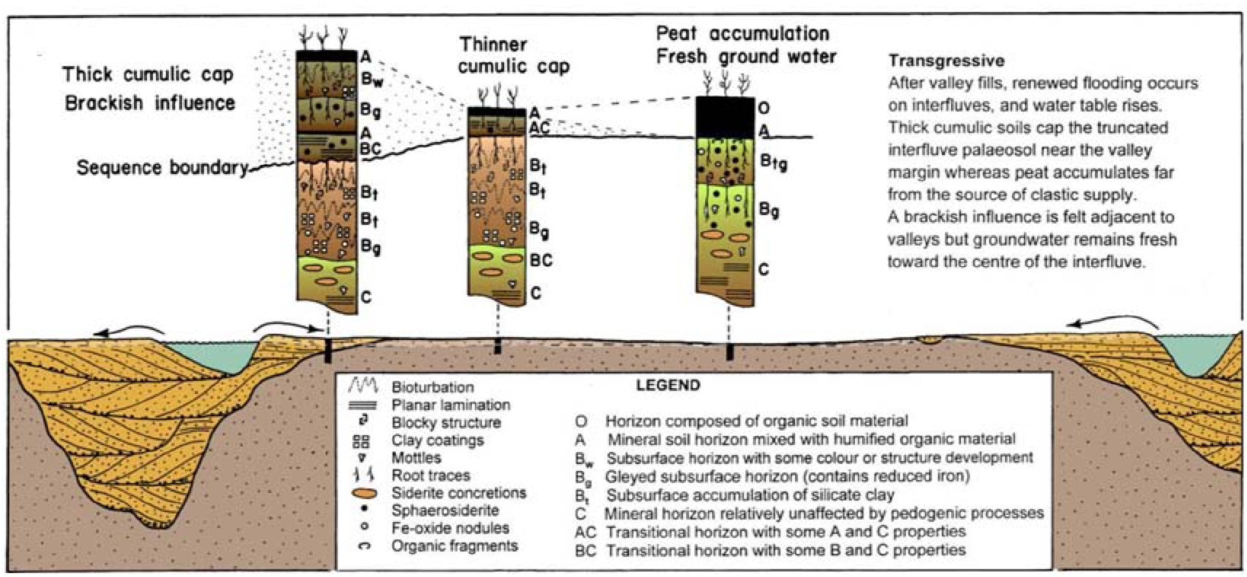


Fig. 11. Lateral variability in interfluve paleosols (after renewed sedimentation) depicted as a function of sedimentation rate and distance to the channel margin (McCarthy and Plint, 2003).

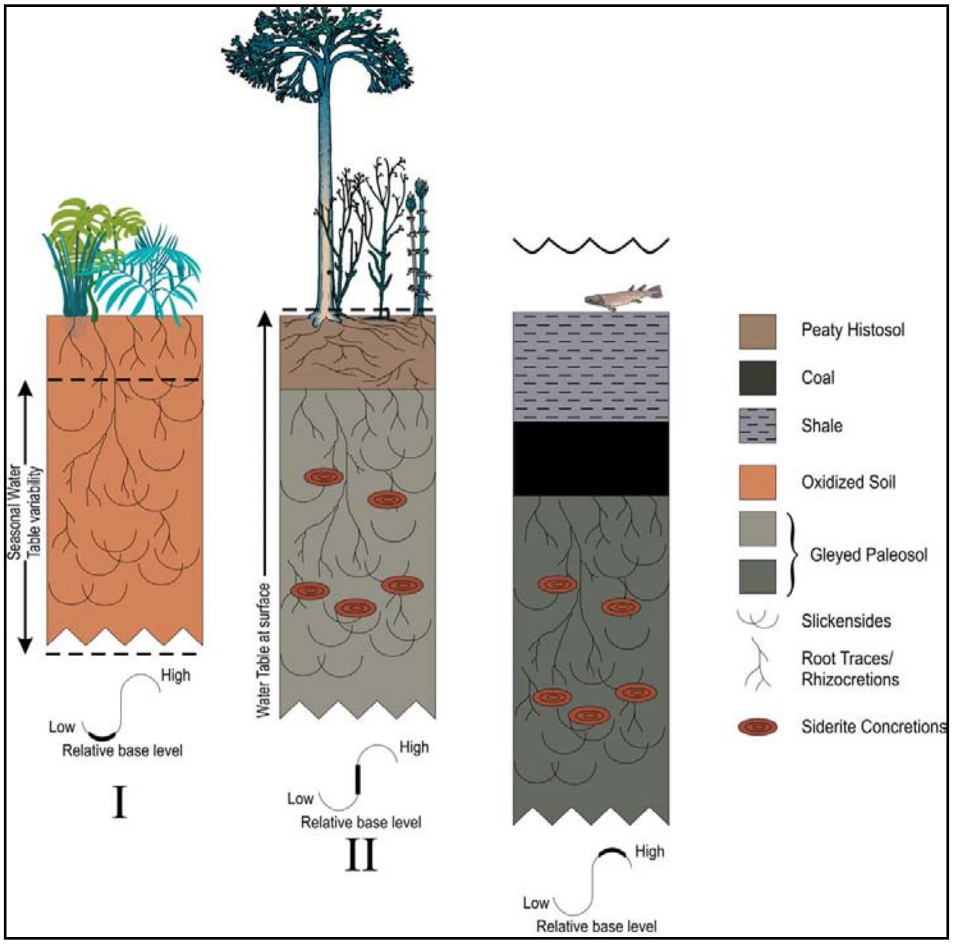
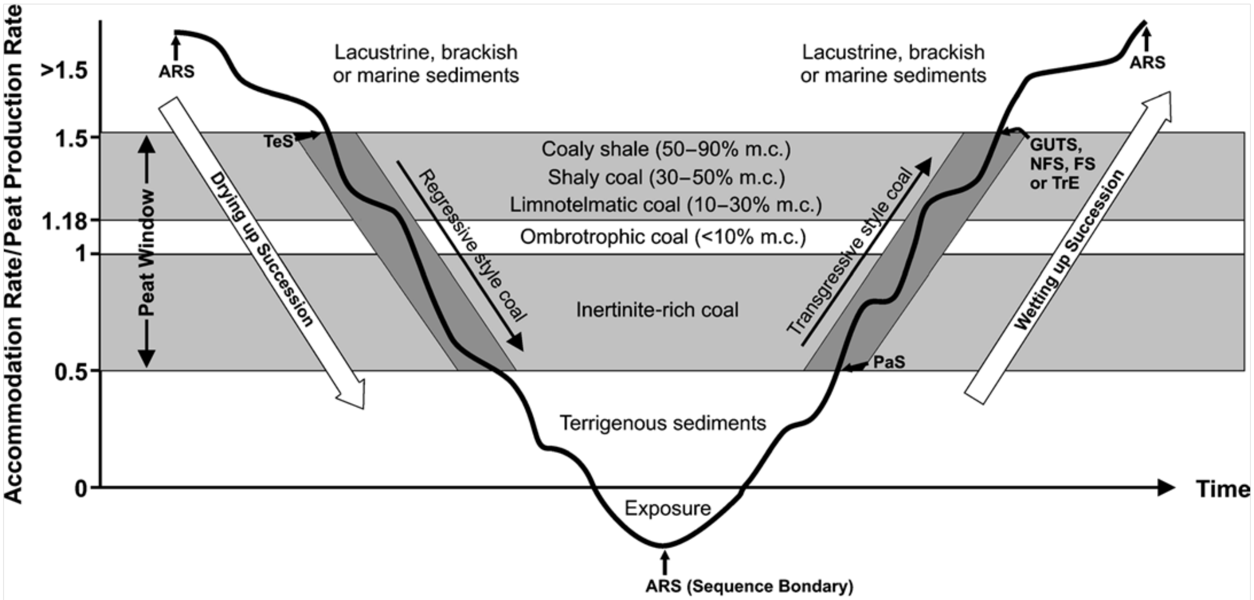


Fig. 12. Sequence of paleosol formation from well-drained to poorly-drained conditions depicted as a function of base-level change in the Pennsylvanian Crooked Fork Group, East Tennessee (Driese and Ober, 2005).



	Surface	Explanation	Hiatal / Nonhiatal
TeS	Terrestrialization Surface	Initiation of peat formation caused by upward shallowing	Nonhiatal
PaS	Paludification Surface	Initiation of peat formation caused by upward deepening	Hiatal or nonhiatal
GUTS	Give-up Transgressive Surface	Gradual termination of peat formation caused by upward deepening	Nonhiatal
ARS	Accommodation Reversal Surface	Transition between shallowing and deepening upward (and vice versa)	Hiatal or nonhiatal
NFS	Nonmarine Flooding Surface	Abrupt deepening of nonmarine facies	Hiatal
FS	Marine Flooding Surface	Abrupt deepening of marine facies	Hiatal
TrE	Transgressive Surface of Erosion	Abrupt deepening of facies associated with sediment reworking	Hiatal

Fig. 13. Diagram shows compositional variation in coal seams as a function of accommodation change. Increase in shale content and inorganic minerals during high accommodation and oxidation, reworking and increased inertinite content with decrease in accommodation (Davies et al., 2006).

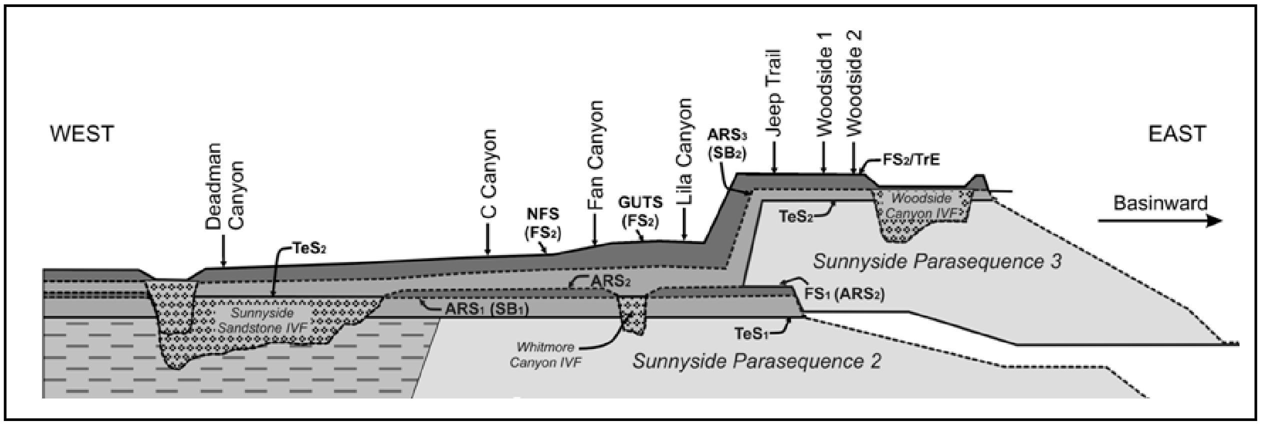


Fig. 14. Sequence-stratigraphic correlation between continental and marine strata using facies trend in coal seams (Davies et al. 2006).

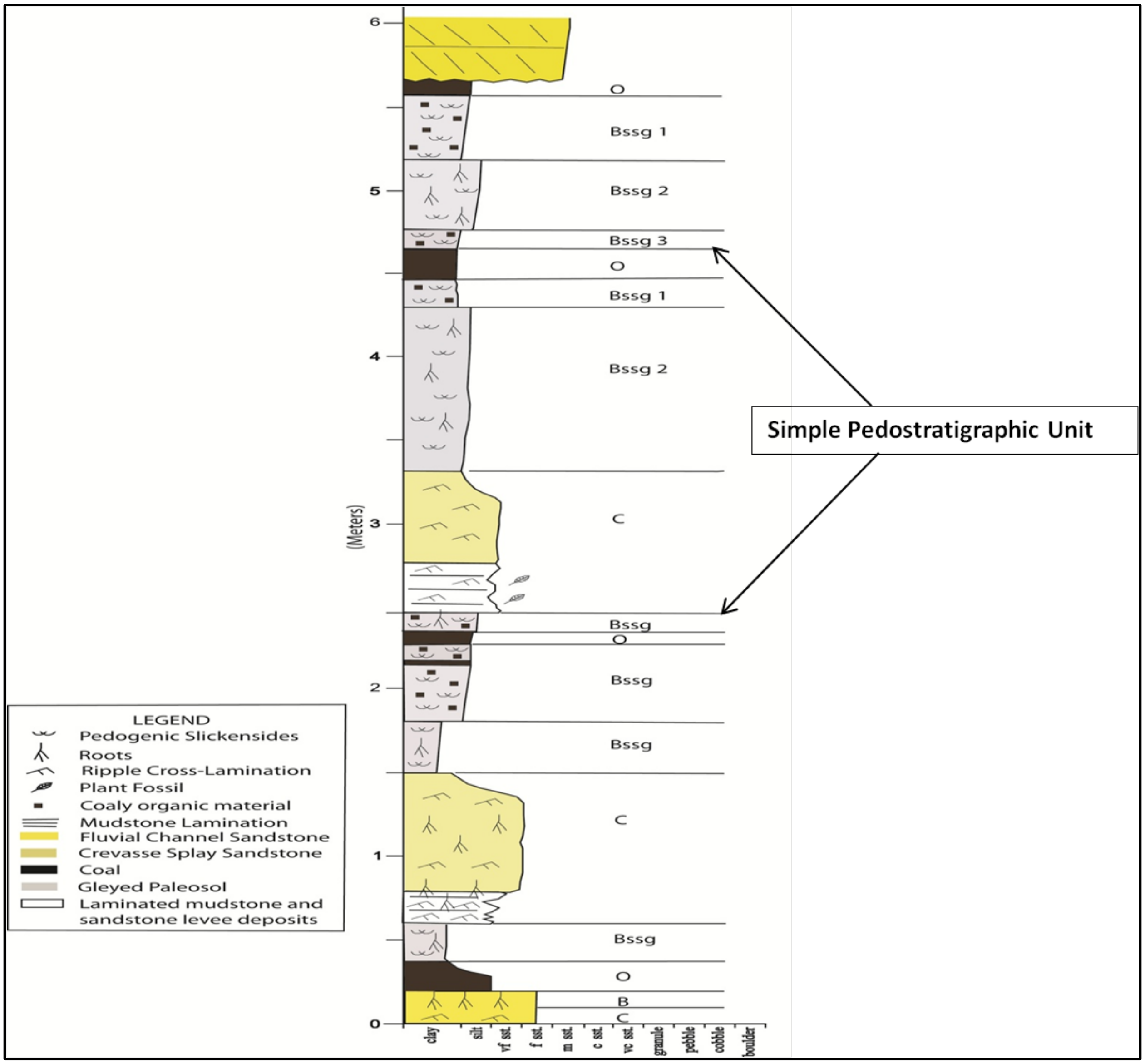


Fig. 15. A measured floodplain section showing paleosols and coals. Four simple pedostratigraphic units are shown in this section and are capped by coals. Crevasse-splay deposits may indicate periods of high accommodation that led to river bifurcation, thereby temporarily disrupting pedogenic development.