Lithofacies, Architecture and Sequence Stratigraphic Interpretation of the Upper Pennsylvanian Indian Cave Sandstone, Northern Midcontinent Shelf, U.S.A.

(southeastern Nebraska).

by

Steven A. Fischbein

A DISSERTATION

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Doctor of Philosophy

Major: Geosciences (Geology)

Under the Supervision of Professor Christopher R. Fielding

Lincoln, Nebraska

December, 2005

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The Virgilian “Indian Cave Sandstone” (ICS) is herein redefined as at least four incised valley fills (IVFs) of at least two different ages. These IVFs are composed of irregularly bounded, tabular-lenticular units of trough cross-bedded sandstone, grading vertically into tabular-lenticular units of mudstone-and-sandstone-dominated heterolith. Three IVFs, wider (< 2 km) than they are deep (> 30 m), are composed of multiple storeys grading upward from fluvial-to-estuarine facies to upper-estuarine facies. Storey boundaries are delineated by bounding surfaces underlying conglomerates with heterolithic clasts. One IVF (Honey Creek, NE) is smaller than the others, (> 0.5 km wide and > 25 m deep) and appears to be composed of a single-storey fill dominated by fluvial-to-estuarine facies.

A sequence boundary delineates the base of each IVF, with lowstand, transgressive, and highstand system tracts represented by vertical changes in lithology. Sequence boundaries are delineated by bounding surfaces underlying conglomerates with carbonate and mudrock clasts of the cyclothem host rocks. Outside of the confines of the IVFs, sequence boundaries are correlated to the position of interfluve paleosols interpreted to be contemporaneous with the IVFs.

Two IVFs (Peru and Shubert, NE), are younger than previously believed, and contain a record of at least 30 m of relative sea-level change. The top of the third IVF (Brownville, NE) has been modified by Quaternary erosion and the base is not exposed, thus the exact stratigraphic position and associated relative sea-level change cannot be determined. The Honey Creek IVF is the oldest and smallest lithosome, and also is the only unit with an upper bounding surface that meets the original stratigraphic definition of the ICS. These deposits represent the filling of accommodation on the high Midcontinent shelf during periods of fluctuating relative sea-level.

The IVFs and associated paleosols correlate to regional paleosols identified as fifth order sequence boundaries by other investigators. Thus, relative sea-level changes of at least (or >) 30 m can be correlated to fifth order cycles.

Acknowledgements

The following organizations and individuals are gratefully recognized for their help and support: University of Nebraska, Department of Geosciences; University of Nebraska, School of Natural Resources – Conservation and Survey Division; Lincoln Gem and Mineral Club; Nemaha Natural Resource District; Mr. Jim Swenson and Mr. Tom Morrison, Nebraska Game and Parks – Indian Cave State Park; Mr. John Swigart, Nebraska State Historical Society; Mr. and Mrs. Elmer Duerfeldt, Mr. Roger Kuhn, Mr. Carroll Reeves, Mr. and Mrs. Richard Hayek, and numerous other private property owners in Nemaha and Richardson Counties; Nebraska Public Power District – Cooper Nuclear Generating Station; and Mr. Roger Pabian for historical perspective, location and comparison of reference sections, and invertebrate fossil identification.

In particular I would like to acknowledge my committee members for their guidance and critical review; Dr. David Harwood for pointing me in the right direction when I needed a compass; and Dr. Christopher Fielding and Dr. R. Matt Joeckel for taking on a non-traditional student, being damn good advisors, technical sounding boards, patient listeners, supportive mentors, and all around fun people to work with in both the field and office. You kept your sense of humor through endless discussions both on and off the outcrop, and that meant more than you will know. I would like to especially acknowledge Matt Joeckel for germinating the seed of this project for probably close to 20 years, and allowing me to have a crack at cultivating it.

Dedication

I dedicate this work to my wife Robin and my children Sarah and Ben. Your willingness to leave the teeming metropolis for the unknowns of Nebraska was a good decision for us all, and one we will all always look back on with a raised eyebrow and a smile (You're moving where…Nebraska? Are you nuts? Yeah, maybe just a little). Your unwavering love and support throughout this endeavor allowed me to realize a lifetime dream, but ultimately we all worked hard for this and you share equally in the outcome. I love you…Thanks!

I also dedicate this to my parents Irwin and Sarah Fischbein, who had the good sense to teach me that education is the one thing that cannot be taken away, and encouraged me to continue to go to school, even at the tender age of 43. It's not so much better late than never, than it is to recognize when opportunity knocks you need to answer the door. Thanks always for your love and support.

Finally, in memoriam, to Geoffrey Davidson Woodard, mentor and friend – Look boss, I did it!

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1 - Introduction

The Indian Cave Sandstone in southeastern Nebraska is a thick sandstone-dominated rock unit conspicuously different from the enclosing mudrock-and-limestone-dominated cyclothems, yet it is not easily accounted for using existing models of Midcontinent cyclothem deposition (Moore, 1936; Heckel, 1977, 1980). Cyclic Pennsylvanian sedimentation in the northern Midcontinent was first proposed by Weller (1930). Afterward, Wanless and Weller (1932) recognized a natural succession of lithofacies (the cyclothem), which they interpreted as the result of cyclic sedimentation. Wanless and Shepard (1936) proposed that Gondwanan glacioeustatic controls were the drivers for cyclothem deposition in the Midcontinent, with the organization of cyclothem lithofacies postulated to reflect the waxing and waning of Gondwanan ice sheets. The cyclothem model has been subject to modification, and Moore's (1936) "Kansas Cyclothem" included a disconformable basal sandstone unit (.0), and overlain by a shale (.1) or coal (also .1), then marine shale (.2), overlain by marine limestone (.3), followed by marine shale (.4), marine limestone (.5), marine shale (.6), marine limestone (.7) and ultimately overlain by marine to nonmarine shale (.8 - .9). Heckel (1977, 1980, 1994) proposed a cyclothem model that was glacioeustatically controlled and consisted of four main elements. Heckel's (1977, 1980) model is a genetic stratigraphic sequence composed of (1) a regressive basal "outside shale" consisting of sandstone and mudrock, associated with coals and paleosols, (2) a transgressive "middle limestone"; (3) a "core black shale" representing the deepest water conditions; and (4) a regressive “upper limestone”. Thus the lithologic succession delineated in a single cyclothem reflects an inferred time of maximum ice volume (a sea-level lowstand) interpreted from the basal sandstones, to an inferred time of minimum ice volume (a sea level highstand) reflected in the occurrence of the black shale. The intervening middle and upper limestone reflect stages of transgression and regression driven by volumetric changes in Gondwanan glacial ice (Heckel, 1977, 1980).

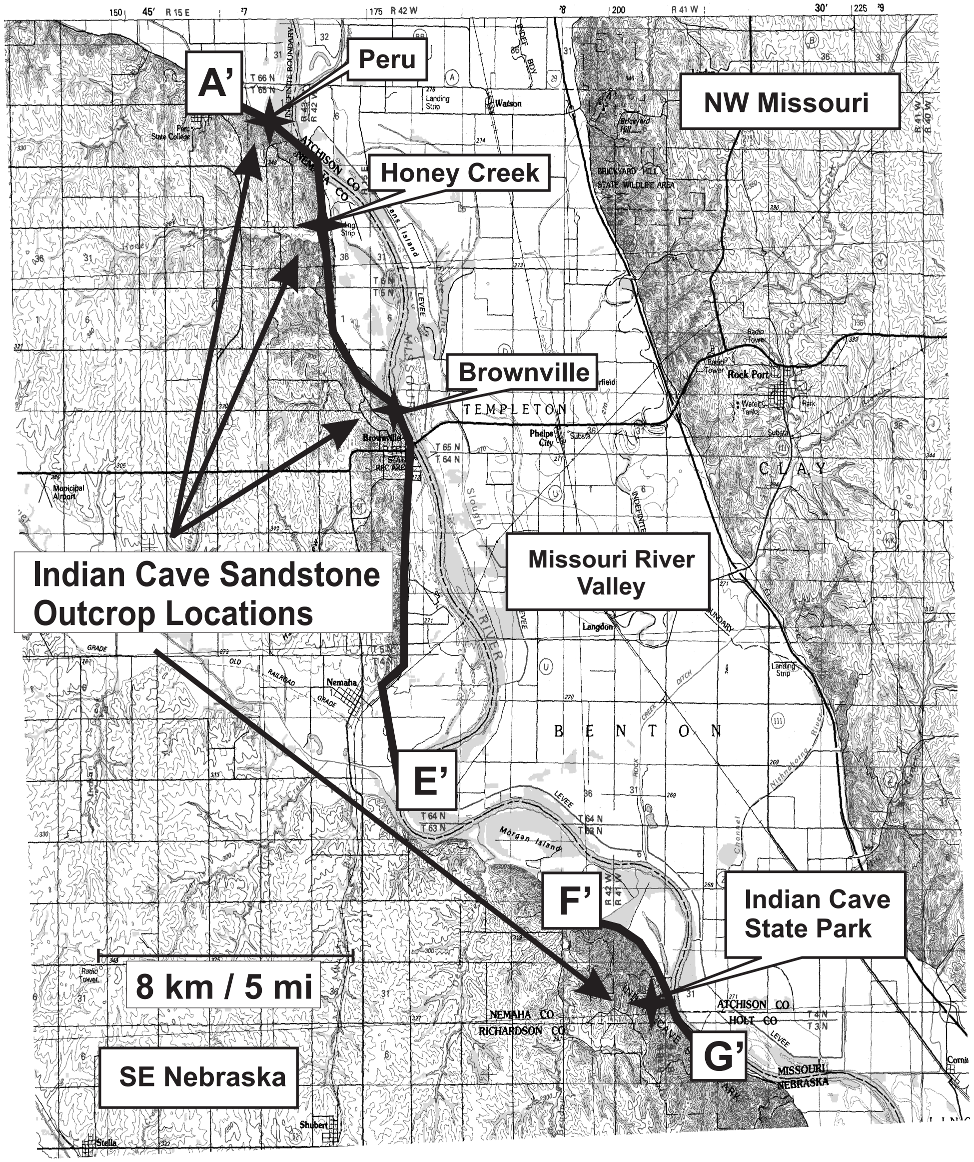
Sea-level change associated with the waxing and waning of Gondwanan ice volume has been the subject of considerable debate, especially in consideration of the extremely limited and localized nature of glaciogenic strata in the southern hemisphere rock record (Isbell et al., 2003; Jones and Fielding, 2004). Estimates of sea-level change in the northern Midcontinent cyclothems range from upwards of 100 – 200 m (Ross and Ross, 1987; Heckel, 1980), to +/- 100 m (Heckel, 1980; Soreghan and Giles, 1999), to 60 – 70 m (Moore, 1964; Adlis et al., 1988) to 50 – 80 m (Isbell et al., 2003) and 45 – 75 m (Crowley and Baum, 1991). However, only thorough investigations of physical evidence for sea-level change in local stratigraphic records will significantly improve the resolution of these estimates.

Commonly, the “outside shale” of Pennsylvanian cyclothems (Heckel, 1977, 1980) contains thick-channelized sandstone bodies reflecting the constraints of low accommodation. These bodies have not been investigated comprehensively from the perspective of modern stratigraphic architecture and sequence stratigraphy. Such sandstone bodies occur at multiple stratigraphic levels across the northern Midcontinent region (Moore, 1936; Mudge, 1956; Mudge and Yochelson, 1962; Ossian, 1974). These units have been interpreted as deltaic in origin (Ferm, 1974; Horne and Ferm, 1974; Ossian, 1974), even in the absence of diagnostic evidence. More recently, however, some have been interpreted as incised valley fills (IVFs), and these strata display evidence of a variety of fluvial and estuarine depositional environments. The IVF strata are the record of sedimentation in the limited accommodation space available during periods of subaerial exposure of the near-equatorial epicontinental platform (Archer et al.,1994; Kvale and Barnhill, 1994; Archer and Feldman, 1995; Feldman et al., 1995; Kvale and Mastalerz, 1998; Bowen and Weimer, 2004; Feldman et al., 2005).

Subaerially-exposed epicontinental platform settings are relatively poorly understood because erosion, rather than deposition, dominates and there is little or no accommodation space. However, river systems must degrade their beds when sea-level falls, incising the exposed platform to a depth equivalent to the drop in sea-level. At standstill or during a subsequent transgression, the incised valley becomes accommodation space for sediments, most of which formerly bypassed it.

Sedimentation within incised valleys will reflect depositional processes operating in the incised valley. Depositional systems along depositional strike in the valleys will vary through time as they are affected by the sea-level change. A transect through a filled incised valley may record multiple depositional environments (Dalrymple et al., 1992; Shanley et al., 1992; Dalrymple et al., 1994; Zaitlin et al., 1994), and any given stratigraphic position in the vertical succession will reflect a point in time where the interpreted depositional environment was dominant. Incised valley fill(s) may be the only substantive sedimentary record of stillstand and the early phases of transgression that are laterally equivalent to contemporaneous paleosols. Therefore, the investigation of incised valley fills is an essential part of understanding of regional depositional systems, and has even more widespread promise in the interpretation of global sea-level change during the geologic past.

The Indian Cave Sandstone (ICS), located on the Late Pennsylvanian northern Midcontinent platform, represents one such analogue worthy of documentation. This dissertation investigates the sedimentology and stratigraphic context of the ICS in southeastern Nebraska (Fig. 1). The research is directed at unraveling the geologic history and depositional environments under which these strata were deposited; identifying and describing the stratigraphic architecture of the ICS; describing a sequence stratigraphic model that accounts for the ICS as a system; and delineating constraints on Late Pennsylvanian sea-level change on the Midcontinent epicontinental platform associated with Gondwanan glaciation. Hypotheses to be tested are: (1) the ICS reflects deposition in an incised valley; (2) the ICS is a multistoried sandstone body; (3) the ICS is not a continuous sandstone unit, and is present at more than one stratigraphic level; (4) the ICS is underlain by a sequence boundary, parasequence boundaries may be present within ICS strata, and evidence for a system tract hierarchy can be identified; (5) estimates of Late Pennsylvanian



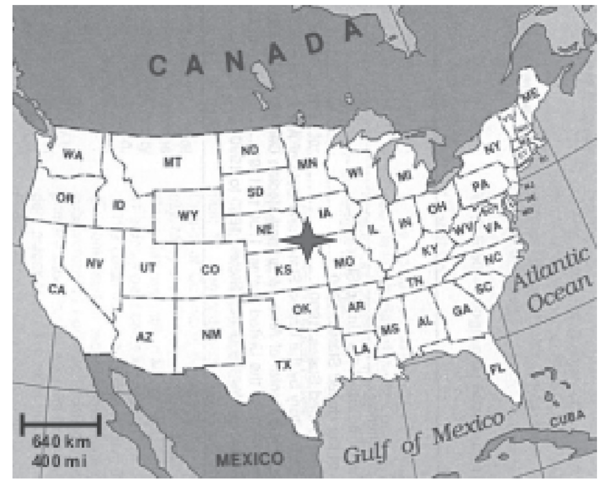


Figure 1:

Location maps with inset map showing position of study area relative to North America and USA. Topographic map is a expanded view of study area showing locations of primary exposures investigated, and cross-section locations A' - E' and F'-G'.

sea-level change may be delineated through fully penetrating stratigraphic sections of the ICS.

2 - Regional Geologic Setting

During the Pennsylvanian, the North American Platform was positioned at near-equatorial paleolatitude (Fig. 2; McKee and Crosby, 1975; Blakey, 2003; Scotese, 2005). The periodic retreat of epicontinental seas exposed the low-relief platform to weathering and erosion that at times led to the development of extensive fluvial systems. The characteristics of these systems were controlled by climate (Feldman et al., 2005) and by both local and regional structural elements (Fig. 3). Streams in areas far from the Midcontinent such as the Michigan Basin and the Maritime Provinces of Canada may have drained southwestward towards the Forest City and Ouachita Basins (Chestnut, 1994; Archer and Greb, 1995). Southeastward drainage from the Central Kansas Uplift, and the Ancestral Rocky Mountains is also postulated (Archer and Greb, 1995; Bowen and Weimer, 2003; 2004). As a result, the erosion of exposed cratonic rocks generated sediment that was delivered to the fluvial systems from the continental interior, and ultimately to regional depocenters such as the Forest City Basin, Salina Basin, Anadarko Basin, Illinois Basin, Hugoton Embayment and Ouachita Basin. Some of these sediments were then re-deposited within the entrenched fluvial systems as sea-level fluctuations continued through Late Pennsylvanian time (Dalrymple et al., 1994; Zaitlin et al., 1994; Archer et al., 1994; Feldman et al., 1995; Archer and Feldman, 1995).

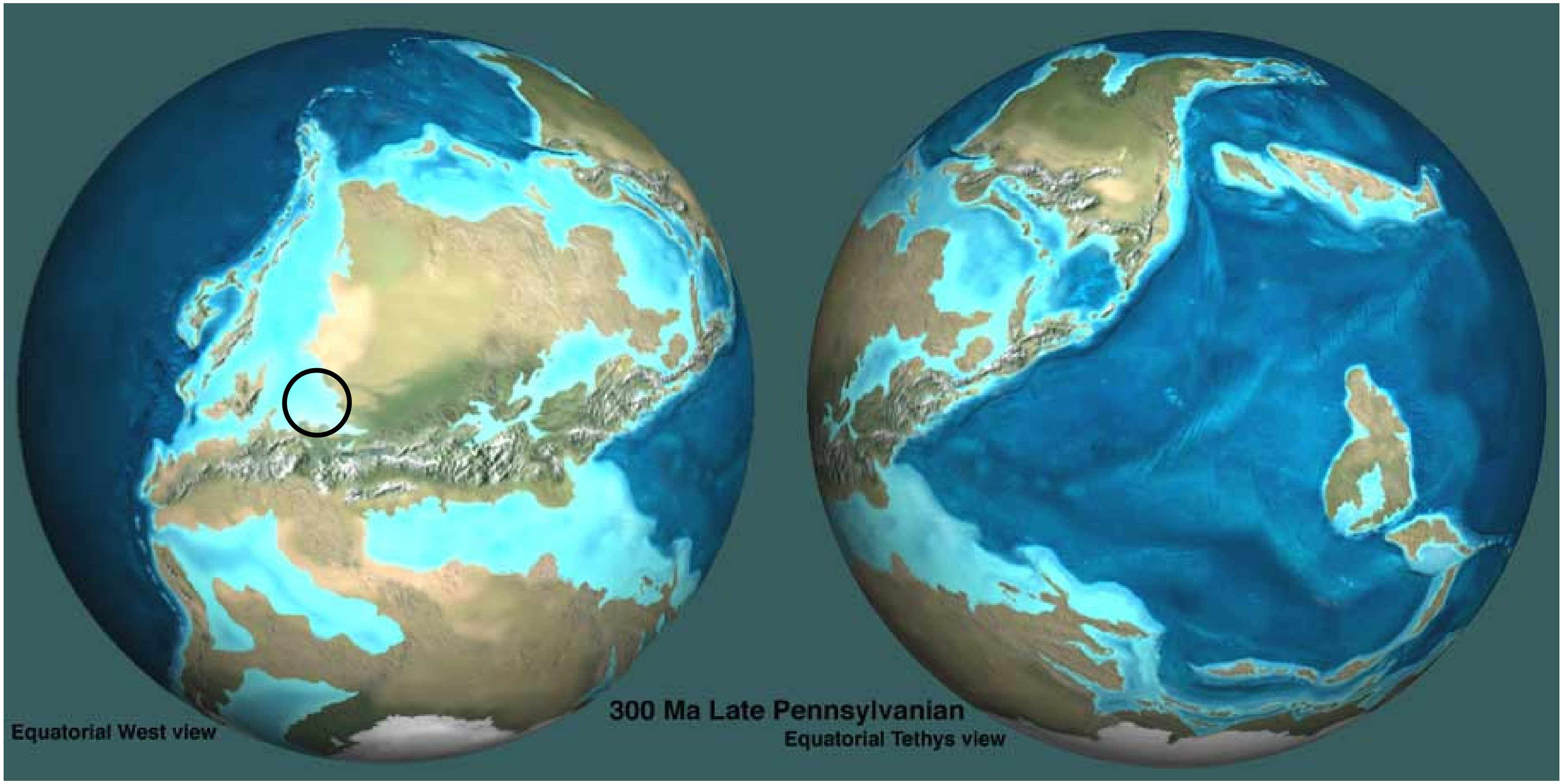


Figure 2: Late Pennsylvanian paleogeographic reconstruction showing land mass distribution and idealized open ocean and inland sea and embayment locations (from Blakey, Northern Arizona University website, http://jan.ucc.nau.edu/~rcb7/300_Penn_2globes.jpg, **2005). Area circled in left view generally represents the study area in Late Pennsylvanian time.**

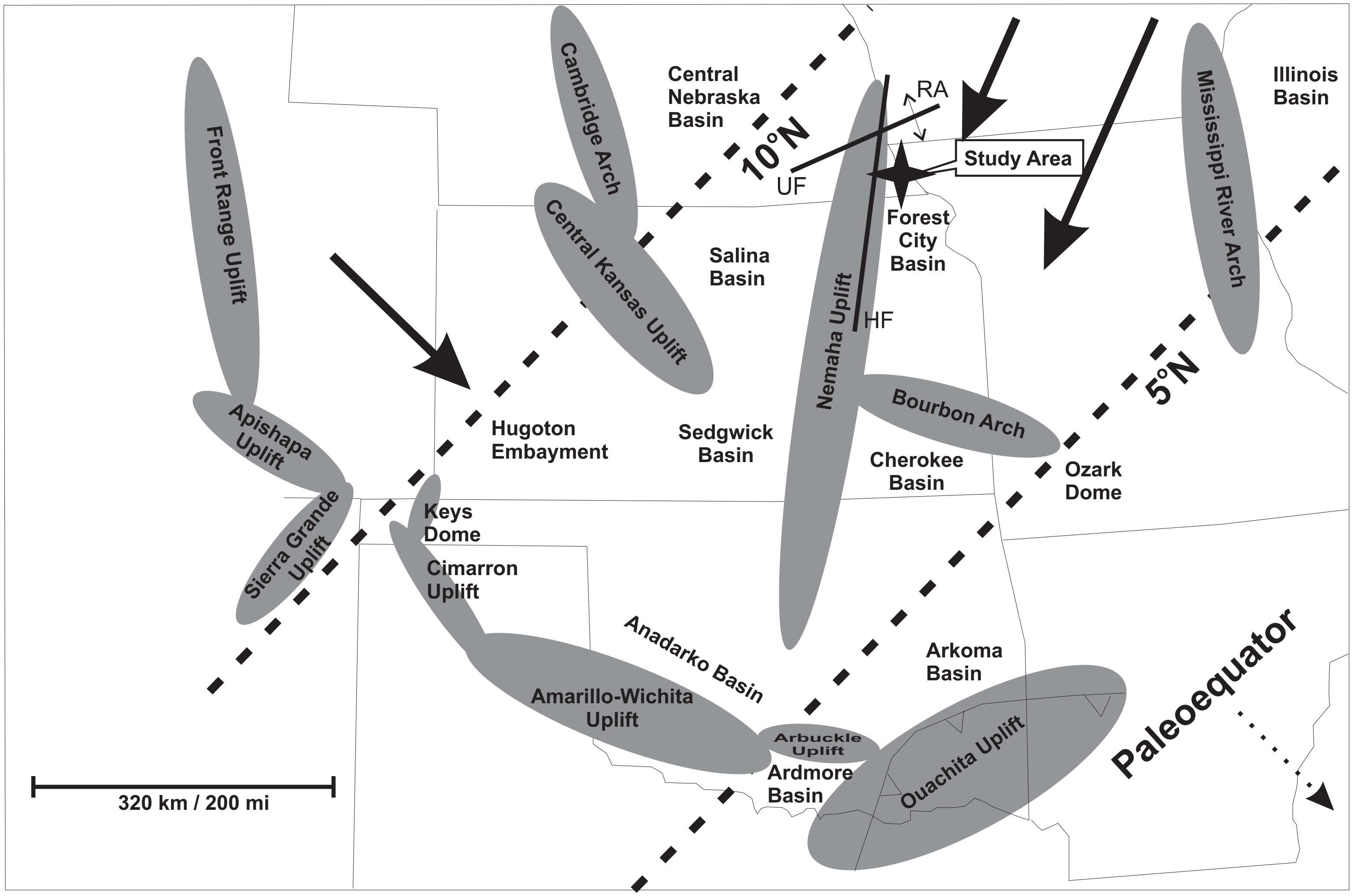
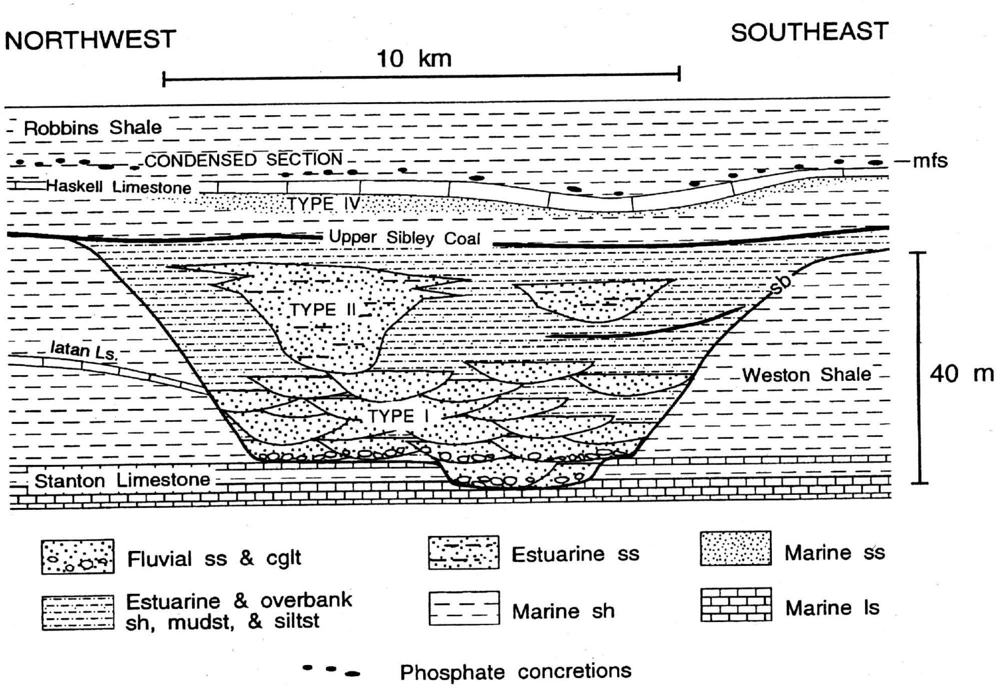


Figure 3: Map showing dominant Pennsylvanian paleogeographic elements of the region (modified from McKee, 1975; Salcedo, 2004). Star - general location of study area. Arrows indicate inferred regional drainage directions from Archer and Greb (1995) UF = Union Fault, RA = Redfield Anticline, HF = Humbolt Fault.

Sandstone bodies in the Pennsylvanian of the Midcontinent have been interpreted as distributary channel sands, crevasse splays, prograding delta lobes, offshore bars, and barrier islands (Ferm, 1974; Horne and Ferm, 1974; Ossian, 1974; Heckel, 1980). More recently, however, some deposits have been reinterpreted as fluvial-estuarine facies. Such upper estuary and middle estuary facies in modern systems may be deposited hundreds of kilometers upstream from a coastline (Nichols and Biggs, 1985; Shanley et al., 1992; Dalrymple et al., 1994; Zaitlin et al., 1994; Archer et al., 1994; Kvale and Barnhill, 1994; Feldman et al., 1995; Archer and Feldman, 1995; Brenner et al., 2003).

In one example, Archer et al., (1994), Archer and Feldman (1995) and Feldman et al. (1995) have interpreted the vertical sequence of facies within the Lower Virgilian Tonganoxie Sandstone Member of the Stranger Formation of the Douglas Group in northeastern Kansas to represent deposition in an estuary subject to a progressively rising sea-level. These facies are in vertical and horizontal association within a depression (interpreted to be a paleovalley) incised into underlying marine shale and/or limestone (Fig. 4). The associated basal erosion surfaces are unconformities that represent sequence boundaries, and form the base of the lowstand systems tract (LST), formed during periods of maximum sea-level regression and subaerial exposure. These surfaces also mark the base of the incised valley fill (IVF) (Archer et al., 1994; Archer and Feldman, 1995; Feldman et al., 1995). Other less extensive surfaces are preserved within the IVF, and are interpreted to be ravinement or transgressive



Schematic cross section of the Tonganoxie paleovalley in the study area. mfs = maximum flooding surface, sb = sequence boundary, ss = sandstone, cglt = conglomerate, sh = shale, mudst = mudstone, siltst = siltstone, ls = limestone.

Figure 4: Architectural model proposed by Feldman et al. (1995) showing vertical and horizontal relationships of facies and architectural elements. Type-I sandstones represent lowstand amalgamated fluvial sandstone channel fills. Type-I sandstones are overlain by estuarine argillaceous rippled sandstone and sandy mudstone that contain Type-II sandstones. Type-II sandstones represent tidal point bars in the fluvial to estuarine transition zone; Type-III sandstones (not present in this idealized trunk channel view) represent bay head deltas formed at the updip limits of major and minor tributaries; Type-IV sandstones represent broad discontinuous sheet-like sandstones of shallow marine origin, overlain by marine limestone (from Feldman et al., 1995).

surfaces, or indicators of marine flooding (Fig. 4). The stratigraphically-lowest ravinement or transgressive surface, immediately above the LST delineates the base of the transgressive system tract (TST). Other surfaces may also be present within the IVF that are not LST or TST boundaries, but may represent parasequence boundaries or other autogenic erosional processes (Archer and Feldman, 1995).

Using outcrop and subsurface data from both boreholes and mines, Archer and Feldman (1995) and Feldman et al (1995) mapped three dimensional distributions of the Tonganoxie IVF deposits. On the basis of surface and subsurface data, they defined specific characteristics of Tonganoxie IVF deposits, including: (1) a fluvial facies, consisting of basal conglomeratic sandstones and cross-bedded sandstones lacking clay drapes, and suggestive of a braided fluvial origin (Fig. 4); overlain by (2) an estuarine facies, consisting of inclined heterolithic bedding, heterolithic rhythmites and silty rhythmites (Fig. 4). These estuarine facies are overlain by, and/or interbedded with, (3) outer estuarine facies composed of relatively clean, sheet-like sandstone units containing flat-topped ripples, ladder-back ripples, ripple fans, and parallel laminations with bioturbation, suggestive of sand-flat and bar deposition (Fig. 4). Finally, estuarine and outer estuarine facies are overlain by (4) an extensively bioturbated lower shoreface sandstone that grades or transitions upwards to fossiliferous marine limestones (Fig. 4).

In the Tonganoxie Sandstone, a vertical succession of facies representing fluvial channel, upper estuary, middle estuary, outer estuary, nearshore, and offshore facies provides a geologic record of the transgression of an incised valley at a shelf-edge proximal position on an epicontinental platform (Dalrymple et al., 1994; Zaitlin et al., 1994; Archer and Greb, 1995; Feldman et al., 1995; Archer and Feldman, 1995). Other examples of fluvial, tidally-influenced or estuarine facies assemblages found within deposits interpreted to be IVFs include the Lower Pennsylvanian Raccoon Creek Group of the Illinois Basin in Indiana (Kvale and Barnhill, 1994); the Upper Cretaceous Pine Ridge Sandstone in southeastern Wyoming (Martinsen, 1994); the Lower Pennsylvanian Lee Formation, Caseyville Formation and Morrow Formation of the Central Appalachian and Illinois Basin and Hugoton Embayment respectively (Archer and Greb, 1995); the Lower Pennsylvanian Morrow Formation of the Hugoton Embayment of western Kansas and eastern Colorado (Bowen and Weimer, 2003); and the Lower Cretaceous Nishnabonta Member of the Dakota Formation (Brenner et al., 2003).

Joeckel (1989, 1994, 1995, 1999) identified multiple, laterally-extensive subaerial exposure surfaces in the Midcontinent Pennsylvanian. Regionally, paleosols were developed on these surfaces during regressive events. Joeckel (1994, 1995) also implied that at least some of these paleosols are developed on interfluves between contemporaneous incised valleys. Olzewski and Patzkowski (2003) and Wardlaw et al. (2004) later recognized widespread paleosols within the Upper Pennsylvanian section, and in some cases correlated these paleosols to incised valleys. Therefore, in addition to the recognition of fluvial, tidally influenced and estuarine facies within IVFs, paleosols may be found to be laterally equivalent with incision surfaces, and may in part be contemporaneous to incised valley fills.

The pattern of fluvial, tidally-influenced, and/or estuarine facies, coupled with persistent, stratigraphically-equivalent paleosols, and the identification of an underlying disconformity identified as a sequence boundary, establishes a set of physical criteria for the recognition of incised valley systems. This pattern is especially useful in those cases where the lateral margins of an IVF (i.e., the valley walls) are not visible, but where the fill can be mapped as a discrete body, and correlated with laterally-equivalent paleosols.

3 - Indian Cave Sandstone

3.1 - Lithology

The Indian Cave Sandstone (ICS) crops out along the Missouri River Valley in southeastern Nebraska, and northwestern Missouri (Fig. 1). The study area is bounded in part by major structural features (Fig. 3), although none of these were highly active at the time the ICS was deposited.

The best exposures of the ICS can be found at (1) Indian Cave State Park east of the town of Shubert, Nebraska (Figs. 1 and 5), (2) along the Steamboat Trace Trail, south-southeast of Peru, Nebraska (Figs. 1 and 5), (3) along Honey Creek (Figs. 1 and 5), and (4) along the Steamboat Trace Trail, at the Nebraska Highway 136 Missouri River bridge in Brownville, Nebraska (Figs. 1 and 5). One small road cut and bluff exposure also exists in the eastern bluffs of the Missouri

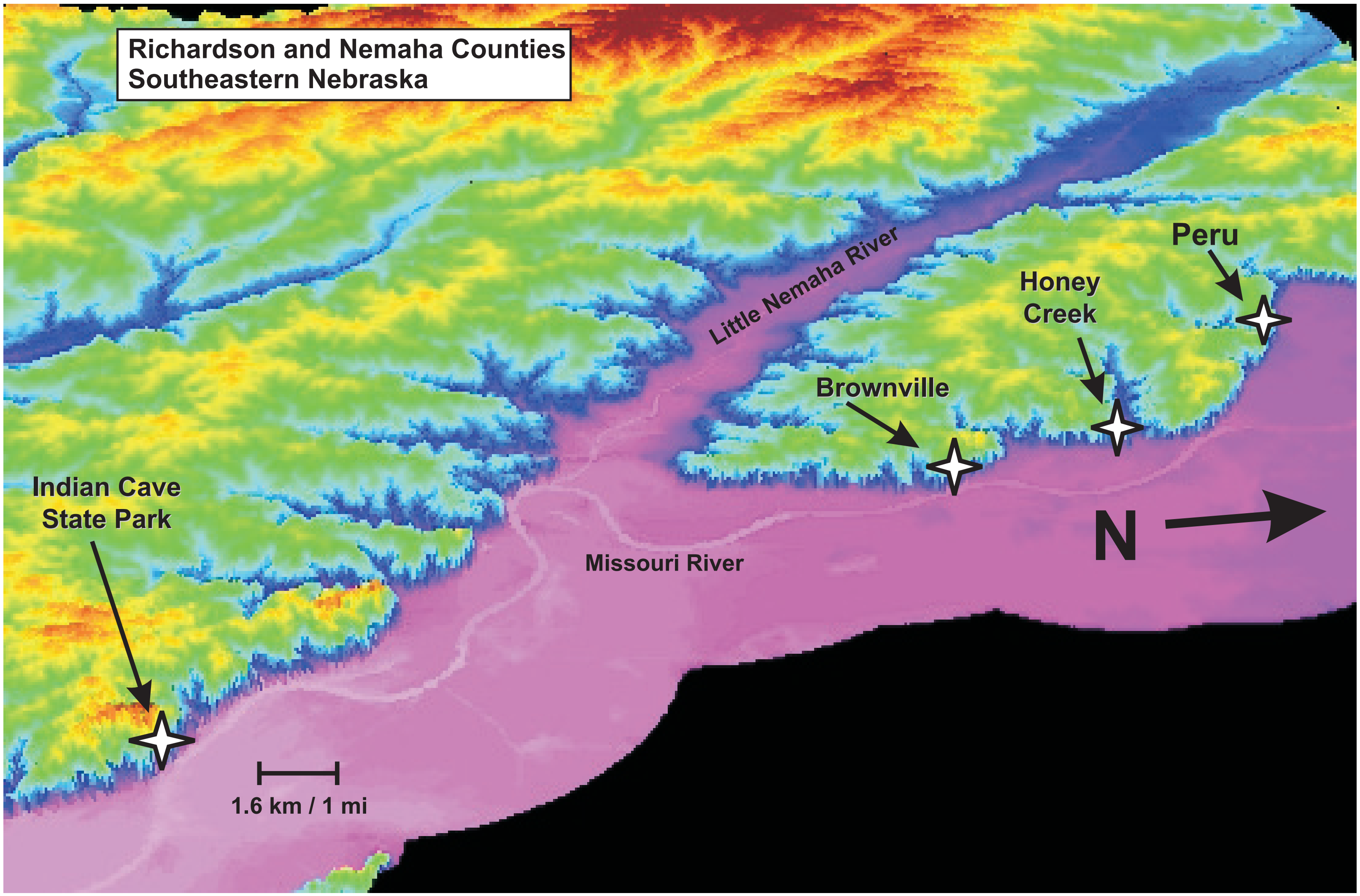
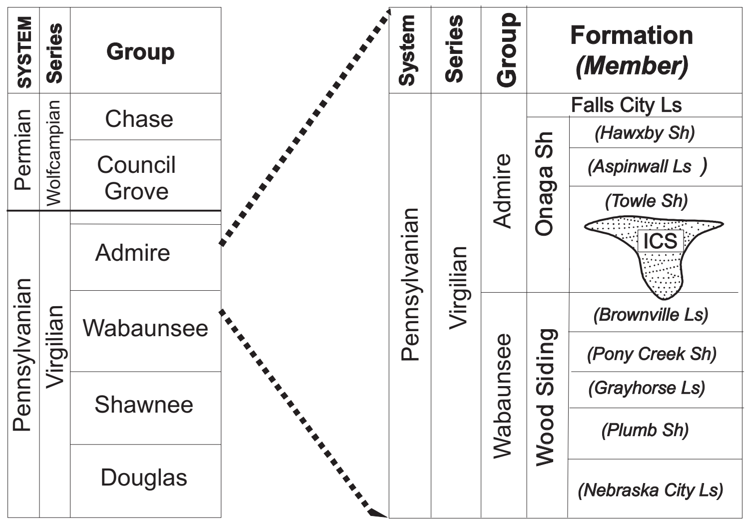


Figure 5: **Primary outcrop locations for this investigation shown on draped and shaded digital elevation model (DEM) for the study area. DEM exaggeration 10x.**

River Valley, north of Rockport, Missouri. Possible ICS equivalents have been reported from Wabaunsee, Jackson and Chautauqua counties in northeastern Kansas (Mudge, 1956), and in Greenwood County in southeastern Kansas (Mazzullo et al., 2005).

The ICS is considered to be a subunit of the Towle Shale Member of the Onaga Shale Formation and has been designated, at various times, as either Upper Pennsylvanian or Lower Permian (Moore, 1936; Mudge, 1956; Mudge and Yochelson, 1962; Ossian, 1974; Archer and Feldman, 1995) (Fig 6). In fact, multiple, isolated channel sandstones have been reported within the Towle Shale (Mudge, 1956). The exact location of the ICS type section is unknown, but is reported to be in the vicinity of what is now Indian Cave State Park (ICSP), in Richardson County, Nebraska (Moore, 1936; Mudge and Yochelson, 1962). At ICSP, the ICS is composed of a massive, cliff-forming, carbonate-cemented, micaceous, quartz arenite to subarkose (Mudge, 1956; Ossian, 1974), consisting of multiple storeys of planar to trough cross-bedded or finely laminated sandstone and silty sandstone, with mudrock laminae or drapes. Conglomerate occurs near the base of some ICS bodies, and contains clasts of limestone and mudrock (Ossian, 1974). Eurypterids, vertebrates (representing a variety of sharks and tetrapods) and ammonites have been found within the unit (Barbour, 1914; Ossian, 1974). At Peru and ICSP, thin discontinuous units of carbonaceous shale and coal occur either within the main sandstone body, or above the main sandstone body. Mudrocks associated with the coals or carbonaceous deposits contain abundant plant remains.



Stratigraphic column from existing literature (Mudge, 1956; Moore and Mudge, 1956; Mudge and Yochelson, 1962; Ossian, 1974; Burchett, 1977) showing the ICS to be a subunit of the Towle Shale, overlain by the Aspinwall Limestone and underlain by the Brownville Limestone. Columns 1 through 4 below are schematic stratigraphic sections made from measured sections in this study.

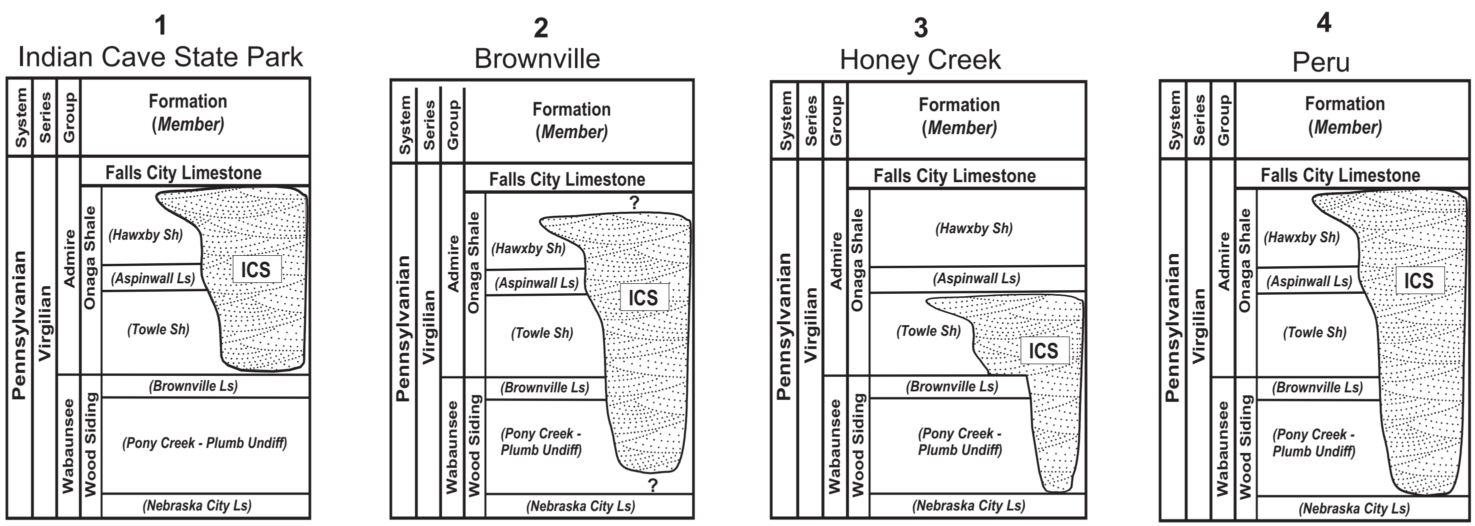


Figure 6: Generalized stratigraphic column from previous workers (modifed from Burchett 1977; Pennsylvanian-Permian boundary revised according to Davydov et al. (1998) ICS = Indian Cave Sandstone. Stratigraphic columns1 - 4 are location specific stratigraphic columns delineated during this investigation (Column 1 - Type Area).

The generalized section of interest for this study, in ascending stratigraphic order, comprises the uppermost formation of the Richardson Subgroup of the Wabaunsee Group (Wood Siding Formation), and the lowermost formations of the Admire Group (Onaga Shale and Falls City Limestone) and their respective members (Fig. 6). Specifically, this investigation focuses on the interval bounded below by the Nebraska City Limestone, and above by the Falls City Limestone (Fig. 6).

3.2 – Age

The age designation of the Towle Shale, and thus the ICS member as well, has been controversial. Moore (1936) placed the Pennsylvanian-Permian boundary at the disconformity between the Towle Shale and the ICS (Fig. 6). Mudge (1956) identified the ICS as a member of the Towle Shale Formation of the Lower Permian Admire Group. Later that same year, Moore and Mudge (1956) reclassified the Towle Shale as a member of the Onaga Shale Formation of the Admire Group. They considered the ICS as a bed within the Towle Shale member, retained an Early Permian age designation, and placed the Pennsylvanian-Permian boundary at the contact between the Brownville Limestone and the Towle Shale (Fig. 6). In a regional evaluation of Pennsylvanian and Permian rocks in Kansas, Mudge and Yochelson (1962), found no faunal evidence for placing the Pennsylvanian-Permian boundary at the base of the Towle Shale, but concluded that the boundary placement should be retained for practical purposes.

Ossian's (1974) biostratigraphic palynological work on the ICS strata indicated that the ICS is Late Pennsylvanian in age, correlatable to the Stephanian B and C (Virgilian) interval. Other biostratigraphic investigations of this portion of the stratigraphic section also place the Pennsylvanian-Permian boundary higher in the section than that proposed by Moore (1936) and Moore and Mudge (1956). On the basis of the coincident first occurrence of a fusulinid species *Pseudoschwagerina kansanensis* and the conodont genera *Streptognathodus* and *Sweetognathus*, Baars et al. (1994) proposed that the Pennsylvanian-Permian boundary be moved yet farther upward to the base of the Neva Limestone (stratigraphically higher than the Pennsylvanian-Permian boundary shown on Figure 6). Davydov et al. (1998) subsequently moved the Pennsylvanian-Permian boundary lower than proposed by Baars et al. (1994), but still higher than the unconformable boundary represented at the base of the ICS, on the basis of fusulinid and conodont biostratigraphy. The new boundary location proposed by Davydov et al. (1998) is in the Red Eagle Limestone Formation of the Council Grove Group (general position of Pennsylvanian-Permian boundary shown on Fig. 6). Wardlaw et al. (2004) cite the boundary as specified by Davydov et al. (1998) being between the Glenrock Limestone Member and overlying Bennett Shale Member of the Red Eagle Limestone. Therefore, the most recent placement of the Pennsylvanian-Permian boundary in the Midcontinent Region is significantly higher than the disconformity at the base of the ICS as the boundary. The boundary diagnosis of Davydov et al. (1998) is adopted herein, and the ICS is placed in the Upper Pennsylvanian.

3.3 - Previous Work

The earliest known reference to the ICS was made by Meek in 1867 (in Hayden, 1872), around Peru, NE on the Missouri River. Work at this time was limited. Meek described sections in the ICS south of Peru, and first documented coal in the area. Barbour (1907) provided the first report on the only commercial coal operation in the history of Nebraska, the Honey Creek mine, located between Peru and Brownville, NE. Pepperberg (1908 and 1910) described paleobotanical specimens collected from the Peru outcrops of the ICS, and detailed descriptions of the Honey Creek coal deposit. Later, Barbour (1914) and Whitford (1916) described eurypterids and plant fossils in the ICS outcrops in Peru.

Condra (1927) documented the sandstone outcrops around Peru, but erroneously placed the ICS much higher in the section, just below the Americus Limestone. Moore and Moss (1934), and Moore (1936) subsequently revised the age of the Peru and Indian Cave exposures from Late Pennsylvanian to Early Permian. These investigators emphasized large channel sandstone bodies incised to depths of 30 m or more below the Brownville Limestone, and interpreted a significant disconformity between the Aspinwall Limestone and the Brownville Limestone.

Mudge (1956) reported on the ICS in Kansas and Nebraska while documenting channel sandstone bodies in the Lower Permian and Upper Pennsylvanian. Mudge (1956) summarized five other workers' explanations for the formation of channelized sandstone deposits in Midcontinent cyclothems: (1) marine deposition (Stout, 1931); (2) large scale deformation of the earth's crust (diastrophism) (Weller, 1930); (3) subsidence combined with glacioeustatic sea-level fluctuations (Wanless and Sheppard, 1936); (4) differential subsidence together with a change in sea-level (Moore, 1936); (5) deltaic deposition associated with uplift and erosion (Twenhofel, 1932). Mudge (1956) concluded that cycles of submergence and emergence occurred repeatedly during the time period under investigation, and concurred with Moore's interpretation.

Harding (1950) concluded that the ICS was a channel deposit, but could not establish its provenance using heavy minerals. Moore and Mudge (1956) reclassified the regional Pennsylvanian-Permian section, and relegated the Towle Shale to a member of the Onaga Shale Formation, and the ICS as a subunit of the Towle Shale. Mudge and Yochelson (1962) published on the section specifically regarding the issue of stratigraphic placement of the systemic boundary (see previous discussion of age assignment).

Ossian (1974) carried out the most detailed work on the ICS to date, providing an interpretation of depositional environments based on a preliminary evaluation of the sedimentology, macro-paleontology and palynology of the ICS. He concluded that the sandstone and associated siltstone, shale, coal and limestone of the ICS were deposited in a prograding deltaic environment, with facies present representing: (1) prodelta muds; (2) marshes; (3) natural levees; (4) distributary channels; (5) crevasse splays; (6) deltaic destructional facies; and (7) offshore carbonates. He also concluded that clastic sediments found in the ICS were derived from an exposed highland on the Nemaha Ridge to the west. This hypothesis is now known to be erroneous because: (1) the core of the Nemaha Ridge was buried by mid-Missourian time, significantly earlier than the time of formation of the ICS; (2) the bedrock outcrops in the Keyser Quarry adjacent to the conglomeratic sandstones used to infer provenance for the ICS are actually the Plattsmouth Limestone Member of the Oread Limestone Formation (Shawnee Group), a stratigraphically lower interval; and (3) the referenced pebbly sandstone and conglomeratic deposits were interpreted to be Pleistocene in age by Burchett (unpublished field data), and were found in the field during this investigation to contain clasts of Sioux Quartzite, not known to have been exposed during Virgilian time, (pers. comm., R.M. Joeckel, 2004; Burchett , 1970; Nebraska Geologic Survey, unpublished geological field maps compiled by Burchett). No work has been completed on the ICS in southeastern Nebraska in the thirty years since Ossian's dissertation, a time of significant advance in stratigraphic methodology, and of major insights into the identification and recognition of fluvial-estuarine deposits and facies.

4 - Methods

This investigation was predominantly outcrop-based, but also includes limited subsurface data. Key stratigraphic sections were measured and correlations were made across outcrops between Peru and Barada, Nebraska and at Rockport, Missouri. At the same time, sedimentologic data were collected and analyzed so that facies could be described, and facies distributions within the predominantly two dimensional outcrops were documented.

Outcrops included natural bluff faces, as well as roadcuts, inactive railroad cuts, abandoned quarries, and plowed fields. Continuous to discontinuous, large outcrops along the Nemaha Natural Resource District (NNRD) Steamboat Trace Trail and at Indian Cave State Park are the main data sources for this study (Figs. 1, 5). Some known outcrops, however were inaccessible due to the steepness of cliff faces, and/or the instability of weathered outcrops. Where accessible, stratigraphic sections were measured directly using either a tape and hand level, or a Jacobs Staff. Where applicable, stratigraphic sections were measured remotely using a LaserTech™ Impulse 200 laser rangefinder.

Stratigraphic section logs were prepared with CorelDraw™ 12.0 software using a standardized logging template created by committee through the Sed/Strat Group at UNL, under the direction of Professor Fielding (Appendix A – Stratigraphic Logs). Log symbology was also standardized through committee of the UNL Sed/Strat Group.

Three boreholes were drilled by the University of Nebraska Conservation and Survey Division (CSD) as part of this investigation: two along the Steamboat Trace trail southeast of the town of Peru (Appendix A: Map 1, Logs 15-A-04 and 15-A-04B), and one along the county road south of Honey Creek (Appendix A: Map 3, Log 16-A-04). Cores from these boreholes are archived in the Conservation and Survey Division core library in Lincoln, NE.

A series of historical borehole records were also found within the UNL-CSD well file archives and were utilized for stratigraphic correlation in the southern study area around Indian Cave State Park. These boreholes were drilled as part of a mineral assessment in the late 1960's and early 1970's. Few other subsurface data were found.

Elevation and position surveying using a SOKKIA™ total station theodolite were also undertaken for approximately 10 miles of the 25 mile long study area to obtain trail surface elevations, road surface elevations, and reference elevations of key rock units. The surveying was conducted in the study area along Steamboat Trace Trail and Indian Cave State Park (Brownville Limestone, Aspinwall Limestone and Falls City Limestone) (Appendix B – Elevation Survey Data).

Digital images of outcrops were collected and compiled into photomosaic panels at resolutions of 1.25, 2, and 4 megapixels. These panels were then utilized for geologic interpretation by creating stratigraphic line drawing overlays and outcrop maps using CorelDraw™ 12.0.

5 - Stratigraphy

Confusion in the geologic literature, and degradation or total loss of type and reference sections, necessitated re-evaluation of the stratigraphic context of the ICS. Specifically, it was critical to understand the continuity of stratigraphic units within the study area, and the exact stratigraphic position of each of the sandstone bodies purported to be the ICS. Therefore, new measured section data were collected within the stratigraphic interval of interest.

For this investigation, the uppermost formation of the Wabaunsee Group (the Wood Siding Formation), and the lowermost formations of the Admire Group (the Onaga Shale and Falls City Limestone), comprise the interval of interest (Table 1). The Wabaunsee Group was long considered to be the uppermost part of the Pennsylvanian System in Nebraska and Kansas, however, a subsequent revision of the Pennsylvanian-Permian boundary (see Section 3.2 – Age) moves the boundary significantly higher in the stratigraphic section, to roughly the middle of the Admire Group, and places the ICS well within the Pennsylvanian System (Fig. 6).

The Wood Siding Formation contains five members (Fig. 6, Table 1) and is overlain by the Onaga Shale Formation, which contains three members (Fig. 6, Table 1). The Onaga Shale is overlain by the Falls City Limestone (Fig. 6) that also contains three members (Table 1). The ICS has been considered as a subunit of the Towle Shale, overlain by the Aspinwall Limestone, and underlain by the Brownville Limestone (Fig. 6), however the results of this investigation indicate ICS bodies are found in at least two *different* stratigraphic intervals (see Section 5.1: Stratigraphic Position of the ICS; Appendix C: History of Stratigraphic Nomenclature).

Formation	Member	Thickness	Major Lithology
Falls City Limestone	Lehmer Limestone	0.54 – 1.2 m	Limestone: Basal unit (0.3 m thick) light brown, to tan and white evenly laminated and bedded limestone composed dominantly of gastropod and pelecypod fragments (packstone to grainstone). Upper unit medium brown to tan and slightly gray fossiliferous limestone composed of shell fragments of pelecypods, gastropods, brachiopods and crinoids (packstone to grainstone). Middle portion of upper unit may be partially laminated with blocky mudstone clasts, with vuggy, fenestral texture with limonite stain.
Falls City Limestone	Reserve Shale	1.5 – 2.5 m	Mudrock: Yellowish-tan, tan, red, and olive-gray grading to dark gray and black mudrock, poorly exposed.
Falls City Limestone	Miles Limestone	0.3 m	Limestone: Gray, tam to pale brown, yellowish, blue-gray and gray-brown to red fossiliferous limestone with abundant trace fossils and shell fragments (mudstone to wackestone).
Onaga Shale	Hawxby Shale	1.2 – 5.8 m	Mudrock: Tan, blue, blue-gray to gray, brown, green, red-brown, gray-green and purple silty mudrock. Local red paleosol 50-60 cm above base, and local thick sandstone bodies (30 m). ICS bodies at Peru and Indian Cave State Park originate in this unit. ICS body at Brownville may also originate in this unit.
Onaga Shale	Aspinwall Limestone	0.3 – 0.9 m	Limestone: Bluish gray fossiliferous limestone containing pelecypod, crinoid and brachiopod fragments (mudstone to wackestone). Locally may be two beds separated by thin mudrock unit
Onaga Shale	Towle Shale	1.8 – 6.4 m	Mudrock: Gray, red and green interbedded mudrock with local paleosols and boxwork fracture fill. Shell fragments and bioturbation common locally. Unit is reported by previous investigators to contain ICS as a subunit, but this is only true for ICS body found at Honey Creek.
Wood Siding	Brownville Limestone	0.75 – 1.8 m	Limestone: Light bluish green to tan and gray mottled fossiliferous limestone containing abundant shell fragments, crinoid columnals and gastropods (mudstone to wackestone). A red-brown sandy to silty fossiliferous mudrock or shaly limestone interbed common locally in middle to upper third of unit.
Wood Siding	Pony Creek Shale	1 - 7.6 m	Mudrock: Gray to brown, maroon, and green-red or red-green mottle mudrock that locally contains beds of sandstone, sandy mudrock, conglomerate and coal. Paleosol common in middle to upper portion of this unit Honey Creek Coal is found within the uppermost 4 m of this unit. In this study, unit is undifferentiated from the Plumb Shale.
Wood Siding	Grayhorse Limestone	NA	Not present in study area.
Wood Siding	Plumb Shale	2.1 - 6 m	Mudrock: Gray, to locally maroon, green or green-gray, clayey mudrock, locally silty or sandy, and may contain lenses or beds of sandstone, sandy mudrock, conglomeratic shale, or conglomerate. In this study, unit is undifferentiated from Pony Creek Shale.
Wood Siding	Nebraska City Limestone	0.3 – 1.3 m	Limestone: Gray fossiliferous limestone weathering red brown to gray mottled with crinoid, shell and bryozoan fragments (mudstone to wackestone). Immediately overlies very thin (2-4 cm) Lorton Coal.

Table 1: Stratigraphic Interval of Interest: Summary table showing formation and member names, thickness range and major lithologic components of each unit.

5.1 - Stratigraphic Position of the ICS

The ICS in the type locale (ICSP) rests beneath the Falls City Limestone, and above the Brownville Limestone (Fig. 6: Column 1). This position is stratigraphically higher than indicated in the literature (Moore, 1936; Harding, 1950; Moore and Mudge, 1956; Mudge, 1956; Mudge and Yochelson, 1962; Ossian, 1974). At the three other locales investigated, the ICS was found to occupy similar, but different stratigraphic positions. At Peru, the ICS lies between the Falls City Limestone and the Nebraska City Limestone (Fig. 6: Column 4). At Honey Creek, the ICS lies below the Aspinwall Limestone and in places rests unconformably on the Brownville Limestone. However, in borehole logs from the Honey Creek Mine site, the ICS is documented to penetrate the Brownville Limestone and terminates above the Nebraska City Limestone (Fig. 6: Column 3). At Brownville, neither the top nor bottom of the ICS sandstone body can be observed, and exposures of the ICS occupied the stratigraphic interval of the Aspinwall Limestone and Brownville Limestone. Therefore, the ICS body at Brownville is neither overlain by the Aspinwall Limestone, nor underlain by the Brownville Limestone (Figure 6: Column 2), and its exact stratigraphic position remains uncertain.

Stratigraphic correlation of Wood Siding Formation members, Onaga Shale members, and Falls City Limestone between the four ICS exposure sites shows the stratigraphy of this interval to be relatively flat lying and continuous. However, the ICS sandstone bodies are notably out of context with the surrounding stratigraphy, and can be mapped as isolated packages of strata in at least four locations within the study area. The occurrence of the ICS bodies at more than one stratigraphic position indicates the at least some of the ICS lithosomes are genetically unrelated, and of different ages.

6 - Lithostratigraphic Correlation

Four important questions concerning the stratigraphy of the ICS arose during this study: (1) What is the stratigraphic position of the ICS, and is that consistent with published literature? (2) Do all units considered to be ICS record the same stratigraphic interval? (3) Are all correlative ICS bodies in the study area known? (4) Are the ICS bodies continuous or isolated?

Extensive field work was conducted in order to address these questions. This work was complicated by the thickness of Quaternary cover, extensive vegetation, poor quality of exposures, and degradation or complete loss of reference sections. Nonetheless, long stratigraphic sections (6.5 to 7.5 km) could be mapped in the field, and correlated across exposures along the Missouri River bluffs. Photomontages of portions of the sections were assembled for detailed lithostratigraphic correlations and architectural analysis across individual outcrops (Figs. 7, 8, 9, 10, 11 12; Plates 1 and 2).

Five continuous cross-sections generated from photographs and field observations are tied by a common measured section or point, with the exception of a 5 km gap between Aspinwall Ferry and the northern end of ICSP. The cross-sections are assembled: North Peru to South Honey Creek (Fig. 11: Section 1); South Honey Creek to North Brownville (Fig. 11: Section 2); South Brownville to Little Nemaha River (Fig. 11: Section 3); Lippold Ranch to Aspinwall (Fig. 12: Section 4); and North Indian Cave Sate Park to South Duerfeldt Farm (Fig. 12: Section 5), and are also shown at larger scale on Plates 1 and 2.

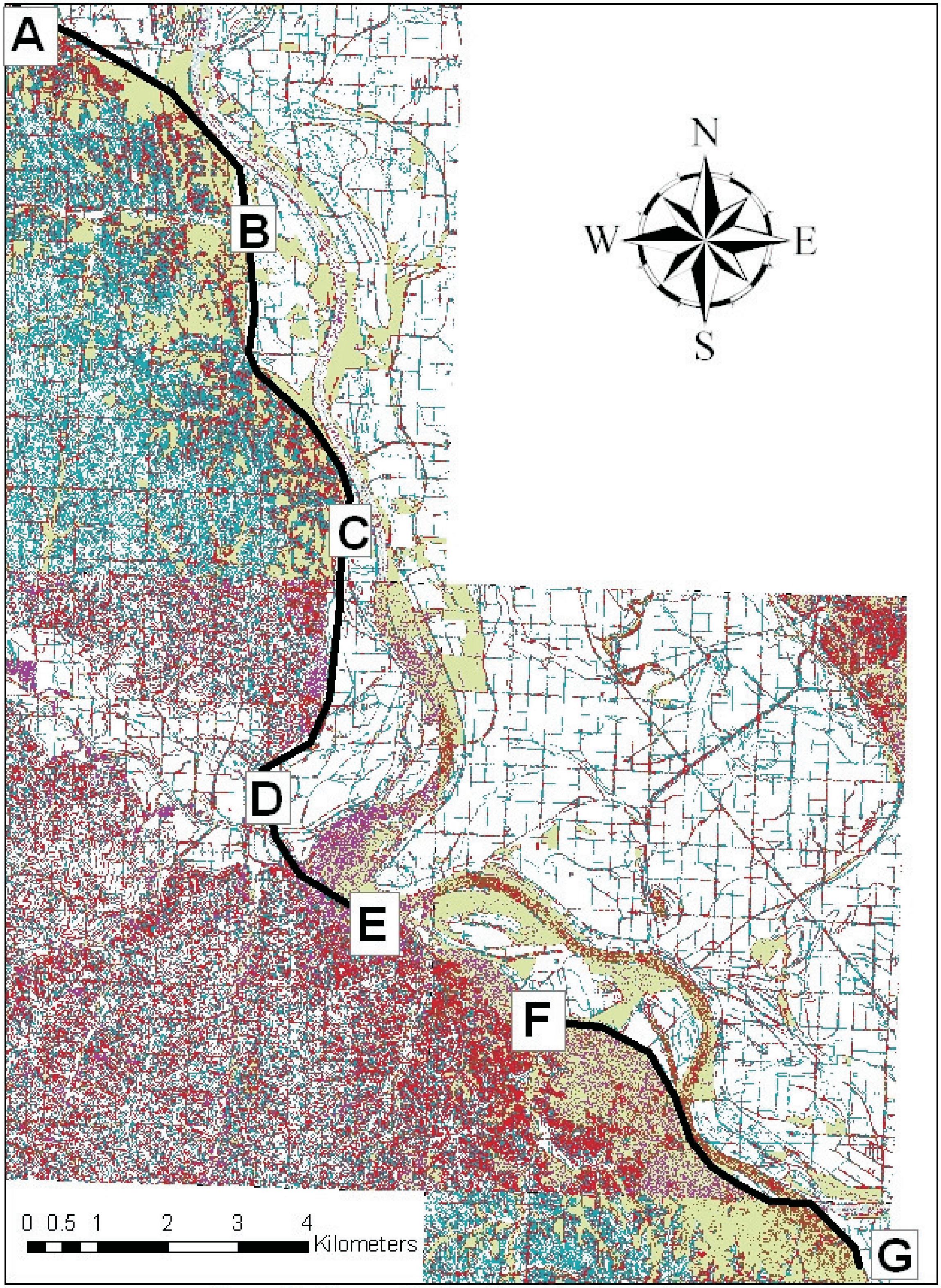


Figure 7: Cross-Section Location Index Map:
A, B, C, D, E, F, and G are endpoints of cross-section panels. See
Figures 8, 9, and 10 for expanded views of each section location

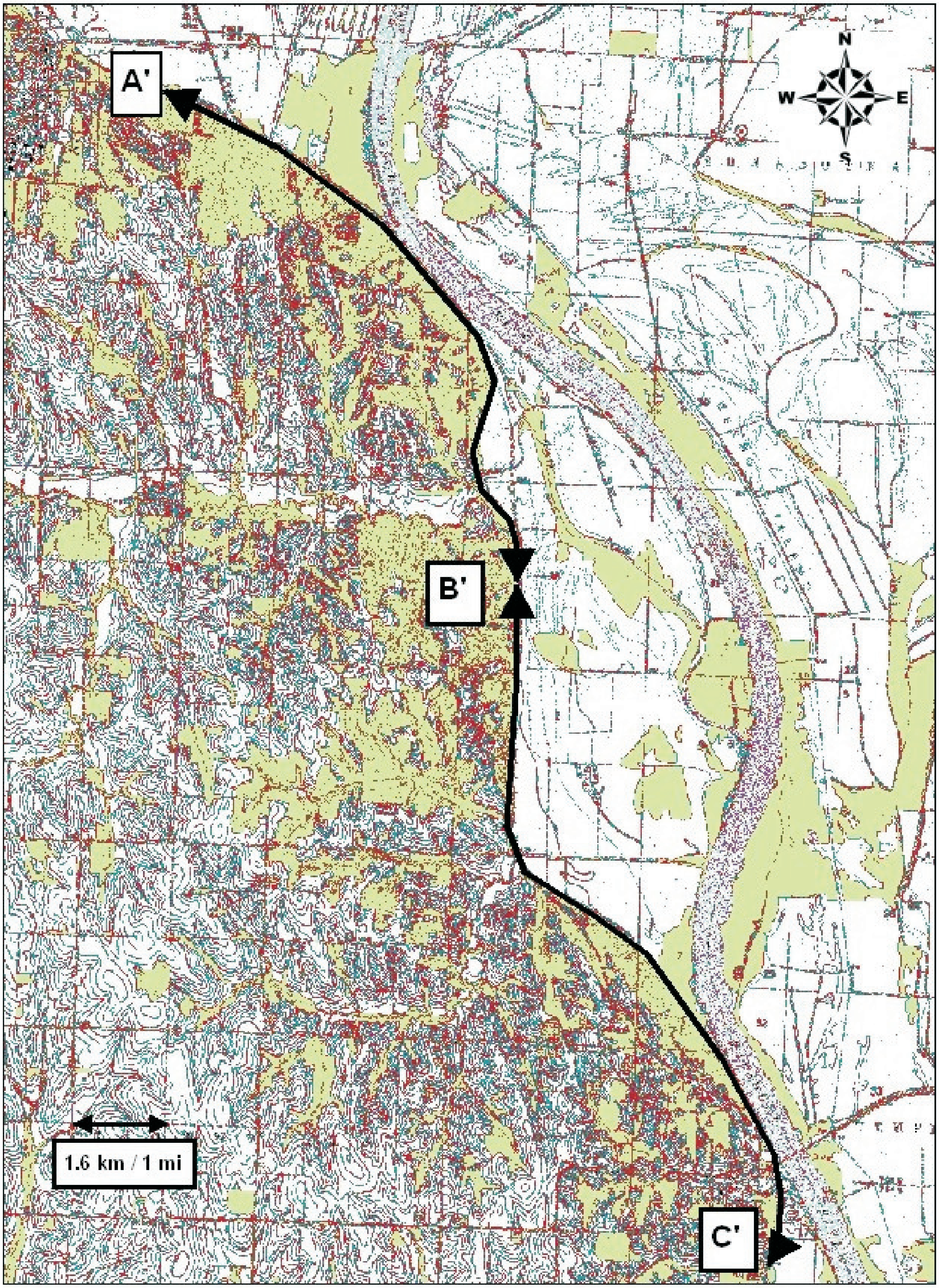


Figure 8: Cross-section location map for lithostratigraphic correlation sections A'-B' and B'-C'

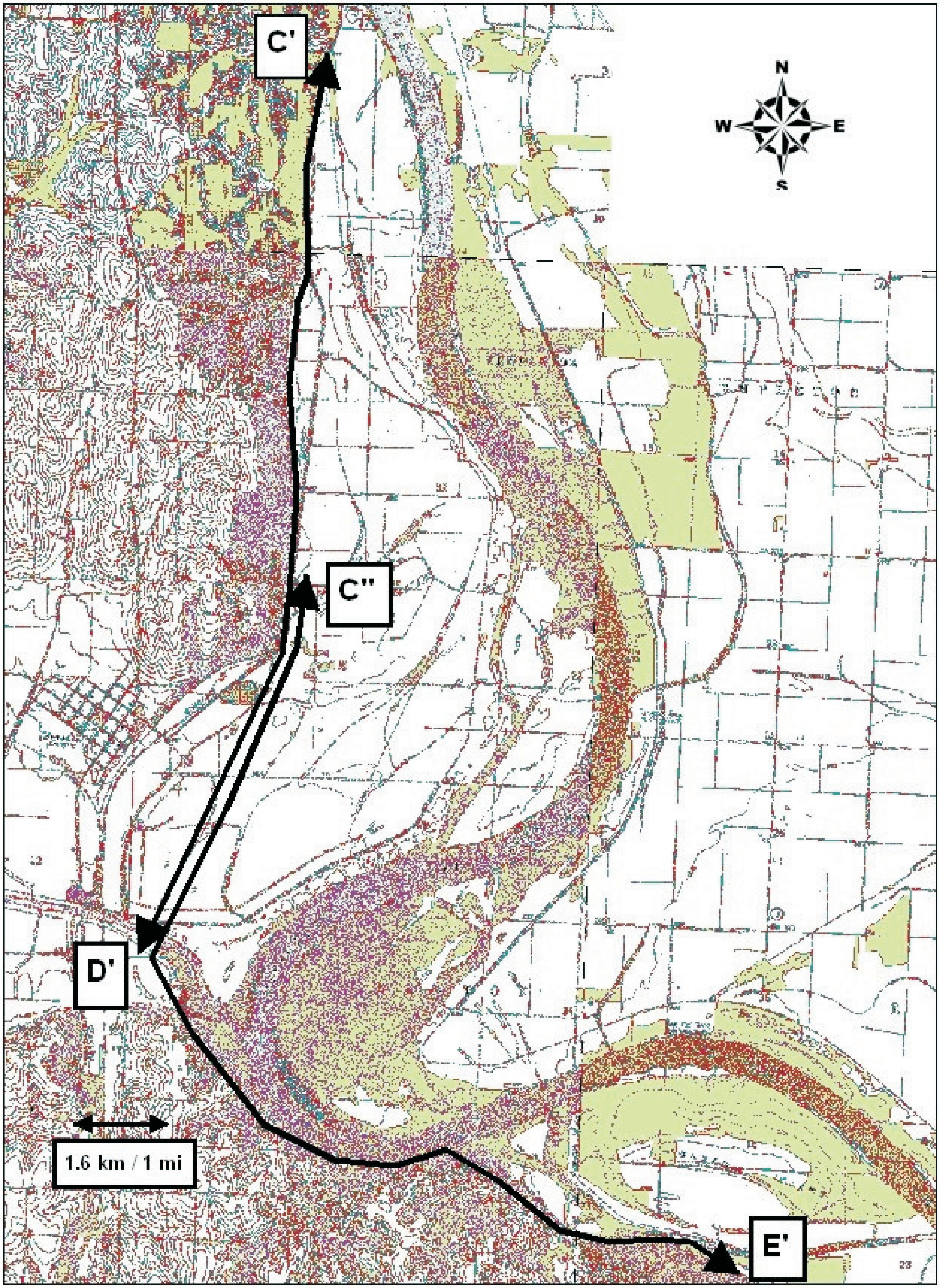


Figure 9: Cross-section location map for lithostratigraphic correlations sections C'-D' and C"-E'

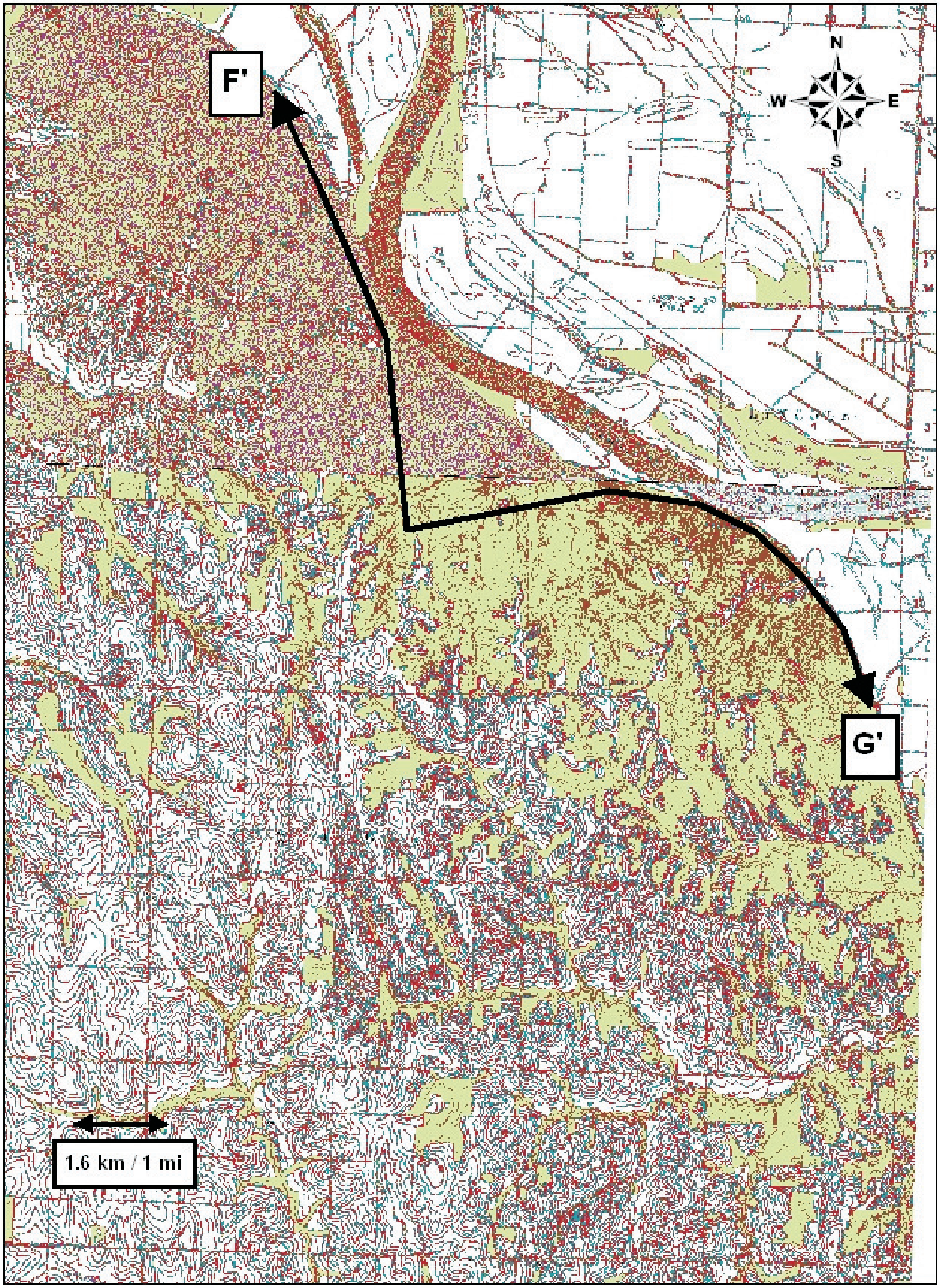


Figure 10: Cross-section location map for lithostratigraphic correlation section F'-G'.

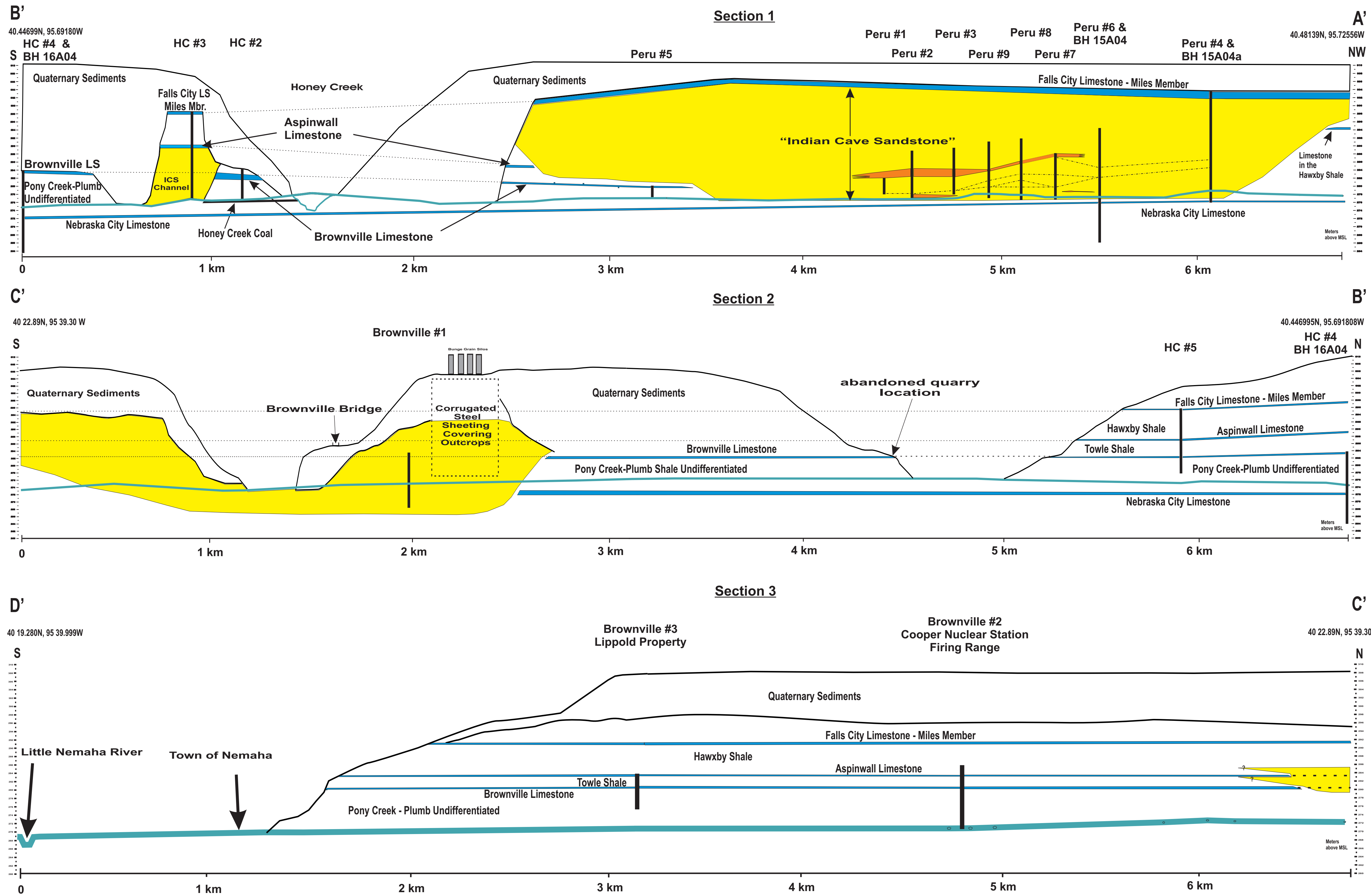


Figure 11: Cross-sections A'-B', B'-C' and C'-D' (Sections 1, 2 and 3 respectively. Section 1 shows stratigraphic positions of Peru ICS body and Honey Creek ICS body. Section 2 shows stratigraphic position of Brownville ICS body. Section 3 shows inferred continuation of Brownville ICS body, as well as correlative stratigraphy from Nebraska City Limestone through Falls City Limestone. Enlargement on Plate 1.

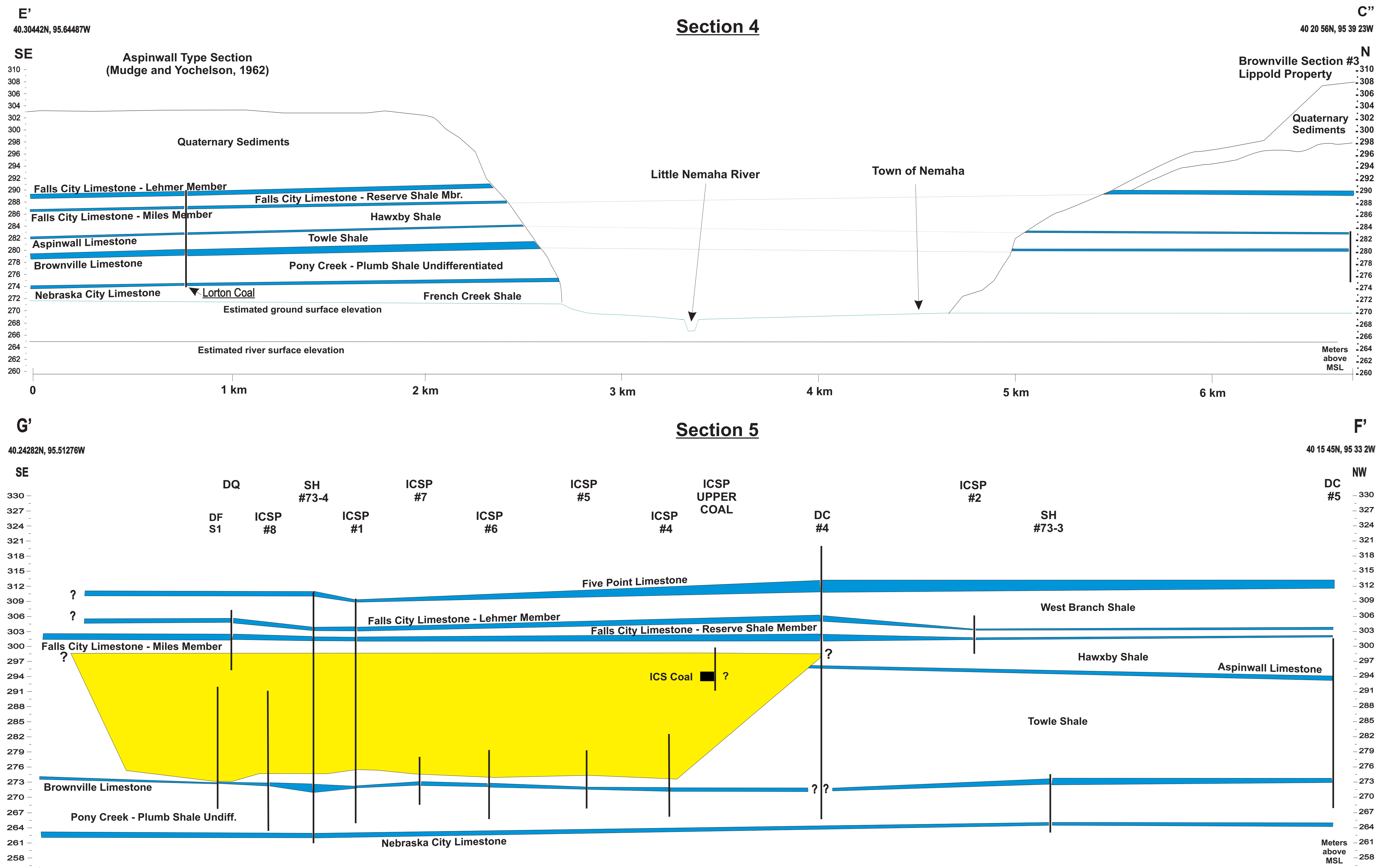


Figure 12: Cross-section C"-E' and F'-G' (Sections 4 and 5 respectively). Section 4 shows stratigraphic correlation from Nebraska City Limestone through Falls City Limestone. Section 5 shows stratigraphic position of ICS body at Indian Cave State Park (ICSP). DQ = Duerfeldt Quarry, DC = Duerfeldt Corehole, DF = Duerfeldt Farm, SH = State Borehole, ICSP # = measured section

In general, the stratigraphy of the studied interval is uniform throughout the study area. Stratigraphic units dip between <1° and 3°. Local dip and thickness variations account for changes of 1 – 3 m or more in elevation of beds. In the vicinity of Aspinwall, units dip as much as 2° – 3° to the south, and therefore exposures are generally lower in elevation southward at ICSP. At the southern end of the ICSP, units begin to dip back to the north at about 1°.

Four incised sandstone bodies were found within the study interval: Peru, Honey Creek, Brownville, and Indian Cave (Figs. 11 and 12). The lateral margins of the incised bodies were not exposed, so boundaries are placed in the general area where sandstone outcrops were no longer evident in surrounding cyclothem outcrops. At Peru (Fig. 11, Plate 1: Section 1), a basal contact is not directly visible above grade, but was delineated on the basis of core data collected during this investigation. At the Honey Creek coal mine site (Fig. 11, Plate 1: Section 1), the basal contact is not exposed but was recorded in boreholes drilled by CSD in 1974. However, west of the mine site, within the main drainage for Honey Creek, there are exposures of the incised channel, and the basal contact here was observed in at least two locations (see also Section 9, Fig. 33). It is important to note here that the basal contact seen in the drainage along Honey Creek is stratigraphically higher than that noted from the CSD borehole, possibly as a result of varying depths of channel incision. Unfortunately, because of the two dimensional nature of the cross-section, this change in elevation of the basal incision surface cannot be mapped.

At Brownville (Fig. 11, Plate 1: Section 2), the lateral and basal margins of the sandstone body are not exposed, although lateral margins are bracketed by the absence of sandstone outcrops. Placement of the basal contact is conjectural. It is likely that the Falls City Limestone caps the incised sandstone body at Brownville: sections measured here by Meek (1867) and Harding (1950) show sandstone overlain by limestone, shale and loess. Harding (1950) also claimed that sandstone is exposed from near the base of the Falls City Limestone down to river level.

At ICSP (Fig. 12, Plate 2: Section 5), the lateral margins of the ICS are bracketed by the absence of sandstone outcrops. The basal contact at ICSP is well defined, being traceable for more than 1.6 km (1 mi). At the Duerfeldt property, immediately to the south, the contact is well exposed, and the sandstone appears to rest directly on the eroded Brownville Limestone, which is underlain by the Pony Creek-Plumb undifferentiated.

In locations where incised sandstone bodies were not found, cyclothems appeared uniform throughout the study area and this projected continuity of strata is reflected in the cross-sections (Fig. 11, Plate 1: Section 3; Fig. 12, Plate 2: Section 4).

The ICS has historically been considered a relatively continuous rock unit with some variation of exposure along strike based on depth of scour along its base (Moore, 1936; Mudge and Yochelson, 1962). However, data presented herein shows the ICS to be: (1) composed of sandstone bodies of limited lateral extent (> 2 km) encased within cyclothem host rocks; (2) found in at least two different stratigraphic intervals within the study area, with the Honey Creek body being older than other sandstone bodies historically considered to be equivalent; and (3) incised to different depths (up to 30m) at each exposure location. These data indicate that the ICS is not a single genetic unit, but rather represent multiple incised-valley-fills of at least two different ages on the Late Pennsylvanian northern Midcontinent Shelf. Incised-valley widths may exceed 2 km with depths of at least 30 m.

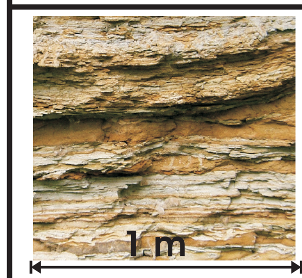
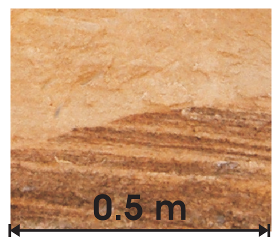
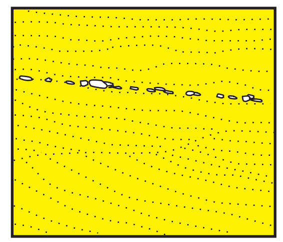
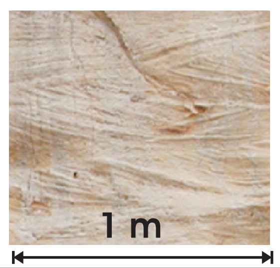
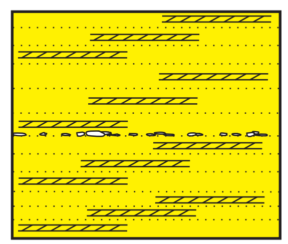
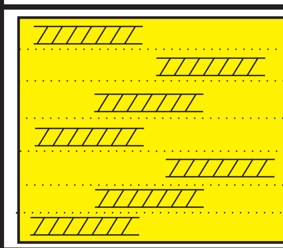
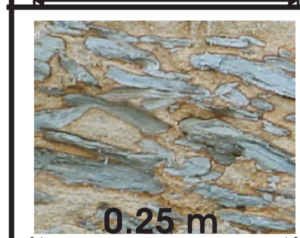
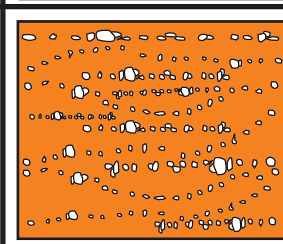
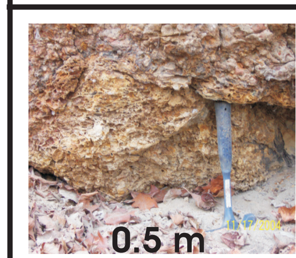
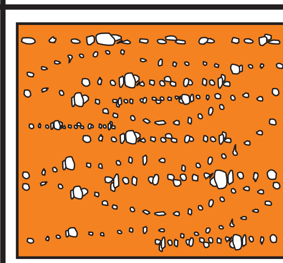
7 - Facies Analysis of the Indian Cave Sandstone (ICS)

Seven lithofacies (Table 2) are identified in the ICS bodies: (1) basal intraformational conglomerate (**Ci_b**); (2) intraformational heterolithic-clast conglomerate (**Ci_h**); (3) large scale trough cross-bedded sandstone (**St_1**); (4) small scale trough cross-bedded sandstone (**St_2**); (5) low angle cross-bedded sandstone (**S_L**); (6) sandstone-dominated heterolith (**H_1**); (7) mudstone-dominated heterolith (**H_2**) The characteristics of each of the seven facies are discussed below.

7.1 Basal Intraformational Conglomerate Facies (Ci_b)

Facies Ci_b is sandy matrix-to-clast supported, poorly to moderately sorted mudrock and carbonate clast conglomerates found at, or near, the base of exposures of the ICS, and overlying erosion surfaces (Fig 13; Table 2). Clast size ranges from granule to boulder, but granules and pebbles are the most common. Clasts are composed dominantly of limestone and mudrock derived

Table 2: Indian Cave Sandstone Lithofacies

Facies Photo	Facies Symbol	Facies Code	Facies Description
		H_2 / H_1	Mudstone Dominated Heterolith (H_2). Interlaminated and interbedded mudstone, siltstone and sandstone. 60-80% mudstone/siltstone in laminae and beds 1mm - 30 cm thick. 20-40% sandstone, very fine to fine, in laminae and beds 1 mm - 50 cm. Units evenly distributed and can contain local microfaults and rare trace fossils. Sandstone Dominated Heterolith (H_1) Interlaminated and interbedded sandstone siltstone and mudstone. 40-80% sandstone in laminae and beds 5 mm 50 cm, 10 -20% siltstone in laminae 1-20 mm, 10-30% mudstone in laminae and beds 1mm - 50 cm. Rare eurypterids, rare trace fossils. These facies can be found in vertical succession or laterally interfingering.
		S_L	Low Angle Cross-Bedded Sandstone. Fine to medium and micaceous. Laminated to bedded with internal ripple cross-lamination. Organic rich laminae and drapes along ripples. Mud draping along some bedding planes. Scattered pebble layers common along basal scour surfaces.
		St_2	Small Scale Trough Cross-Bedded Sandstone. Fine to medium, micaceous in part. Tabular units typically 0.25 m thick or less and frequently grade into Facies S_L and St_1. Individual cross-sets may scour or be cut by other units of same facies - scour and fill dominant. Pebble layers along scour surfaces common.
		St_1	Large Scale Trough Cross-Bedded Sandstone. Fine to medium, micaceous in part. Tabular cross-bed sets from 0.25 to 1 m thick grade laterally into Facies St_2. Units occur commonly at base of exposed sections and either floor the deposit or are the first sandstone body above basal conglomerates. Trough bases may be rippled and mud draped and individual beds grade vertically into ripple cross-bedded, flaser, wavy and lenticular bedding at bed tops.
		Ci_h	Intraformational Heterolithic Conglomerate. Units are composed dominantly of clasts of shale and heterolithic rip-up clasts in a fine sand matrix. Clast size ranges from granule to cobble with granule and pebble most abundant. Clasts are platy, and are typically aligned with long axis parallel to bedding, with some crude imbrication in places. Clast-to-matrix supported.
		Ci_b	Basal Intraformational Conglomerate: Units found at or near the basal contact of exposures. Clasts are composed dominantly of limestone and shale, in a fine to medium sand matrix with varying amounts of coal and coaly traces. Clast size ranges from granule to boulder. Wood, plant debris abundant,fossils in limestone clasts common, vertebrate fragments common. Clast-to-matrix supported.

A)

B)

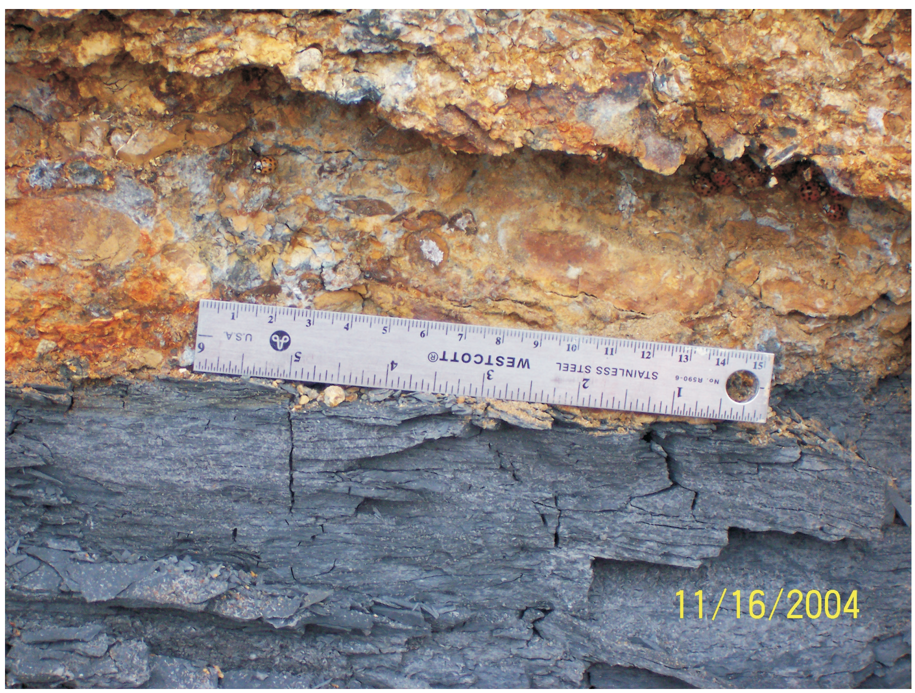


Figure 13: Examples of Facies Ci_b - basal intraformational conglomerate. A) Rare boulder and cobble conglomerate. B) More common pebble conglomerate in contact with underlying Towle Shale at Indian Cave State Park (ICSP).
Rock hammer for scale in Photo A is 28 cm (11 in) long.

from the enclosing cyclothems, with varying amounts of coalified peat rafts and coaly traces. Fossil wood, plant debris, and vertebrate remains are abundant (Ossian, 1974). Where boulder-and cobble-sized clasts are present, they are dominantly limestone, and contain a variety of marine fossils. Ci_b deposits are generally lenticular to wedge-shaped in cross-section and vary in thickness from one clast (1 – 2.5 cm) up to > 2 m . Beds typically vary in thickness along strike and may be traced along outcrop for tens to hundreds of meters. There is no evidence of bioturbation.

Interpretation

Facies Ci_b represents channel-lag deposits generated during periods of maximum incision. Clasts for the conglomerate are derived locally from the incision surface into the host rock and result from erosion of incised surfaces and the subsequent winnowing of fines or the migration of gravel bars along the floor of the channel (Collinson, 1986, p 50; Collinson, 1996, p 72-73; Reineck and Singh, 1986, p 266-267; Miall, 1992, p 136).

7.2 Intraformational Heterolithic-Clast Conglomerate Facies (Ci_h)

Facies Ci_h is sandy matrix-to-clast supported, poorly to well sorted, granule to cobble conglomerate, deposited along scoured surfaces. Pebble to cobble size clasts are the most common (Fig. 14A; Table 2). Clasts consist of angular to well rounded and platy fragments of mudstone-dominated heterolith, and minor amounts of sandstone-dominated heterolith and mudrock clasts. Rarely, where conglomerates are well sorted, there is crude bedding and clasts

A)

B)

Figure 14: Examples of Facies Ci_h - intraformational heterolithic conglomerate A) the most common occurrence of elongate rounded and platy clasts of mudrock and heterolith, pebble to cobble in size. B) A more rare occurrence of mudrock pebbles with *Neuropteris* leaf impressions on the surfaces of clasts (pencil pointing at fossil).

are slightly imbricated. Rarely, there is evidence for disaggregation of organic mats, where clasts appear to be composed of leaf fossils, the imprints of which are apparent on clast faces that parallel bedding surfaces (Fig. 14B). Fossil wood fragments are rare, and there is no evidence of bioturbation. Units range from <0.1 m to > 1 m in thickness and may be traced for up to 100 m along outcrop, and are typically lenticular to sheet-like. In every case, this facies underlies, overlies or interfingers with trough cross-bedded sandstone facies.

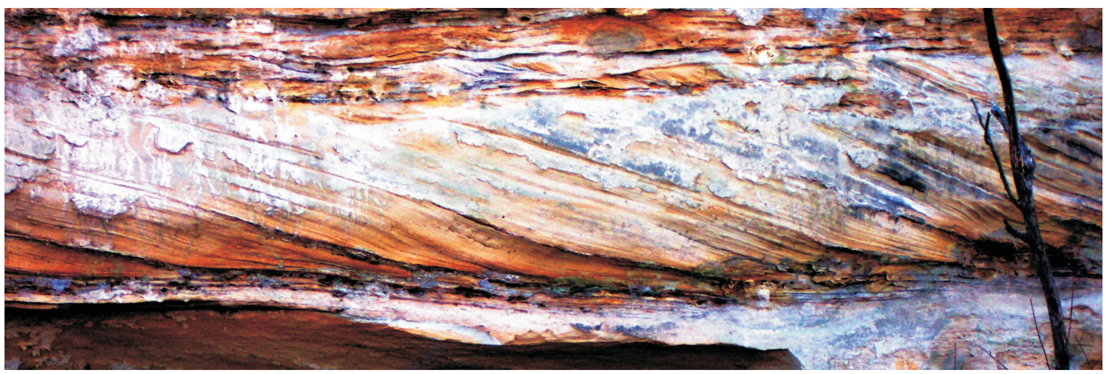
Interpretation

Facies Ci_h was generated by the penecontemporaneous fragmentation of exposed weakly-consolidated, sediments during channel erosion and migration. These conglomerates formed lags where only H_2 facies (see Section 7.7) were available for incorporation from bank erosion, or from massive bank failure. Blocks of bank material entrained in the flow were quickly disaggregated and redeposited, and this facies is always found separating trough cross-bedded sandstone strata (Collinson, 1986, p. 32, 50; Collinson, 1996, p. 64; Reineck and Singh, 1986, p. 267; Miall, 1992, p. 136).

7.3 Large Scale Trough Cross-Bedded Sandstone Facies (St_1)

Facies St_1 is fine-to-medium-grained, well sorted, micaceous, sandstone in tabular cross-sets ranging from 0.25 m to 1 m thick (Figs. 15, 16; Table 2). These units are typically found within 1 – 3 m above the base of exposures and either floor the ICS bodies or are the first units found above, or interbedded with,

Figure 15:
Facies St_1 - Large Scale Trough Cross-Bedded Sandstone
Example from lower exposures at Peru. Cross-sets at this location are 1 m thick, and paleoflow is to the southwest (obliquely into the page from right to left). Line drawing compiled from photo overlay.



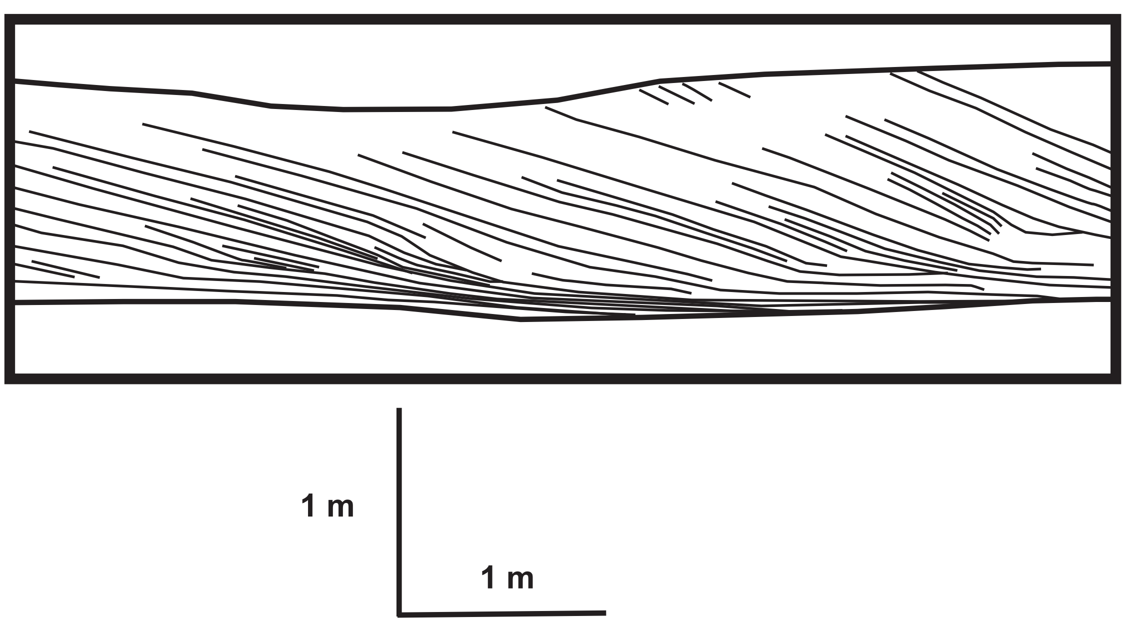
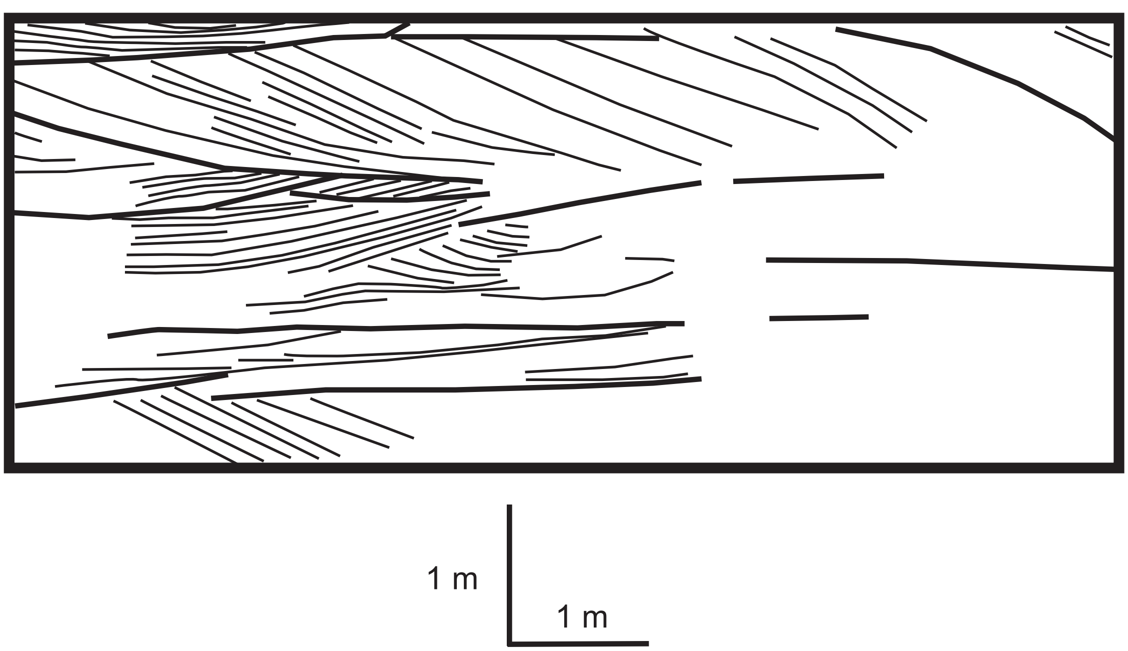


Figure 16:
Facies St_1 - Large Scale Trough Cross-Bedded Sandstone
Largest cross-sets seen at Peru exposures truncated, and scoured by, numerous other cross-sets. Paleoflow to southwest (obliquely into page from right to left). Line drawing compiled from photo overlay.



Facies Ci_b. In some places, units may be traced for greater than one hundred meters along outcrop. Units grade laterally and vertically into facies St_2. Trough bases are locally ripple cross-laminated and mud draped with individual beds that grade vertically into ripple cross-bedded, flaser, wavy and lenticular bedding at bed tops. No evidence of bioturbation was noted in this facies.

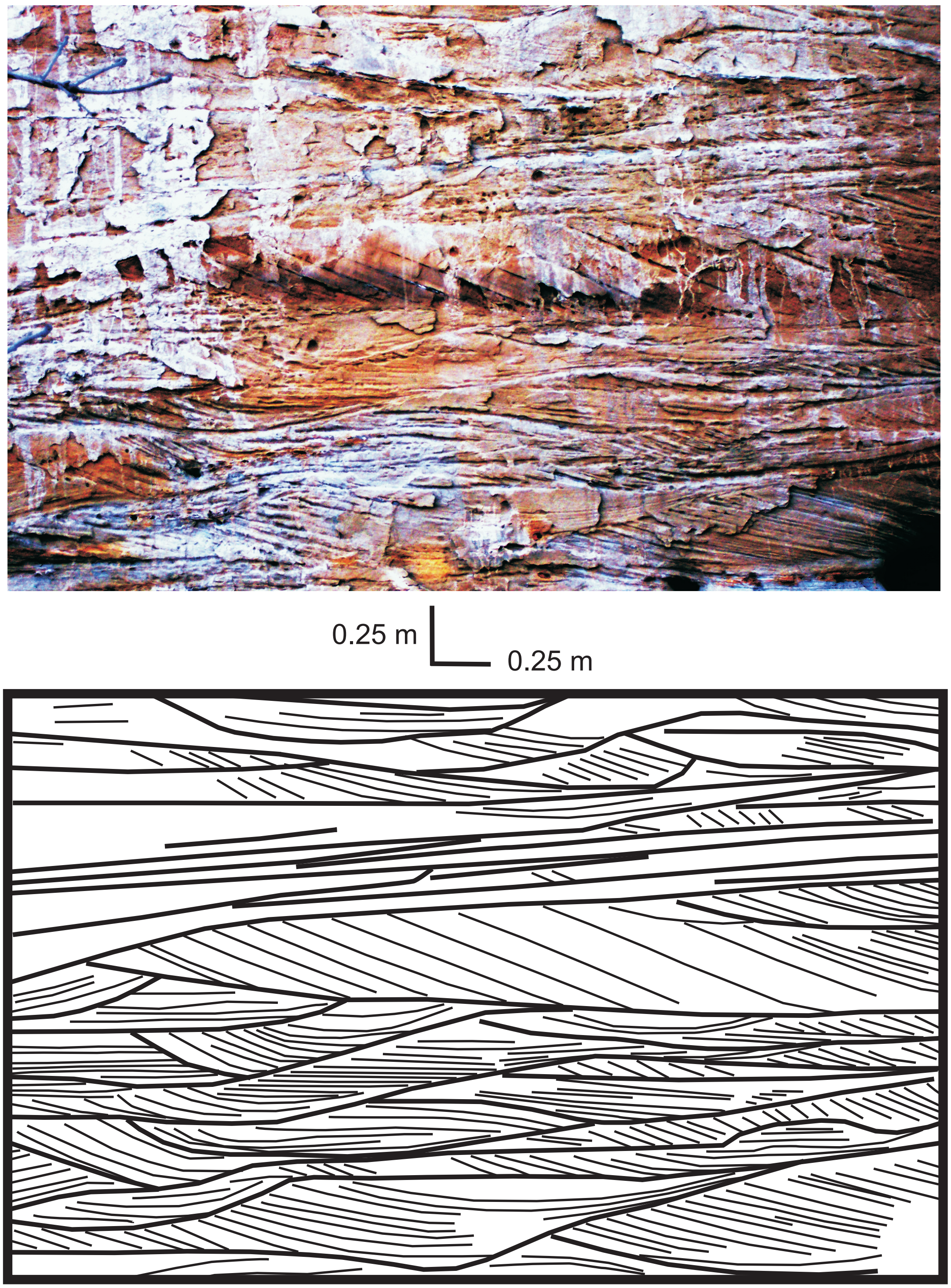
Interpretation

Facies St_1 represents the deposition of large, simple, subaqueous 3D dunes (Ashley, 1990). Ripple cross-lamination plus flaser, wavy and lenticular bedding, along with associated mud-draping at the tops of individual units, indicate either waning flow regimes and quiescent or slackwater phases, or reversing flow regimes and associated slack-water phases (Miall, 1977; Reineck and Singh, 1986 p. 99-100, p.109-118; Collinson and Thompson, 1989, p. 66-69, 75-86) .

7.4 Small Scale Trough Cross-Bedded Sandstone Facies (St_2)

Facies St_2 is fine-to-medium-grained, well sorted, micaceous sandstone in tabular to lenticular cross-bed sets < 0.25 m thick (Fig. 17; Table 2). This facies grades both laterally and vertically into facies St_1 and S_L, and individual cross-bed sets may be scoured by other units of the same two facies. Pebble layers are common along scoured surfaces. Individual units may be traced for tens to > 100 m along outcrop. No evidence of bioturbation was noted in this facies.

Figure 17:
Facies St_2 - Small Scale Trough Cross-Bedded Sandstone
Example from Peru exposures. Interbedded, scoured and truncted cross-sets. Paleoflow to southwest (obliquely into page from right to left). Line drawing compiled from photo overlay



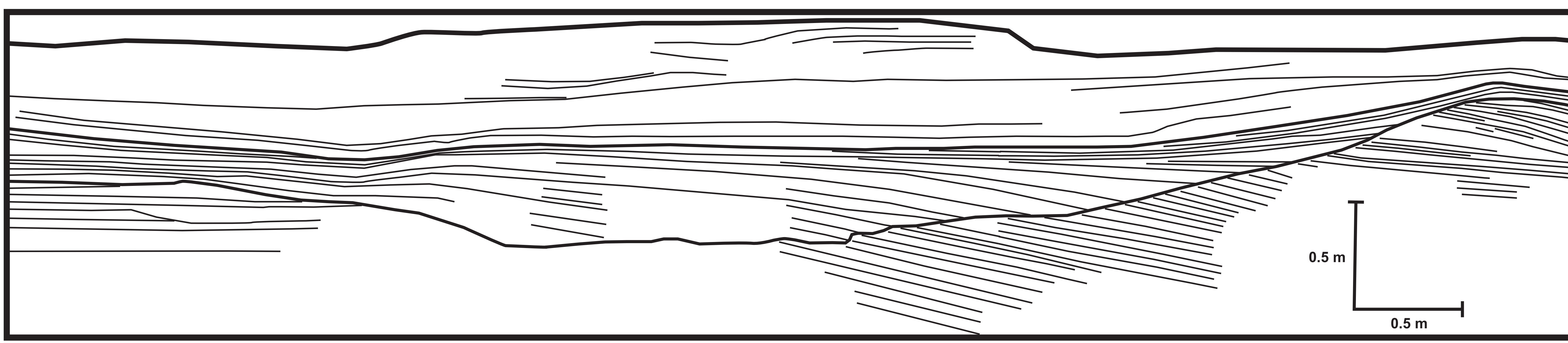
Interpretation

Facies St_2 represents sand deposition in small, simple to compound, subaqueous 3D dunes (Ashley, 1990). This facies was likely deposited under lower flow regimes than the facies St_1, or may represent forms that were compound or contemporaneous with the St_1 facies, and deposited during waning flow events. Where a clear bounding surface is present between the St_1 and St_2 facies, then it is likely that these units were deposited by different flow events. Where no clear demarcation can be found between the two facies, then it is likely that the St_2 facies is a compound element on the backs of the dunes of the St_1 facies (Miall, 1977; Rubin and McCulloch, 1980; Dalrymple, 1984; Allen and Collinson, 1974; Ashley, 1990; Collinson, 1986, p. 28-30; Collinson and Thompson, 1989, p. 75-77).

7.5 Low Angle Cross-Bedded Sandstone Facies (S_L)

Facies S_L is composed of well sorted, fine-to-medium-grained, micaceous sandstone. These units are laminated to bedded, with each stratum inclined from less than 1° (almost plane-parallel) to no greater than 10° (Fig. 18; Table 2). Micaceous, organic-rich and/or mud drapes are evident along some bedding planes. Pebble layers are scattered to common along basal scour surfaces. Individual units may be from less than 0.25 m (0.8 ft) to upwards to 0.75 m (2.5 ft) thick, and may be traced along outcrop for tens of meters. No evidence of bioturbation was noted in these units.

Figure 18:
Facies S_L - Low Angle Trough Cross-Bedded Sandstone
Example from Peru, roughly 10 m above basal expsosure. Multiple sets of low angle cross-bedding, with middle set deposited along obvious scour surface (geologist pointing at scour with machete). Line drawing compiled from photo overlay.



Interpretation

Facies S_L represents deposition in low angle, simple, 2D, subaqueous dunes (Ashley, 1990). This facies was deposited by shallow high velocity flows into low relief scours under transitional upper flow regime conditions (Miall, 1977; Miall, 1978; Rust, 1978). Where the lower contacts are visible, the units in most cases rest on a scoured surface (see Fig. 18).

7.6 Sandstone-Dominated Heterolith Facies (H_1)

Facies H_1 is composed well sorted, fine-to-medium-grained, micaceous, sandstone interbedded or interlaminated with mudrock. The mudrock portions of this facies contain abundant, fine plant fragments and coal fragments. Rare invertebrate traces also appear along bedding planes in this facies, and Barbour (1914) and Ossian (1974) reported eurypterids from exposures of this facies at Peru.

The proportion of sandstone to mudstone ranges from 50 to 75 percent in this facies (Fig. 19, 20; Table 2). Where ripples in the sandstone are fully preserved, then mudrock drapes the ripple forms. In some cases, these are climbing ripples, and can be identified as continuous wavy bedding over the extent of the exposure. Where ripples are only partially preserved, discontinuous wavy or flaser bedding and lenticular bedding are present. At a few localities, multiple ripple forests are mudrock-draped, and bounded both above and below by mudrock-draped erosion and reactivation surfaces (Fig. 19). This facies may

Figure 19:
Facies H_1 - Sandstone Dominated Heterolith
Example from lower Peru exposures. Ripple cross-laminated sandstone with mud drapes along ripple foresets and along reactivation surfaces. Line drawing compiled from photo overlay.

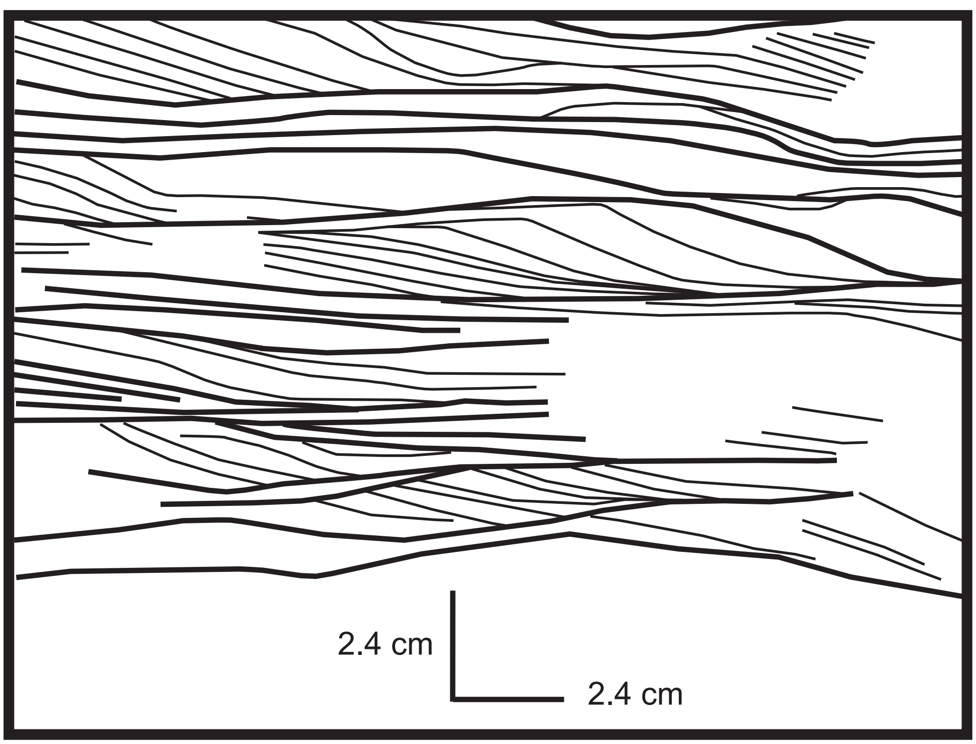
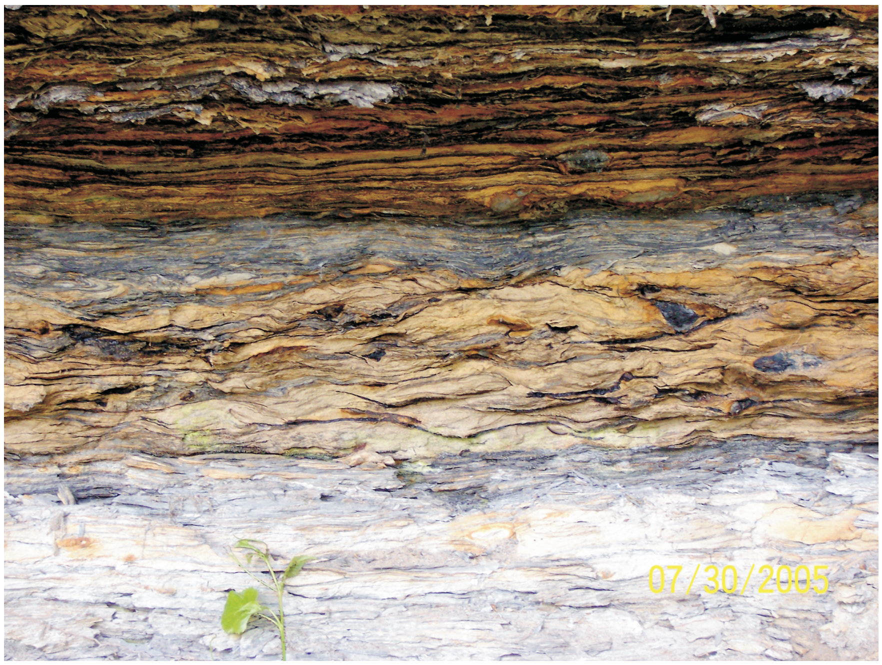
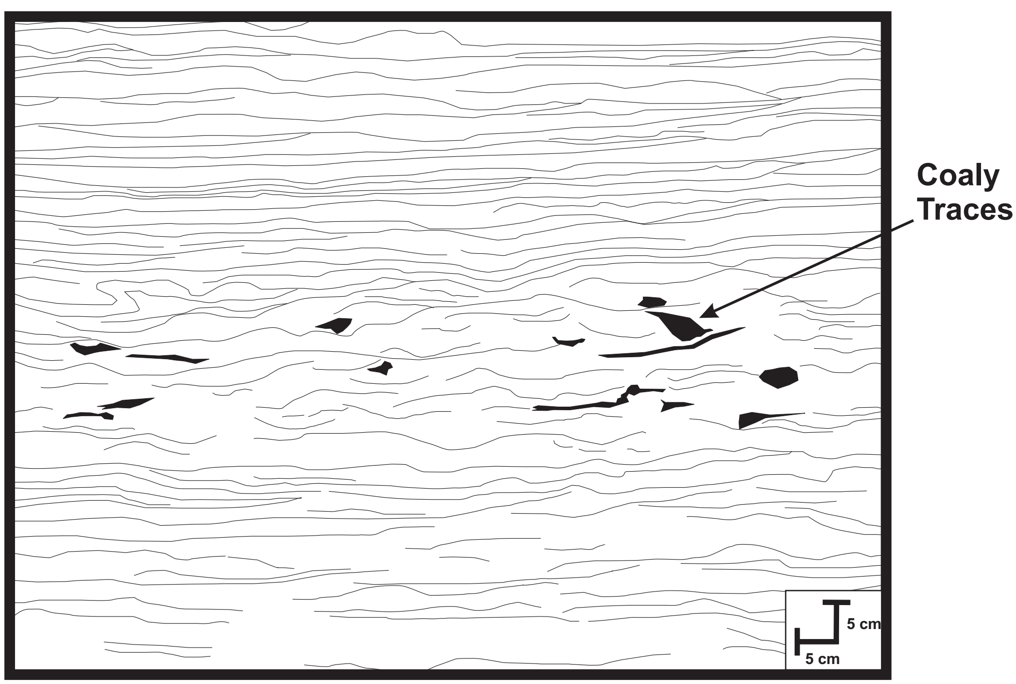


Figure 20:
Facies H_1 - Sandstone Dominated Heterolith
Example from Brownville exposures, ripple cross-laminated sandstone
with mudstone and organic drapes, coaly traces, wavy and flaser lamination.



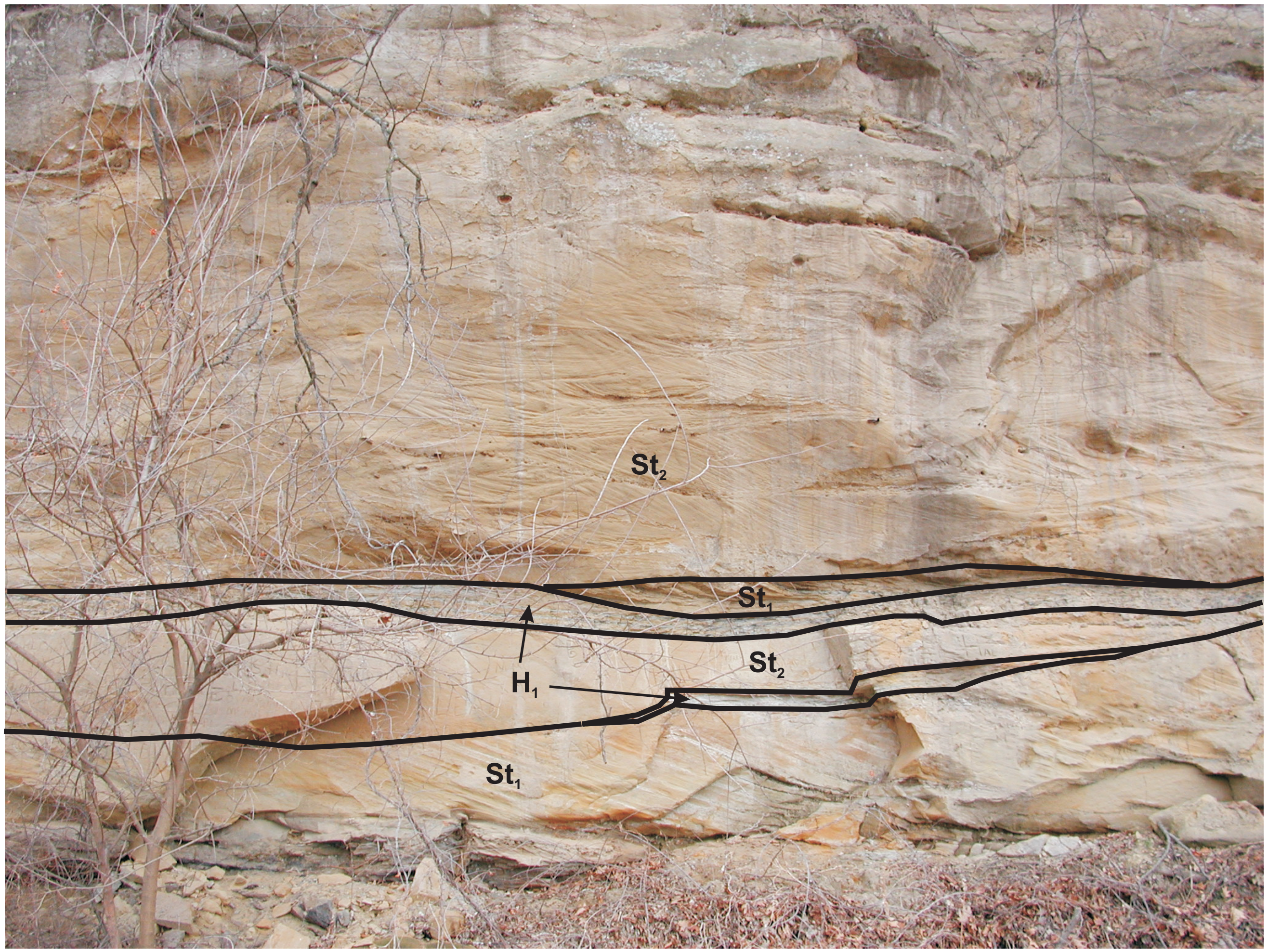


be found gradationally overlying facies St_1 or as discrete units scoured into the tops of facies St_1, that are in turn truncated and scoured by an overlying St_1 or St_2 facies (Fig. 21), or are found associated with Facies H_2 (see section 7.7).

Interpretation

Facies H_1 represents migrating ripples that could have been formed by one of three different mechanisms. This facies could have been generated by counter-current cross lamination resulting from flow separation from dune tops, and a reverse lee eddy established in front of the avalanche face of the dune, driving ripples in a counter current direction up the dune face (Collinson and Thompson, 1989 p. 79–80). Alternatively, this facies could have been deposited during periods of waning flow or quiescence following the deposition of the St_1 facies. Waning flows following the emplacement of the St_1 dunes would generate ripple cross-laminated and bedded strata. Continued waning flow especially to quiescence, following ripple deposition generated the mud drapes, as is common in many tidal settings. More likely, given the stacked vertical nature of these rippled and draped strata, the ripples were generated by waning flow following St_1 dune deposition, or just gentle flows. Mud drapes were generated by continued waning flow and slackwater associated with flow standstill, resulting perhaps from the inland reach of tidal influence. Reactivation surfaces and associated ripples were generated by lower flow regime subordinate currents, and subsequent mud drapes on these surfaces were deposited during the next tidal flow reversal, through waning flow and associated slack water phase prior to the return to the dominant current (Reineck and Wunderlich, 1968;

Figure 21:
Facies H_1 in association with Facies St_1 and St_2, Example from lower exposures at Peru. Facies H_1 interbedded with Facies St_1 and St_2 along scoured and gradational contacts. Lower H_1 strata in abrupt scour contact with lower St_1 strata, and upper H_1 strata in gradational contact with lower St_1 strata but in abrupt scour contact with overlying St_1 and St_2 strata.



Klein, 1977, p. 39-47; Reineck and Singh, 1986, p. 109-118; Collinson and Thompson, 1989, p. 67-68; Nio and Yang, 1991, p. 3-27; Gastaldo et al., 1995, p. 171-181).

7.7 Mudstone-Dominated Heterolith Facies (H_2)

Facies H_2 is composed of interlaminated to interbedded mudrock and silty mudrock and lesser amounts of interbedded and interlaminated sandstone. The mudrock content in these strata ranges from 50 percent to >75 percent, and sandstone laminae or beds may be evenly or unevenly distributed throughout a given unit. Commonly, sandstone or siltstone is evenly distributed as laminae, and the strata have a banded or pinstriped appearance (Figs. 22A and B; Table 1). Sandstone is commonly ripple cross-laminated. Rare large vertical burrows (2 cm by 10 cm) were noted in this facies, as was evidence of microfaulting (Fig. 22B). Rare, thin (1 – 2 cm), continuous coaly partings can be found within this facies. These coaly strata are dominantly composed of leaves and organic debris. Where sandstone intervals are thick enough to reach bed scale, they can weather as lenticular ledges showing extensive ripple forms and horizontal burrows identified as *Planolites*. At some localities, these sandstone strata contain abundant fossil wood debris, with *Calamites* being the dominant form, and many fragments of other organic debris common (Fig. 23). Some of these subordinate sandstone units are continuous along strike for a few meters to tens of meters, or can be lenticular bodies that are exposed over a horizontal distance of no more than a few meters.

A)

B)

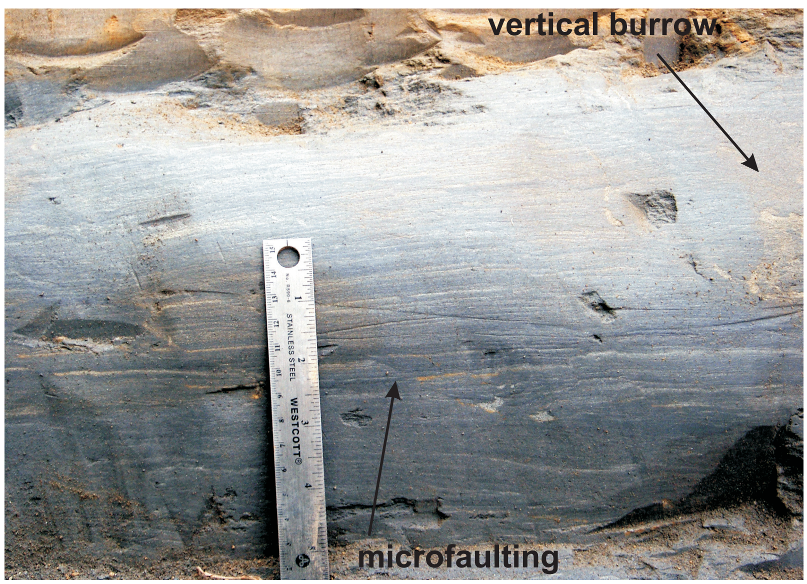


Figure 22: Examples of Facies H_2 - Mudstone Dominated Heterolith
A) Natural exposure in the uppermost outcrops at Peru (above lower sandstone outcrops). B) Hand excavated exposure also within the uppermost outcrops at Peru. Note finely laminated nature of the unit, light colored laminae are either sandstone or coarse siltstone. Micro-faulting to right of ruler (in B), and vertical burrow along upper right margin of photo (in B). Ruler is 15 cm long.

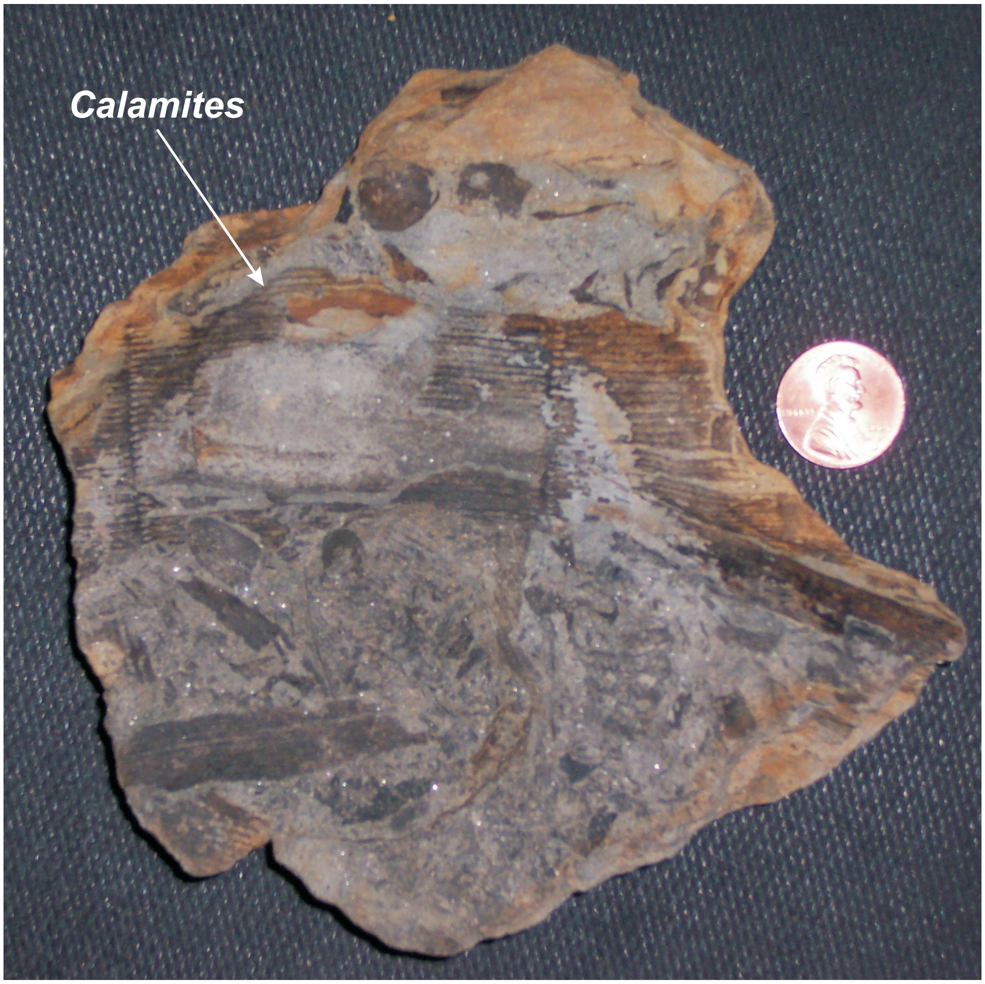


Figure 23: Example of fine-grained sandstone from a lens in Facies H_2 from Indian Cave State Park (ICSP). Specimen contains abundant plant debris and an excellent example of *Calamites.* Penny for scale is 1.9 cm across.

Interpretation

Facies H_2 represents deposition under low-energy flow to slackwater conditions in a tidal environment that was colonized by a limited suite of biota. Lower flow regime and slackwater tidal processes are evidenced by the rhythmic alternations in grain-size from lamina to lamina, or bed to bed, from mudrock to sandstone (Reineck and Wunderlich, 1968; Terwindt, 1975, p. 85-89; Klein, 1977, p. 39-47; Archer, 1998, p. 59-68; Reineck and Singh, 1986, p. 112-118, p. 123-131; Nio and Yang, 1991, p. 3-27; Gastaldo et al., 1995, p. 171-181;).

8 - Facies Associations

Lithostratigraphic correlations and facies analyses (Sections 6 and 7, respectively) indicate that ICS sandstone bodies were deposited as valley and channel fills in dominantly fluvial environments under some tidal influence. The ICS lithosomes can thus be interpreted as incised valley-or-channel-fills on the subaerially exposed shelf platform, recording at least two regressive-transgressive cycles. Regressions are interpreted from stratigraphically separate incision surfaces, which define the boundaries of the incised valleys (Honey Creek being the oldest; Peru, Brownville, and ICSP being the youngest), and transgressions are interpreted from the associated incised-valley-fills. The depositional environments interpreted from stratigraphic sections include fluvial, tidally-influenced fluvial, and estuarine. Therefore, the seven lithofacies identified herein can be grouped into two major facies associations characterizing specific depositional environments: (1) fluvial-to-estuarine association, and (2) upper estuarine association.

8.1 - Fluvial-to-Estuarine Facies Association and Interpretation

Facies Ci_b, St_1, St_2, S_L, Ci_h and H_1 are found in the fluvial-to-estuarine facies association. At some locations, the deposition of these units appears to have been dominated by more fluvial processes (e.g., lower exposures at ICSP), and in other locations tidal processes are more evident (e.g., lower exposures at Peru and Brownville). On the whole however, there is not a clear transition from fluvial to tidal deposition.

Facies Ci_b and St_1 everywhere occupy the lowest positions in the ICS sandstone bodies, and Facies Ci_b typically floors the deposits, but they also interfinger with St_1 units near the base. At Peru, the basal conglomeratic facies is exposed as a lens over a horizontal distance of several meters (Fig. 24) and passes laterally into a bed a few centimeters thick containing log casts, petrified wood fragments and coaly traces. At ICSP, this facies forms the base of the exposures as a wedge-shaped body ranging from a few centimeters to > 2m thick composed of pebble- to boulder-sized intraformational clasts (Fig. 13). Facies Ci_b represents the coarsest deposits in the ICS bodies, and these units are the channel lag deposits generated at the time of maximum incision. Because these strata are typically composed of well rounded and moderately-well sorted clasts of the surrounding host rocks, and terrestrial detritus (plant, wood, other organic fragments, coal clasts and coaly traces), it is unlikely that they were deposited from anything other than a local fluvial source. They most likely lie either within, or very close to, the lowest accommodation points in the system. These deposits represent the switching of the depositional system from a dominantly erosional state to a dominantly depositional one as the incised valley became accommodation space when sea-level began to rise. Alternatively, it is possible that the shift from incision to deposition may have been induced by an upstream change in runoff pattern, but there is no independent evidence for such a change in climate.

Facies St_1, and St_2 record the migration of dunes on lateral bars and point bars in a large fluvial system. Because exposures of these bodies are

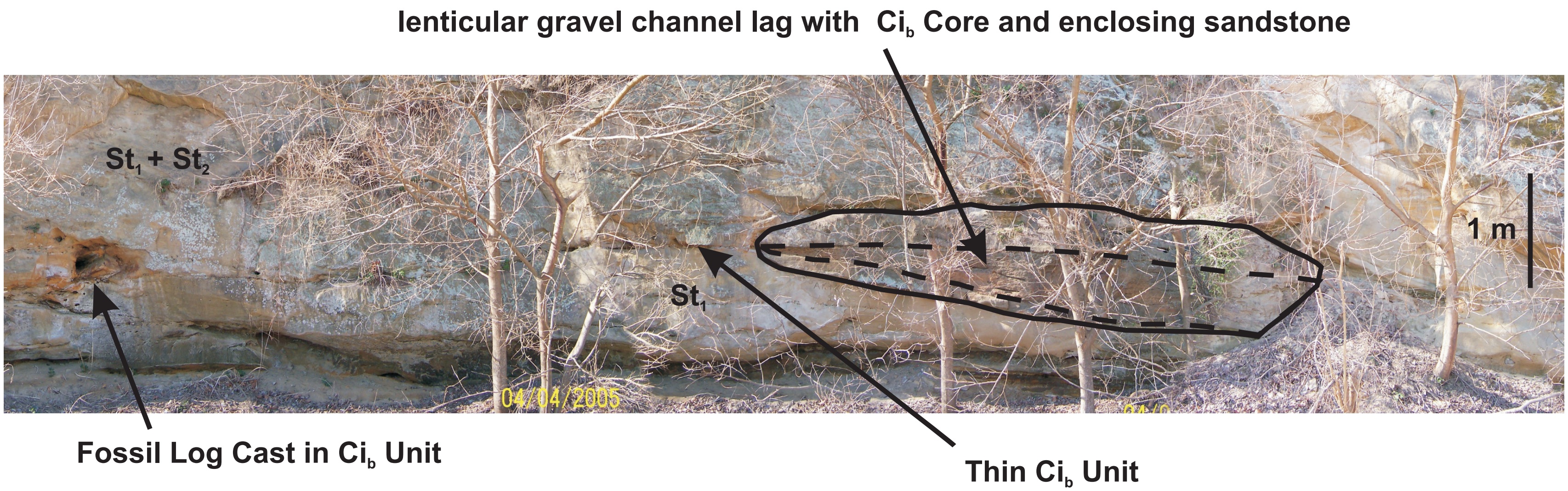


Figure 24: Photo shows Ci$_b$ as gravel lag deposit and the interbedded character of St$_1$ enclosing Ci$_b$. Facies Ci$_b$ strata thin laterally from thick lens to form thin lag along surface indicated with fossil logs and limb casts common at this locality. Gravel lens is roughly 4 m long and 1 m thick. View looking west-southwest, paleoflow is to southwest (obliquely into page from right to left). Outcrop located in basal exposures near north end of outcrops at Peru (roughly 200 meters south of Peru Section #4), approximately 1.5 m above trail level.

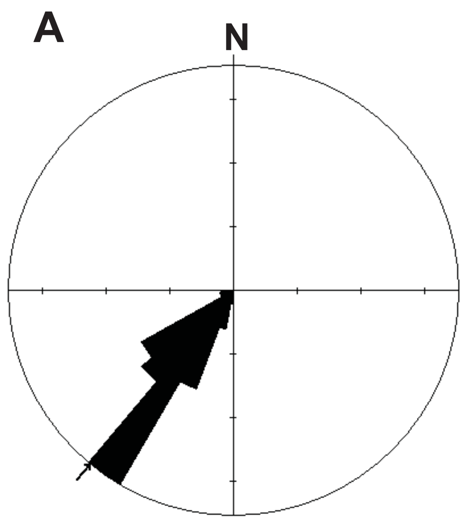
predominantly two-dimensional and oblique to paleoflow, it is difficult to ascertain lateral versus downstream accretion. However, in the few places where the attitude of major bounding surfaces can be determined, the surfaces appear to strike and dip the same as trough cross-beds, making downstream accretion the likely depositional mechanism. Paleocurrent data from Peru, and Brownville indicate an average paleoflow direction to the southwest, while data from Honey Creek indicate a south-southwest paleoflow, and from ICSP indicate a southeast paleoflow (Fig. 25).

Where a bounding surface separates Facies St_1 from St_2, it is likely that the units were deposited by separate flow events, and facies St_1 represents deposition under deeper water conditions than does facies St_2. Where the contact between these two facies is gradational, then it is likely that the St_2 dunes were superimposed on those of St_1, and represent either a change in water depth (shallowing), or periods of lower or waning flow.

Facies S_L is generally found immediately above the laterally-interfingering and vertically-stacked St_1, and St_2 facies. These deposits are always floored by pervasive scoured surfaces. Stacked S_L units extend laterally for tens of meters and can exceed 3 m in thickness, although no individual S_L set is thicker than 1 m. Stacked S_L units represent a higher flow regime (Rust, 1978; Miall, 1978) than those represented by facies St_1, and St_2. The underlying substrates (mainly Facies St_1, and St_2) were extensively eroded during these higher-flow-regime conditions.

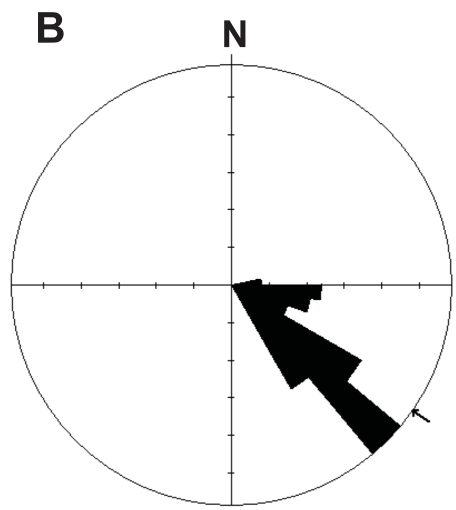
Figure 25: Compilation of paleoflow data for ICS bodies investigated - Individual rose diagram azimuth plots for each study site. Plots show polar distribution of paleocurrent data from trough cross-beds collected from Facies St_1 and St_2. Number of data points and average paleoflow direction shown under each rose diagram.

Peru
Paleoflow Data



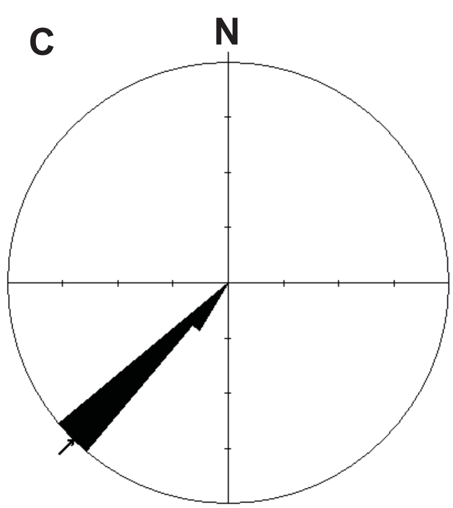
48 Data Points
Southwest Average, 219°

Indian Cave State Park
Paleoflow Data



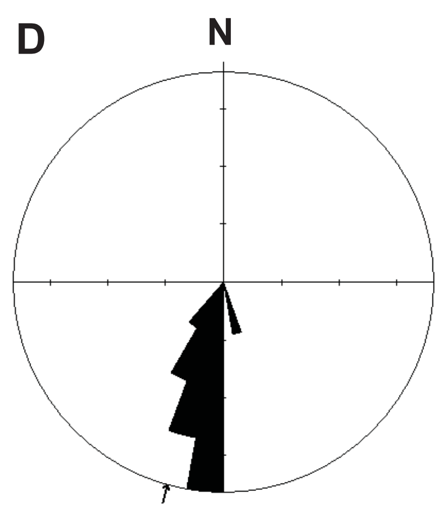
75 Data Points
Southeast Average, 124°

Brownville
Paleoflow Data



10 Data Points
Southwest Average, 224°

Honey Creek
Paleoflow Data



11 Data Points
South-Southwest Average, 195°

Facies Ci_h commonly appears in association with facies S_L, usually as the basal unit of an overlying sequence of S_L, but in some instances it is interbedded with an S_L facies sequence. The association of facies Ci_h and S_L relates strongly to the above interpretation for the origin of the S_L facies. The generation of intraformational conglomerates likely represents the highest flows, and the most destructive erosional events in the depositional history of the ICS bodies. The clast types found in Facies Ci_h are not found anywhere else in the stratigraphically lower, or laterally adjacent deposits, and the lithologies of Ci_h clasts can only be found in the overlying facies association (see Estuarine Facies Association – H_2 Facies). These intraformational conglomerates represent periods of downcutting and cannibalization of older substrates, either because a substrate has been completely removed, or because an adjacent deposit has been eroded by channel expansion and redeposited as an intraformational conglomerate, (Laury, 1971; Collinson, 1996, p. 64; Naylor et al., 1998; Falcon-Lang et al., 2004; Gibling et al., 2005).

Despite outcrop limitations, it seems reasonable to assume that channel expansion is the main mechanism for the generation of the Ci_h facies. An excellent example to support this hypothesis is the occurrence of the Ci_h facies in the lowest visible outcrops at the southernmost Peru exposures (Fig. 26). At this location, facies Ci_h is interpreted to represent a large-scale bank failure with subsequent short-term entrainment and then redeposition of the resulting clasts of overbank sediment. The main mass of clasts of the Ci_h facies at this location is a breccia, and long stringers of the Ci_h facies interfinger into facies S_L in the

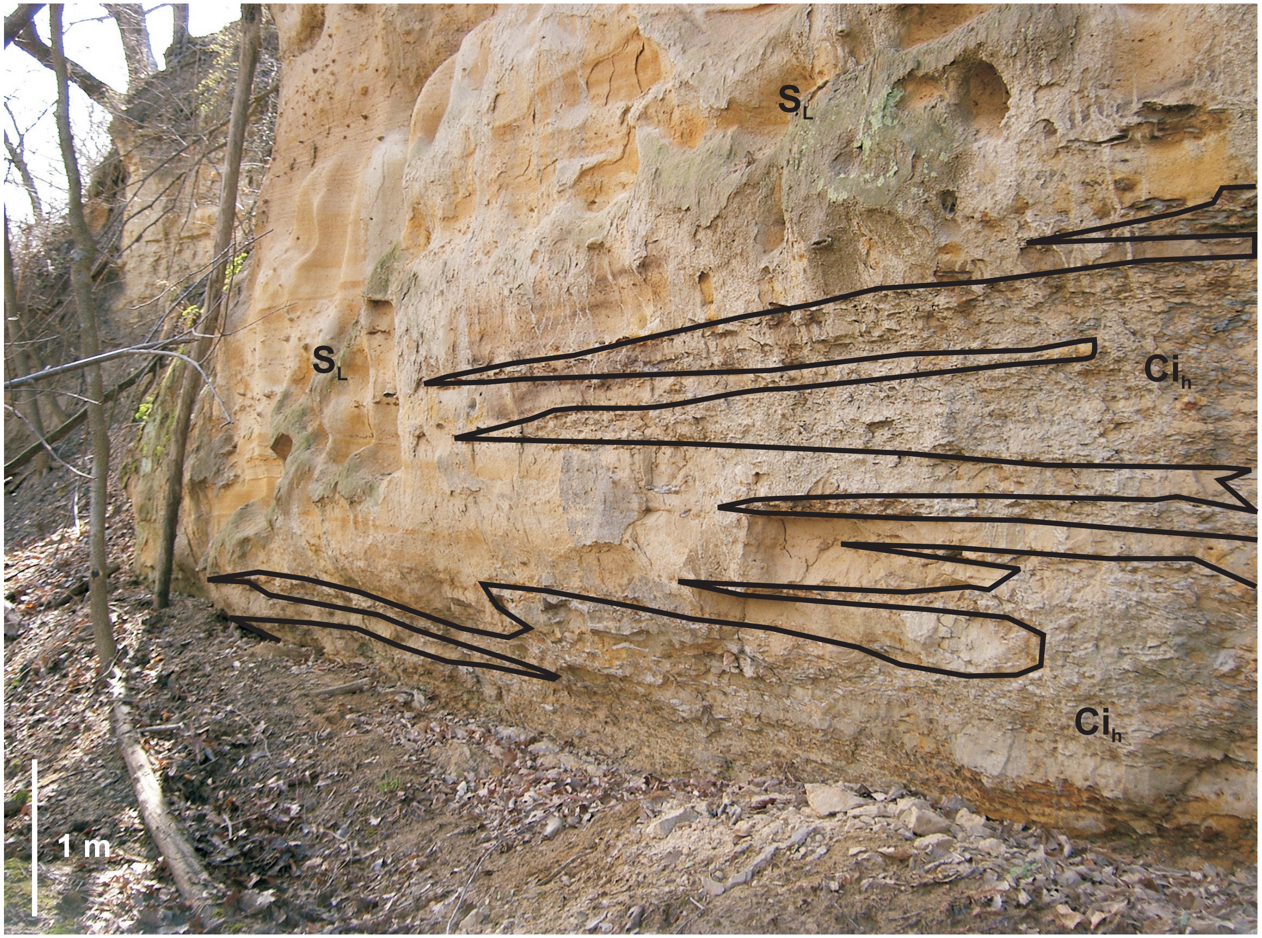


Figure 26: Southernmost end of main ICS exposures at Peru showing interfingering character of Facies Ci_h and Facies S_L. This exposure is close to the base of the ICS body at Peru, and Facies Ci_h here is interpreted to represent the record of a localized bank collapse through channel expansion.

downcurrent direction. Because this outcrop represents one of the stratigraphically-lowest parts of the ICS body at Peru, the interpretation implies that channel expansion is the main mechanism for the generation of the Ci_h facies. Additionally, there is no other evidence at this stratigraphic level for the occurrence of the clasts found in these deposits.

In those instances where facies H_1 is present atop trough cross-beds, the strata contain evidence of mud-draped ripple cross-lamination, flaser, wavy and lenticular bedding (Fig. 19 and 20). These units represent quiescent or slack water conditions after the deposition of a rippled substrate. Possible depositional environments include either stranded pools in a fluvial channel, or a slackwater phase developed through a countercurrent subordinate flow, which could occur at the farthest upstream reach of a flood tide in a fluvial-estuarine system.

Commonly, facies H_1 includes more than one set of mud draped ripples (Figs. 19, 20 and 27A and B). Where mud draped ripples occur gradationally above Facies St_1 and/or St_2, then these deposits are interpreted as one flow event, with waning stage ripples superimposed on Facies St_1 and/or St_2. Where vertically stacked mud draped ripples occur above this point, then these succeeding strata are interpreted to represent multiple tidal cycles (Fig. 27A and B) (Reineck and Wunderlich, 1968; Klein, 1977, p. 39-48; Terwindt, 1975, p. 85-89, 93-101; Nio and Yang., 1991, p. 19-25; Tessier et al., 1995, p. 259-271; Alam, 1995, p. 329-341; Lanier and Tessier, 1998, p. 109-117). Thus, where Facies Ci_b, St_1, St_2 and H_1 are present in a gradational vertical succession, fluvial dominated

A)

B)

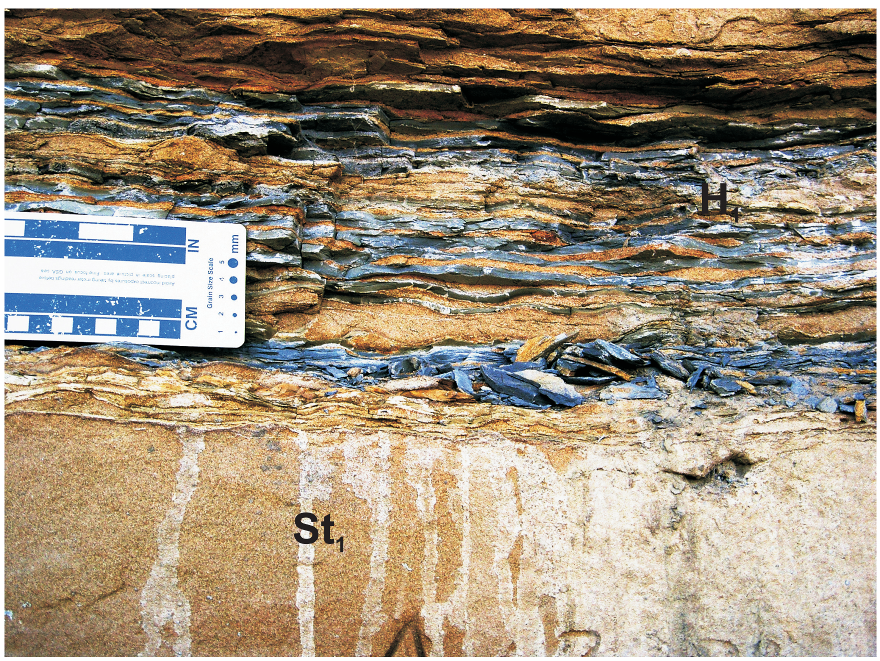


Figure 27: A) and B) Examples from Peru exposures, Facies St_1 grading vertically into Facies H_1, with overlying H_1 units stacked in vertical succession. Units display wavy, flaser, and lenticular lamination and bedding styles typical of tidally influenced deposition (Reineck and Wunderlich,1968 Terwindt, 1975; Klein, 1977; Tessier, et al., 1995; Alam, 1995). These types of associations, along with the those shown on Figures 19 and 20 are interpreted to be indicative of tidal influence.
A) Ruler is 15 cm, B) GSA Scale, bottom bar in cm.

sedimentation is interpreted, and the succeeding stacked H_1 strata are interpreted as more tidally-influenced deposits.

These depositional mechanisms suggest a location in the uppermost reaches of a fluvial-to-estuarine system where flow during the neap tide period is dominantly fluvial, but spring-tides are characterized by a subordinate tidal inflow. Deposits generated during the neap tide period dominate the stratigraphic record in this facies association, and these predominantly fluvial strata account for the low dispersion of paleoflow data primarily in facies St_1 and St_2 (Fig. 25). In this facies association, the dominant paleoflow is either towards the southeast (ICSP) (Fig. 25B); the southwest (Peru, Brownville) (Fig. 25A, C), or south-southwest (Honey Creek) (Fig. 25D). Fluvially-dominated units would only be deposited during neap periods in the uppermost straight-to-meandering portion of the fluvial-to-estuarine system (Fig. 28) (Dalrymple et al., 1992). Fluvial processes also account for the minimal preservation and scoured remnants of the H_1 facies, as these units would tend to be eroded by fluvial-dominated flow during neap periods. Although spring periods would produce tidal flux far enough upstream to create tidally-influenced fluvial deposits, the currents would not be strong enough to scour and/or totally remove the record of fluvial deposition. Thus, the deposits contain both fluvial and tidal signatures but fluvial deposits dominate overall.

Although the sedimentological characteristics of the fluvial-to-estuarine transition have not been documented in detail in the existing geological literature, the interpretation of a tidally-influenced fluvial depositional environment for the ICS is entirely consistent with both modern (Dalrymple et al., 1991; Dalrymple et al., 1992: Dalrymple and Makino, 1993; Tessier, 1993; Lanier and Tessier, 1995; Tessier et al., 1995) and ancient (Zaitlin et al., 1994; Dalrymple et al., 1994; Feldman et al., 1995; Tessier et al., 1995; Archer and Feldman, 1995; Bowen and Weimer, 2003; Feldman et al., 2005), examples proposed by other investigators. Using the Dalrymple et al., (1992) model in combination with Lanier and Tessier's (1995) sedimentologic characterizations, the ICS facies discussed above would be located in the uppermost reaches of the "straight-meandering-straight" portion of the estuarine system where river currents dominate, but still below the tidal limit (Fig. 28). This facies association would be within the fluvial-to-estuarine transition proposed by Dalrymple et al., (1992) or the estuarine-fluvial zone defined by Nichols and Biggs (1985).

8.2 - Upper Estuarine Facies Association and Interpretation

Facies S_L, H_1 and H_2 are found in the upper estuarine facies association. This facies association is found exclusively in the uppermost portions of the ICS bodies, but it can only be delineated at a gross scale due to the poor nature of outcrops.

The upper estuarine facies association is typically floored by facies S_L, and S_L strata are increasingly interbedded with both H_1 and H_2 facies upward, producing a fining-upwards sequence that begins in the upper portions of the subjacent fluvial-to-estuarine facies association. S_L strata typically have a

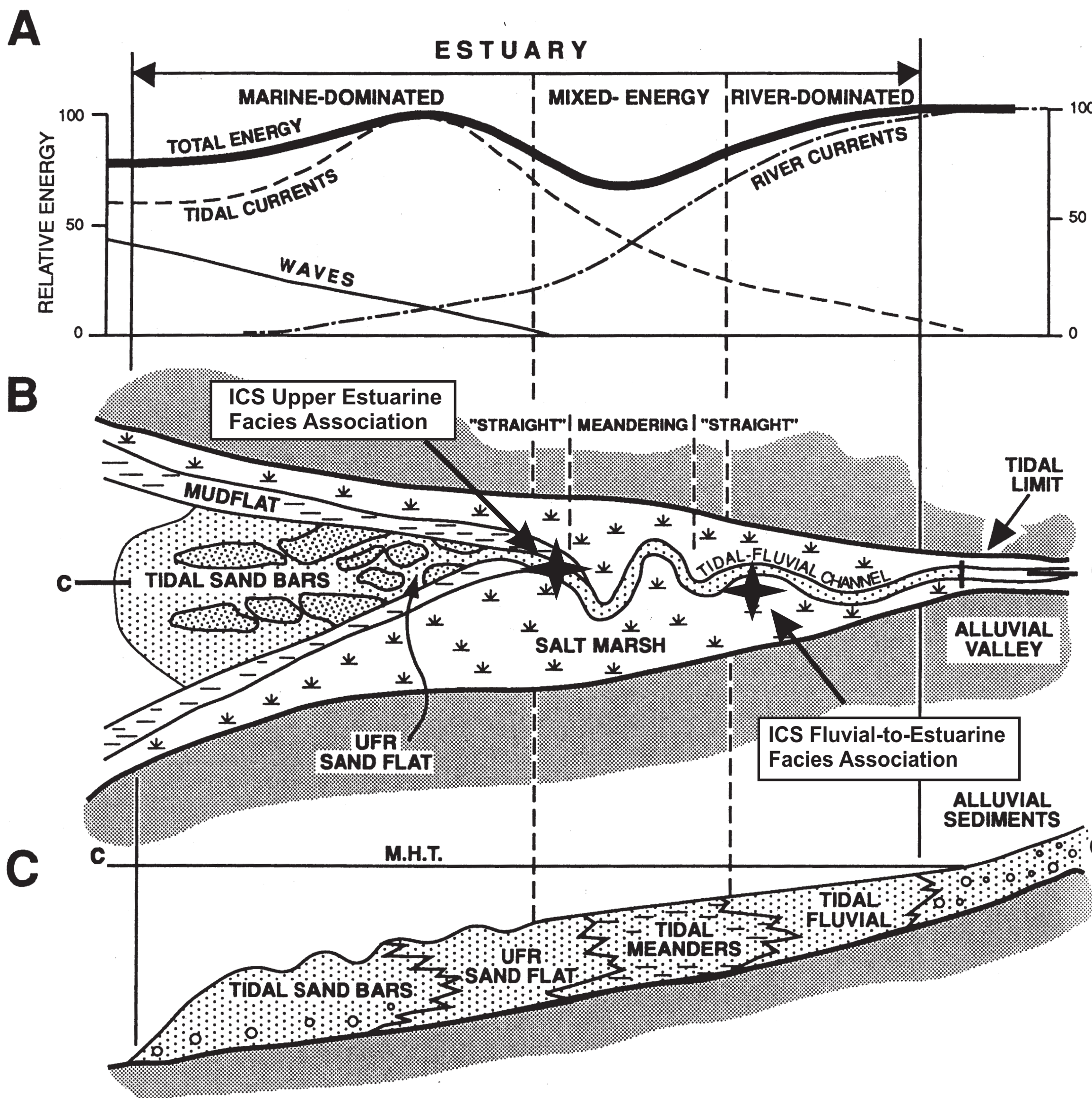


Figure 28: Dalrymple et al. (1992) model for an idealized tidally dominated estuary. A) distribution of energy input; B) predicted morphological elements show in plan view; C) a hypothetical logitudinal section through the idealized system. Interpretation of depositional environments of the facies assemblages of the ICS bodies (shown as stars) located within the “straight-meandering-straight” section of the estuarine funnel, below the tidal limit (modified from Dalrymple et al., 1992).

gradational contact with overlying H_1 strata, or appear as lenses and stringers encased within Facies H_2 (Fig. 29). In this facies association, facies S_L contains well-preserved and abundant organic fragments, coaly traces, petrified wood and plant debris, with *Calamites* being ubiquitous (Fig. 23). In some cases, plant debris tend to be oriented parallel to bedding and with long axes transverse to flow, while in other cases preserved material does not appear to have a preferred orientation. Trace fossil abundance, while low and of extremely low diversity, increases from none to rare in the fluvial-to-estuarine facies association to rare to common in the upper estuarine facies association, with an apparent increase vertically that reaches a maximum in the uppermost reaches of the upper estuarine facies association.

Facies H_2 becomes dominant vertically through the sections and displays a clear rhythmic banding in the continuous alternation of laminae of mudrock and very fine sandstone or coarse siltstone. Commonly these rhythmic alternations appear as light and dark banding or pinstriping. Individual sandstone or siltstone laminae are commonly ripple cross-laminated, and the immediately overlying mudrock lamina drapes the ripples. Facies H_1 is commonly interbedded with Facies H_2, and is more abundant lower in the section than higher (within this association), and sandstone strata where bedded in the facies H_1 thin upward and become laminated with the higher proportion of facies H_2. The estimated H_1/H_2 ratio ranges from 60/40 at the base of this facies association to 0/100 percent at the top.

Figure 29: Uppermost Peru exposures and location of Peru #4 measured section (see Appendix A) showing upper estuarine facies association. Contact with fluvial-to-esturaine association shown as black line below geologist. Above black line, Facies H_1, H_2 and S_L become interbedded with H_2 becoming dominant vertically. Ledges sticking out above geologist are lenticular S_L sandstone bodies encased in Facies H_2.

Facies S_L is interpreted as shallow tidal-channel deposits in the uppermost reaches of an estuary. The tendency of these units to become more dispersed and isolated upward records the transgression of the system, and its evolution from fluvial dominance to estuarine dominance. Facies H_1 and H_2 are interpreted as rhythmic sands and muds in a mud-dominated, strongly tide-influenced setting. These units were probably deposited in the uppermost reaches of an estuary, near the head of the estuarine funnel or within the lowermost portions of the “straight-meander-straight” section proposed by Dalrymple et al. (1992) (Fig. 28).

This interpretation of an upper estuarine facies association is consistent with both modern (Klein, 1977; Nichols and Biggs, 1985; Dalrymple et al., 1992; Dalrymple et al., 1994; Wells, 1995; Klein, 1998) and ancient (Clifton, 1982; Weimer et al., 1982; Shanley et al., 1992; Zaitlin et al., 1994; Archer and Feldman, 1995; Feldman et al., 1995; Kvale and Mastalerz, 1998; Bowen and Weimer, 2003; Bowen and Weimer, 2004; Feldman et al., 2005) examples proposed by other investigators. The upwards fining and progression towards greater dominance of Facies H_2 upward in the section may reflect an evolution from tidal creek/channel and sand flat environment towards a mudflat dominated environment as the system was progressively transgressed. This interpretation also accounts for an observed upward increase in abundance and diversity of trace fossils. This increase is consistent with ichnofaunal assemblages for upper estuarine brackish water environments that are characterized by limited, diminutive traces of low diversity (Pemberton and Wightman, 1992; Gingras et al., 1999; Buatuois et al., 2002; Bann and Fielding, 2004; Hovikoski et al., 2005).

In the few places where the topmost exposures in the ICS bodies can be observed, the upper estuarine facies association is overlain by gray to green shale that is generally massive and appears heavily bioturbated. These units are in turn overlain by locally bioturbated marine limestones containing abundant marine fossils (brachiopods, pelecypods, crinoids, bryozoans). This change in depositional style is interpreted to represent the final phase of the transgressive event controlling the deposition of the ICS bodies, and signals the transition from coastal to open-marine environments. The shales record the development of a marine embayment, and the overlying marine limestone represents subsequent offshore carbonate-bank deposition during ongoing sea-level rise. These latter two units are not considered part of the ICS bodies because they likely have much greater areal distributions than the valley-confined ICS bodies.

The data and interpretations presented thus far indicate the ICS bodies are clearly incised into the surrounding cyclothems, and that the incised fills record at least two transgressive cycles. At least two of the incised valley fills investigated are not contemporaneous. Valley incision occurred during sea-level drawdown, and the fill was emplaced during subsequent sea-level rise, or through multiple sea-level cycles.

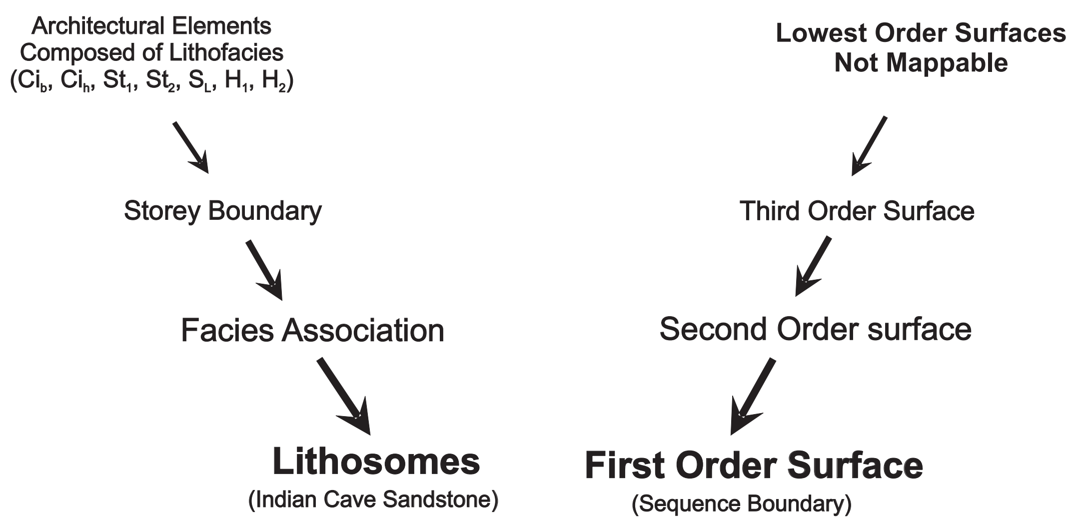
9 - Stratigraphic Architecture

ICS sandstone bodies are composite in character and contain a natural hierarchy of bounding surfaces. Some bounding surfaces floor an entire ICS body, while others are localized and delimit facies associations, storey boundaries, lithofacies, individual beds, or sub-bed scale features. The best examples of bounding surfaces appear within the fluvial-to-estuarine facies association. Three orders of bounding surfaces are recognized on the basis of scale: the lowest-order surfaces are the most laterally-extensive ones, and the highest-order surfaces, although they are the most common, are the also the most localized (Fig. 30). Lower-order bounding surfaces were not always identifiable in outcrop, and therefore they are not easily mapped. These lower-order surfaces bound macroform and mesoform architectural elements, and are wholly contained within third order surfaces.

9.1 - First Order Surfaces

First order surfaces are basal incision surfaces that mark the boundaries between the enclosing cyclothems and the ICS sandstones bodies. These surfaces likely correspond to regional surfaces of erosion and/or locations of subaerial weathering on adjacent interfluves. Three first order surfaces were directly identified in this investigation, and a fourth is interpreted: all of these

Figure 30: ICS Stratigraphic Architecture - Hierarchy of Scale



surfaces are at the bases of ICS sandstone bodies (Fig. 11, Plate 1: Section 2; Fig. 12, Plate 2: Section 5; Figs. 13, 31, 32; 33, 34 and 35). First order surfaces are exposed at Honey Creek and ICSP, with the best exposures found at ICSP along the main road between the boat launch road and the south end of the park.

At ICSP the incision surface is found within the Towle Shale approximately 1.5 – 3 m above the underlying Brownville Limestone, where Facies Ci_b or St_1 abruptly overlies mudrock (Figs. 31 and 32). The surface undulates approximately 0.3 m over a horizontal distance of roughly 15 m.

A first order surface with less than 1 m of relief appears at the base of the Honey Creek sandstone body approximately 1.6 km upstream (west) from the Honey Creek Mine Site (Fig. 33). At this location, the surface separates the Brownville Limestone from the overlying ICS facies St_1. Outcrop relationships and CSD rotary test hole logs in the vicinity of the Honey Creek Mine site suggest that the first order ICS surface there cuts through the Brownville Limestone and into the underlying Pony Creek-Plumb Undifferentiated (Figs. 34, 35; Appendix A: borehole 2-B-74). Significantly, outcrops of the ICS body immediately south of the mine site occupy the stratigraphic interval where the Brownville Limestone has been eroded (Figure 35). The first order surface at Peru is not exposed, but it has been delineated from boreholes 15A04 and 15A04b and is interpreted to be flat-lying (Fig. 11: Section 1).

At Brownville, a first order surface is implied for the ICS body (Fig. 11: Section 2). No direct evidence of this surface is visible in outcrop. But, from the

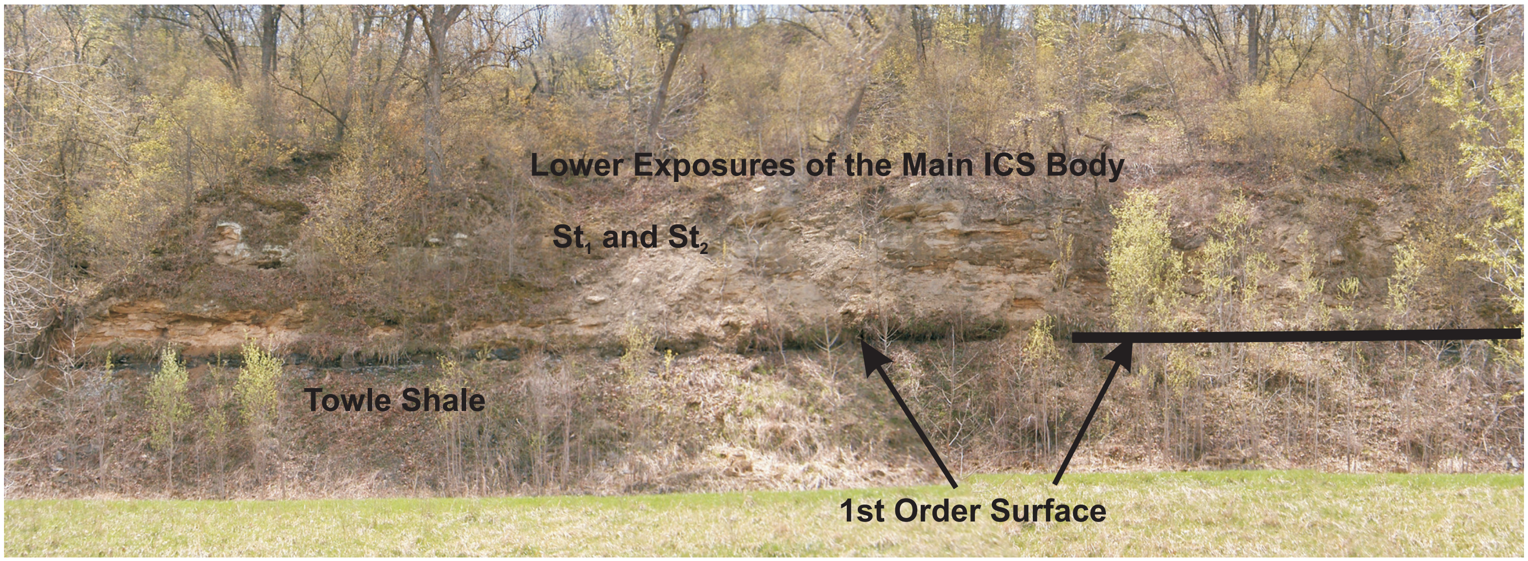


Figure 31: Example of 1st order bounding surface from Indian Cave State Park. Exposure is along main road, near south end of park, within 500 m south of the road to the boat launch ramp. This view shows the lower fluvial-to-estuarine sandstone of the ICS directly overlying the marine Towle Shale. The Brownville Limestone is obscured by brush. Heavy black line highlights location of first order surface (sequence boundary). Total height of exposure at this is location roughly 10 m (33 ft). View to south, paleoflow is to the southeast (obliquely into photo from right to left). See Figure 32 for general location of this exposure at ICSP.

Figure 32:
Stratigraphic Architecture - Indian Cave State Park
Boat Ramp Road to South Park Boundary
Location of First Order Bounding Surface (Sequence Boundary)

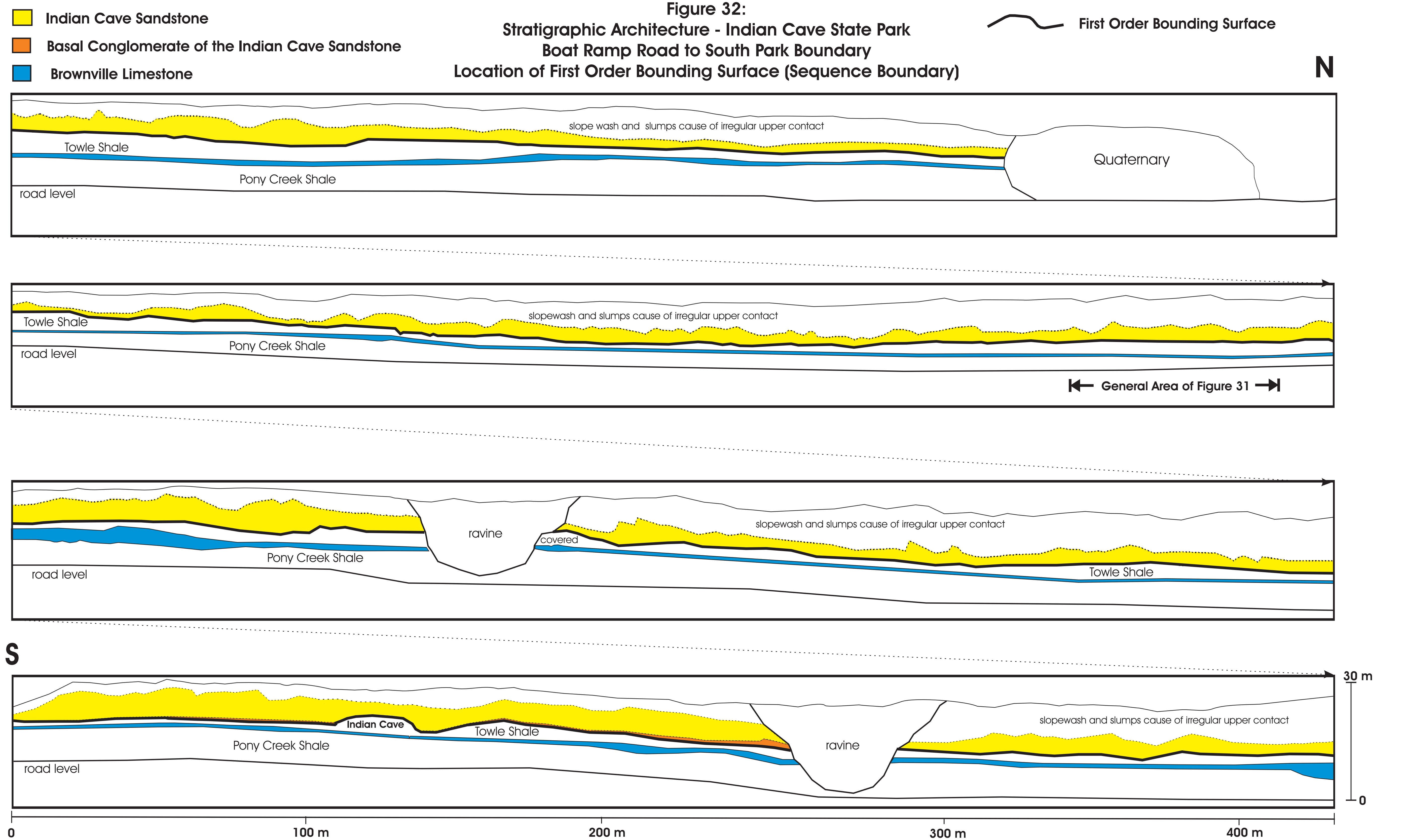
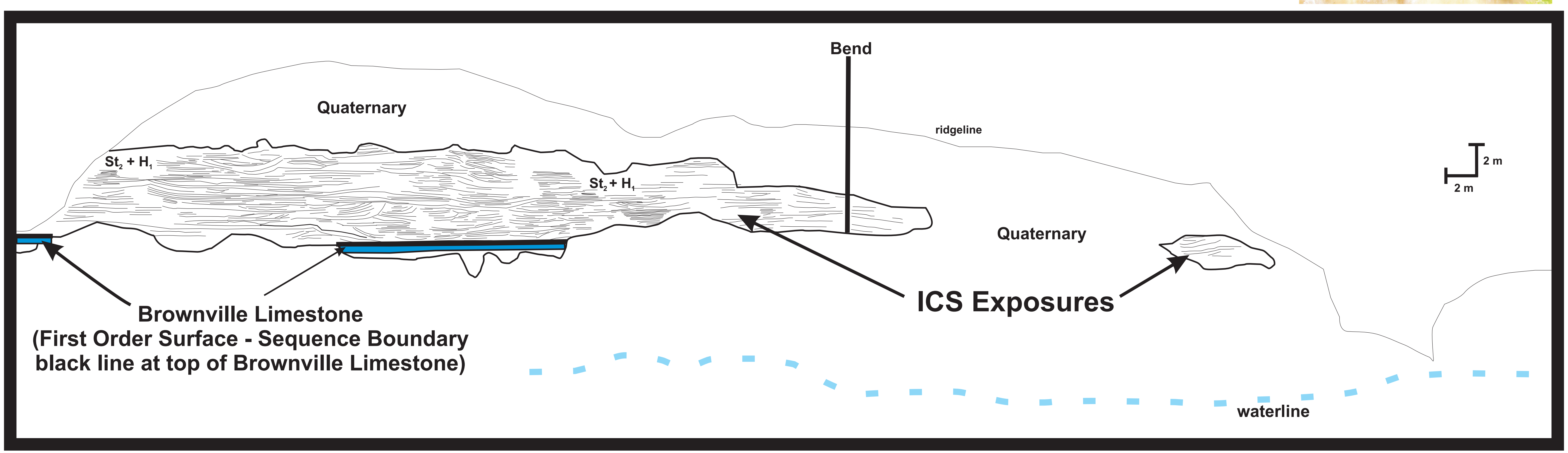


Figure 33:
Honey Creek ICS Body - Exposures along Honey Creek, Stratigraphic Architecture - First Order Bounding Surface (sequence boundary).
In this view, Honey Creek ICS body rests unconformably on the Brownville Limestone (see lower line drawing). View is looking south-southeast and paleoflow is to the south-southwest (obliquely into photo from left to right). GPS coordinates along Honey Creek are 40.44810N, 95.70746W, approximately 1 mile west (upstream) of Honey Creek Mine Site.
Note bend in section, and geologist for scale (roughly 1.8 m, circled). First order surface is just above geologist's head in photo.



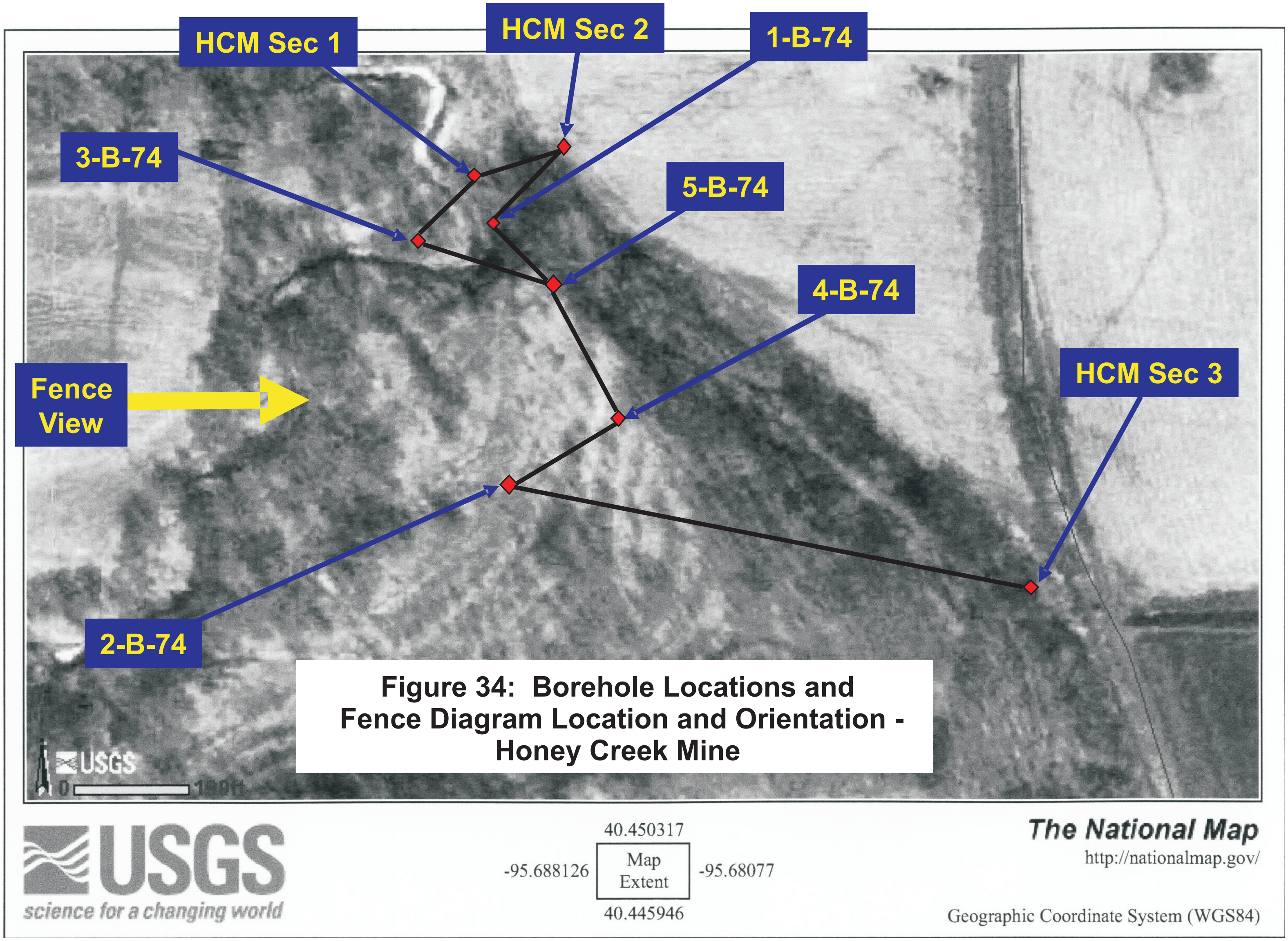


Figure 34: Borehole Locations and Fence Diagram Location and Orientation - Honey Creek Mine

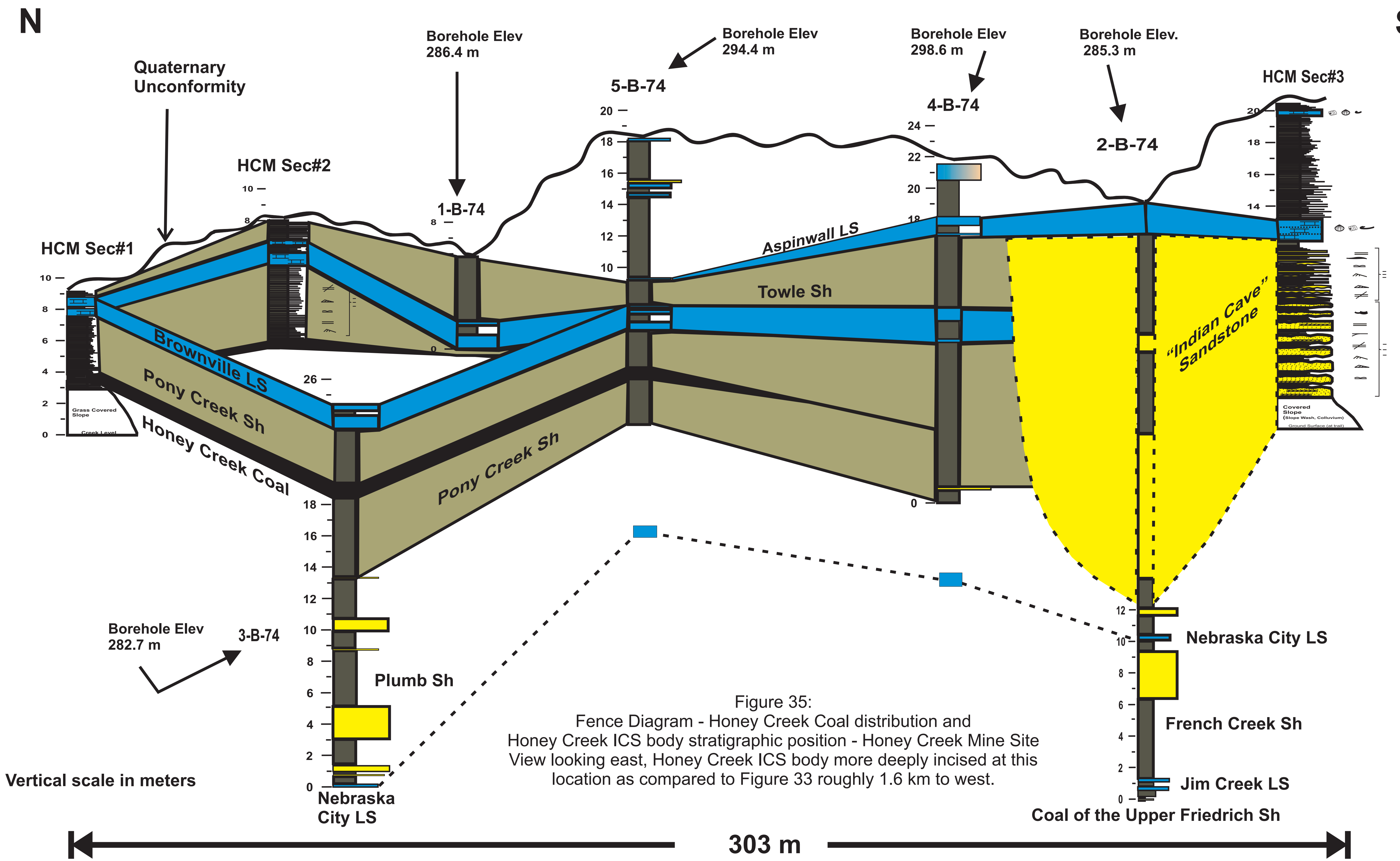


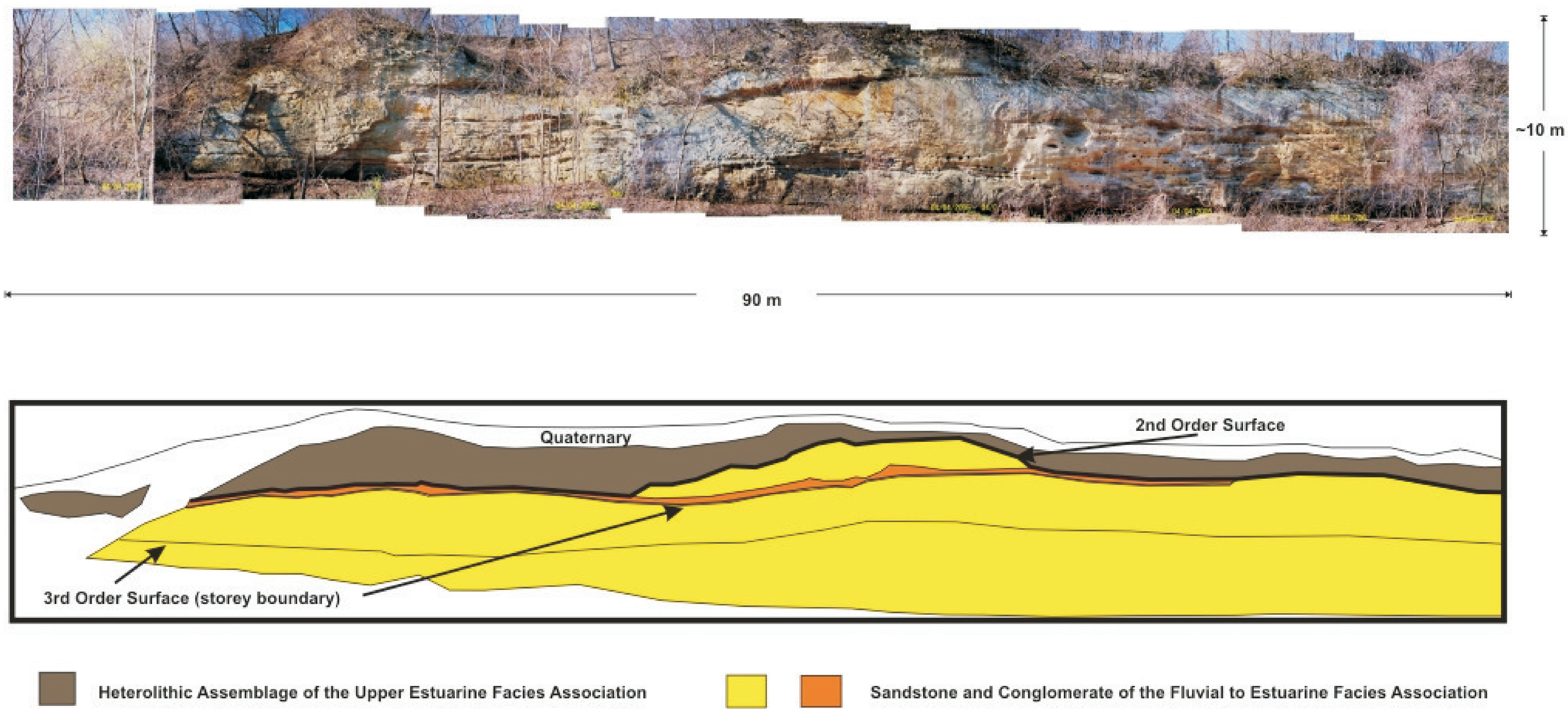
Figure 35:
Fence Diagram - Honey Creek Coal distribution and
Honey Creek ICS body stratigraphic position - Honey Creek Mine Site
View looking east, Honey Creek ICS body more deeply incised at this
location as compared to Figure 33 roughly 1.6 km to west.

limited lateral extent of the sandstone body at Brownville, the ICS body there occupies the stratigraphic interval where the Aspinwall and Brownville Limestones and the Pony Creek-Plumb Undifferentiated should be exposed, but are missing. Thus a basal erosion surface must inferred. South of Brownville, at the CNS weapons range and the Lippold Farm, multiple paleosols are present above and below the Brownville and Aspinwall Limestones (Fig. 11, Plate 1: Sections 2 and 3). It is likely that one of these paleosols correlates to the first order surface below the Brownville ICS body, most likely one above the Aspinwall Limestone, as the Brownville ICS body is interpreted to cut out the stratigraphic interval including the Aspinwall Limestone.

9.2 - Second Order Surfaces

Second order surfaces in ICS sandstone bodies are fully contained by a first order surface. The second order surfaces delimit depositional systems and mark the boundaries between the fluvial-to-estuarine facies association and the upper estuarine facies association (Figs. 36). All lower-order bounding surfaces are bounded by second order surfaces. The second order surfaces commonly exhibit a highly undulatory profile. This is most likely due to differential erosion and slope failure at, or above a contact, and relief along the contact. Outcrops of second order bounding surfaces are incompletely exposed and these surfaces do not appear to have a preferred orientation.

Figure 36: Stratigraphic Architecture, Peru Exposures - Second and Third Order Bounding Surfaces
Second order surface separates lower fluvial-to-estuarine facies association(yellow) from overlying upper estuarine facies association (brown).
Third order surfaces are found internal to the fluvial-to-estuarine facies association and mark breaks in sandstone bodies interpreted as storey boundaries.
View is looking west-southwest and paleoflow is to southwest (obliquely into page from right to left).



9.3 - Third Order Surfaces

Third order surfaces are contained within the fluvial-to-estuarine facies association and can be traced for tens to hundreds of meters across exposures. Third order surfaces are interpreted to represent storey boundaries because they contain groups of even lower-order, less-extensive bounding surfaces delimiting the extent of smaller-scale macroform and mesoform architectural elements (Miall, 1985) (Figs. 37, 38). The bounding surfaces of these lowest-order architectural elements were not consistently identifiable in outcrop, and therefore they were not mapped or interpreted.

Where third order surfaces have been recognized at Peru and ICSP, they are relatively flat and have preferred orientations as an apparent dip from largely two-dimensional exposures. At Peru, third order surfaces appear to dip south-southwest and strike west-northwest, at ICSP these surfaces dip south-southeast and strike to the east-northeast. At both Peru (paleoflow southwest, Fig. 25A) and ICSP (paleoflow southeast, Fig. 25B), third order surfaces appear to dip slightly oblique to the dip of the cross-beds. In some cases, a third order surface is subtle because a surface may extend across an outcrop, but nonetheless appear to be conformable with the underlying unit. In other locations the same surface truncates underlying units. In yet other cases, third order surfaces are obvious because they are floored by facies Ci_h and mark an abrupt transition from underlying fine grained sediments to overlying intraformational conglomerates. Such a transition marks a significant change in states of flow, and also indicates periods or downcutting or channel expansion (see fluvial-to-

Figure 37: Stratigraphic Architecture - Peru Exposures, Third Order Bounding Surfaces
Vertical sandstone exposures along Steamboat Trace trail at Peru. Third order surfaces (storey boundaries) represented by heavy lines.
Lower order surfaces contained within third order surfaces shown with thin lines represent bed and sub-bed scale features (bed tops, bottoms, or individual cross-beds).
View looking west, paleoflow to southwest with groups of paleoflow readings shown by circles with inset arrows indicating direction relative to north (see Figure 25 for paleoflow summary).

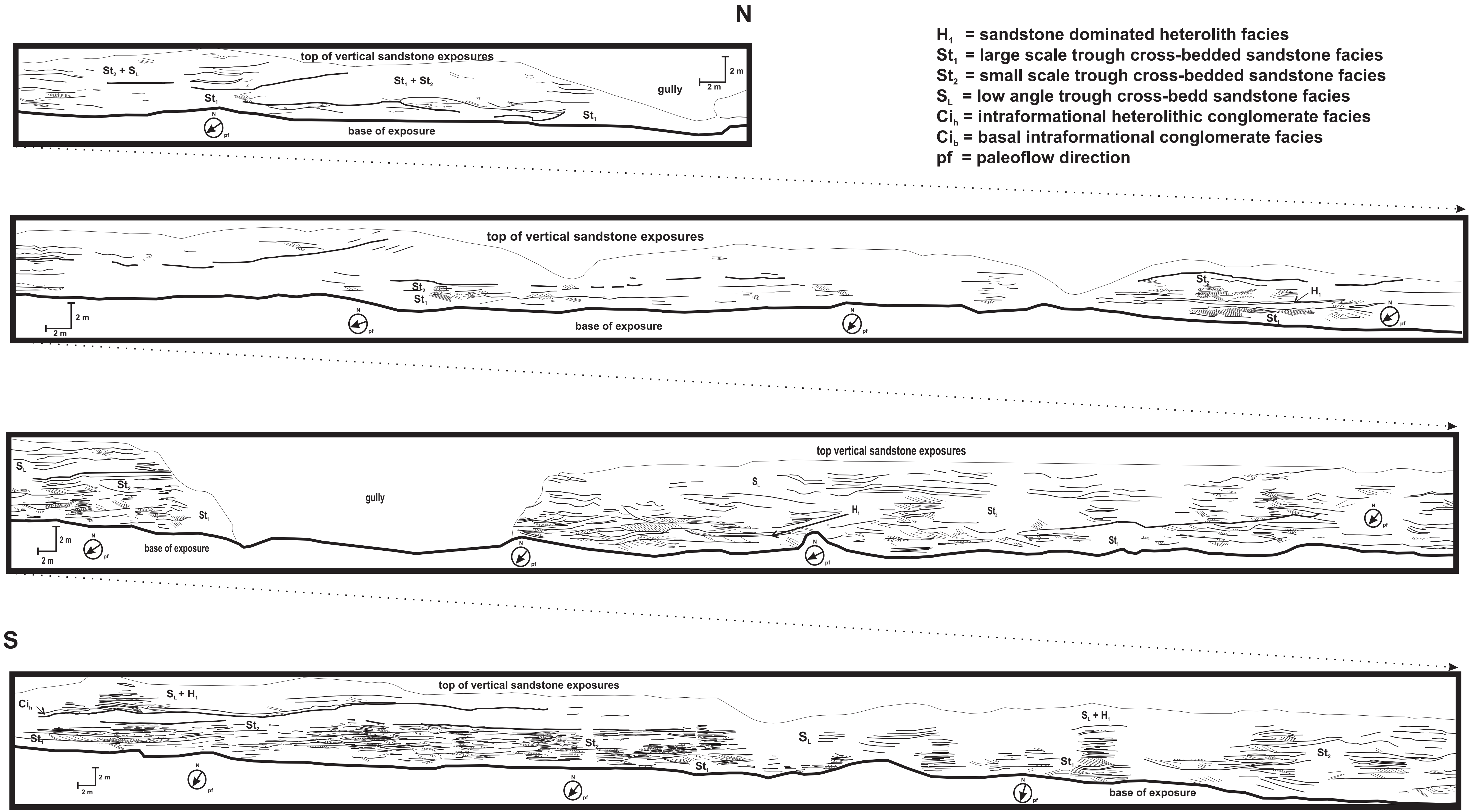
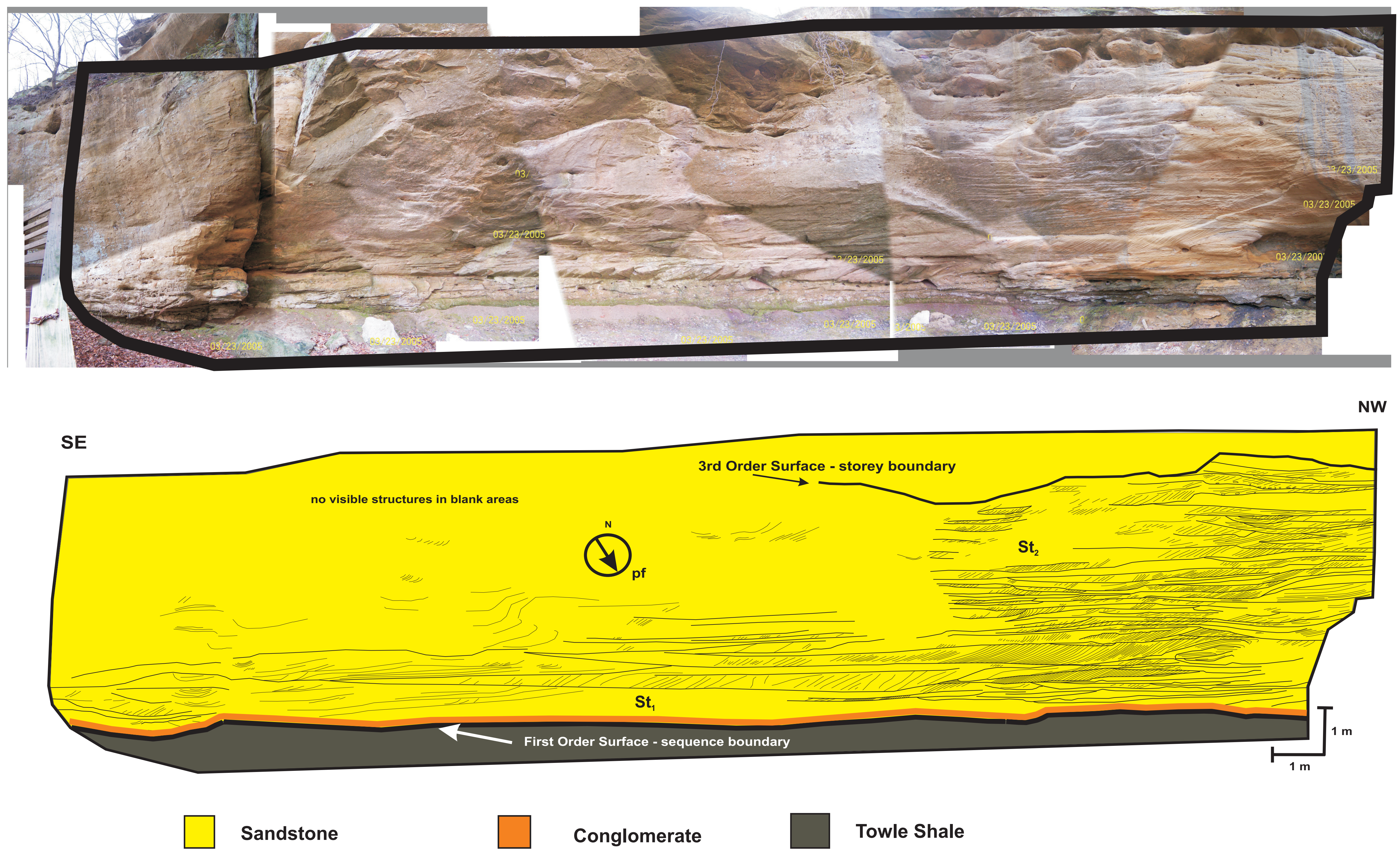


Figure 38: Stratigraphic Architecture - Indian Cave State Park. Exposure at "Indian Cave" First and Third Order Bounding Surfaces. First order surface (sequence boundary) is located at base of exposure at contact between conglomerate and underlying Towle shale. Third order surface (storey boundary) located near top of exposure and shown by heavy line on line drawing. Third order surface subtly truncates underlying strata, but is also marked by unit of Facies Ci_h out of frame of photo to right. Lower order bounding surfaces contained within third order surface shown with thin lines and represent bed and sub-bed scale features (bed tops, bottoms and individual cross-beds). View looking southwest, paleoflow to southeast (obliquely into photo from right to left) as indicated by circle with directional arrow relative to north (see Figure 25)



estuarine facies association). These changes may have been driven by base level fluctuations or by significant climatic (discharge) events in the watershed.

No third order surfaces were recognized in the Honey Creek ICS body. The Honey Creek ICS body has the narrowest lateral extent, and is interpreted to be a single-storey fill.

The bounding surfaces interpreted in ICS sandstone form the basis of a generalized sequence stratigraphic interpretation. Specifically, first order surfaces bound each ICS body and result from major falls in relative sea level. Second order surfaces likewise delineate boundaries between facies associations, and therefore are interpreted as evidence for abrupt marine transgressions. Third order surfaces, on the other hand, are not utilized in the sequence stratigraphic interpretation because they mark lower order discontinuities within the fluvial-to-estuarine facies association.

10 - Sequence Stratigraphic Model

In sequence stratigraphy, a *sequence* is composed of a package of genetically related strata, bound at its base and top by unconformities that pass laterally into conformable surfaces (Vail et al., 1977; Van Wagoner et al., 1988; Shanley and McCabe, 1994; Posamentier and Allen, 1999). The unconformities and laterally-correlative conformities bounding the genetically-related sequence are considered to be *sequence boundaries* when the genetically-related strata above the boundary are out of context with the strata below the boundary. Furthermore the sequence boundary must be recognizable regionally (Vail et al., 1977; Van Wagoner et al., 1988; Vail et al., 1991; Shanley et al., 1992; Shanley and McCabe, 1994; Posamentier and Allen, 1999). One example would be marine strata overlain by nonmarine strata and separated by an unconformity, which correlates to a widespread paleosol, or series of paleosols. The paleosols, in turn, are conformable within an otherwise unbroken succession of marine strata that overlie the nonmarine strata. This stacking of unconformities and correlative conformities bounding genetically-related strata would satisfy the criteria for both a *sequence* and a *sequence boundary* (Van Wagoner et al., 1988; Archer et al., 1994; Feldman et al., 1995; Heckel, 1998; Posamentier and Allen, 1999; Olszewski and Patzkowsky, 2003). The ICS sandstone bodies studied herein meet these criteria, and therefore they can be interpreted genetically using a sequence stratigraphic model.

At least three of the four ICS bodies directly overlie marine strata, and their basal contacts (first order surfaces) mark abrupt changes from marine shale (ICSP) or limestone (Peru and Honey Creek) to non-marine strata. Therefore, these basal ICS contacts are unconformable, having resulted from relatively abrupt basinward shifts in sedimentation. Where these units display a comparatively continuous fluvial-to-estuarine transition, however, the genetically-related stratigraphic units are the fining-upward sequences within the ICS bodies above the sequence boundary (Dalrymple et al., 1992; Shanley et al., 1992; Archer et al., 1994; Dalrymple et al., 1994; Zaitlin et al., 1994; Feldman et al., 1995; Archer and Feldman, 1995; Posamentier and Allen, 1999).

Using a sequence stratigraphic paradigm, a progression of events in the evolution of an ICS system can be developed from field data. First, a regression produced by a fall in relative sea-level exposed marine-dominated strata to fluvial erosion. During this regression, the low-gradient high shelf must have been subaerially exposed, and fluvial systems previously in equilibrium with the former sea-level were forced to adjust. Simultaneously, interfluves underwent subaerial weathering, and paleosols were developed regionally (Joeckel, 1989, 1994, 1995, 1999). As relative sea-level continued to fall, fluvial systems re-equilibrated, and thus incised the formerly inundated shelf (Dalrymple et al., 1992; Shanley et al., 1992; Archer et al., 1994; Dalrymple et al., 1994; Zaitlin et al., 1994; Feldman et al., 1995; Blum and Price, 1998; Posamentier and Allen, 1999; Blum and Tornqvist, 2000). This dynamic adjustment formed the incised valleys and/or channels containing the ICS system. Meanwhile, widespread interfluve paleosols developed on the regional extension of the sequence boundary. During late sea-level fall or stillstand, grade-adjusted fluvial systems finally began to accumulate sediments atop the incision surface (Figs. 31, 32, 39 and 40; Plates 1 and 2) (Dalrymple et al., 1992; Shanley et al., 1992; Archer et al., 1994; Dalrymple et al., 1994; Zaitlin et al., 1994; Archer and Feldman, 1995; Feldman et al., 1995; Blum and Price, 1998; Posamentier and Allen, 1999; Blum and Tornqvist, 2000).

By definition, a sedimentary succession deposited during relative sea level fall, associated stillstand, and slow initial rise is the Lowstand Systems Tract (LST) of Posamentier and Allen (1999). Thus, the basal infilling of the incised

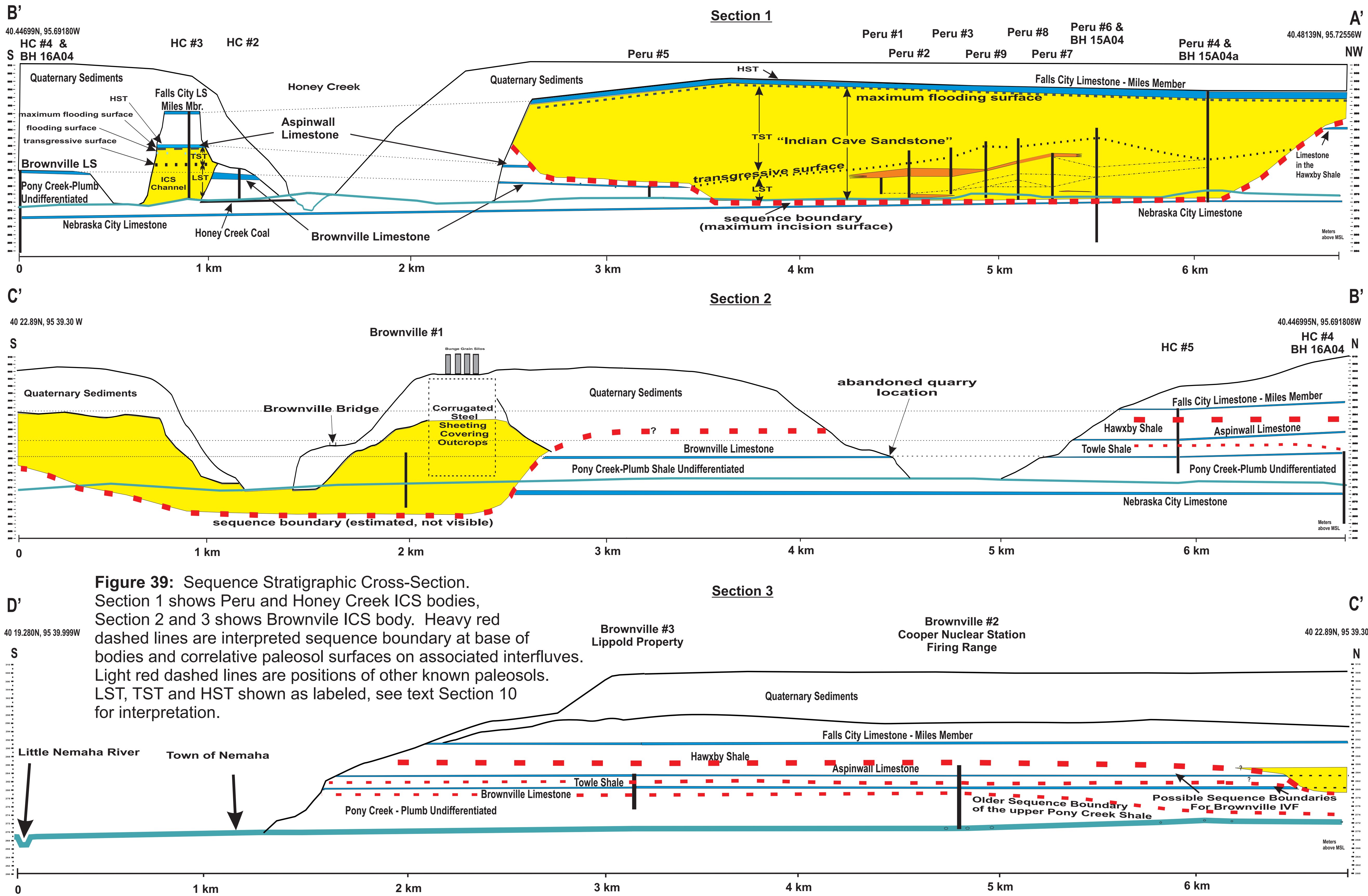
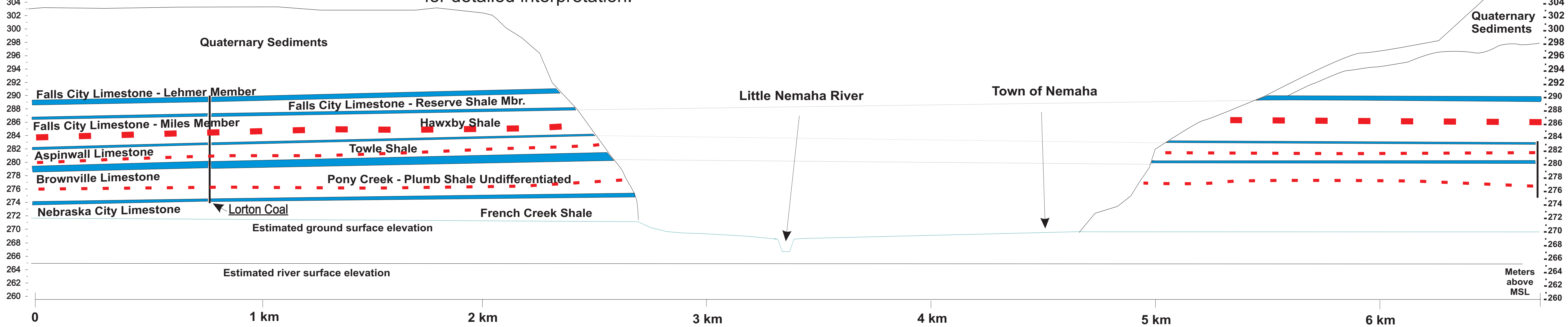


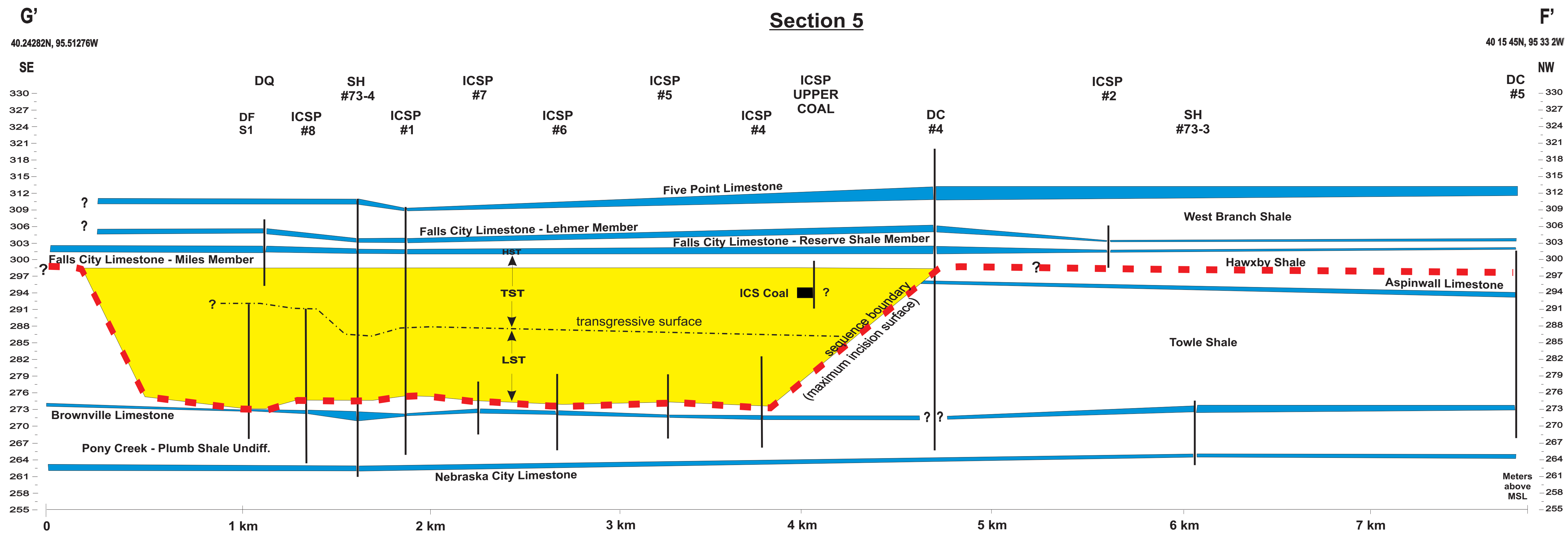
Figure 39: Sequence Stratigraphic Cross-Section. Section 1 shows Peru and Honey Creek ICS bodies, Section 2 and 3 shows Brownvile ICS body. Heavy red dashed lines are interpreted sequence boundary at base of bodies and correlative paleosol surfaces on associated interfluves. Light red dashed lines are positions of other known paleosols. LST, TST and HST shown as labeled, see text Section 10 for interpretation.

Section 4

Figure 40: Sequence Stratigraphic Cross-section. Section 4 shows interfluve paleosol interpreted as the sequence boundary as heavy red dashed line, extended from CNS Weapons Range section to south. Other known paleosols shown as thin red dashed lines. Section 5 shows ICS body at ICSP with sequence boundary shown with heavy red dashed line along with correlative interfluve paleosol. LST,HST and TST shown as labeled, see text Section 10 for detailed interpretation.



Section 5



valley represents the LST (Figs. 39 and 40; Plates 1 and 2) (Archer et al., 1994; Zaitlin et al., 1994; Archer and Feldman, 1995; Posamentier and Allen, 1999). In the case of the ICS bodies as a group, it is clear that these basal units were deposited during at least two separate events. The Honey Creek sandstone body lies lower in the stratigraphic section than the Peru, Brownville and ICSP sandstone bodies, making it an older sequence. Therefore, a minimum of two regressive-transgressive cycles are recorded.

The subsequent transgression is represented by the upward increase in tidal influence in the IVF. Sea-level fluctuations likely influenced sedimentation far upstream in an IVF fluvial-estuarine system because of the high shelf position and low surface gradients. These systems continued to fill with tidally-influenced fluvial strata until the transgression advanced inland far enough to force a comparatively abrupt switch to upper-estuarine sedimentation. Switching is reflected by the second-order bounding surfaces between the lower fluvial-to-estuarine fill and the upper estuarine fill. These bounding surfaces are flooding surfaces (FS) and also constitute the base of the Transgressive Systems Tract (TST) (Figs. 39 and 40; Plates 1 and 2) (Dalrymple et al., 1992; Shanley et al., 1992; Archer et al., 1994; Posamentier and Allen, 1999).

As relative sea-level continued to rise, and the incised valley system was progressively drowned, deposits within the valley responded through the accommodation of more upper estuarine sediments. However, extremely low surface gradients and the resultant abrupt transgression prevented the deposition or preservation of middle and/or lower estuarine facies. Instead, as the system was rapidly transgressed it became part of a broad marine embayment, where bioturbated marine muds were deposited atop upper estuarine facies. The furthest-inland encroachment of sea level is represented by the top of this marine mud (shale), and is the Maximum Flooding Surface (MFS) (Figs. 39 and 40; Plates 1 and 2) (Dalrymple et al., 1992; Zaitlin et al., 1994; Posamentier and Allen, 1999).

As sea-level continued to rise, terrigenous sedimentation moved far landward, and offshore carbonate deposition was initiated. A carbonate-bank environment is represented by limestone units overlying nearshore marine shales. These limestones represent the Highstand Systems Tract (HST) (Figs. 39 and 40; Plates 1 and 2) (Shanley et al., 1992; Archer et al., 1994; Shanley and McCabe, 1994; Posamentier and Allen, 1999).

This model is based on the assumption that the ICS bodies represent deposits located significantly updip of the lowstand shoreline in a very low-gradient epicontinental platform. Indeed, estimates of gradients on the Midcontinental shelf are 10^{-1} to 10^{0} m/km, with imposed structural dips ranging no more than 0.15° - 0.25° (Heckel, 1977, 1980; Olszewski and Patzkowsky, 2003). Therefore vast areas of the North American continent were alternately submerged and exposed by periodic fluctuations in sea level (Fig. 41) (Heckel, 1980; Archer and Feldman, 1995; Scotese, 2003; Feldman et al., 2005; Blakey, 2005). Incised valleys provide a means to directly measure minimum amplitudes of sea-level change. The maximum thickness of an IVF, from the basal sequence boundary

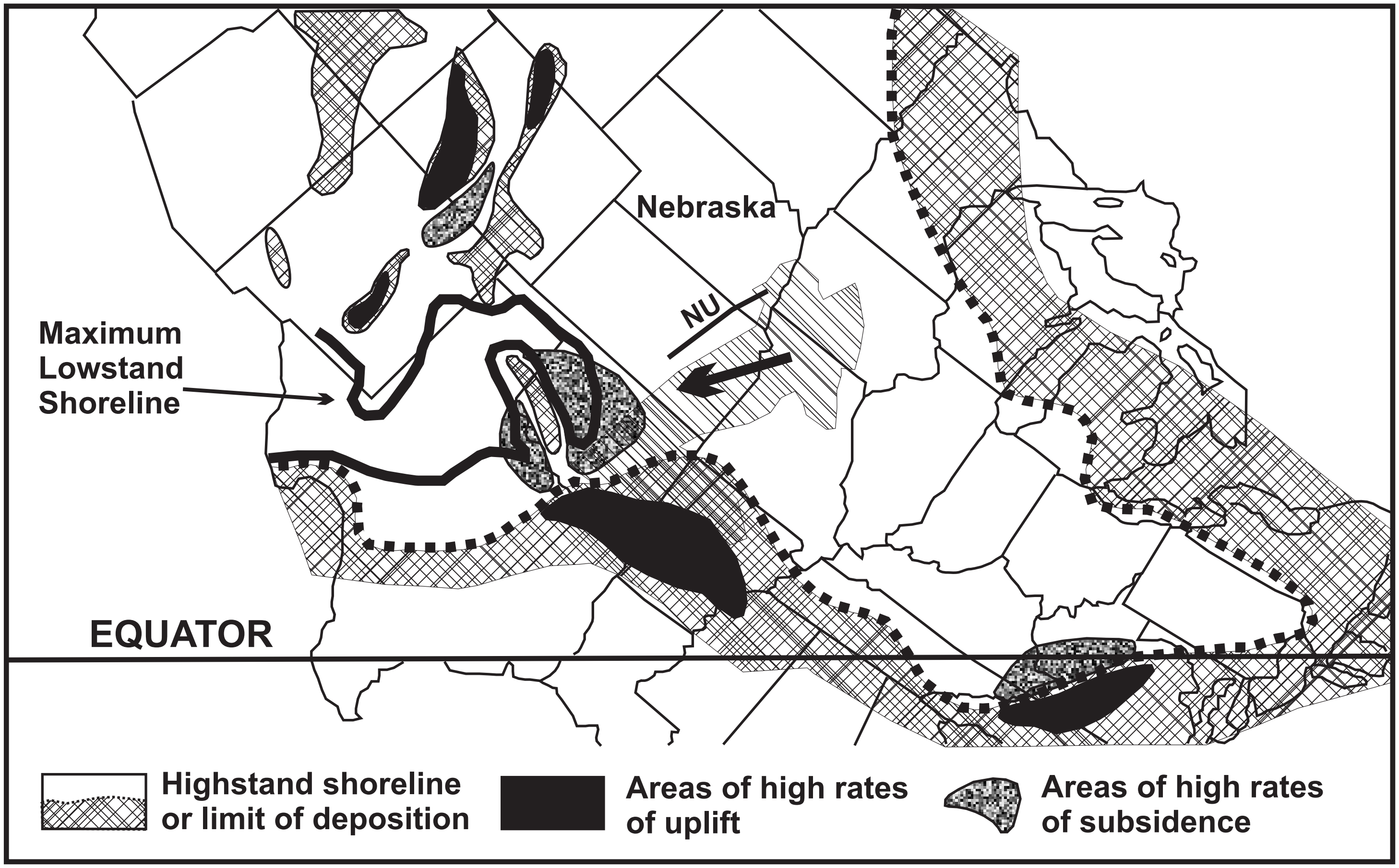


Figure 41: Middle to Late Pennsylvanian paleogeographic map show highstand and lowstand shoreline. Note the location of southeastern Nebraska relative to shoreline positions. Parallel lines = Pennsylvanian Outcrop in Midcontinent; Black Arrow = Depositional Dip; NU = Nemaha Uplift; (modified from Feldman et al. 2005).

to the top of the top of the highstand systems tract, is the minimum estimate. For three of the four ICS bodies described herein, this estimate is 30 m.

Paleosols are the contemporaneous interfluvial record of valley incision. The Pony Creek, Towle, and Hawxby shale members all show evidence for pedogenesis. In the study area, these paleosols lie well above the basal incision surfaces, and are present where the ICS bodies are absent. Therefore some of these paleosols are interpreted as the interfluves for the ICS bodies. Paleosols identified in the Towle Shale are correlated to the Honey Creek ICS body, and in the Hawxby Shale are correlated to the Peru, Brownville and ICSP bodies.

Pennsylvanian IVFs have been described in many places across North America, from the Midcontinent, to the Appalachian Basin and Nova Scotia . (Archer et al., 1994; Gibling and Bird, 1994; Archer and Feldman, 1995; Feldman et al., 1995; Heckel et al., 1998; Aitken and Flint, 1994; Kvale and Barnhill, 1994; Bowen and Weimer, 2003, 2004). All of these IVF systems appear to share similarities. Each IVF is underlain by a recognizable sequence boundary, and the strata composing the fill are described as fluvial-to-estuarine deposits. The incision surfaces bounding these IVF strata record sea-level fall, and are the sequence boundaries. Subsequent sea-level rise and transgression of the system is recorded by the fluvial-to-estuarine lithofacies deposited in the accommodation space.

Some differences are also apparent in these geographically diverse IVFs. Some of these IVFs are highly composite and paleosols have not been identified on the associated interfluves (Bowen and Weimer, 2003, 2004). Others indicate outer and middle estuary facies have been preserved, such as estuarine mouth bars, tidal sand bars, extensive tidal rhythmites, bayhead deltas, shelly ravinement surfaces and a diverse array of trace fossils (Kvale and Barnhill, 1994; Archer et al., 1994; Archer and Feldman, 1995; Feldman et al., 1995; Bowen and Weimer, 2003). Facies preservation in an estuarine system is complex, and is a function of many inter-related factors including sediment supply, wave or tide domination, size and shape of the drowned valley, river and tidal currents, wave activity, the relative position within the estuarine system, and the evolutionary stage of the estuary system (Dalrymple et al., 1992, 1994). While facies identified can be associated with models of estuarine systems, no generalized model can explain the variability in real examples, whether modern or ancient (Dalrymple et al., 1994).

The relative abundance of Pennsylvanian IVFs indicates that the Pennsylvanian shelf of North America was characterized by punctuated subaerial exposure and development of incised fluvial systems. These incised systems, when transgressed, became accommodation and recorded the development of fluvial-to-estuarine systems on the epicontinental platform. From the IVFs investigated in this study, this record reflects frequent sea-level change (four IVFs of at least two different ages in 30 - 40 m of section) with only modest fluctuations in sea level (30 m) as compared to 60 – 200 m postulated by others (Moore and Adlis, 1964; Heckel, 1980; Ross and Ross, 1987; Soreghan and Giles, 1999) The periodicity of these punctuated subaerial exposure events is evident in the stratigraphic record, although the timeframes associated with this periodicity are currently a matter of conjecture.

10.1 - Timeframes and Cyclicity

Evidence for high frequency sea-level fluctuations has been recognized in cyclic successions globally (Saunders et al., 1979; Busch and Rollins, 1984; Ross and Ross, 1985; Algeo and Wilkinson, 1988; Goldhammer et al., 1990; Maynard and Leeder, 1992; Miller and West, 1993; Olszewski and Patzkowski, 2003; Wardlaw et al., 2004) although not all workers agree that apparent cyclicity reflects any natural organization (Wilkinson et al., 2003). Disconformities identified at subaerially exposed surfaces with characteristic regional paleosols have been interpreted as sequence boundaries in dominantly marine strata (Goldhammer et al., 1990; Joeckel, 1991,1994; Miller and West, 1993; Heckel, 1994; Wilkinson et al., 2003, Feldman et al., 2005).

On the basis of the sequence of rock units and assemblages, Wardlaw et al., (2004) and Olszewski and Patzkowski (2003) interpret an ordered hierarchy of stratigraphic sequences, as well as sea-level fluctuations throughout the Upper Pennsylvanian-Lower Permian of the Midcontinent (Fig. 42 and 43). In their interpretations, as well as others (Miller and West, 1993; Joeckel, 1991, 1994, 1999; Heckel, 1998) the widespread occurrence of paleosols within certain portions of the section serve as evidence for emergence and prolonged subaerial exposure.

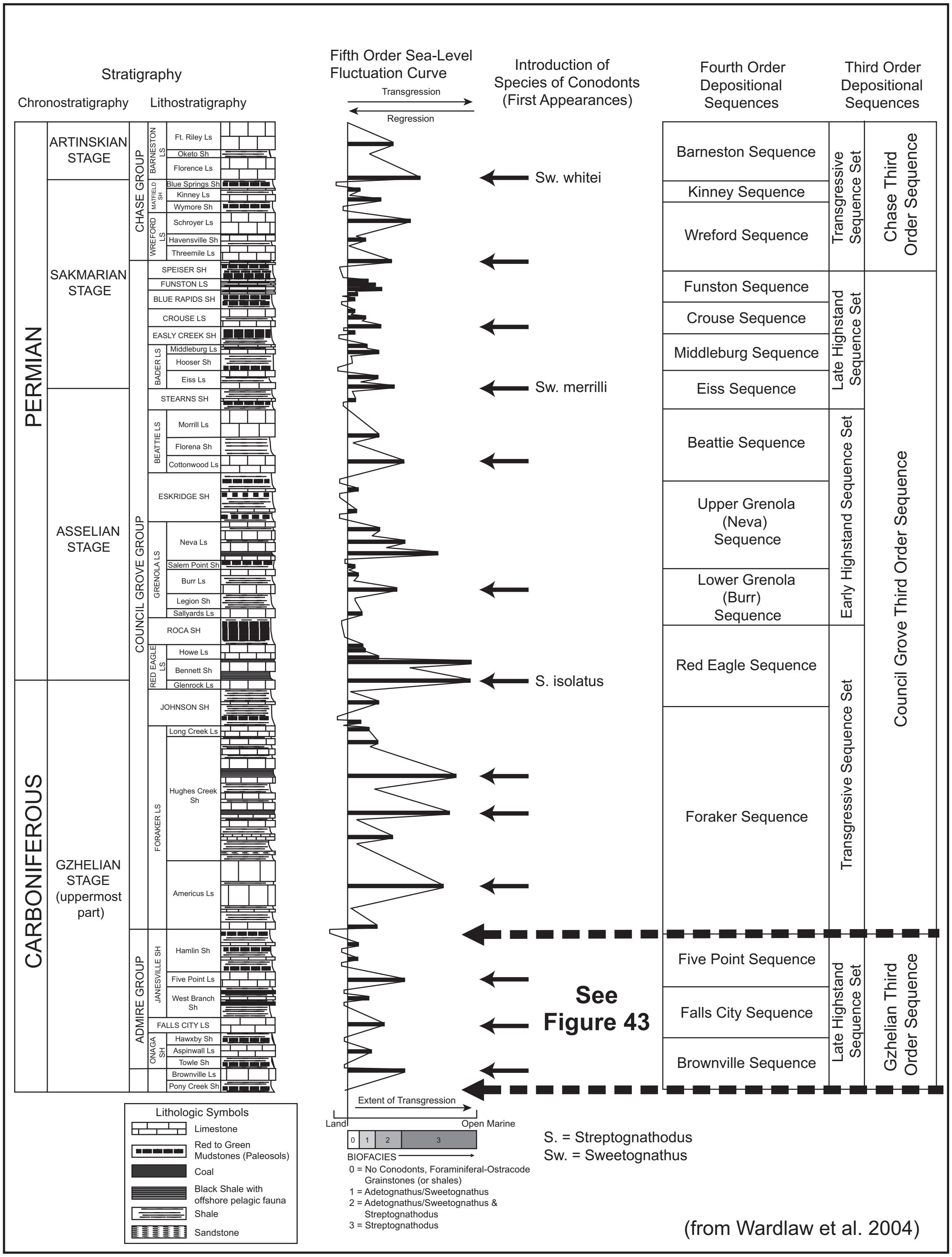


Figure 42: Regional sequence stratigraphic interpretation from Wardlaw et al. 2004 for the Midcontinent. Regional paleosols identified on this diagram were also identified by Olszewski and Patzkowski (2003) in their sequence stratigraphic interpretation of the Midcontinent for this portion of the section. Area between heavy dashed lines is interval of interest for this investigation, and an expanded view of this portion of the section is shown on Figure 43, along with localized correlative elements.

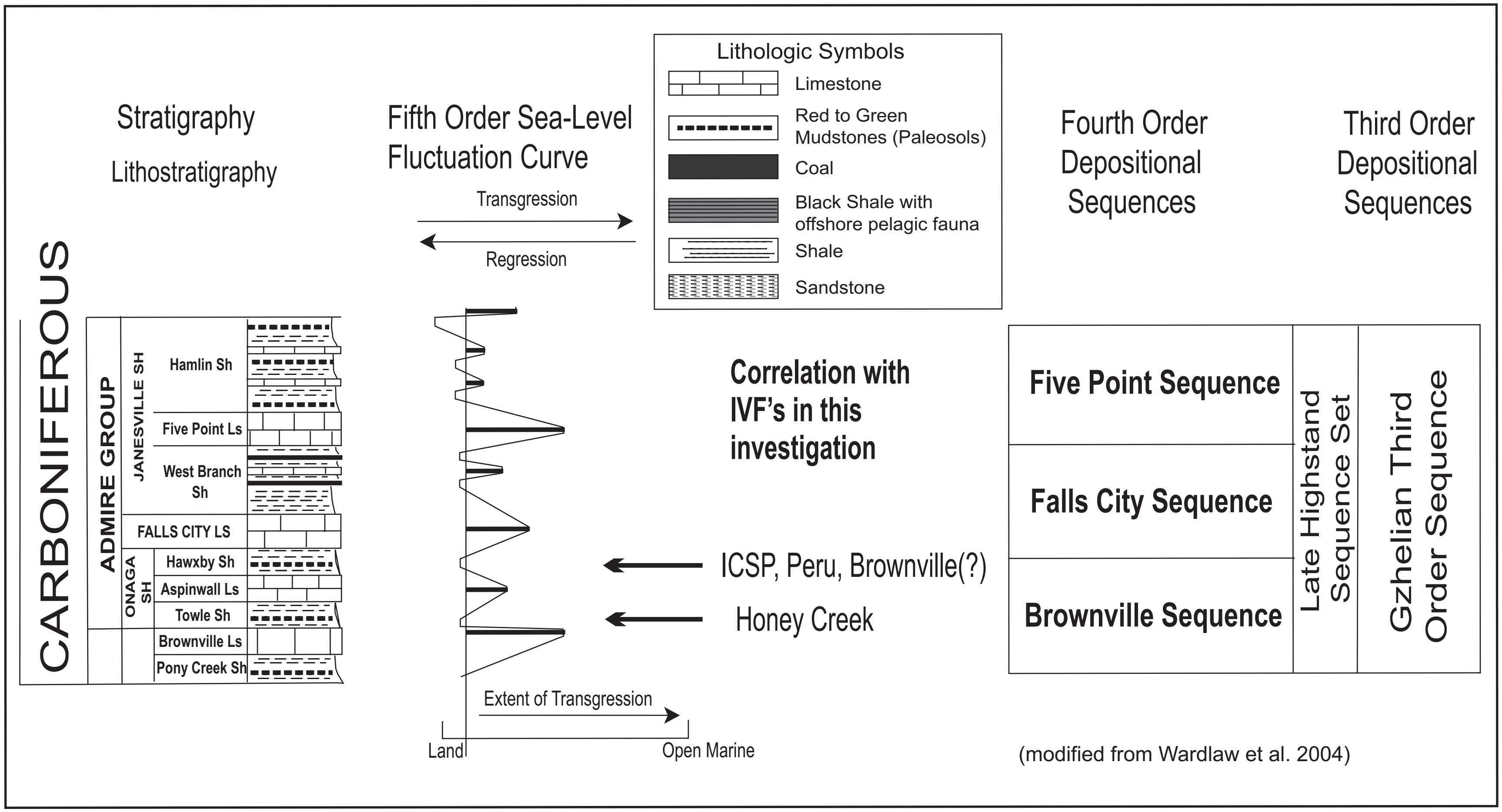


Figure 43: Enlargement of portion of stratigraphic section from Figure 42 covering the stratigraphic interval of this investigation. Incision surfaces marking the sequence boundaries for ICS bodies are here correlated to regionally recognized paleosols delineated by both Olszewski and Patzkowski (2003) and Wardlaw et al. (2004). Sequence boundary for the ICSP and Peru ICS bodies correlate to regional paleosols identified in the Hawxby Shale and the Honey Creek ICS body correlates to a regional paleosol identified in the Towle Shale. Brownville ICS body assignment to the Hawxby paleosol is tentative due to uncertainty of stratigraphic position of this ICS body.

Wardlaw et al. (2004) propose that the stratigraphic interval containing the ICS bodies represents a Gzhelian third-order sequence composed of three fourth-order sequences (Brownville Sequence, the Falls City Sequence, and Five Point Sequence). They also interpret a fifth-order sea level curve from widespread subaerial exposure surfaces and paleosols found within the Pony Creek Shale, Towle Shale, West Branch Shale and Hamlin Shale (Fig. 43).

Olszewski and Patzkowsky (2003) interpret areally extensive paleosols as evidence for bounding surfaces within composite fourth order sequences. Two fourth order composite sequences include the Richardson Composite Sequence (Dover Limestone through Aspinwall Limestone) and the Falls City/Five Point Composite Sequence (Aspinwall Limestone through the Hamlin Shale). Within each composite sequence, certain regional paleosol surfaces correlate to incised valley fills (in Kansas) and define a class of fifth-order cycles (Nearshore Cycles) (Olszewski and Patzkowsky, 2003).

Paleosols identified as fifth order sequence boundaries by both Olszewski and Patzkowsky (2003) and Wardlaw et al., (2004) correlate to the position of paleosols in this study. In this investigation, paleosols in the Towle and Hawxby shale members are interpreted to correlate as the remnants of the exposed interfluves of the associated incised valleys (see Section 10 above and Figs. 39 and 40). As Wardlaw et al. (2004) utilize a more refined terminology with respect to stratigraphic position (as compared to that of Olszewski and Patzkowsky, 2003), their terms are used herein to make the following correlations between this investigation and their work as follows: the Honey Creek ICS body would correspond to a fifth order sequence found within the fourth order Brownville Sequence of the third order Gzhelian Late Highstand Sequence. The ICSP and Peru ICS bodies would correspond to a fifth order sequence found within the fourth order Falls City Sequence of the third order Gzhelian Late Highstand Sequence (Fig. 43). The stratigraphic position of the upper and lower contacts of the Brownville ICS body are currently unknown, however, it is known that the Brownville body is younger than the Brownville sequence, as it occupies the stratigraphic position of both the Brownville and Aspinwall limestones. This stratigraphic position would make it at least equivalent to the fifth order sequence found in the fourth order Falls City Sequence, or possibly younger.

Because the ICS bodies can be interpreted to correlate to fifth order sequences, then minimum sea-level fluctuations of 30 m can also be associated with these sequences, and that at least two events can be further associated with two fourth order cycles. In short, this would indicate that ice volume in the Southern Hemisphere must have fluctuated such that it controlled base level fluctuations in the Northern Hemisphere by a minimum of 30 m at fifth order frequencies, and this happened repeatedly within the Upper Pennsylvanian portion of the section.

As the ICS clearly does not represent one genetic unit, but rather units of different ages, and meets the definition of an allostratigraphic unit (NACSN – North American Stratigraphic Code: Article 58, 1983), it is herein proposed that these units be informally renamed correlative to their specific location, with an IVF suffix, followed by the name of the interpreted fifth order sequence. As such, the proposed naming is as follows: Honey Creek IVF – Brownville Sequence; Peru IVF – Falls City Sequence; Indian Cave IVF – Falls City Sequence; Brownville IVF – Falls City Sequence(?) tentative.

The ICS, historically considered to be a single genetic unit, is herein reinterpreted as multiple incised-valley-fills of at least two different ages on the Late Pennsylvanian northern Midcontinent Shelf. Glacio-eustatic events drove valley incision, with maximum incision occurring during sea-level lowstands. Valley dimensions may exceed 2 km in width and are at least 30 m deep. Incision surfaces are interpreted architecturally as first order bounding surfaces, and sequence stratigraphically as sequence boundaries. Paleosols were developed outside the confines of the incised valleys on the adjacent interfluves. These contemporaneous surfaces are interpreted as the lateral continuation of the sequence boundaries.

These incised valleys were filled during subsequent sea-level rise. Analysis of facies associations found within strata in the IVF indicate that initial valley infilling was dominated by fluvial-to-estuarine sedimentation, and these deposits represent the lowstand systems tract (LST). Storey boundaries have been identified within the fluvial-to-estuarine facies association, and these storey boundaries are interpreted architecturally as third order bounding surfaces. Continued transgression is marked by an abrupt vertical shift from the fluvial-to-estuarine facies association to the upper estuarine facies association, and the surface separating these two facies associations is interpreted as a transgressive surface. Architecturally this surface is interpreted as a second order bounding surface. The upper estuarine facies association is interpreted to represent the transgressive systems tract (TST).

As transgression proceeded, and the incised valleys were flooded above the level of the interfluves, sedimentation was no longer confined to the valley fills. These deposits are represented by marine shale overlying the IVF deposits, and the marine shale in turn is overlain by marine limestone. These strata represent the deepest water facies, and the contact between the marine shale and the marine limestone is interpreted as the maximum flooding surface (MFS) and the marine limestone is interpreted to represent the highstand systems tract (HST).

Sequence boundaries identified in this investigation have been correlated to regional fifth order sequence boundaries identified by Olzewski and Patzkowski (2003) and Wardlaw et al. (2004). The correlation to a regional sequence stratigraphic framework provides a means to estimate sea-level change at fifth order frequencies. These data indicate that a minimum of 30 m of sea-level change can be associated with fifth order frequencies during the Late Pennsylvanian on the northern Midcontinent Shelf.

11 – Summary and Conclusions

From the data collected during this investigation, the following can be concluded:

1. In southeastern Nebraska alone, two or more stratigraphic intervals contain sandstone bodies that have previously been referred to as the Indian Cave Sandstone. At the location reported to be the type locality (now known as Indian Cave State Park), the Indian Cave Sandstone lies below the base of the Falls City Limestone and above the base of the Towle Shale. At Peru, Nebraska, an "Indian Cave" sandstone body is overlain by the Falls City Limestone, but underlain by the Nebraska City Limestone, indicating much deeper local incision. At Honey Creek an "Indian Cave" sandstone body is overlain by the Aspinwall Limestone and locally underlain by the Brownville Limestone, thereby meeting the original definition of the Indian Cave Sandstone. However, this unit is incised below the Brownville Limestone at other localities. At Brownville, Nebraska, the base and top of a putative "Indian Cave" Sandstone body could not be identified. However, the sandstone body at Brownville occupies a stratigraphic position from above the Aspinwall Limestone down into at least the Pony Creek-Plumb Undifferentiated, making it younger than the body at Honey Creek. This body may or may not be correlative to those found at Peru and Indian Cave State Park.

A type section, in the strictest sense, for the Indian Cave Sandstone does not exist. A section measured in the "type area" (Moore and Moss, 1934;

Moore, 1936; Mudge, 1956; and Mudge and Yochelson 1962) is herein suggested for adoption as a reference section.

2. The standing deltaic interpretation of the Indian Cave Sandstone in Nebraska (Ossian, 1974) is incorrect. All of the ICS sandstone bodies in Nebraska consist of upward-fining sequences of trough cross-bedded sandstones and conglomerates, small-scale trough cross-bedded sandstone interbedded with intraformational conglomerates, sandstone-dominated heterolith and mudstone dominated heterolith. The sequence is overlain by marine shale and limestone representing offshore deposition.

Basal parts of sandstone bodies are interpreted as deposits from the uppermost reaches of a tidally-influenced river system, in the fluvial-to-estuarine transition. The upper finer-grained exposures are interpreted as upper estuarine deposits most likely found in the lowest portion of the “straight-meandering-straight” portion of the upper estuary, or in the upper part of the estuarine funnel as defined by Dalrymple et al. (1992). The overlying marine units are interpreted to represent marine embayment and carbonate bank environments found in progressively deeper water as transgression proceeded, and are not considered part of the main ICS bodies.

3. The minimum overall sea-level fluctuation required to deposit the Indian Cave Sandstone and overlying marine units was 30 m (100 ft) as determined from fully-penetrating measured section thickness of the ICS bodies.

4. Sandstones formerly assigned to the Indian Cave Sandstone were deposited in multiple incised valleys at different times. The basal incision surface and associated interfluves of the incised valleys represent sequence boundaries. The subsequent infilling of the incised valley with sediments from the fluvial-to-estuarine transition produced a Lowstand Systems Tract (LST). The overlying abrupt change in sedimentation to finer grained deposits of the upper estuary define the position of the Flooding Surface (FS), and the start of the Transgressive Systems Tract (TST). The first occurrence of marine shale over the top of the upper estuarine fill marks the position of the Maximum Flooding Surface (MFS), the base of which marks the top of the ICS bodies, and the limestone overlying the marine shale is interpreted to represent the deepest water facies and is synonymous with the Highstand Systems Tract (HST).

5. Sequence boundaries underlying the Indian Cave Sandstone bodies were correlated with local paleosols. The paleosols stratigraphically correlate with a series of regional paleosols recognized by Olszewski and Patzkowski (2003) and Wardlaw et al. (2004). These investigators used the regional paleosols to define fifth order sequences boundaries. This correlation implies that that ice volume fluctuations in the Southern Hemisphere must have been such that at least 30 m of sea-level drawdown and recovery could be achieved at fifth order frequencies.

6. Because the Indian Cave Sandstone bodies are now interpreted as different incised valley fills of different ages, and can be considered an allostratigraphic unit, a new informal naming scheme for these units is herein proposed. The Indian Cave Sandstone bodies presently known in the study area are proposed to be renamed in accordance with the Wardlaw et al. (2004) scheme as: Peru IVF – Falls City Sequence; Indian Cave IVF – Falls City Sequence; Honey Creek IVF – Brownville Sequence; Brownville IVF – Falls City Sequence (?) tentative.

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APPENDIX A

Stratigraphic Logs and Location Maps

Section Name: Aspinwall Calibration Section

Location (lat/long): 40.30442N, 95.64487W

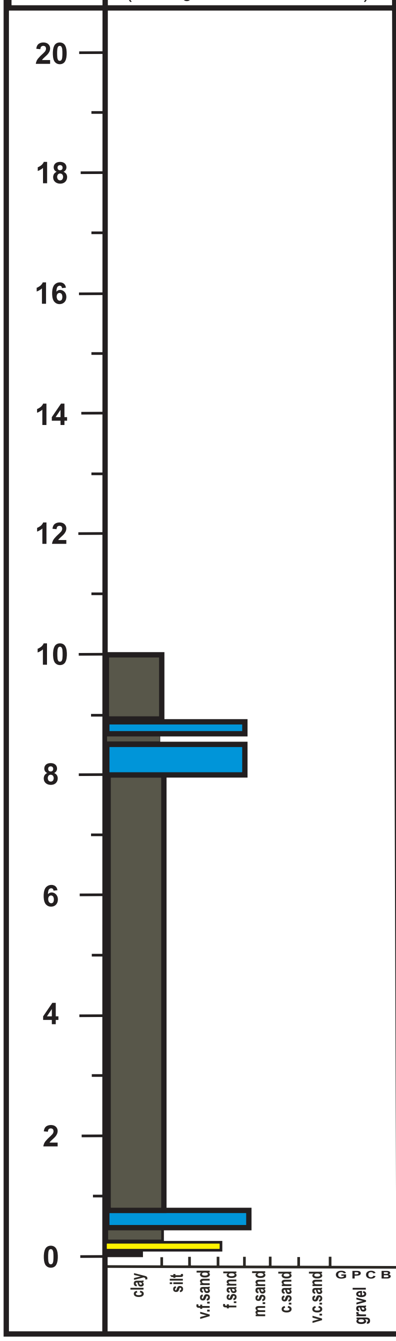
Total Thickness Measured: 9.06 m

Date Measured: 04/08/2005

Measured By: Fischbein, S.A., Joeckel, R.M.

Thickness (Meters)

Graphic Log (Lithologies, Structures, Fossils)



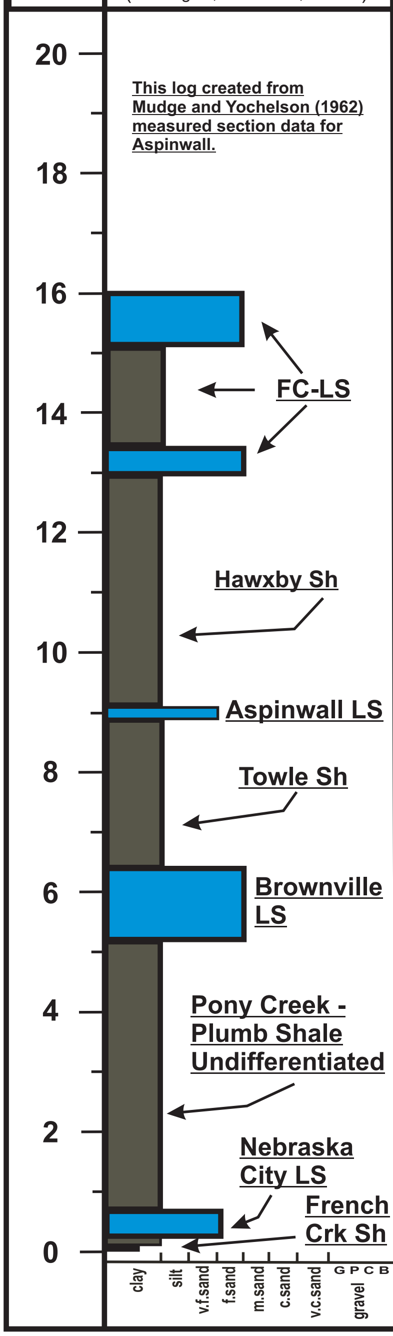
Facies	Depositional Environment	Lithologic Description
		Falls City Limestone blocks not found in place, however, all float blocks found immediately above Brownville were tan to whitish tan, and slightly orangish, weathering gray to gray with greenish tint grainstone that would be classified as "coquinoid" limestone by older terminology Outcrop found on main roadway of same unit measured 1 to 1.2 m thick.. Not measured above Brownville, very limited outcrop, blocks of Falls City Limestone found, but not in place. Overlying unit dominatly shale and mudstone dominated heterolith. This would equate to Hawxby Shale.
0.85-0.91 m		**Brownville Limestone:** Gray, weathering brown to tan packstone to wackestone w/ brachs, gastropods and fusilinids, 2.5Y7/4-7/6, 5Y7/1. 16-22 cm Shale interbedm green-gray to dark gray, fissile, mottled, with some brachs, 10YR6/1-7/1 w/mottles N4/0. 14 cm LS, gray weathers brown to tan as above, mudstone to wackestone, 55 cm
7.4 m		**Pony Creek-Plumb Shale Undifferentiated:** Shale to mudstone dominated heterolith with rip x-lam sandstone lenses and and interbeds up to 70 cm thick.
0.3 m		**Nebraska City Limestone:** Gray, weathers tan to brown, mottled red, highly bioturbated 30 cm
0.35 m	Lorton Coal	**French Creek Shale:** Sandy shale, brown w/reddish mottles, 25 cm Sandstone, gray, rip x-lam w/plant, coal frags 10 cm Coal,to shale w/coal laminae, 10 cm

Section Name: Aspinwall Type Section #1

Location (lat/long): 40 17 57.9N, 95 38 36.1W **Total Thickness Measured:** 16 m (53.1 ft)

Date Measured: 1962 **Measured By:** M.R Mudge, E.L. Yochelson

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Facies	Depositional Environment	Lithologic Description
0.74 m 1.62 m 0.3 m		**13.25 - 16 m, Falls City Limestone:** **Lehmer Limestone Member** 74 cm, Limestone, soft, gray, massive, weathers blocky; oolitic, porous, bedding planes apparent on weathered surface; thin gray clay lentils 2 to 5 cm long parallel with bedding; pelecypod fragments very abundant, stromatolite nodules. **Reserve Shale Member** 162 cm Shale, covered. **Miles Limestone Member** 30 cm, Limestone, gray, weathers tan, blocky to irregular plates; coquina, especially in lower 21 cm; top part contains thin zone of *Crurithyris* and other brachiopods and bryozoans, crinoid columnals, and pelecypods.
4.38 m		**8.87 - 13.25 m, Hawxby Shale:** 45 cm, Shale, gray-green, thin bedded, limonite nodules abundant in upper part. 24 cm, Siltstone, tan, massive to thin-bedded. 369 cm, Shale, clayey, gray to gray green, blocky; purple tint on weathered surface; tan zone in upper-part, fractures filled with calcite.
0.1 m		**8.77 - 8.87 m, Aspinwall Limestone:** 10 cm, Limestone, light-gray with green tint, medium hard, "coquina of fossil fragments".
2.32 m		**6.45 - 8.77 m, Towle Shale:** 232 cm, Shale, silty, tan maroon and gray in lower part. Poorly exposed.
1.25 m		**5.2 - 6.45 m, Brownville Limestone:** 42 cm, Limestone and calcareous shale, medium hard, light-brown, fine-grained, with *Marginifera* and other brachiopods. 82 cm, Limestone, hard, light brown, massive, weathers tan and blocky. Abundant *Marginifera; Crurithyris* and other brachiopods and crinoid columnals common
4.59 m		**0.61 - 5.2 m, Pony Creek Shale and Plumb Shale Undifferentiated:** 313 cm Green-gray shale, mostly covered. 173 cm Green-gray shale grading to maroon shale in upper part. Thin bedded, iron stains and plates common.
0.36 m		**0.25 - 0.61 m, Nebraska City Limestone:** Hard, gray, weathering tan, massive; weathers blocky to shaly in upper part, abundant fossil fragments; brachiopods and bryozoans.
0.25 m	Lorton Coal	**0 - 0.25 m, French Creek Shale:** 15 cm Gray weathering tan calcareous shale with brachiopod fragments. 10 cm Coal, black, thin bedded.

Section Name: Aspinwall Type Section #2

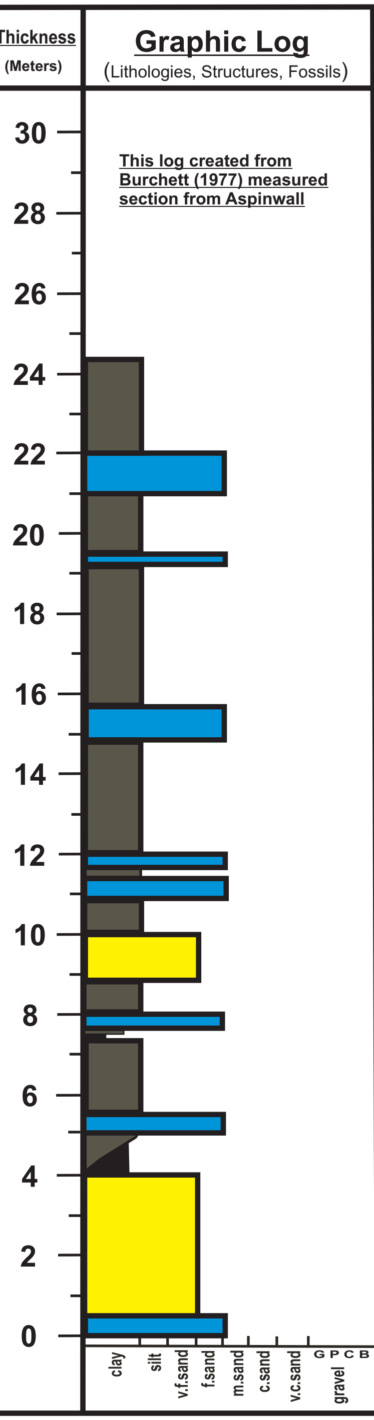
Page 1 of 1

Location (lat/long): 40.30442N, 95.64487W

Total Thickness Measured: 24.5 m

Date Measured: 1977

Measured By: Burchett, R.R.



Facies	Depositional Environment	Lithologic Description
		West Branch Shale: Shale, maroon, silty, 30 cm Shale, greenish gray, silty, massive, 130 cm Calcareous boxwork with interbedded greenish gray shale, 70 cm Shale, greenish gray, silty w/limy layers, 106 cm
1.03 m	Falls City Limestone	**Lehmer LS:** gray, blocky, porous, abun pelcypods and fossil frags, 103 cm
1.5 m		**Reserve Shale:** olive grading down to dark gray and black, 150 cm
0.24 m		**Miles LS:** gray, blocky, dense, psuedo-oolitic, algal, pebbly, Osagia. 24 cm
3.54 m		**Hawxby Shale:** Shale w/white limy nodules, 48 cm Shale, green w/lavender stain. 24 cm Shale yellow w/green mottles, 54 cm Shale, olive green w/limy layers, 150 cm Shale, bluish green, 45 cm Shale, red, 33 cm
0.5-0.75 m		**Aspinwall LS:** gray, blocky to crumbly, contains black fossil frags, 50 - 75 cm
2.61 m		**Towle Shale:** Shale, green with red mottles, micaceous, 120 cm Shale, red 140 cm Shale, dark gray to black, 1 cm
0.66-1 m		**Brownville LS:** LS, dark gray, impure, 15-21cm Shale, dark gray, calcareous, 1-30 cm LS, darj gray weathering russett, abun brachs, 50 cm
5.72 m		**Pony Creek - Plumb Shale, Undifferentiated:** Shale, gray sandy, 180 cm Sandstone, blusih gray, very fine grained, shaly and limy, 212 cm Shale, maroon, massive, silty, 180 cm
0.5 - 0.7 m		**Nebraska City Limestone:** Dark gray, impure, abundant brachs, shaly in middle, 50 - 70 cm
5.47 m	Lorton Coal French Creek Coal	**French Creek Shale:** Shale, Bluish Gray, 15 cm Coal, black, platy, subbituminous, 12 cm Shale, gray plastic, 180 cm Limestone, gray weathering brown, silty, impure, contain gastropods 45 cm Shale, dark gray, abundant Chonentes,, 60 - 120 cm Coal, black, subbituminous, nonpersisitent, 0 - 45 cm Sandstone, gray to buff, silty, abundant leaf fragments 180 cm
0.2 m		**Jim Creek Limestone:** Gray, impure, contains abundant Chonetes

Section Name: Brownville Section #1 - Brownville Bridge Section

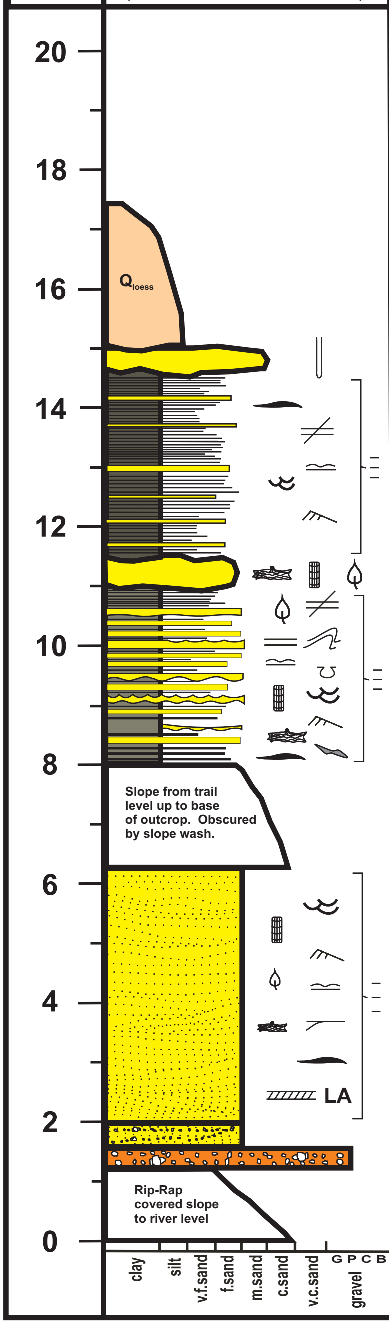
Location (lat/long): 40.40103N, 95.65467W

Total Thickness Measured: ~15.2 m (~50 ft)

Date Measured: 12/26/2004

Measured By: S.A. Fischbein, S.A. Fischbein, B.A.Fischbein, R.S. Klipper-Fischbein with hand level and tape.

Thickness (Meters) | **Graphic Log** (Lithologies, Structures, Fossils)



Facies	Depositional Environment
St_2	Tidally Influenced Fluvial Channel
H_2	Estuarine
St_2	Tidally Influenced Fluvial Channel
H_1	Estuarine
S_L	Tidally Influenced Fluvial Channel
Ci_h	

Lithologic Description

15 m - ?, Quaternary Loess: Forms slopes with heavy vegetation, or near vertical faces.

14.7 - 15 m, Sandstone: 5YR8/4; Yellow, fine to medium, with white carbonate filled voids. Bottom surface shows trace fossils as crawling traces or burrows.

11.5 - 14.7 m, Sandstone Dominated Heterolith: 5YR5/4, N5, N1, N2; Brown, gray and black interlaminated sandstone, siltstone and organic laminae. 60 - 80% very fine to fine sandstone in laminae and beds 5 to 15 cm thick, evenly distributed. 20 - 4-% Siltstone and organic laminae 1 -5 mm thick. Ripple cross-laminaed and parallel laminated, with wavy and flaser lamination and coal fragments.

11 - 11.5 m, Sandstone: N5; Gray, very fine to fine, micaceous, trough cross-bedded with layer of compressed logs along base and in lower third of unit. Many logs completely replaced by marcasite.

8 - 11 m, Sandstone Dominated Heterolith: 5YR4/4, 5YR5/6; Light to dark brown interbedded sandstone, siltstone with organic rich laminae. Very fine to fine sandstone 60 - 80% in laminae and beds 5 mm to 15 cm. N1, N2, N5 organic laminae and siltstone laminae 1 - 5 mm evenly distributed throughout unit. Abundant wood and plant fragments replaced by marcasite, and/or marcasite nodules, distributed throughout unit along laminae and bedding. Very micaceous. Coaly traces and organic rip-up fragments along base of exposure, and coaly traces throughout unit.

6.2 - 8 m, Covered Slope

2 - 6.2 m, Sandstone: N5, N6, Gray, low angle cross-bedded and plane parallel-bedded. Ripple, wavy, flaser, and lenticular lamination with clay partings and drapes along bedding 5 to 10 cm thick. Abundant organics along laminations and appear as dominant fill for flaser and wavy forms. Outcrop is preferentially cemented from base and up 1 - 2 m along an obvious discolored cementation front. Abundant wood and plant fragments distributed through upper part of unit.

1.5 - 2 m, Sandstone: N6, Gray, low angle and ripple cross-laminated with dispersed flat pebbles.

1.3 - 1.5 m, Conglomerate: N5; Gray, matrix supported, intraformational flat pebble conglomerate

0 - 1.3 m, Rip-Rap Covered Missouri River Bank

Section Name: Brownville Section #2 - CNS Weapons Range

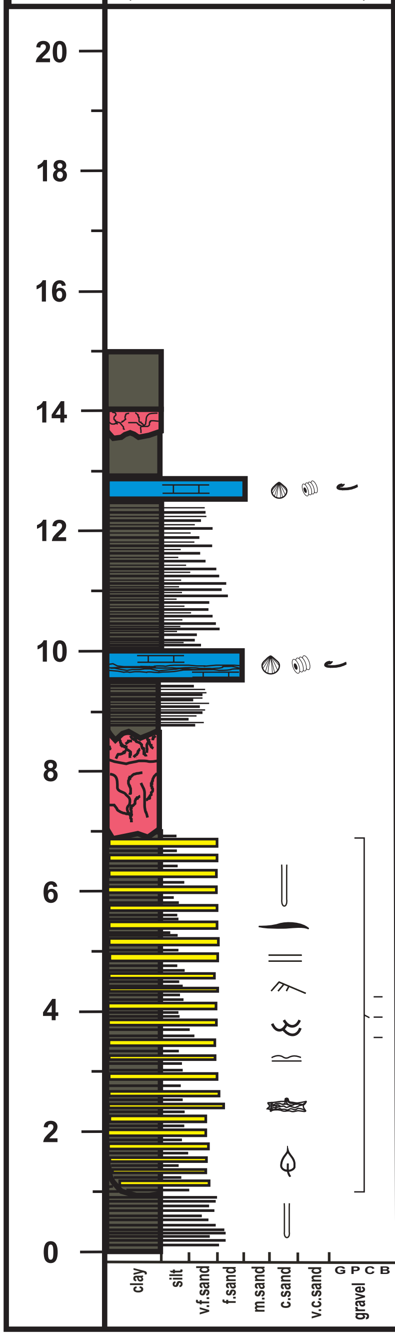
Location (lat/long): 40 21 46N, 95 39 28W

Total Thickness Measured: ~15 m (~50 ft)

Date Measured: 07/20/2004

Measured By: S.A. Fischbein, R.M. Joeckel direct measure with tape on fresh cut face.

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



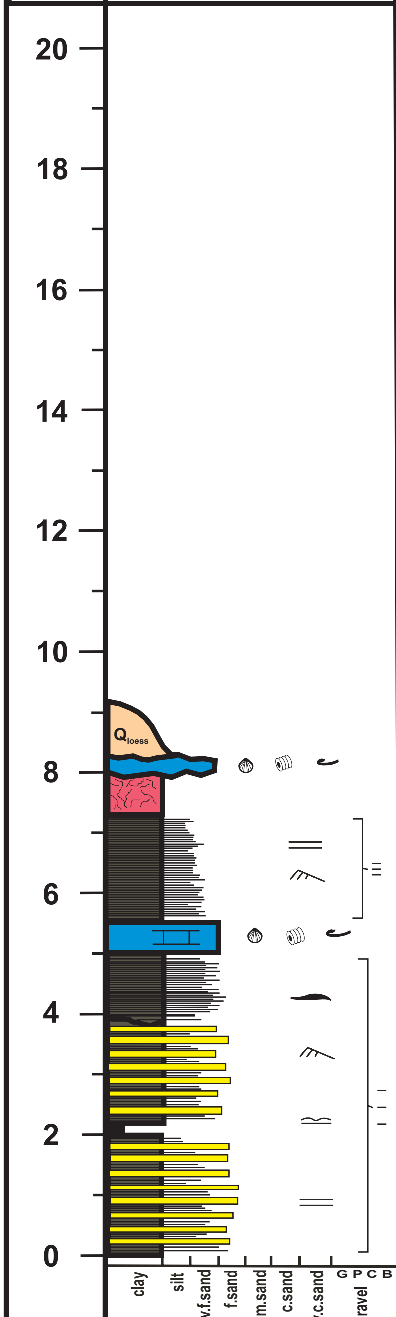
Facies	Depositional Environment	Lithologic Description
M_1	Offshore?	**12.9 - 15m+, Hawxby Shale:** 10R5/4, 10R4/6, 10R3/4 Red to red-brown shale, laminated to massive, with strong red paleosol developed at 50 to 60 cm above base, and continues up to 80 cm where surface is truncated by undulatory contact. Overlying is shale, 5B5/6, 5PB5/2; blue to blue-gray laminated fissile shale that weathers more gray (N5) on exposure. This is last exposure in vertical face, remainder of slope covered by landscape fabric (jute/burlap).
M_2	Carbonate Platform	**12.5 - 12.9 m, Aspinwall Limestone:** N5, 5YR6/4; Gray on fresh surface, weathering tan, fossiliferous mudstone/wackestone, crinoids and brachiopods.
H_2	Estuarine	**10 - 12.5 m, Towle Shale:** 2.5YR5/4; Reddish Mudstone Dominated Heterolith. Interlaminated shale and silty shale in alternating reddish and light red/gray laminae 1-5 mm evenly distributed.
M_2	Carbonate Platform	**9.5 - 10 m, Brownville Limestone:** N5, 5YR6/4; Gray on fresh surface, weathers tan to brown, wackestone/packstone with crinoids and brachiopods.
H_2	Estuarine	**Pony Creek -Plumb Shale Undiff.** **0 - 9.5 m, Heterolithic Assemblage with Paleosol:** **8.5 - 9.5 m, Mudstone Dominated Heterolith:** 5Y7/1, 2.5YR7/1; Gray interlaminated sandy shale and shale. 60-70% laminated gray shale 1- 5 mm with 30-40% fine sandy shale laminae 1- 3 mm, evenly distributed throughout unit.
	Subaerial	**7 - 8.5 m, Paleosol:** 2.5YR4/4; Red massive mudstone paleosol with highly undulatory upper contact. Upper 30-40 cm, 5Y6/2, vertisol with truncated synformal slickensides. Mudstone is blocky and has hackly fracture with common small pressure faces <1cm. Rounded carbonate nodules, few elongate > 20-30 cm, root traces 15 mm diameter frequently outlined by clusters of carbonate nodules.
H_1 & H_2	Estuarine	**2 - 7 m, Sandstone Dominated Heterolith:** 2.5YR4/4, 2.5YR5/4; Reddish interlaminated and interbedded sandstone, siltstone and shale. 40-60% very fine sandstone in laminae and beds 1 to 20 mm. 40 to 60% shale and siltstone in laminae 1 to 5 mm, evenly distributed. Units are parallel-laminated to ripple cross-laminated with minor scouring along bases of some beds or laminae. Mottled in places (5Y6/2 and 7/1). Abundant organic debris along laminae and bedding including leaf and plant fragments and wood. Burrows trace to common. **0 - 2 m, Mudstone Dominated Heterolith:** 5PB5/2, weathering 5YR6/4; Gray, weathering tan, interlaminated shale, sandy shale and siltstone. 70-90% shale and sandy shale in 1 to 5 mm laminae with 10-30% siltstone laminae 1 to 5 mm evenly distributed.Burrows common. Top of unit strongly truncated along arcuate surface that dips from north to south across cut face with relief of 2 to 4 m.

Section Name: Brownville Section #3 - Lippold Ranch

Location (lat/long): 40 20 56N, 95 39 23W **Total Thickness Measured:** ~9 m (~30 ft)

Date Measured: 07/22/2004 **Measured By:** S.A. Fischbein, R.M. Joeckel

Thickness (Meters) | **Graphic Log** (Lithologies, Structures, Fossils)



Facies	Depositional Environment	Lithologic Description
		8.3 m +, Quaternary Loess: 5Y7/6, 5YR7/2, 5YR6/4; Yellow brown to brown forms slopes and near vertical faces where exposed in cuts.
M_2	Carbonate Platform	**8 - 8.3 m, Aspinwall Limestone:** 5YR6/4; Light brown to brown highly weathered limestone with highly undulatory upper and lower contacts. Fossiliferous, crinoid and shell fragments.
H_2	Subaerial to Estuarine	**Towle Shale** **5.5 - 8 m, Mudstone Dominated Heterolith:** N5, 2.5YR4/4, 5YR6/4, 5P4/2, N2; Gray, grading to brown, reddish-brown, gray, tan/buff, purple and red, silty/sandy laminated shale that grades to a red paleosol at top of unit with calcareous boxwork fracture fill (slickenside fill)
M_2	Carbonate Platform	**5 - 5.5 m, Brownville Limestone:** 10Y8/2, 5Y7/6, 5YR6/4, N5; Yellow to brown grading to gray, fossiliferous with abundant crinoids, brachiopods and shell fragments.
H_1 & H_2	Estuarine	**Pony Creek - Plumb Shale Undiff.** **0 - 5 m, Sandstone Dominated Heterolith:** N5-N7, 5YR6/4, 5YR5/6, 2.5YR4/4; Gray, to light gray, tan, brown, grading vertically to reddish brown interlaminated sandstone, siltstone and shale. 30-50% sandstone in laminae and lenses 1 to 50 mm randomly distributed; 10 - 20% siltstone laminae 1 to 5 mm; 30 - 40% shale laminae 1 to 10 mm. 2 - 6 cm coal located in unit 100 ft to south of where section measured. Carbonaceous shale roughly 1 m below limestone in close proximity to prominent erosion surface. Unit becomes dominantly red-brown above this surface.

Section Name: Duerfeldt Farm Section

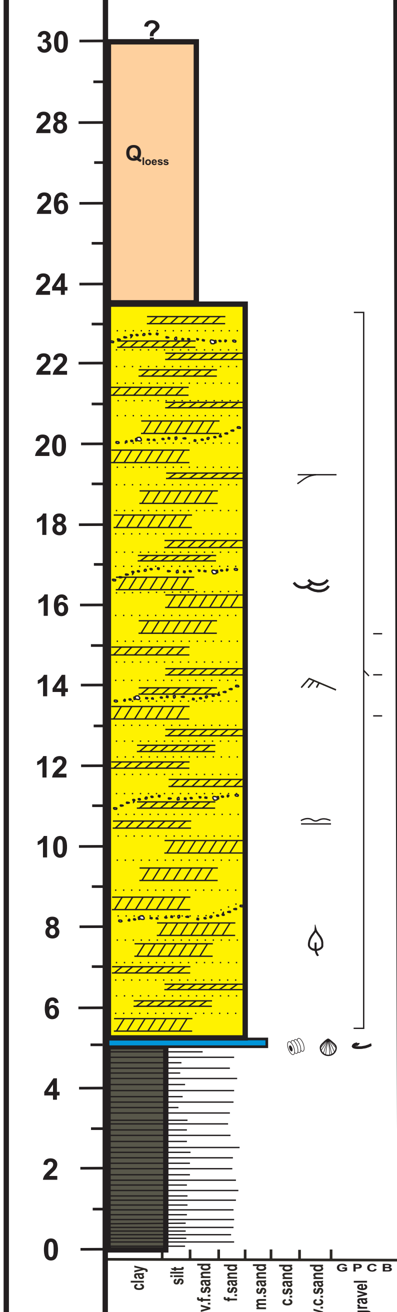
Location (lat/long): 40.24282N, 95.51276W

Total Thickness Measured: 25 m + (82.5 ft) (over 35 m to top of hill)

Date Measured: 04/01/2005

Measured By: Fischbein, S.A., using tape and hand level.

Thickness (Meters) | **Graphic Log** (Lithologies, Structures, Fossils)



Facies	Depositional Environment	Lithologic Description
		Quaternay Loess: Rests unconformably on top of sandstone with undulatory contact. Contact usually covered by slope wash. Loess cover present from upper sandstone contact to the top of hill, as much as 15-20 m above contact.
S_L & St_2 & St_1	Fluvial Channel to Tidally Influenced Fluvial Channel	Indian Cave Sandstone: light brown, tan and buff, very fine to fine with some medium, trough cross-bedded, with both large and small scale trough sets and low angle cross-bedding. Ripple cross-lamination dominant with sporadic or scattered mud pebbles/rip-up clasts. Pebbles commonly iron stained and have siderite(?) or marcasiste(?) weathering rind around clasts. Interbeds of gray to gray brown and tan-brown silty sandstone and sandy siltstone common, with plant debris along lamination and bedding planes. Forms vertical faces in upper part, but lower portions of outcrops at this location are mostly covered with only scattered outcrops along slopes. In lowest exposures, sandstone can be found resting directly on underlying limestone. No basal conglomerates were observed at this locale.
M_2	Carbonate Platform	Brownville Limestone: Thin at this location, seen as one bed below sandstone. Weathers tan to brown, gray on fresh surface, brachs and crinoids
M_1	Offshore to Tidal	Pony Creek - Plumb Shale Undiff. Undifferentiated: Mudstone dominated heterolith, 60-80% shale and silty shale laminae and beds 5 mm - 5 cm, 20-40% sandstone and silty sandstone laminae and beds 1 mm - 5 cm

Section Name: Duerfeldt Corehole # 2

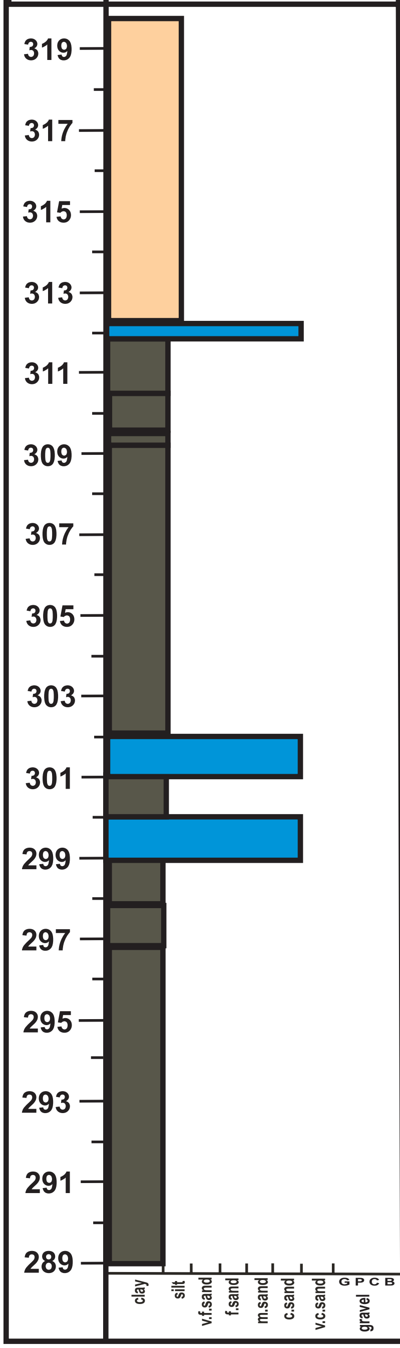
Location (lat/long): See Borehole Map

Total Thickness Measured: 60.6 m (200 ft)

Date Measured: 12/1970

Ground Surface Elevation: 319.7 m (1055 ft)

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Quaternary Overburden

Limestone

“Yellow Clay”

“Blue Clay”

Reddish Shale

Blue Shale

Yellow Limestone

Blue Shale

Grey Limestone

Blue shale

Black Shale

Blue Shale

Section Name: Duerfeldt Corehole #2

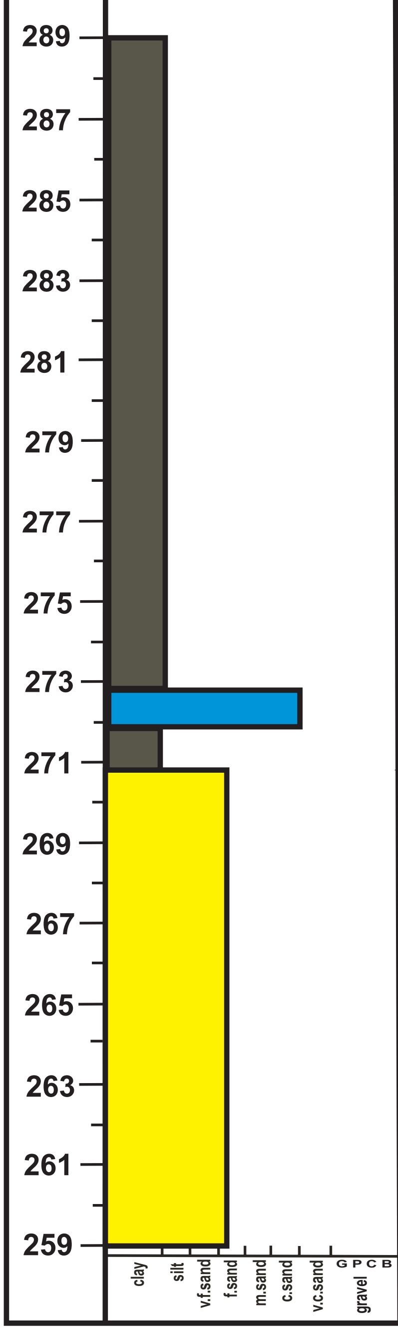
Location (lat/long): See Borehole Map

Total Thickness Measured: 60.6 m (200 ft)

Date Measured: 12/1970

Ground Surface Elevation: 319.7 m (1055 ft)

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description
289 – 272.8				Blue Shale
272.8 – 271.8				Grey Limestone
271.8 – 270.8				Blue Shale
270.8 – 259				Sandstone

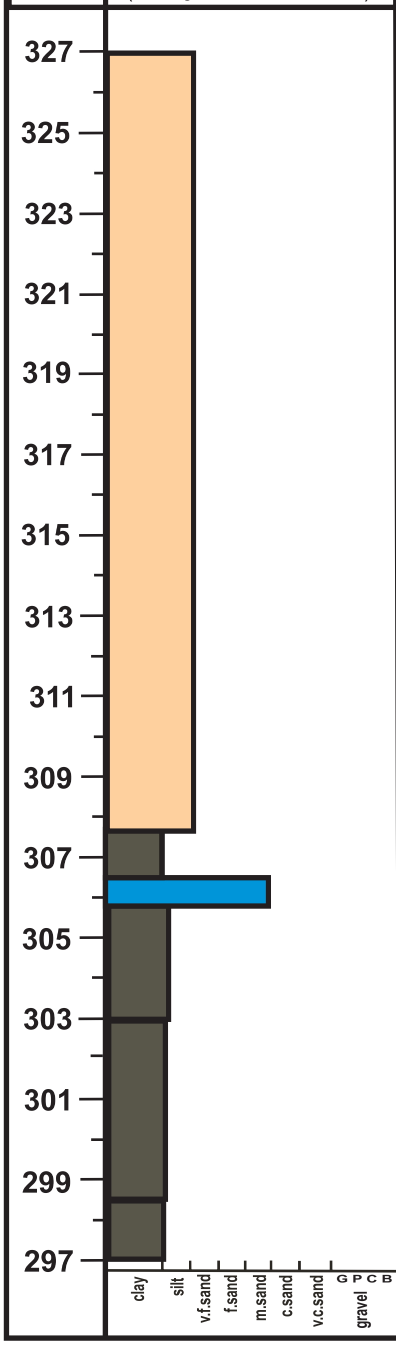


Section Name: Duerfedlt Corehole #3

Location (lat/long): See Borehole Map | **Total Thickness Measured:** 66.6 m (220 ft)

Date Measured: 12/1970 | **Ground Surface Elevation:** 330.3 m (1090 ft)

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Lithologic Description:

Quaternary Overburden

“Clay”

Soft Yellow Limestone

Shale (no color noted)

Red Shale

Blue Shale

Section Name: Duerfeldt Corehole #3

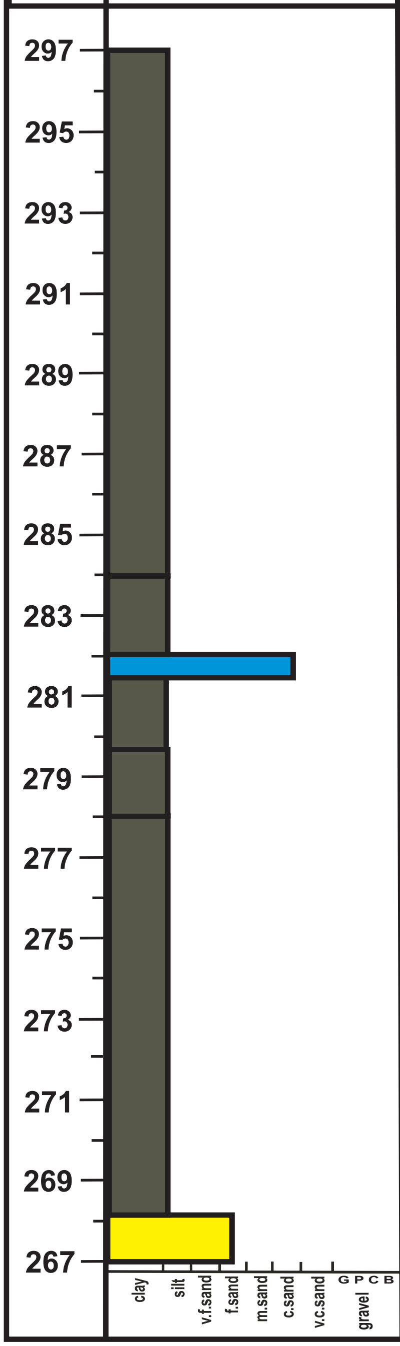
Location (lat/long): See Borehole Map

Total Thickness Measured: 66.7 m (220 ft)

Date Measured: 12/1970

Ground Surface elevation: 330.3 m (1090 ft)

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Blue Shale

Red Shale

Blue Shale

Red Shale

Blue Shale

Sandstone from 59.4 m to 63.6 m
Blue Shale from 63.6 m to 66.6 m
(bottom of hole)

Section Name: Duerfeldt Corehole #4

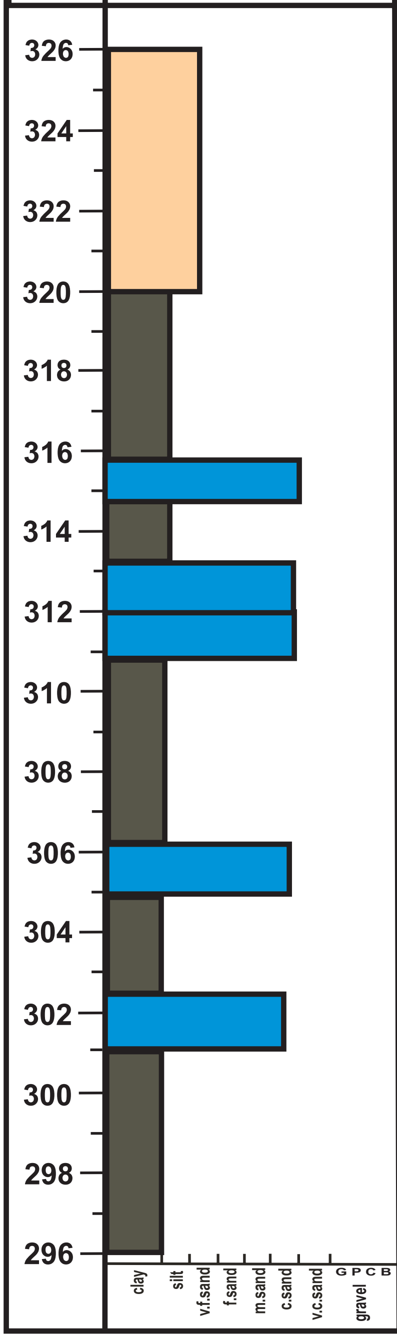
Location (lat/long): See Borehole Map

Total Thickness Measured: 51.5 m (170 ft)

Date Measured: 12/1970

Ground Surface Elevation: 318.2 m (1050 ft)

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Quaternary Overburden

Grey Shale

Yellow Limestone

Grey Shale

Pink Limestone

Yellow Shaley Limestone

Grey Shale

Hard Blue Limestone

Blue Shale

“Chalky Shaley Lime”

Blue Shale

Section Name: Duerfeldt Corehole #4

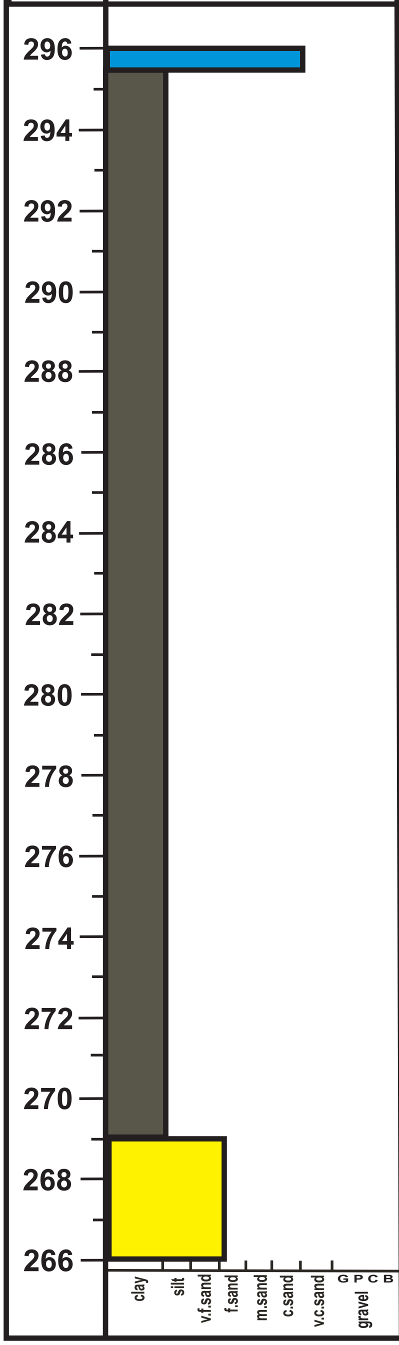
Location (lat/long): See Borehole Map

Total Thickness Measured: 51.5 m (170 ft)

Date Measured: 12/1970

Ground Surface Elevation: 318.2 m (1050 ft)

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Interval	Lithologic Description
~296–295.5	Limestone
~295.5–269	Blue Shale
~269–266	Sandstone

Section Name: Duerfeldt Corehole #5

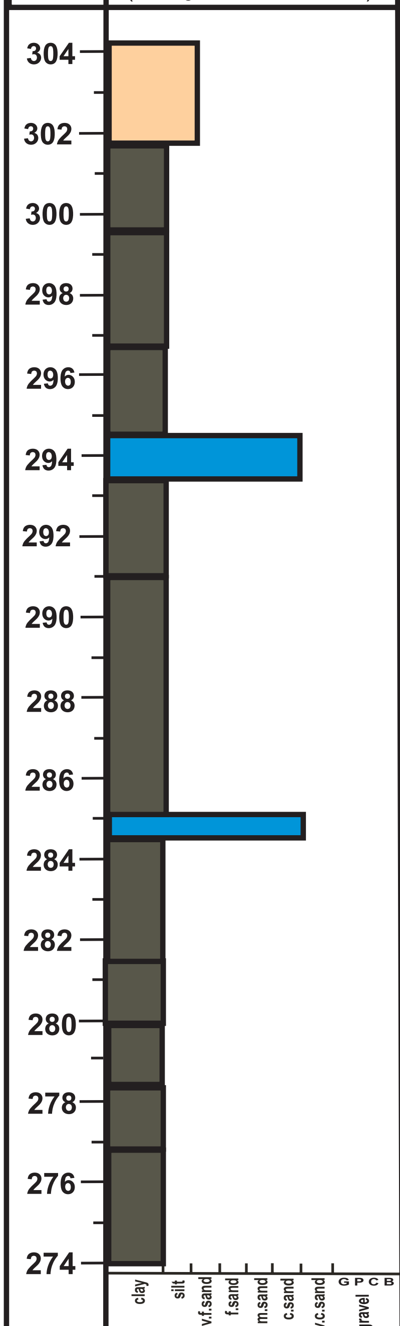
Location (lat/long): See Borehole Map

Total Thickness Measured: 36.4 m (120 ft)

Date Measured: 12/1970

Ground Surface Elevation: 304.5 m (1005 ft)

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Lithologic Description

- Quaternary Overbruden
- Grey Shale
- Red Shale
- Blue shale
- Hard Blue Limestone
- Blue shale
- Grey Shale
- Hard Blue Limestone
- Blue Shale
- Grey Shale
- Blue Shale
- Grey shale
- Blue Shale

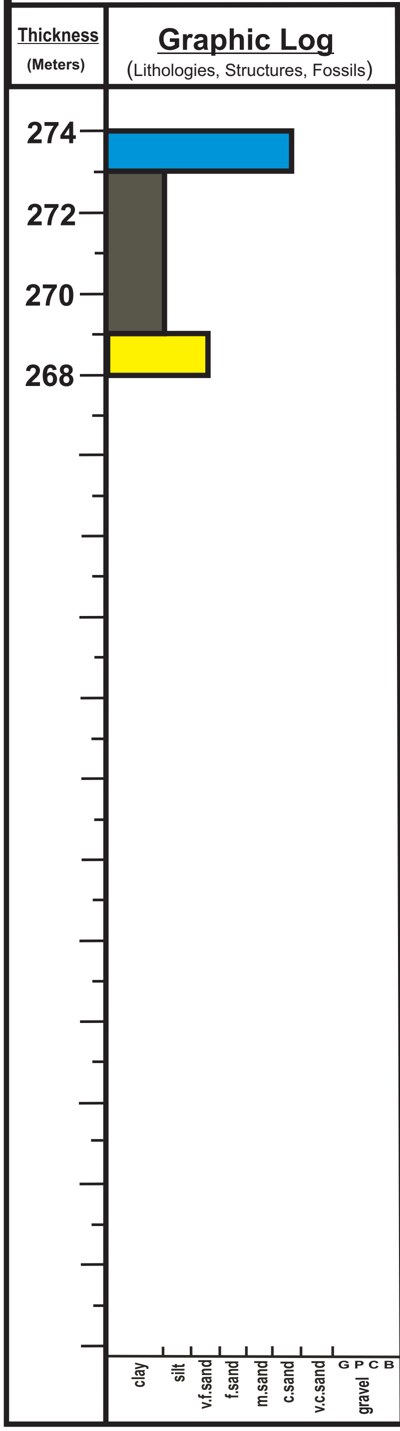
Section Name: Duerfeldt Corehole #5

Location (lat/long): See Borehole Map

Total Thickness Measured: 36.4 m (120 ft)

Date Measured: 12/1970

Ground Surface Elevation: 304.5 m (1005 ft)



Thickness (Meters)	Facies	Depositional Environment	Lithologic Description
274			Hard Blue Limestone
272–270			Blue Shale
268			Sandstone Bottom of Hole

Section Name: Duerfeldt Corehole #6

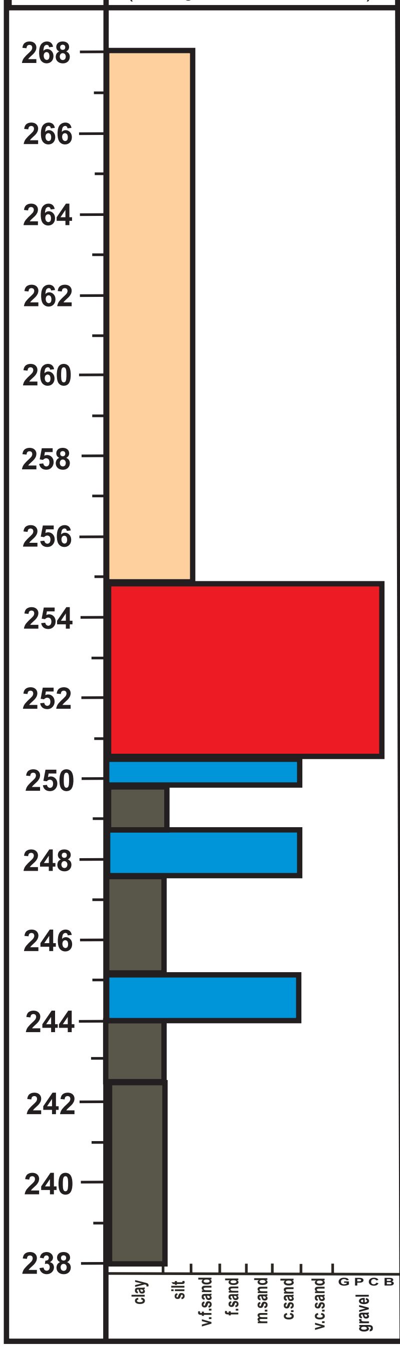
Location (lat/long): See Borehole Map

Total Thickness Measured: 36.2 m (120 ft)

Date Measured: 01/1971

Ground Surface Elevation: 268 m (885 ft)

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Lithologic Description
Quaternary Flood Plain Sediments
Quaternary River Gravels
Hard Limestone
Shale
Hard Limestone
Blue shale
Hard Limestone
Blue shale
Sandy Shale

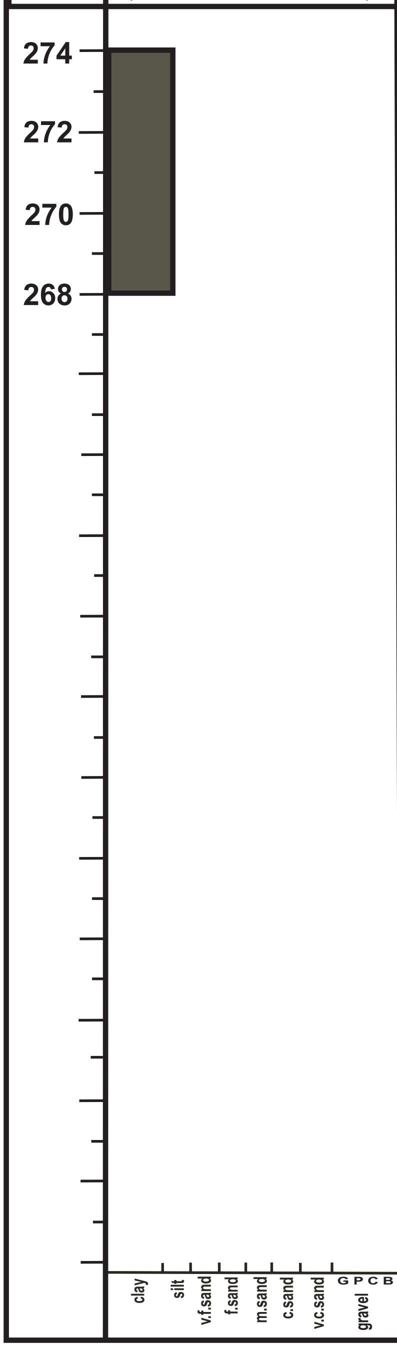
Section Name: Duerfeldt Corehole #6

Location (lat/long): See Borehole Map

Total Thickness Measured: 36.2 m (120 ft)

Date Measured: 01/1971

Ground Surface Elevation: 268 m (885 ft)

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description
274–268				Sandy Shale

Section Name: Duerfeldt Quarry

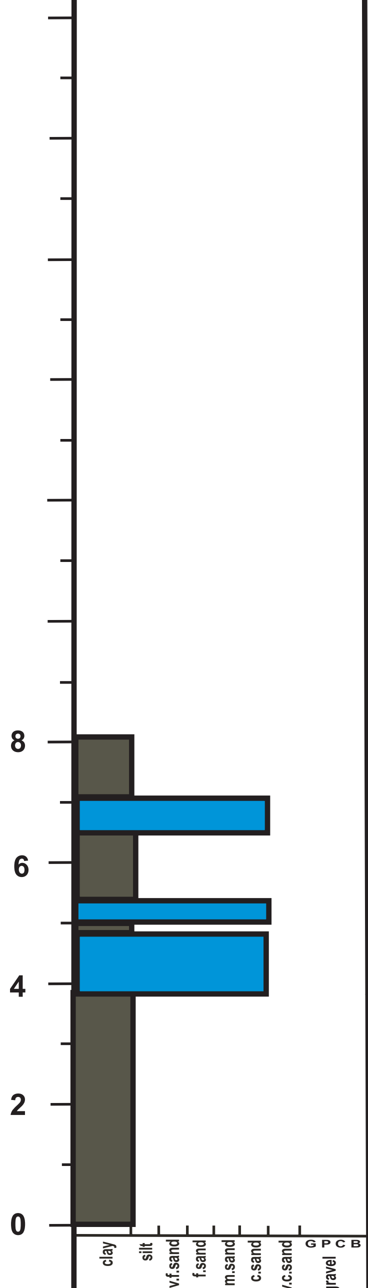
Location (lat/long): Old quarry northwest of farmhouse

Total Thickness Measured: 8.5 m (28 ft)

Date Measured: ~1970

Measured By: CSD personnel (Ray Burchett?) In early 1970's

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Limestone - tan, lavendar and gray brown, massive to wavy structured near top with limonite filling. Thin rusty brown shale interbed

Shale - dark gray, almost fissile, brown mottling in top 0.3 m (1 ft)

Limestone - massive, tough, brownish tan, speckeled, detrital shell. 0.3 m shale, greenish-gray calcareous. 1 m Limestone - yellowish-brown with gray seams, discontinuous, nodular with clayey filling.

Shale - gray, tan, grading down to reddish lavender. At bottom of section shale is light gray, hard and calcareous overlying a rusty and yellow clayey shale.

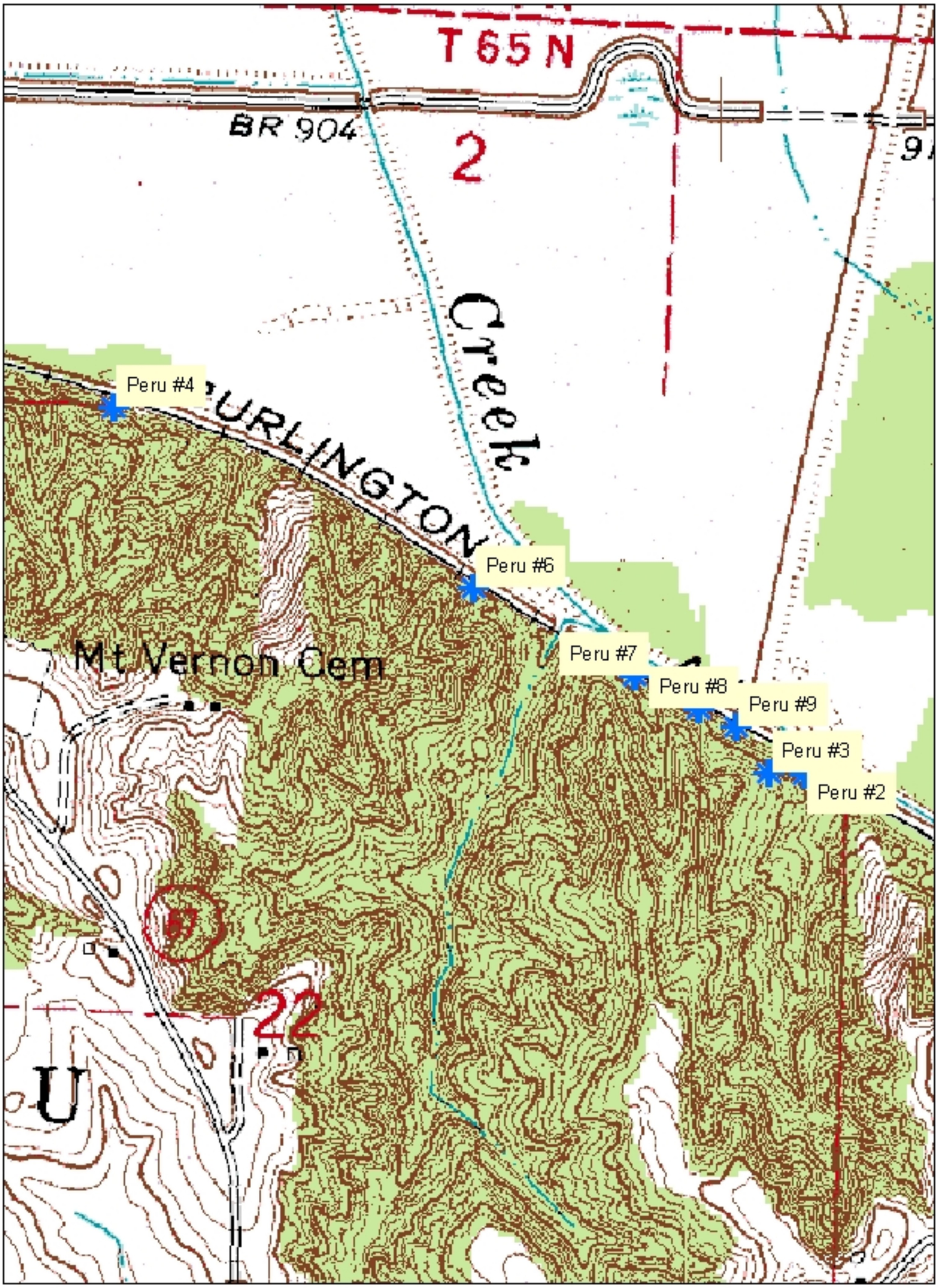


Figure A-1: Peru North Measured Section Locations

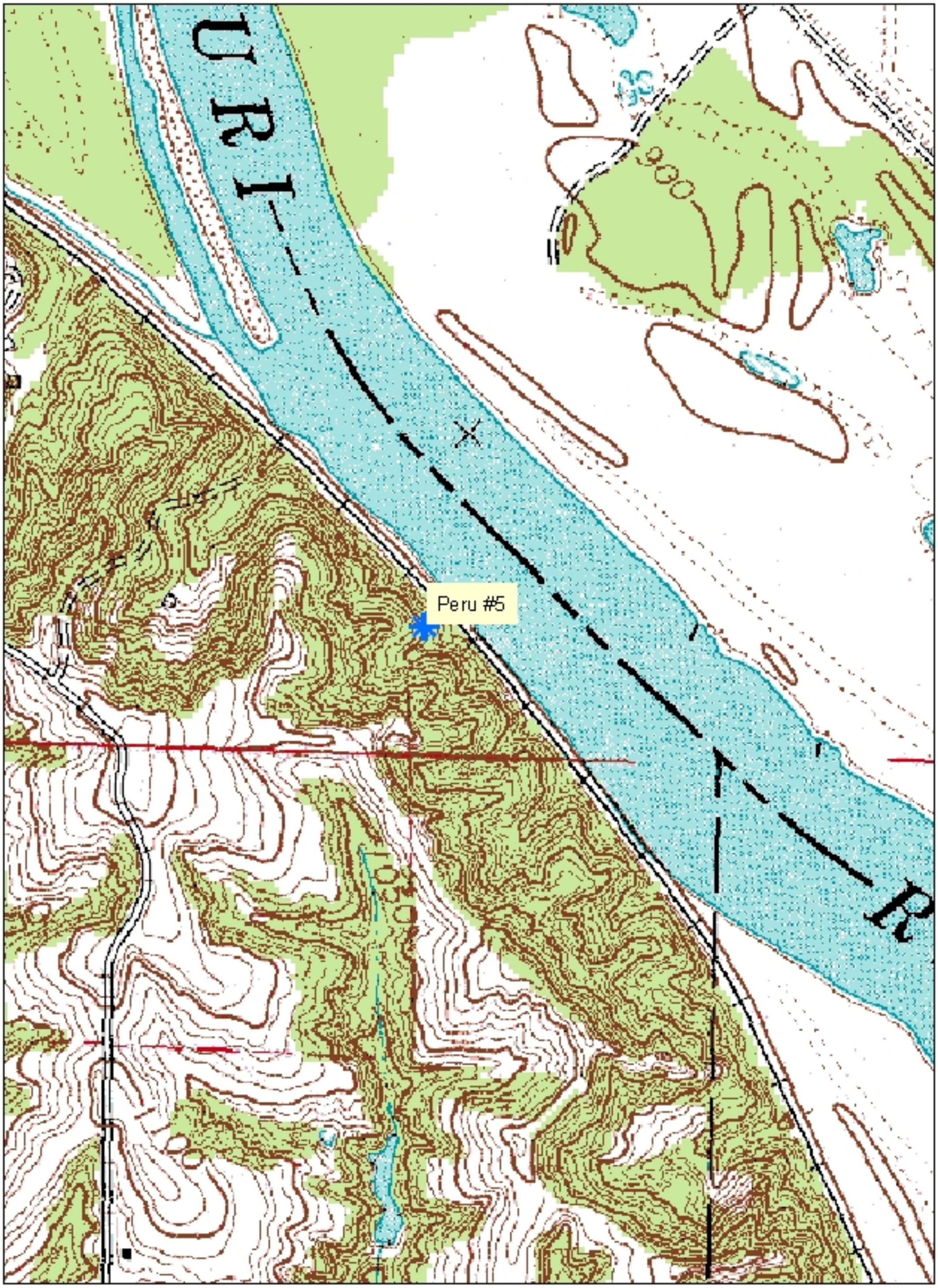


Figure A-2: Peru South Measured Section Location.

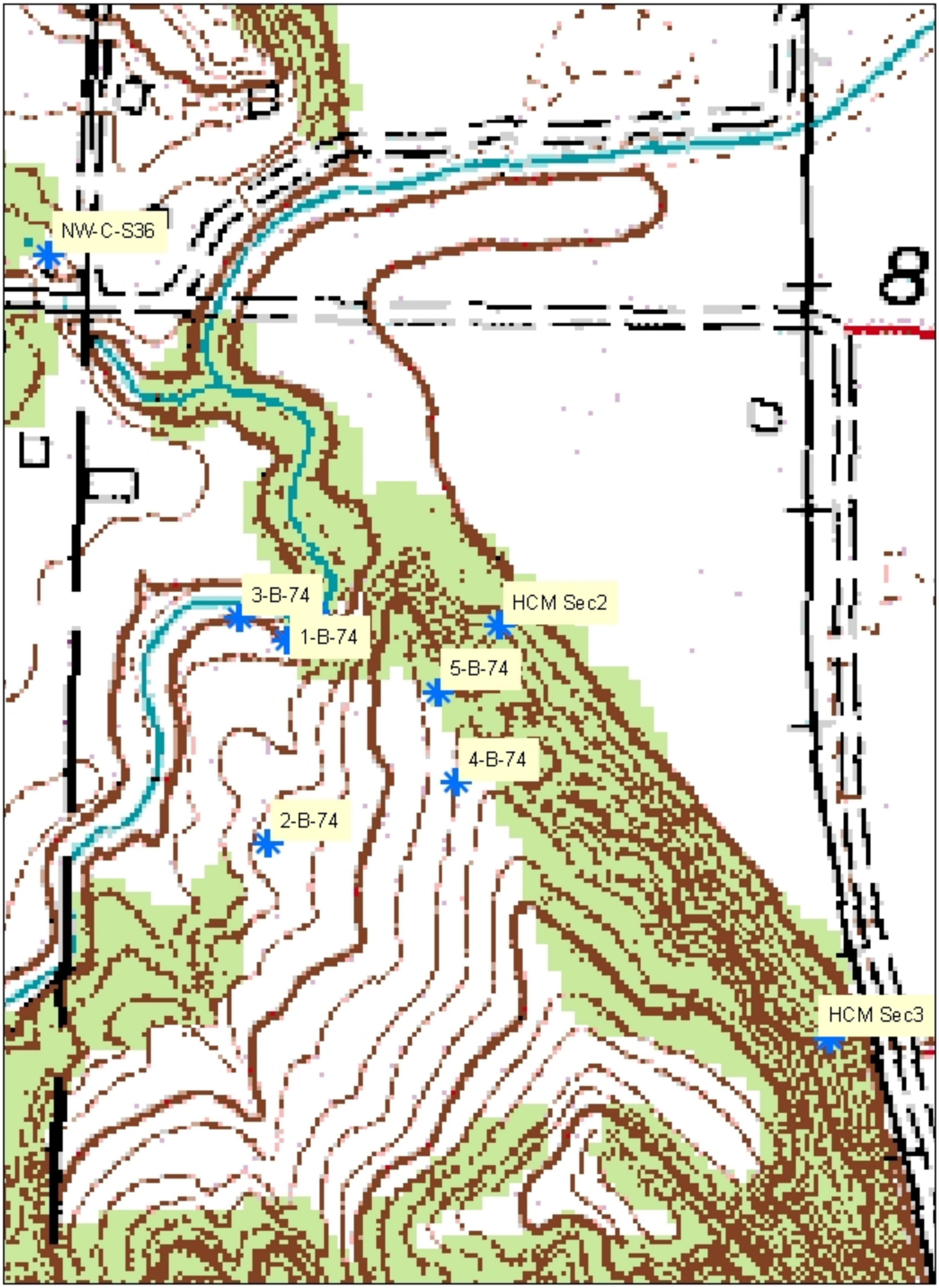


Figure A-3: Honey Creek Mine Section and Borehole Locations

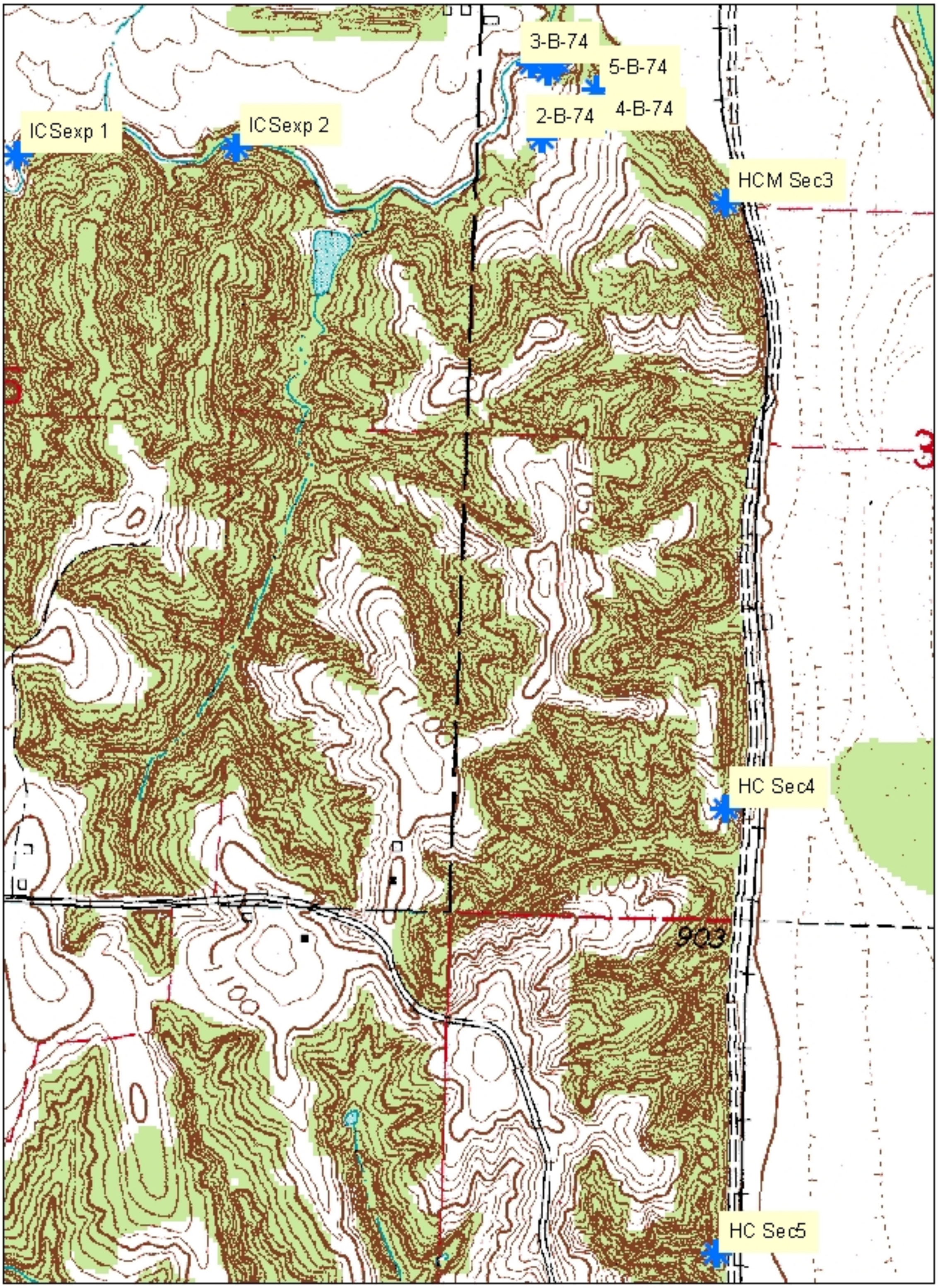


Figure A-4: Honey Creek South and West Section Locations

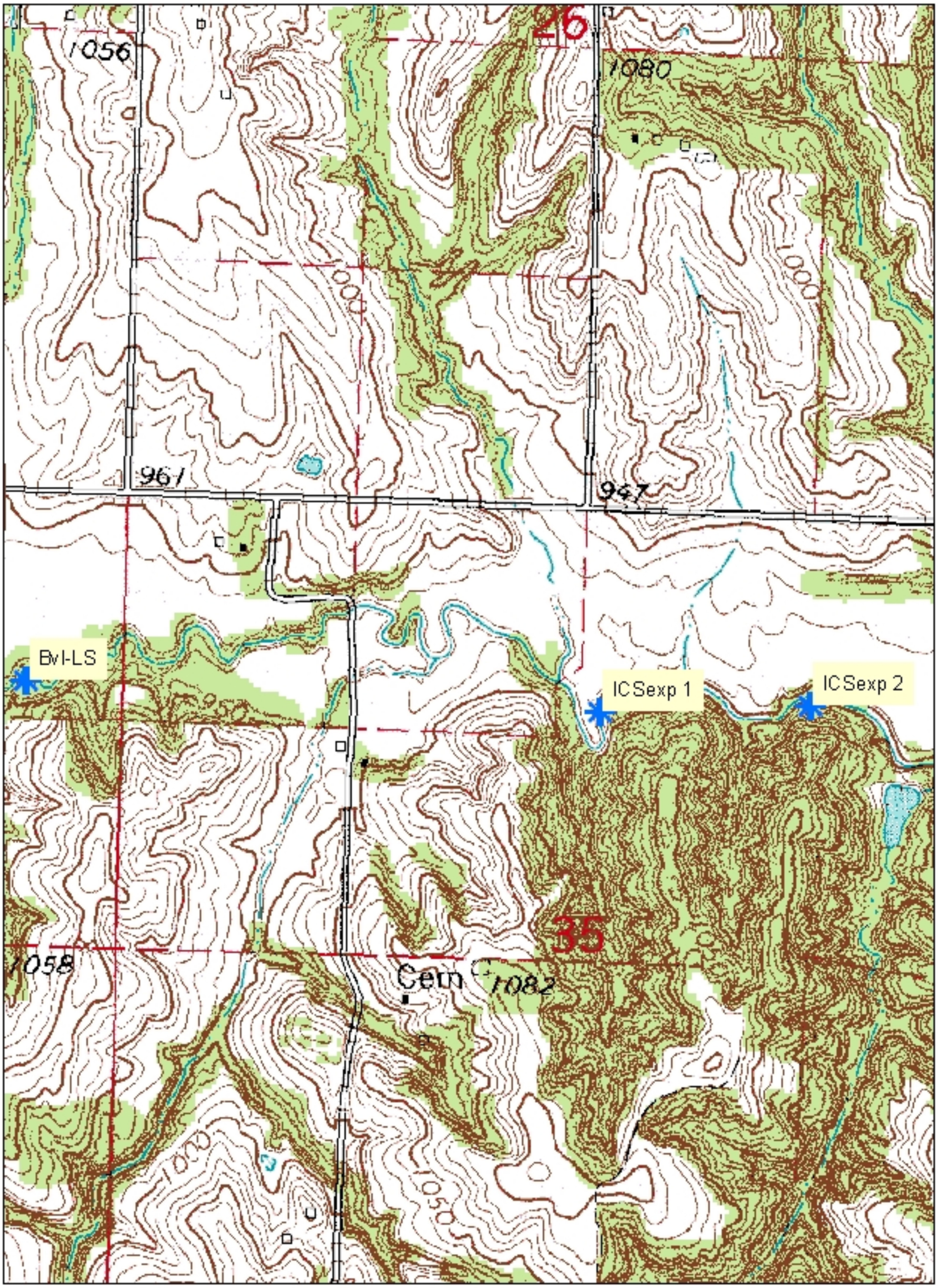


Figure A-5: Honey Creek West Outcrop Locations

Figure A-6: Brownville Section Locations

Figure A-7: Aspinwall Section and Outcrop Locations

Figure A-8: Indian Cave State Park Section Locations

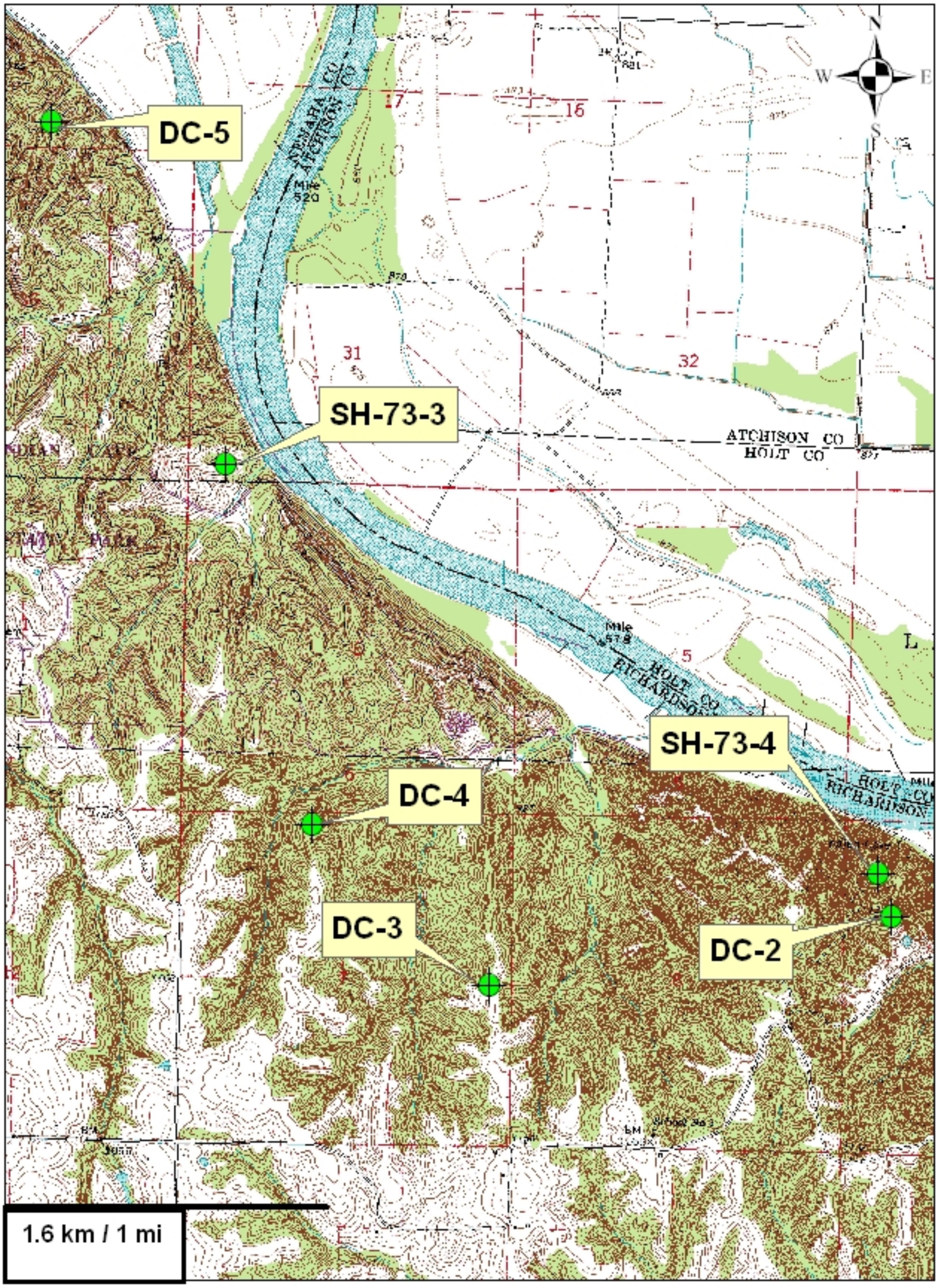


Figure A-9: Indian Cave State Park Borehole Location Map
SH = State Borehole; DC = Duerfeldt Borehole

Section Name: Honey Creek Borehole 1-B-74

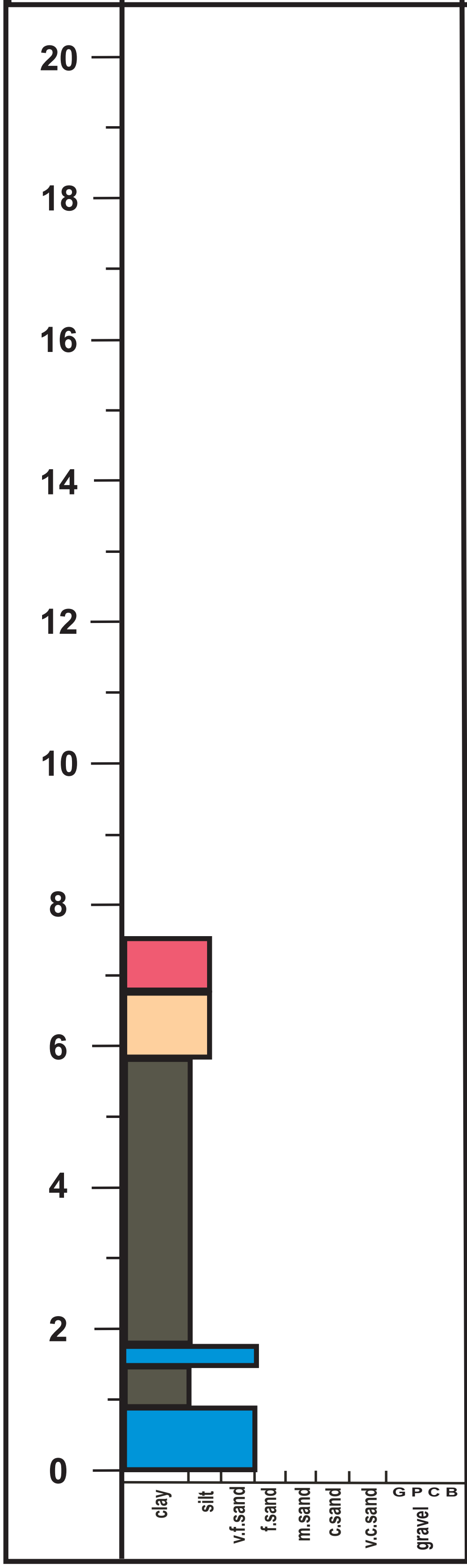
Location (lat/long): 40.45077N, 95.68704W

Total Thickness Measured: 7.25 m (23.9 ft)
Surface Elev. 945 ft

Date Measured: 06/17/1974

Measured By: R. Burchett

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Quaternary Loess

Towle Shale

Hawxby-Towle (Burchett)

Brownville Limestone

Section Name: Honey Creek Borehole 2-B-74

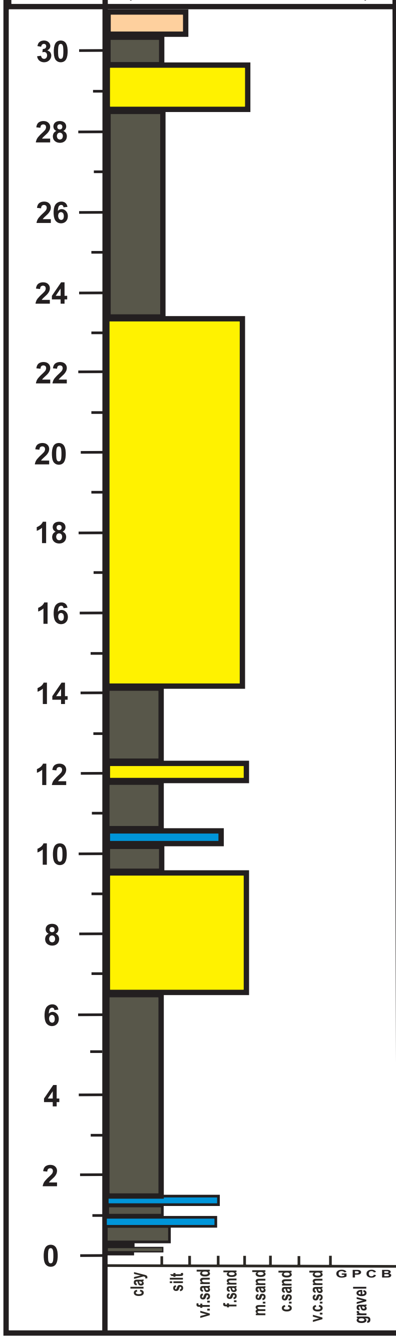
Location (lat/long): 40.44889N, 95.685417W

Total Thickness Measured: 39 m (130 ft)
Surface Elev. 941.5 ft

Date Measured: 06/18/1974

Measured By: R.R. Burchett

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Lithologic Description

4 m loess overlie 6.2 m shale above uppermost sandstone unit

Indian Cave Sandstone

Pony Creek -Plumb Shale Undiff

Dry Shale? (Burchett)

Nebraska City LS

Dover Limestone? (Burchett)

French Creek Shale

Pillsbury Shale? (Burchett)

Maple Hill Limestone? (Burchett)

Jim Creek LS

Wamego Coal (Burchett)

Coal in upper Friedrich Shale

see Mudge & Yochelson, 1962

Section Name: Honey Creek Borehole 3-B-74

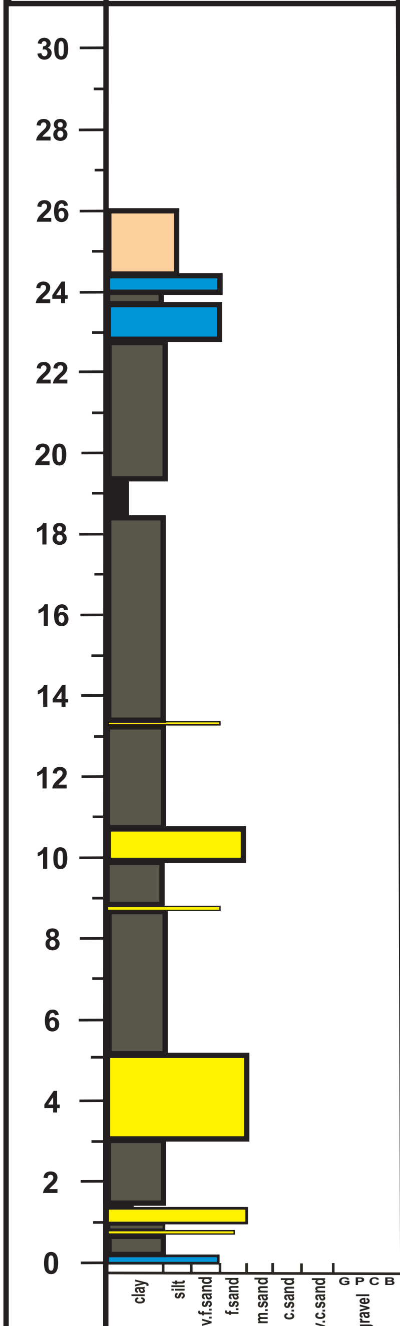
Location (lat/long): 40.44899N, 95.68573W

Total Thickness Measured: 26 m (85.7 ft)
Surface Elev. 933 ft

Date Measured: 06/19/1974

Measured By: R.R. Burchett

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Brownville Limestone

Pony Creek-Plumb Undiff

Wood Siding/Stotler Fms? (Burchett)

Honey Creek Coal

Pony Creek- Plumb Shale Undiff

Wood Siding/Stotler Fms? (Burchett)

Nebraska City LS

Dover Limestone (Burchett)

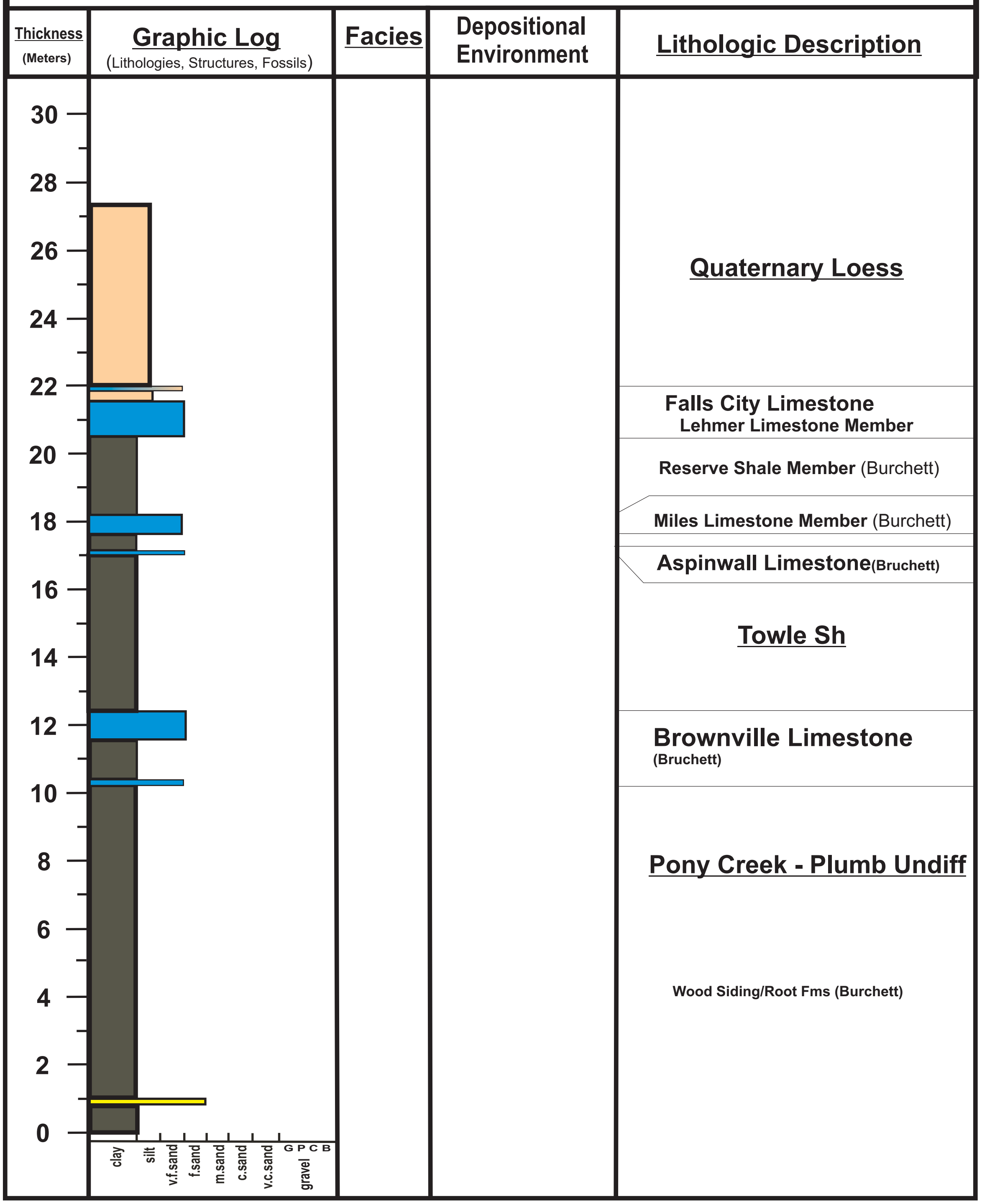
Section Name: Honey Creek Borehole 4-B-74

Location (lat/long): 40.44821N, 95.68428W

Total Thickness Measured: 27.4 m (90ft)
Surface Elev. 985.5 ft

Date Measured: 06/20/1974

Measured By: R.R. Burchett



Section Name: Honey Creek Borehole 5-B-74

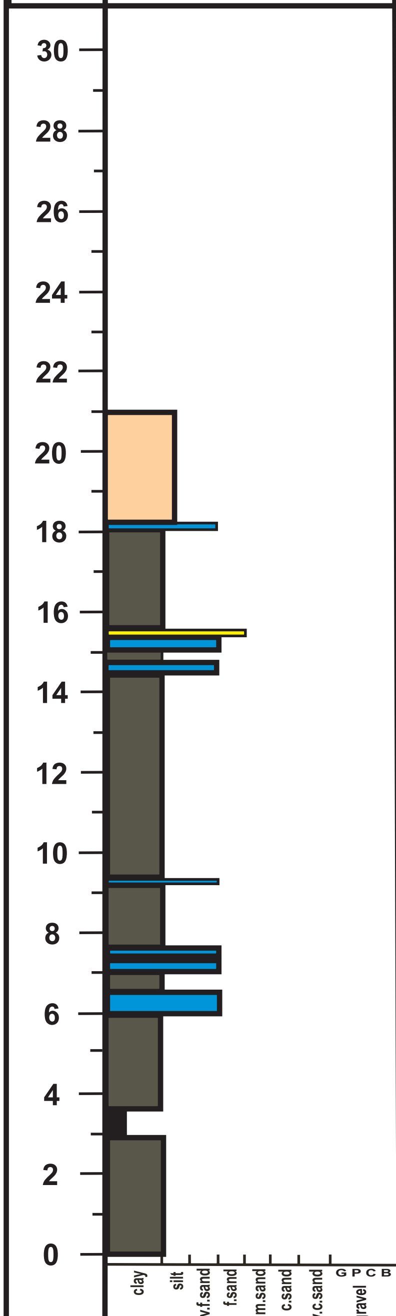
Location (lat/long): 40.44865N, 95.68443W

Total Thickness Measured: 21 m (70 ft)
Surface Elev. 971.5 ft

Date Measured: 06/21/1974

Measured By: R.R. Burchett

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Lithologic Description

Quaternary Loess

FC-Lehmer Mbr (Burchett)

FC-Reserve Mbr (burchett)

FC - Miles Mbr (Burchett)

Hawxby Sh

Hawxby-Towle Shales (Burchett)

Aspinwall LS

Towle Sh

Brownville LS (Burchett)

Pony Creek (Burchett)

Honey Creek Coal

Section Name: Honey Creek Mine #1

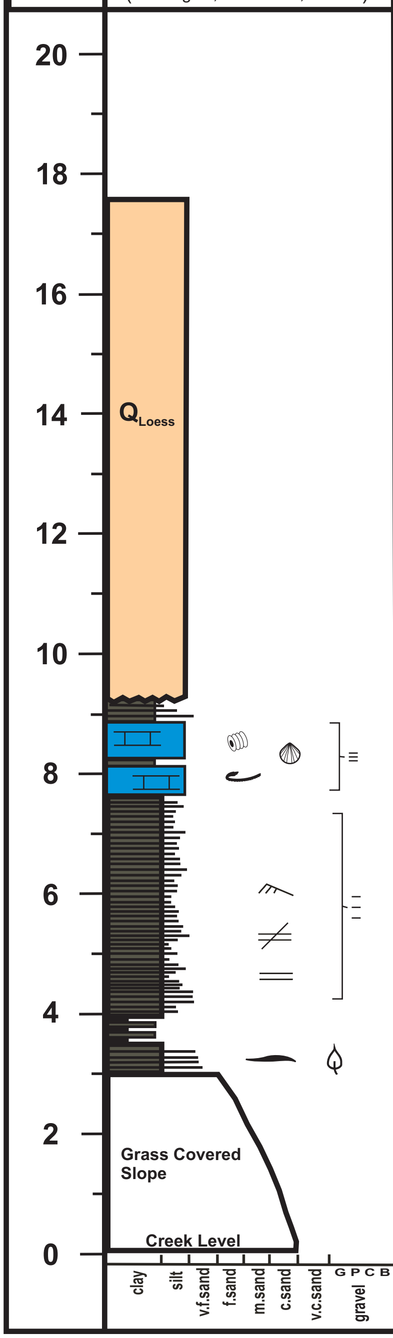
Location (lat/long): 40.44904N, 95.68526

Total Thickness Measured: 17.6 m (58 ft)

Date Measured: 12/20/2004

Measured By: S.A. Fischbein using hand level, tape and brunton.

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Facies	Depositional Environment
M_2	Carbonate Platform
H_2	Estuary?
Coal	Swamp
H_2	

9.4 - 17.6 m, Quaternary Loess: 7.5YR5/4, 7.5YR6/4; Brown to tan, blocky and vertically fractured. Forms near vertical faces, but will also for slick slopes. Loess cover extends to top of ridge above former mine site. Some limestone blocks noted near ridge top along strike to south on east and northwest facing slopes.

8.9 - 9.4 m, Towle Shale: 10YR7/4, 10YR5/1, 2.5YR4/6; Tan, gray and red fissile shale to heterolith. Highly sheared due to surface creep. Immediately overlain by contrasting brown loess in near vertical face.

7.6 - 8.9 m, Brownville Limestone: 10YR7/3, N5; Tan to gray mottled and weathered packstone to mudstone with abundant shell fragments. 2.5YR4/4, Red-brown shaley heterolith interbed up to from 12 to 30 cm thick with abundant shell fragments and organic debris (wood fragments) bioturbated.

Pony Creek-Plumb Shale Undiff.

3.8 - 7.6 m, Mudstone Dominated Heterolith: Slope mostly covered, but windows through slope wash indicate variable colored (red, yellow, tan and gray) heterolith.

3.3 - 3.8 m, Honey Creek Coal: Black, sub-bituminous to carbonaceous shale with pockets of bituminous coal. Clayey discontinuous partings. Appears scoured along upper contact.

3 - 3.3 m, Mudstone Dominated Heterolith. 10YR8/6, 10YR6/3, N5, yellow, tan and gray, stickly silty clay in part with abundant plant fragments and wood, complete leaf remains.

Grass covered slope down to creek level in Honey Creek. Ground Frozen with no windows through cover. Geology unknown but inferred from east facing slope of bluff that is dominantly a mud dominated heterolith.

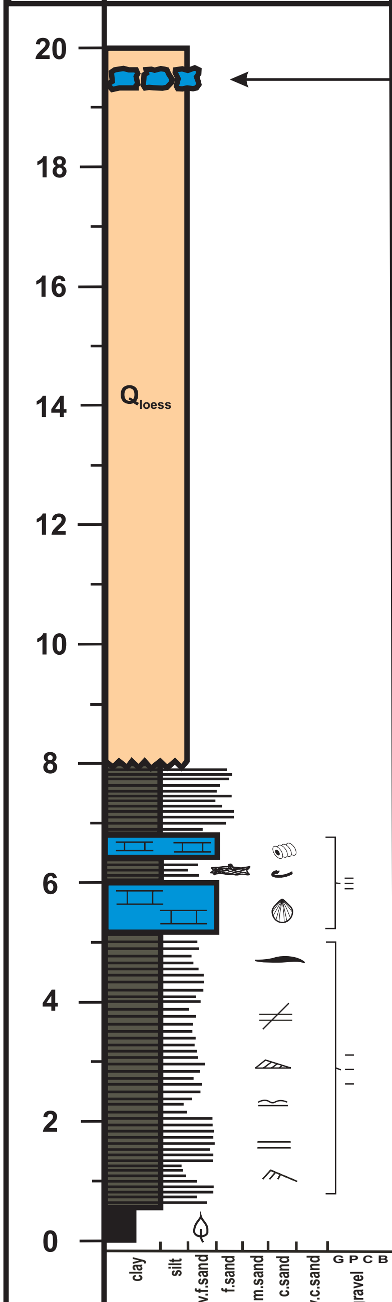
Section Name: Honey Creek Mine #2 (on east facing Missouri River Bluff)

Location (lat/long): 40.44900N, 95.68407

Total Thickness Measured: ~21 m (~70 ft)

Date Measured: 12/20/2004

Measured By: S.A. Fischbein using hand level, tape and brunton

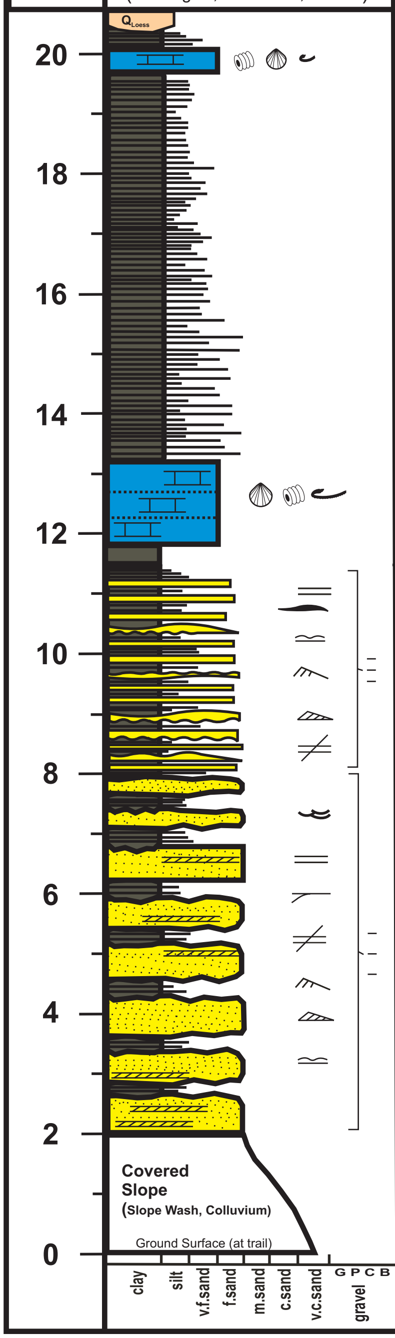
Thickness (Meters) / Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description
			

Interval	Facies	Depositional Environment	Lithologic Description
~19.5 m (float line)			Limestone block float line along east facing slope and on opposite side of ridge at edge of plowed field near same elevation.
8 - 20 m			**8 - 20 m, Quaternary Loess:** 7.5YR5/4, 7.5YR6/4; Brown to tan, blocky and vertically fractured. Forms slick slopes. Loess cover extends to top of ridge above former mine site. Limestone blocks noted near ridge top along strike to south on east facing slope, as indicated. Float line of blocks likely represents underlying outcrop. Minor exposures in windows in loess cover appears to be underlying heterolith.
6.8 - 8 m	H_2	Estuary?	**6.8 - 8 m, Towle Shale** 10YR7/4, 10YR5/1, 2.5YR4/6; Tan, gray and red fissile shale to heterolith. Highly sheared due to surface creep. Immediately overlain by contrasting brown loess in near vertical face.
5.2 - 6.8 m	M_2	Carbonate Platform	**5.2 - 6.8 m, Brownville Limestone:** 10YR7/3, N5; Tan to gray mottled and weathered packstone to mudstone with abundant shell fragments. 2.5YR4/4, Red-brown shaley heterolith interbed up to from 12 to 30 cm thick with abundant shell fragments and organic debris (wood fragments), bioturbated.
0 - 5.2 m	H_2	Estuary?	**0 - 5.2 m, Pony Creek -Plumb Shale Undiff:** 10YR8/6, 10YR6/3, N5, 2.5YR4/4; Yellow, tan, brown and gray mudstone dominated heterolith, sandy and silty in part. Red to red-brown color changes in profile possible paleosols. Erodes to form brown to red-brown slopes and slope wash.
0 - 0.3 m	Coal	Swamp	**0 - 0.3 m, Honey Creek Coal:** Large coal pile at surface adjacent to outcrop. Plowed field east of ourcrop indicates pieces of coal and heterolith in overturned blocks. Coal appears in-situ at very base of slope at field level.

Section Name: Honey Creek Section #3 - South Cut Section

Location (lat/long): 40.44701N, 95.68182W
Total Thickness Measured: ~20.5 m (~67.7 ft)
Date Measured: 12/20/2004
Measured By: S.A. Fischbein with hand level, tape, and brunton.

Thickness (Meters) | **Graphic Log** (Lithologies, Structures, Fossils)



Facies	Depositional Environment	Lithologic Description
		Quaternary Loess
H_1		
M_2	Carbonate Platform	
H_2	?	**13.2 - 19.5 m, Hawxby Shale: Mudstone Dominated Heterolith** This portion of section taken from floor of cut in top of slope. This area is dominantly covered with slope wash and debris from loess and limestone upslope. However, exposures through overburden indicate tan to gray and brown, mudstone dominated heterolith with 60 - 80% shale and siltstone laminae 1 - 20 mm and 20 - 40% sandstone laminae 1 - 100 mm.
M_2	Carbonate Platform	**11.9 - 13.2 m, Aspinwall Limestone:** 5YR6/4, N5; Tan to gray limestone, faintly to strongly bedded, crinoid and shell fragments common.
M_1	Offshore	**11.5 - 11.9 m, Shale:** 10GY5/2, 5G6/6; Green to green-gray, faintly laminated, very distinct from units above and below. Slightly fissile, forms small fissle blocks 1 cm square when digging out exposure.
H_1	Upper Estuary	**7.9 - 11.5 m, Sandstone Dominated Heterolith:** 10YR5/3, 5YR7/1, N5; Brown to tan sandstone with light gray laminated and brown heterolith. 50-80%, very fine to fine sandstone in laminae and beds 1 to 30 cm thick. 20 - 50% siltstone and shale laminae in units 1 - 40 mm thick interbedded and evenly distributed with sandstones. Ripple, flaser, wavy and lenticular cross-laminated and parallel laminated.
H_1 & St_2 & S_L	Tidally Influenced Fluvial Channel	**2 - 7.9 m, Sandstone with Heterolith Interbeds:** Sandstone, 5YR6/4; brown to light brown and tan, Very fine to fine, trough cross-bedded to low angle cross-bedded, with ripple cross-lamination and flaser and wavylamination. Units 1 to 2 ft thick, interbedded with: Heteroltih, 7.5YR5, 2.5YR4/4; Gray to tan, with siltstone and sandstone laminae with ripple cross-lamination, flaser and wavy lamination. Sandstones grade vertically in places into heterolith, and in others places show sharp undulatory, scoured contact.
		0 - 2 m, Covered Slope: Slope covered from trail level to base of outcrops with slope wash, colluvium, plants and grasses.

Section Name: Honey Creek Section #4 - Borrow Pit

Location (lat/long): 40.43786N, 95.68144W

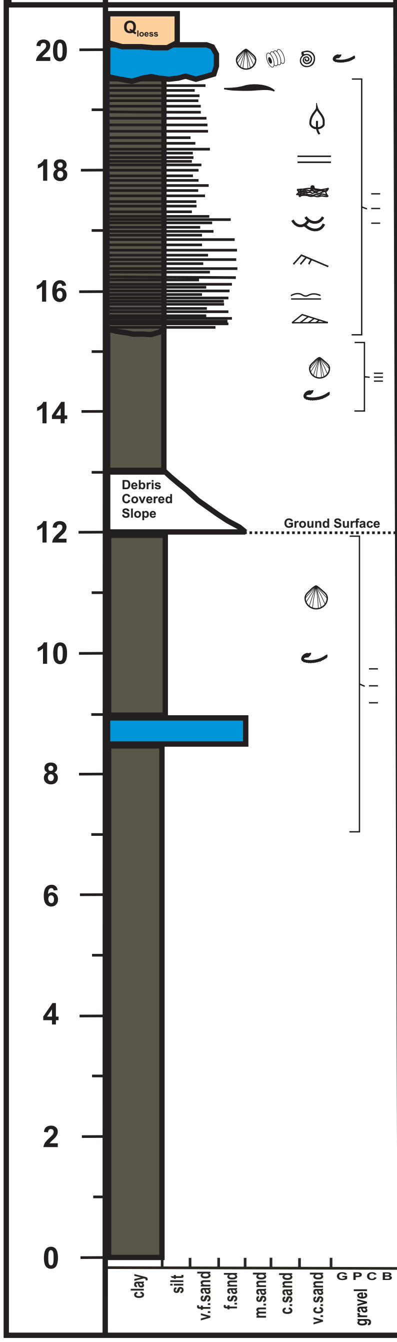
Total Thickness Measured: ~20 m (~7.3 m asg, 12.7 m bsg) (~64 ft, 24 ft asg, 40 ft bsg)

Date Measured: 12/21/2004

Borehole Surface elev = 276.5 m (912.5 ft)

Measured By: S.A.Fischbein, C.R. Fielding, drilling; S.A. Fischbein with hand level and tape above surface grade (asg).

Thickness (Meters) | **Graphic Log** (Lithologies, Structures, Fossils)



Facies	Depositional Environment	Lithologic Description
		Quaternary Loess
M_2	Carbonate Platform	**7.5 - 8.2 m, Brownville Limestone:** 25 cm of massive 5YR6/4 tan limestone over 25 cm 5Y6/4-6R4/2 red to gray shell bed
H_2	Estuarine?	**Pony Creek Shale-Plumb Shale Undiff.** **3.4 - 7.5 m, Mudstone Dominated Heterolith:** 5Y8/4, 5YR6/4, N5, 10YR6/6, 5R4/6;70 - 90% Buff, tan,gray, orange and red silt and sandy shale laminae,1 - 5 mm, 10 - 30% sandstone and siltstone stringers and laminae evenly distributed. Thin carbonaceous shale 50 cm below limestone, no fauna, but scattered wood and leaf fragments.
M_1	Offshore	**1 - 3.4 m, Shale:** 5G5/6, 10GY5/2; Green to greenish-gray, laminated to massive with brachiopod, pelecypod and crinoid fragments.
		0 - 1 m, Covered Slope: Slope wash, colluvium and debris.
	Borehole 16A04	**0 - -3m, Shale grading downward to Paleosol:** 10YR5/1 with 10YR6/4, 6/8 mottles. Mudstone becomes more brecciated and "paleosolic" downward. Best developed at 280-300 cm down.
		Nebraska City Limestone Weathered limestone, 2.5YR7/0 with 10YR5/3, 4/3, 3/3 mottles. Highly weathered fossil frags of shells and bryazoans, almost indistinct.
		French Creek Shale Siltstone, 10YR3/3, sandy and clayey, 0-10% sandstone, 0-20% shale, dominantly brown with mottled base. Sandstone - 7.5YR6/0, silty, very fine, laminated and ripplie cross-laminated, fissile. Silty Shale/Shaley Siltstone - 7.5YR7/0 Shale - 7.5YR7/0, 7/2, massive to laminated, becomes fissile siltstone 7.5YR5/0, shaley. Grades to more heterolithic character at 6 m, laminated and ripple cross-laminated with no color change. Grades to more fissile shale below 5 m with no color change, silty and massive in part, blocky. Inceasing purite content downward with pyrite 1 mm or less ins size. Remains fissile to bottom of hole.

Section Name: Indian Cave State Park #1 - ICS Cave Section

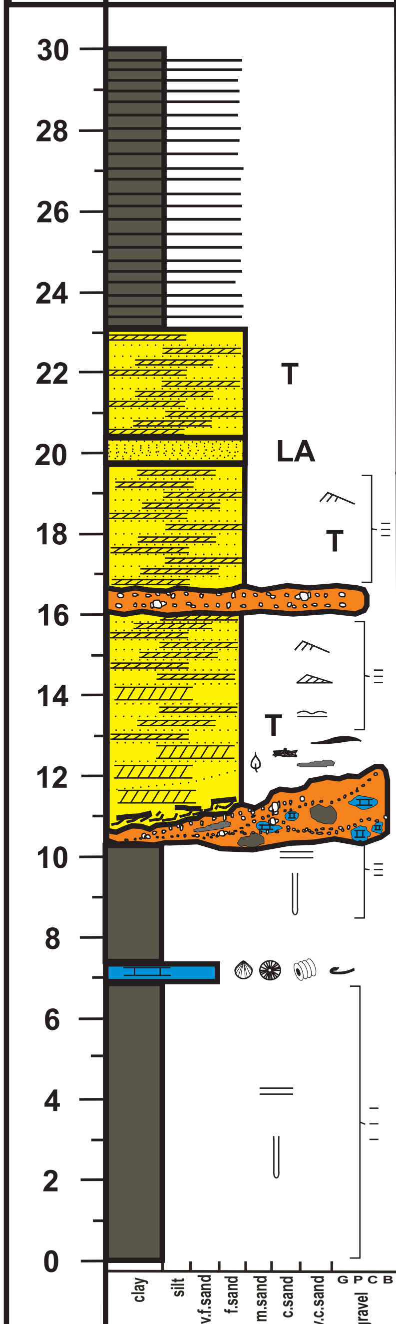
Location (lat/long): 40.24672N 95.51790W (Base of Section)

Date Measured: 7/28, 11/16, 11/17, 2004

Total Thickness Measured: 48 m (159 ft)

Measured By: S.A. Fischbein with hand level, Jacob Staff, and tape plus incorporation of CSD Log above cave from ~1970

Thickness (Meters) | **Graphic Log** (Lithologies, Structures, Fossils)



Facies	Depositional Environment	Lithologic Description
		21.4 -36 m - Sandstone and Mudstone Dominated Heterolith: Roughly evenly distributed throughout outcrop. Described by CSD as: Mixed sand and clay lenses, and dark gray clay. Mixed brown sand and clay lenses; lenticular and inclined stratification; sand and shale, micaceous and buff. Sandstone, very hard, massive and bedded with mica, medium gray; shale and sand, gray; shale sandy, grayish-tan.;
St_2	Fluvial Channel	**9.9 - 21.4 m, Lower Indian Cave Sandstone**
S_L		**0 - 11 m, Sandstone:** 10YR7/4, 5YR6/4, 5YR5/6; Yellow-brown to brown, very fine to medium, large scale trough cross-bedded (0.25 - 0.75 m) and small scale trough cross-bedded (<0.25 m), and low angle cross-bedded. Lower contact sandstone rests directly on 1) underlying shale; 2) basal conglomerate, or 3) Coal. Contact is very sharp and undulatory regardless of underlying unit. Small scale txb increases in upward through section.
St_2		**4.8 m above basal contact, an Intraformational Conglomerate** 0.6 m thick is located. Angular to subrounded, platy and elongate clasts composed of heterolithic fragments (H_1 + H_2 type heterolith). **8.5 m above basal contact, low angle cross-bedded to plane parallel bedded** unit 0.6 m thick. Beds weather in relief and are easily defined, but no internal structure can be seen in individual beds.
Ci		**Basal Contact Units**
St_1 & St_2		**Coal (variable thickness 0 - 1- cm):** N1, 5YR2/1 Black, shiny, subbituminous, occurs as stringers or along cross-bedding as discontinuous inclined lenses.
Ci		**Basal Conglomerate (variable thickness 0 - 2m):** Angular to rounded clasts of limestone, siltstone, and mudstone. Matirx supported with clast range from granule to bouder (mm to >30 cm) and fossil fragments of shells and crinoid columnals common. Clean sand lenses also common and range from 15 to 50 cm thick and 1 to 3 m long.
M_1	Offshore	**7.4 - 9.9 m, Towle Shale:** N4-N5, 5YR4/4, 10R3/4; Shale, gray to medium gray, brown to red-brown, massive to fissile. Trace shells, shell fragments and burrows.
M_2	Carbonate Platform	**6.8 - 7.4 m, Brownville Limestone:** 5YR6/4, 5YR5/6, N5; Limestone, gray, weathering tan to brown, with shaley interbed 15 cm from top, 5 to 10 cm thick. Fossiliferous, especially in upper part, abundant crinoid columnals and shell hash.
M_1	Offshore	**0 - 6.8 m, Pony Creek-Plumb Undiff:** 5YR3/4, N5; Dark brown to gray shale, weathers to clayey slick slope, poor exposures. Pit samples indicate massive to laminated shale with some traces.

Section Name: Indian Cave State Park - Indian Cave Coal

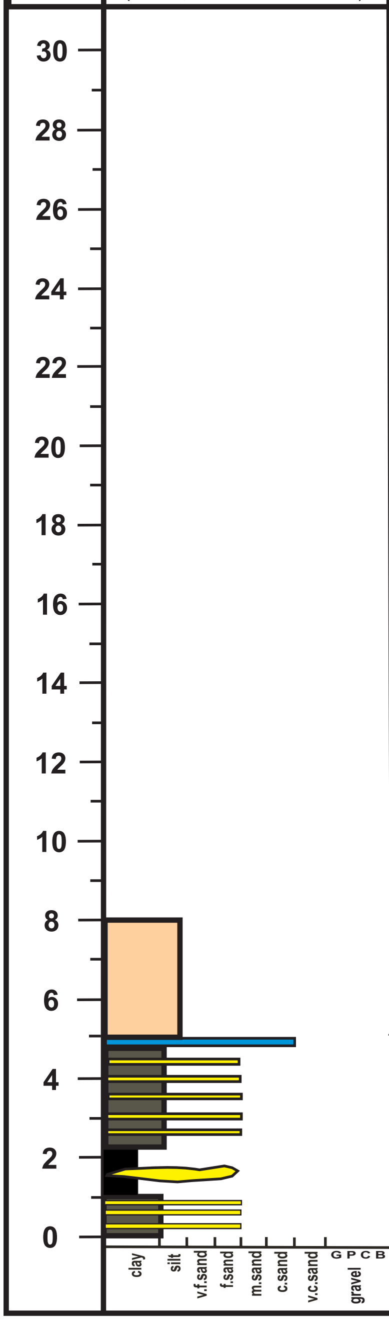
Location (lat/long): 40.24563N, 95.54599W

Total Thickness Measured: ~ 8 m (26.4 ft)

Date Measured: 03/27/2005

Measured By: S.A. Fischbein, B.A. Fischbein, R.M. Joeckel

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Lithologic Description (top to bottom):

Quaternary Sediments

Limestone - Weathers creamy to yellowish, gray on fresh surface, bioturbated.

Mudstone dominated heterolith - gray to brown, 60-90% mudstone in units 3 to 10 cm; 10-40% sandstone laminae and beds 10 mm to 5 cm thick. More shale to top.

Coal - Black, massive to fissile, shiny on fresh surfaces, cleat faces heavily oxidized white-red, covered with grayish slopewash.

Shale -gray to light gray with sandstone stringers and large coalified wood fragments. Pyrite/Siderite unit at base of section 5 cm thick sitting on top of gray saturated shale at creek level.

Section Name: Indian Cave State Park Section #1 - ICS Cave Section

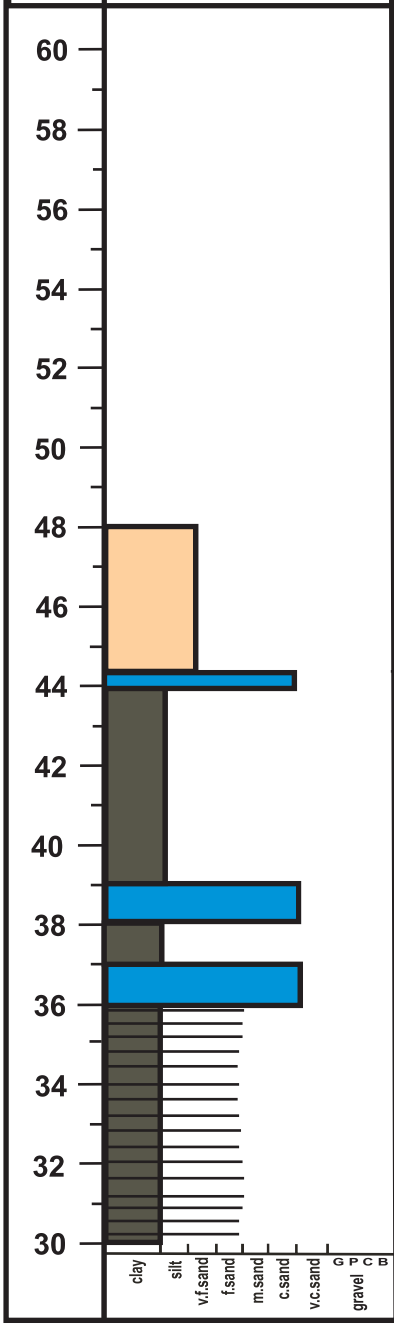
Location (lat/long): 40.24672N 95.51790W

Total Thickness Measured: 48 m (159 ft)

Date Measured: Upper Section April, 1971
Lower Section 11/2004

Measured By: Section from base to top of cave by Fischbein, S.A with staff and tape. Above Cave from CSD log 4/71.

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Quaternary Overburden
sand, silt, clay.

Five Point Limestone- massive, tough brown-tan, speckled

West Branch Shale:
Silty clay w/ limestone nodules, yellow-gray and gray shale filling. Shale, light greenish gray, reddish-brown, red, clayey.

Shale - red, purple and green in upper part, gray to gray-brown with boxwork in middle part, reddish and gray in lower part.

Lehmer Limestone Member - massive, tough, light gray with rust spots, thin shale interbed, fibrous xtals in voids

Reserve Shale Member - dark gray to yellowish-tan, very calcareous.

Miles Limestone Member - large nodular yellowish-tan, gray, hard.

Upper Indian Cave Sandstone
24.1 - 36 m, Sandstone and Mudstone Dominated Heterolith, evenly mixed:
Described by CSD as Shale, gray, sandy and clayey, mottled with red-rusty brown and gray; sandy and grayish tan, 1/4” coal smut; sandstone, very hard, massive and bedded; sandstone, massive and inclined; lenticular and inclined stratification, sandy shale, buff, sand and shale; mixed sand and shale; mixed sand and clay lenses.

Section Name: Indian Cave State Park #2 - Quarry Campsite Section

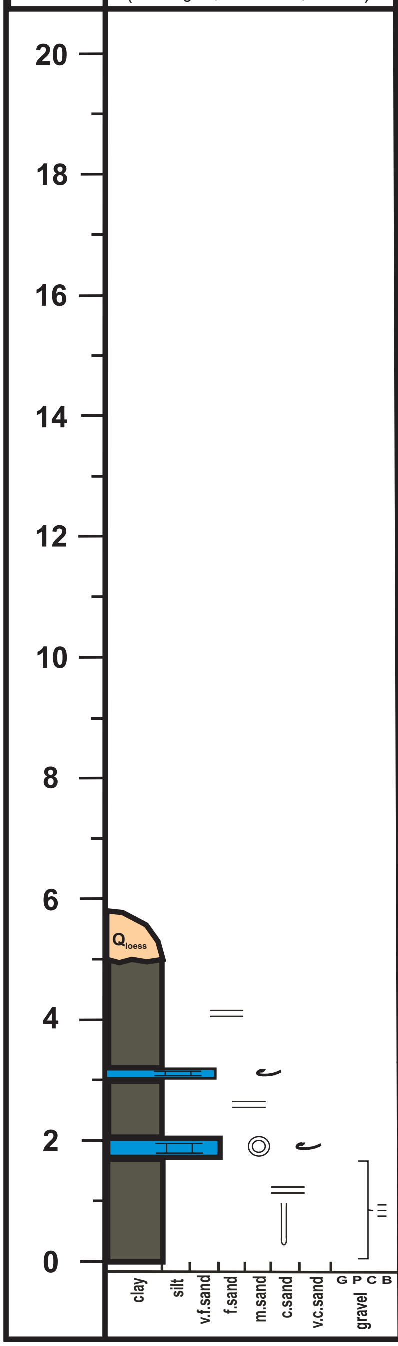
Location (lat/long): 40 15 37N, 95 33 16W

Total Thickness Measured: 5 m (16.5 ft)

Date Measured: 07/28/2004

Measured By: S.A. Fischbein with tape and Jacob Staff

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



This section begins approximately 1.8 m below working surface of Quarry Campsite location and continues through quarry and into prominent ridge between pit toilets and eastern-most lean-to.

Facies	Depositional Environment	Lithologic Description
		4.98 m +, Quaternary Loess: 5YR5/6, brown, forms slick slopes to near vertical and vertical faces, creates abundant slope wash.
		3.18 - 4.98 m, West Branch Shale: N5, 5YR6/4, 5R4/6; Gray, weathering tan to red shale, hard, bedded to fissile, rings with hammer when hit. Poorly exposed and covered by slope wash, exposures generated through hand dug pits. Upper contact not exposed, ~180 cm measured.
M_1	Offshore	**3 - 3.18 m, Falls City Limestone (Lehmer Mbr):** 10YR6/6, 10R6/6, N5; Red-orange, weathers gray, limestone with red to orange and tan laminae, plane parallel to very wavy, fenestrated fabric with possible fossil fragments in voids, and obvious spar filling voids.
M_2	Carbonate Platform	
M_1	Offshore	**2.1 - 3 m, Fall City Limestone (Reserve Shale Mbr):** 5YR6/4, 5R4/6, N5; Tan to red and gray shale to shaley platy limestone, fossiliferous, mostly covered.
M_2	Carbonate Platform	**1.8 - 2.1 m, Falls City (Miles Mbr) Limestone:** N5, 5YR3/2, 5R4/6; Gray-brown, red, weathers gray, **Intrasparite** with well rounded grains of fossil frags, oolites, and micrite.
M_1	Offshore	**0 - 1.8 m, Hawxby Shale:** N5, Gray to dark gray shale, massive with scattered traces on rare bedding. Upper 20 cm is tan to gray mottled, highly weathered limy shale or shaly limestone. Lower exposures red-orange mottled, exposures generated from hand dug pits. Base not exposed.

Section Name: Indian Cave state Park #3 - River/Creek Confluence

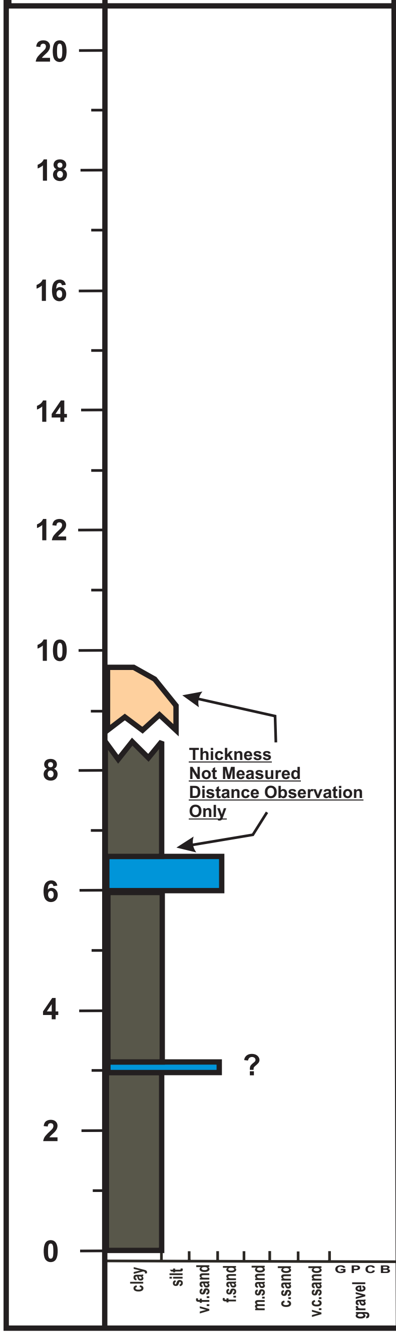
Location (lat/long): 40 15 45N, 95 33 21W

Total Thickness Measured: 6.6 m (21.7 ft)

Date Measured: 07/28/2004

Measured By: S.A. Fischbein using tape and Jacob Staff

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



6.6 - ?, Shale overlain by Quaternary Loess: Vertical faces here were not accessible at time of measurment. Only distance observation made, indicating gross lithology of shale overlain by loess with approximate thickness of 2 m. Outcrop ends at slope break at top of Missouri River bank..

6 - 6.6 m, Nebraska City Limestone: Gray, weathers tan to brown. Shale/shaly limestone seam in middle to lower part of unit, 5 - 8 cm thick. No obvious fossils in hand sample, but shoreline below this unit is littered with highly fossiliferous blocks that may originate from this unit, the suspect lower unit, or as imported rip-rap.

Unit was approximately 7.6 m above water level at time of measurement (4.5 m above high water mark)

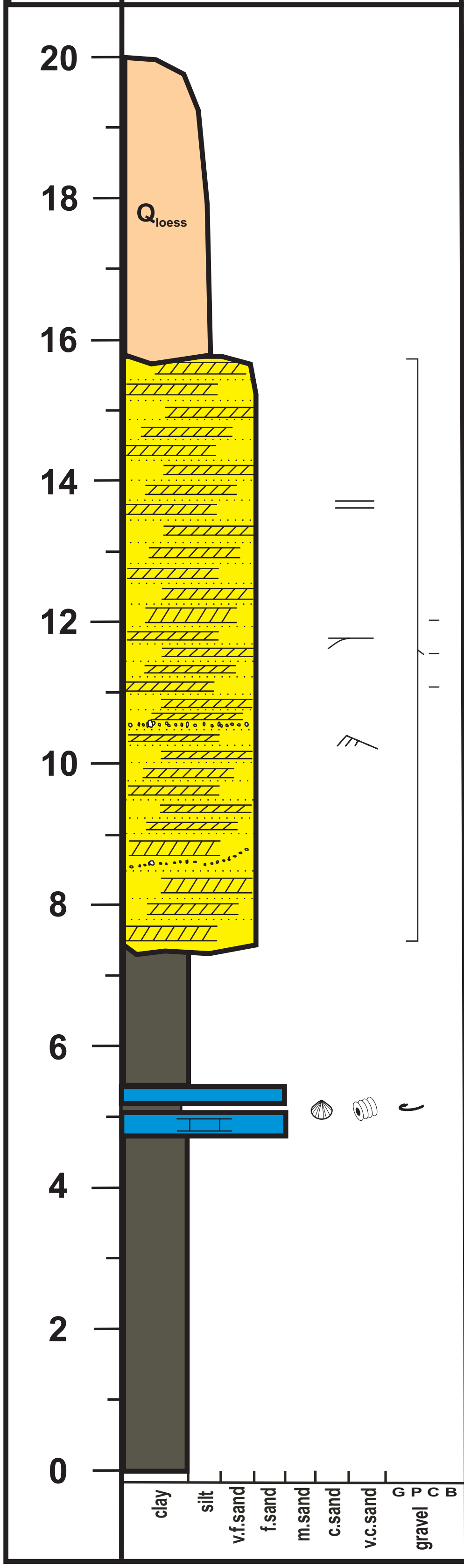
0 - 6 m, French Creek Shale: Gray with red-orange mottles, bedded to laminated, fissile. Exposures appear to continue down to river level and below. Roughly halfway in slope face, approximately 3 m above river level, is a sandy limestone ledge roughly 15cm thick. Cannot discern if this is bank rip-rap or in-place. Unit does not continue into near vertical face to north where shale or mudstone dominated heterolith is exposed. The limestone forms platy blocks that are highly fossiliferous and contain burrows, tracks and trails.

Section Name: Indian Cave State Park Section #4

Location (lat/long): 40.25139N, 95.53559W **Total Thickness Measured:** 20 m (66 ft)

Date Measured: 03/17/2005 **Measured By:** Fischbein, S.A.

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Facies	Depositional Environment	Lithologic Description
		Quaternary Loess
St_2 & St_1	Fluvial Channel to Tidally Influenced Fluvial Channel	Indian Cave Sandstone
M_1	Offshore	Towle Shale
M_2	Carbonate Platform	Brownville Limestone
M_1	Offshore	Pony Creek-Plumb Shale Undifferentiated

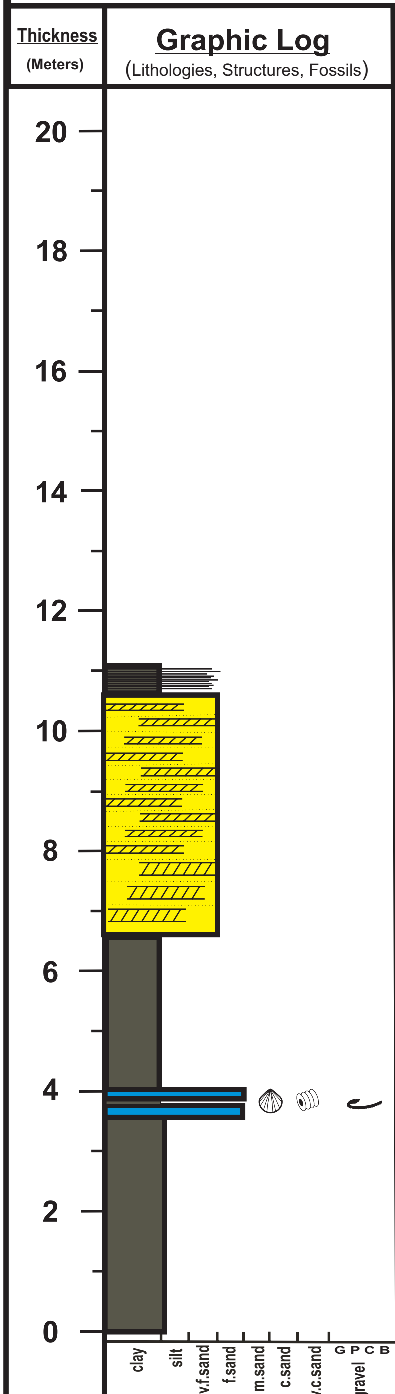
Section Name: Indian Cave State Park Section #5

Location (lat/long): 40.25009N, 95.53190W

Total Thickness Measured: 11 m (33 ft)

Date Measured: 03/07/2005

Measured By: Fischbein, S.A. Using Impulse Laser



Facies	Depositional Environment	Lithologic Description
H_1/H_2		
St_2 & St_1	Tidally Influenced Fluvial Channel	Indian Cave Sandstone
M_1	Offshore	Towle Shale
M_2	Carbonate Platform	Brownville Limestone
M_1	Offshore	Pony Creek-Plumb Shale Undifferentiated

Section Name: ICSP Section #6

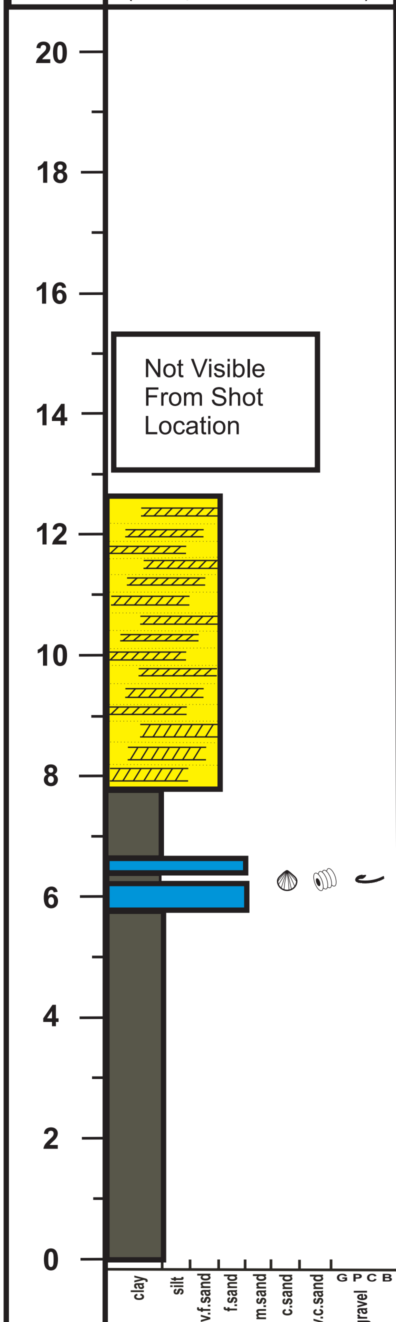
Location (lat/long): 40.24869N, 95.52489W

Total Thickness Measured: 12.63 m (41.68 ft)

Date Measured: 03/17/2005

Measured By: Fischbein, S.A., Using Impulse Laser Rangefinder

Thickness (Meters) | **Graphic Log** (Lithologies, Structures, Fossils)



Facies	Depositional Environment	Lithologic Description
St_2 & St_1	Tidally Influenced Fluvial Channel	Indian Cave Sandstone
M_1	Offshore	Towle Shale
M_2	Carbonate Platform	Brownville Limestone
M_1	Offshore	Pony Creek-Plumb Shale Undifferentiated

Section Name: ICSP Section #7

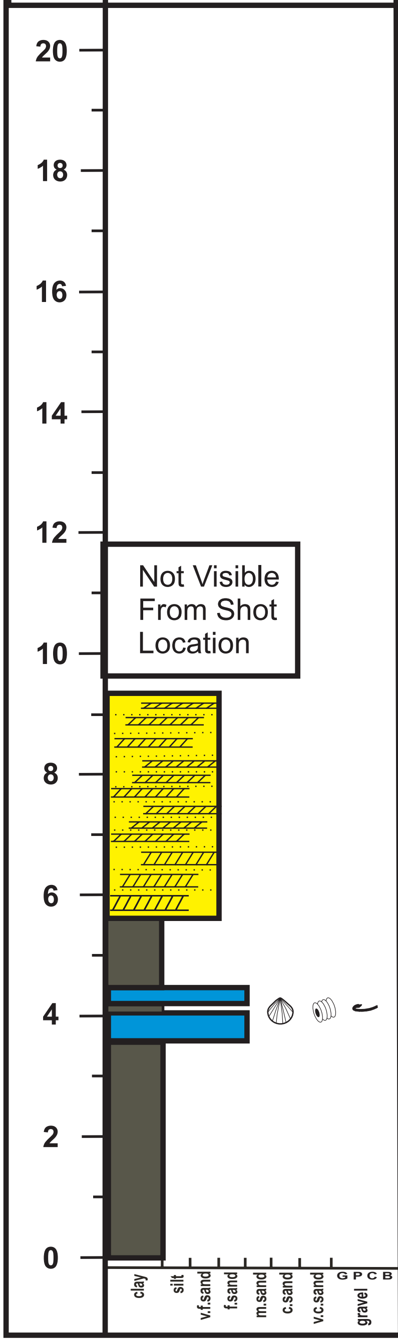
Location (lat/long): 40.24786N, 95.52149W

Total Thickness Measured: 9.35 m (30.855 ft)

Date Measured: 03/17/2005

Measured By: Fischbein, S.A., Using Impulse Laser Rangefinder

Thickness (Meters) | **Graphic Log** (Lithologies, Structures, Fossils)



Facies	Depositional Environment	Lithologic Description
St_2 & St_1	Tidally Influenced Fluvial Channel	Indian Cave Sandstone
M_1	Offshore	Towle Shale
M_2	Carbonate Platform	Brownville Limestone
M_1	Offshore	Pony Creek-Plumb Shale Undiff.

Section Name: ICSP Section #8

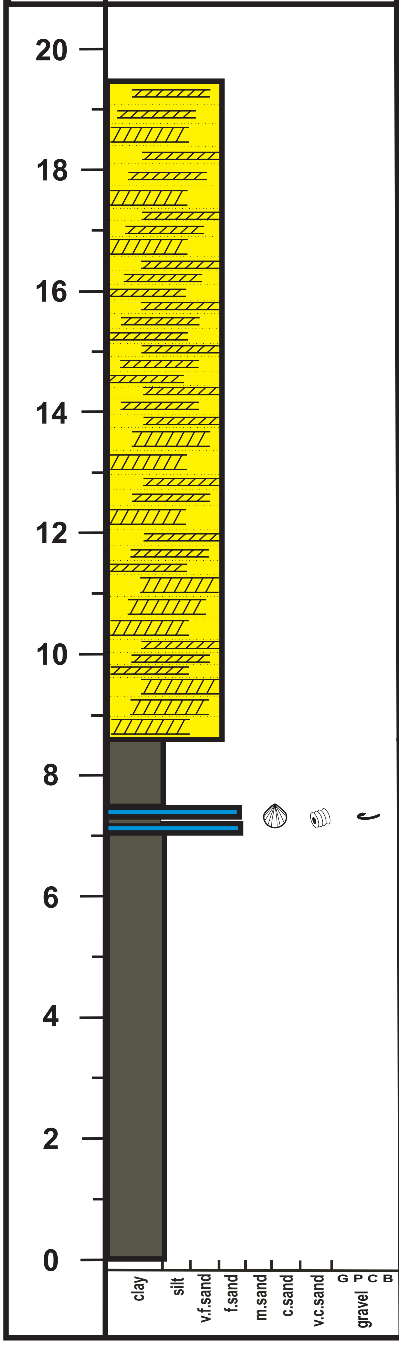
Location (lat/long): 40.24864N, 95.51790W

Total Thickness Measured: 19.46 m (64.22 ft)

Date Measured: 03/17-2005

Measured By: Fischbein, S.A. Using Impulse Laser Rangefinder

Thickness (Meters) | Graphic Log (Lithologies, Structures, Fossils)



Facies	Depositional Environment	Lithologic Description
St_2 & St_1	Fluvial Channel	Indian Cave Sandstone
M_1	Offshore	Towle Shale
M_2	Carbonate Platform	Brownville Limestone
M_1	Offshore	Pony Creek-Plumb Shale Undiff

Section Name: Peru #1

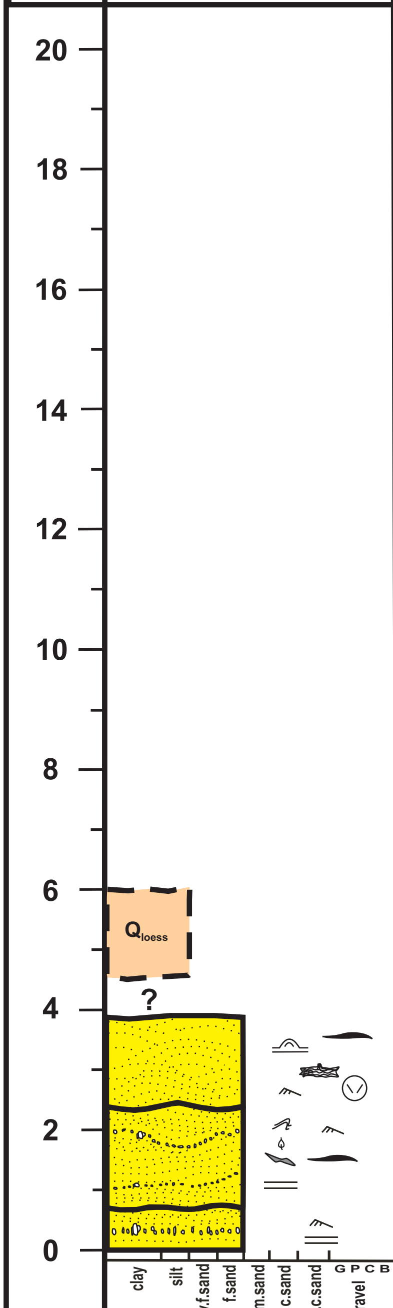
Location (lat/long): 40 28 32N, 95 42 22W

Total Thickness Measured: 3.9 m (12.8 ft)

Date Measured: 04/06/ 2004

Measured By: S.A. Fischbein, R.M. Joeckel

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



This section located in gully immediately south of section Peru #2, and base of section is located 1.6 m above base of trail post number 18, located on west side of trail, roughly 200 feet south of pumphouse.

Quaternary Loess - Clayey Sandy Silt: 2.5YR7/4, 6/6; Blocky in part, forms slopes and steep walls in gullies. Contact with underlying sandstone unknown due to slope wash cover.

Facies	Depositional Environment	Lithologic Description
St_2	Tidally Influenced Fluvial	**2.4 - 3.9 m, Sandstone** - 5YR6/1 to 6/4: Fine to very fine, horizontal and ripple cross-laminated, trough cross-bedded. Very micaceous along bedding surfaces. Carbonaceous laminae common. Rare to scattered concretions containing plant debris and wood. Carbonate cemented.
S_L	Fluvial Channel	**0 - 2.4 m, Sandstone** - 5YR6/4, very fine to fine, horizontal lamination with some ripple cross-lamination. Dispersed intraformational clast pebbles of heterolith and carbonaceous organic debris with leaf impressions preserved on heterolith clast faces. Clast size ranging from 1 - 4 cm. Soft sediment deformation as small folds 8 - 10 cm in amplitude and 20-30 cm across.

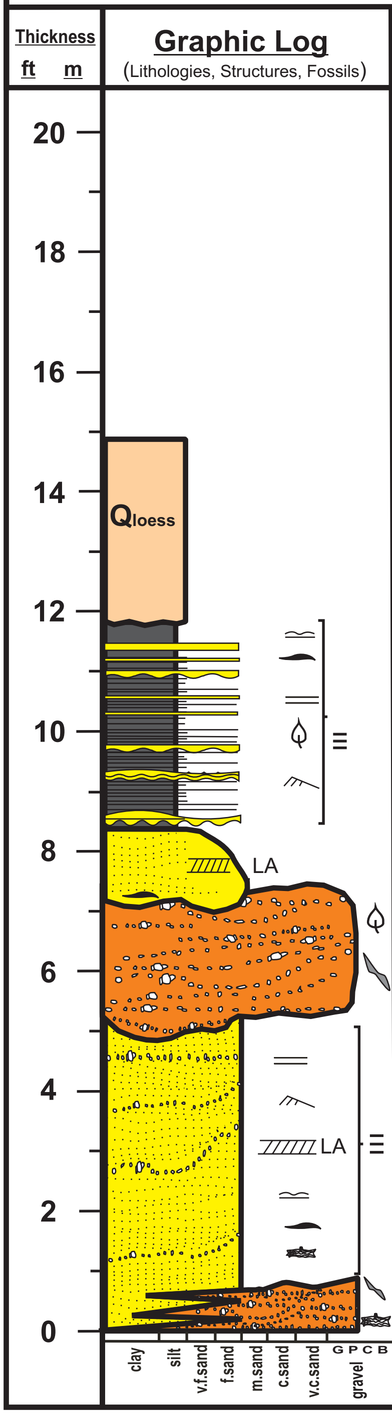
Section Name: Peru #2

Location (lat/long): 40 28 32N, 95 42 24W

Total Thickness Measured: 14.2+ m (46.6+ ft)

Date Measured: 04/06/2004

Measured By: S.A. Fischbein, R.M. Joeckel



Facies	Depositional Environment	Lithologic Description
		11.2 - 14.2$^{\pm}$ m, Quaternary Loess - Clayey Sandy Silt: 2.5YR7/4, 6/6; Blocky in part, forms vertical to near vertical exposures at top of outcrop.
H_1	Upper Estuary	**8.25 - 11.2 m, Sandy Heterolith** - Sandstone units 2 to 10 cm thick interbedded with sandy and silty shale units 1 to 15 cm thick. Sandstones: 7.5YR6/3, 10YR7/3,8/4; Fine to very fine, horizontally laminated to ripple cross-laminated and wavy-bedded/laminated. Sandy-Silty Shale: 7.5YR5/3, 3/4, 5YR4/4; Horizontal laminated with ripple cross-laminated and wavy to lenticular laminated silty fine sand. Coaly traces and leaf fossils trace to common.
S_L	Tidally Influenced Fluvial Channel	**6.7 - 8.25 m, Sandstone:** 10YR7/4, 5Y6/4: Low angle cross bedded dominated by plane parallel and ripple cross-lamination and abundant scour surfaces. Very silty laminae 1 to 5 mm with adundant organic material, very dark brown to black against brown to tan of sandstone. Both sandstone and laminae very friable. Coaly debris and traces along laminae.
Ci	Fluvial Channel	**4.5 - 6.7 m, Conglomerate** - Matrix 7.5YR6/4, 10YR6/3; Clasts 7.5YR4/3, N4; Matrix supported with angular to rounded intraformational clasts of heterolith and shale containing plant fragments, leaf and wood fossils. Clast size ranges from 1 to 25 cm with pebbles oriented with flattened side parallel to bedding. Base of units appears to dip SE
S_L	Tidally Influenced Fluvial Channel	**0.9 - 4.5 m, Sandstone** - 10YR8/3, 7/3, 6/3; Fine to very fine, scattered medium, low angle cross-bedded and ripple cross-laminated, massive in places. Dispersed pebbles along bedding with iron staining and siderite rinds. Base truncates underlying unit along scour surface.
Ci	Fluvial Channel Bank Collapse	**0 - 0.9 m, Conglomerate** - Matrix color, 7.5YR6/3 & 5/4; Clast color, 7.5YR5/4, N5, N4; Matrix supported with clasts of angular to subrounded heterolith. Clast size range 1 to 200 cm. Interfingers to south with overlying sandstone

Section Name: Peru #3

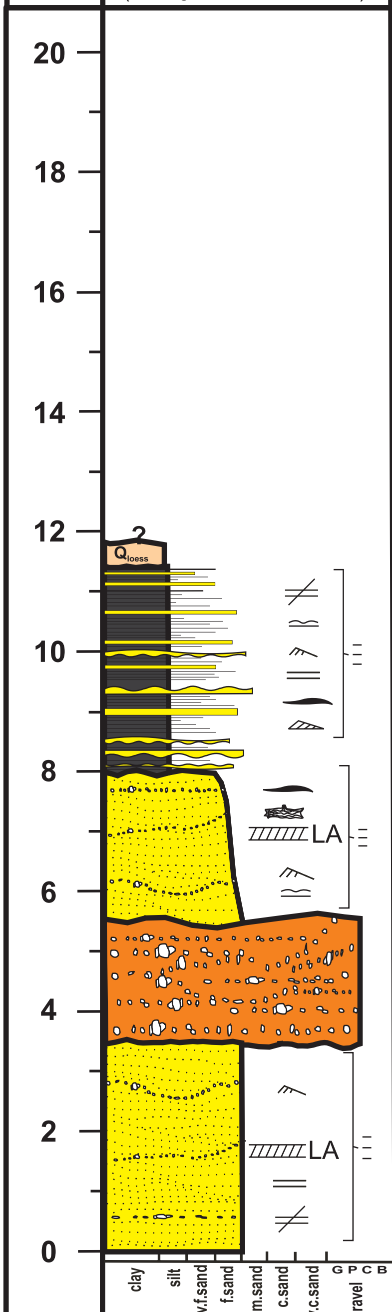
Location (lat/long): 40 28 32N, 95 42 26W

Total Thickness Measured: ~ 11.75 M (~38.5 ft)

Date Measured: 04/16/2004

Measured By: S.A. Fischbein, R.M. Joeckel

Thickness (Meters) / Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description
			Quaternary Loess
	H_1	Upper Estuary	**7.78 - 11.5 m +, Sandy Heterolith:** Sandstone units 2 to 15 cm thick interbedded with sandy and silty shale units 1 to 15 cm thick. Sandstone: 7.5YR6/3, 10YR7/3, 8/4; fine to very fine, horizontally laminated to ripple cross-laminated, wavy bedded and laminated. Shales: 7.5YR5/3, 3/4; 5YR4/4; 2.5Y4N4; 2.5Y8NB: Sandy and silty laminations in shale are white to light gray with ripple cross-lamination, wavy lamination and lenticular lamination.
	S_L	Tidally Influenced Fluvial Channel	**5.33 - 7.78 m, Sandstone:** 10YR7/4 Low angle cross-bedded dominated by plane parallel and ripple cross-lamination with organic drapes. Faint in places with dispersed nearly spherical, discoid oblate mud pebbles 1 to 6 cm in diameter. Form sets of ripples abundant and average 3 mm in amplitude. Upper and lower bounding surfaces are scoured, with upper portion transitioning into ripple dominated forms that are well cemented with abundant organics and very micaceous.
	Ci	Fluvial Channel	**3.5 - 5.33 m, Conglomerate:** Matrix; 7.5YR6/3 & 5/4, Clasts; 7.5YR5/4, N5, N4: Matrix supported with clasts of angular to subrounded heterolith and shale. Clast size range from 1 to 200 cm.
	S_L	Tidally Influenced Fluvial Channel	**0 - 3.5 m, Sandstone:** 5Y6/4; Low angle cross-bedded, with plane parallel and ripple cross-lamination. Scattered pebbles some with wood fragment cores, others claystone or heterolith clasts. Scour surfaces dominant throughout unit.



Section Name: PERU #4

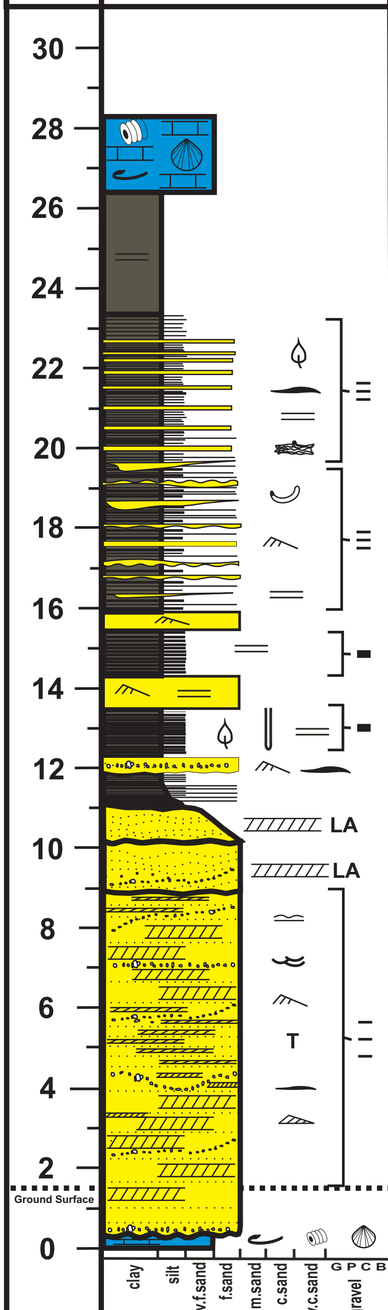
Location (lat/long): 40 28 47N, 95 43 04W

Total Thickness Measured: 28.25 m (~93 ft)

Date Measured: 04/29/2004

Measured By: S.A. Fischbein, R.M. Joeckel

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Facies	Depositional Environment
M_2	Carbonate Platform
M_1	Marine Embayment?
H_2	Upper Estuary
H_1	Upper Estuary
S_L	Upper Estuary
H_2	Upper Estuary
S_L	Upper Estuary
H_2	Upper Estuary
S_L	Tidally Influenced Fluvial Channel
S_L - H_2	Tidally Influenced Fluvial Channel
S_L	Tidally Influenced Fluvial Channel
St_2 & St_1	Tidally Influenced Fluvial Channel
M_2	Carbonate Platform

NOTE: This log includes ~2 m of subsurface borehole data collected from beneath base of outcrop

Lithologic Description

25 - 26.5 m, Falls City Limestone, Miles Member: 10YR8/4 in upper part, 5BG7/1 in lower part with mottled10YR7/4; Lower part highly weathered in soil profile. Abundant trace fossils and shell fragments

22 - 25 m, Shale: 2.5YRN6, 5/2, 4/4; massive to weakly fissile with minor sand stringers.

17.03 - 22.0 m, Mud Dominated Heterolith: 5YR7/1, 5/1, 4/1, 6/3, 5/4; Shale with laminated light brown gray to brown and tan laminae of siltstone and very fine sandstone. Plant fossils of complete and partial leaves and wood fragments along laminae as discrete units up to 1 cm thick.

14.07 - 17.73, Sand Dominated Heterolith: 5YR7/1, 5/1, 10YR4/1, 7/3; Laminated to bedded and massive shale units 2 to 20 cm thick interbedded with sandstone units 10 to 30 cm thick defined by scoured contacts.

13.75 - 14.07 m, Sandstone: 10YR5/3, 5/1; fine to very fine, very micaceous, laminated to thin bedded, ripple cross-lamination 1 to 3 mm thick. Varies along strike, forms ledges, contain *planolites*

12.38 - 13.75, Mud Dominated Heterolith: 10YR5/1, 7/1, 8/3; Rhythmically alternating gray, light gray and tan silty shale laminae. Weakly fissile.

11.64 - 12.38, Sandstone: 10YR8/3, 6/3, 6/1; Fine to very fine, laminated to ripple cross-laminated.

10.64 - 11.64 m, Mud Dominated Heterolith: 10YR4/1, 6/1, 7/4; rhythmically alternating gray and tan silty laminae averaging less 2 mm. Weakly fissile, plant debris evident along lamination and bedding planes. Rare trace faossils, one vertical burrow noted 12 cm long by 4 cm wide. Microfaults noted to offset laminae on mm scale.

10.3 - 10.64 m, Sandstone: 10YR6/4; Fine to very fine, ripple cross-laminated with scattered organic debris and pebbles

8.5 - 10.3 m, Sandstone grading to Heterolith: Sandstone - 10YR5/3, 8/4; Fine to very fine, ripple cross-laminated units 8 to 10 cm thick grading vertically into Silty, Sandy, Shale 10YR6/1, 5/1, 4/1 with siltstone laminae. Siltstone-shale units range from 5 to 8 cm thick, with siltsone ripple cross-laminated.

7.5 - 8.75 m, Sandstone: 10YR5/3, 8/4, 6/1; Very fine to fine with scattered pebbles. Low angle trough cross-bedded with scoured bases, laminated and ripple cross-laminated.

-1.5 - 7.5 m, Sandstone - 10YR5/3, 6/4, 8/4, 6/1: Very fine to fine, with scattered pebbled surfaces. Large and small scale trough cross-bedding (less than 0.25 m to ~1m) with complete ripple forms preserved along trough bottoms. Where Section measured, outcrops obscured by slumps, lithologies collected from adjacent outcrops.

-1.75 to -1.5 m, Grayhorse Limestone: 5YRN5; Gray limestone, sandy, sparry, shell fragments.

Section Name: Peru #5

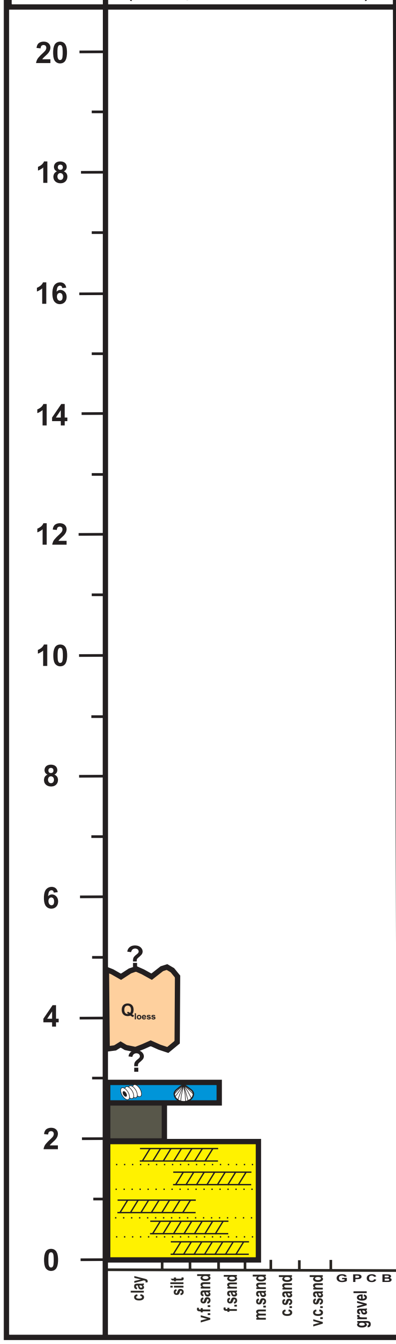
Location (lat/long): 40 28 00N, 95 41 30W

Total Thickness Measured: 2.89 m (~9.5 ft)

Date Measured: 6/30/2004

Measured By: S. A. Fischbein

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description
				Quaternary Loess: Contact and thickness unknown due to excessive slope cover.
			Carbonate Platform	**2.59 - 2.9 m, Brownville Limestone:** 5Y5/1-5Y4/1, Medium to dark gray limestone with abundant crinoid and brachiopod fragments.
				0 - 2.59 m, Pony Creek- Plumb Shale Undiff: 7.5YRN5 Trough cross-bedded carbonate cemented sandstone overlain by 5G5/1-5G4/1 shale, fully saturated, mottled, water seeping from unit, to saturated to observe any structures.



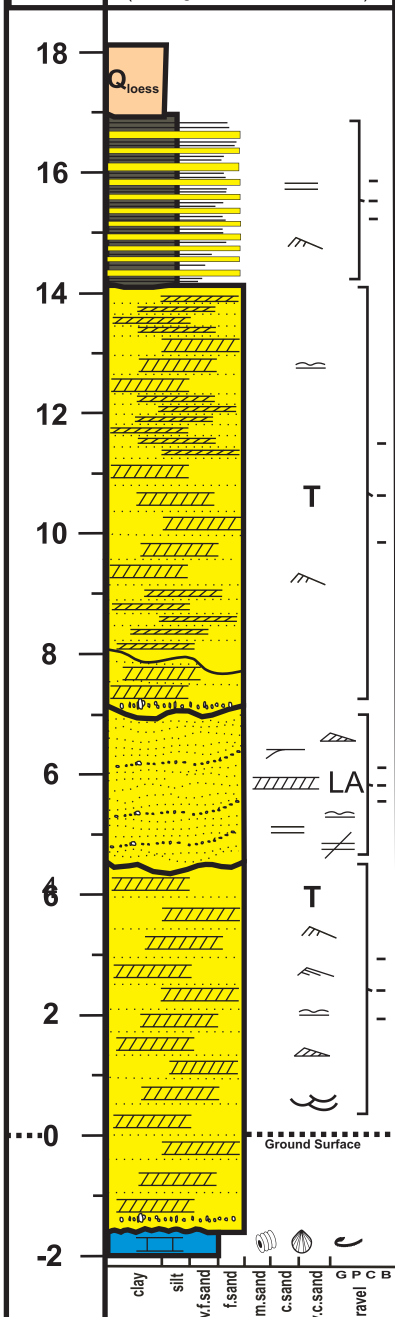
Section Name: Peru #6

Location (lat/long): 40.47766N, 95.71199W

Total Thickness Measured: 18.13 m (~59.9 ft)

Date Measured: 02/04/2005

Measured By: S.A. Fischbein using LaserTech ImpulseLR 200 laser rangefinder.



Facies	Depositional Environment	Lithologic Description
		16.48 - 18.13 m, Quaternary Loess
H_1 & H_2	Upper Estuary	**14.16 - 16.48 m, Heterolithic Assemblage:** Interbedded sandstoen and shale units of varying thickness. Units cannot be physically accessed due to position on vertical face, but appear the same as those seen at the GSB locale.
St_2 & St_1	Tidally Influenced Fluvial Channel	**7.20 - 14.16 m, Sandstone:** Large and small ale cross-bedded units interfinger in this portion of section. Scour surfaces prominent especially in lower part. Pebble layer near base. Units cannot be physically accessed due to position on vertical face.
S_L		**4.65 - 7.20 m, Sandstone:** Low angle to near planar cross-bedded with single pebble lag along bedding. Scour surfaces are also low angle. Units appear planar from distance. Units cannot be physically accessed due to position on vertical face.
St_1		**-1.5 to 4.65 m, Sandstone:** Large scale trough cross-bedded with trough bases ripple cross-laminated. Trough grade to flaser, wavy and lenticular bedding at the tops of most beds, with complete mud drapes on fully to partially preserved ripple forms.
M_2	Carbonate Platform	**-1.5 to -2 m, Nebraska City Limestone:** 5BG6/1; 7.5YR6/0; Gary to blue-gray limestone, sandy and sparry with crinoid and shell fragments. Biomicrite/Wackestone.

Section Name: Peru Section #6 (inclusive of Peru Borehole #1)

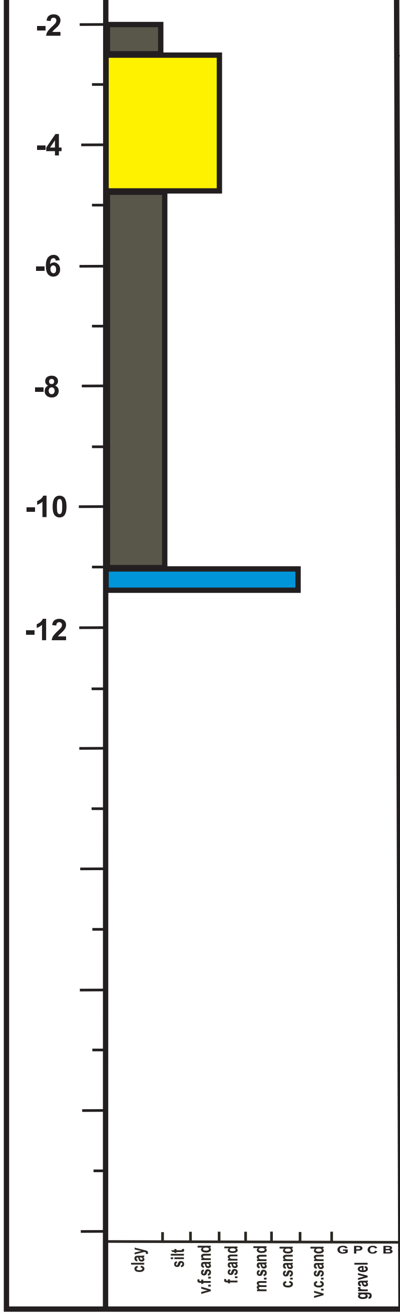
Location (lat/long): Type lat/long here

Total Thickness Measured: 11.8 m below grade (39 ft)

Date Measured: 08/2004

Measured By: Fischbein, S.A., Continuous core w/auger rig

Thickness (Meters) | **Graphic Log** (Lithologies, Structures, Fossils)



Facies	Depositional Environment	Lithologic Description
	French Creek Shale	Sandy Silty Shale with sandstone stringers and silty clayey very fine sandstone 7.5YR7/0
		Sandstone - 10YR6/4, very fine, micaceous, looks massive but fissile in core, breaks to chips with pressure. Grades downward to sandstone with gray 7.5YR7/0 interbeds with mottling, very micaceous.
		Siltstone - 10YR6/1, slightly sandy, clayey in part with lenses of clay. Laminated, fissile ripple cross-laminated, becomes dominantly mudstone dominated heterolith downward with moderate bioturbation. 60-90% silty shale and clayey siltstone, 10-40% very fine sandstone and silty sandstone, laminated, fissile, ripple cross-laminated in light gray and dark gray lamination. Clay content increases downward and unti becomes shale 0.5 m above lower limestone. Lower shale (10YR6/1) is massive with slight mottling, very calcareous in lower part.
	Jim Creek Limestone	Limestone - 7.5YR5/0, gray with scattered brachiopod fragments, trace crinoid frags. Becomes shaley limestone at bottom of core, laminated, fissile, slightly clayey. Biomicrite/Mudstone

Section Name: Peru #7

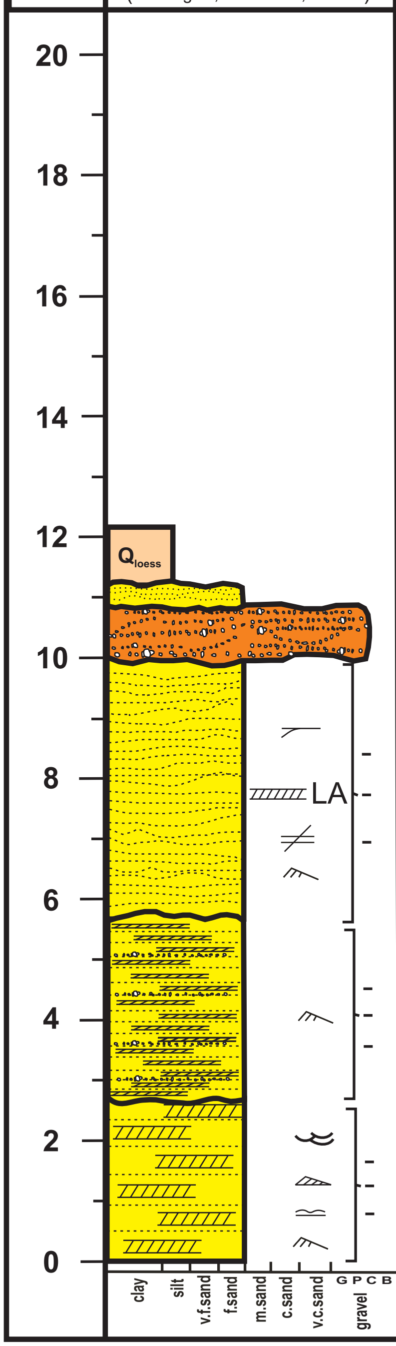
Location (lat/long): 40.47668N, 95.70939W

Total Thickness Measured: ~12.17 m (~40.16 ft)

Date Measured: 02/04/2005

Measured By: S.A. Fischbein using Lasertech ImpulseLR 200 laser rangefinder.

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Facies	Depositional Environment	Lithologic Description
		11.21 - 12.17 m: Quaternary Loess
S_L	Tidal Infuenced Fluvial Channel	**10.92 - 11.21 m Sandstone"** Low angle cross bedded to small scale trough trough cross-bedded unit as below._.
Ci	Fluvial Channel	**10.06 - 10.92 m, Conglomerate:** Clasts composed of heterolithic fragments
S_L	Tidally Influenced Fluvial Channel	**5.64 - 10.06 m, Sandstone:** Low angle cross-bedded to near planar bedded units with scoured based. Units cannot be physically accessed due to position on vertical face.
St_2		**2.7 - 5.64 m, Sandstone:** Small scale cross-bedded units with scattered pebble layers. Units cannot be physically accessed due to position on vertical face.
St_1		**0 - 2.7 m, Sandstone:** Large scale trough cross-bedding with preserved ripple forms in along trough bases. Troughs units grade vertically in within beds to flaser, wavy and lenticular bedding at the tops of most beds, with complete mud drapes on partially to fully preserved ripple forms.

Section Name: Peru #8

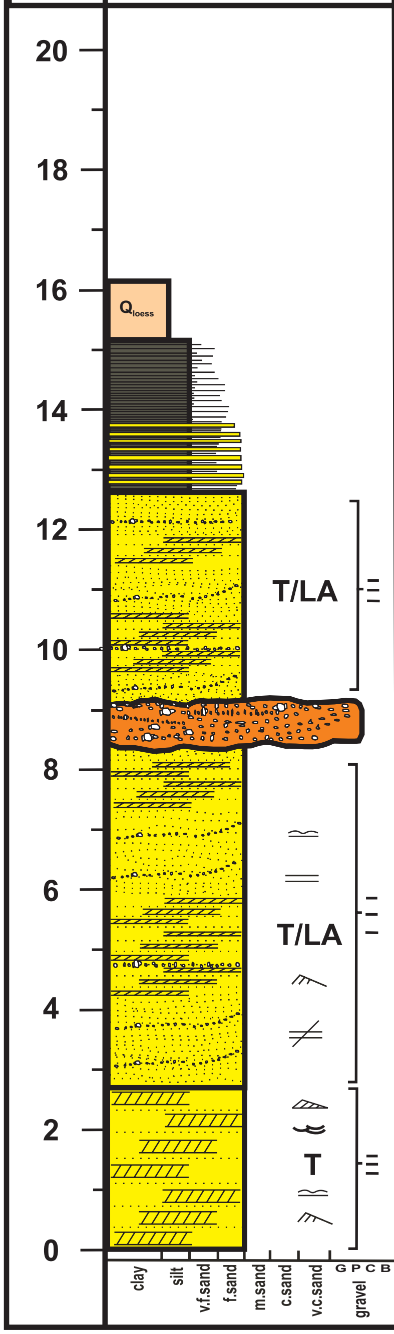
Location (lat/long): 40.47629N, 95.70835W

Total Thickness Measured: ~16.12 m (~53.2 ft)

Date Measured: 02/04/2005

Measured By: S.A Fischbein using LaserTech ImpulseLR 200 laser rangerfinder

Thickness (Meters) | **Graphic Log** (Lithologies, Structures, Fossils)



Facies	Depositional Environment	Lithologic Description
		15.17 - 16.12 m, Quaternary Loess
H_2 & H_1	Upper Estuary	**12.62 - 15.17 m, Heterolithic Assemblage:** Interbedded sandstone and shale units of verying thickness. Units cannot be physically accessed due to position on vertical face but appear same as units at GSB and Pumphouse locales.
St_2 & S_L	Tidally Influenced Fluvial Channel	**9.18 - 12.62 m, Sandstone:** Low angle trough cross-bedded to planar units interbedded with small scale trough cross-bedded units. Pebble layers present along basal scours. Unit not physically accessible due to position on vertical face.
Ci	Fluvial Channel	**8.12 - 9.18 m, Conglomerate:** Clasts composed of wide size range of heterolithic fragments
St_2 & S_L	Tidally Influenced Fluvial Channel	**2.71 - 8.42 m, Sandstone:** Low angle to near planar cross-bedded with single pebble layers along bedding scour surfaces. Grades in-and-out of small scale trough cross-bedded units. Units cannot be physically accessed due to position on vertical face.
St_1		**0 - 2.71 m, Sandstone:** 5YR6/4 Large scale trough cross-bedding with trough bases ripple cross-laminated. Individual beds grade vertically from trough to ripple cross laminated with flaser, wavy and lenticular bedding at tops of beds with fully to partially preserved mud drapes.

Section Name: Peru #9

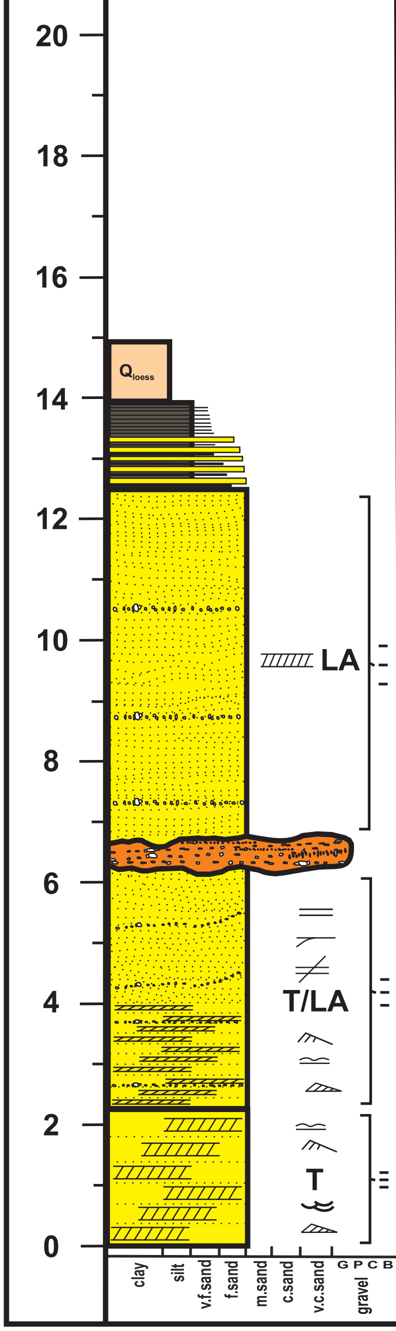
Location (lat/long): 40.47634N, 95.70832

Date Measured: 02/04/2005

Total Thickness Measured: ~14.91 m (~49.2 ft)

Measured By: S.A. Fischbein using LaserTech ImpulseLR 200 laser rangefinder

Thickness (Meters) | **Graphic Log** (Lithologies, Structures, Fossils)



Facies	Depositional Environment	Lithologic Description
		13.91 - 14.91 m, Quaternary Loess
H_1/H_2	Upper Estuary	**12.47 - 13.91 m, Heterolithic Assemblage:** Interbedded sandstone and shale units of varying thinkness. Units cannot be physically accessed due to position on vertical face.
S_L	Tidally Influenced Fluvial Channel	**6.75 - 12.47 m, Sandstone:** Low angle to near planar cross-bedded with single pebble layers scattered along scour surfaces. Units cannot be physically accessed due to position on vertical face.
Ci	Fluvial Channel	**6.27 - 6.75 m, Conglomerate:** Clasts composed of a wide size range of heterolithic fragments.
S_L, St_2, St_1	Tidally Influenced Fluvial Channel	**0 - 6.27 m, Sandstone:** 5YR6/4; Large scale trough cross-bedding at base of unit grading upward through small scale trough cross-bedding to low angle trough cross-bedding. Basal unit is ripple cross laminated along base of troughs, and individual units grade vertically into ripple , flaser, wavy and lenticular bedding. Small scale trough cross-bedded units ans low angle units contain scattered pebble layers along basal scour surfaces. Upper units cannot be physically accessed due to position on vertical face.

Section Name: State Borehole #73-3

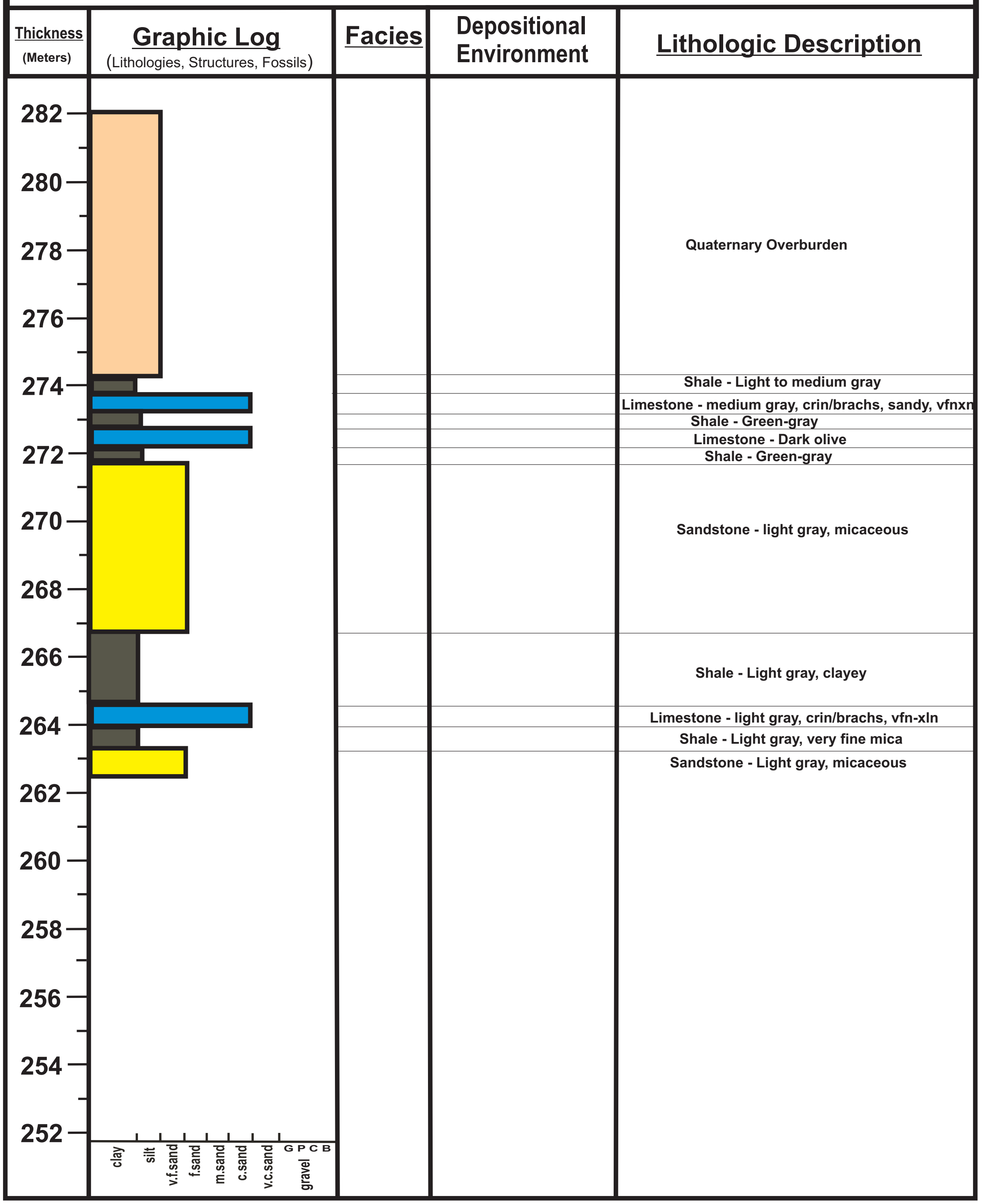
Page 1_ of _1

Location (lat/long): Type lat/long here

Total Thickness Measured: 19.7 m (65 ft)

Date Measured: 07/1973

Ground Surface Elevation: ~281.8 m (~930 ft)



Section Name: State Borehole #74-3

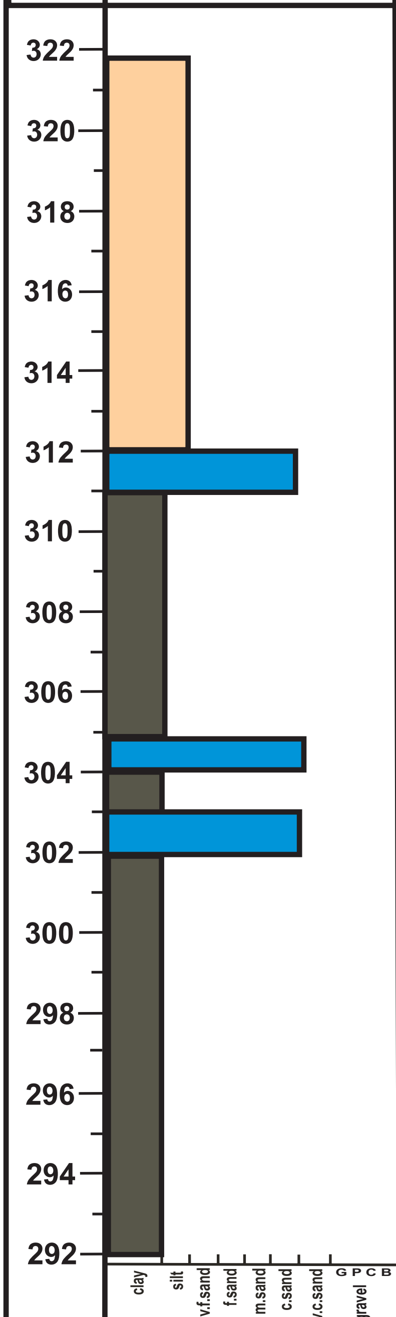
Location (lat/long): See Borehole Map

Total Thickness Measured: 90.9 m (300 ft)

Date Measured: 07/1973

Ground Surface Elevation: 321.8 m (1062 ft)

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Quaternary Overburden

Falls City Limestone

Lehmer Limestone Member -
Red-yellow, oolitic looking, gastropods

Reserve Shale Member
Dark gray to black, carbonaceous.
Trace limestone units through this interval, light gray to dark gray and tan, some with black inclusions and pebbly appearance.
Other shales in the interval are green-gray and light green-gray.

Miles Limestone Member -
Limestone - pale yellow;
Shale - dark olive;
Limestone - light gray, yellow psuedo oolites, “algal looking”.

Shale - light gray to green-gray, medium gray, and some black carbonaceous.
Trace limestone - brown and gray, finely crystalline

Bottom 4 meters contains very fine mica

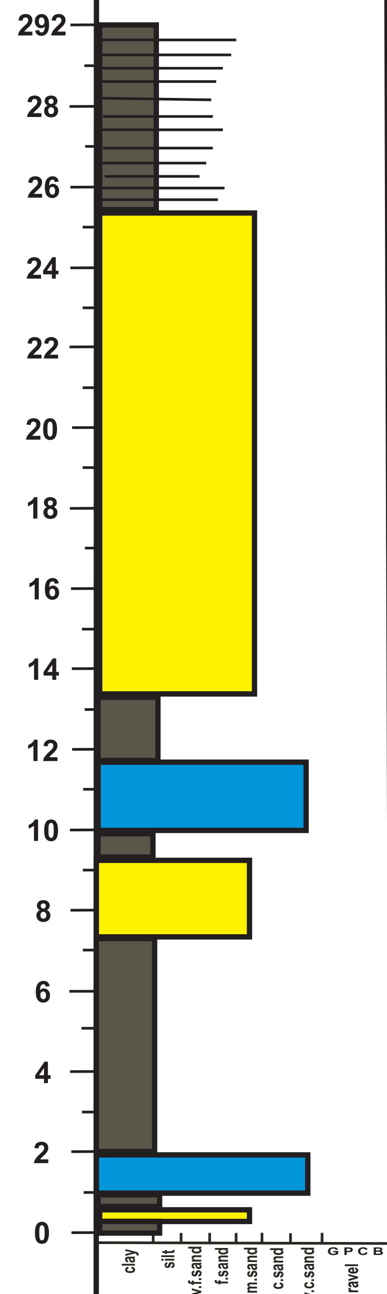
...Top of Indian Cave Heterolith???.

Section Name: State Borehole #73-4

Location (lat/long): See Borehole Map | **Total Thickness Measured:** 90.9 m (300 ft)

Date Measured: 07/1973 | **Ground Surface Elevation** 321.8 m (1062 ft)

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Shale - medium to light gray with very fine mica and very thin interbedded sandstone units, very hard. Micaceous and pyritic sandy shale, dark olive and sandstone.

Indian Cave Sandstone, limy hard, light green-gray, very fine grained micaceous.

Towle Shale - light gray, clayey

Brownville Limestone - gray, finely crystalline, sandy, pyritic, crinoids.

Pony Creek Plumb Shale Undiff

Shale - dark olive

Sandstone - light green gray, very fine, micaceous.

Shale - light to dark gray nad olive

Nebraska City Limestone - Dark gray

French Creek Shale - black carbonaceous and light gray,trace sandstone.

Section Name: Watson-Rockport #1

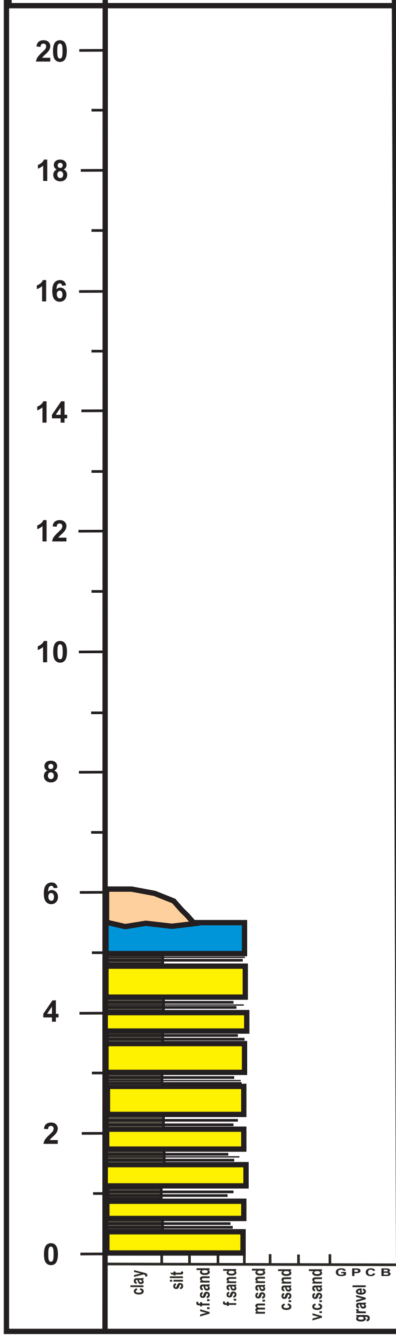
Location (lat/long): 40.48236N, 95.59065W

Total Thickness Measured: 5.4 m (18 ft)

Date Measured: 03/04/2005

Measured By: S.A. Fischbein using hand level and tape

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Quaternary Loess: Not Measured

5 - 5.4 m, Brownville Limestone: 5YR5/6 N5; Crinoidal, shelly, 1-5 mm micritic intraclasts

0 - 5 m, Pony Creek- Plumb Shale Undiff: 5Y6/6, 10GR5/2; Interbedded sandstone and sandstone dominated heterolith. Sandstone, very fine to fine, well cemented to friable, trough cross-bedded with obvious scour and fill, ripple cross-laminated, with dislodged blocks on slope showing prominent oscillation ripples on exposed bedding surfaces.

Section Name: Watson-Rockport #2

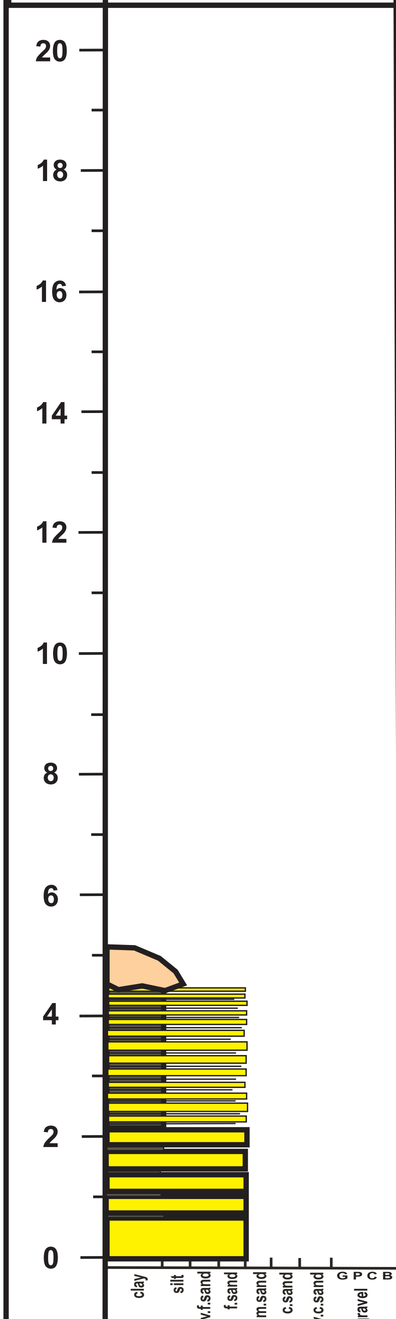
Location (lat/long): 40.45822N, 95.58426W

Total Thickness Measured: 4.5 m (15 ft)

Date Measured: 03/04/2005

Measured By: S.A. Fischbein with hand level and tape.

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Quaternary Loess: Not Measured

0 - 4.5 m, Pony Creek -Plumb Shale Undiff:
5Y6/6, 5Y7/6,
10Y8/2; Low angle trough cross-bedded sandstone in tabular units with basal scours from base of outcrop up to 0.6 m.
0.6 m - 2.5 m, small scale trough cross-bedded tabular beds 18 - 30 cm thick with ripple cross-laminated,l sandstone dominated heterolith tops (1 - 3 cm thick) to each bed.
2.5 - 4.5 m, sandstone dominated heterolith with full ripple forms, micaceous and organic drapes on ripples, with some flaser and lenticular bedding.

Section Name: Watson-Rockport #3

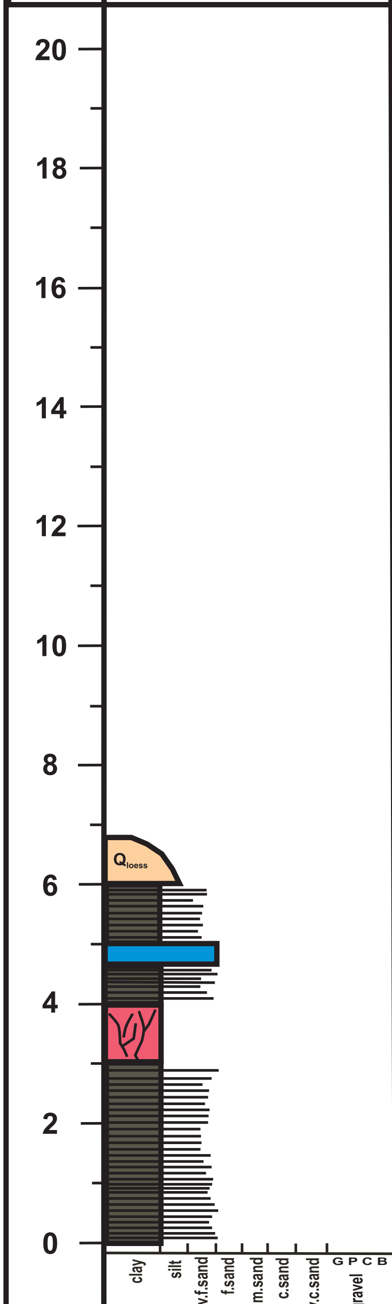
Location (lat/long): 40.44385N, 95.57368W

Total Thickness Measured: 5.75 m (19 ft)

Date Measured: 03/07/2005

Measured By: S.A. Fischbein using hand level and tape

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Quaternary Loess: Not Measured

4.7 - 5 m, Brownville Limestone: 5YR5/6, N5; crinoidal, shelly with dominant intraclasts.

Pony Creek-Plumb Shale Undiff

4 - 4.7 m, Mud Dominated Heterolith: As below, with more 5YR6/4 color.

3 - 4 m, Purple Paleosol: 5P4/2; Irregular upper contact, unit dominated by discordant fractures creating blocky texture resembling peds. Fracture surfaces commonly stained red.

0 - 3 m, Mud Dominated Heterolith: 7.5YR5/2-6/3; Slope mostly covered, but where exposed, shale with sandy-shale and silty-shale interbeds and laminae. 20 % sandstone interbeds and laminae, 3 - 15 mm, evenly distributed. Good exposures require digging.

Section Name: Watson-Rockport #4

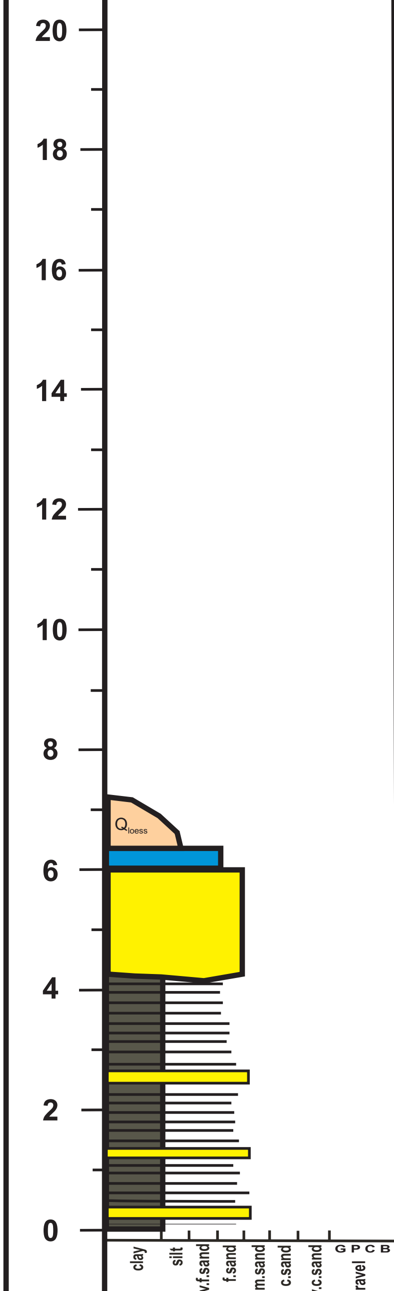
Location (lat/long): 40.42760N, 95.56537W

Total Thickness Measured: 6 m (20 ft)

Date Measured: 03/07/2005

Measured By: S.A. Fischbein using hand level and tape

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Quaternary Loess: Not Measured

6 - 6.25 m, Brownville Limestone: 5YR5/6, N5; crinoidal, shelly, with dominant intraclasts.

Pony Creek - Plumb Shale Undiff

4.2 - 6 m, Sandstone: 5YR5/2, 5YR6/4; Brwon to tan, and gray, fine to very fine, Small scale troughcross-bedded to low angle cross bedded, and ripple cross laminated.

0 - 4.2 m, Heterolithic Assemblage: 5YR6/4, 5YR5/6, 10YR5/4; Mixture of sandstone and mudstone dominated heterolithic strata. Details could not be collected due to pack of unattended dogs chasing me from outcrop.

Section Name: Watson-Rockport #5

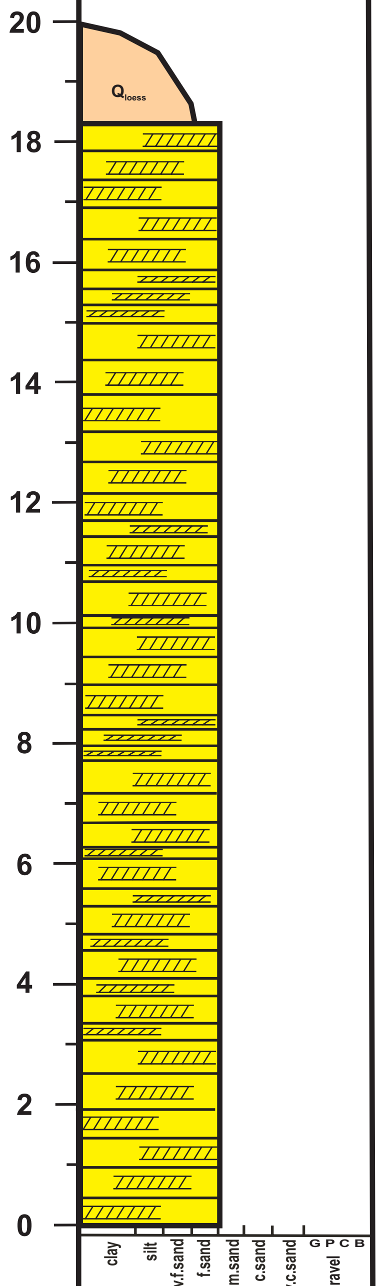
Location (lat/long): 40.43499N, 95.56875W

Total Thickness Measured: 18.2 m (60 ft)

Date Measured: 03/0702005

Measured By: S.A. Fischbein using hand level and tape

Thickness (Meters)	Graphic Log (Lithologies, Structures, Fossils)	Facies	Depositional Environment	Lithologic Description



Indian Cave Sandstone

0 - 18.2 m, Sandstone: Likely Peru Equivalent; 5YR6/4, 5YR5/6, 5YR5/2, 10YR5/4, N5; Brown to light brown, pale brown, and yellow-brown. Gray on fresh surface. Fine to very fine, massive to trough cross-bedded, TXB in both large (>0.25 m) scale and small (<0.25 m) forms. Paleoflow ranged from 220-250, with some examples of perfect trough sets oriented directly out of face, and oriented at 225 degrees. Slope here is very steep, and forested. Outcrops begin at road level, and poke out through slope cover up slope. Some areas of small cliff forms up to 1.5 m high, but most exposures smaller. Section capped with loess immediately above, and as far as can be seen through woods.

APPENDIX B

Elevation Survey Data and Location Maps

Appendix B - Survey Data

Indian Cave Sandstone Survey Data

All data NAD 1927 UTM Zone 15
Elevations normailized relative to set benchmarks: Peru data corrected to Zbolt, a known construction benchmark; Brownville data corrected to benchmark on northwest bridge abutment; and at Indian Cave State Park, data corrected to USGS benchmark at well near house on Duerfeldt Farm.

Data sets separated as collected.

Peru Survey Data

NAME	LOCATION	NOTE	X	Y	Z	FILENAME	DATABASE	ZRELTOWELL	ZRELTOBOLT	FT_CONV
Survey Station	Steamboat Trace	elevation transfer point	50253.128	49633.051	1002.328			277.745	279.412	916.69500732422
Survey Station	Steamboat Trace	elevation transfer point	50345.318	49496.290	1001.951			277.368	279.035	915.45800781250
Survey Station	Steamboat Trace	elevation transfer point	50410.978	49421.391	1001.848			277.265	278.932	915.11999511719
Survey Station	Steamboat Trace	elevation transfer point	50555.354	49325.168	1000.145			275.562	277.229	909.53302001953
Survey Station	Steamboat Trace	elevation transfer point	50737.494	49246.573	1000.373			275.790	277.457	910.28100585938
Survey Station	Steamboat Trace	elevation transfer point	50967.925	49178.923	1000.964			276.381	278.048	912.21997070313
Survey Station	Steamboat Trace	elevation transfer point	50971.280	49181.784	1000.806			276.223	277.890	911.70202636719
Survey Station	Steamboat Trace	elevation transfer point	51220.752	49130.228	1001.332			276.749	278.416	913.42700195313
Survey Station	Steamboat Trace	elevation transfer point	51456.998	49042.269	999.555			274.972	276.639	907.59698486328
Survey Station	Steamboat Trace	elevation transfer point	51759.730	48870.584	999.479			274.896	276.563	907.34802246094
Survey Station	Steamboat Trace	elevation transfer point	51771.203	48862.675	999.485			274.902	276.569	907.36798095703
Survey Station	Steamboat Trace	elevation transfer point	51927.727	48791.910	999.909			275.326	276.993	908.75897216797
Survey Station	Steamboat Trace	elevation transfer point	51939.814	48786.260	1000.143			275.560	277.227	909.52600097656
Survey Station	Steamboat Trace	elevation transfer point	52081.344	48726.920	1001.074			276.491	278.158	912.58099365234
Survey Station	Steamboat Trace	elevation transfer point	52092.592	48721.825	1001.008			276.425	278.092	912.36401367188
Survey Station	Steamboat Trace	elevation transfer point	52338.778	48582.260	999.068			274.485	276.152	906.00000000000
Survey Station	Steamboat Trace	elevation transfer point	52347.176	48579.519	999.326			274.743	276.410	906.84600830078
Survey Station	Steamboat Trace	elevation transfer point	52441.601	48534.465	1000.206			275.623	277.290	909.73297119141
Survey Station	Steamboat Trace	elevation transfer point	52455.319	48526.179	1000.267			275.684	277.351	909.93298339844
Survey Station	Steamboat Trace	elevation transfer point	52711.702	48339.311	999.684			275.101	276.768	908.02001953125
Survey Station	Steamboat Trace	elevation transfer point	52723.964	48331.062	999.612			275.029	276.696	907.78399658203
Survey Station	Steamboat Trace	elevation transfer point	52929.249	48199.337	998.929			274.346	276.013	905.54302978516
Survey Station	Steamboat Trace	elevation transfer point	52946.901	48185.918	998.890			274.307	275.974	905.41601562500
Survey Station	Steamboat Trace	elevation transfer point	53379.145	47830.569	1000.255			275.672	277.339	909.89398193359
Survey Station	Steamboat Trace	elevation transfer point	53395.553	47816.809	1000.253			275.670	277.337	909.88702392578
Survey Station	Steamboat Trace	elevation transfer point	53484.980	47730.817	1000.465			275.882	277.549	910.58300781250
Survey Station	Steamboat Trace	elevation transfer point	53492.977	47722.863	1000.643			276.060	277.727	911.16699218750
Survey Station	Steamboat Trace	elevation transfer point	53612.849	47596.703	999.796			275.213	276.880	908.38800048828
Survey Station	Steamboat Trace	elevation transfer point	53620.839	47587.896	999.762			275.179	276.846	908.27600097656
Survey Station	Steamboat Trace	elevation transfer point	53727.955	47465.253	999.227			274.644	276.311	906.52099609375
Survey Station	Steamboat Trace	elevation transfer point	53735.248	47456.752	999.491			274.908	276.575	907.38702392578
Survey Station	Steamboat Trace	elevation transfer point	53821.351	47359.771	998.825			274.242	275.909	905.20202636719
Survey Station	Steamboat Trace	elevation transfer point	53846.651	47327.650	998.897			274.314	275.981	905.43798828125
Survey Station	Steamboat Trace	elevation transfer point	54113.580	46853.561	998.358			273.775	275.442	903.66998291016
Survey Station	Steamboat Trace	elevation transfer point	54173.268	46752.460	999.069			274.486	276.153	906.00299072266
Survey Station	Steamboat Trace	elevation transfer point	54304.845	46088.151	1000.917			276.334	278.001	912.06597900391
Survey Station	Steamboat Trace	elevation transfer point	54303.656	46078.553	1001.738			277.155	278.822	914.75897216797
Survey Station	Steamboat Trace	elevation transfer point	54302.967	46077.988	1000.963			276.380	278.047	912.21697998047
Survey Station	Steamboat Trace	elevation transfer point	54303.409	46051.938	1000.935			276.352	278.019	912.12500000000
Survey Station	Steamboat Trace	wellhead914ft	49858.690	49929.546	1003.170	peru	elevpnt	278.587	280.254	919.45697021484
Survey Station	Steamboat Trace	sw corner of station slab	50152.951	49761.952	1002.506	peru	elevpnt	277.923	279.590	917.27899169922
Survey Station	Steamboat Trace	bs2	50249.256	49640.475	1002.357	peru	elevpnt	277.774	279.441	916.78997802734
Survey Station	Steamboat Trace	bs3test	50249.225	49640.453	1002.362	peru	elevpnt	277.779	279.446	916.80603027344
Survey Station	Steamboat Trace	st08test	50971.293	49181.791	1000.675	peru	elevpnt	276.092	277.759	911.27197265625
Survey Station	Steamboat Trace	swbolttest	54303.409	46051.938	1000.989	peru	elevpnt	276.406	278.073	912.30200195313
LS In Hawxby	Steamboat Trace	middle	50554.919	49286.794	1016.876	peru	unit	292.293	293.960	964.42401123047
Falls City	base		51211.173	49095.306	1024.686	peru	unit	300.103	301.770	990.04699707031
Falls City		middle	51216.299	49089.251	1026.173	peru	unit	301.590	303.257	994.92602539063
Falls City	base		52682.027	48279.087	1029.250	peru	unit	304.667	306.334	1005.02001953125
Brownville	base		53477.093	47713.623	1002.383	peru	unit	277.800	279.467	916.87500000000
Brownville	base		53617.043	47578.495	1003.214	peru	unit	278.631	280.298	919.60198974609
Brownville	base		53734.823	47448.250	1003.345	peru	unit	278.762	280.429	920.03100585938
Aspinwall	base		53807.276	47350.757	1007.185	peru	unit	282.602	284.269	932.63000488281
Survey Station	Steamboat Trace	elevation transfer point	54387.006	45564.499	999.439			274.856	276.523	907.21697998047
Survey Station	Steamboat Trace	elevation transfer point	54381.645	45564.916	999.450			274.867	276.534	907.25299072266
Survey Station	Steamboat Trace	elevation transfer point	54074.413	45855.700	999.655			275.072	276.739	907.92498779297
Survey Station	Steamboat Trace	elevation transfer point	54073.605	45850.806	999.848			275.265	276.932	908.55902099609
Survey Station	Steamboat Trace	elevation transfer point	54080.396	45794.055	1004.892			280.309	281.976	925.10699462891
Survey Station	Steamboat Trace	elevation transfer point	54077.357	45794.062	1004.935			280.352	282.019	925.24798583984
Survey Station	Steamboat Trace	elevation transfer point	54439.037	45357.765	997.587			273.004	274.671	901.14099121094
Survey Station	Steamboat Trace	elevation transfer point	54442.931	45341.058	997.734			273.151	274.818	901.62298583984
Survey Station	Steamboat Trace	elevation transfer point	54441.435	45231.017	997.996			273.413	275.080	902.48199462891
Survey Station	Steamboat Trace	elevation transfer point	54439.028	45224.371	998.329			273.746	275.413	903.57501220703
Survey Station	Steamboat Trace	elevation transfer point	54440.261	44835.643	998.760			274.177	275.844	904.98901367188
Survey Station	Steamboat Trace	elevation transfer point	54438.993	44843.066	998.885			274.302	275.969	905.39898681641
Survey Station	Steamboat Trace	elevation transfer point	54466.153	44693.306	997.690			273.107	274.774	901.47900390625
Survey Station	Steamboat Trace	elevation transfer point	54467.235	44681.640	997.608			273.025	274.692	901.21002197266
Survey Station	Steamboat Trace	elevation transfer point	54465.687	44566.372	997.417			272.834	274.501	900.58300781250
Survey Station	Steamboat Trace	elevation transfer point	54460.271	44462.109	998.052			273.469	275.136	902.66601562500
Survey Station	Steamboat Trace	elevation transfer point	54452.408	44307.848	998.262			273.679	275.346	903.35498046875
Survey Station	Steamboat Trace	elevation transfer point	54452.575	44291.184	998.224			273.641	275.308	903.22998046875
Survey Station	Steamboat Trace	elevation transfer point	54471.872	43881.564	998.342			273.759	275.426	903.61798095703
Survey Station	Steamboat Trace	elevation transfer point	54471.898	43872.039	998.394			273.811	275.478	903.78802490234
Survey Station	Steamboat Trace	elevation transfer point	54471.971	43797.708	997.867			273.284	274.951	902.05902099609
Survey Station	Steamboat Trace	elevation transfer point	54472.586	43786.621	997.803			273.220	274.887	901.84899902344
Survey Station	Steamboat Trace	elevation transfer point	54508.290	42977.173	998.870			274.287	275.954	905.34997558594
Survey Station	Steamboat Trace	elevation transfer point	54508.511	42969.194	998.895			274.312	275.979	905.43200683594
Survey Station	Steamboat Trace	elevation transfer point	54531.479	42852.390	999.224			274.641	276.308	906.51098632813
Survey Station	Steamboat Trace	elevation transfer point	54529.490	42859.693	999.132			274.549	276.216	906.20898437500
Survey Station	Steamboat Trace	s. cut elev of missing brownvill	54355.340	45554.785	1004.654	peru	elevpnt	280.071	281.738	924.32598876953
Survey Station	Steamboat Trace	100e post	54376.663	45568.872	999.727	peru	elevpnt	275.144	276.811	908.16101074219
Survey Station	Steamboat Trace	nail on bridge	54571.829	42759.003	999.308	peru	elevpnt	274.725	276.392	906.78698730469
Survey Station	Steamboat Trace	nail on bridge	54576.649	42749.817	999.303	peru	elevpnt	274.720	276.387	906.77001953125
Survey Station	Steamboat Trace	bolt on bridge-elev 906.87ft	54579.275	42747.390	999.330	peru	elevpnt	274.747	276.414	906.85900878906
Survey Station	Steamboat Trace	peru sta36b	54508.511	42969.194	998.895	peru	elevpnt	274.312	275.979	905.43200683594
Brownville	base		54190.561	45719.439	1004.733	peru	unit	280.150	281.817	924.58502197266
Brownville	upper		54190.868	45716.897	1006.594	peru	unit	282.011	283.678	930.69097900391
Brownville	base		54158.955	45762.545	1004.325	peru	unit	279.742	281.409	923.24700927734
Brownville	upper		54157.203	45762.792	1005.716	peru	unit	281.133	282.800	927.80999755859
Brownville	base		54067.207	45776.144	1004.526	peru	unit	279.943	281.610	923.90600585938
Brownville	upper		54067.121	45773.476	1006.083	peru	unit	281.500	283.167	929.01397705078
Honey Creek Coal	base	honey creek coal	54065.733	45782.578	1000.650	peru	unit	276.067	277.734	911.19000244141

Aspinwall	base		54344.418	45552.962	1012.069	peru	unit	287.486	289.153	948.65301513672
Aspinwall	upper		54344.186	45551.824	1012.531	peru	unit	287.948	289.615	950.16900634766
Falls City	base		54325.479	45547.989	1020.306	peru	unit	295.723	297.390	975.67700195313
Falls City	upper		54325.352	45547.964	1020.678	peru	unit	296.095	297.762	976.89801025391
Brownville	base	honey creek borrow pit 1	54427.754	44700.365	1006.653	peru	unit	282.070	283.737	930.88397216797
Brownville	upper	honey creek borrow pit 2	54426.527	44571.581	1006.482	peru	unit	281.899	283.566	930.32299804688
Brownville	upper	honey creek borrow pit 2	54426.563	44571.588	1007.039	peru	unit	282.456	284.123	932.15100097656
16A04 Bore Loc		honey creek borrow pit 2 boreh	54436.608	44556.444	1001.038	peru	unit	276.455	278.122	912.46301269531
Brownville	base		54443.156	43804.831	1004.901	peru	unit	280.318	281.985	925.13598632813
Brownville	upper		54443.018	43804.917	1005.273	peru	unit	280.690	282.357	926.35699462891
Aspinwall	base		54434.711	43810.567	1009.487	peru	unit	284.904	286.571	940.18200683594
Aspinwall	upper		54434.557	43810.707	1010.119	peru	unit	285.536	287.203	942.25598144531
Falls City	base		54427.518	43815.694	1013.848	peru	unit	289.265	290.932	954.48999023438
Falls City		middle	54425.729	43816.982	1014.991	peru	unit	290.408	292.075	958.23999023438
Falls City	upper		54420.016	43820.960	1018.158	peru	unit	293.575	295.242	968.63000488281
Towle Paleosol	upper	towle paleosol	54437.185	43809.569	1008.273	peru	unit	283.690	285.357	936.19897460938
Brownville	base		54439.561	43755.284	1005.055	peru	unit	280.472	282.139	925.64202880859

Brownville Survey Data

NAME	LOCATION	NOTE	X	Y	Z	FILENAME	DATABASE	ZRELTOBRID	FT_CONV
Survey Station	Steamboat Trace	elevation transfer point	748.303	-1455.073	999.149			272.636	894.46398925781
Survey Station	Steamboat Trace	elevation transfer point	749.207	-1467.946	999.091			272.578	894.27398681641
Survey Station	Steamboat Trace	elevation transfer point	777.260	-1586.656	999.503			272.990	895.62597656250
Survey Station	Steamboat Trace	elevation transfer point	779.527	-1593.146	999.173			272.660	894.54302978516
Survey Station	Steamboat Trace	elevation transfer point	858.978	-1755.320	998.543			272.030	892.47601318359
Survey Station	Steamboat Trace	elevation transfer point	861.994	-1762.413	998.296			271.783	891.66601562500
Survey Station	Steamboat Trace	elevation transfer point	729.469	-2723.739	997.187			270.674	888.02697753906
Survey Station	Steamboat Trace	elevation transfer point	733.220	-2716.110	997.032			270.519	887.51898193359
Survey Station	Steamboat Trace	elevation transfer point	781.950	-2557.878	997.857			271.344	890.22497558594
Survey Station	Steamboat Trace	elevation transfer point	780.455	-2566.418	997.471			270.958	888.95898437500
Survey Station	Steamboat Trace	ne post of rifle range	737.796	-2636.634	997.284	brownvil	elevpnt	270.771	888.34600830078
Survey Station	Steamboat Trace	concrete post by gate of range	729.171	-2723.617	997.161	brownvil	elevpnt	270.648	887.94201660156
Survey Station	Steamboat Trace	sta10a	781.950	-2557.878	997.857	brownvil	elevpnt	271.344	890.22497558594
Brownville	base	estimated	536.242	-2604.057	1007.556	brownvil	unit	281.043	922.04602050781
Aspinwall	base	estimated	526.887	-2603.469	1011.669	brownvil	unit	285.156	935.53997802734
Brownville		estimated-location unknown	535.079	-2567.852	1007.536	brownvil	unit	281.023	921.97998046875
Brownville	base		532.373	-2673.096	1006.561	brownvil	unit	280.048	918.78100585938
Brownville	upper		532.222	-2674.082	1007.209	brownvil	unit	280.696	920.90698242188
Aspinwall	base		526.155	-2631.484	1009.431	brownvil	unit	282.918	928.19702148438
Aspinwall	upper		526.055	-2631.612	1009.796	brownvil	unit	283.283	929.39501953125
Brownville	base		529.513	-2639.655	1006.511	brownvil	unit	279.998	918.61700439453
Brownville	upper		529.404	-2641.141	1007.018	brownvil	unit	280.505	920.28100585938
Survey Station	Steamboat Trace	elevation transfer point	1014.867	751.206	999.667			273.154	896.16400146484
Survey Station	Steamboat Trace	elevation transfer point	1015.116	744.002	999.657			273.144	896.13098144531
Survey Station	Steamboat Trace	elevation transfer point	999.846	630.624	999.575			273.062	895.86199951172
Survey Station	Steamboat Trace	elevation transfer point	997.568	622.813	999.555			273.042	895.79602050781
Survey Station	Steamboat Trace	elevation transfer point	840.444	59.410	1001.559			275.046	902.37097167969
Survey Station	Steamboat Trace	elevation transfer point	839.044	49.556	1002.096			275.583	904.13299560547
Survey Station	Steamboat Trace	elevation transfer point	774.499	-982.765	998.801			272.288	893.32202148438
Survey Station	Steamboat Trace	elevation transfer point	774.082	-991.467	998.807			272.294	893.34197998047
Survey Station		benchmark lf0723	951.647	1259.704	1011.620	brownvil	elevpnt	285.107	935.37902832031
Survey Station		sta04b	839.044	49.556	1002.096	brownvil	elevpnt	275.583	904.13299560547

Indian Cave State Park Survey Data

NAME	LOCATION	NOTE	X	Y	Z	FILENAME	DATABASE	ZRELTOWELL	FT_CONV
Brownville	base		447.712	967.638	1007.884	indcave	unit	276.242	906.29498291016
Brownville	upper		447.528	967.640	1008.414	indcave	unit	276.772	908.03399658203
Brownville	base		182.899	1059.330	1006.550	indcave	unit	274.908	901.91802978516
Brownville	upper		182.906	1059.230	1006.916	indcave	unit	275.274	903.11901855469
Brownville	base		86.557	1075.171	1006.018	indcave	unit	274.376	900.17297363281
Brownville	upper		86.116	1075.469	1006.517	indcave	unit	274.875	901.80999755859
Brownville	base		12.208	1090.219	1003.924	indcave	unit	272.282	893.30297851563
Brownville	upper		6.370	1090.147	1005.781	indcave	unit	274.139	899.39501953125
Survey Station		station1	1000.000	1000.000	1000.000	indcave	elevpnt	268.358	880.42901611328
Survey Station		wellhead w/monument	970.387	608.517	1003.094	indcave	elevpnt	271.452	890.58001708984
Survey Station	road	station2a	518.549	1006.298	999.429	indcave	elevpnt	267.787	878.55603027344
Survey Station	road	station2b	513.153	1006.314	999.226	indcave	elevpnt	267.584	877.89001464844
Survey Station	road	station2b2	513.118	1005.942	999.214	indcave	elevpnt	267.572	877.84997558594
Survey Station	road	station2b3	513.117	1005.923	999.212	indcave	elevpnt	267.570	877.84399414063
Survey Station	road	station3a	169.059	1072.204	1003.425	indcave	elevpnt	271.783	891.66601562500
Survey Station	road	station3b	169.899	1067.824	1003.363	indcave	elevpnt	271.721	891.46197509766

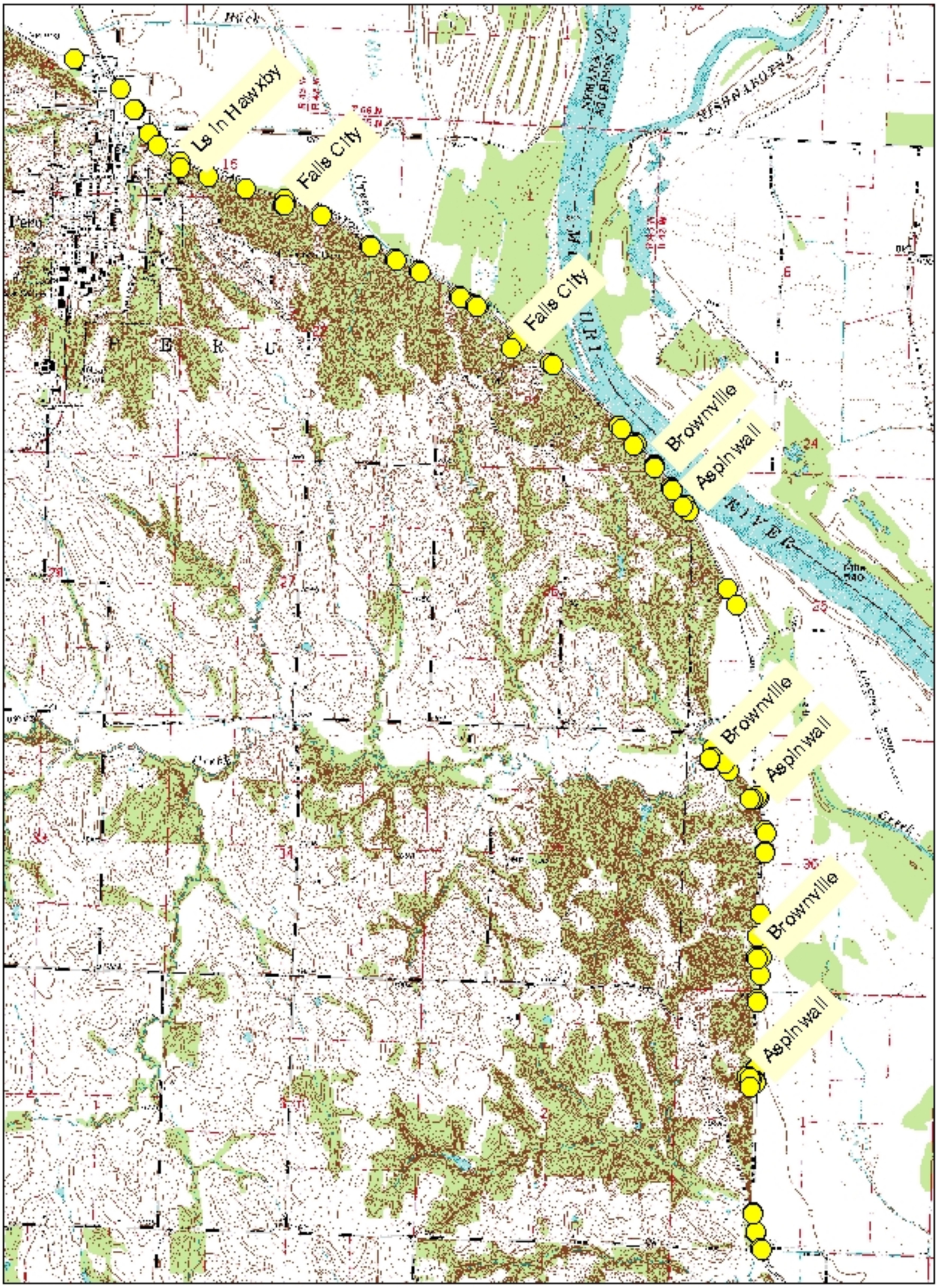


Figure B-1: **Survey Station Locations and Stratigraphic Tie Points Peru to South Honey Creek**

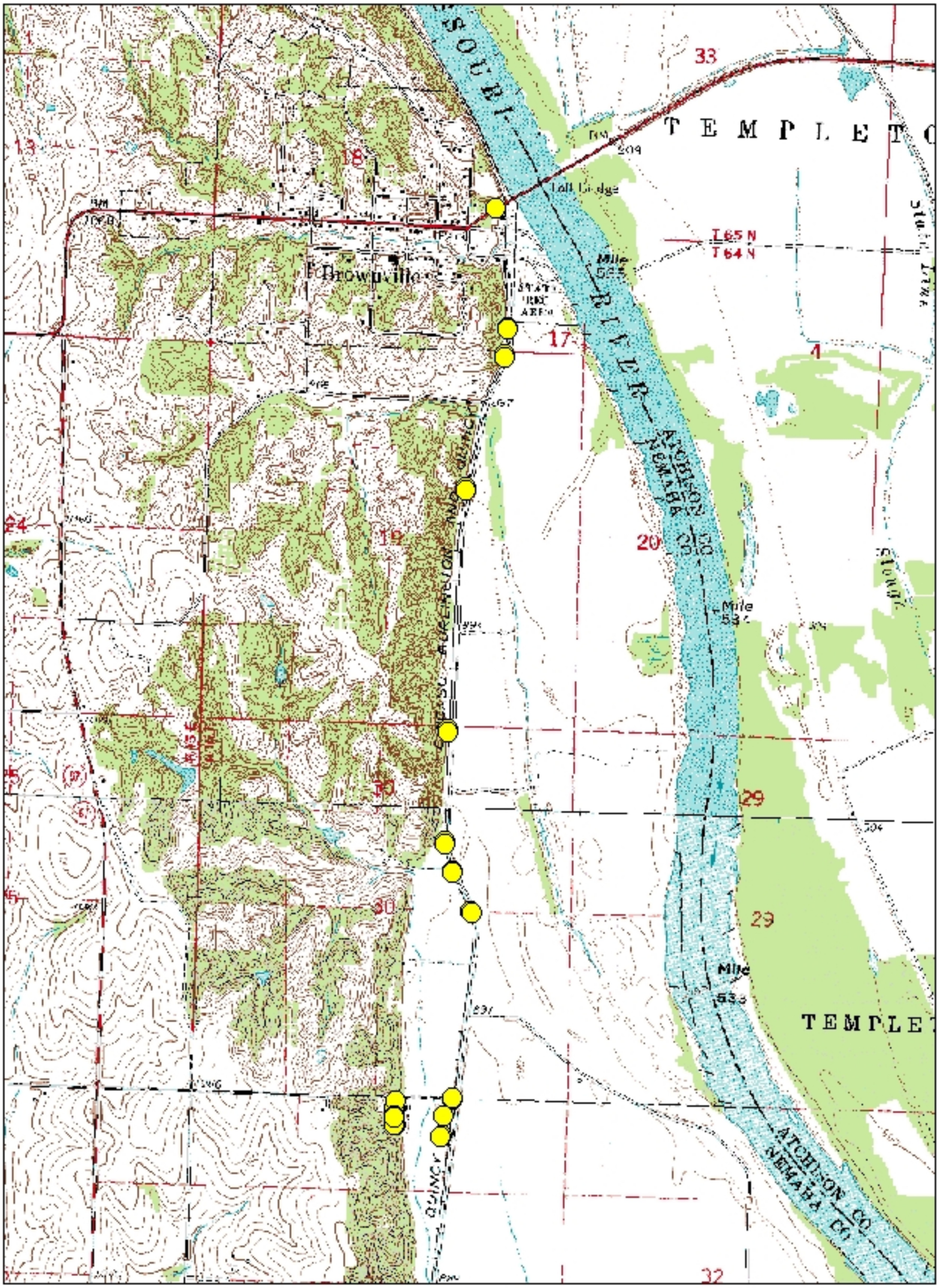


Figure B-2 **Survey Station Locations**
Brownville Bridge to CNS

Figure B-3: Survey Station Locations and Stratigraphic Tie Points
CNS Weapons Range

Figure B-4: **Stratigraphic Tie Points Indian Cave State Park - North of Cave**

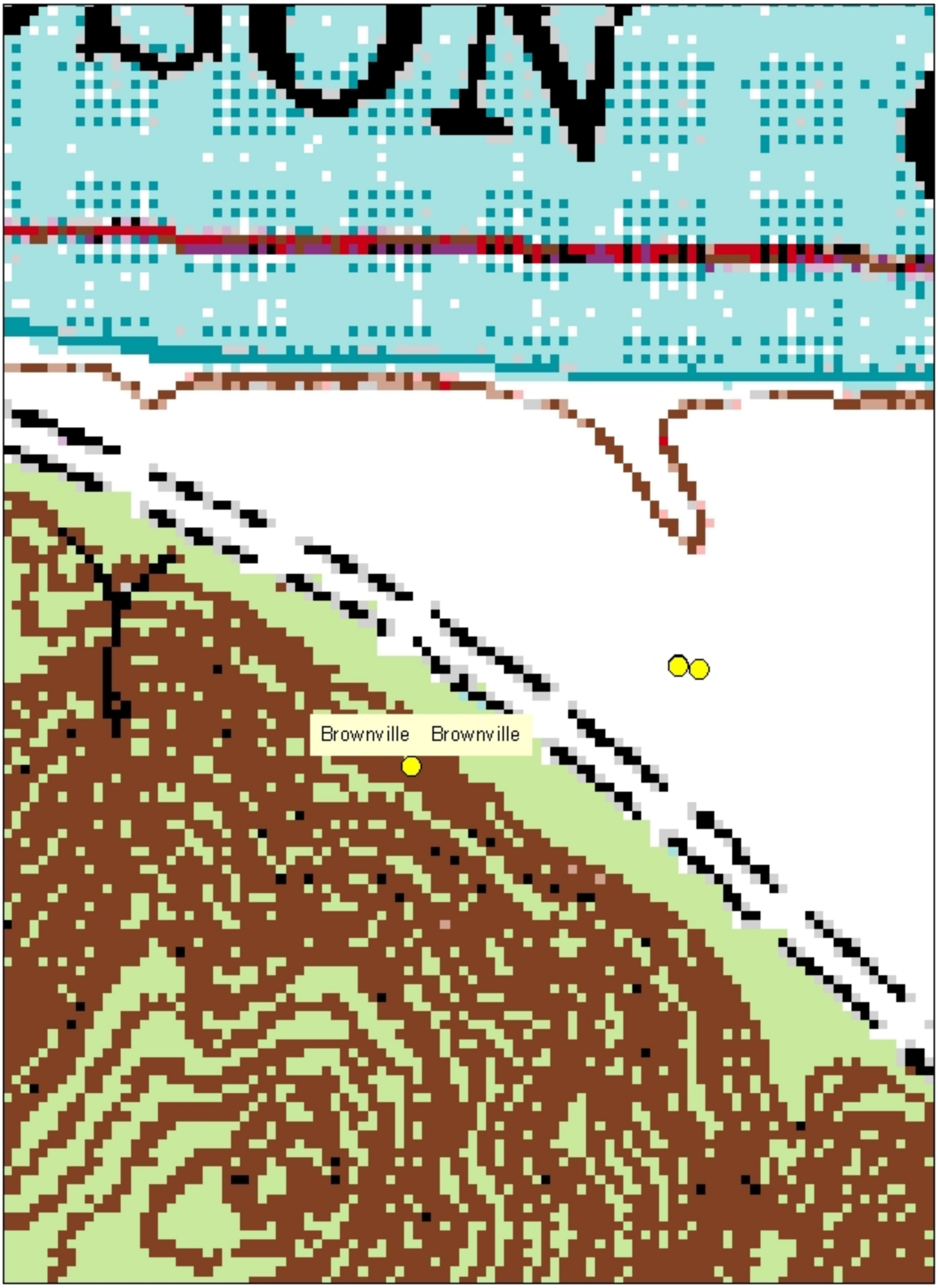


Figure B-5: **Stratigraphic Tie Points Indian Cave State Park - South of Cave**

APPENDIX C

History of Stratigraphic Nomenclature

Figure C-1: Nebraska City Limestone Outcrops Near Aspinwall
Nebraska City Limestone is exposed at base of photo and immediately overlies the Lorton coal at this location. The Brownville Limestone crops out in th hillside above the Nebraska City Limestone and the Pony Creek Shale-Plumb Shale Undifferentiated occupies the slope between the two limestone units. See line drawing for interpretation.

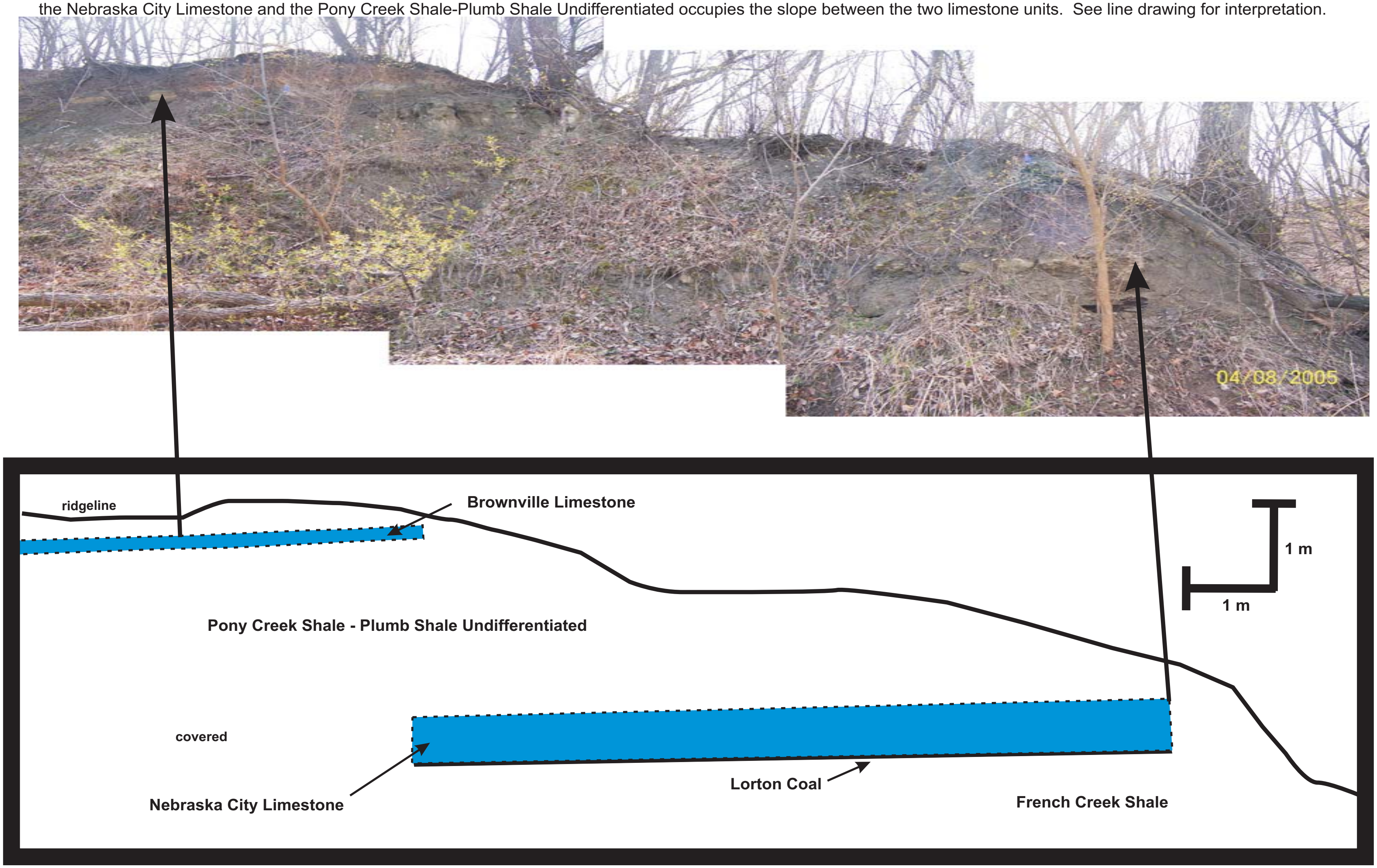
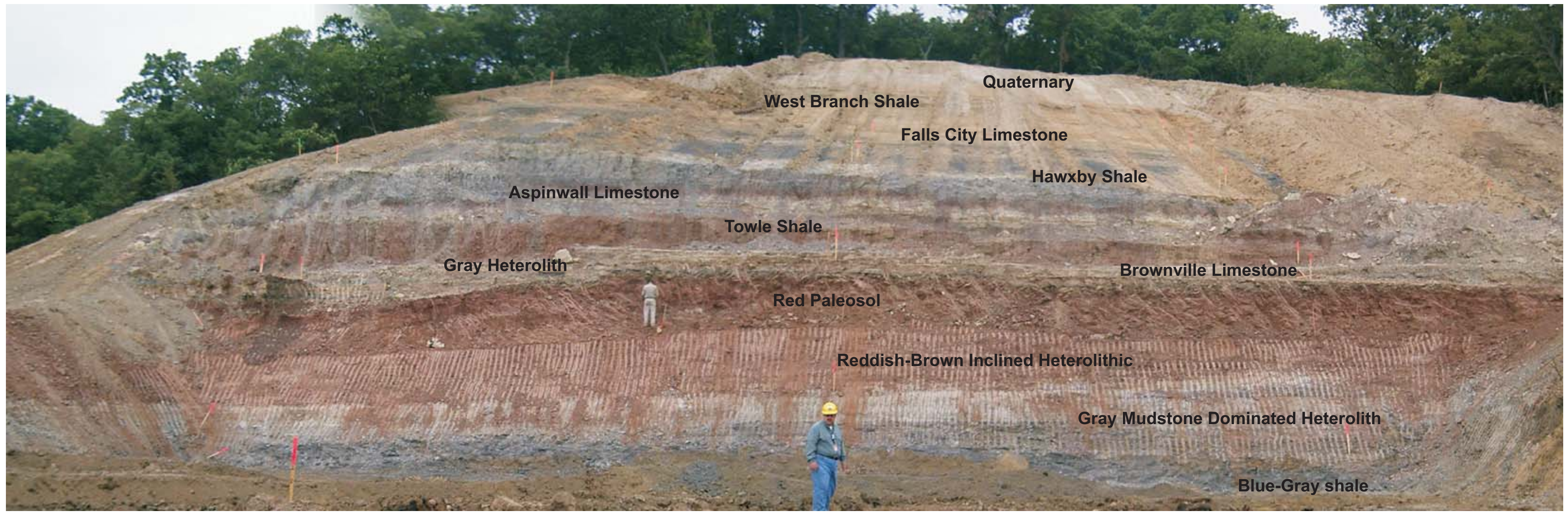


Figure C-2: Cooper Nuclear Station - Weapons Range
Exposure of fresh cut in bluff face during the construction of the Cooper Nuclear Station practice weapons range (CNS Weapons Range). This exposure covers the stratigraphic interval from the Pony Creek-Plumb Shale Undifferentiated upwards through the West Branch Shale. Only the lowermost exposures are now visible and cover the interval from the top portion of the Pony Creek Shale through to the lowest exposures of the Hawxby Shale.



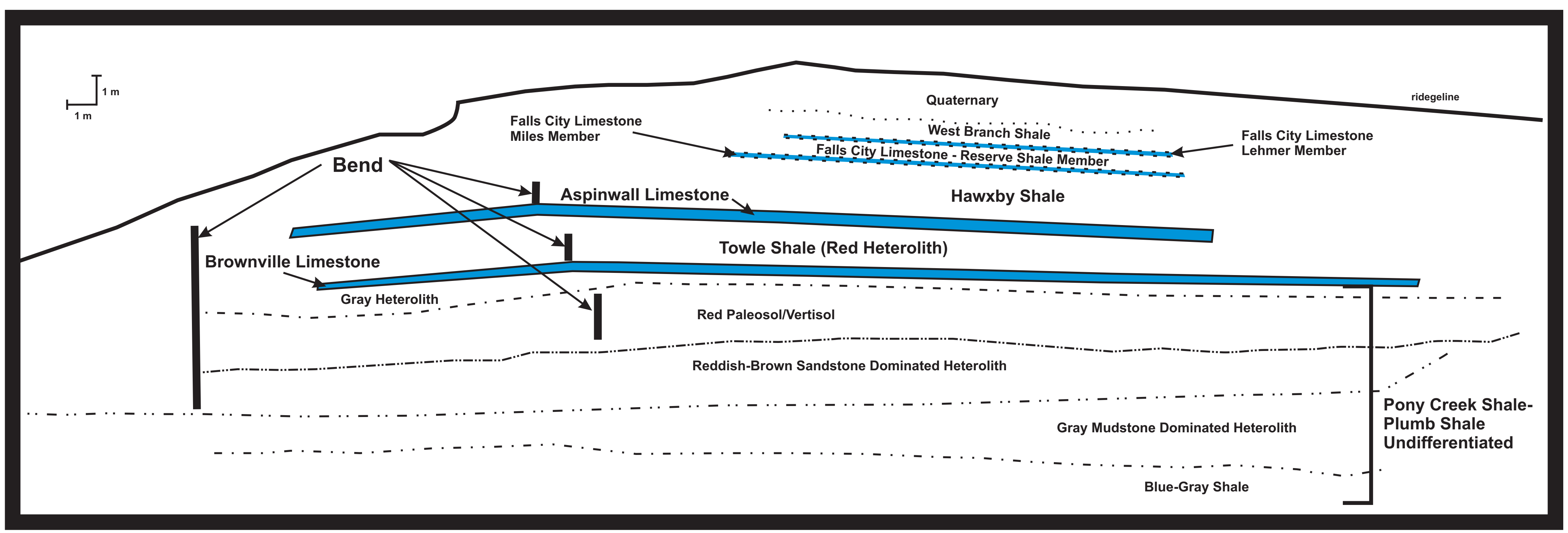


Figure C-3: Honey Creek Mine Site - Honey Creek Coal
Hand excavated exposure of the Honey Creek Coal Seam. Photo shows total thickness of coal at this location. Coal is underlain by an underclay rich in leaf fossils and wood debris and overlain by Quaternary debris. Shovel Length = 1 m

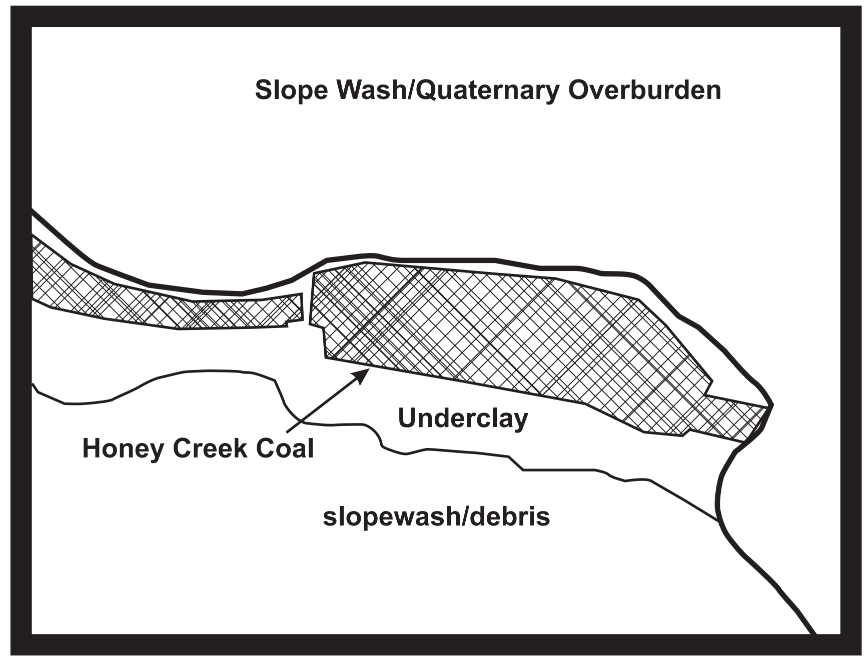
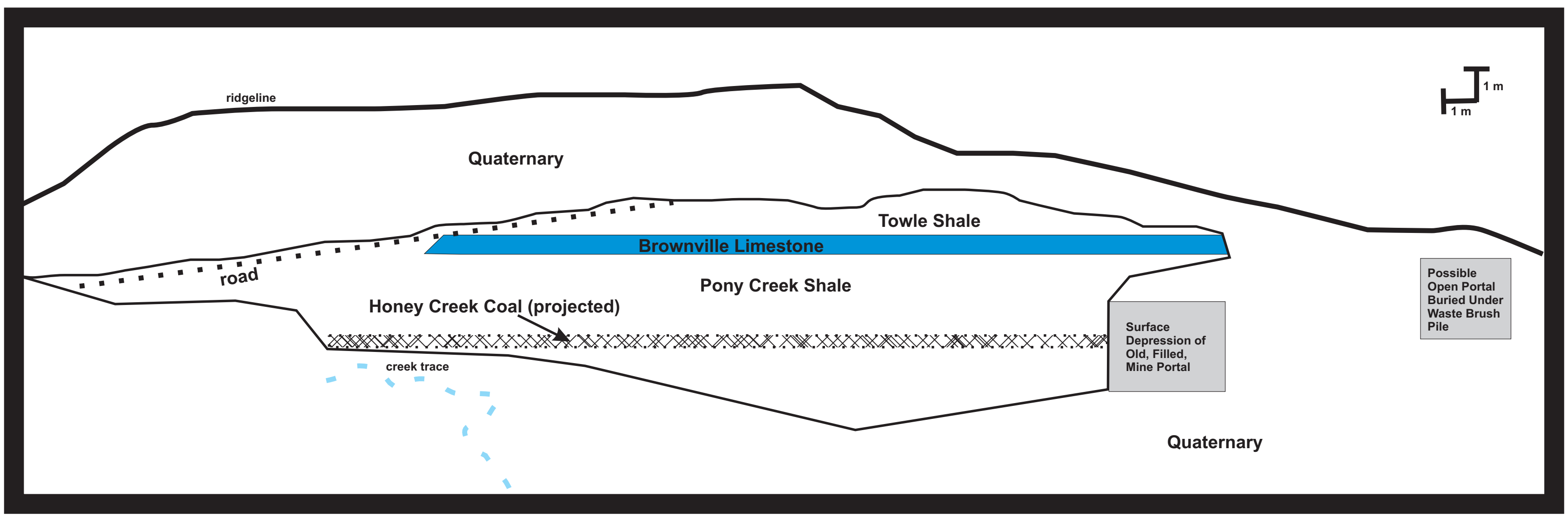


Figure C-4:Honey Creek Mine Site - Excavated and Projected Outcrop Distribution of Honey Creek Coal.
Location of former Honey Creek Mine operations (circa 1906 - 1910). Coal may still be found as shown in Fig. C-3.
Former adit location were identified as noted depressions in hillside, and are collapsed or have been filled



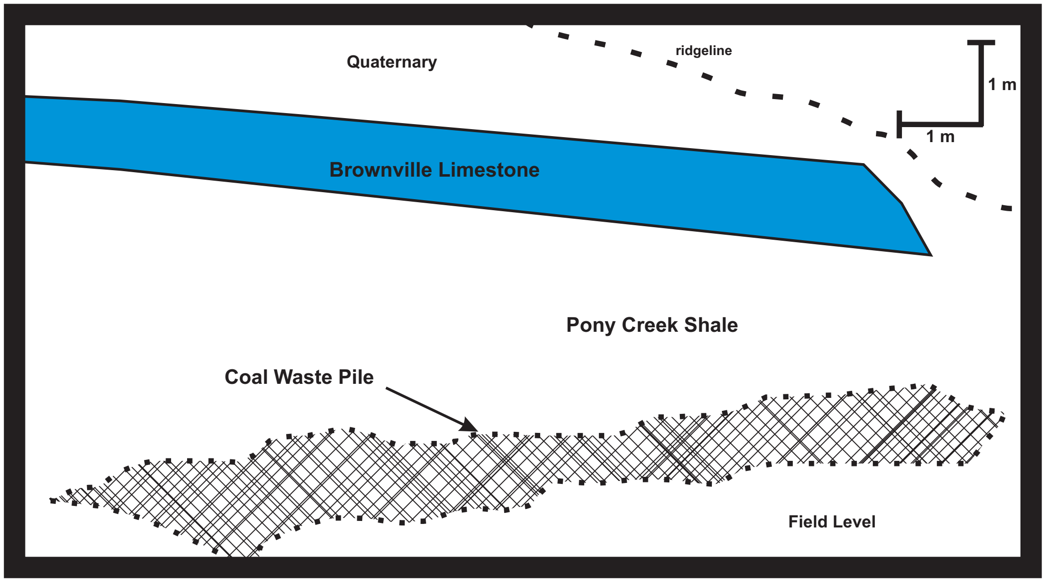


Figure C-5:
Honey Creek Mine Site - Coal Distribution
East Bluff Facing Missouri River

Honey Creek Coal sits roughly at field level at this location (picture foreground), and is located within the Pony Creek Shale, approximately 3.6 m (12 ft) below the Brownville Limestone.

Coal spoils are piled at foot of bluff, likely on top of coal outcrop. Spring plowing in adjacent field reveals clods of fresh coal and associated underclay.

Figure C-6: Brownville Limestone through Falls City Limestone - South Honey Creek Quarry Boy standing on top of Bbrownville Limestone, and the paleosol of the Towle Shale is exposed at the level of his head. Aspinwall Limestone exposedt above the Brownville Limestone, followed by the Hawxby Shale, and Falls City Limestone.

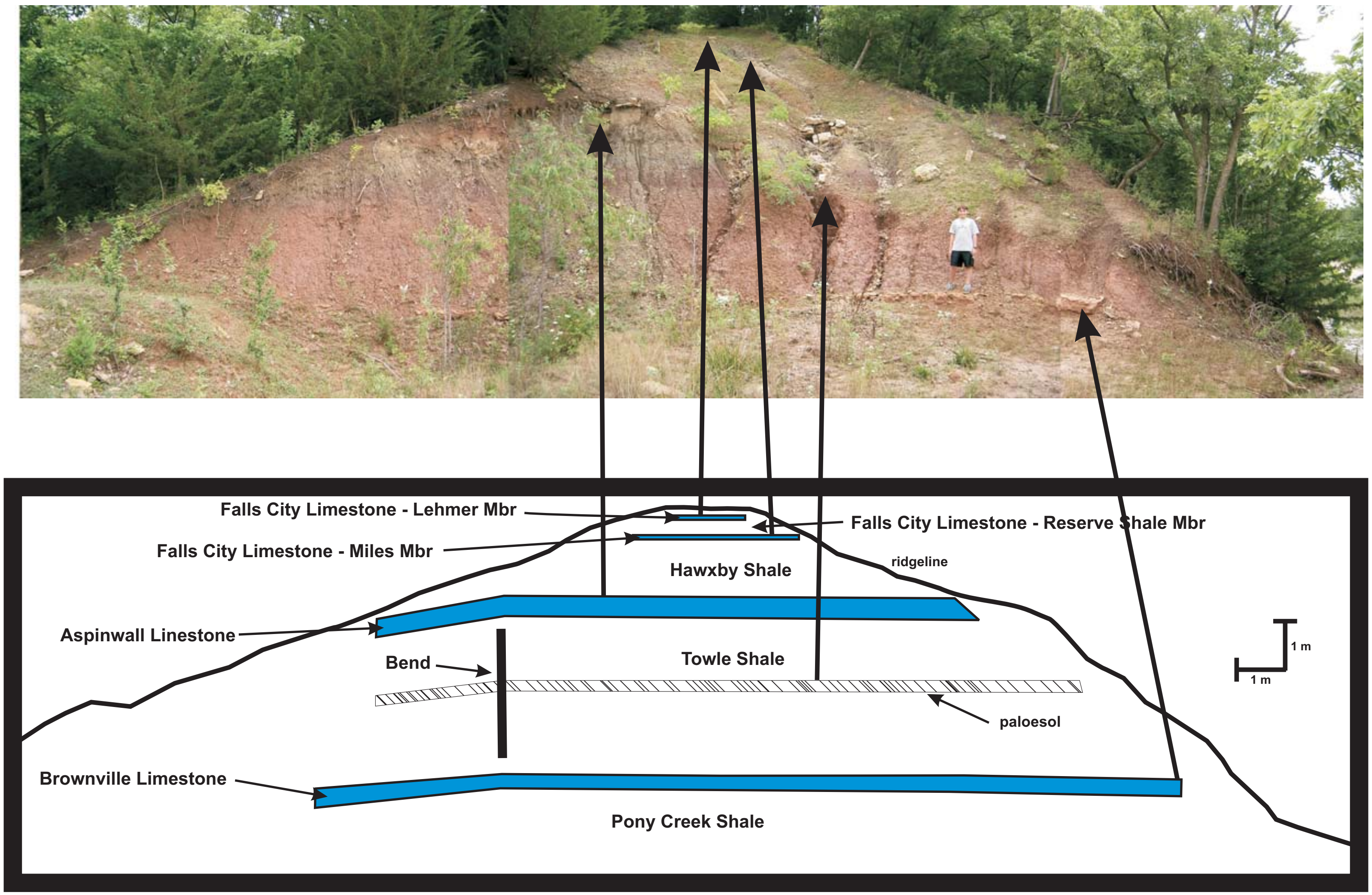


Figure C-7:_ Barbour's 1914 Cross-Section of the Missouri River Bluffs - South of the Town of Peru.
Prior to this investigation, this was the only published cross-section rocks of the ICS in the area.

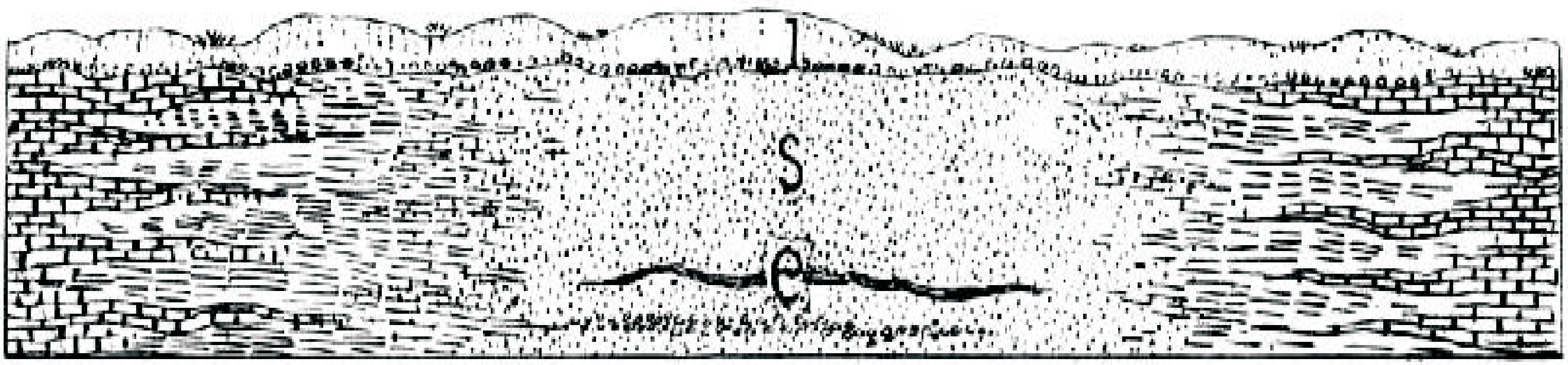


Fig. 2. Section a mile in length, about 1 mile south of Peru, Nebraska.
1, Loess underlaid by drift.
s, Sand grading into shale and then to limestone.
e, Eurypterid shales.
The coarse conglomerate below e contains fossil logs and limbs.

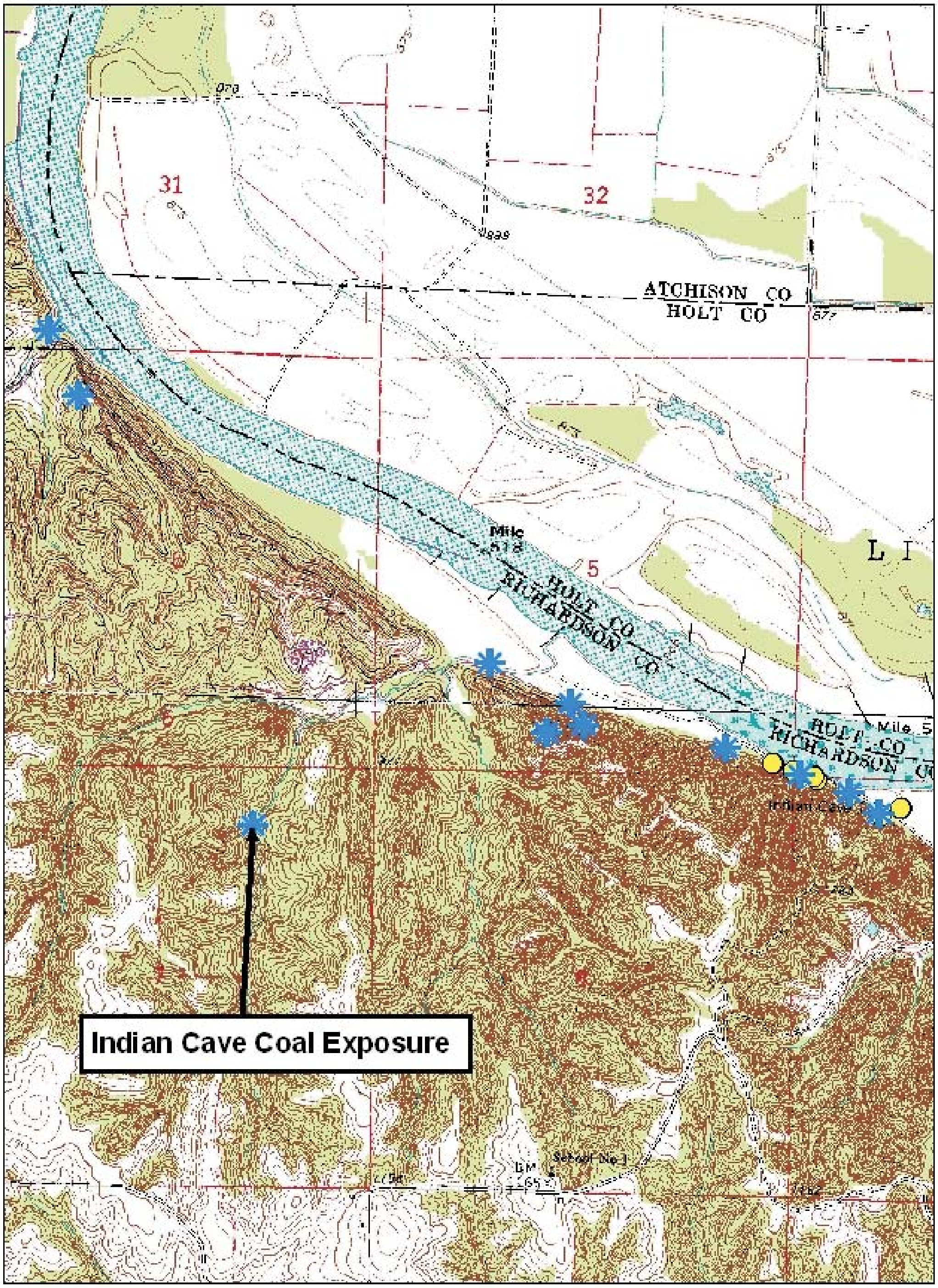


Figure C-8: Location Map for the Indian Cave Coal
(40.24563N, 95.54599W)

Figure C-9: Photomoasic of Indian Cave Coal, Indian Cave State Park - Upper Indian Cave Sandstone (40.24563N, 95.54599W)
This figure is the first documentation of the coal found in the upper Indian Cave Sandstone. The coal was found in a creekbank exposure along an unnamed creek within the park boundaries, and was exposused for roughly 30 m along strike. View is looking to the south-southeast, and coal is exposed roughly 1 m above the creek bed. See lower drawing for interpretation.

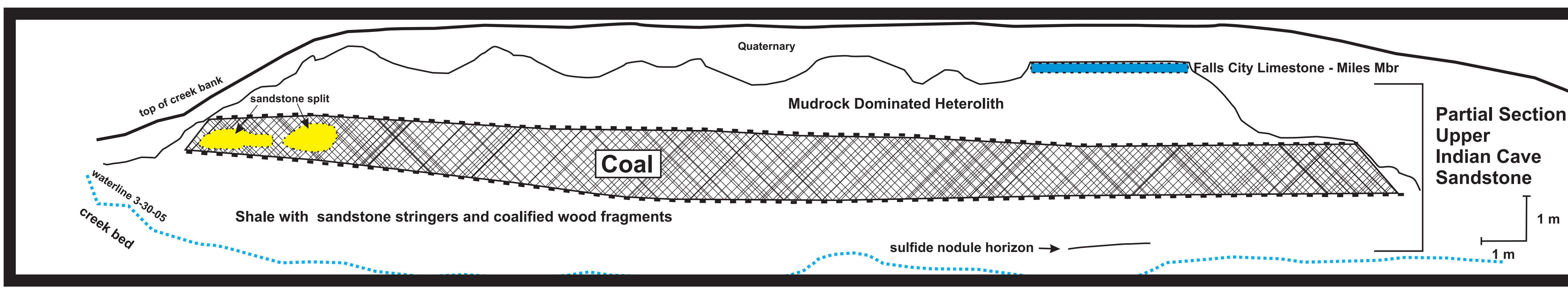


Figure C-10: Exposures of the Lehmer Limestone Member of the Falls City Limestone located on county road west of Highway 67 and east of Jarvis Creek at 40.31428N, 95.69060W (south of the town of Nemaha). Both the upper and lower portions of the member are well exposed at this location, and locally dip 2 - 3 degrees to the south. These units can be traced along contour to the east and south along the hillsides of the Little Nemaha River and the bluffs of the Missouri River following a line of former quarries.

Appendix C – History of Stratigraphic Nomenclature

This appendix contains documentation to support Sections 5 and 6 of this dissertation and provides both historical references and data collected as part of this research. These data were deemed too detailed for the text body of this dissertation, but the information is important and serves as single reference point for the stratigraphic interval of interest.

The following two paragraphs reiterate the introduction to Section 5 of this document, and figures or tables referenced in these paragraphs can be found in the body of the dissertation. Where other figures referenced are contained with this appendix, these will have a designator of C-#, for example, (Fig. C-1) would refer to the first figure within this appendix. In all other cases, if a figure is designated as (Fig. #) then the figure can be found within the body of the dissertation.

Stratigraphic Interval of Interest – Pennsylvanian System

For this investigation, the uppermost formation of the Wabaunsee Group (the Wood Siding Formation), and the lowermost formations of the Admire Group (the Onaga Shale and Falls City Limestone), comprise the interval of interest (Table 1). The Wabaunsee Group was long considered to be the uppermost part of the Pennsylvanian System in Nebraska and Kansas, however, a subsequent revision of the Pennsylvanian-Permian boundary (see Section 3.2 – Age) moves the boundary significantly higher in the stratigraphic section, to roughly the middle of the Admire Group, and places the ICS well within the Pennsylvanian System (Fig. 6).

The Wood Siding Formation contains five members (Fig. 6, Table 1) and is overlain by the Onaga Shale Formation, which contains three members (Fig. 6, Table 1). The Onaga Shale is overlain by the Falls City Limestone (Fig. 6) that also contains three members (Table 1). The ICS has been considered as a subunit of the Towle Shale, overlain by the Aspinwall Limestone, and underlain by the Brownville Limestone (Fig. 6), however the results of this investigation indicate ICS bodies are found in at least two *different* stratigraphic intervals (see Section 5.1: Stratigraphic Position of the ICS)

Wabaunsee Group

<u>Wood Siding Formation</u>

Nebraska City Limestone

The Nebraska City Limestone is the basal member of the Wood Siding Formation and was named by Condra (1927) for exposures in a working clay pit southeast of the town of Nebraska City (Fig 6). Condra (1927) considered the unit to be a subunit of the Pony Creek Shale, which in turn was a subunit of the McKissick Grove Shale Member of the Wabaunsee Group. The McKissick Grove name has long since been discarded (but may be seen in older literature), and the Nebraska City Limestone has been elevated to formation rank, within the Wabaunsee Group. It was originally described as dark bluish gray limestone, massive, quite hard, sandy and pebbly, forming large rectangular blocks, and weathering from buff to brownish and slabby, 0.6 – 0.86 m thick (Condra, 1927). Mudge and Yochelson (1962) describe the Nebraska City Limestone as dark gray to tan-brown, varying from massive and hard to shaly and soft, grading laterally and vertically into very calcareous shale over short distances, and weathering to irregular shaly blocks and chips. The unit is reported as averaging 0.3 m thick, but varies up to 1.3 m thick.

In this investigation, the Nebraska City Limestone was found: beneath the ICS at Peru in borehole 15A04 (40° 28' 43"N, 95° 42' 51"W) at 1.25 m below surface (and hit, but not cored at 1.9 m below surface in borehole 15A04b (40° 28' 47"N, 95° 43' 04"W)); south of Honey Creek in borehole 16A04 (40° 26' 17"N, 95° 40' 53"W) at 3 m below surface; along the base of the bluffs, roughly 4.5 – 6 m above river level in the vicinity of Aspinwall (40.30442°N, 95.64487°W), south of the confluence of the Little Nemaha River and the Missouri River at the base of the eastern bluff line; and roughly 4.5 – 6 m above river level below the Quarry Campsite at Indian Cave State Park (ICSP) where the bluffs extend all the way to river level (40° 15' 45"N, 95° 33' 21"W). The Nebraska City Limestone from this investigation is described in a fresh sample from core 15A04 as a gray limestone (7.5YR6/0) with crinoid and shell fragments (biomicrite to wackestone). In core 16A04 the unit was highly weathered, red-brown and gray mottled in color (2.5Y7/0 with 10YR5/3-4/3-3/3 mottles) and contained shell fragments and bryozoans (biomicrite or wackestone). In outcrop (at Aspinwall and ICSP) the unit was tan to brown and gray on a weathered surface and gray with red/brown mottling (bioturbated) on a fresh surface, and shaly in the middle to lower part with some crinoid and shell fragments (biomicrite or wackestone). Unit ranged 0.3 – 0.6 m thick (Appendix A: Logs: 15A04; 16A04; Aspinwall; Camping Quarry). The very thin (2 – 4 cm) Lorton Coal was found immediately beneath the Nebraska City Limestone in the vicinity of Aspinwall, and this correlated well with sections measured at Aspwinall by Mudge and Yochelson (1962) and Burchett (1977) (Fig. C-1).

Pony Creek Shale – Plumb Shale Undifferentiated

The Plumb Shale conformably overlies the Nebraska City Limestone (Mudge and Yochelson, 1962). In northeast and central Kansas, the Plumb Shale is reported to be overlain by the Grayhorse Limestone, which is in turn overlain by the Pony Creek Shale. Where the Grayhorse Limestone member is missing, the Plumb Shale and Pony Creek Shale are difficult to differentiate (Mudge and Yochelson, 1962). The Plumb shale was named by Mudge and Burton (1959) for exposures in Plumb Township, southeastern Wabaunsee County, Kansas. The Grayhorse Limestone was named by Bowen (1918) for exposures in Osage County, Oklahoma. The Pony Creek Shale was named by Condra (1927) for exposures east of Pony Creek, from 2 miles south of Falls City to the Kansas-Nebraska state line. Condra and Reed (1943) reported that the Grayhorse Limestone is not consistently recognized, nor persistent, within Nebraska. Thus the interval above the Nebraska City Limestone and below the Brownville Limestone, where the Grayhorse Limestone is absent is occupied by the two shale units, the Plumb Shale and the Pony Creek Shale (Mudge and Yochelson, 1962).

No robust outcrops were found where any differentiation of the two units could be attempted. Therefore, for this investigation, the rock units found in the interval between the Nebraska City Limestone and the Brownville Limestone remain undifferentiated, and are designated as the Pony Creek Shale – Plumb Shale Undifferentiated (Pony Creek-Plumb Undifferentiated) .

In general, the Plumb Shale is described as commonly gray to locally maroon, green or green-gray, clayey shale that is locally silty or sandy and can contain beds or channels composed of sandstone, sandy shale, conglomeratic shale and conglomerate. The Plumb shale is reported to average 3 m in thickness, with a minimum of 2.1 m and a maximum of 6 m, but can be thicker where channelized units are present (Mudge and Yochelson, 1962). A large channel located in central Kansas (Echo Cliff Locality) was reported to be either a channel of Plumb age 12 m thick overlain by a channel of ICS age, or a multistoreyed channel of ICS age exceeding 12 m in thickness (Mudge and Yochelson, 1962).

The Pony Creek Shale is reported as a gray to brown, maroon, and green-red or red-green mottled clayey shale to a silty variegated shale that locally contains beds of sandstone, sandy shale, conglomerate, and coal (Mudge and Yochelson, 1962). Channel deposits are prevalent throughout the unit, and are recognized in many areas throughout central and northern Kansas, although the exact stratigraphic position, correlation and depth of these channel units does not appear resolved. The unit is reported to average 2.6 m in thickness, but ranges from about 1 to 7.6 m in thickness (Mudge and Yochelson, 1962).

In this investigation the Pony Creek-Plumb Undiff. was found as a buff, orange, red, yellow, tan, brown, and gray (5Y8/4, 5YR6/4, 5R4/6,10YR8/6, 10YR6/3, N5, 2.5YR4/4) laminated mudrock with subordinate interlaminated fine sandstone and coarse siltstone, with local abundant plant and wood fragments. Lithology varied depending on outcrop location, and consisted of up to 90% mudrock in laminae 1 – 5 mm thick and 10 – 30% sandstone stringers and laminae evenly distributed, with thin carbonaceous shale laminae locally persistent. The lower part of the unit was green to greenish-gray shale, laminated to massive with abundant pelecypods and brachiopods, and minor crinoid fragments. The contact with overlying laminated mudrock is in most places sharp, but may be gradational in places.

At the Cooper Nuclear Generating Station practice weapons range (CNS Weapons Range) A vertical face was cut in the bluffs during construction, exposing the uppermost portions of the Pony Creek-Plumb Undifferentiated. through the lowermost part of the Hawxby Shale. Permission to enter the site must be granted from Nebraska Public Power District-CNS Security, as the site is an active weapons range.

The description listed below is from the stratigraphic section measured in the Pony Creek-Plumb Undifferentiated at the CNS Weapons Range (See Appendix A - CNS Weapons Range, 40° 20’ 56”N, 95° 39’ 23”W). This was one of the best exposures available at the time, and the description applies to much of the interval seen throughout the study area. The upper portion of the Pony Creek-Plumb Undifferentiated at this location was dominated by a paleosol and interbedded laminated mudrock and laminated sandstone (heterolithic) channel fill. The location of the paleosol correlates to the position of a paleosol, or significant color change, found at other locations, but the character of the paleosol was best developed at this site.

Gray interlaminated sandstone and mudrock immediately below the Brownville Limestone were found to overly 1.5 m of a red mudstone paleosol with abundant slickensides and truncated upper contact (paleovertisol). The mudstone had a hackly fracture with common small pressure faces and rounded carbonate nodules, and root traces. This was in turn underlain by a reddish interlaminated mudrock and sandstone with 40 – 60% very fine sandstone in laminae and beds from 1 – 20 mm and 40 – 60% mudrock in laminae 1 – 5 mm, evenly distributed. Units are parallel-laminated to ripple cross-laminated with basal scouring, some mottling, and abundant plant debris including leaf and wood fragments. This unit is subsequently underlain by a gray, weathering tan, interlaminated mudrock and very fine-grained sandstone. 70 – 90% mudrock in laminae 1 – 5 mm and 10 – 30% sandstone laminae 1 – 5 mm, evenly distributed, with burrows common. This unit is strongly truncated along the face of the exposure with the surface dipping from north to south along the face of the exposure. This unit is was underlain by a blue-gray shale to the bottom of the exposure (Fig. C-2).

Where heterolithic units (interlaminated mudrock and sandstone) do not dominate the exposures, then small sandstone channels are present, that are filled by fine to very fine-grained cross-bedded and ripple cross-laminated sandstones. These sandstones commonly display flaser and lenticular bedding, symmetrical and asymmetrical ripples, bidirectional ripple cross-lamination, local mud drapes and hummocky cross stratification. This is especially noticeable in the uppermost portions of the exposures between Peru and Brownville, as well as in most exposures in Missouri, from Rockport north to Watson.

In Missouri, exposures along the highway frontage road (no formal road name) between Rockport and Watson are uppermost Pony Creek-Plumb Undifferentiated. Previous investigators identified the thin sandstones found uppermost in the parts of these roadcuts as ICS, but during this investigation a limestone was found to directly overly these strata (in the roadcuts), and it has been correlated to the Brownville Limestone from its relative position on the western side of the Missouri River Valley, some five to six miles away. Therefore the outcrop area of the ICS on the east side of the Missouri River Valley is significantly reduced from those identified in previous investigations, and the areal exposure of the Pony Creek-Plumb Undifferentiated is expanded.

At the mouth of Honey Creek, at the former Honey Creek Mine site (40.44904°N, 95.68526°W), the Pony Creek-Plumb Undifferentiated was found to include the Honey Creek Coal (Figs. 34, 35, C-3, C-4, C-5). This coal seam is reported to have been up to 0.9 m thick, and hand-excavated exposures of the coal made during this investigation revealed thicknesses of 0.3 to 0.5 m (Fig C-3). The Honey Creek Coal was found to be carbonaceous shale to sub-bituminous coal, containing clayey discontinuous partings. The general outcrop and subsurface distribution of the coal, incorporating data from boreholes from a mine site assessment conducted by Burchett (1977), is fairly flat lying (Fig. 34, C-4, C-5; Appendix A, Logs: Honey Creek, CNS Weapons Range, Aspinwall and ICSP, Boreholes 1-B-74 through 5-B-74).

Brownville Limestone

The Brownville Limestone was named by Condra and Bengston (1915) for exposures along the western Missouri River Bluffs from Honey Creek to southeast of the town of St. Deroin. The Brownville Limestone was originally described as light bluish-green limestone, weathering lighter with the lower part massive and the upper part somewhat nodular, ranging in thickness from 0.75 – 1.8 m (Condra and Bengston, 1915). Condra (1949) describes the type locality for the Brownville Limestone as being in the Missouri River bluffs, southwest of the railway station at Brownville, Nebraska (original building foundation at 40° 23' 44" N, 95° 39' 12" W). This places the type locale somewhere in the east half of Sec 19, T5N, R16E, and this location corresponds well to the estimated type section location noted by Mudge and Yochelson (1962) as being in the NW1/4, SE1/4, Sec 19, T5N, R16E. Brownville Limestone outcrops are roughly ½ mile south of the old railway station foundation, and points south from there. A new reference section for the Brownville Limestone has been exposed in the bluffs at the CNS weapons range site (Fig. C-2).

Mudge and Yochelson (1962) describe the Brownville Limestone as an excellent marker bed, consisting of gray-brown to bluish-gray limestone weathering light to dark brown, and occurring as either two beds, separated by a thin calcareous shale bed, or as one bed, ranging in thickness from 0.3 m – 1.4 m, with an average thickness of 0.67 m. Burchett (1977) describes the Brownville from the Aspinwall type section location as 0.5 m of dark gray limestone weathering russet with abundant brachiopods, 0.9 – 0.3 of dark gray calcareous shale, and 0.15 – 0.21 m of impure, dark gray limestone.

The following description from this investigation is a combined description from measured sections at Honey Creek; CNS weapons range; Lippold Farm; Aspinwall; and Indian Cave State Park. The Brownville Limestone was found to be a tan to gray mottled weathered packstone to mudstone, 1.3 m thick containing abundant shell fragments, crinoid columnals, fusilinids, and gastropods. At places along strike, the packstone nature of the unit becomes prominent, and shell beds composed of the brachiopods *Derbia* and *Crurithyris* (identification by R. Pabian, CSD – Emeritus) were found in the lower half of the outcrop, where the unit appears excessively weathered. An excellent example of this can be found in borrow pit exposures located 40° 26’ 17”N, 95° 40’ 53”W south of Honey Creek. A red-brown mudrock interbed 12 to 30 cm thick was located in the middle to upper half of the limestone. The mudrock contained abundant shell fragments, organic debris, and wood fragments, and was highly bioturbated. The mudrock interbed was prominent at Honey Creek, but was absent immediately to the south in borrow pit and quarry exposures of the unit (Fig. C-6). At the CNS weapons range (Fig. C-2) the interbed was present as a calcareous shale and shaly limestone and was not seen at Lippold Farm south of the CNS site. At Aspwinall Ferry the interbed was present, but was green-gray to dark gray, and considerably more shaly, and contained a few brachiopods. At Indian Cave State Park, the interbed was also present, but was a calcareous shale to shaly limestone, with some fossils fragments (Appendix A, Logs: Honey Creek, CNS weapons range, Aspinwall, and ICSP, Boreholes 1-B-74 through 5-B-74).

Admire Group

Onaga Shale

The Onaga Shale was named by Moore and Mudge (1956) for exposures near the city of Onaga, Kansas, and the type section is located in a east-west road cut in the SW1/4, SW1/4, Sec. 2, T8S, R10E. This formation includes all units found between the Brownville Limestone and the Falls City Limestone and has three members; the Towle Shale; the Aspinwall Limestone; and the Hawxby Shale.

Towle Shale

The Towle Shale was named by Moore and Condra (1932) for exposures on the Towle farm located southwest of Falls City, Nebraska (SW1/4, Sec 20, T1N, R16E), and is described as a gray clayey shale containing beds of sandy and silty shale and sandstone bounded by the Brownville Limestone below, and the Aspinwall Limestone above (Mudge and Yochelson, 1962). Condra (1935) describes the Towle Shale as 0.3 m gray shale, overlain by 3.3 m red shale, overlain by 0.6 – 0.75 m of gray shale with a total thickness of 4.25 m. This generally agrees with Mudge and Yochelson's (1962) assessment that the unit consists of green shale, overlying red shale, that in turn overlies gray shale, with a total thickness ranging from 1.8 – 6.4 m. The ICS is considered subunit of the Towle Shale, and Condra and Reed (1943) give formational status to the Towle and member status to the ICS, while Moore and Mudge (1956) reclassify the Towle Shale to member status of the Onaga Shale, and relegate the ICS to bed status within the Towle Shale. Moore and Mudge's definition (1956), being the most recent classification, is adopted in this work.

During this investigation, the best exposures of the Towle Shale were found in an old quarry location south of Honey Creek (40° 25' 52"N, 95° 40' 54"W), the CNS weapons range (40° 21' 36"N, 95° 39' 28"W), the Lippold Farm (40° 20' 56"N, 95° 39' 23"W), and at ICSP beneath the main outcrops of the ICS at (40.24672°N, 95.51790°W to 40.25139°N, 95.53559°W). Where the complete interval of the Towle Shale was found, it ranged from 2.5 – 5.1 m in thickness.

At the old quarry south of Honey Creek, the Towle Shale consisted of 2.7 m of purple to maroon (5P4/2, 10R4/2), massive, bioturbated shale with a paleosol near the top, overlying a 0.6 m thick red (5R3/4) paleosol, that in turn was overlying a 1.8 m thick red mudrock (5R5/4, 5R4/6) (Fig. C-6).

At the CNS site, the Towle Shale was found as a 2.5 m thick red (2.5YR5/4), interlaminated mudrock consisting of alternating reddish and red-gray laminae 1 – 5 mm thick, even distributed (Figure C-2).

At the Lippold Farm, the Towle Shale consisted of a 2.5 m thick, gray, grading to brown, reddish-brown, tan-buff, purple and red (N5, 2.5YR4/4, 5YR6/4, 5P4/2, N2) laminated mudrock that grades upward to a red paleosol with calcareous boxwork fracture fill.

At ICSP, the Towle Shale was found as gray to medium gray, and brown to red shale that was locally fissile, containing shells, shell fragments, and was highly bioturbated. Only the lowest portion of the Towle is exposed at ICSP, as the full thickness is truncated and overlain by the ICS.

Indian Cave Sandstone

Harding (1950), Mudge (1956), Mudge and Yochelson (1962), Ossian (1974), and Mazzullo et al. (2005) generally attribute the designation of the type section and first description of the ICS to publications by Moore and Moss (1934) and Moore (1936). While these publications are likely the first to mention a sandstone at Indian Cave, or the "Indian Cave Sandstone" by name, there is no mention in them of a type section location near "Indian Cave" in Nebraska, and there is no type section found published within the literature. Furthermore, no evidence or reference was found to a published or unpublished type section from the Nebraska CSD or any other state or federal agency. One incomplete measured section from the CSD files dated April, 1971 was found.

Moore and Moss (1934) make no specific mention of the ICS, but rather refer to the following: "*Recent detailed field studies have brought to light the fact that there is a disconformity at the base of the Admire shale which, at present, is considered the uppermost formation of the Pennsylvanian. This disconformity is manifested by channel sandstones which cut out at least 100 feet of underlying* *formations. Channels of this type have been found in southeastern Nebraska, at Indian Cave and Peru, in northwestern Kansas at Dover, and in southern Kansas near Cedarvale*.". Moore (1936) only mentions the ICS in passing (one sentence, page 201) as a unit marking the base of the Big Blue Series, and shows one figure (page 50) with the ICS as the basal unit, but makes no mention of the type section description or location. Moore (1940) also makes no reference to a type section, but refers to Moore and Moss (1934) as the discovery of an "*important but obscure disconformity that is marked mainly by large channel sand fillings*".

Research summaries herein indicate that the first published reference to the sandstone that will ultimately be given the name "Indian Cave Sandstone" can be found in Meek (1867, pg 109, 110) where he describes sandstone outcrops near the city of Peru. Pepperberg (1908) worked on the flora from the Peru sandstone outcrops, but refers to Meek's (1867) work for description of lithologies. Barbour (1914) provides the earliest comprehensive description and interpretation of the sandstone outcrops at Peru. This reference details the geology of a newly discovered eurypterid locality, and his description states that the Missouri River bluffs in this area consist of beds of limestone and shale that grade (laterally) to shale, then to sandstone, and then back to shale and limestone. This publication also contains the only known published cross-section compiled for the Peru (Indian Cave Sandstone) outcrops (Fig. C-7).

Harding (1950) provided the first record of a measured section at the location known as "Indian Cave". This measured section (his Section No. 5 – Indian

Cave Section, Indian Cave Sandstone (Sec 5, 6, 9, T3N, R17E)), is incomplete in the middle and lower portions due to poor exposures but he records a total thickness of 41.5 m from the base of the ICS through the Hawxby Shale. While Harding's section thickness is likely correct, his stratigraphic correlations are not. As previously discussed, the Towle Shale, in the study area, does not exceed 5.1 m, and is not documented in the literature to exceed 6.4 m. Harding's section calls for 12.1 m of covered slope between the Aspinwall Limestone and the top of the ICS. If this correlation was correct, then the ICS would be placed squarely in the middle of the Pony Creek-Plumb Undifferentiated interval, rather than between the Aspinwall and Brownville Limestones, as indicated in other literature.

Mudge (1956) states that the type section for the ICS is located at Indian Cave, Nebraska and that outcrops in the center of Sec 9, T3N, R17E are possibly the type locality of the "ICS Member". He reports that the upper and lower contacts of the channel fill are not exposed, but a massive bed of sandstone 6 – 7.6 m thick is exposed 6 – 9 m below two thin limestone beds resembling the Aspinwall Limestone in Kansas. He also clearly states that due to the known occurrence of sandstone channels 3 - 6m below the Towle Shale (meaning in the Pony Creek – Plumb Undifferentiated.) he was not certain if this sandstone was a channel of the Towle Shale.

Mudge and Yochelson (1962) essentially reiterate what Mudge (1956) documented earlier with regard the type locality, and the questionable position of the sandstone outcrops within the overall stratigraphic section, with one notable exception. In this report, they clearly state that the precise location of the type locality is not recorded, which implies that no type section exists for the ICS. Mudge and Yochelson (1962) state that the Peru outcrops, were somewhat better exposed than those at Indian Cave, especially in the upper part, and they found that the massive cross-bedded sandstone of the lower section are overlain by sandy and clayey beds of shale that contained thin beds of limestone in the upper part. In this case, they make a tentative correlation of the thin limestone beds with the Aspinwall Limestone.

Ossian (1974, pg 20) measured sections in putative ICS outcrops, but there are no measured sections incorporated with, or as an addendum to, his dissertation, and there are no general descriptions of stratigraphic sections found within that document. He does discuss facies, but provides no measured section evidence to support his assertions, and therefore there are no locations that can be revisited to verify his work. This is particularly problematic in attempting to confirm his facies analysis, and in evaluating his paleoflow direction data, as his direction data indicate almost a 180 degree difference from paleoflow direction data collected in this study.

During this investigation, a section was measured through the Indian Cave Sandstone, at Indian Cave State Park from river level, through the “Indian Cave” itself to the uppermost reaches of the bluff above the cave. This measured section differs from any data previously collected in that it has a documented location (40.24672°N, 95.51790°W); the base of the section was well exposed as was the base of the ICS; and any upper portions of the section that were covered during measurements were added in by using the Nebraska CSD measured section dated April, 1971, measured when the upper reaches were exposed, but the lower portions covered. This provides for the first time a complete measured section through the ICS in the location reported to be the "type location". This section should, at a minimum, become the reference section for the ICS (Appendix A , Log: Indian Cave State Park – ICS Cave Section, pages 1 & 2). In addition, independent verification of the majority of this section was found in a subsurface borehole log recorded in 1973 that was drilled as part of the planning for the State Park. At that time, a borehole (Appendix A, Log: SH73-4) was drilled in the ridge above the cave location, and this log correlates very well with the compiled measured section mentioned above. This log was found in the CSD files after measurement of the section in this report in the type locality. Schematic stratigraphic sections for the type locality based on the measured section from this investigation is given in Fig. 6, as well as a similar schematic section for exposures at Peru, Honey Creek and Brownville.

The total section thickness at ICSP, from the base of the ICS to the unconformity between the Pennsylvanian bedrock and overlying Quaternary sediments is 44. 5 m (146.9 ft), with a total thickness of the upper and lower portions of the ICS of 26.1 m (86.1 ft). As such, if the maximum available formation thickness between the Brownville Limestone and the Aspinwall Limestone is not recorded to exceed 6.4 m (21 ft), then it impossible to place the ICS in the interval spanned by the Towle Shale. This also holds true for exposures at Peru, where the ICS body was found overlain by the Falls City Limestone, but was incised to the top of the Nebraska City Limestone.

Indian Cave Coal

During this investigation a new coal seam was discovered within the boundaries of ICSP. This coal, herein called the Indian Cave Coal, was found at a location removed from the main cliff-forming lower exposures, approximately 1.2 km southwest from the northern end of the main exposures at ICSP (40.24563°N, 95.54599°W; Fig. C-8; Appendix A, Log: Indian Cave State Park – Indian Cave Coal). In general, the seam is 120 cm thick and is composed of bituminous coal containing minor carbonaceous shale, sandstone partings, and interbeds. A sandstone body that splits the seam is also located roughly 15 meters to the north along strike. Above the coal is gray and brown to red-brown interlaminated mudrock and sandstone with dark gray and red-orange interbeds. This unit is in turn overlain by brown to tan and buff limestone (Falls City Limestone – Miles Member?). Quaternary alluvial sediments and loess overlie the limestone to the top of the creek bank (Fig C-9). The lateral extent of the coal body cannot be determined from surface exposures. Of interesting note, this is the thickest coal unit ever discovered in the State of Nebraska.

Aspinwall Limestone

The Aspinwall Limestone was named by Condra and Bengston (1915) for exposures near the former town of Aspinwall Ferry (N1/2, Sec 20, T4N, R16E), and was reported to be exposed in places between Peru, Brownville, Nemaha, Aspinwall, St. Deroin and near Indian Cave. It is described as a massive limestone, 0.3 – 0.6 m thick, light brown mottled with numerous pelecypods, crinoids, and fragments of brachiopods, that is “persistent, soft and easily worked” (Condra and Bengston, 1915). Mudge and Yochelson (1962) measured a stratigraphic section at the type locality and reported that it is not an accurate representation of the Aspinwall Limestone, being only 0.09 m thick (Appendix A, Log: Aspinwall Type Section #1). They describe the Aspinwall from various outcrops to range from 0.3 – 0.9 m thick, and composed of one or two beds of bluish-gray limestone, and where there are two beds, to be separated by a shale. They indicate that southward into Kansas, the interval containing the Aspinwall Limestone also contains many thin limestone beds, of which one or more may correlate to the type section, but that the correlation is uncertain. Mudge and Yochelson (1962) give numerous descriptions for the Aspinwall Limestone in Kansas, where the unit is quite different from the type section, and appears to change substantially from place to place.

Burchett (1977) also measured a section in the type locality, and his log compares closely with Mudge and Yochelson’s (1962) measured section (Appendix A, Log: Aspinwall Type Section #2). In this investigation, a partial section was measured near Aspinwall that tied quite well to the base of both Mudge and Yochelson’s (1962) and Burchett’s (1977) measured sections (Appendix A, Log: Aspinwall Calibration Section). During this investigation exposures of the Aspinwall Limestone and strata above were no longer available for study near the type section as either the outcrops were mined out, buried, or were on inaccessible property.

In this investigation, good exposures of the Aspinwall Limestone were found at the Honey Creek Mine Site; the quarry south of Honey Creek; the CNS weapons range; and the Lippold Farm (Appendix A). The Aspinwall Limestone was readily recognized as the next limestone unit immediately above the Brownville Limestone. A combined description from those measured sections indicates that the Aspinwall Limestone is gray, weathering tan (N5, 5YR6/4), massive to faintly and strongly bedded, fossiliferous mudstone/wackestone containing crinoids and brachiopods (Figs. C-2, C-6).

Hawxby Shale

The Hawxby Shale was described by Condra and Reed (1943) for exposures on the Hawxby Farm in Nemaha County, Nebraska (SE1/4, Sec 7, T4N, R15E). They described the section as 3 – 3.6 m of light gray calcareous shale, with the middle an lower zones composed of blue-gray and dark orange-red argillaceous shale. The upper portion weathers crumbly and contains calcareous blades within joints. As stated above, Mudge and Yochelson's (1962) measured section, and Burchett's (1977) measured section were deemed reliable, and their descriptions were utilized although exposures containing the Hawxby Shale no longer exist or cannot be accessed. Mudge and Yochelson (1962) describe the Hawxby Shale as gray to olive-drab, red, green and purple clayey shale that is silty and may contain local thin clayey limestone lenses. The unit is reported to average 2.9 m in thickness and ranges from 1.2 – 5.8 m.

In this investigation, the Hawxby Shale was best exposed at the CNS weapons range; the quarry south of Honey Creek; and the Honey Creek - South Cut section (Figs. C-2, C-6; Appendix A). A combined description from the measured sections indicates the Hawxby Shale varies from a tan to gray, brown and green interlaminated mudrock and sandstone with 60-80% mudrock laminae, 1 – 20 mm thick, and 20-40% sandstone laminae 1 – 100 mm thick, evenly distributed, to a red to red-brown, gray-green, and purple shale (10R5/4, 10R4/6,10R3/4), laminated to massive, with strong red paleosol developed at 50 to 60 cm above base, and continuing up to 80 cm up where the surface is truncated by an undulatory contact. Overlying is blue to blue-gray (5B5/6, 5PB5/2), laminated fissile shale that weathers more gray (N5) on exposure.

Falls City Limestone

The Falls City Limestone was originally proposed by Condra and Bengston (1915) to contain one bed of limestone, and was subsequently modified by Moore et al (1934) to include a second bed of limestone and intervening shale, with the type section located in the Lehmer Quarry southwest of Falls City, Nebraska (Sec 32, T1N, R16E). The unit was described by Condra and Bengston (1915) as one massive limestone bed, or limestone separated by shale seams, 0.5 to 1.7 m thick, brownish mottled and specked with rusty iron stain, very fossiliferous, with pelecypods dominating, soft on a fresh surface, and hardening upon exposure.   Condra (1935) proposed member names for the units included in the Falls City Limestone, but these names were never adopted by the Kansas Survey or the U.S.G.S., and therefore do not appear in literature describing the Falls City Limestone outside the State of Nebraska. Outside Nebraska, the units are informal and are called, in ascending stratigraphic order, Units 1, 2, and 3 (Mudge and Yochelson, 1962). In Nebraska, the accepted nomenclature is as proposed by Condra (1935, pg 5) and the units, in ascending stratigraphic order are called the Miles Limestone Member, the Reserve Shale Member, and the Lehmer Limestone Member.

Miles Limestone

Named by Condra (1935) for exposures "in the high hill west of Miles Ranch, about two miles southwest of Falls City", the unit was described as blue gray, locally weathering brown, soft and porous, 0.3+ m (1+ ft) thick. Mudge and Yochelson (1962), describe their Unit 1 (the Miles Limestone equivalent) as averaging 0.3 m in thickness as a "coquina" of abundant fossil fragments in the lower part, and with zones containing the brachiopods *Crurithyris, Derbia, Chonetes* and some bryozoans, crinoids and pelecypods in the upper part.

Descriptions from the former Aspwinall Ferry site by Mudge and Yochelson (1962) and Burchett (1977) are also included here, for exposures no longer accessible, but located directly in the study area. These descriptions indicate the Miles Limestone is gray, weathering tan in blocky to irregular plates. A coquina in lower 21 cm with the top part containing a thin zone of Crurithyris and other brachiopods and bryozoans, crinoid columnals, and pelecypods, 0.3 m thick (Mudge and Yochelson, 1962) and is locally psuedo-oolitic, algal and pebbly, contains *Osagia*, and is 0.24 m thick (Burchett, 1977).

In this investigation, the Miles Limestone was described from exposures at Peru Section #4; the quarry south of Honey Creek; and ICSP Sections #1 and #2 (cave and camping quarry sections); with accessible exposures found in road cuts to the west of the former Aspinwall site, along Highway 67 south of the Little Nemaha River at 40.30768°N, 95.67160°W (Appendix A). A combined description of the Miles Limestone is as follows: tan to very pale brown, yellowish, blue-gray, gray, and gray-brown to red (10YR8/4, 5BG7/1, N5, 5YR6/4, 5YR3/2, 5R4/6) biomicrite to wackestone with very pale brown mottles (10YR7/4). Abundant trace fossils and shell fragments, 0.9 - 1.5 m thick (Fig. C-6; Appendix A).

Reserve Shale

Named by Condra (1935) for exposures "in the upland near the [Nebraska] state line, northwest of Reserve, Kansas the Reserve Shale was described as a blue-gray shale 1.4 m thick. Mudge and Yochelson (1962) describe their Unit 2 (the Reserve Shale equivalent) as a gray to olive-drab and blue-gray clayey shale, ranging from 0.15 m – 5.15 m thick and averaging about 1.5 to 2.5 m thick. Descriptions from the former Aspwinall site by Mudge and Yochelson (1962) and Burchett (1977) indicate the Reserve Shale to be red, olive-gray grading down to dark gray and black shale, mostly covered, 1.5 - 1.62 m thick. In this investigation, the Reserve Shale was described from the old quarry south of Honey Creek (Fig. C-6); and ICSP Sections #1 and #2 as follows: Dark gray to yellowish-tan, tan, and red (5YR6/4, 5R6/4, N5) shale to shaly-platy limestone, fossiliferous, poorly exposured (Appendix A).

Lehmer Limestone

Named by Condra (1935) for exposures in “the top bed in the Lehmer Quarry, about 4 miles southwest of Falls City” , the Lehmer Limestone was described as limestone, gray, weathering brown, soft, porous, 0.9 – 1.2 m thick. Mudge and Yochelson (1962) describe their unit 3 (the Lehmer Limestone equivalent) as a relatively hard, dense, gray, massive limestone that can be argillaceous and composed of minute ooliths, and also contains abundant fragments of pelecypods and gastropods, with common thin gray lenses of clay (shale) 2.54 -5 cm thick distributed parallel to bedding. Ooliths and fossil fragments are typically parallel to bedding, or the unit can be composed almost entirely of intact shells of pelecypods, and gastropods with trace brachiopods. The unit ranges from 0.54 to 1.2 m thick. Descriptions from the former Aspwinall site by Mudge and Yochelson (1962) and Burchett (1977) indicate the Lehmer Limestone to be soft, gray, massive, limestone weathering blocky and is oolitic and porous, with bedding planes apparent on weathered surface. Thin gray clay lenses 2 to 5 cm long can be seen parallel to bedding, pelecypod fragments are abundant, stromatolite nodules rare, 0.74 m - 1.03 m thick.

In this investigation, the Lehmer Limestone Member was described from the old quarry south of Honey Creek; ICSP Sections #1 and #2, and from roadside outcrops on Highway 67 located on the south side of the Little Nemaha River valley, west of Aspinwall at 40.30768N, 95.67160W, and from an exposure on a county road west of Highway 67, and east of Jarvis Creek at 40.31428°N, 95.69060°W (Fig. C-10; Appendix A).

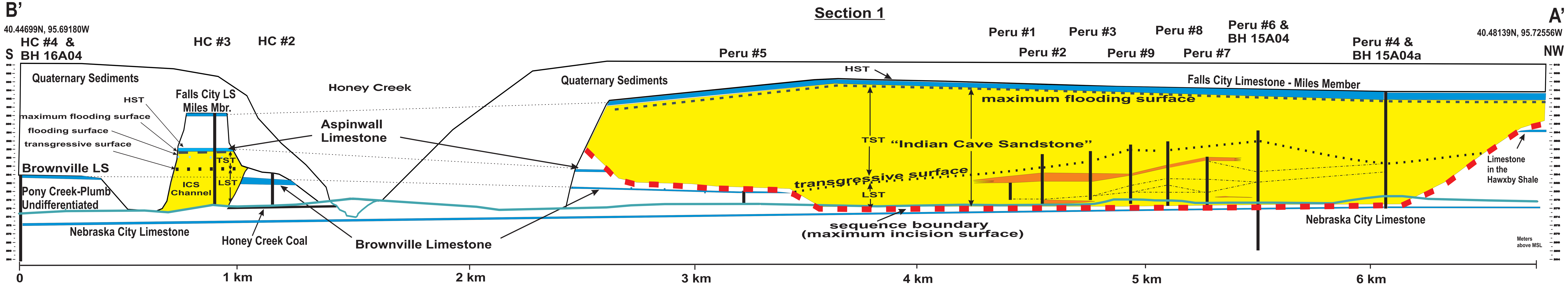
The unit is described from this investigation as follows: The basal Lehmer Limestone is composed of light tan, gray and white, evenly laminated to bedded grainstone composed dominantly of gastropod and pelecypod fragments oriented parallel to bedding, 0.3 m thick. The upper Lehmer Limestone is a grainstone, weathering brown, gray and tan, containing shell fragments of pelecypods, gastropods, some brachiopods and crinoids, 1 m thick. In ICSP, the unit becomes reddish-orange and tan to gray.. Portions of the unit are laminated and porous, with a vuggy, almost fenestral fabric. At ICSP, a prominent layer of mud chips or blocky mudstone clasts is found in the middle of limestone unit (Appendix A).

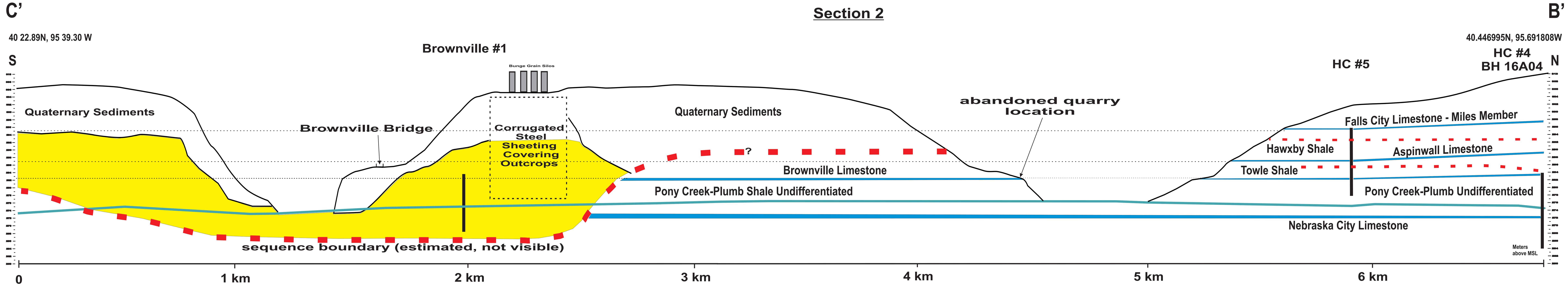
This upper Lehmer Limestone can be found outcropping in the woods roughly 15 - 23 m above the prominent ICS sandstone outcrops, and can be found flooring the ICSP “Camping Quarry” and at the former quarry location located directly above the “Indian Cave”. In most places exposures are covered with Quaternary debris, but a fairly continuous line of exposures can be traced along strike in the park, and these outcrops line up with former quarry locations both inside and outside the park. This line of former quarries can be traced along contour between the 284.5 – 295.5 m interval from the park, northward along the bluffs, and then northwest along the southern slopes of the drainage for the Little Nemaha River, where the units are found to dip 2 – 3 degrees to the south.

PLATES

Plate 1 - Sequence Stratigraphic Cross-Sections A through D

Plate 2 – Sequence Stratigraphic Cross-Sections C” - G





Sequence Stratigraphic Cross-Section.
Section 1 shows Peru and Honey Creek ICS bodies,
Section 2 and 3 shows Brownvile ICS body. Heavy red dashed lines are interpreted sequence boundary at base of bodies and correlative paleosol surfaces on associated interfluves.
Light red dashed lines are positions of other known paleosols.
LST, TST and HST shown as labeled, see text Section 10 for interpretation.

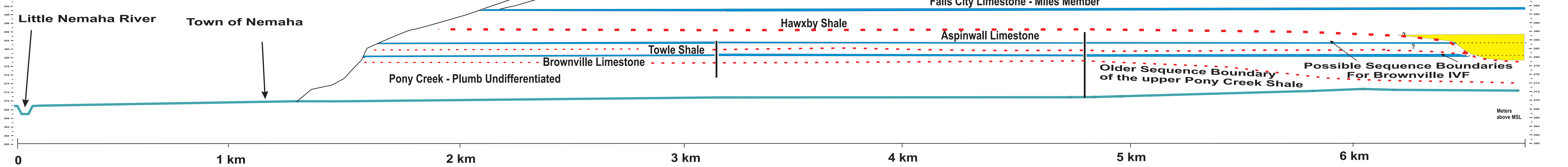


Plate 1:

Regional Cross-Sections Displaying Stratigraphic Correlation of Key Rock Units and Sequence Stratigraphic Interpretation.

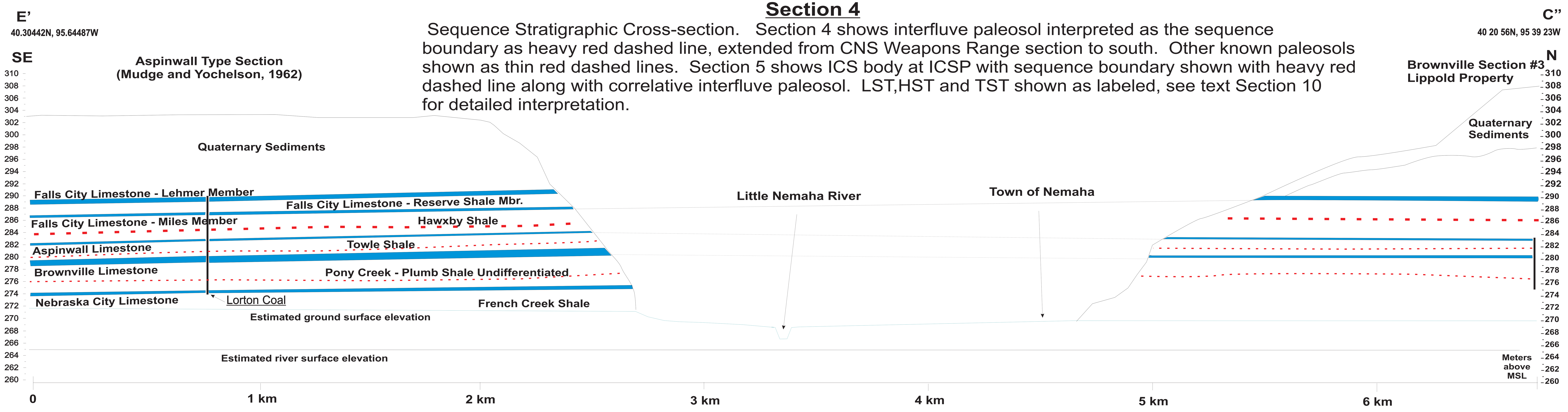
Section 1 = Peru to South Honey Creek.

Section 2 = South Honey Creek to South Brownville

Section 3 = South Brownville to Little Nemaha River

Section 4

Sequence Stratigraphic Cross-section. Section 4 shows interfluve paleosol interpreted as the sequence boundary as heavy red dashed line, extended from CNS Weapons Range section to south. Other known paleosols shown as thin red dashed lines. Section 5 shows ICS body at ICSP with sequence boundary shown with heavy red dashed line along with correlative interfluve paleosol. LST,HST and TST shown as labeled, see text Section 10 for detailed interpretation.



Section 5

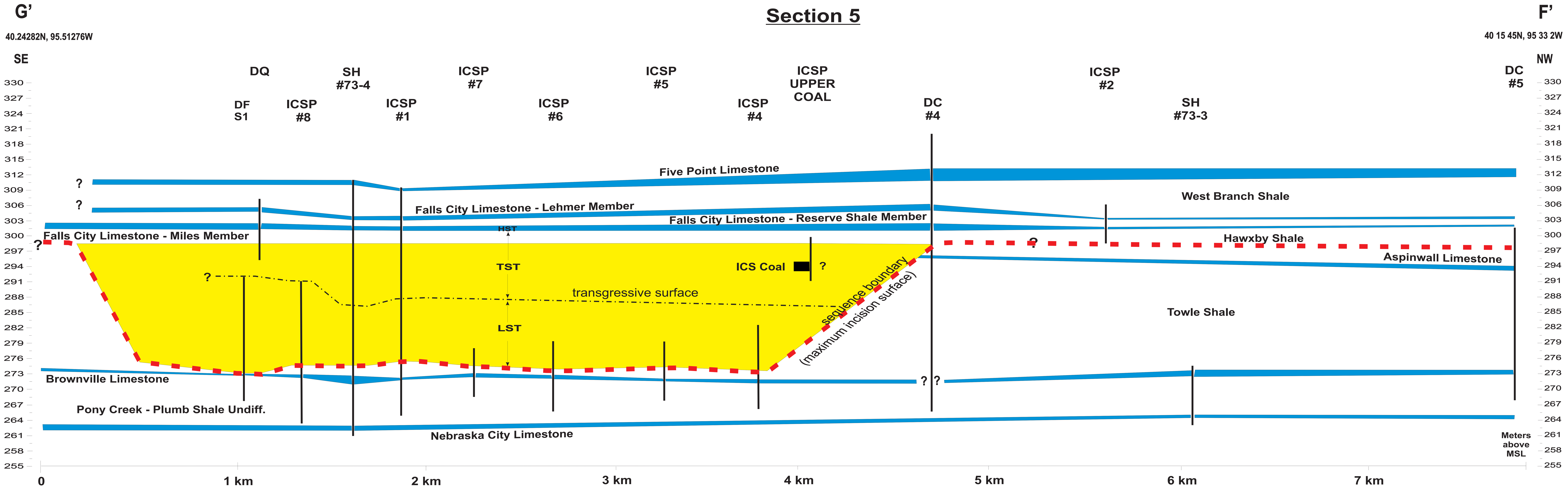


Plate 2:

Regional Cross-Sections Displaying Stratigraphic Correlations of Key Rock Units and Sequence Stratigraphic Interpretation.

Section 4 = Lippold Farm to Aspinwall

Section 5 = North Indian Cave State Park to South Duerfeldt Farm.