

Overview

The Pembina Member of the Upper Cretaceous Pierre Shale and the Boyne member of the Upper Cretaceous Carlile Formation outcrop 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; Tovell, 1948). The Pembina Member is overlain by the Millwood Member of the Pierre Shale and is underlain by the Gammon Ferruginous Member of the same formation. The Boyne Member of the Carlile Formation underlies the Pierre Shale (Bamburak and Nicolas, 2009).

Pembina Member

The member is characterized by at least 17 buff nonswelling calcium montmorillonite (altered volcanic ash) beds found interbedded with variable thicknesses of marine black carbonaceous, pyritic shale, found mainly near the base of the member. The beds range in thickness from 1.0 cm to 30 cm. In outcrop, bentonite 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 present in the subsurface of southwestern Manitoba, northeastern North Dakota and southern Saskatchewan, as shown by thousands of petroleum wells.

Boyne Member

Numerous beds of nonswelling calcium bentonite are also present within the Boyne Member, which is usually comprised of a speckled chalky shale unit overlying a speckled calcareous shale unit (Bamburak and Nicolas, 2009). According to Tovell (1948), the bentonite in the Boyne Member is either greenish-yellow or grey-blue in colour in outcrop, depending on the extent of weathering. The top and bottom of each bentonite bed is normally bounded by orange (limonitic) material. The Boyne Member of the Carlile Formation is also present in the subsurface of southwestern Manitoba, northeastern North Dakota and southern Saskatchewan. However in North Dakota and adjacent states, the member is recognized as the Niobrara Formation (McNeil and Caldwell, 1981, p. 37).

Previous Studies

Pembina Member

The first reported visual correlation of Pembina Member bentonite beds 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 bed in a vertical sequence of up to eight beds 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 beds at six outcrop and pit sections (**Localities A-F, Figures 1 and 2**).

The visual, fossil and age dating correlation of bentonite beds 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.

The process of visual correlation of the Pembina Member, described below, was first presented last year in a poster by Bamburak et al. (2012). The poster demonstrated that visual correlation of bentonite beds is 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 beds in the Pembina Member by Bannatyne (1963, p. 15) was predicated on recognition of the thickest bed in an outcrop, test pit or quarry section within a sequence of four closely spaced bentonite beds, the Quartet beds (Bamburak et al., 2012). **Figure 3** depicts a schematic geologic section of the lowermost bentonite beds in the Pembina Member of the Pierre Shale. The schematic was constructed using previously published data (**Figure 2**) and field observation at **Localities 1, 6, 8 and 10** (located in **Figure 1**) and at other localities in the Pembina Hills area.

Boyne Member

Tovell (1948) visually correlated the Boyne Member bentonite beds in the Pembina Valley-Deadhorse Creek area as depicted in his diagram 47-7B. Three bentonite beds at the base of the member were considered to be “an excellent mapping horizon” at 8 localities extending over a distance of 8 km from NW23-1-7W1 to SE4-1-6W1. The horizon was used to interpret structure across the area. Tovell also depicted multiple bentonite beds near the top of the Boyne Member, at his locality 43 (situated 200 m north of the Canada-U.S. border in diagram 47-7B, but he did not attempt visual correlation of these beds.

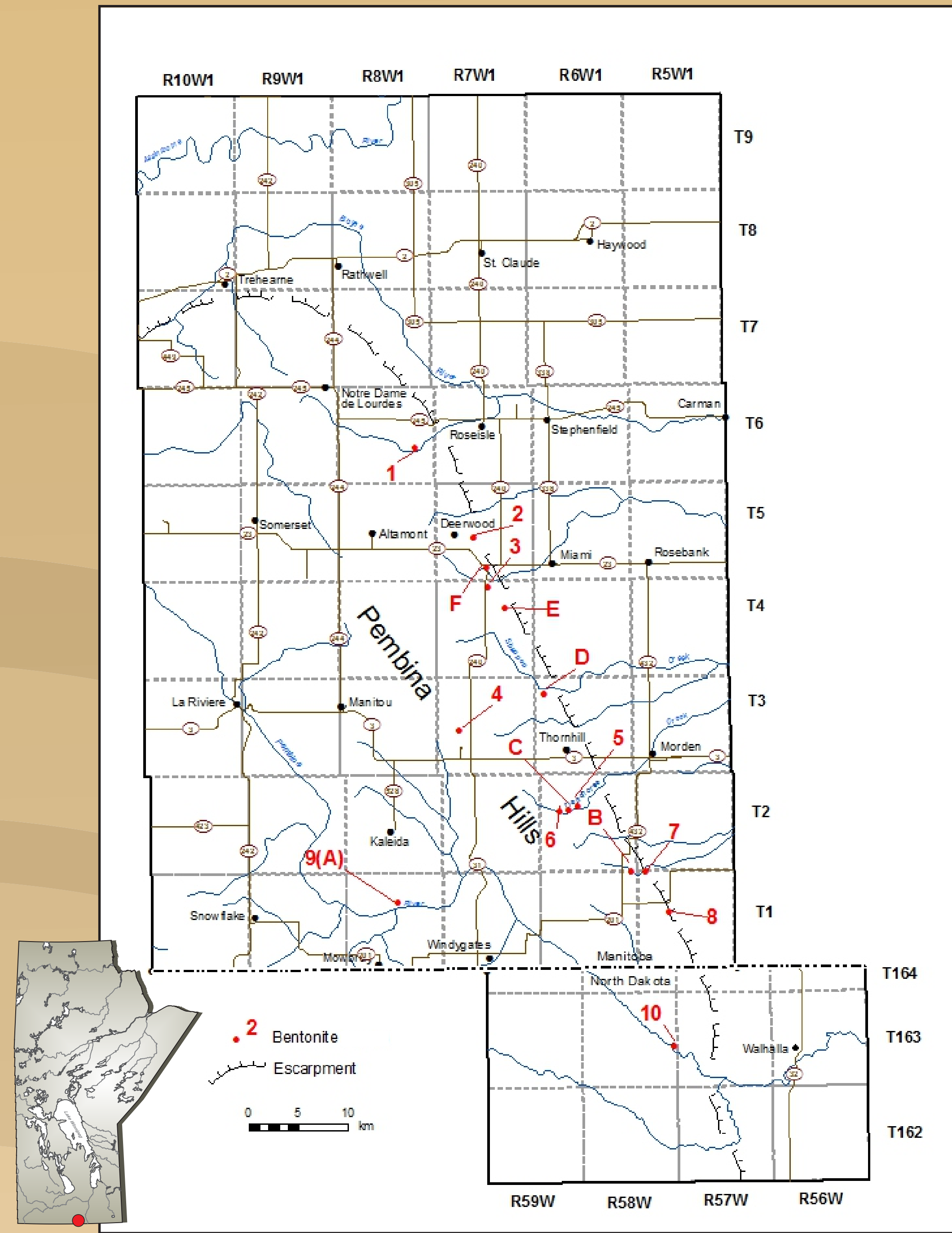


Figure 1: Selected Pembina and Boyne member localities (**A to F** and **1 to 10**) with numerous bentonite beds in the Pembina Hills area of southwestern Manitoba and northeastern North Dakota. Note: **Locality A** in **Figure 2** is the same as **Locality 9**.

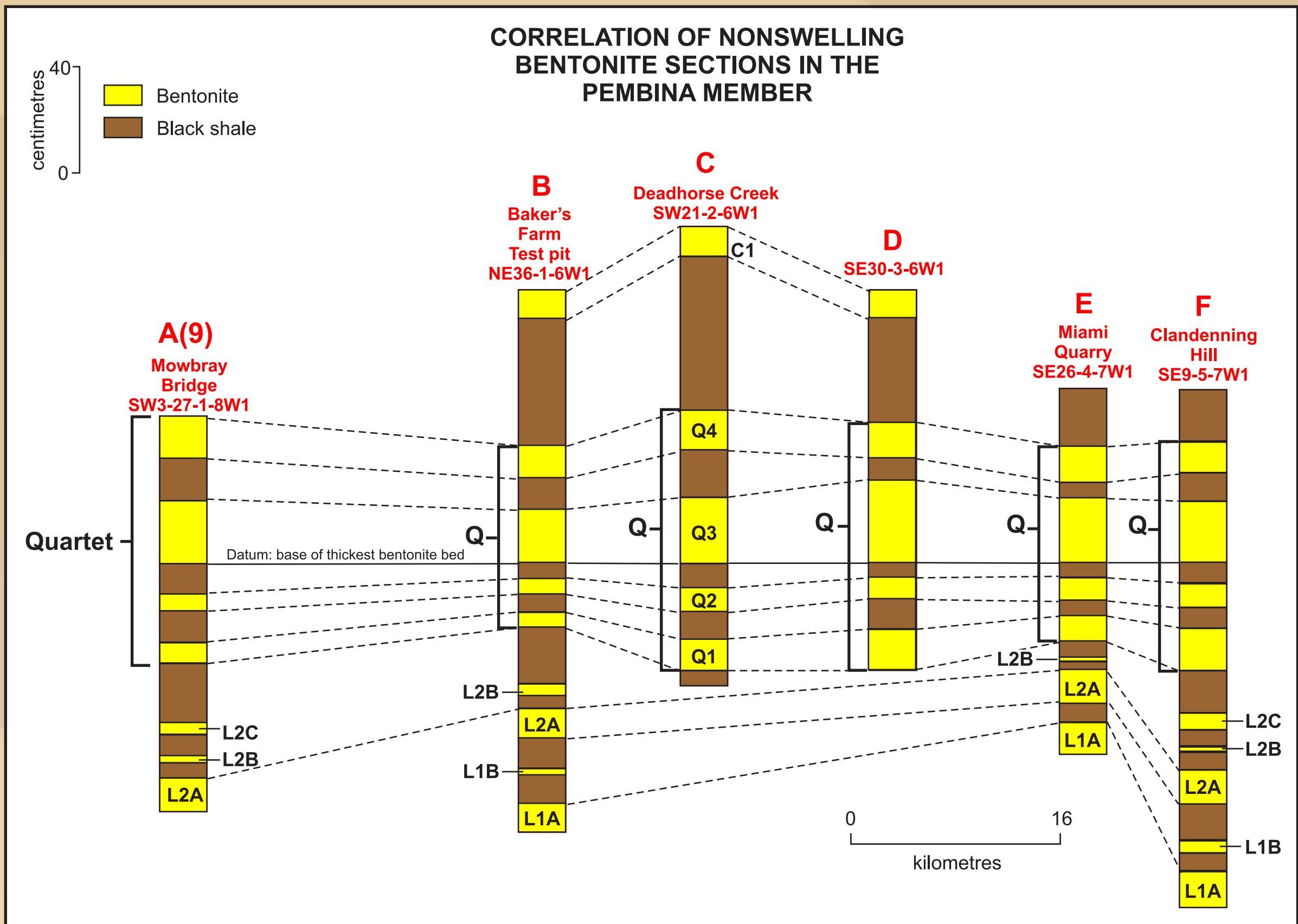


Figure 2: Correlation of nonswelling bentonite sections at six localities (**A to F**, shown in **Figure 1**) in the Pembina Member in the Pembina Hills area of southwestern Manitoba (modified from Bannatyne, 1963, p. 15). **Locality A** is also **Locality 9** shown in **Figure 1**.

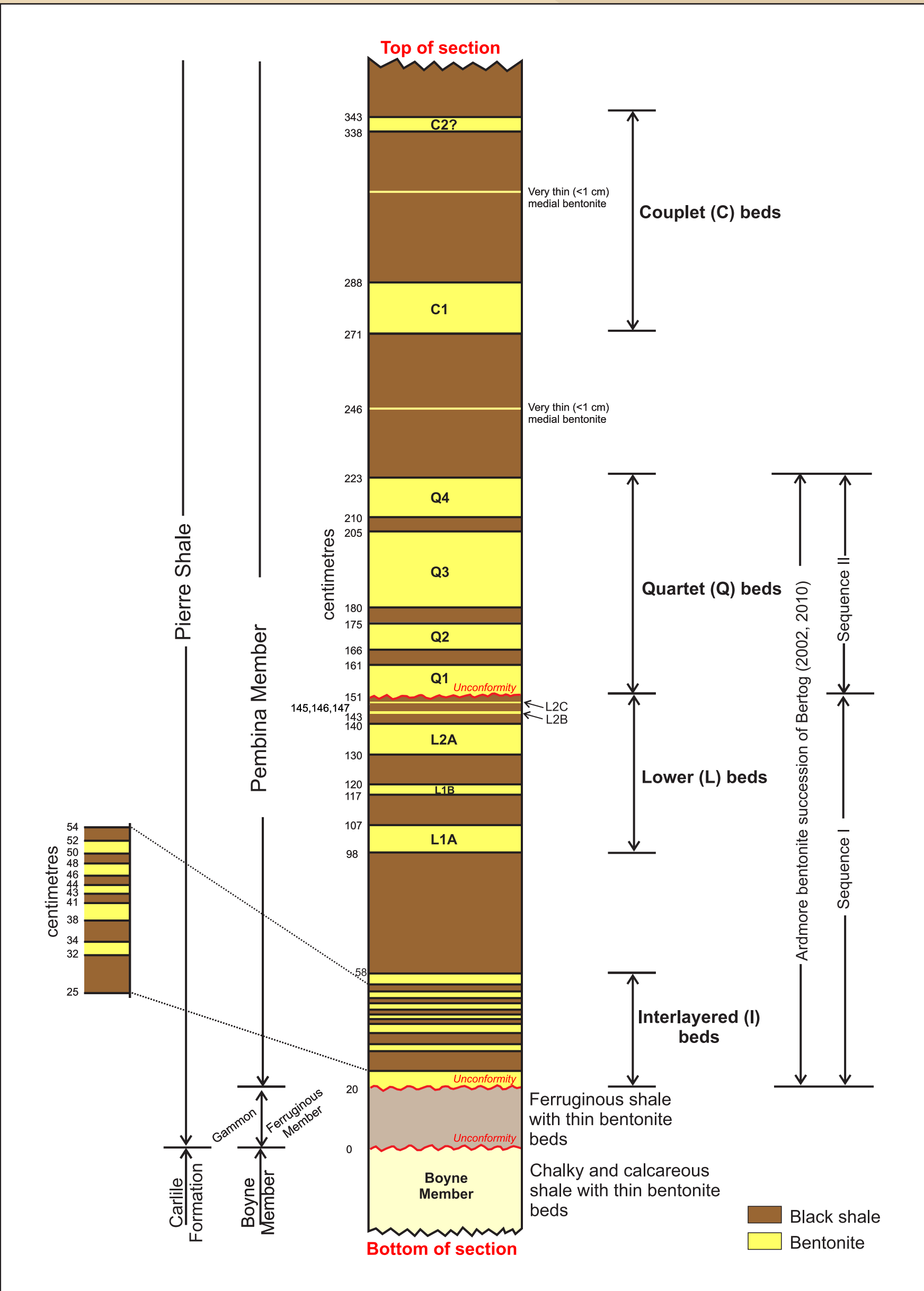
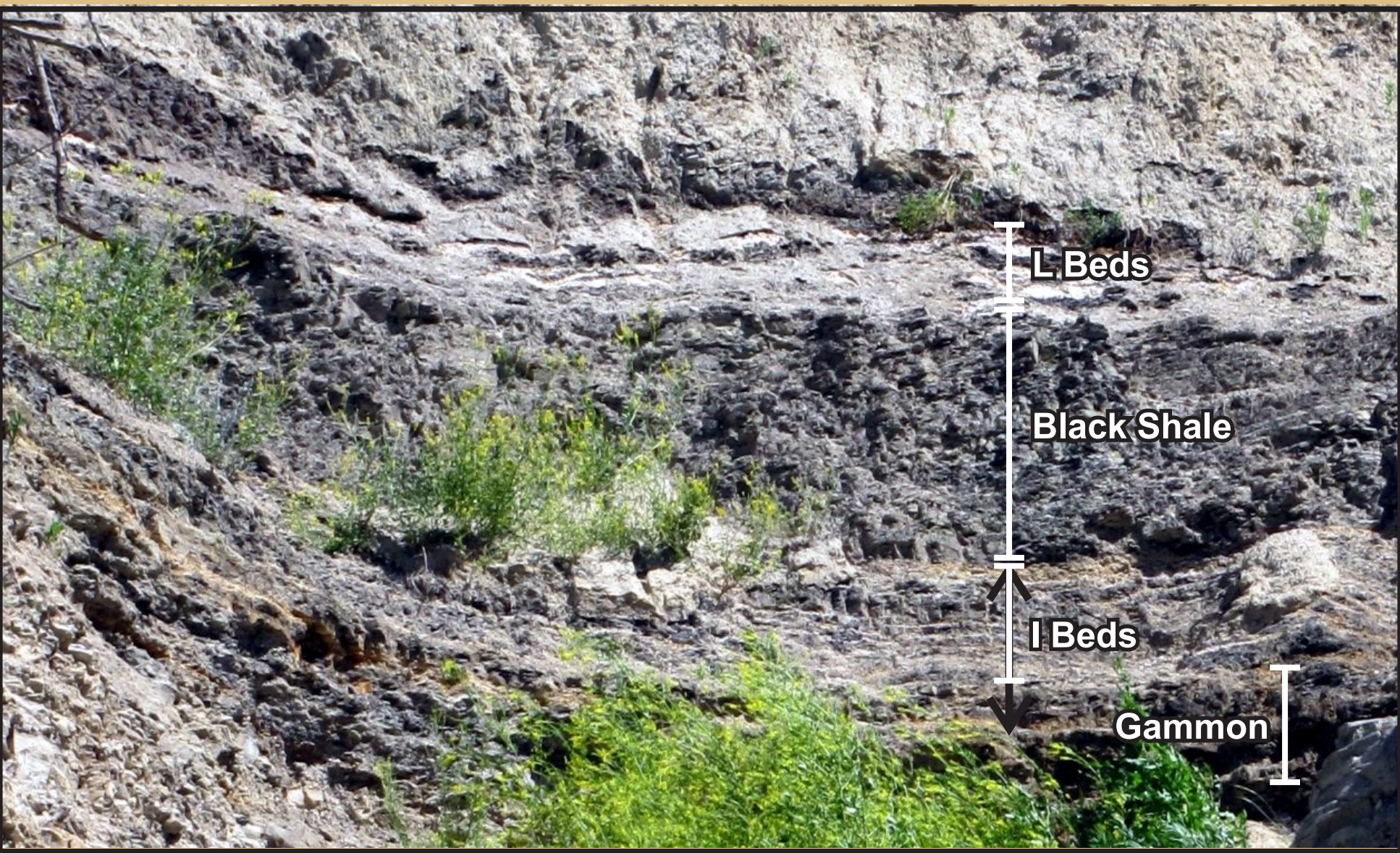
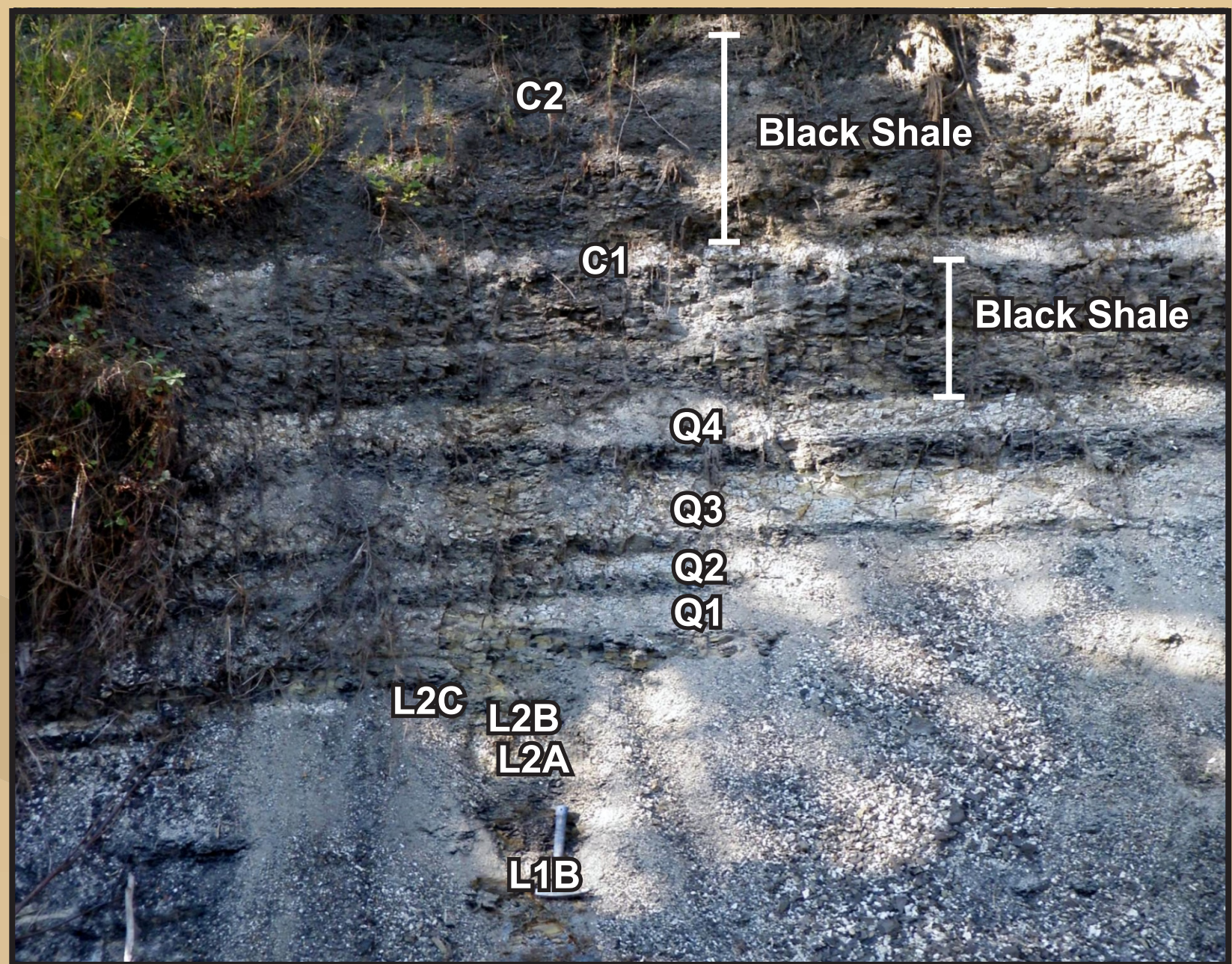


Figure 3: Schematic representation of lowermost bentonite beds in the Pembina Member and underlying units in the Pembina Hills area, Manitoba and North Dakota.



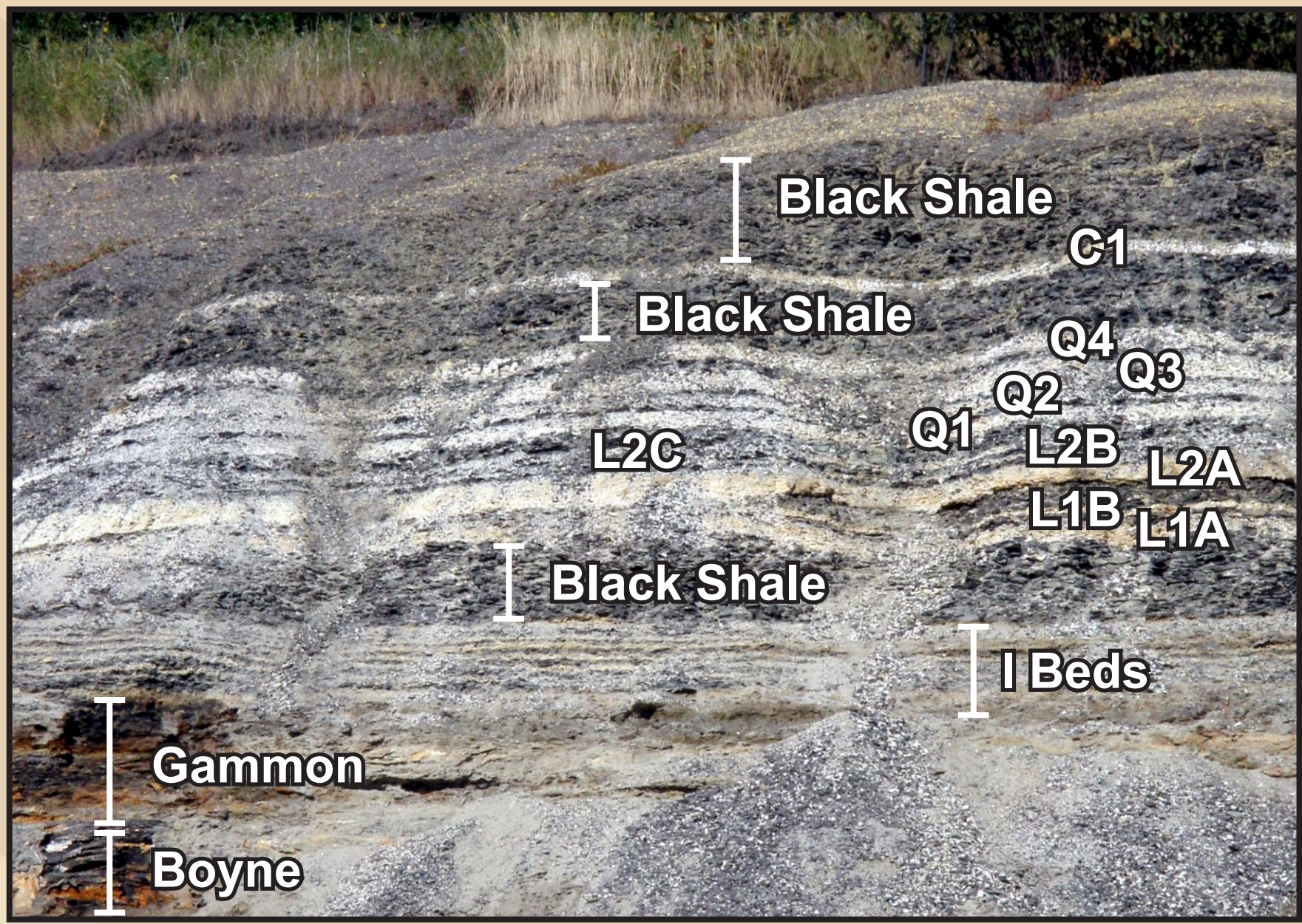
Locality 1: Roseisle Creek Bridge Outcrop; 13-11-06-08W1; NAD 83, 539650E, 5480027N (2012-06-28). Pembina Member overlying Gammon Ferruginous Member. Disturbed L beds in Pembina Member could not be subdivided at this location.



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



Locality 8: Stonehenge Road Cut; 12-21-01-05W1; NAD 83, 566979E, 5433657N (2011-09-11). Pembina Member overlying Gammon Ferruginous Member of the Pierre Shale, overlying Boyne Member of the Carlile Formation.



Locality 10: Little Pembina River, North Dakota Road Cut; 13-163N-58W; NAD 83, 567221E, 5421884N (2011-08-12). Pembina Member overlying Gammon Ferruginous Member of the Pierre Shale, overlying Boyne Member of the Carlile Formation. L2B and L2C beds are present at this location.

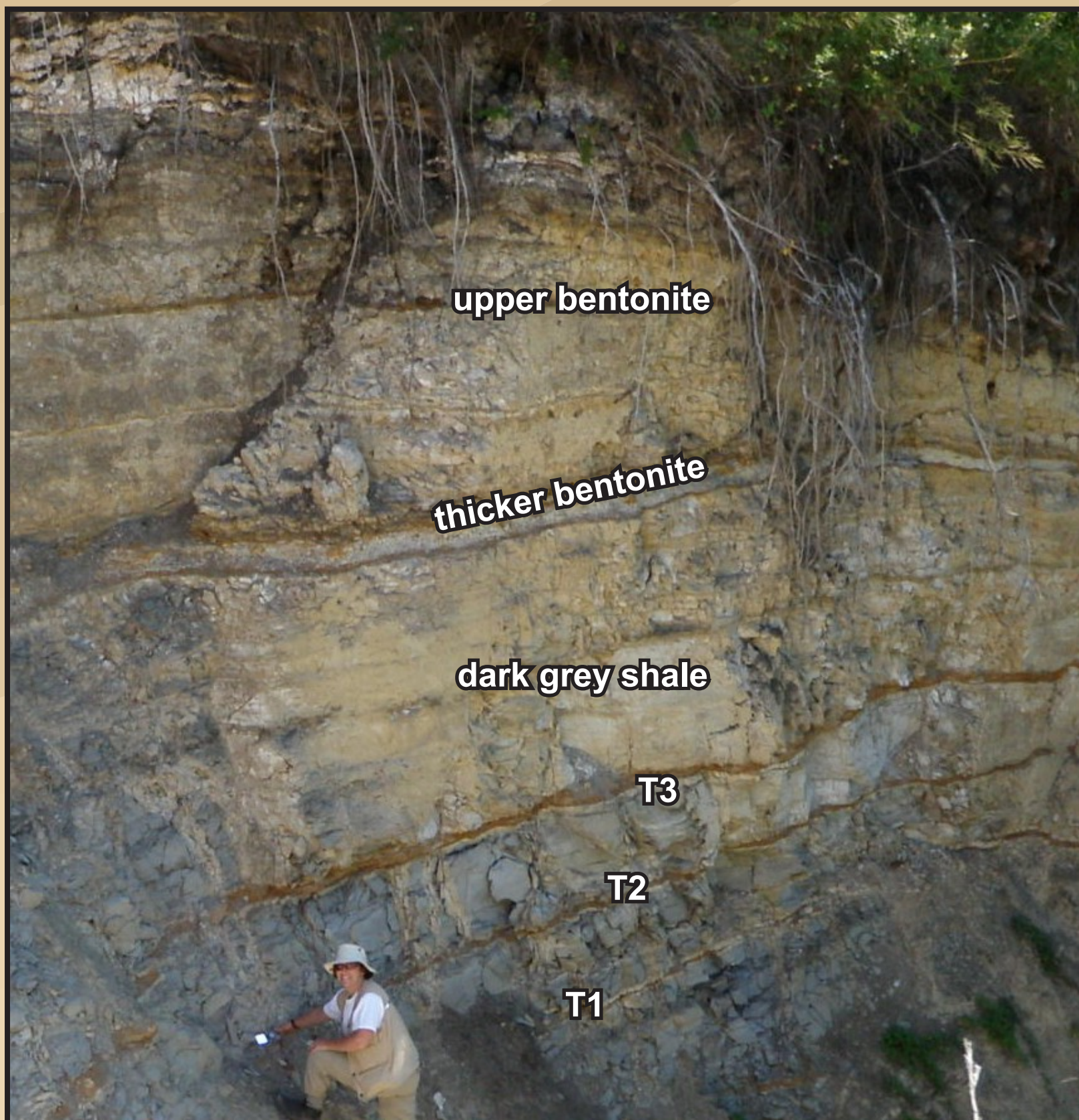
Present Study

Boyne Member

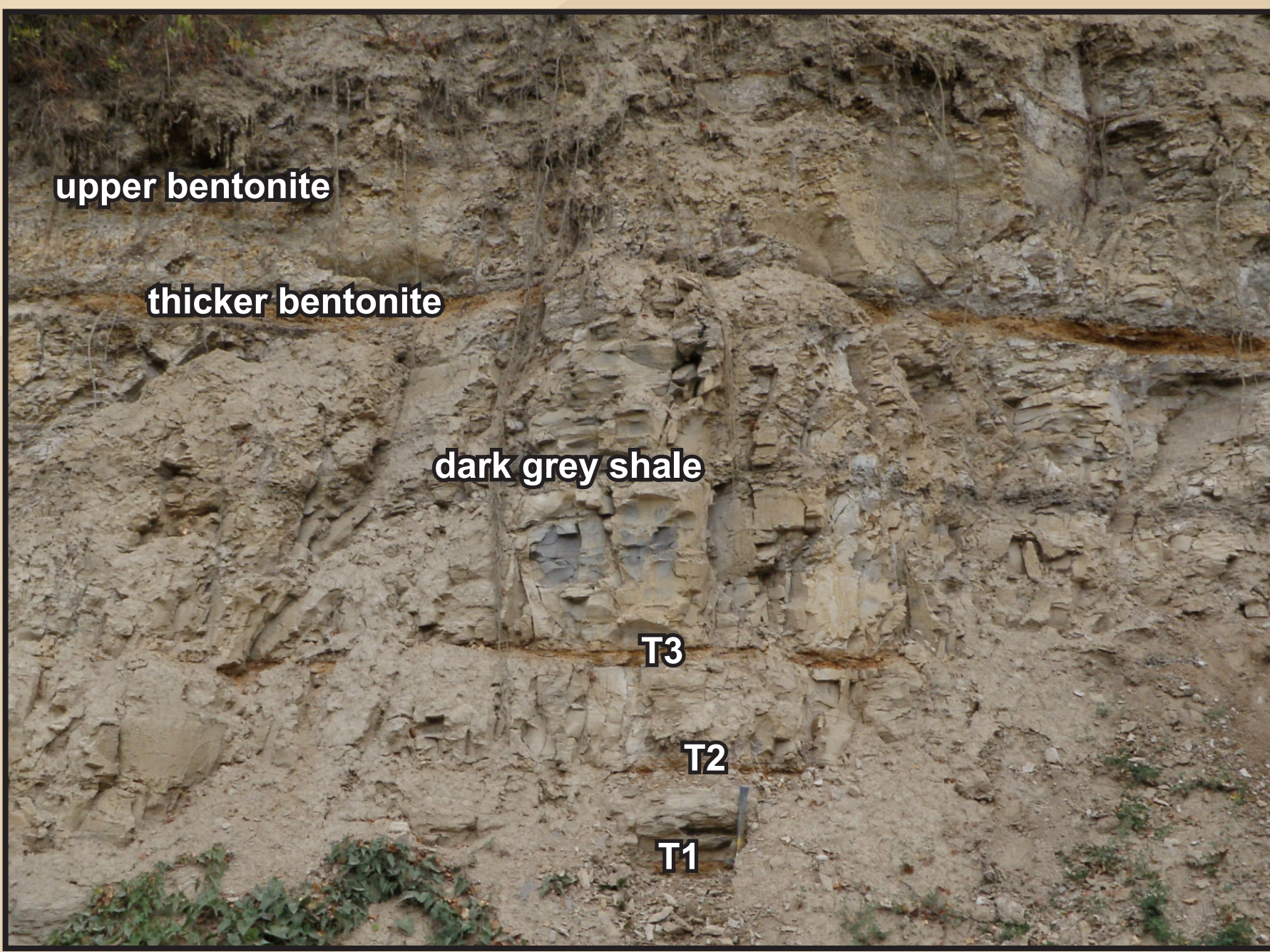
As indicated earlier, Tovell (1948) visually correlated three bentonite beds at the base of the Boyne Member along the Pembina Valley. Further work is required in the future to confirm and extend these correlations; however bentonite beds have been visually correlated near the top of the member at two locations, 37 km. apart, north and south of the Canada-U.S. border.

Spencer's ditch (located in **Figure 1, Locality D (North)**), a southerly-trending ravine into Shannon Creek, has been incised into the relatively soft Upper Cretaceous beds due to repetitive spring meltwater run-off from a large holding pond, situated to the north of Dunston Road (section road 18N). Annually, an ice plug in the culvert beneath the road holding back the water in the pond, gives way with sudden force, which results in substantial downcutting of the bedrock. On the east wall of Spencer's ditch, 2 m of glacially disturbed white bentonite beds within black shale of the Pembina Member of the Pierre Shale can be seen overlying about 10 m of buff Boyne Member, with numerous thin orange-coloured bentonite beds (**Locality D (North)**). The trio of three bentonite beds, herein named the Trio beds (T1 to T3), can be seen at the bottom of the photo; and a grey-orange “thicker bentonite” bed can be seen in the upper third of the photo.

Three Sisters Hill roadcut (located in **Figure 1, Locality 10 (East)**) is situated on the east valley wall of the Little North Pembina River. The roadcut has 5 bentonite beds and a dark grey shale bed within the upper buff chalky Niobrara Formation (**Locality 10 (East)**) that are remarkably similar in positioning and size to those seen in the Boyne Member of the Carlile Formation at Spencer's ditch (above). The position of the bentonite beds also show striking similarity to those of depicted in the locality 43 columnar section of Tovell (1948, diagram 47-7B), but further work is required to confirm this interpretation.



Locality D (North): Spencer's ditch; 15-31-03-06W1; NAD 83, 553843E, 553843N (2011-08-17). Boyne Member of the Carlile Formation.



Locality 10 (East): Little Pembina River, Three Sisters Hill Road Cut; SE18-163N-57W; NAD 83, 568626E, 5420940N (2011-09-12). Boyne Member of the Carlile Formation.

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