Overview

The Pembina Member of the Cretaceous Pierre Shale outcrops along the southern extent of the Manitoba Escarpment and within the Pembina River Valley of southwestern Manitoba and northeastern North Dakota (Bannatyne, 1963, 1982, 1984). The Pembina Member is underlain by the Gammon Ferruginous Member of the Pierre Shale and is overlain by the Millwood Member of the same formation (Bamburak and Nicolas, 2009). The member is characterized by at least 17 buff nonswelling calcium montmorillonite (altered volcanic ash) seams found interbedded with variable thicknesses of marine black carbonaceous, pyritic shale, found mainly near the base of the member. The seams range in thickness from 1.0 cm to 30 cm. The 25 cm thick seam composed of dense pink bentonite was prized by the former operator, Pembina Mountain Clays Limited, as the most valuable of all the seams. After acid activation of the bentonite, the finished product was utilized as an adsorbant to decolourize or to remove impurities from: tallow, animal fats, waxes, waste lube oils, petroleum feed stocks; and from linseed, canola, soybean, palm, sunflower, coconut and peanut oils (Bamburak and Christopher, 2004, p. 75).

In outcrop, the bentonite seams can also be stained a yellowish color caused by the presence of jarosite (Bannatyne, 1963, 1984; Nicholls, 1988); and significant amounts of magnetite and other dark minerals were noted in bentonite samples by Guillet (1989). Where overburden is greater than 7 m, the unweathered bentonite is usually bluish-grey, probably due to reducing conditions (Bannatyne, 1963). The Pembina Member is also present in the subsurface of southwestern Manitoba, northeastern North Dakota and southern Saskatchewan, as shown by thousands of petroleum wells. The bentonite seams generally thicken to the west, but the overburden also rapidly increases in thickness to 12 to 15 m (Hatcher and Bamburak, 2010a, p. 182).

Previous Studies

The first reported visual correlation of Pembina Member bentonite seams in the Pembina Hills area of southern Manitoba was by Morgan (1940, p. 2). Morgan depicted, in a table, the relative position of the thickest seam in a vertical sequence of up to eight seams within the Pembina Member at three localities (Leith and Charlewood, 1957). The sites (distributed over a length of 1.2 km in the vicinity of Shannon Creek, 8 km northwest of Morden, Manitoba) were: the O'Day pit in NW29-3-6W1; the O'Day adit in NW31-3-6W1; and the Spencer pit in NE31-3-6W1. This was followed graphically by Bannatyne (1963, p. 15), with the correlation of up to 9 seams at six outcrop and pit sections (***Localities A-F, Figures 1 and 2***).

The visual, fossil and age dating correlation of bentonite seams from Mowbray, Manitoba (***Locality 1, Figure 1*** and ***Locality A, Figure 2***) to Cavalier County, North Dakota, across the Canada-U.S. border was carried out by Gill and Cobban (1965, p.A8) and by McNeil and Caldwell, (1981, Text-figure 18). Enhancement and extension of these correlations from North Dakota into South Dakota, Montana, Wyoming and Kansas (using mineralogic, petrographic, and geochemistry techniques) was done by Bertog (2002); Bertog et al. (2007, p. 35); and Bertog (2010, p. 11). And, recently, Hatcher and Bamburak (2010a, b) described the recent results of fossil pollen and spore (palynological) investigations as control for vertebrate fossil stratigraphic positioning within the Pembina Member over a distance of 18 km in the Pembina Hills area.

Present Study

This poster attempts to demonstrate that despite the enhanced methods of correlation (described above), visual correlation of bentonite seams is still a useful, quick and relatively inexpensive tool that can be utilized in the field and office, especially utilizing new digital photographic techniques and equipment.

Figure 2 shows that the visual correlation of bentonite seams in the Pembina Member by Bannatyne (1963, p. 15) was predicated on recognition of the thickest seam in an outcrop, test pit or quarry section within a sequence of four closely spaced bentonite seams, herein named the Quartet beds. The Quartet beds (Q1 to Q4) formed the top of the six beds selectively extracted from black shale host rock by Pembina Mountain Clays Limited (former operator) (Bannatyne, 1963, p. 11; Ross, 1964, p. 43), as shown in ***Figure 2***, Section E from the Miami Quarry. The lower beds L1A and L2A were also extracted at various quarry sites (Hatcher and Bamburak, 2010a, Figure GS-16-2) by Pembina Mountain Clays, but L2C, L2A and L1B (if present) were not recovered from the black shale. Average thickness of bentonite recovered between the top of Q4 and the bottom of L1A was about 0.75 m over a total mined 1 m thickness (Ross, 1964, p. 43; Bannatyne and Watson, 1982, p. 45).

Figure 3 depicts a schematic geologic section of the lowermost bentonite seams in the Pembina Member of the Pierre Shale. The schematic was constructed using previously published data (***Figure 2***) and field observation at ***Localities 1 to 10*** (located in ***Figure 1***) and at other localities in the Pembina Hills area. From bottom to top, the Gammon Ferruginous Member (***Localities 1, 3, 8 and 10***) usually forms the base of the Pierre Shale, overlying the Boyne Member of the Carlile Formation, but may be absent due to erosion during the Upper Cretaceous (McNeil and Caldwell, 1981, p. 65). The Gammon Ferruginous is overlain by a thinly interlayered sequence of black shale and bentonite seams, herein named the Interlayered (I) beds (***Localities 1, 3, 5, 8 and 10***), that averages 0.38 m in thickness. The I beds comprise five individual bentonite seams ranging from 1-2 cm in thickness and interlayered 2-4 cm thick shale intervals that are bracketed at the top and bottom by 5 cm thick bentonite seams. Overlying the I beds is a 40 cm thick unnamed lower black shale bed (***Localities 1, 3, 5, 8 and 10***) that does not appear to contain even very thin bentonite seams. Above the 40 cm black shale bed are, herein named, the Lower bentonite (L) beds (***Locality 1***). The thicker (9 cm) bentonite seam (L1A) at the bottom of L beds is usually overlain by10 cm of black shale and a thin (3 cm thick) L1B bentonite seam, as seen at ***Localities 3-5, 7-12***). This interval is repeated upwards with the thicker (10 cm) L2A bentonite seam that is overlain by black shale containing one thin (1 cm) seam (L1B, ***Localities 4, 5, 7-9, 12***); or sometimes two thin (1 cm) bentonite seams - L2B and L2C (***Localities 3, 6, 10 and 11***). According to Bertog (2010, p. 9-12), the preceding description is within Sequence I of the Ardmore bentonite succession (***Figure 3***) that is present within the Burning Brule Member of the Sharon Springs Formation of South Dakota. Sequence I is bounded bottom and top by unconformities, which have removed previously deposited beds.

Above the unconformity at the top of Sequence I, the Quartet (Q) beds (72 cm thick from the base of Q1 to the top of Q4, ***Localities 2-7, 9-12***) were deposited as the basal bed of Sequence II (***Figure 3***). As noted above, the Quartet beds were extracted as a resource by Pembina Mountain Clays, with the prized Q3 seam averaging 25 cm in thickness. Above the Q beds is a lower 48 cm interval of black shale (***Figures 4, 6, 7 and 10***), with a thin (<1 cm thick) medial bentonite seam. And, overlying this black shale interval is a 17 cm thick bentonite seam (C1 of Bertog, 2002, p. 81, 122; Bertog et al., 2007, p. 34), the lowermost of the two seams of her "Bentonite Couplet". Above, the C1 bentonite seam is a 50 cm interval of black shale with a thin (<1 cm thick) medial bentonite and a 5 cm thick bentonite (Locality 6), which is interpreted to be the C2 seam of Bertog (2002, p. 81, 122); Bertog et al. (2007, p. 34). Bertog (2002, p.81) noted that in the eastern Black Hills of South Dakota, that each seam of the Bentonite Couplet is 25 cm thick and that they are separated by less than 5 cm of shale. However, Bertog et al. (2007, p. 36, 47) indicated that south of the Black Hills (at Wasserburger Ranch, South Dakota) that the C1 bentonite seam is 27 cm thick and the C2 bentonite is 15 cm thick, separated by over 45 cm of black shale.

Above the interpreted C2 bentonite seam in ***Figure 3*** (and at ***Locality 6***), there is a variable thickness of black shale present, which is dependent upon the extent of many superposed erosional intervals during the Cretaceous and later.

Bannatyne (1963, p. 7) reported that the thicknesses of the bentonite seams in the Pembina Member generally remains consistent across the Pembina Hills area, as shown in ***Figure 2***. However, the thicknesses of the intervening black shale beds can vary noticeably. The beds are thinnest in the Thornhill area (***Figure 1***) and they thicken to the north towards Miami, and more markedly to the southwest towards Pembina River. According to Bertog (2002, p. 45-47; 2010, p. 12), very low sedimentation rates of black shale can result in the deposition of multiple bentonite seams with no shale between them, to form a composite bentonite in the deepest part of an axial basin. Whereas, on the adjacent stable platform higher black shale sedimentation rates could result in an interval of multiple bentonite seams with intervening black shale beds that are laterally correlative with the composite bentonite. This may indicate that the 0.38 m thick Interlayered (I) Beds at the base of the Pembina Member in the Pembina Hills area (as depicted in ***Figure 3***) can be correlated with the 1-m thick basal bentonite at the base of the Ardmore bentonite succession in the Black Hills of South Dakota.

Acknowledgements

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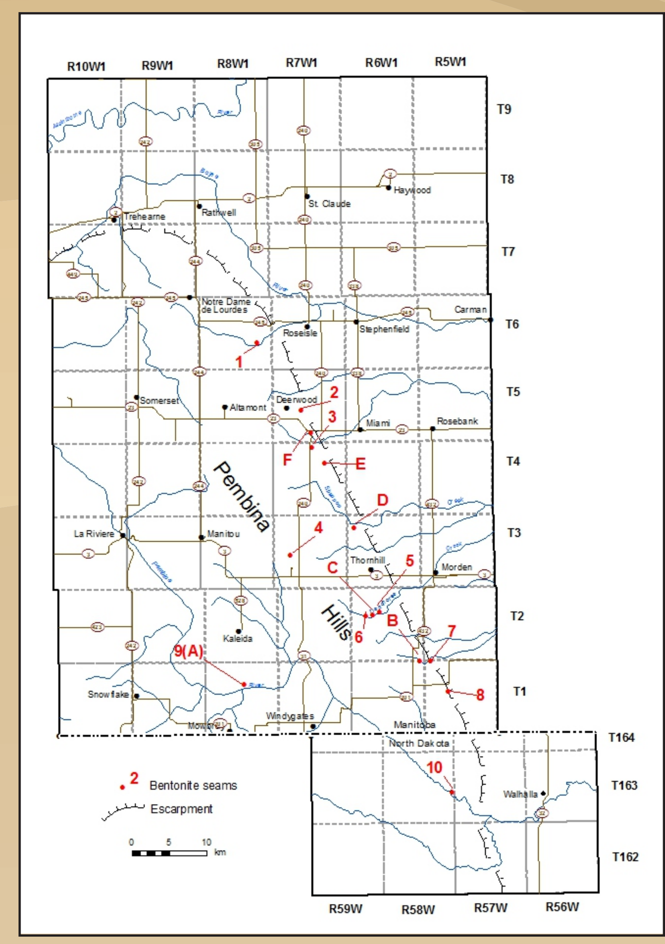


Figure 1: Selected Pembina Member localities (***A to F*** and ***1 to 10***) with numerous bentonite seams in the Pembina Hills area of southwestern Manitoba and northeastern North Dakota. Note: ***Locality A*** in ***Figure 2*** is the same as ***Locality 9*** in the photos.

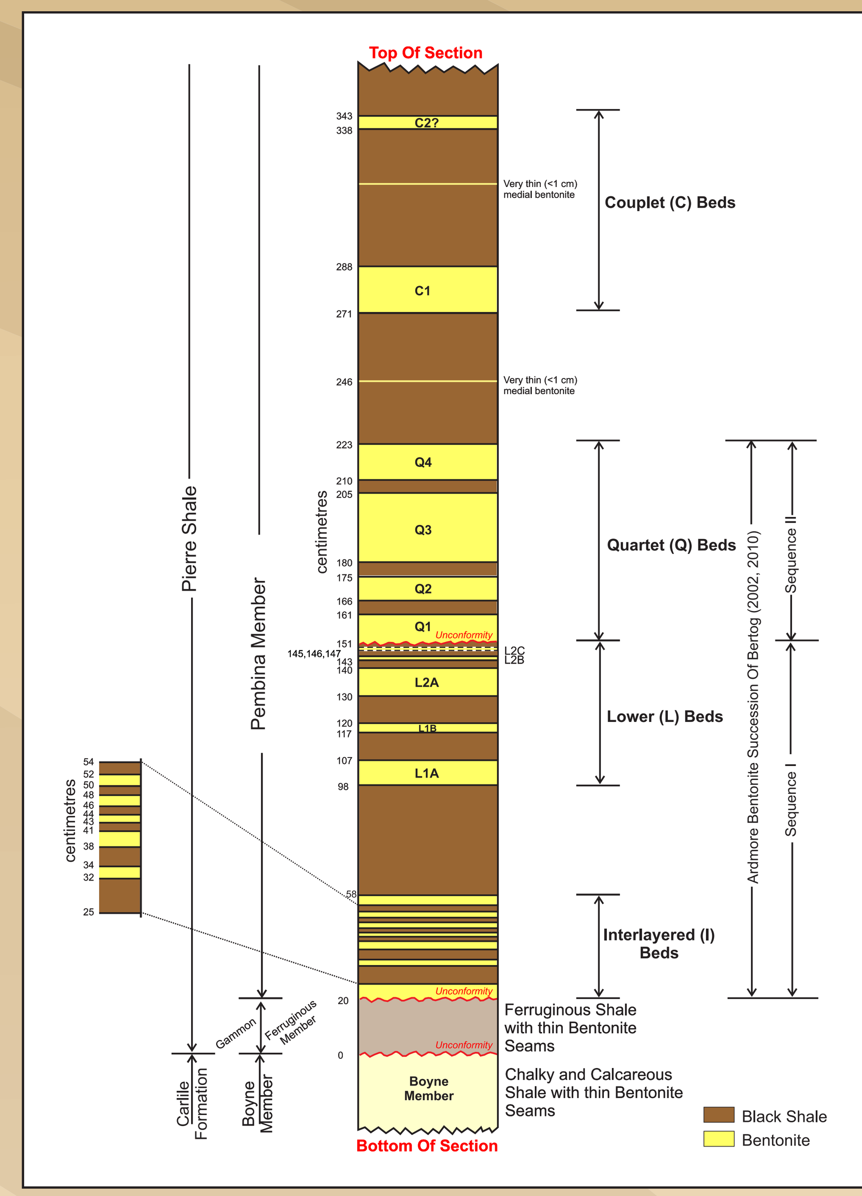


Figure 3: Schematic representation of lowermost bentonite seams in the Pembina Member and underlying units in the Pembina Hills area, Manitoba and North Dakota.

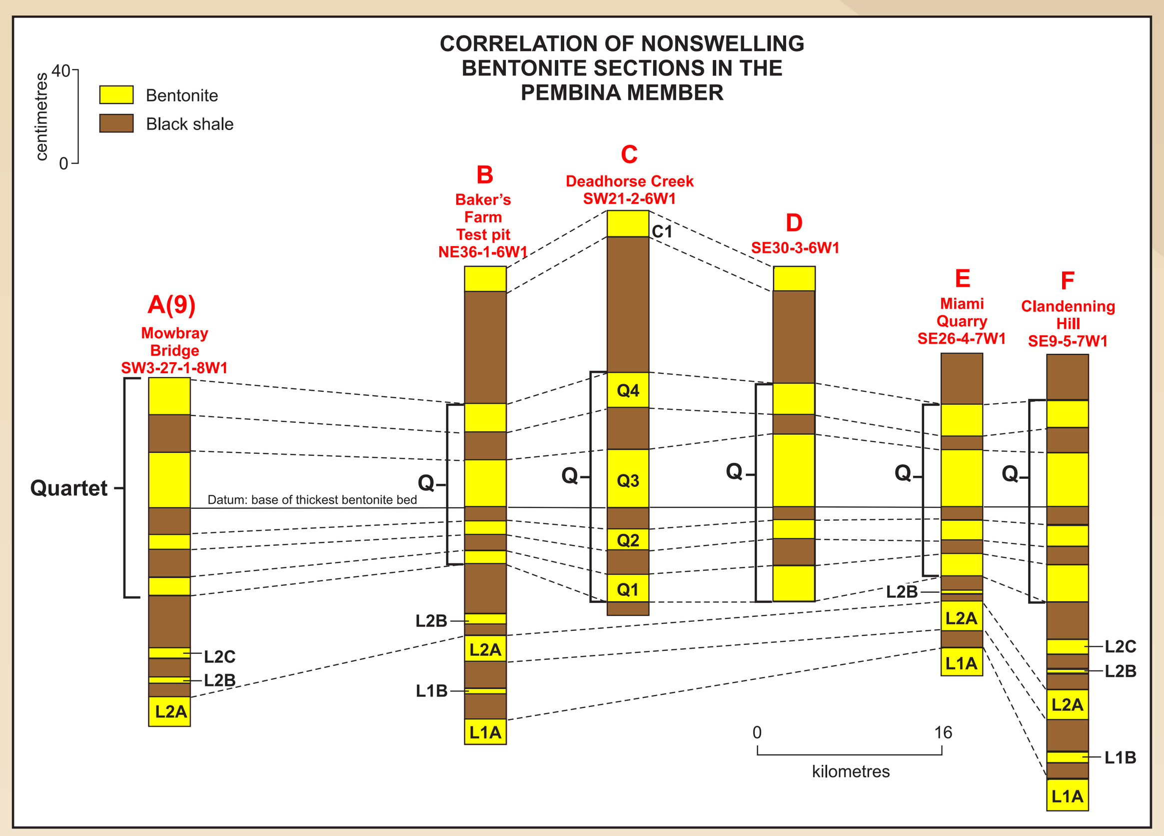
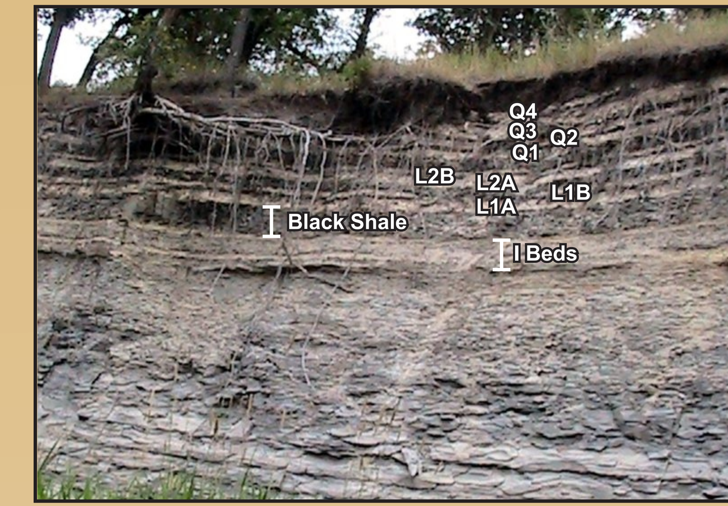


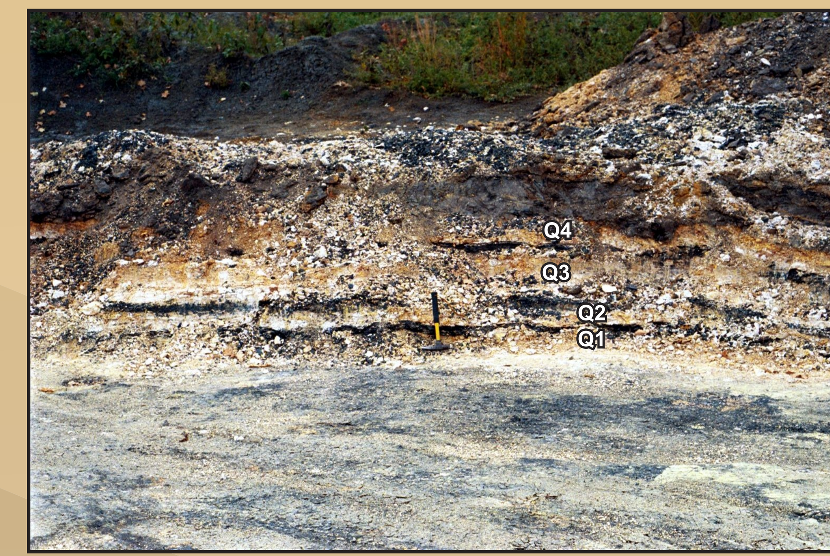
Figure 2:Correlation of nonswelling bentonite sections at six localities (***A to F***, shown in ***Figure 1***) in the Pembina Member in the Pembina Hills area of southwestern Manitoba (modified from Bannatyne, 1963, p. 15). ***Locality A*** is also ***Locality 9*** shown in the photos and in ***Figure 1***.

Locality 1: Roseisle Creek Bridge Outcrop; 13-11-06-08W1; NAD 83, 539650E, 5480027N (2012-06-28). Disturbed L beds could not be subdivided at this location.

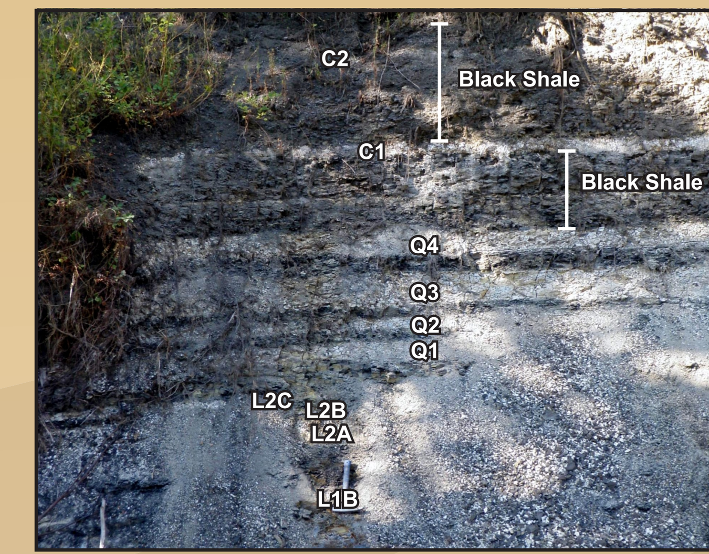


Locality 5: Deadhorse Creek Downstream Outcrop; N21-02-06W1; NAD 83, 557500E, 5443750N (photo provided by T. Epp, 2011-08-15).

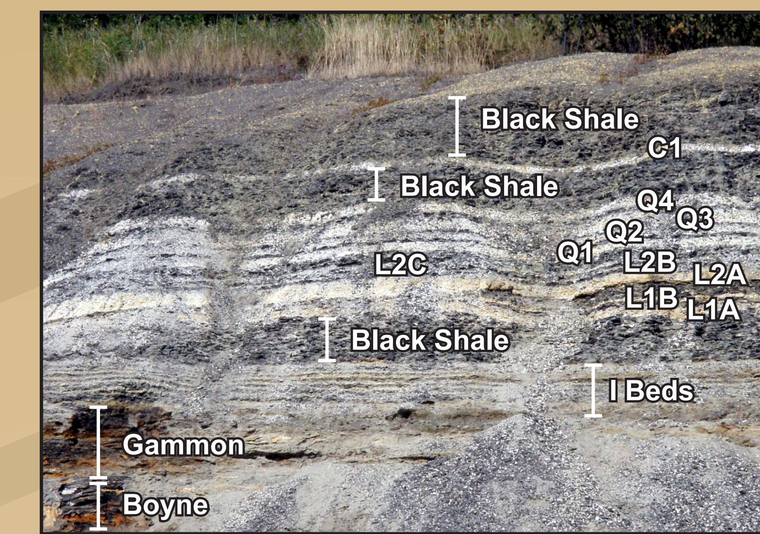
Locality 9: Mowbray (McLeod) Bridge Outcrop (also shown in ***Figure 2***, ***Section A***); 04-27-01-08W1; NAD 83, 539092E, 5434243N (photo published in Wickenden (1945, p. 83)), (1939?).



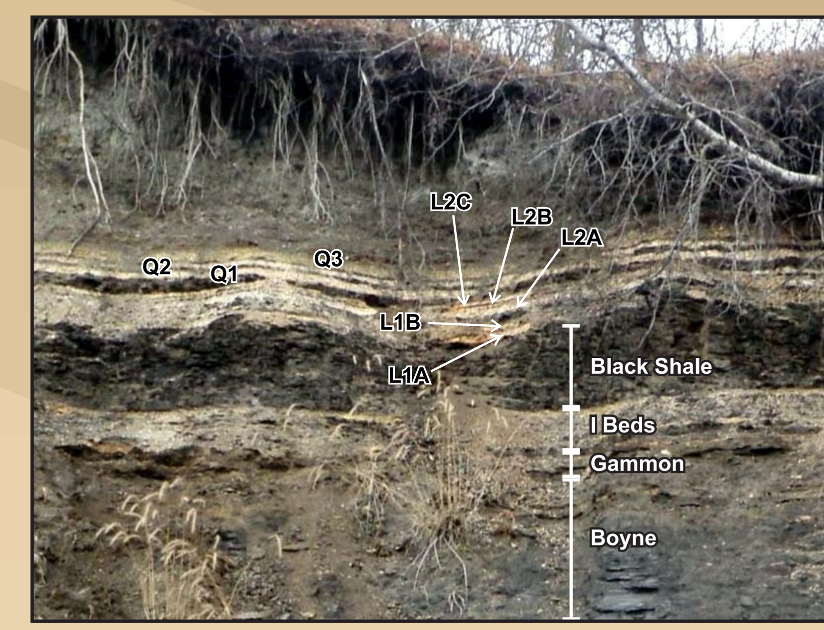
Locality 2: Bird River Resources Inc. Quarry QL-1530; 10 & 11-16-05-07W1; NAD 83, 547049E, 5471240N. The Quartet beds (Q1 to Q4) are exposed in the quarry, as seen in 2001 (2001-10-12).



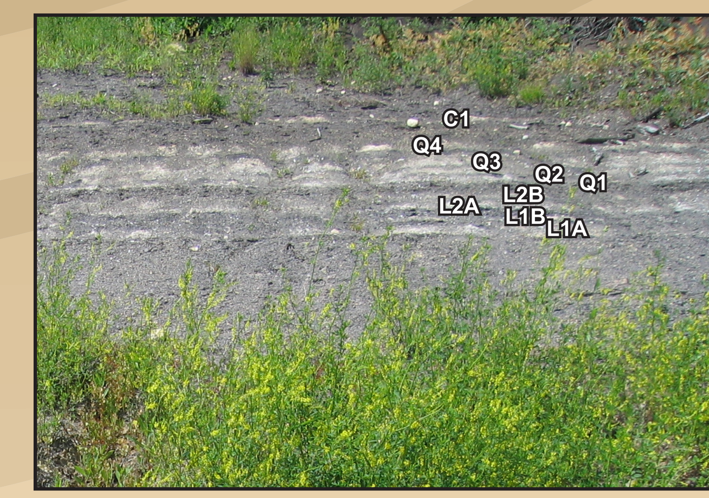
Locality 6 : Deadhorse Creek Upstream Outcrop; 11-20-02-06W1; NAD 83, 555980E, 5443179N (2011-08-17). L2B and L2C beds are present at this location.



Locality 10: Little Pembina River, North Dakota Road Cut; 13-163N-58W; NAD 83, 567221E, 5421884N (2011-08-26). L2B and L2C beds are present at this location.

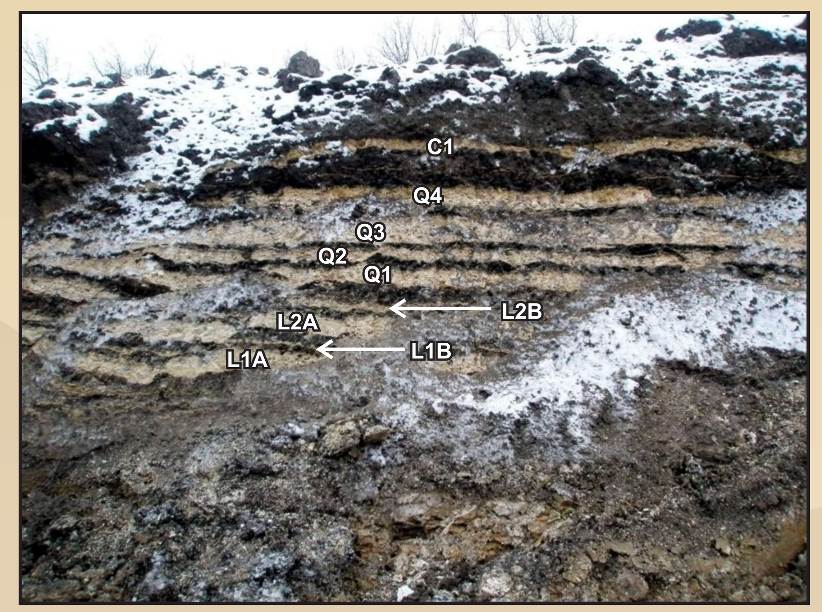


Locality 3: South Tobacco Creek Outcrop; 13-34-04-07W1; NAD 83, 546203E, 5466768N (2012-10-24. L2B and L2C beds are present at this location.

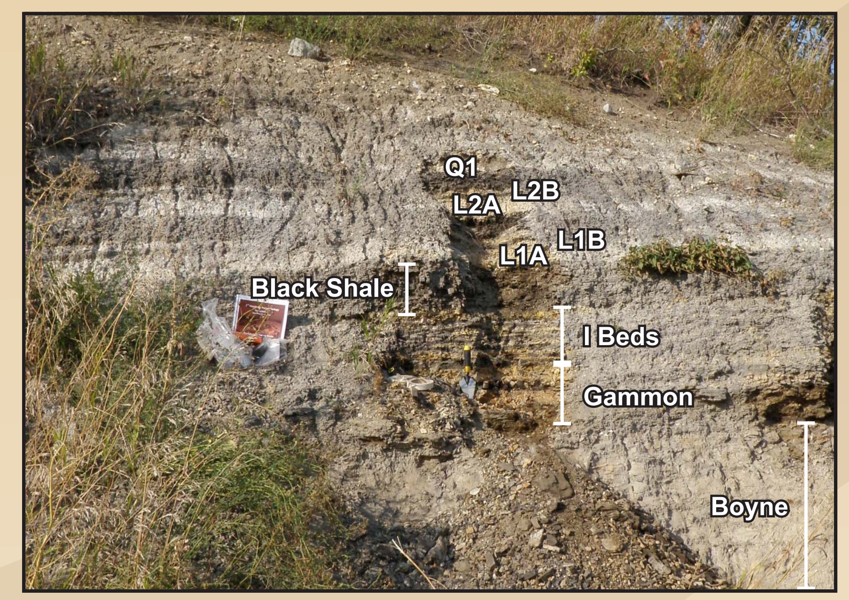


Locality 7: Friesen Road Cut; 04-07-02-05W1; NAD 83, 563579E, 5439347N (2008-07-09). Although this outcrop has been weathered, it is still possible to visually correlate beds.

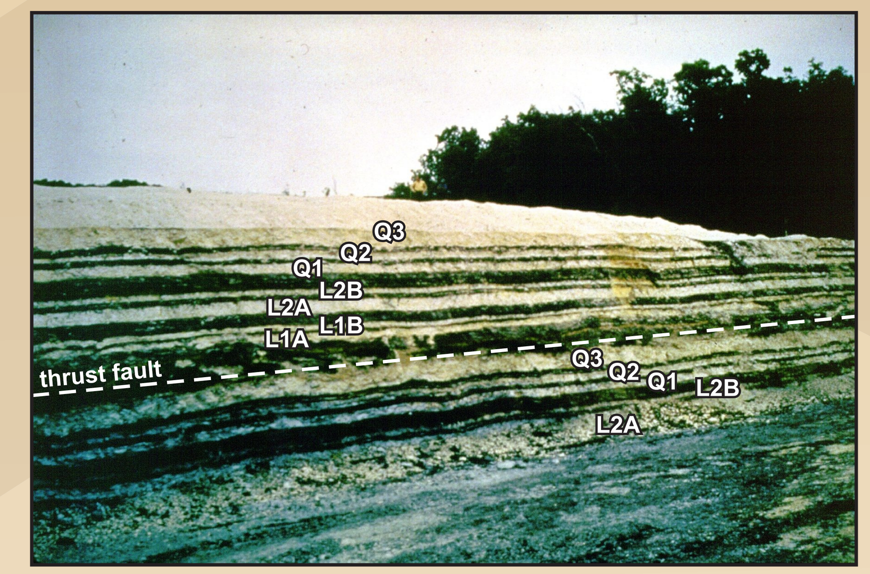
Locality 11: Unknown Outcrop - Lumgair South? (location is not shown in ***Figure 1***); 20-03-06W1? (photo provided by Canadian Fossil Discovery Centre, Morden). Although outcrop has been severely disturbed (probaby due to glacial action), it is still possible to visually correlate beds). L2B and L2C beds are present at this location.



Locality 4: Enbridge Pipeline Site (rehabilitated, section is no longer visible); 13-17-03-06W1; NAD 83, 554920E, 5452001N (2008-11-??).



Locality 8: Stonehenge Road Cut; 12-21-01-05W1; NAD 83, 566979E, 5433657N (2011-09-11).



Locality 12: Unknown Quarry - Friesen? (location is not shown in ***Figure 1***); 07-02-05W1?. According to Miami Museum Incorporated, 1974, p. 7), the vertical repetition of bentonite seams is due to faulting (or horizontal thrusting, probably due to ice push, as shown by the dashed line).

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