LOG JAM DEPOSITS IN THE BOSS POINT FORMATION, NEAR JOGGINS, NOVA SCOTIA

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Abstract

The Boss Point Formation, part of the Cumberland Group, consists mostly of sandy braidplain and muddy lacustrine facies. The braidplain facies mainly comprise stacked, trough cross-bedded channel deposits, which contain accumulations of woody material, logs, and in some cases, thin coal seams within some of the bedsets. The muddy lacustrine facies nonerosively overlie the braidplain facies, and are thought to provide evidence for channel abandonment and avulsion. One outcrop near the base of the formation was studied in detail due to its particularly good exposure of the wood debris, which is present in different sandstone bodies within a section of about 3 m in thickness. The stratigraphy and sedimentology were described, and the size of wood fragments was measured, along with the thickness of the log-rinds. High-resolution photographs were taken in order to calculate the proportion of wood to sediment. From this, the amount of compaction that occurred to the wood-bearing beds during burial can be estimated, and their original thickness after deposition but prior to burial can be found. The findings show that the original depth of the channel was about 8.2 m, and though the lateral extent of the channel could not exactly be determined, it is thought to be quite large. Stratigraphic analysis shows that the debris is associated with flooding events, and the presence of shales above the log accumulations strongly suggests that the accumulations contributed to the abandonment of the channels. Our information, combined with previous studies of plant fossils in the area, suggest that the woody accumulations constitute a log jam deposit in the Boss Point Formation. The deposits in this area can also be compared to other log jam deposits, in Nova Scotia, USA and Poland. Recent evidence from palynology shows that the age of the Boss Point Formation is Yeadonian to Langsettian, older than any other documented log jam deposit. As a result, the data obtained from the deposits in this area not only provide information on how ancient channel systems were affected by the jamming, but also show one of the first instances of plants having evolved to be in sufficient numbers and to be large enough to significantly affect the dynamics of fluvial systems.

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Chapter 1 – Introduction

1.1 Introduction

In modern river environments, rivers can be choked by plant material, logs, pieces of trees, and sometimes whole trees themselves. This material dams the river, and can bring about avulsion, which is defined as the flooding of the river out of its current channel, and into a newly incised channel or a pre-existing one. Though the cause of avulsion is difficult to identify in ancient channel deposits, the process of log-jam-induced avulsion has been inferred in a few different cases (Gibling et al., 2010). Thus, log jams are an important process in shaping and defining the evolution of rivers and their associated flood plains. This happens often in the modern setting, and the mechanism and effects have been extensively researched. An example of this is Tonghi Creek in southeast Australia, where it was shown that large woody debris makes up 576 m^3/ha over an area of 187 km^2. Of this, 10.4% of the blockages block more than 10% of the channel cross-sectional area, which is significant enough to cause flooding and avulsion (Webb et al., 2003).

There are few documented occurrences of log-jam induced avulsion around the world, and they go back as far back as the Pennsylvanian, as discussed below. Further back beyond that, log jams would have been rare. This is because plant life had not evolved to be of sufficient size or in sufficient numbers to be capable of blocking rivers until the Middle Devonian (Gibling et al., 2010). The Pennsylvanian Boss Point Formation of Nova Scotia contains many log accumulations (Browne & Plint, 1994) that may be log jams. The formation consists mostly of sandy braidplain and muddy lacustrine facies, some of which contain large woody debris. Whereas there is evidence that avulsion took place, the study will look at whether or not this avulsion was caused by the accumulations of large woody debris.

1.2 Study Area

The Boss Point Formation represents part of the Lower Pennsylvanian (Langsettian) section of the Cumberland Group, deposited in the Cumberland Basin of northern Nova Scotia. The formation was studied in detail by Browne and Plint (1994). Studies of sedimentology and stratigraphy prior to this 1994 paper had inferred also that the Boss Point Formation was deposited from a braided river system (Falcon-Lang and Scott, 2000). Browne and Plint (1994) found that the formation consisted of successions of two main facies: sandy braidplain facies and muddy lacustrine facies. The braidplain facies is made up of stacked, trough cross-bedded channel deposits that contain accumulations of woody material, and in some cases, thin coal seams. Occurences of this woody debris may then represent ancient log-jam deposits. The muddy lacustrine facies is found to overlie the braidplain facies sharply but nonerosively at numerous levels. This implies that lacustrine deposition was initiated by rapid, low-energy flooding. In the lower part of every succession, a layer of lacustrine mudstone is erosively overlain by the braidplain sandstone. This is an indication of avulsion, during which the flood of the river system caused the river to incise a new channel in the floodplain deposits (Browne and Plint, 1994). Additionally, within the braidplain facies, stacked sandstones and thin mudstones provide evidence of channel abandonment and avulsion.

One outcrop in particular was studied for its good exposure of the wood debris. The outcrop is found along the beach, north of Lower Cove, near Joggins, Nova Scotia (Fig. 1.1). The debris is present in abundance through about 3 meters of sandstone at the top of a channel body. A thin layer of shale lies nonerosively on top of that, indicating local channel abandonment and avulsion. The age of the deposit is inferred from the age of the Boss Point Formation. Since it lies near the base of the formation, the deposit is provisionally dated as Yeadonian to Langsettian (Utting et al., 2010), part of the Lower Pennsylvanian subperiod.

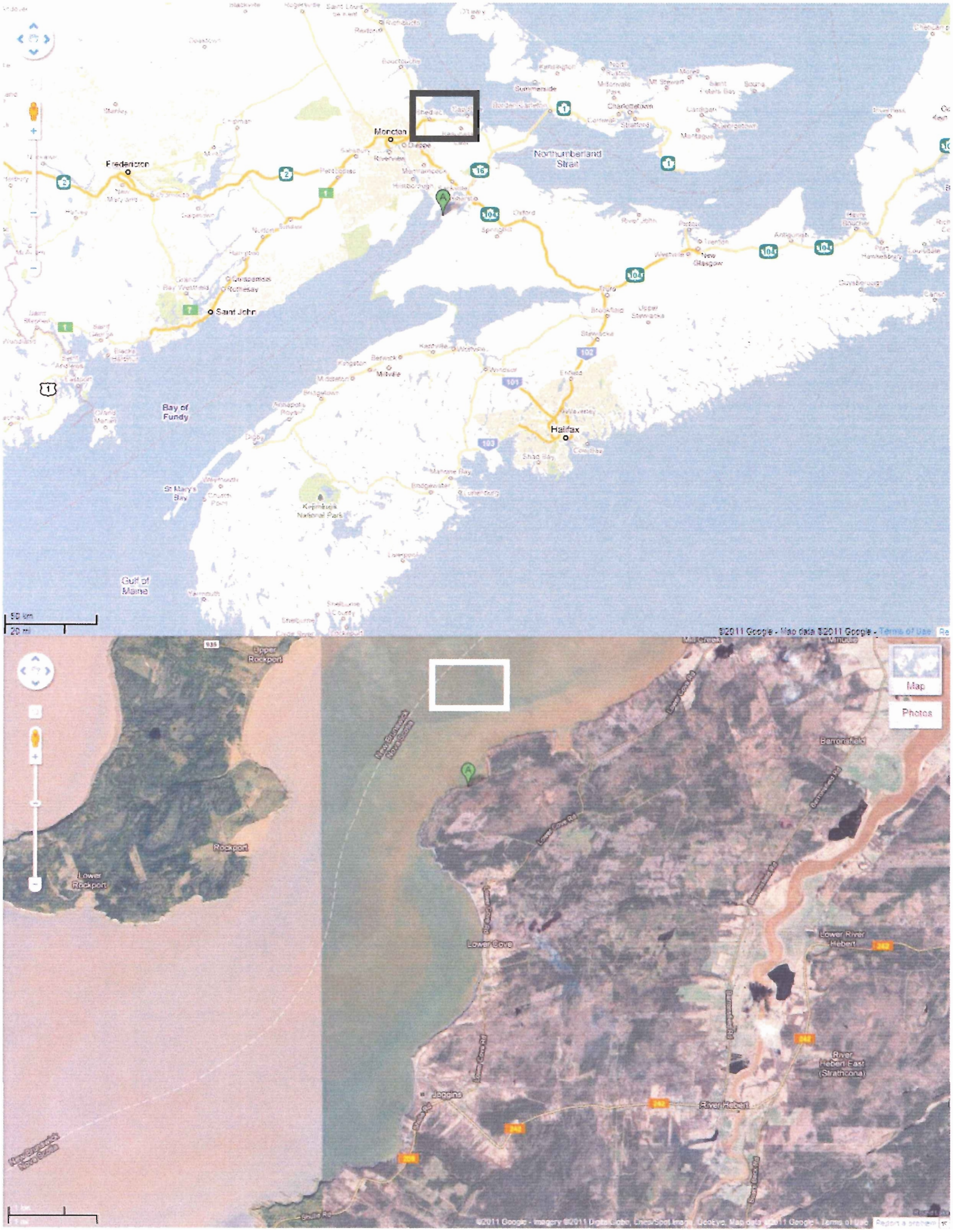

Figure 1.1 Location of the studied outcrop. Top: Broader, map view of the location. Bottom: Closer, satellite view of the location. Location in both pictures is denoted by the arrow within the boxes.

1.3 Other Ancient Log Jams

There have been previous studies of ancient log jams, similar to those found in the Boss Point Formation. Pennsylvanian log jam deposits can be found as close as the Sydney Basin of Nova Scotia. The South Bar Formation (Bolsovian to Asturian) shows successions of sandstone capped with layers of large woody debris and coal; shales that cap the woody debris are cut into by younger channel sandstones. Avulsion is thought to have taken place due to abrupt changes in paleoflow direction between channel bodies below and above the woody debris. This implies that the river switched to a different location on the plain and later reoccupied the alluvial tract with a strongly different orientation. The blockage caused by the debris is thought to have been sufficient to have caused this avulsion (Gibling et al., 2010). These log jam deposits are similar to the occurrence in the Boss Point Formation documented in this study, but the Boss Point occurrence is older. Another Pennsylvanian (Langsettian) deposit found in Alabama was found to contain log debris with an orientation perpendicular to the direction of sediment transport, and in part for this reason was interpreted as a log jam (Gastaldo and Degges, 2007).

1.4 Objectives

Whereas previous studies indicate that avulsion has happened in the Boss Point Formation, the present study aims to find indications of flooding and avulsion within the studied outcrop, and more importantly, to see if this avulsion was caused by log jams. For this to occur, the blockage ratio (the proportion of channel cross-sectional area filled by woody debris) needs to be high enough to dam up the river. To find the blockage ratio, we need to find out how much compaction took place, and the percentage of wood within the beds. If we can show that avulsion took place here due to the large woody debris, then the Boss Point log jams would be one of the oldest, if not the oldest, documented log jam deposit in the world, being Early Pennsylvanian in age. Another significant implication would be that plants at the time of the deposition were large enough and present in sufficient quantities to dam up the river and bring about avulsion.

Chapter 2 - Methodology

2.1 Methods

Since the aim of this study is to determine whether or not avulsion can occur due to log jams at this time, we need to first find indications that avulsion took place. To do this, the sedimentology, stratigraphy and paleocurrents were analyzed. To find out how much of a role the large woody debris played, the proportion of wood to sediment was found, allowing an estimation of compaction ratio to assess the original log-jam thickness. This, combined with thin section analysis of the beds, would give us a good understanding of the avulsion history, and allow an inference of its cause.

2.2 Debris Percentage

The amount of wood debris within the beds is required to estimate compaction. Once the proportion of wood to sediment is known, this information may be used to infer how much of the compaction of the bed was due to the large woody debris and how much was due to sediment. This would then allow estimation of the thickness of the bed as a whole before compaction took place. There were various methods considered to calculate wood percentage, each with its own flaws. The most direct method would be to take a sample from the outcrop, crush it, weigh it, and subject it to high temperature and then weigh it again. This would burn away the carbon of the wood debris, and the difference in mass before and after burning would indicate how much carbon was removed, and therefore how much wood debris is present. There are two main flaws in this method, one being the assumption that only carbon would be removed by burning, which is likely not the case because other substances, such as water in clays or trapped volatiles, would also be volatilized. The other main flaw is the location and remoteness of the outcrop. It is not easy to get to, and a large sample would be difficult to retrieve. Another method would be to measure differences in density within the debris-filled bed and a bed of similar lithology that did not have any wood in it. Since the density of organic material is less than that of the surrounding sediment, it could help to give an estimate of the proportions. Equipment for this method would be expensive, and it was not clear that a bed of similar composition to the debris-filled beds was present. Point counts and digitized photographs of the outcrop as a whole were also considered, but these were decided to be too time consuming and not sufficiently accurate.

As a result, the best method was determined to be graphical editing of high-resolution photographs of a cross section of the log jam beds. A section of a photograph, deemed to be representative in terms of debris exposed, was run through the photo-editing software Adobe Photoshop©. The contrast and resolution of the picture was altered so that the woody material would stand out more clearly, so that it could be digitally colored over. This was done using a paintbrush tool that allowed the pieces to be colored over directly. The editing was done carefully, so as not to affect the pictures in any other ways that could skew the data obtained. The number of colored pixels was then divided by the total number of pixels to give the percentage of colored pixels, and thereby the percentage of debris. The limitation of this method is that it assumes a perfectly vertical, sheared-off face in order to avoid visual distortion of the wood fragments. The exposed cross section face is not perfectly sheared off as there are gouges and areas jutting out. This limitation is not very significant because as planar a face as possible was selected.

2.3 Compaction

At the outcrop, the widths of pieces of wood were measured, along with the thickness of rinds. The width measured is considered equivalent to the diameter of the large woody fragments before compaction. This is because the piths of the trees rot out, leaving only the outermost layer. Once compaction takes place, the log is flattened, so that the previous diameter becomes the width (Fig. 2.1). The thickness of the rinds would then represent the thickness after compaction. The amount of compaction of individual pieces of large woody debris is then found by comparing the width with the rind thickness (doubled if a complete log is present). When this is combined with the proportion of wood to sediment, the total compaction of the beds can be found. This would give us the original thickness of the log-bearing sediment in the channel body prior to compaction.

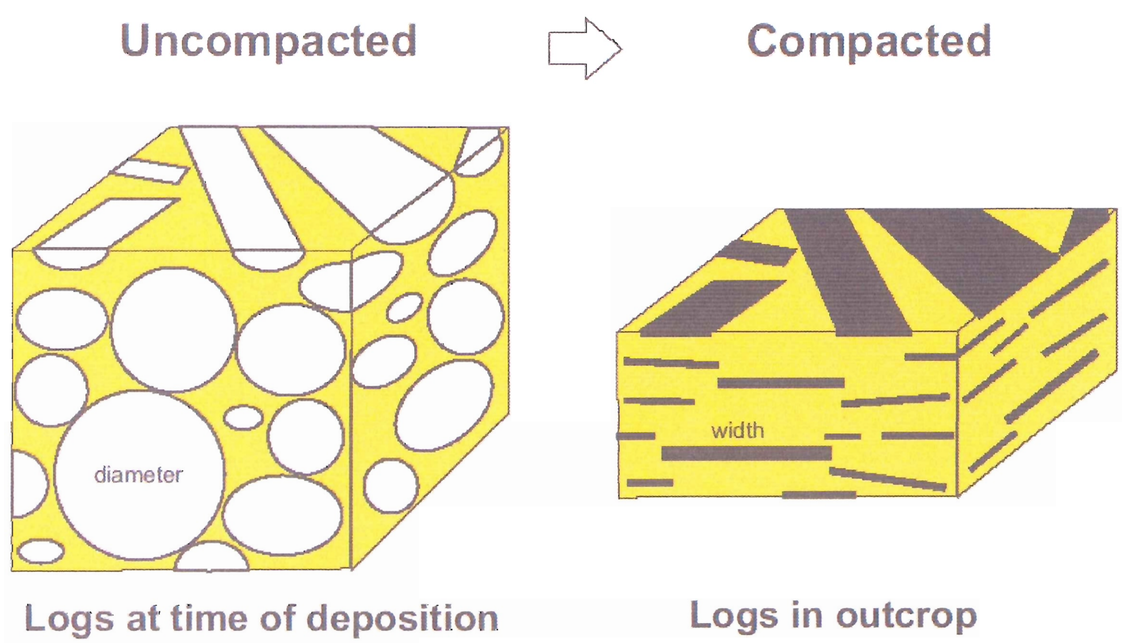

Figure 2.1 Compaction of the logs during burial, illustrating why the widths represent diameters. Modified from Gibling et al. (2010).

2.4 Outcrop Work

The sedimentological features of the outcrops were studied, along with the stratigraphy based on bed-by-bed measurements. These data were then graphically represented in a stratigraphic column using the program SedLog (Zervas et al., 2009). This log helps represent where avulsion took place within the column based on analysis of lithological information and sedimentary structures. The paleocurrents of the different beds were analyzed, in order to assess at what level any radical change in paleoflow took place, possibly related to avulsion. However, only one bed yielded suitable paleoflow information because of poor exposure of the rest of the beds. Hand samples were also taken from the main beds for further study and thin section analysis, to provide compositional information about the channel bodies. Looking at the wood debris in thin section also provided information on the interaction between the debris and surrounding grains during compaction.

Chapter 3 – Outcrop Analysis

3.1 Field Work Analysis

The study area is divided into two sections. The first, main section (Fig 3.1) is 10.9 m thick, and contains 14 recognized beds. Information obtained from the field was put into SedLog software, and a stratigraphic log was created (Fig 3.2). The beds are mostly made up of packages of fine-to medium-grained sandstone, with silty beds on top. The beds of sandstone contain trough cross beds and planar beds implying cycles of different energies. Plant debris and mudclasts are found in some of the beds. Three main beds were found to contain the large woody debris thought to represent a log jam material.

The second section is much thinner, only 2.01 m in thickness and is made up of nine beds (Fig 3.3). A stratigraphic log of this section was also generated with SedLog (Fig 3.4). The beds are mainly made up of alternate conglomerate and sandstone with the same previously seen apparent composition and grain size. This section contained two beds containing large woody debris thought to possibly represent log jam material. The main thing to note about this bed is that the large woody debris is in the conglomerate, whereas in section one woody debris was associated with sandstone. This coal may be a thin layer of peat, or a single, very large coalified log. Judging from the size and extent of the layer, it is likely a layer of peat.

The sections are separated by an area of about 2 m high and 2 m across, with the top 0.75 m being covered by a slump of sediment. The exposed area is made up of beds of large woody debris followed by a bed of pebble conglomerate. The slump is thought to be due to erosion, and the loose sediment covers the beds in a way that makes it difficult to link up the sections on either side. The orientation of the section suggests that the slump is covering the regular contact between the siltstone of section one and the conglomerate of section two.

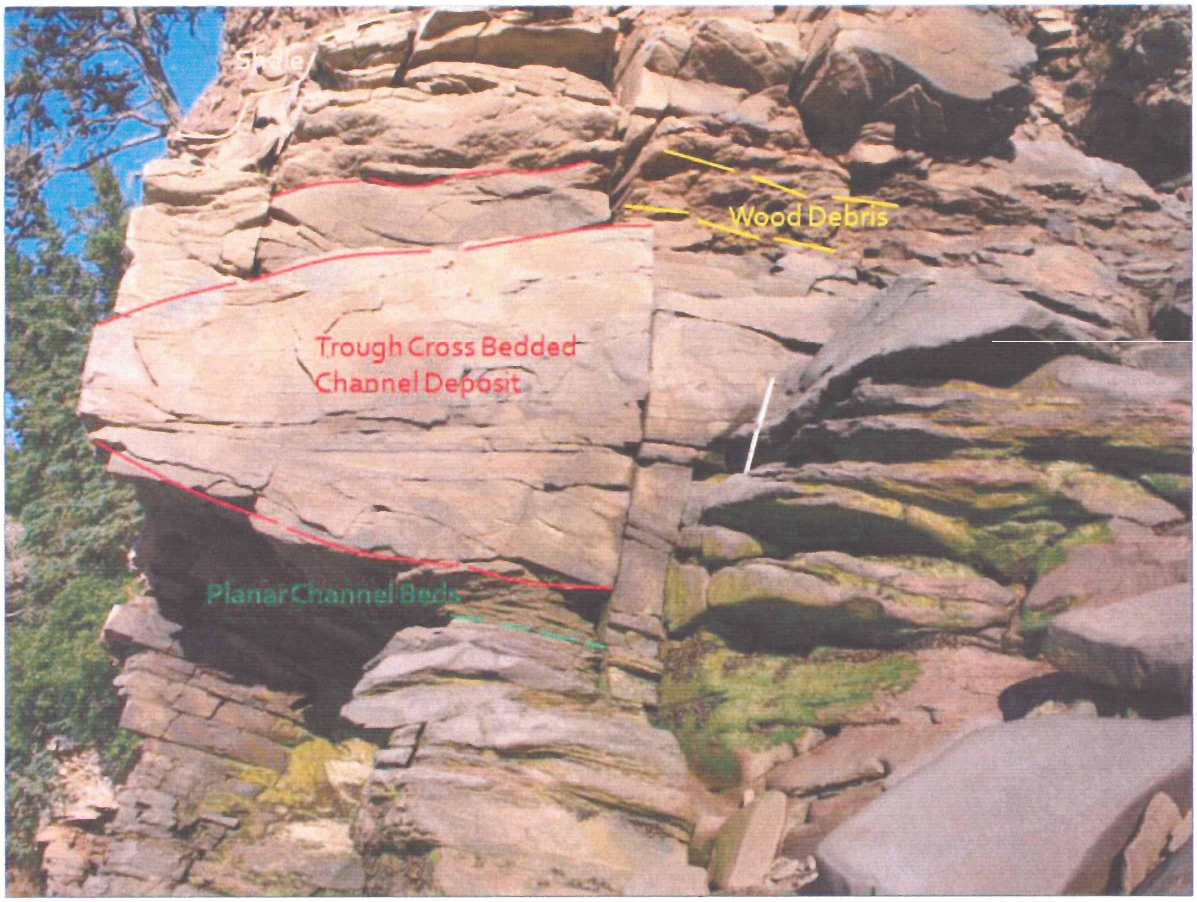

Figure 3.2 Photograph of the first section, meter stick for scale.

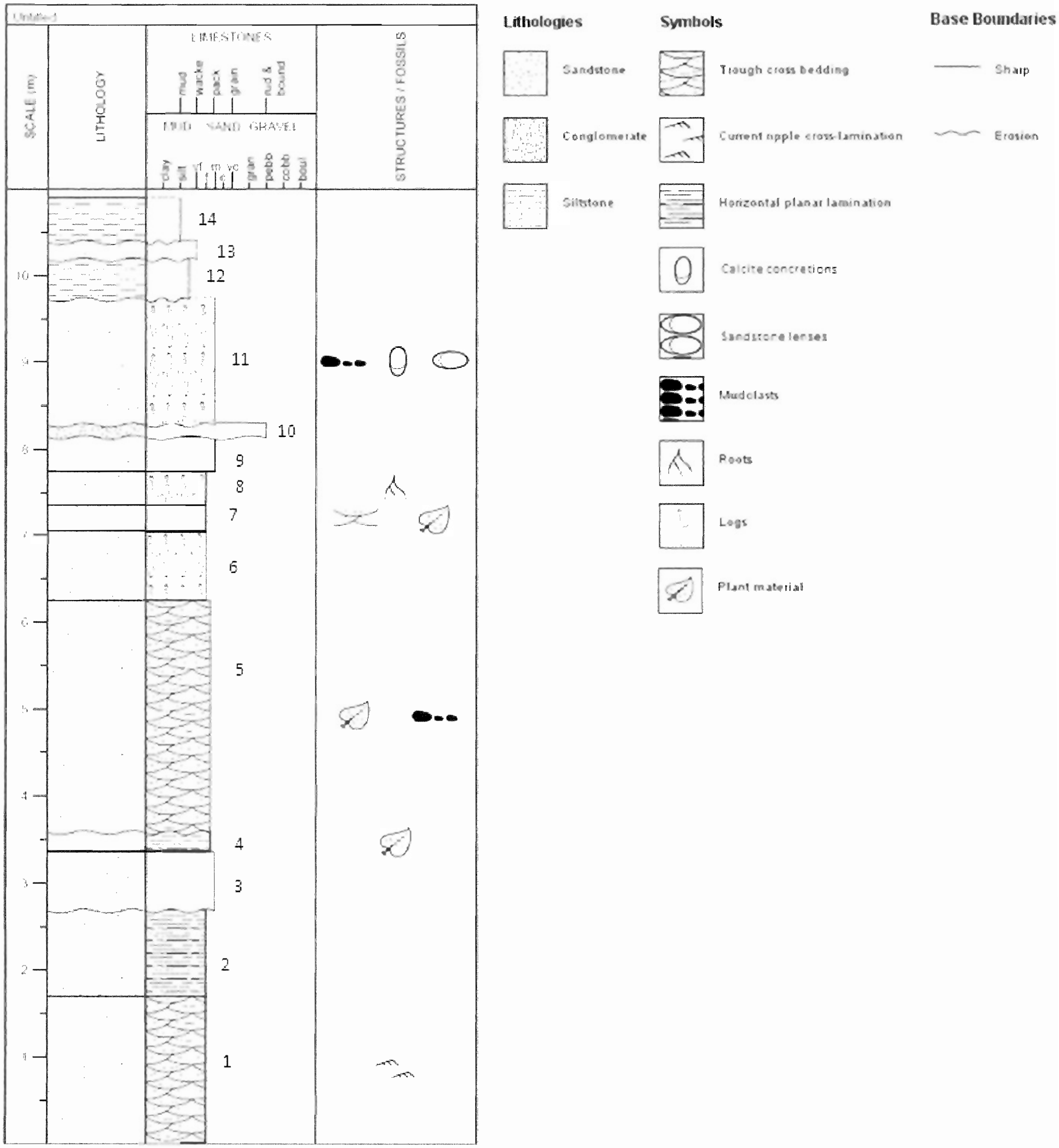

Figure 3.3 Stratigraphic log of first section. The numbers next to the sections represent the bed number.

Figure 4.3 Photograph of second section, meter stick for scale.

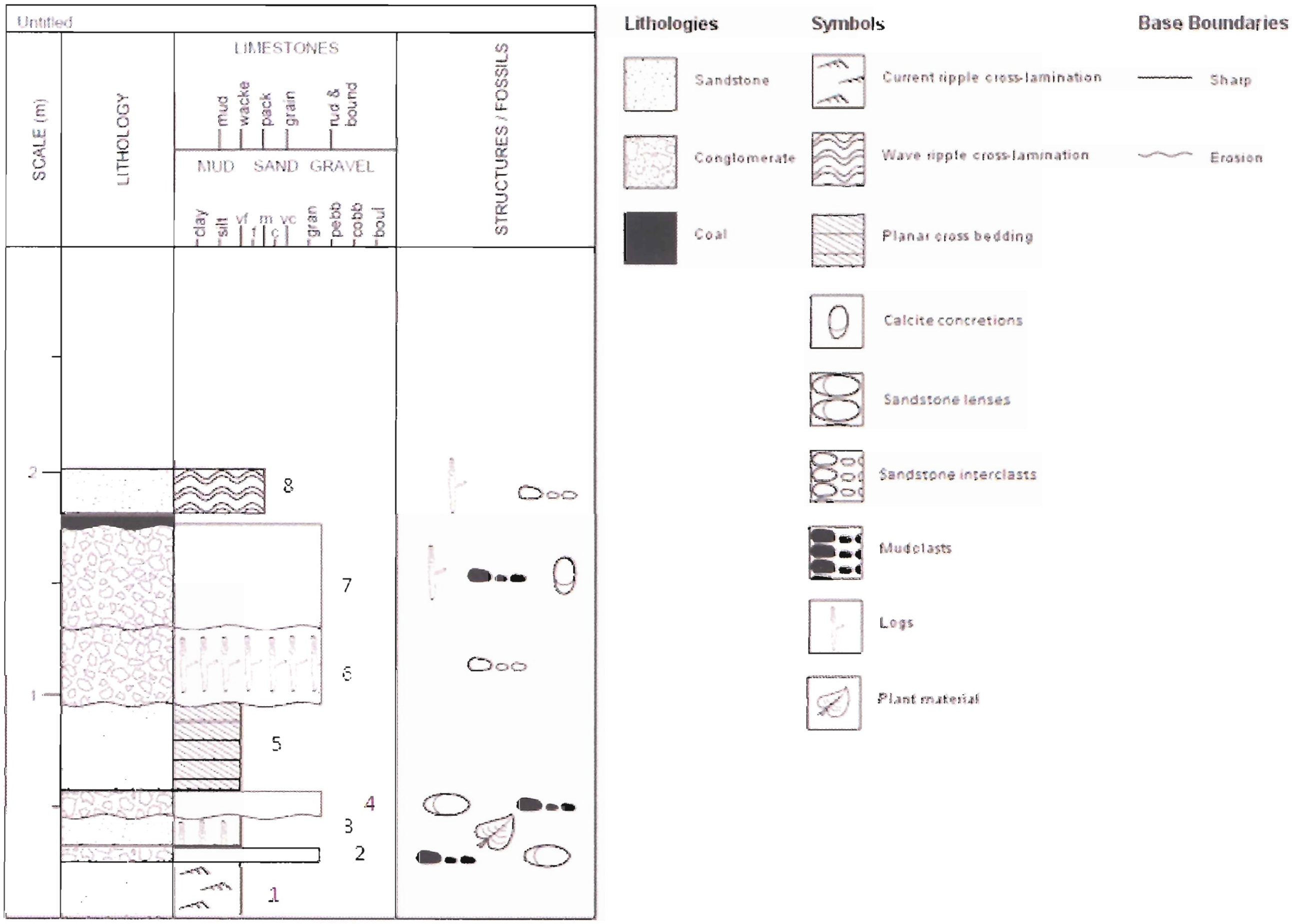

Figure 3.5 Stratigraphic log of second section. The numbers next to the sections represent the bed numbers.

3.2 Stratigraphy and Sedimentology Analysis

As stated before, the sections are mainly made up of sandstone and conglomerate layers, usually capped with siltstone. Section 1, Bed 1 consists of fine-grained sandstone with a thickness of 1.7 m. This bed also contains trough cross-beds, which can reach thicknesses of 35 cm. Bed 2 is also made up of fine-grained sandstone, with a thickness of 1 m. It contains planar stratified beds. Bed 3 is about 65 cm thick, and is made up of medium-grained sand with no discernible features. These first three beds show an upward decrease in energy. This is implied by the shift from large trough cross-beds, to planar beds and then to a featureless bed. Bed 4 is about 25 cm thick, and is made up of fine-grained, planar-stratified sandstone. This bed also contains traces of plant debris. Bed 5 is a 2.65 m thick layer of fining upward sandstone, from medium to fine, containing trough cross-beds up to 60 cm in thickness. This bed also contains plant fragments and small mud clasts. Bed 6 is 80 cm in thickness, and is the first bed to contain large woody debris. No structures are seen, though if there were any, they would likely have been destroyed by the compaction associated with the wood. Bed 7 is about 30 cm thick, and contains some small plant fragments and cross-bedding. Bed 8 is 40 cm thick, and is the next bed to contain large woody debris, larger than those found in Bed 6. It also contains some trough cross-beds, although it is assumed that most were destroyed during compaction. Bed 9 is 40 cm thick, and is made up of medium grained sand, with no apparent structures. Bed 10 is 15 cm of conglomerate, with gravel sized clasts. Bed 11 is 1.45 m in thickness, and contains sand lenses, carbonate clasts and mud clasts. Bed 12 is 45 cm thick, and composed of fissile siltstone. Bed 12 is 20 cm thick, and is made up of very fine sand. Bed 13 is 50 cm thick, and is also made up of siltstone. These last three beds are quite eroded, and are covered by slumps of sediment. There is little difference in grain size in section one, but the successions tend to show a small upward decrease in grain size.

In section 2, Bed 1 consists of 25 cm of very fine sandstone, with ripple cross-lamination, up to 3 cm thick. Bed 2 is a conglomerate layer, about 7 cm in thickness. The clasts are up to 2 cm in thickness, and contain carbonates. Bed 3 is 15 cm thick, very fine sandstone rich in large woody debris. Bed 4 is another conglomerate layer of 10 cm thickness, with clay and carbonate clasts as large as 2 cm. Bed 5 is 40 cm of cross-bedded, very fine sandstone. Bed 6 is a 35 cm thick conglomerate containing woody debris and sandstone lenses, with particles as large as 3 cm. Bed 7 is 45 cm in thickness, with plant debris, mud clasts and carbonate concretions. Finally, Bed 8 is 20 cm thick, and made up of laminated medium sand. Over both sections, the conglomerate layers are thought to represent channel lag, which signifies the bottom of a new channel. The silt and mud is thought to indicate channel abandonment and local avulsion, since they are thought to be deposited as fine sediment in the abandonment of the channel.

3.3 Large Woody Debris Sizes

The beds containing large woody debris in section one are thicker and better exposed than those of section two. As stated before, the main three beds containing large woody debris from section one were beds 6, 8 and 11. Because of the better accessibility of bed 8, it was divided into upper and lower sections. Bed 11 was not as accessible or exposed, and therefore, not as many pieces were measured. The sizes of 50 fragments of woody debris were measured in each of these beds, and these measurements were used to estimate the compaction of the beds by comparing their widths (representing the original diameter)with the average thickness of the rinds in flattened logs (representing the compacted remnant). The compaction that takes place due to burial makes it difficult to tell exactly which rinds were double and which were single. The only pieces of debris for which single rinds could be easily identified were the sediment-filled pieces, and those were few in number. Because of this, the average thickness of the rinds measured was calculated and applied to each bed as the preferred thickness after compaction. The average rind thickness (2.9 mm) comes from measurements done throughout all the beds containing large woody debris. Tables 1 through 3 show the widths of the counted pieces in the beds.

No.	Width (cm)	Preferred Thickness (mm)	No.	Width (cm)	Preferred Thickness (mm)
1	1.1	2.9	**26**	0.6	2.9
2	0.7	2.9	**27**	0.9	2.9
3	0.5	2.9	**28**	0.8	2.9
4	0.4	2.9	**29**	0.4	2.9
5	1.8	2.9	**30**	0.3	2.9
6	1.1	2.9	**31**	0.7	2.9
7	0.3	2.9	**32**	2.4	2.9
8	0.7	2.9	**33**	0.3	2.9
9	3.7	2.9	**34**	0.7	2.9
10	0.6	2.9	**35**	0.3	2.9
11	1.4	2.9	**36**	0.4	2.9
12	0.8	2.9	**37**	0.2	2.9
13	0.9	2.9	**38**	0.7	2.9
14	0.5	2.9	**39**	1.1	2.9
15	0.4	2.9	**40**	0.3	2.9
16	0.6	2.9	**41**	0.6	2.9
17	0.5	2.9	**42**	0.4	2.9
18	0.7	2.9	**43**	0.5	2.9
19	0.9	2.9	**44**	3.3	2.9
20	1	2.9	**45**	0.6	2.9
21	1.9	2.9	**46**	0.7	2.9
22	0.6	2.9	**47**	1.3	2.9
23	0.3	2.9	**48**	0.3	2.9
24	0.9	2.9	**49**	0.2	2.9
25	0.7	2.9	**50**	0.7	2.9
Total (of 50 measurements)	41.7	145			
Average (of 50 measurements)	0.83				
Compaction ratio (organics)	2.88				

Table 3.1 Bed 6 data for width of woody fragments

No.	Width (cm)	Preferred Thickness (mm)	No.	Width (cm)	Preferred Thickness (mm)
1	2.8	2.9	**26**	0.8	2.9
2	1.3	2.9	**27**	1.7	2.9
3	2.9	2.9	**28**	1	2.9
4	4.4	2.9	**29**	2.1	2.9
5	1.5	2.9	**30**	1.4	2.9
6	2.4	2.9	**31**	0.7	2.9
7	0.9	2.9	**32**	0.6	2.9
8	2	2.9	**33**	1.1	2.9
9	0.9	2.9	**34**	1.1	2.9
10	1.2	2.9	**35**	0.9	2.9
11	1	2.9	**36**	1.2	2.9
12	1.7	2.9	**37**	5.3	2.9
13	1.9	2.9	**38**	1.2	2.9
14	3.1	2.9	**39**	0.9	2.9
15	1	2.9	**40**	1	2.9
16	0.6	2.9	**41**	0.9	2.9
17	4.2	2.9	**42**	2	2.9
18	11.2	2.9	**43**	2.3	2.9
19	7.1	2.9	**44**	6	2.9
20	3.3	2.9	**45**	2.4	2.9
21	8.2	2.9	**46**	3.1	2.9
22	1.1	2.9	**47**	5.9	2.9
23	2.3	2.9	**48**	3.3	2.9
24	0.7	2.9	**49**	2.4	2.9
25	1.1	2.9	**50**	0.8	2.9
Total (of 50 measurements)	118.9	145			
Average (of 50 measurements)	2.38				
Compaction ratio (organics)	8.20				

Table 3.2 Lower portion of Bed 8 data for width of woody fragments

No.	Width (cm)	Preferred Thickness (mm)	No.	Width (cm)	Preferred Thickness (mm)
1	16.2	2.9	**26**	1.2	2.9
2	12.1	2.9	**27**	1.2	2.9
3	3.6	2.9	**28**	2.4	2.9
4	5.2	2.9	**29**	2.8	2.9
5	0.6	2.9	**30**	2.7	2.9
6	1.3	2.9	**31**	3.3	2.9
7	1.7	2.9	**32**	2.9	2.9
8	3.2	2.9	**33**	4.5	2.9
9	4.9	2.9	**34**	1.4	2.9
10	1.5	2.9	**35**	0.7	2.9
11	4.2	2.9	**36**	1.9	2.9
12	3.1	2.9	**37**	0.9	2.9
13	0.6	2.9	**38**	1.3	2.9
14	5.6	2.9	**39**	0.4	2.9
15	3.3	2.9	**40**	1	2.9
16	0.7	2.9	**41**	2	2.9
17	0.6	2.9	**42**	1.1	2.9
18	1.4	2.9	**43**	0.5	2.9
19	1.1	2.9	**44**	1.4	2.9
20	0.9	2.9	**45**	8.3	2.9
21	0.6	2.9	**46**	1.2	2.9
22	6.7	2.9	**47**	0.2	2.9
23	4	2.9	**48**	1.1	2.9
24	1.2	2.9	**49**	2	2.9
25	15.4	2.9	**50**	1.4	2.9
Total (of 50 measurements)	147.5	145			
Average (of 50 measurements)	2.95				
Compaction ratio (organics)	10.17				

Table 3.3 Upper portion of Bed 8 data for width of woody fragments

Table 3.1 shows the large woody debris measurements for Bed 6. As can be seen, widths were smaller than in any of the other beds, with an average size of 0.83 cm. About 90% of the wood fragments in this bed were less than 0.3 cm wide and could not be measured reliably. Only 11 out of the 50 recordings are larger than 1 cm. Among those 11, only three are larger than 2 cm. Total combined rind thickness is 14.5 cm, and the total combined width is 41.7 cm. Since the total of widths represents the combined diameters of the large woody debris prior to compaction, and the combined rind thicknesses represent the combined thickness after compaction, the compaction ratio for organic material is estimated at 2.88.

Table 3.2 shows the large woody debris of the lower part of Bed 8. About 90% of the fragments here were less than 0.6 cm wide. The measured widths in this section of the bed are larger than those found in Bed 6, with an average size of 2.38 cm. While most pieces are small, three pieces are large, between 7 and 11 cm. Total combined rind thickness is 14.5 cm, and the total combined width is 118.9 cm. This gives an organic compaction ratio of about 8.2.

Table 3.3 shows the large woody debris of the upper part of Bed 8. About 60% of the fragments in this bed were less than 0.5 cm wide. The largest measured widths are found in this bed, with an average width of 2.95 cm. While still mostly small pieces, a few large pieces measured up to 16.2 cm wide. Total combined widths are 147.5 cm, giving an organic compaction ratio of about 10.17.

A few measurements were taken of Bed 11. Large woody debris pieces were as small as 0.3 cm, with one piece wider than 30 cm. This bed also contained coal lenses, as much as about 3 cm thick.

There are two main things to note from these results. The first is the organic compaction ratios. When this is combined with the sand compaction ratio and the proportions of wood to sediment within the beds, we can estimate how much the whole beds compacted, and find out how thick they were prior to this compaction. The other thing to note is the size of the wood debris. While most of the measured pieces were quite small, a few pieces were very large, with widths (diameters) greater than 7 cm, and in one case as much as 30 cm. These large pieces are thought to behave like anchors that hold the smaller pieces in place. Thus, if there are a few large pieces, small wood debris could still block up the rivers.

3.4 Thin Sections:

Thin sections were made from samples taken from specific beds within the outcrop. These were not beds containing large woody debris, because those would have been difficult to make thin sections out of. Instead, some of the other sandstone beds were chosen, since the sand component is thought to have the same composition as the beds containing the large woody debris. The beds in question are Beds 4, 5 and 7, and they have very similar compositions. The first thing noticed about the thin sections is that they contain about 5% opaques (Fig 3.5). These opaques are considered wood fragments, and are mostly very small, and could not be seen with the naked eye. Only one bed has a wood fragment large enough to be seen by the naked eye, the thin section from bed 5. The piece is about 2 cm long, and about 0.5 mm in width. In this thin section sample, the wood fragment is pushed into the intergranular spaces between the quartz grains (Fig 3.6). This is thought to be due to the compaction that occurred after burial. While mostly (greater than 80%) quartz, the thin sections also contained plagioclase, microcline, chlorite, biotite, muscovite and trace amounts of zircon. They also contain sand-sized clay aggregates (Fig 3.7). The sections contain about 10% clay, and while this may affect later compaction estimates, the change would be negligible, since it is in such small amounts and is located within the interstices between framework grains. One main thing worth mentioning is that the Bed 3 section contained a considerable proportion of calcite. The calcite acted as cement between some quartz grains, and would have stopped compaction from fully taking place during early burial, based on the floating texture (Fig. 3.8). The presence of twisted grains of muscovite also indicates compression (Fig 3.9).

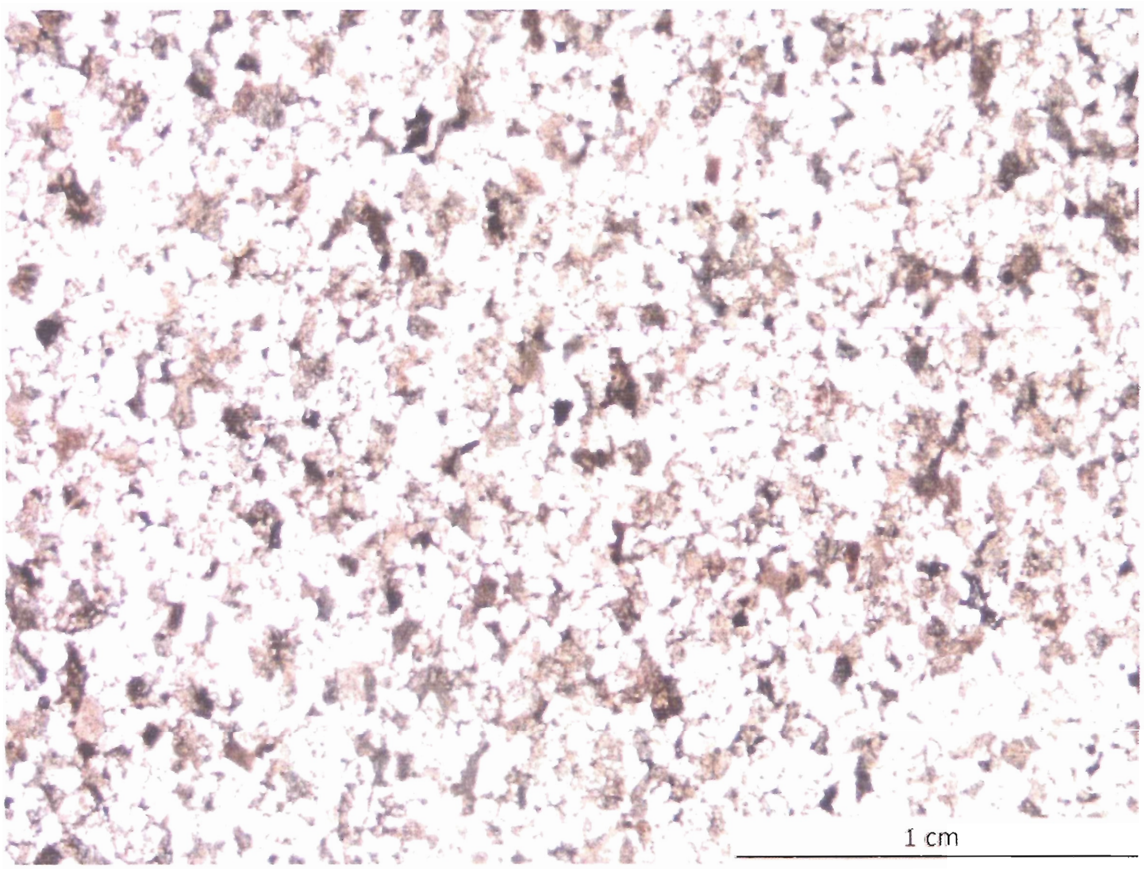

Figure 3.6 Thin section of bed 4. The white grains are quartz, and make up most of the sample. The dark grains are assumed to be small pieces of wood debris.

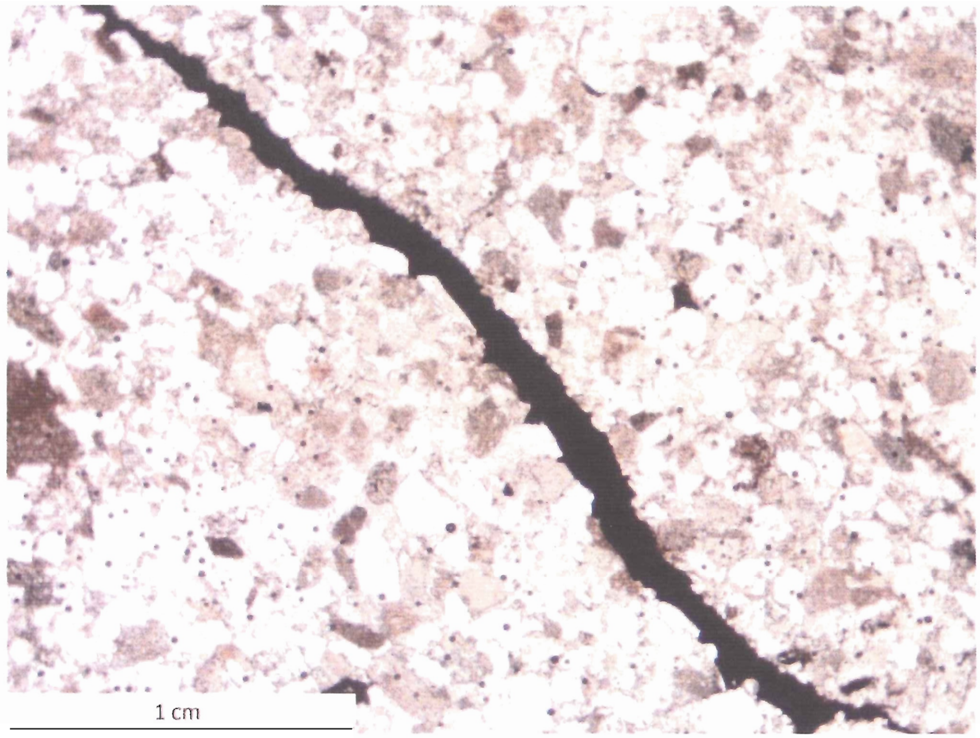

Figure 3.8 The piece of wood. Note the compaction and the melding of the wood into the quartz grains.

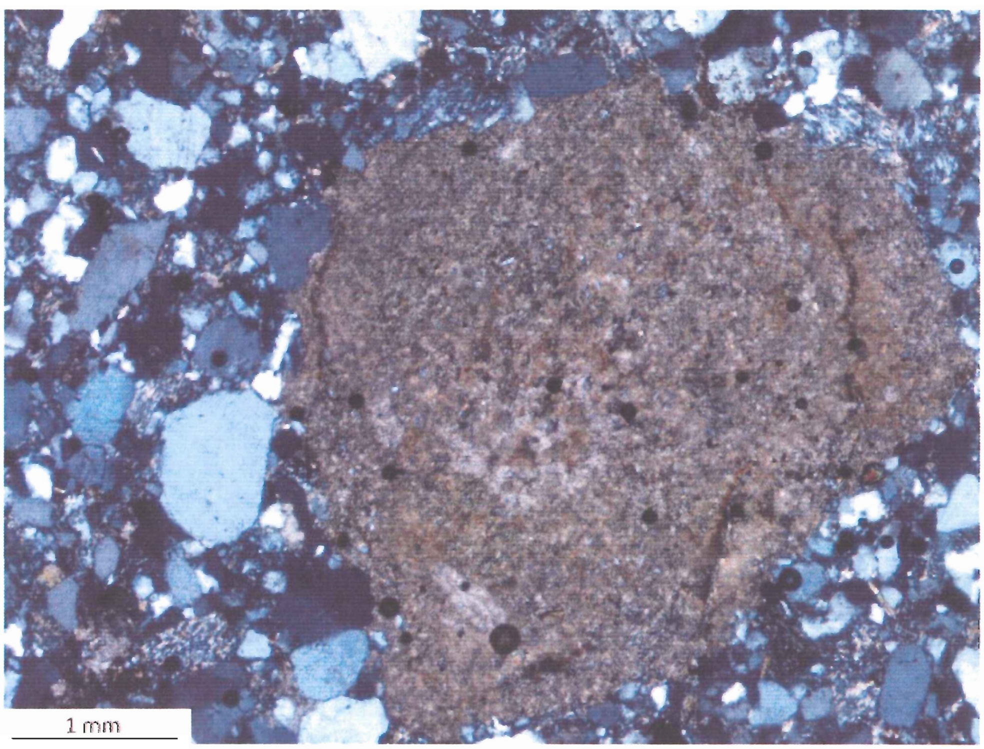

Figure 3.7 A sand sized clay fragment in cross polars

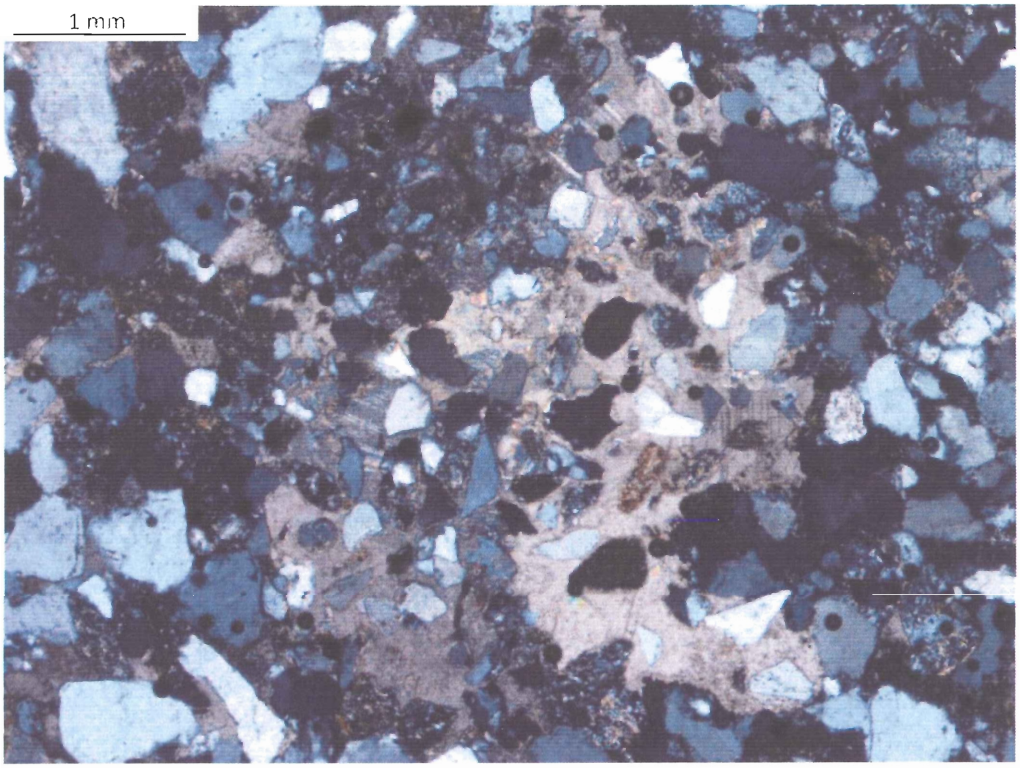

Figure 3.10 Calcite cement holding quartz grains. Note how the quartz grains are not apparently touching within the calcite, implying point contacts between framework grains

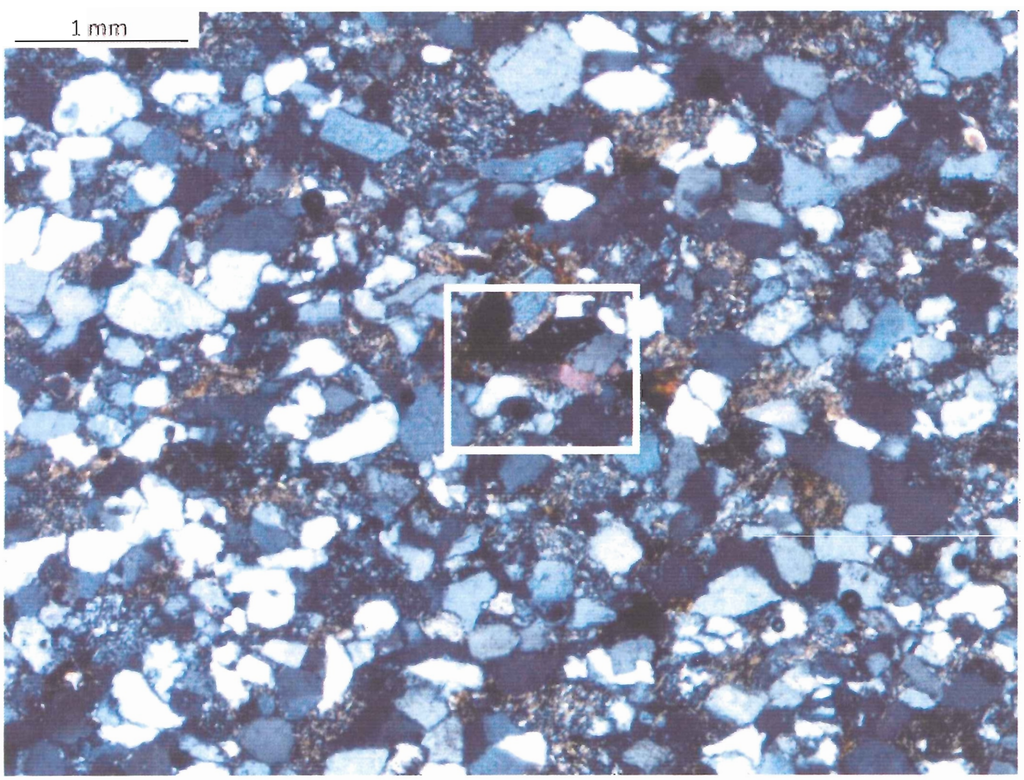

Figure 3.9 The twisted muscovite shown in the box.

Chapter 4 – Wood to Sediment Proportion

The previously described digital photograph representation method of determining proportions of wood to sediment was used on photographs of Bed 6 (Figs. 4.1-4.3), as well as the upper (Figs. 4.4-4.6) and lower parts of Bed 8 (Figs. 4.7-4.9). These beds were the main beds analyzed for large woody debris due to their exposure and accessibility. The results of this test are shown in Table 4.1.

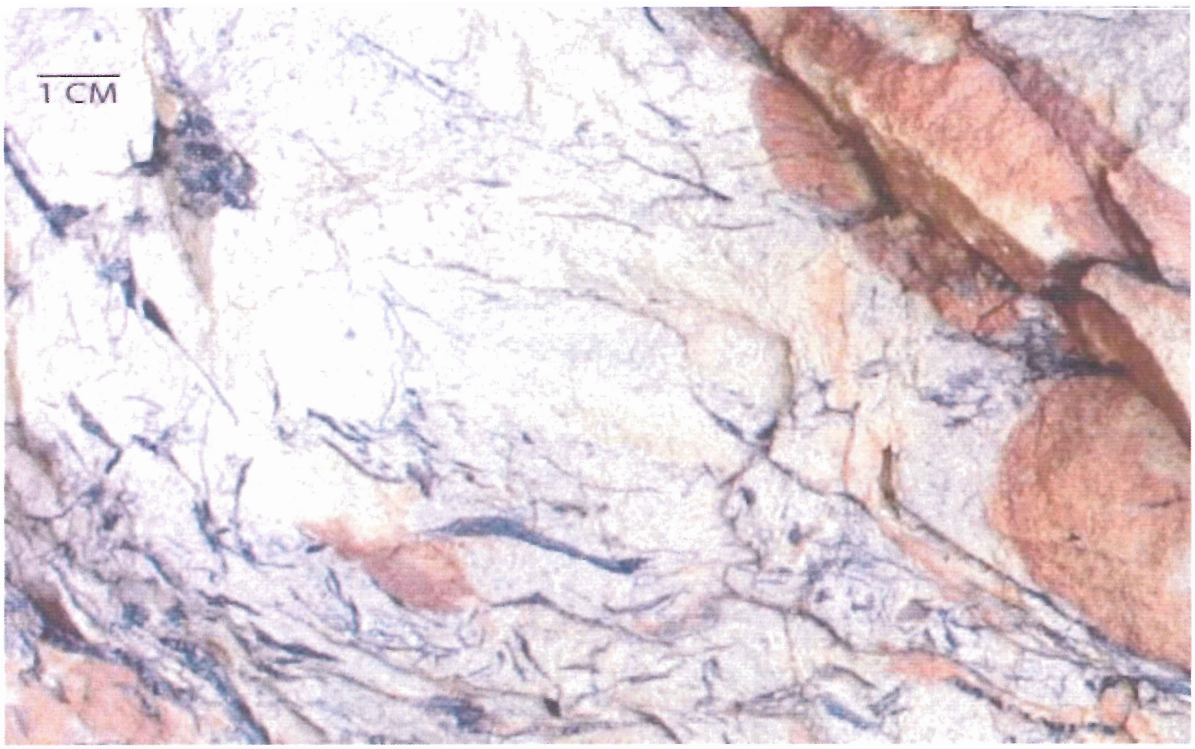

Figure 4.11 Photograph of the representative section of Bed 6

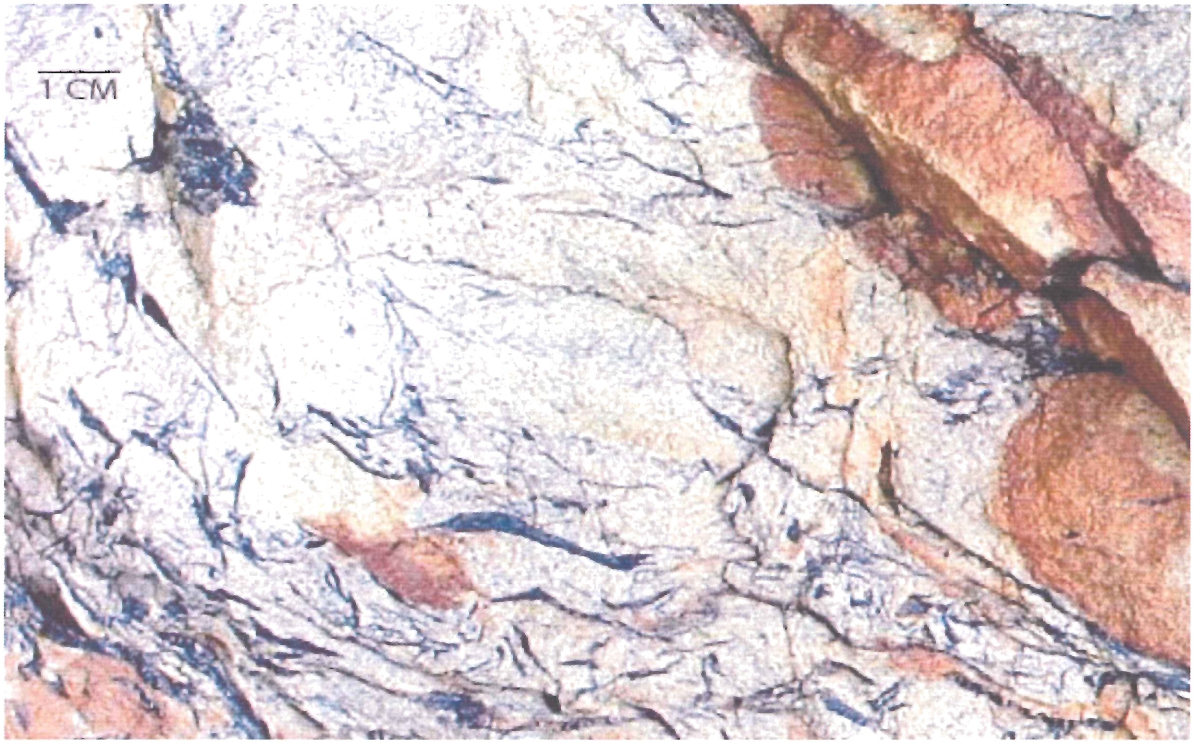

Figure 4.2 Photograph of the representative section of Bed 6 after enhancement. Pieces of wood debris are clearer and stand out more. Note that this bed contains the least amount of debris and also contains overall smaller pieces.

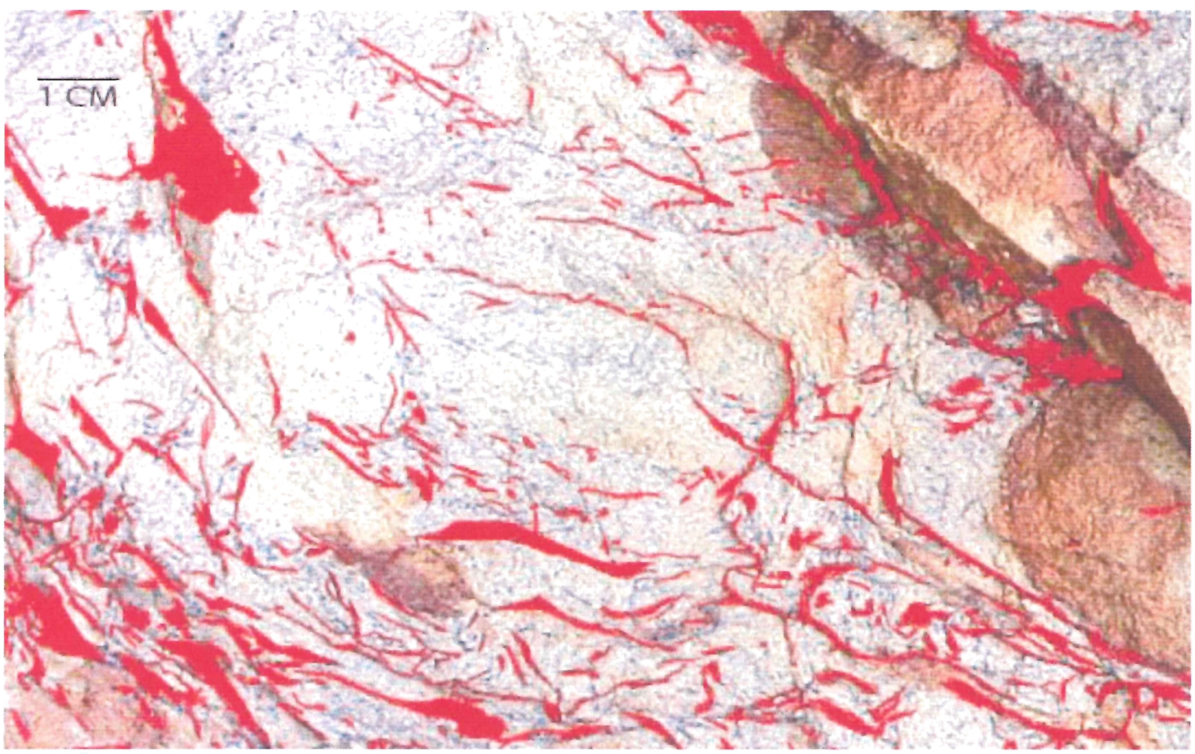

Figure 4.3 Photograph of the representative section of Bed 6 after enhancement, with the woody debris colored in.

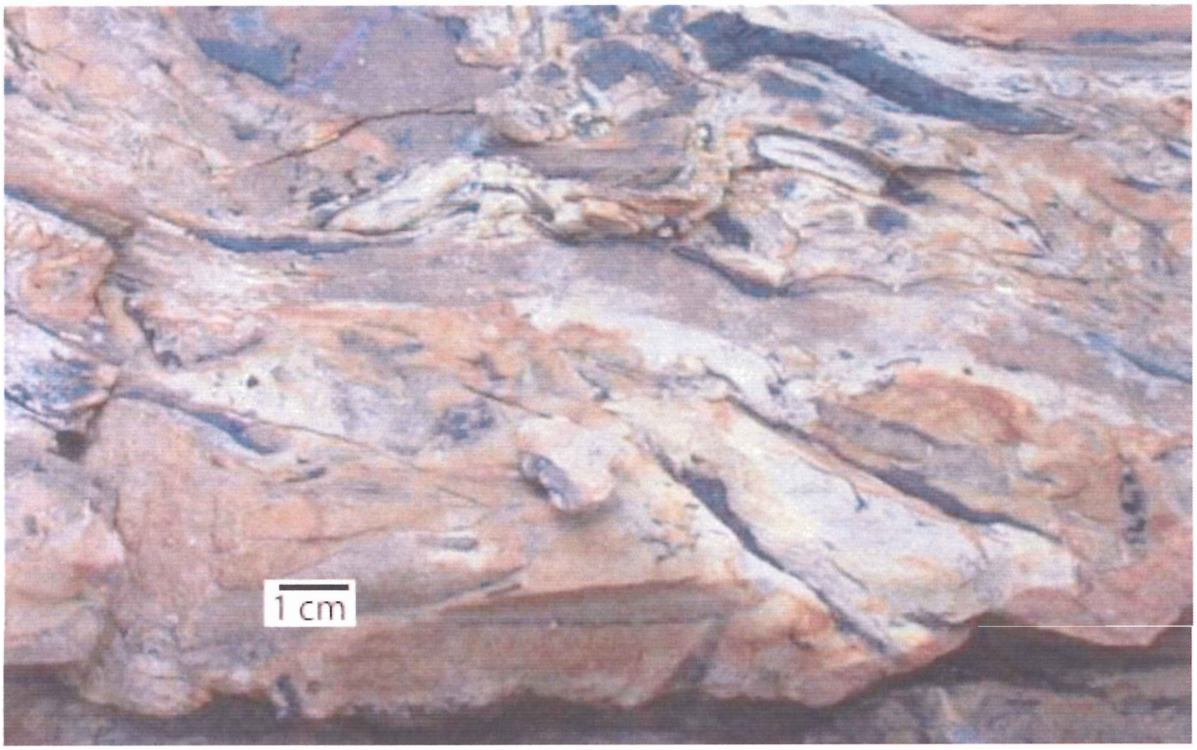

Figure 4.4 Photograph of the representative section of the lower part of Bed 8.

Figure 4.5 Photograph of the representative section of the lower part of Bed 8 after enhancement. Wood debris pieces are larger here than in Bed 6.

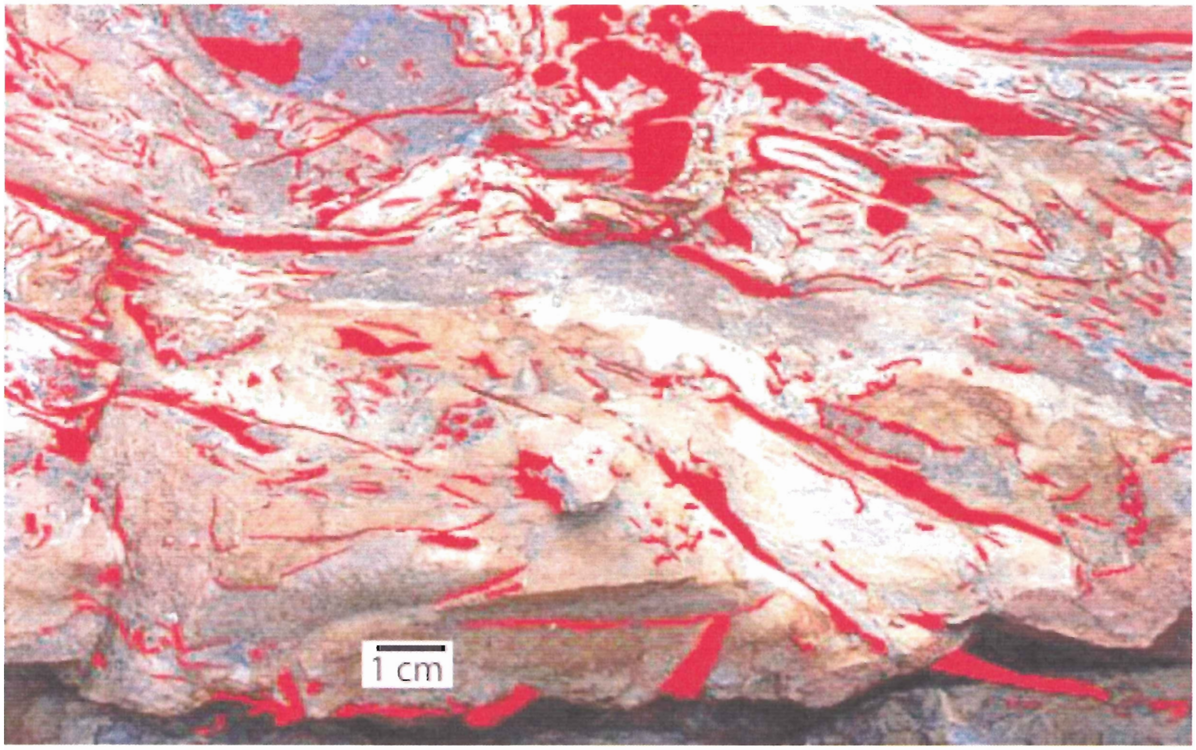

Figure 4.6 Photograph of the representative section of the lower part of Bed 8 after enhancement, with the woody debris colored in.

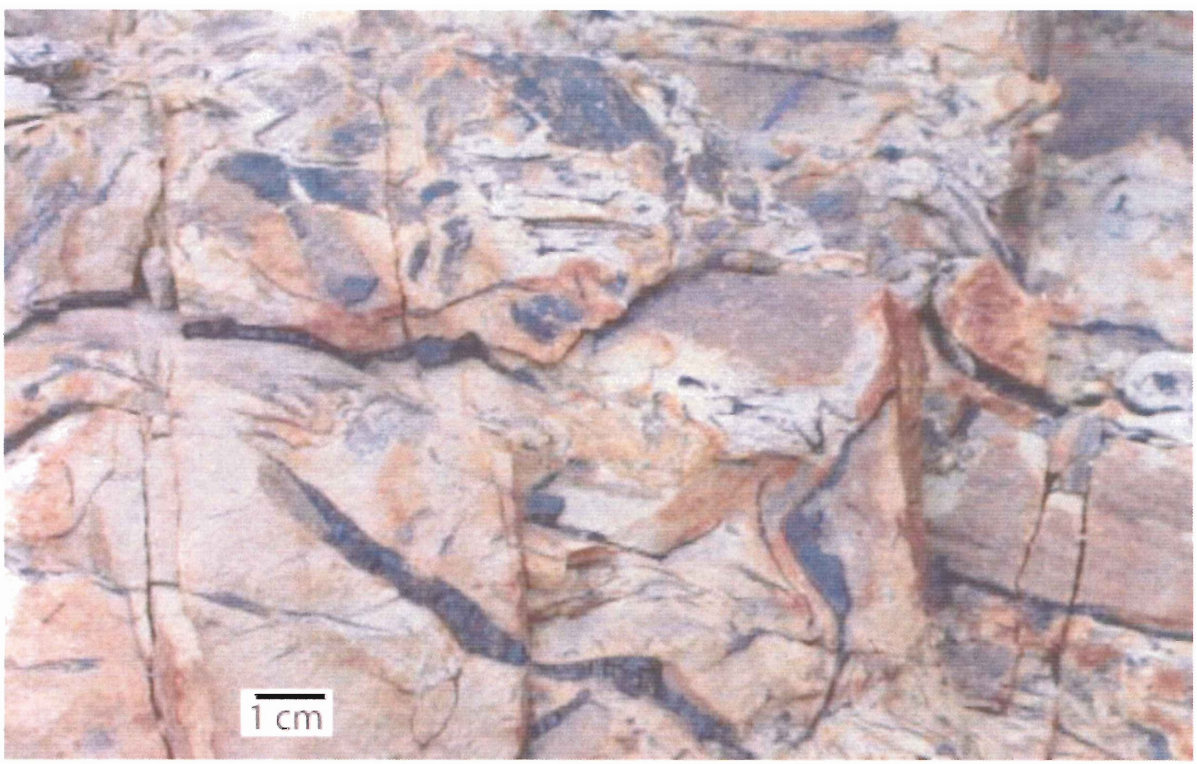

Figure 4.7 Photograph of the representative section of the upper part of Bed 8.

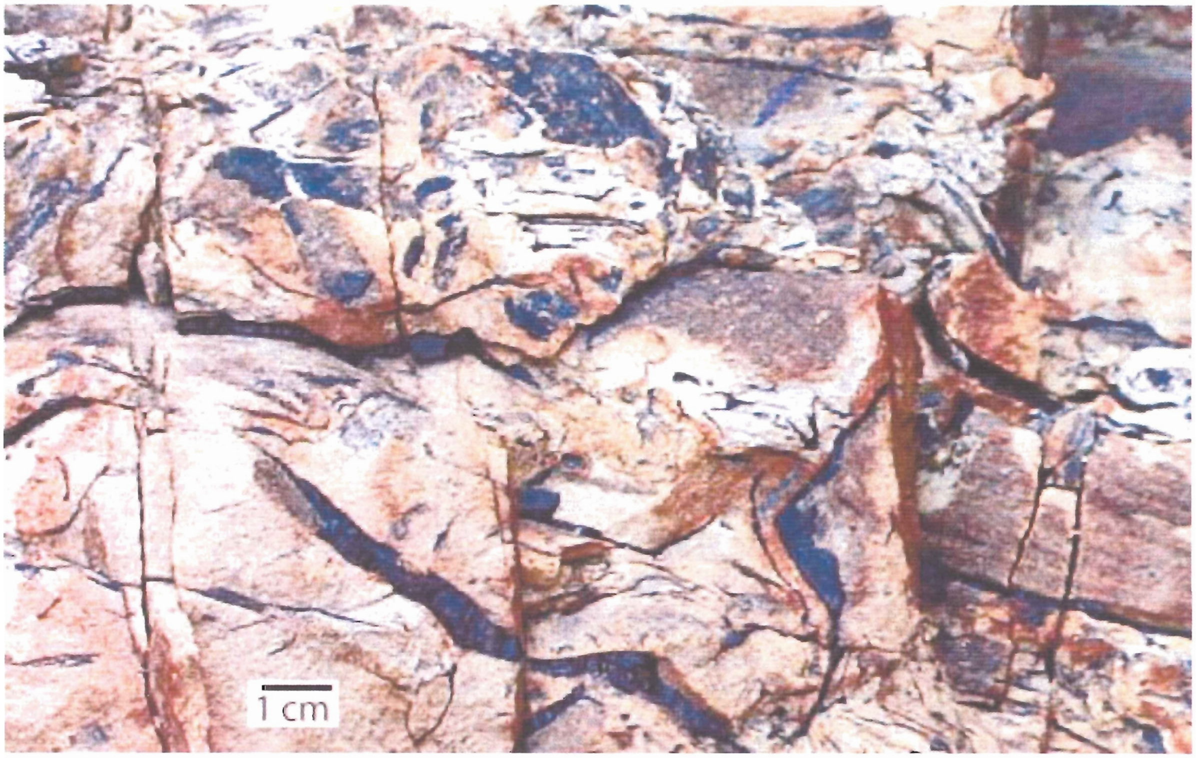

Figure 4.8 Photograph of the representative section of the upper part of Bed 8 after enhancement. Note how the woody debris here is larger than in the other sections.

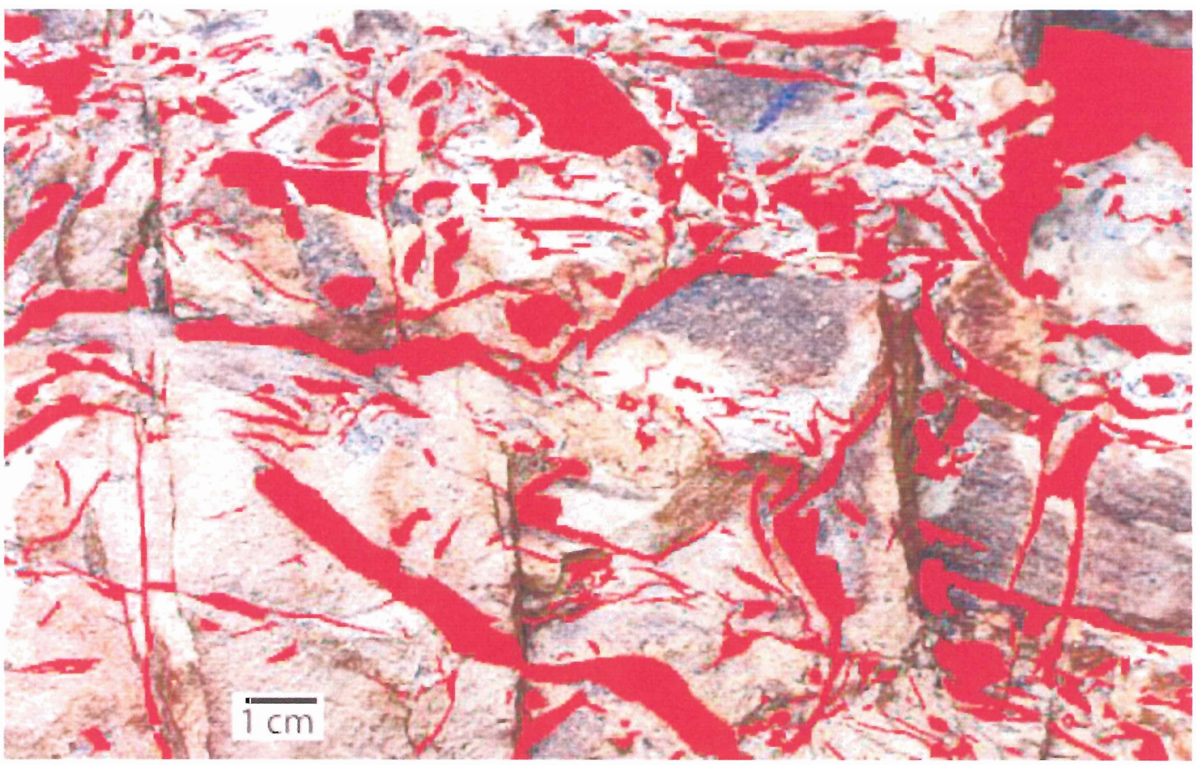

Figure 4.9 Photograph of the representative section of the upper part of Bed 8 after enhancement, with the woody debris colored in.

	Bed 6	Lower Bed 8	Upper Bed 8
Colored in pixels of debris	32753	42244	49183
Total pixels	196845	195091	196768
Proportion of wood to sediment	0.17	0.22	0.25
Average clast size	0.83	2.38	2.95
Bed type	Fine sandstone, irregular stratification	Fine sandstone, trough crossbedded	Fine sandstone, trough crossbedded, root clasts

Table 4.1 Proportions of wood to sediment in the beds, along with the average clast size and bed features in each.

The upper section of Bed 8, in addition to having the largest average clast size, is shown to have the highest proportion of wood to sediment with a value of almost 0.25. This section contains trough cross-beds and root fragments, and is thought to represent higher energy than the other beds because it contains the largest wood clasts. The lower section of Bed 8 has a proportion of wood to sediment that is a little less than the upper section, with a value of 0.216, along with a smaller average clast size. The bed features here are similar to the upper section, but the bed contains smaller cross-beds, and no root clasts. This implies a lower energy environment. Bed 6 has both the smallest average clast size and the lowest proportion of wood to sediment, with a value of 0.166. No cross-beds are seen in this section, though there was some irregular stratification of layers. This implies a lower energy environment than in Bed 8, or that the features could have been destroyed during the compaction of the woody debris.

The proportions of wood to sediment obtained for each section are combined with their respective estimated values of organic compaction and the value of compaction of sand to give the overall bed compaction. Previous studies have shown that sand has a compaction value of 1.1 (Ethridge & Schumm, 1978). The resulting values are shown in Table 4.2.

	Bed 6	Lower Bed 8	Upper Bed 8
Compaction ratio (organics)	2.88	8.20	10.17
Compaction ratio (sand)	1.10	1.10	1.10
Propotion of organics	0.17	0.22	0.25
Propotion of sand	0.83	0.78	0.75
Organics compaction	0.48	1.78	2.54
Sand compaction	0.92	0.86	0.83
Total compaction	1.40	2.64	3.37

Table 4.2 Table showing the compaction estimates of the sections. The organics compaction ratios are multiplied by the proportion of the organics in the respective sections, and the sand compaction ratio is multiplied by the proportions of sand. The results are added together to give the total compaction of each section.

The results show that most compaction took place in the upper section of Bed 8, followed by the lower section of Bed 8, with the least compaction being in Bed 6. The beds that have the higher proportion of organics show the largest amount of total compaction. Aside from providing an estimate for the original thickness of the beds prior to compaction, these values are needed to estimate the blockage ratio for the log jam accumulation. In general terms, the results show that the beds containing the large woody debris were as much as 3.37 times thicker, prior to compaction, than they are now.

Chapter 5 - Discussion

5.1 Paleoflow Direction

Changes in paleoflow direction between beds are needed to determine whether or not regional avulsion took place (i.e., the relocation of the channel to a distant part of the floodplain). This is because different paleoflow directions in stacked channel bodies imply that the channels would have been oriented in different directions, and each bedset would therefore represent a different channel altogether. This would mean that avulsion took place so that the channel would be able to switch directions, and then later come back to reoccupy the same location with a different orientation. Another use of paleoflow is to estimate blockage by using it along with the lateral extent of the cliff-face on either side of the outcrop to infer the size of the channel.

The accessibility and exposure of the channel bedforms made it difficult to measure paleoflow direction. As such, only one measurement could be taken, and that was from cross-beds in Bed 5, with a reading of 094°. Since we could not obtain any more readings, paleoflow analysis from previous studies in the Boss Point Formation by Browne and Plint (1994) are used. The value measured over the course of our study is in accord with the overall southeast trend measured by Browne and Plint (Fig 5.1) throughout the Boss Point Formation. No paleoflow measurement was obtained from channel deposits above our study interval, and the orientation of subsequent channels could not be assessed.

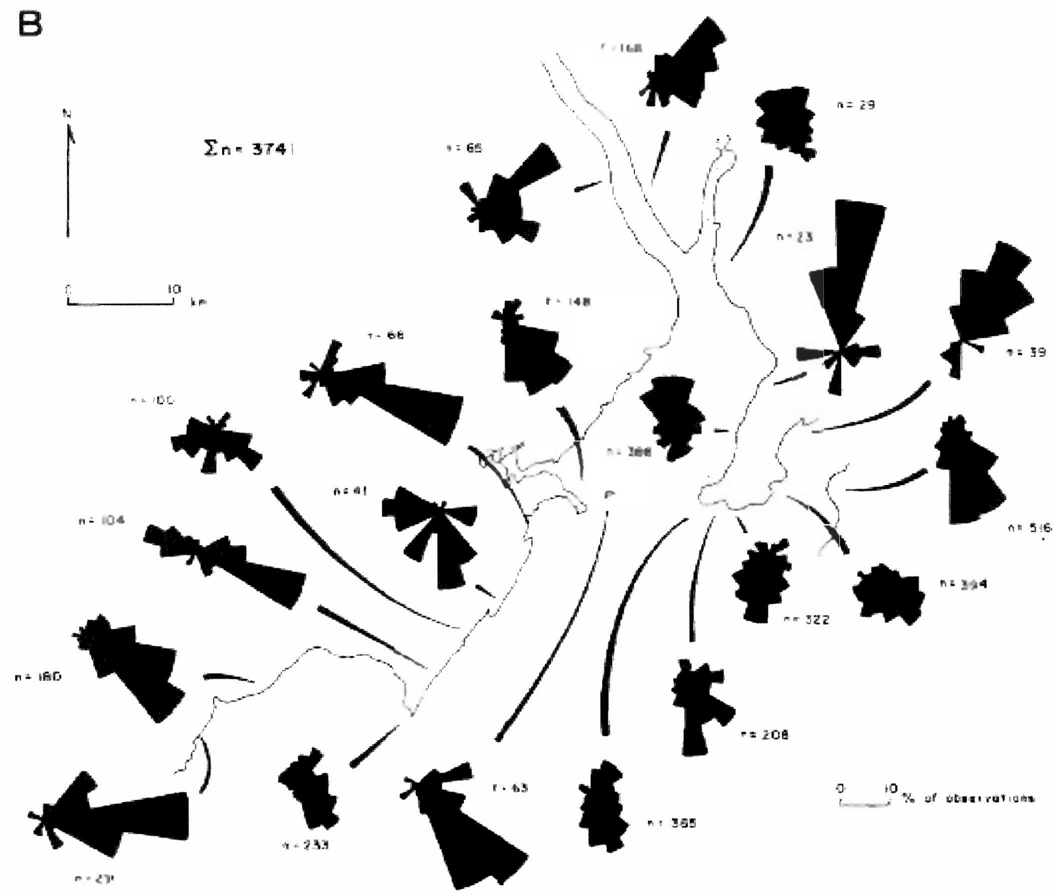

Figure 5.12 Figure showing rose diagrams of measured paleoflow orientations all around the Boss Point Formation. As can be seen, the average direction of lineation is in the general southeastern direction. Rose diagram on right-hand side with 516 measurements represents the Boss Point Formation north of Joggins. Modified from Browne & Plint (1994).

5.2 Channel Dimensions and Blockage

A log jam is considered to block part of a channel, and in order to be capable of blocking the river, it needs to be attached to the base of the river. As such, the base of the bedsets containing the large woody debris is considered to represent the base of the channel at that time. Mudstone at the top of Section 1 is considered to represent the upper part of the channel, since it represents the fine sediment deposited due to flooding after abandonment.

Since the average measured paleoflow by Browne and Plint (1994), along with our measured value, is in a southeastern direction, paleoflow during deposition of Section 1 was effectively going into the cliff (Fig 5.2). Because of this, it can be inferred that the channel bodies extend laterally on either side of the outcrop, along the cliff-face. Exactly how far the studied channel body extends is not known: the outcrop is discontinuous adjacent to the study site, and channel bodies could not be correlated with precision. From the thickness of the beds, however, it can be assumed that the channel had originally extended at least several meters in both directions. In support of this, discontinuous small outcrops of shale are present along ~20 m of the bank adjoining the outcrop, correlating with the shale at the top of Section 1. A range of values are used as the widths, and they are combined with the decompacted thickness of the large woody debris-bearing beds to estimate the cross-sectional area of the river channel at the start of log deposition.

Figure 5.13 Map view of the green arrow showing the location of the outcrop, with the black arrow pointing in the direction of average paleoflow lineation and the blue arrow indicating north.

The problem with this assumption is that our section consists of interbedded large woody debris and sandstone beds. Because of the size of the beds and their properties, it is safe to assume that they collectively represent a single large channel, with a compacted thickness of about 3.7 m, overlain by 0.95 m of avulsion material. The interbeded sandstone must be taken into consideration when applying decompaction. The incorporation of the sandstone units, however, is not expected to have such a significant impact on results because the sandstone beds are thin and their decompaction ratio is only 1.1. Decompaction will not be applied to the avulsion material on top because decompaction of siltstone is variable, depending on water content at the time of deposition; alluvial muds in seasonal-flow settings are commonly tough and cohesive at surface. Because of this, the siltstone beds were not included in the calculation of decompaction, but they were taken into account when estimating blockage. The beds that make up the avulsion material are beds 12 and 14, made up of silt. It should also be noted that Bed 10, made up of conglomerate, is given a compaction estimate of sandstone (1.1). Although it is thought that the compaction of conglomerate is less than the estimation of sandstone, the underestimation should not affect the results much due to the thinness of the bed.

There is also the problem that there is little data for Bed 11, which contains large woody debris. Not much data was obtained about this bed, due its poor exposure and accessibility. All that is known is that it contains a significant amount of woody debris, a little less than the upper section of Bed 8. The woody debris in Bed 11 is somewhat larger, though, and there were numerous pieces larger than 20 cm. As such, the decompaction value of this bed is taken to be similar to that of upper Bed 8. The decompaction value of Bed 8 will also be taken as the average of the upper and lower sections.

The results of the calculation are found in Table 5.1. The cross-sectional area of each channel was found using 20 m, 50 m, 100 m and 200 m as widths. The top siltstone layer extended on top of the cliffs for some distance, so the channel is inferred to have been at least 20 m in width. The widths of the log jams are more difficult to estimate, but the log-bearing units can also be seen extending a few meters on either side. Because of this, a range of width values (5, 10, 15 and 20 m) was also used to estimate the cross-sectional area of the log jams. Using this information, we can estimate how much blockage there would have been in the channel.

Bed Number	Compacted Thickness (m)	Decompaction estimate	Bed Type	Decompacted Thickness (m)
6	0.8	1.4	LWD	1.12
7	0.3	1.1	Sandstone	0.33
8	0.4	3.16	LWD	1.26
9	0.4	1.1	Sandstone	0.44
10	0.15	1.1	Conglomerate	0.17
11	1.45	3.37	LWD	4.89
12	0.45	-	Silt	-
13	0.2	1.1	Sandstone	0.22
14	0.5	-	Silt	-
Total (m)	3.7	-	-	8.43

Table 5.1 Table showing the thicknesses of the beds that make up the large channel, their decompaction ratios, the bed types and the decompacted thicknesses. LWD signifies beds containing Large Woody Debris. Note that the silt beds were not taken into account when calculating the totals.

Jam Thickness (m)	Assumed Jam Width (m)	Jam Cross-sectional Area (m2)	Channel Thickness (m)	Assumed Channel Width (m)	Channel Cross-sectional Area (m2)
7.27	5	36.35	9.38	20	187.51
7.27	10	72.71	9.38	50	468.78
7.27	15	109.06	9.38	100	937.55
7.27	20	145.41	9.38	200	1875.10

Table 5.2 Table showing the cross-sectional areas of the log jam and the channel, using the assumed ranges of widths. The channel thickness takes into account the overlying 0.95 m of avulsion material.

Blockage (%)	Channel Cross-sectional Area (m2)	**187.51**	**468.78**	**937.55**	**1875.10**
Jam Cross-sectional Area (m2)					
36.35		19.39	7.75	3.88	1.94
72.71		38.77	15.51	7.75	3.88
109.06		58.16	23.26	11.63	5.82
145.41		77.55	31.02	15.51	7.75

Table 5.3 Table showing the blockage ratio using the cross-sectional areas calculated using the range of widths. Note that about 10% blockage is thought to be needed to induce avulsion.

The first thing to note is the total decompacted thickness of channel coming up at about 8.43 m. This is a significantly deep channel, and the high estimates of the widths of the channel are further justified. The total decompacted thickness of the log jam beds comes out to be about 7.27 m, while the total decompacted thickness of the channel comes out to be about 9.38 m, with the addition of the avulsion material. Depending on the assumed cross-sectional areas, the blockage ratio of the channel from the log accumulations varies considerably, with extreme values of about 1.94% and 77.55% for the channel. Some of the values are considered to be under and over estimates, because of the size of the channel. Realistically, the width of a channel of 8.43 m depth would be between 50 and 100 m. The log jam width would probably have been between 5 to 15 m. From this, the blockage estimate works out to be between 7.75% to 15.51%. Thus, under reasonable estimates, the logs were present in sufficient numbers to cause avulsion in the channels, since the blockage estimates work out to be very close to, if not exceeding, the 10% required to induce avulsion (Webb & Erskine, 2003).

5.3 Plant Life

One of the important aspects of determining whether this deposit is a log jam deposit is identifying the plant life that makes up the large woody debris. Ancient plant material is mainly identified by markings on the outermost layer. The problem with any ancient log jam deposit, though, is that the transportation of the woody debris wears down this outer layer, and that makes identification very difficult (Gibling et al., 2010), even for skilled paleontologists. As a result, we will have to rely on previous studies of the Boss Point Formation to understand the plants responsible for making up the large woody debris.

A previous study by Falcon-Lang and Scott (2000) has found that the Boss Point Formation is abundant in cordaitaleans, a group of plants closely related to conifers. These plants were found to consist of large woody trunks, sometimes reaching to over a meter in diameter, and being capable of growing to over 20 meters in height. They are known to have existed between 318 to 299 Ma, and to have been widespread near rivers and wetlands.

5.4 The Niklas Equation

Niklas (1994) developed a logarithmic equation that uses the diameter of trees to predict their heights. The equation is as follows:

$$\log_{10}(H) = 1.59 + 0.39\log_{10}(D) - 0.18(\log_{10}D)^2$$

where H is height, and D is assumed to be diameter at breast height (Gibling et al., 2010). A problem with using this equation is that most of our measurements are small, and are thought to be of either pieces of logs or twigs and branches. There were a few larger values, though. The results of using this equation are found in Table 5.2.

Bed	**Diameter (m)**	**Resulting height (m)**
Bed 8 (Upper)	0.162	14.7
Bed 8 (Upper)	0.154	14.26
Bed 8 (Lower)	0.112	11.38
Bed 8 (Lower)	0.082	8.99
Bed 6	0.019	2.43

Table 5.4 Table showing the results of using the Niklas equation

As can be seen, the values show that some of the pieces were quite large, though they were not in large numbers. Log jams can still form, since only a few larger pieces are needed to anchor and trap smaller pieces, allowing them to contribute to blocking (Webb et al., 2003). A problem with these results is that the diameter at breast height could not be determined for transported fragments, and that there were no full log measurements. This would mean that the given tree heights are not exact, though they are expected to be close.

5.5 Validity as a Log Jam Deposit

There has been much evidence presented to support the fact that the Boss Point Formation does indeed contain log jam deposits. Firstly, the woody debris is thought to be made up of cordaitaleans (Falcon-Lang & Scott, 2000), conifer-like trees that are known to grow tall and in dense forests. Their woody composition and ability to grow to such large sizes makes them good candidates to produce log jams. Estimated channel dimensions estimated using stratigraphic data and paleoflow directions give indications that blockage of the channel bodies was more than the required 10%, needed to cause avulsion. Though most pieces of measured debris were small, there are enough large pieces to act as anchors to hold the smaller pieces in place and allow a dam to form. Previous studies also show that avulsion has in fact taken place in this formation (Browne & Plint, 1994). Our own field data also show that avulsion has taken place at our outcrop, and that it is associated with the beds bearing the large woody debris, based on the presence of the log accumulation immediately below a shale that marks channel abandonment.

All this suggests that the large woody debris present in the Boss Point Formation brought about at least some of the avulsion that took place, and that the study site is indeed a log jam deposit.

5.6 Other Log Jam Deposits

The Pennsylvanian South Bar Formation of Sydney, Nova Scotia was also found to have log jam deposits, which were studied in detail by Gibling et al. (2010). The formation is a braided-fluvial deposit, consisting of successions of up to 6 meter thick sandstone, capped by up to 2.5 meter thick layers of coalified wood debris and coal intraclasts, which is overlain by mudstone indicating channel abandonment. Overall compaction estimates also put the beds bearing the large woody debris at being four times their current thickness prior to compaction. These beds are larger than those found in the Boss Point log jam outcrop, and the compaction is also apparently greater, with the maximum compaction of Boss Point beds being at about 3.6. The woody debris in South Bar consists of lycopsids, calamiteans, pteridosperms and cordaitaleans. Cordaitaleans acted as the key members here, trapping the rest of the plant matter to form the blockages. The log jams in the present study are thought to mainly consist of cordaitaleans, and they also would have acted as key members to trap smaller pieces of woody debris.

A Langsettian log jam deposit was also found in Alabama. A localized sandstone splits the Mary Lee coals. Orientation of debris within the sand was found to be perpendicular to paleoflow direction, and evidence has suggested that sediment filled in the basin along with the wood debris simultaneously. Wood debris is thought to have been made up of lycopsid, cordaitaleans, and calamitean trees (Gastaldo & Degges, 2007).

Log jam deposits were also found in a Polish fluvial deposit, thought to be mostly meandering, but possibly also anastomosing. Diverse plant remains are found with fine-to very fine-grained sandstone beds in channel deposits, and show large-scale cross-stratification. The sandstone with plant debris is up to 6.5 m thick, some of which are 30 cm wide and 4.5 m long (Gradzinski & Doktor, 1982).

The main difference between the Boss Point log jams and the rest of these log jams is age. The Sydney South Bar Formation is the youngest, being Bolsovian to Asturian in age (Gibling et al., 2010), the Polish log jams are Langsettian to Duckmantian (Gradzinski & Doktor, 1985), and the Alabama log jams are Langsettian (Gastaldo & Degges, 2007). Recent studies of spores from the basal part of the Boss Point Formation have found it to be Yeadonian to early Langsettian in age (Utting et al., 2010). Not only does this make the Boss Point log jams older than any of the previously mentioned log jams, but it also makes it one of the oldest, if not the oldest, documented log jam deposit worldwide. This provides among the earliest evidence of plant life affecting fluvial systems in this way. Table 5.3 shows more information of the log jams.

Formation	System Type	Grain Size	Plant Debris Species	Age
Boss Point, NS	Braided Fluvial	Fine	Cordaitaleans	Yeadonian to early Langsettian
South Bar, NS	Braided Fluvial	Fine-coarse	Lycopsids, Calamiteans, Pteridosperms and Cordaitaleans	Bolsovian to Asturian
Mary Lee Coal Interval, Alabama	Meandering	Fine-medium	Lycopsids, Calamiteans, and Cordaitaleans	Landsettian to Duckmantian
Mudstone Series, Poland	Meandering, possibly anastomosing as well	Very fine-fine	Cordaitaleans dominant	Langsettian

Table 5.5 Information on different log jams in Pennsylvanian deposits

Chapter 6 - Conclusions

6.1 Observations

Combining the information gained from field work with previous studies of the area and those of other log jam deposits allows a few major conclusions to be drawn about the Boss Point Formation.

1. Avulsion documented throughout the Boss Point Formation is also seen at the outcrop that was focused on during this study. This is mainly implied from the stratigraphy and sedimentology of the section, principally the presence of shales at the top of the succession which mark abandonment of the channel.
2. The species of the plants making up the large woody debris could not be determined from the outcrop, but previous studies indicate an abundance of cordaitaleans within Boss Point Formation. Cordaitaleans were major components in building log jams in other areas, and are known to have existed in sufficient size and numbers to cause log jams in the Boss Point area and time of deposition.
3. The exact width, and therefore the cross-sectional area, of the inferred channel bodies could only be estimated, so the amount of blockage of the channel bodies is not exact. Nevertheless, the blockage is very likely to have been at least 10%, which is the minimum to induce avulsion within some modern rivers.
4. Most of the measured debris was small, but it still contained a few larger pieces. These large pieces are thought to have been enough to anchor the small pieces in place and form a dam within the channel bodies. Applying a decompaction protocol to the beds

with large woody debris suggests that the beds were originally 1.4 to 3.4 times as thick as they are at present, prior to the flattening of the logs during burial.

5. Since significant blockage of the channel bodies can be reasonably inferred to have taken place, blockage due to log accumulation can be linked to the avulsion. This provides strong support for the view that the accumulations of large woody debris acted as log jams within the Boss Point Formation.
6. Palynological data show that the Boss Point Formation is Yeadonian to early Langsettian in age. In comparison to other documented log jam deposits, this appears to be the oldest documented to date. This also means that it provides one of the earliest examples of plants having evolved to be large enough and in sufficient numbers to influence fluvial systems in this way.

6.2 Future Work

The remoteness of this outcrop made gathering enough data difficult. As such, additional data can be gathered from it in order to enhance the model built to understand the log jams of the Boss Point Formation.

1. The lateral extent of the channels on the cliffs on either side of the outcrop can be measured to give a more accurate value for the cross-sectional area of the channels. This can also be applied to the beds containing the large woody debris. Combining these two together would then give a more accurate estimate of blockage taking into account the decompaction ratios for the beds.

2. More paleoflow values can be measured. This would give a better understanding of the fluvial mechanics of the channels, and would also help indicate when and where avulsion took place.
3. More examples of log jam deposits should be looked for throughout the formation, to compare that information with that of the outcrop of this study.
4. Further information on the species of the wood debris of the log jams should be obtained.

7.0 – References

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