Stratigraphy, Sedimentology and Depositional History of the McBean Seam Interval in the Pictou Coalfield, Stellarton Basin

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Introduction

The Stellarton Basin is located in central mainland Nova Scotia (Fig. 1). The basin is home to the Pictou Coalfield (NTS 11E/10) where coal mining has been carried out intermittently since 1818. Concurrent with mining has been the search for additional coal resources. Beginning in the early 1900s drilling formed a key element of many of the coal exploration efforts within

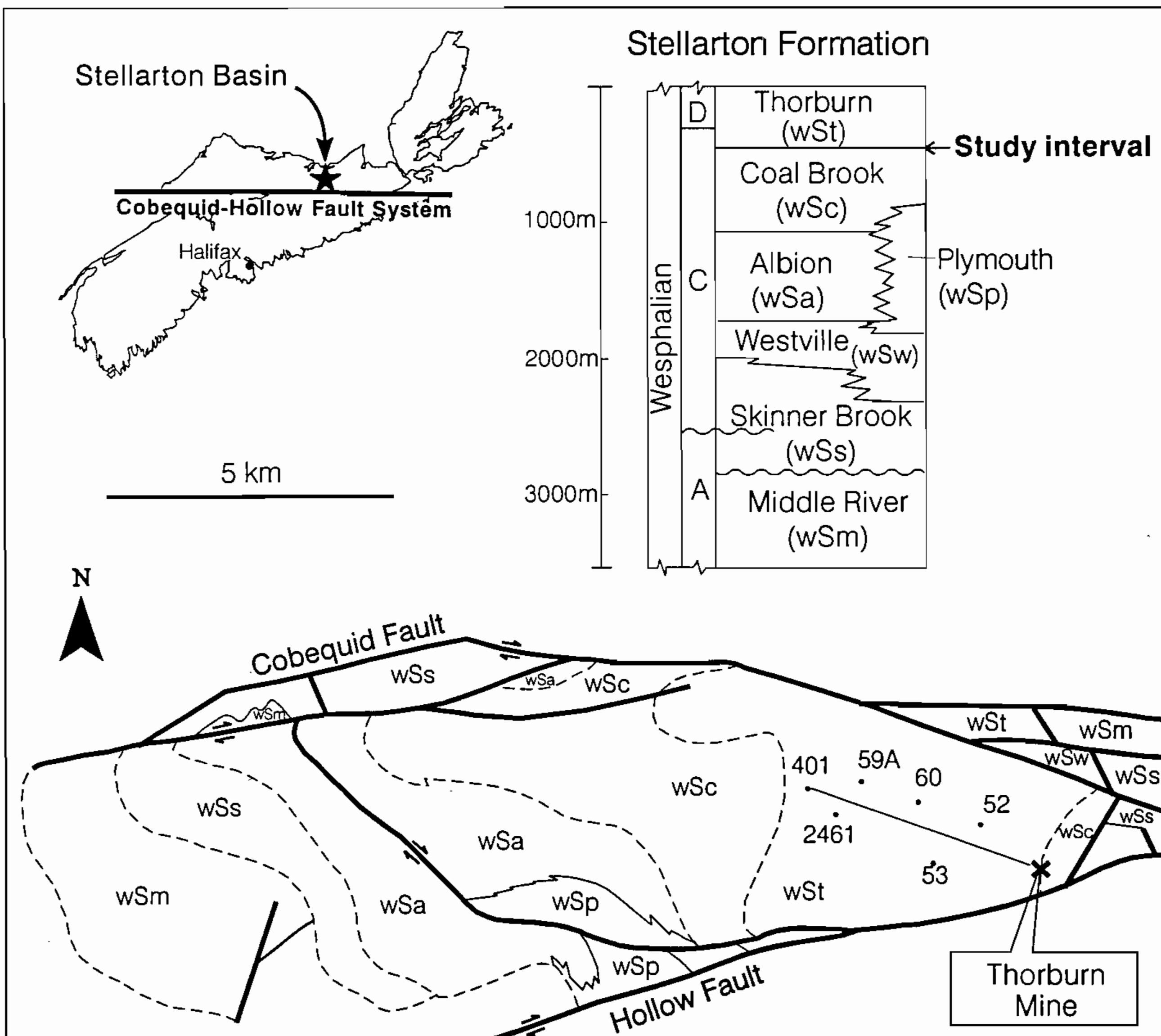

Figure 1. Geological sketch map of the Stellarton Basin indicating member boundaries of the Stellarton Formation, the location of the Thorburn Mine site and the drillholes that were used as part of this study. Also illustrated is a stratigraphic column of the Stellarton Formation showing member sub-divisions.

the basin. This has resulted in over 400 holes being drilled to date. Written records are available for most of the holes and cores are available for many of the holes drilled after 1970. Drilling data have provided an important basis for much of the stratigraphic correlation within the basin. In contrast, less attention has been given to detailed examination of surface exposures.

During the last five years a number of new surface coal mines have opened in the Stellarton Basin. Strata exposed in the highwalls of these mines provide an excellent source of new information on a number of important stratigraphic intervals. The research carried out as part of this project focuses on the McBean Seam and the initial 30 m of strata overlying it. Data were collected from drill cores and from the highwall of the Thorburn Surface Mine (Fig. 1). The purpose of this research is to better understand the stratigraphy, sedimentology and depositional history of the study interval.

General Geology

The Stellarton Basin is a 120 km^2 pull-apart basin that formed during the early Westphalian, at a releasing bend of the Cobequid - Hollow Fault System (Fig. 1). Infilling of the basin began during the Westphalian A and continued until at least the Westphalian D. The basin fill has been assigned to the Stellarton Formation (Fig. 1) and comprises mostly grey mudrock and sandstone interbedded with oil shale and coal. The basin contains 60 oil shale beds and 26 coal seams, including the 14 m thick Foord seam which is the thickest coal seam in eastern Canada.

Rapid coarsening and reddening of strata near the current fault-bounded limits of the basin in the east and southeast indicate that in these areas the paleo-depositional margins are probably close at hand. Elsewhere the depositional limits of the basin are more difficult to determine.

Naylor *et al.* (1989, 1992) interpreted most of the basin fill to consist of lacustrine, lacustrine delta and mire deposits. Lake formation was attributed to rapid basin floor subsidence accompanied by a decrease in sediment supply from regionally sourced rivers. This resulted in the periodic formation of a lake that would cover much of the basin floor. Mires are interpreted to have developed when lacustrine deltas infilled a lake and plants colonized the emergent delta plain. When a lake was completely infilled a mire would develop over large areas of the basin. In contrast, partial infilling of a lake only provided a stable substrate for peat formation closer to basin margins.

Stacked alluvial fan sequences adjacent to basin margins interfinger abruptly basinward with coal, lacustrine and lacustrine delta deposits. Higher basin margin relief is interpreted to be responsible for the development of redbeds and paleosols.

Stratigraphy of the Study Interval

The study interval is located at the base of the Thorburn Member approximately 500 m stratigraphically below the top of the Stellarton Formation (Fig. 1). The interval is 21 to 32 m thick and includes all the strata from the base of the McBean Seam to the top of oil shale #12 (Fig. 2). Our research efforts were confined to the east side of the Stellarton Basin (Fig. 1) where the study interval is much better preserved.

Figure 2 illustrates a southwest to northeast stratigraphic section of the study interval from the Thorburn Surface Mine to drillhole 401 (Fig. 1). The section is approximately 5 km in length and was constructed using existing drill records and new data gathered for this study from the Thorburn Surface Mine and drillholes P59a and 401.

The stratigraphic section illustrates a gradual basinward thinning and pinching out of the McBean Seam accompanied by a gradual thickening of oil shale #13. Mining records from former underground operations on the McBean Seam also clearly indicate a gradual thinning of the seam basinward. The maximum thickness of the McBean Seam is approximately 2.3 m.

Strata between oil shale #12 and #13 consist of grey and minor red mudrock and pale grey fine- to medium-grained sandstone. At the Thorburn Mine, 27 m of strata separate the two oil shales. In contrast, the two oil shale units in drillhole 401 are only 11 m apart. Thinning of the interval basinward is accompanied by a rapid increase in the ratio of mudrock to sandstone. The fine- to medium-grained sandstone, which is common at the Thorburn Mine site, pinches out completely by drillhole P59A.

The uppermost unit of the study interval is oil shale #12. Unlike oil shale #13 this oil shale unit has no coal associated with it. However, oil shale #12 also thickens significantly basinward from 2 m at the Thorburn Surface Mine to approximately 5 m in drillhole 401.

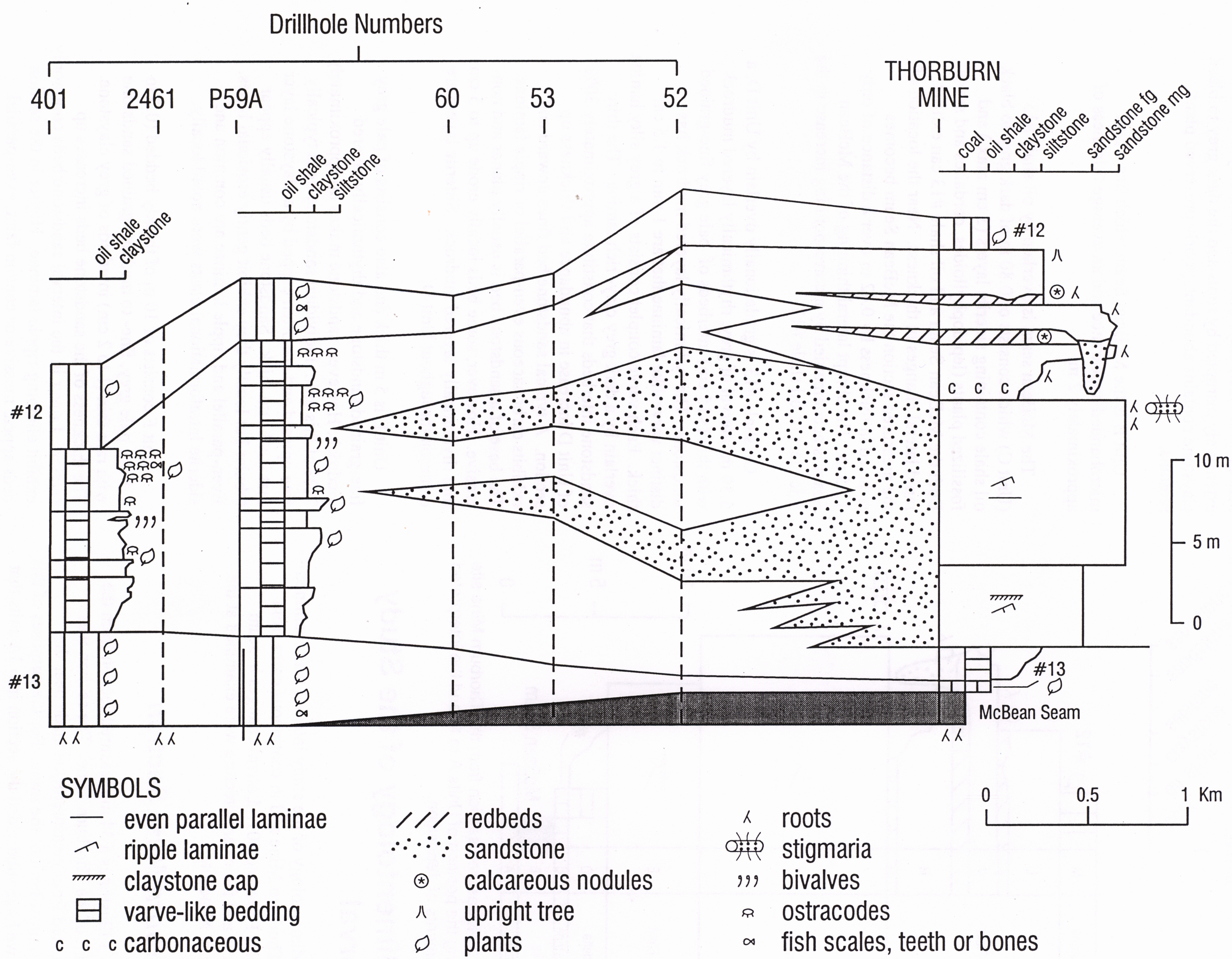

Figure 2. Stratigraphic cross-section of the study interval (see Fig. 1 for location).

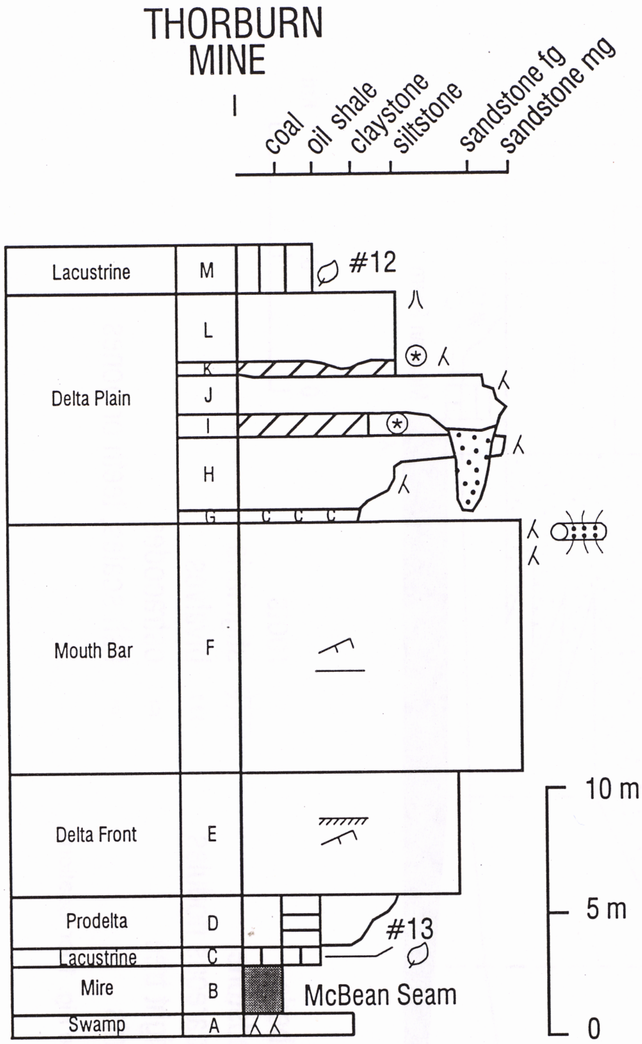

Figure 3. Measured section from the Thorburn Mine site indicating the position of Units A to M and the interpreted environments of deposition.

Sedimentology of the Study Interval

The sedimentology of the study interval was examined at the Thorburn Mine and in continuous cores from drillholes P59a and 401. Lateral changes in seam thickness and facies architecture were examined at the Thorburn Mine site.

Thorburn Mine Section

Figure 3 illustrates a 34 m measured section from the highwall of the Thorburn Mine. The section was constructed from measurements made near the northernmost limit of the mine. For the purposes of this report we have subdivided the section into 14 units that have been lettered A through M (Fig. 3).

Unit A, at the base of the section, consists of a grey-brown silty underclay which is overlain by 0.10 m of dark grey to black claystone. The underclay is extensively disrupted by roots and the dark grey to black claystone contains abundant, poorly preserved plant remains.

Unit B is the McBean Seam which has a dull microbanded appearance and an average thickness of approximately 2 m.

The McBean seam is overlain by oil shale #13 (Unit C) which consists of 0.80 m of dark grey to black oil shale containing siderite layers (3 cm max.) and fossilized plants (lepidophylloides, cordaites and seeds). Both the McBean Seam and oil shale #13 can exhibit rapid lateral changes in thickness. Near the location of the measured section the McBean Seam becomes reduced in thickness by 0.42 m over a distance of only 12.5 m. The abrupt lateral thinning of the McBean Seam is accompanied by a corresponding increase in the thickness of oil shale #13.

Oil shale #13 is gradationally overlain by Unit D, a 5.50 m interval of grey, rhythmically layered mudrock with thin (<15 cm) interbeds of pale grey fine-grained sandstone. The rythmically layered mudrock has distinct varve-like laminae that are 1 mm to 1.5 cm thick. Each varve couplet consists of a grey silty lamina overlain by a dark grey clay- rich lamina. The thin sandstone interbeds that constitute approximately 30% of Unit D increase in abundance and thickness up section. A typical sandstone bed fines upward and exhibits carbonaceous even-parallel or ripple laminae. The base of a sandstone bed is usually planar and non-erosive. However, some beds locally erode up to 5 cm into rhythmically layered mudrock. Siderite layers are common throughout Unit D.

Unit E is 5 m thick and also consists of pale grey fine-grained sandstone and rhythmically layered mudrock. However, sandstone makes up approximately 70% of this unit. Individual sandstone beds typically fine upward and are often capped by a claystone layer that is <1 mm thick. Sandstone beds usually appear tabular but locally they exhibit gently erosional bases. Even-parallel and ripple laminae are common and siderite intraformational clasts were noted locally.

Unit F consists of 10 m of thickly bedded (0.5 to 1.5 m), pale grey, fine- to medium-grained sandstone with rare thin (1 to 2 cm) interbeds of grey claystone. The thickness of the sandstone beds increases up section. Lower in the interval sandstone beds commonly exhibit climbing-ripple laminae. Higher in the section beds appear massive or contain faint, even-parallel laminae. Thicker beds can be low angle cross-stratified and locally have low angle erosional bases that cut up to 1 m into the underlying strata. Millimetre-scale claystone layers cap many of the sandstone beds. A distinctive 20 cm interval of convolute bedding was noted 6.80 m from the base of Unit F. This convolute interval is traceable over large areas of the mine site. Intraformational clasts (grey mudstone and siderite) are locally developed at the base of sandstone beds. Coalified, transported fossil trees were also noted locally. The upper 1.6 m of Unit F is extensively bioturbated by roots and contains well preserved fossil root stocks (stigmaria) and rootlets.

Unit G consists of 0.20 m of rooted, friable grey mudrock with local dark grey to black organic-rich layers up to 5 cm thick.

Unit H is a 3.35 m interval that coarsens upward from grey siltstone to thickly bedded fine- to medium-grained sandstone. The fine- to medium-grained sandstone was observed to grade laterally into siltstone. Siderite nodules and poorly preserved organic matter were observed within the siltstone. Roots are common throughout Unit H.

Unit I consists of approximately 0.50 m of red and green-grey mudrock with calcareous nodules.

Unit J typically consists of approximately 1.5 m of rooted grey siltstone and very fine-grained sandstone. However, a channel developed within Unit J locally cuts down at least 5.5 m to near the top of unit F (Fig. 3). Paleocurrent data and bedding orientation suggest that the same side of the channel is exposed twice. Therefore, the apparent view is of a channel bend, making it difficult to accurately calculate the total channel width and depth. The deepest parts of this channel are typically infilled by up to 1 m of pale grey medium-grained sandstone which contains local pebble-sized lithic clasts. The remainder of the channel fill is lithologically similar to Unit E, consisting of interbedded grey siltstone and pale grey fine-grained sandstone. Only the upper half of the channel fill is rooted.

Unit K is a 0.75 m thick, red and green-grey mudrock interval which contains local to common calcareous nodules.

Unit L is 2.85 m thick and consists of friable grey nodular siltstone with occasional pale grey fine-grained sandstone interbeds (<0.30 m) near the base. The upper 0.90 m of Unit L contains poorly preserved upright trees.

Unit M, the uppermost unit of the section, is oil shale #12. The contact between the oil shale bed and the underlying nodular siltstone is marked by a 0.20 m thick, dark grey fine-grained sandstone with abundant transported plant debris. Oil shale #12 is 1.93 m thick and very organic-rich over the lower 1 m.

Drillholes P59A and 401

In drillholes P59A and 401, the study interval lacks the diversity of facies seen at the Thorburn Mine. Due to the similar vertical arrangement of facies in each of the drillholes the two sections are described together.

In drillholes P59A and 401, the base of the study interval consists of pale grey fine-grained sandstone and siltstone containing abundant roots and local siderite nodules. This interval is correlative with Unit A from the Thorburn Mine section. Abruptly overlying this rooted interval is oil shale #13 (Unit C) which is approximately 5 m thick in both drillholes. Local plant fossils (cordaites, lepidostrobus and seeds) were noted throughout oil shale #13 in both cores. Fossil fish scales and bones were noted near the base of oil shale #13 in drillhole P59A.

The interval between oil shale #12 and #13 thins from 18 m in drillhole P59a to 11.5 m in drillhole 401. Grey rhythmically layered mudrock makes up 90% of the interval. Claystone is the dominant grain size. However, interbeds of siltstone up to 1 m thick were noted locally and siderite layers 0.2 to 2 cm thick are common. Crude coarsening upward cycles are developed at the 1-3 m scale between the two oil shales. In both drillholes 0.08 to 0.35 m interbeds of dark grey to black shale, transitional in character to oil shale, become common within 6 m of the base of oil shale #12. These organic-rich shales contain local plant fossils (cordaites, lepidophylloides, lepidostrobus) and local to abundant ostracodes. A bivalve (*anthracanauta* sp.) rich layer was noted approximately 4 m below oil shale #12 in both drill cores. Rare fish scales and teeth were observed in some organic-rich shales.

Oil shale #12 (Unit M) is 4 m thick in drillhole P59A and 5 m thick in drillhole 401. Plant fossils (cordaites and lepidostrobus) are rare to local within oil shale #12 in both drillholes.

Depositional Environments

Thorburn Mine Section

Figure 3 illustrates the general environment of deposition for each of the units described in the highwall of the Thorburn Mine. A discussion of the specific environment of deposition that has been interpreted for each unit is presented below.

The rooted underclay at the base of Unit A is interpreted to be a paleosol that developed below a forested swamp. Preservation of plant material in the carbonaceous claystone immediately above the underclay suggests that initially the swamp was poorly drained and not well aerated. The upward transition from carbonaceous claystone to coal (McBean Seam, Unit B) marks the development of peat-forming conditions and the change-over from a poorly drained swamp to a mire. Although the onset of peat formation coincides with a reduction in clastic input, the dull microbanded appearance of the McBean Seam suggests frequent, perhaps seasonal, flooding of the mire.

The development of oil shale #13 above the McBean Seam indicates that permanent flooding of the McBean mire ended peat accumulation. However, local thinning of the McBean Seam over very short distances indicates that initially only specific areas of the mire were drowned. Differential subsidence of the mire may have resulted in the local development of drainage channels and ponds. This in turn would have created a topography on the mire surface that was subsequently infilled by the organic-rich muds that were the precursors of oil shale #13. The absence of roots and paleosol features suggests the muds that formed oil shale #13 were never sub-aerially exposed.

The coarsening upward succession (units D, E, and F) deposited above oil shale #13 is interpreted to have been formed by a prograding lacustrine delta. The rhythmically layered mudrocks of Unit D are interpreted to be distal/prodelta deposits. Each varve-like layer contained within this facies may represent an annual depositional event. However, the formation of similar varve-like layers can be attributed to seasonal flood events which could produce more than one layer annually. The thin sandstone beds that constitute approximately 30% of Unit D are interpreted to represent delta front sands interfingering with the prodelta muds.

The sandstone-dominated facies that constitute Unit E are interpreted to be delta front deposits. Normal grading of sandstone beds is attributed to deceleration of flow strength when floodwaters entered the lake. The thin claystone layers that cap individual sandstone beds are interpreted to have formed from clay sized sediment that settled from suspension following a flood event.

Unit F is interpreted to consist of the most proximal of the permanently subaqueous lacustrine delta deposits. Collectively we have referred to these as mouthbar deposits. The common occurrence of climbing-ripple bedding lower in Unit F suggests large amounts of sandy sediment were introduced rapidly from suspension. This would be expected to occur when flood waters carried by a distributary channel initially enter a lake. The low-angle erosional surfaces that occur in the upper part of Unit F were probably formed by broad and shallow subaqueous distributary channels. Not surprisingly, lags formed from transported siderite clasts and plant material are often found in close association with these erosional surfaces. Thicker beds that contain low-angle cross stratification are interpreted as low relief bars that formed adjacent to and in front of subaqueous distributary channels.

Units G through L are interpreted to be delta plain deposits, in part based on the fact that they have been vegetated and subjected to soil-forming processes. The transition from subaqueous delta to delta plain is marked by Unit G. The abundant occurrence of fossil roots at the top of Unit F and within Unit G indicate that Unit G was forested. Therefore, the claystones of Unit G are interpreted to have been deposited in a swamp that formed on the emerging delta. Poor preservation of organic matter suggests the swamp was fairly well aerated.

The mudrocks and sandstones that comprise Unit H are broadly interpreted to have been deposited in the overbank areas of the delta plain. The grey colour, occurrence of siderite nodules, and preservation of organic matter suggest that the overbank areas were poorly drained. Disruption of bedding features by roots indicates that sedimentation rates were low enough to allow plant growth. Rapid lateral lithologic changes (e. g. sandstone to mudrock) indicate that the sandstone probably does not represent sheet flow deposits and, therefore, may have a levee or crevasse splay origin. The coarsening upward trend in Unit H may have been caused by progradation of a crevasse splay into the overbank area.

The transition from Unit H (grey beds with siderite nodules) to Unit I (redbeds with calcareous nodules) indicates that overbank areas became better drained and more mature plaeosols began to form. Improved drainage was probably caused by deeper incision of distributary channels into the delta plain. The sandstone- and mudrock-filled channel described in Unit J is a good candidate for a deeply incised distributary channel. Down-cutting of this channel may have occurred in response to a lowering of base level, caused by a drop in the lake level. Infilling of the channel would require a rise in base level, caused by either a rise in lake level or infilling of the lake with sediment. Rooted grey siltstones that overlie and are developed lateral to the channel are interpreted to be overbank deposits. The red mudrocks of Unit K are interpreted to have the same origin as those in Unit I.

The upward transition from the redbeds of Unit K to the grey mudrocks of Unit L suggests the return of more poorly drained conditions to this area of the delta plain. Unit L still exhibits abundant evidence of paleosol development, including the common occurrence of roots, calcrete nodules and pedogenic slickensides. The poorly preserved upright trees at the top of Unit L suggest that sedimentation rates were periodically relatively high. However, sedimentation rates were clearly low enough to allow for significant soil development. The uppermost unit of the measured section, oil shale #12 (Unit M), is interpreted to represent organic-rich lacustrine mud that was deposited when the sediment supply rate was low. The occurrence of oil shale #12 immediately above Unit L indicates that a significant rise in the water table eventually drowned the delta plain in this location.

Drillholes P59A and 401

Many of the units that were recognized in the Thorburn Mine section are absent in drillholes P59A and 401. However, some units (e.g. oil shales and Unit D) are thicker and contain additional fossils and sedimentary structures that provide further insights into the depositional environments.

The underclay at the base of the Thorburn Mine section was not observed in drillholes P59A and 401. Instead, Unit A consists of sandstone which appears similar to the rooted mouthbar deposits that comprise the top of Unit F in the Thorburn Mine section. However, it is important to note that approximately 400 m west of drillhole 401, on McLellan's Brook, there is a well developed underclay immediately below oil shale #13.

Oil shale units 12 and 13 are once again interpreted to consist of organic-rich lacustrine mud. The occurrence of fish scales and bones in both oil shales indicates that lake waters were rich enough in nutrients and oxygen to support a fish population. The majority of organic material in Stellarton oil shales is highly degraded. Therefore, it is possible that the plant macro-fossils (e.g. Lepidostrobus, Cordaites) preserved within the oil shale beds were more resistant to decay.

The rhythmically layered mudrock unit that separates oil shale units 12 and 13 is interpreted to consist predominately of prodelta deposits. Thin, organic-rich layers within the mudrock appear to be gradational to oil shale and, therefore, may have been deposited when clastic supply to the lake was low. The occurrence of ostracode and bivalve fossils within these organic-rich layers indicates that bottom waters were rich enough in oxygen and nutrients to support a benthic fauna.

Depositonal History

The most complete record of sedimentation and peat accumulation in the study interval is preserved in the Thorburn Mine section. However, to understand the depositional history in more detail it is necessary to look at the possible temporal relationships among all three measured sections.

Pervasive rooting at the base of all the sections indicates deposition of the study interval began with widespread development of a forested swamp. This was apparently followed by re-establishment of lacustrine conditions in more central areas of the basin and development of a peat swamp east of drillhole P59A. Thickening of the McBean Seam toward the eastern end of the basin suggests that the McBean mire was gradually drowned when the central basin lake slowly transgressed eastward. It is possible to estimate the rate at which this transgression occurred by considering how quickly peat accumulated in the McBean mire. Approximately 5 mm of peat accumulates annually in modern tropical mires. An acceptable estimate of the compaction ratio of peat to coal is approximately 10:1. Assuming 5 mm of peat also accumulated annually in the McBean mire it would have taken approximately 4000 years to accumulate enough peat to form 2 m of coal. The McBean Seam is approximately 2 m thick at the Thorburn Mine site and pinches out completely near drilhole P59A. Therefore, the lake shoreline must have transgressed approximately 1 m per year to cover the 3 .75 km between drillhole P59A and the mine site.

It is difficult to be certain if oil shale #13 was deposited as the lake transgressed across the McBean mire. However, thickening of oil shale #13 coincides with thinning of the McBean Seam, suggesting that they may be coeval deposits. Although some of the organic material in the oil shales is undoubtably of algal origin, inter-swamp drainage channels would have carried significant amounts of plant material from the McBean mire to the lake. The clay component of the oil shale could have been supplied from sediment-rich streams that were entering the lake elsewhere in the basin.

Deposition of prodelta muds over oil shale #13 is interpreted to signal an increase in sediment supply to the lake. The coarsening upward succession at the Thorburn Mine site records the gradual progradation of a delta into the lake. However, basinward only prodelta muds were deposited and there is no obvious evidence of the delta progradation.

The abandoned channel developed within Unit J (Figs. 2 and 3) indicates that sediment continued to be transported to the lake even when redbeds and paleosols were developing on the delta plain. However, Figure 2 illustrates that, basinward, no major sandstone units appear to have been deposited contemporaneously with the delta plain deposits in the Thorburn Mine section. This suggests that as the delta plain extended farther into the basin, distributary channels were no longer capable of transporting significant amounts of sand sized sediment to the lake. Therefore, the overall sediment supply to the lake may have decreased as the delta plain developed more fully. Growth of the delta plain would have provided an ever-increasing area for plants to colonize. This in turn would probably have caused an increase in the supply of organic material to the lake. A decrease in sediment supply and an increase in organic nutrients entering the lake may have favoured an overall increase in faunal production. This may account for the dramatic increase in ostracodes, bivalve and fish fossils in the upper 5 to 7 m of the prodelta deposits (Fig. 2).

Development of calcareous paleosols on the delta plain indicates that the rate of vertical accretion of sediment was low. Therefore, the delta plain is interpreted to have gradually sunk below the lake surface due to the combined effects of tectonic- and compaction-related subsidence. Deposition of oil shale #12 immediately above the delta plain deposits indicates sediment supply remained very low. The absence of a coal seam below oil shale #12 may indicate that the delta plain subsided too rapidly to allow peat formation. However, the absence of coal could also indicate that although sediment supply was low, it may still have been too high to allow for peat formation. Other possible factors that could have deterred peat formation are climate and the nature of the plants that colonized the delta plain.

Conclusions

Lacustrine delta deposits in the Stellarton Basin can be broadly sub-divided into prodelta, delta front, mouth bar and delta plain deposits. Each of these lacustrine delta sub-environments comprises a characteristic suite of facies.

It appears that the coal and oil shale deposits of the Stellarton Basin may be coeval. However, further work is required to determine why most delta plain sequences are immediately overlain by oil shale as opposed to coal. Once this is better understood it may be possible to develop new models for coal exploration in the Stellarton Basin.

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