DESCRIPTIVE NOTES

INTRODUCTION

The Westphalian Stellarton Basin is located on a complex of faults in central mainland Nova Scotia. The basin occurs at the junction between the Cobequid Fault to the west, and the Hollow Fault to the east. The Stellarton Basin contains the entire Pictou Coalfield and has historically been the site of substantial mining; more recently the basin has been explored for coalbed methane. As a result of many years of coal exploration, the basin contains over 400 recorded boreholes. Approximately 35 coal seams and about 60 oil shale units may be correlated laterally between boreholes (e.g. Naylor et al. 1989).

Data sources

Because of the economic interest, mapping efforts in the Stellarton Basin date back into the last century. Early maps (e.g. Poole 1904) delineated the outlines of the Pictou Coalfield and the principal seams. Bell (1940) mapped the basin at a scale of 1:24000, determined the biostratigraphic ages of most of the stratigraphic units and established the present division of the Stellarton Formation into members. More recently, the Stellarton area was included in a 1:50 000 compilation of previous mapping by Yeo (1987) who advanced the idea that the basin represents a pull-apart structure at a releasing bend on a dextral fault system (Fralick and Schenk 1981; Yeo and Gao 1987). Detailed maps at 1:5 000 scale, by Naylor et al (1986) and Smith et al (1989), cover all outcrops known at that time in the basin fill.

In the present project, these sources of information have been supplemented by additional field mapping in the areas of less detailed previous coverage, notably the basin margins. Within the basin, the observations shown on this map summarize the results of earlier mapping at larger scales. We show an interpreted geometry of the basin margin which is consistent with all the map data that we are aware of. To the south of the basin, we show boundaries based on Giles (1982), Yeo (1987) and Murphy et al (1991). At the east end of the basin, outcrop is poor, and lithostratigraphic correlations somewhat in doubt; our interpretation of the geometry is consistent with Chandler et al (1997).

An extensive subsurface data set is available for the central, coal-bearing part of the basin. Unpublished maps, based on surveyed coal mine plans by T.B.Haites (held at Nova Scotia Department of Natural Resources), formed the basis for subsurface contours shown here on the Acadia and Sixfoot seams, together with the western half of the contoured area shown for the Foord Seam. Data from boreholes have been compiled by R.D. Naylor (unpublished reports) and by D. Hughes (Hughes & MacNeil 1992, Hughes 1995). In addition, several seismic lines, shot during more recent exploration (Fraser et al 1986), have been reinterpreted. These, together with the borehole data, form the basis for the eastern half of our contour interpretation of the Foord seam (east of East River). Both the borehole and the seismic data leave ambiguities in the trends of subsurface fault intersections with the Foord seam. Our interpretation is therefore based on the assumption that fault trends are similar to those in the better known area of historic mining, west of East River.

STRATIGRAPHY

Pre-Westphalian Units

Pre-Carboniferous units occur only in the southeast corner of the map area, where they are not subdivided. They include Precambrian rocks of the Georgeville Group, Lower Paleozoic Arisaig Group sediments, and Devonian volcanics and redbeds of the McAras Brook Formation. This area forms the western extremity of the Antigonish Highlands; for details of outcrops and the distribution of units, readers are referred to the maps of Murphy et al (1991) and Yeo (1987), and the references cited therein.

South of the basin, Early Carboniferous, mainly Visean rocks of the *Windsor Group* are exposed in the Eureka area (Giles 1982). These include both carbonates and generally fine-grained, red to grey, clastic sedimentary rocks. Significant outcrop and subsurface evaporites occur in this structurally complex area. Recent interpretation by Chandler et al (1997) suggests that low-angle detachment surfaces are present within the Windsor stratigraphy. Small areas of Windsor Group strata are exposed in fault-bounded blocks at the north margin of the basin.

The Windsor Group is overlain by clastic sedimentary rocks of the *Mabou Group*, predominantly of Namurian age. The group consists of variably grey to red, poorly fissile mudstones and very fine to medium sandstones with trough cross-bedding. They are interpreted to represent varied fluvial and lacustrine environments. Mabou Group rocks occupy a large area to the south and west of the Stellarton Basin, where they are intensely deformed by folding and faulting, and are locally overturned. The lack of penetrative fabrics makes this area difficult to interpret structurally. The Mabou Group has not been subdivided into formations, although redbeds appear to be more prominent in the lower part of the group. The area mapped as Mabou Group may include some strata laterally equivalent to the Windsor Group, as suggested by two Visean spore ages obtained from ripple-laminated units adjacent to the southwest margin of the Stellarton Basin. Other clastic units provisionally assigned to the Mabou Group occur in fault-bounded blocks at the east end of the Stellarton Basin, where they are correlative with the Lismore Formation that lies farther east (Chandler et al 1997)

Stellarton Formation

The mid- to late- Westphalian fill of the Stellarton Basin was designated the Stellarton 'Group' by Bell (1940), but is here assigned to a single formation, the Stellarton Formation, of Westphalian age, following Yeo (1987). In the regional stratigraphic nomenclature proposed by Ryan et al (1991) the Stellarton Formation is included, together with other coal-bearing Late Carboniferous units, in the Cumberland Group.

We here include in the Stellarton Formation some early Westphalian rocks at the southwest basin margin, equivalent to part of the Middle River Formation of Yeo (1987) and the Cumberland Group of Bell (1940). We infer that this unit was excluded from the Stellarton Formation by Bell on biostratigraphic grounds; lithostratigraphically the boundary between the units does not justify separation at formation level. The base of the Stellarton Formation, thus re-defined, is placed at the mapped boundary between steeply dipping to overturned, indurated fine-grained clastic sediments of the Mabou Group, and overlying gently dipping, poorly indurated mudrock, sandstone and conglomerate. The contact, an inferred angular unconformity, is not exposed, but its location is constrained within about 50 m at Brown Brook.

The *Middle River Member* of the Stellarton Formation (formerly part of the Middle River Formation of Yeo 1987) consists of interbedded red mudrock, predominantly red, massive, parallel laminated and cross-bedded sandstone, and subordinate well-rounded, red, granule and pebble conglomerate. Upward, the mudrock becomes increasingly mottled with grey-green reduced patches, transitional into the overlying Skinner Brook Member. Previous biostratigraphic work, together with palynological results in this study, indicate Westphalian A age.

The *Skinner Brook Member* consists predominantly of red to grey-green root-mottled mudrock, siltstone, and fine sandstone. Subordinate coarser sandstone and local conglomerate are present near the basin margins. Spore samples from the base of the member indicate Westphalian A ages, whereas the upper parts of the member appear to be Westphalian C. It is possible that the Westphalian B interval is condensed or missing within the member.

The Westphalian C *Westville Member* consists of predominantly grey claystone, wave-rippled siltstone, and minor sandstone, with coal seams near the base. The Scott and Acadia seams have been extensively mined. The upper part of the Westville Member is poorly exposed and is known mainly from boreholes. It consists of a generally monotonous succession of lacustrine mudrock, with minor sandstone intervals.

The base of the overlying *Albion Member* (Westphalian C) is drawn at the reappearance of coal in the subsurface Academy seam, or at laterally equivalent shale where the Academy seam is absent. The present interpretation of structural relationships in the basin suggests that the boundary at the surface is everywhere faulted. Towards the south basin margin, an interval of redbeds (Plymouth Member) separates the Westville and Albion Members. There, the base of the Albion Member is drawn at the transition from predominantly red to predominantly grey lithologies. The Albion Member is a richly coal-bearing succession of grey to black clastic sediments including oil shale, claystone, siltstone and fine sandstone. Coal seams become more abundant towards the north and stratigraphically upward in the member, culminating in the thick Foord seam, the top of which marks the top of the member.

Laterally, the Albion Member passes into the *Plymouth Member* (also Westphalian C). The Plymouth Member consists of predominantly red mudrock, interbedded with red and grey sandstone and minor conglomerate, confined to the southern marginal part of the basin.

The Westphalian C *Coal Brook Member* consists predominantly of grey to black shale, including abundant, laterally continuous oil shale units, and only rare coal. Much of the member is finely laminated. Near basin margins, sandstone beds are more abundant and conglomerates begin to appear. A single widely correlated coal seam, the McLeod, occurs in the middle of the member, but it passes laterally, toward the basin centre, into oil shale.

The base of the overlying *Thorburn Member* (Westphalian C-D?) is placed at the base of the McBean coal seam. The member consists of a varied succession of grey to black oil shale, mudrock and sandstone, and a number of coal seams. that pass westward into oil shale. Minor conglomerates occur at the south margin of the basin. The highest strata of the Thorburn Member occur in two structural basins at the east end of the Stellarton Basin; the upper limit of the member is not seen.

Other Westphalian Units

The *New Glasgow Formation* (equivalent to part of the Middle River Formation and the New Glasgow Formation of Yeo 1987) consists of boulder to granule conglomerate, cross-bedded red sandstone, and subordinate red shale. It is of Westphalian A age at the base. Lower parts of the formation (the Lower Member of Chandler et al 1997, Chandler 1998) are dominated by sandstone; conglomerate predominates in the Upper Member. (Lower and Upper Members are not distinguished on this map).

The overlying *Malagash Formation* (Westphalian C-D) is poorly exposed in the area of this map. At the base, a thin limestone is locally present at the boundary with the underlying New Glasgow Formation. The contact appears conformable, but regional map relationships (Ryan and Boehner 1990, Chandler et al 1998) suggest a significant unconformity. Above the basal limestone there are up to 120 m of fine-grained strata consisting of thinly interbedded grey claystone and sandstone with subordinant oil shale and rare poorly developed coal seams. The remainder of the formation comprises pale grey, fine - to coarse- grained sandstone interbedded with grey and red mudrock. Sandstone units typically comprise multi-storied channel sucessions (14-60 m). Rare impure coal seams are present.

Younger units

The only known younger units in the area are extensive tills and river gravels of inferred Quaternary age. These have not been investigated in the present study, and are not represented on the map, which shows only the bedrock geology.

STRUCTURE

Structural work in the Stellarton Basin dates back to the last century, when the geological setting of coal mines was investigated by Poole (1904). Subsequent extension of coal mines into the Albion Syncline led to further work by the Geological Survey of Canada, culminating in the study of Bell (1940), which identified many of the major faults in the area. During the 1940s and 1950s exploration and mining by the Acadia Coal Company led to the preparation of detailed contour plans of coal seams (T.B. Haites, unpublished data held at Nova Scotia Department of Natural Resources). Haites (1950) interpreted these results in a model involving substantial tectonic shortening. In this hypothesis, the coal seams of the Albion and Westville members were interpreted as equivalent. Subsequent paleobotanical studies (e.g. Hacquebard and Donaldson 1969) have not confirmed this hypothesis. Fralick and Schenk (1981) suggested the Stellarton Basin was a pull-apart basin that formed in an extensional setting in response to dextral slip on the Hollow Fault. Subsequent work by Yeo and Gao (1987) and Gillis (1991) revealed an array of structures consistent with formation of the basin at a releasing bend on a dextral fault system.

Basin boundary structures

Along the southwest basin margin, a variety of Stellarton Formation strata occur in contact with both Mabou and Windsor groups. Between Alma and Hazel Glen the Middle River Member dips gently northeast, away from the mapped contact with intensely deformed, locally overturned Visean and Namurian rocks. This contact, though not exposed, is interpreted as an angular unconformity. Farther south, higher units of the Stellarton Formation rest in contact with Mabou Group rocks. The basin fill is therefore inferred to onlap the southern basin margin, with higher parts of the fill transgressing farther over an adjacent Westphalian upland formed by deformed Mabou and Windsor rocks. In the area of Hazel Glen, Middle River conglomerates dip relatively steeply away from Mabou strata, but show few other signs of deformation. It is likely that this boundary represents a fault-modified unconformity. An angular unconformity is exposed at the contact in East River, where Stellarton Formation conglomerates (Plymouth Member) rest on cross-bedded Mabou Group sandstones.

Several fault-bounded slices occur at the north and northwest basin margin. A block of gently dipping redbeds, provisionally assigned to the Skinner Brook Member, is upthrown along the Fletcher Fault against Coal Brook and Thorburn Member rocks of the basin fill to the south. Farther west, an inferred fault separates these strata from a block characterized by conglomerates, provisionally assigned to the Middle River Member, overlying deformed siltstones of the Mabou Group. Both these blocks are bounded to the north by the Waters Brook Fault. North of this fault is a slice containing unfossiliferous indurated siltstones (Mabou Group) and localized grey, laminated and mylonitic limestones; historical records of gypsum exposures in this area (Poole 1904) confirm the existence of Windsor Group rocks. At the north edge of this block is a slice of poorly indurated siltstones of uncertain affinities which young to the north but dip steeply south.

In the Alma area, conglomerates and sandstones immediately outside the basin (New Glasgow Formation) are near-vertical to overturned, and young to the north. Exposure is poor in the region between the overturned strata and the gently dipping conglomerates and sandstones to the north; the structure is tentatively interpreted as a faulted plunging syncline.

The overall structure at the northwest edge of the basin is thus marked by fault slices which are uplifted relative to the units both north and south. Along both edges of the zone of uplift, strata are near-vertical to overturned, and face outward, away from the structure. This margin of the basin is therefore interpreted as a positive flower structure (e.g. Harding 1985).

Map-scale structures at the other margins of the basin are less clear. Clastic sediments in fault-bounded slices at the eastern end of the basin were regarded as correlative with the Skinner Brook and Westville Members by Bell (1940) and are shown as such in the map, but this correlation is based on lithological similarities only. In the area of McLellan's Brook, the bounding contacts of the basin are unexposed, but are inferred from mapped relationships to be faulted. However, the prevalence of coarse clastic facies along the south margin of the basin suggests that the present faulted boundaries are close to the original depositional margin of the basin in this area.

Structures within the basin-fill

The basin fill is tilted broadly toward the northeast, but the structure is complicated by folds and faults. En-echelon folds trend generally NE-SW, oblique to the basin margins, tightening and becoming more E-W in orientation toward the north margin. Extensional structures (mainly normal faults) strike generally NW-SE to NNW-SSE.

A major fault system strikes NW-SE across the basin west of the worked area of Albion coals. Deformed rocks seen in outcrop indicate the presence of one fault in this zone. The existence of other strands is inferred from borehole and mine records, which suggest that the westernmost fault in the zone (the Acadia Fault of Bell 1940) dips to the northeast and has a stratigraphic throw of at least 350 m. An apparent 'rollover' of strata toward this structure, and the change in strike across the fault, suggest that the fault is listric, flattening at depth, as shown in the cross-sections. We follow Gillis (1991) and Waldron et al (1995) in inferring that this fault zone can be connected with an exposed structure on East River at Plymouth (the Plymouth fault) where Gao (1987) recorded minor structures indicative of oblique dextral and normal motion.

Other mapped faults within the basin involve smaller offsets. Numerous subsurface faults in the New Glasgow area can be mapped using mine-plan data. The majority of these faults strike NW-SE or N-S and indicate significant extension in a direction slightly oblique to the basin margin, consistent with a component of dextral shear strain. Farther east in the basin few faults are mapped at the surface, but a predominance of NW-SE strikes is again observed. In the subsurface, seismic reflections are disrupted at the level of the Albion Member, but become more coherent upward. We infer that extensional faulting affected strata of the basin fill during the development of the basin.

Map-scale folding of the basin fill increases in intensity toward the northern margin. Several large folds can be traced both from patterns of bedding orientation in scattered outcrop and from subsurface mine-plan information (Gillis 1991). Fold axes trend predominantly NNE, with the exception of an area in the vicinity of New Glasgow where the Albion syncline and other folds follow an arcuate pattern, possibly produced by linking of two originally separate folds. West of this area, correlation of surface and subsurface folds suggests that fold axial surfaces dip steeply north, consistent with the inferred flower structure developed at the northwest basin margin.

Farther east in the basin, a complex fold pattern in the Thorburn area involves two structural basins located on the Marsh and McLellan synclines. The individual basins may be related to NW-SE shortening but the overall structure appears to mirror the shape of the eastern basin margin, suggesting that the synclinal structure may result from dip-slip movement on non-planar basin-bounding faults.

EVOLUTION OF THE BASIN

Initiation of the Stellarton basin was preceded by major late Namurian or early Westphalian deformation, which led to brecciation, faulting, and tight folding, with local overturning of the Windsor and Mabou Groups. The Stellarton Formation was deposited with angular unconformity on these units.

The Stellarton basin was initiated at a releasing bend in the Cobequid-Hollow fault system in early Westphalian time. Stratigraphic analysis of the Stellarton Formation by Naylor et al (1989) and others has shown that coarse clastic facies (mainly sandstones, local conglomerates) are concentrated at the south and east basin margins. The present structural margins of the basin in these areas are therefore inferred to approximately follow the syndepositional basin margins. However, to the southwest, the basin may originally have extended significantly beyond its present erosional limit.

The thickest coal and oil shale successions are found in the centre of the basin and extend into the highly deformed northern marginal zone. During deposition of the Albion Member of the Stellarton Formation, subsidence and sediment accumulation were most rapid at the southern basin margin, interpreted as fault-bounded (Waldron 1996). Peat formation during this interval was concentrated at the north basin margin where overall syndepositional subsidence was slowest. Seismic and other subsurface data suggest that significant extensional faulting of the basin fill occurred following deposition of the Albion Member; locally there may be an unconformity at or near the base of the overlying Coal Brook Member. During deposition of the later parts of the formation, the basin floor probably subsided more evenly, with the most rapid rates in the east. However, our knowledge of the later parts of the subsidence history is limited, because erosion has removed the youngest units from the west end of the basin.

Significant shortening affected the basin after the deposition of the youngest basin fill (Thorburn Member), and the youngest strata to the north of the basin (Malagash Formation), both dated as Westphalian C to D. The northwest basin margin is dominated by a positive flower structure. This indicates a kinematic change on the Cobequid-Hollow fault system (possibly to a more east-west direction of motion) which placed the Stellarton Basin on a restraining bend. There is no stratigraphic upper limit on the timing of this deformation; on regional grounds it is assumed to have occurred in latest Carboniferous or Permian time.

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