ARCTIC
VOL. 33, NO. 1 (MARCH 1980), P. 38-49

Tertiary Coal Resources, Eastern Arctic Archipelago

R.M. BUSTIN[1]

ABSTRACT. In the eastern Canadian Arctic Archipelago major coal resources occur within the Late Cretaceous and Tertiary Eureka Sound Formation. The formation, which ranges in thickness from thin erosional outliers on central Axel Heiberg Island to a maximum thickness of 3300 m on Fosheim Peninsula, Ellesmere Island, contains numerous thick seams of coal. The coal is highly variable in quality, but seams of clean, vitrain rich coal is highly variable in quality, but seams of clean, vitrain rich coal several metres thick are present. The rank of the coal ranges from lignite through sub-bituminous to high-volatile bituminous as measured by vitrinite reflectance. Inferred resources within the area of study are calculated as 30 000 million tonnes of which 15 000 million tonnes are lignite, 11 000 million tonnes are sub-bituminous and 4000 million tonnes are high-volatile bituminous.

The area encompassed only a small portion of the known outcrop area of Late Cretaceous and Tertiary coal measures in the Canadian Arctic Archipelago which indicates that considerable further resources are present.

RÉSUMÉ. Dans l'archipel arctique oriental Canadien, la plus grande partie des ressources en charbon se situe dans le crétacé terminal et la formation Eureka Sound du Tertiaire. L'epaisseur de la formation est très mince aux buttes temoins d'érosion de la partie centrale de l'ile d'Axel Héiberg mais elle peut atteintre 3300 m sur la Peninsule de Fosheim dans l'ile l'Ellesmere avec de nombreuses veines épaisses de charbon. La qualité de ce charbon est très variable mais il y a des veines de quelques mètres de charbon propre et riche en vitrinite. La qualite de charbon va de la lignite jusqu' aux charbons bitumineux très volatiles ou sub bitumineux, comme l'indique le pouvoir reflecteur de la vitrinite. Les reserves limitées à cette seule region sont estimées à environ 30.10^9 tonnes dont 15.10^9 tonnes de lignite, 11.10^9 de charbon sub bitumineux et 4.10^9 de charbon bitumineux très volatile.

Cette région n'est qu'une petite partie des affleurements connus dans l'archipel arctique Canadien où la formation crétacé, terminal á Tertiaire est riche en charbon, ceci indique qu'existent des reserves supplémentaires considerable.

Traduit par Alain de Vendegies, Aquitaine Co. of Canada Ltd.

INTRODUCTION

The Late Cretaceous and Tertiary Eureka Sound Formation is the principal coal bearing unit in the Canadian Arctic Archipelago. It is widely distributed extending from Banks Island in the southwest to Ellesmere Island in the northeast.

The presence of Tertiary coal measures in the Canadian Arctic Archipelago has been known for over a hundred years. The location of Fort Conger on southern Ellesmere Island, which served as a base for the early explorers Nares (1875-76), Greely (1881-83) and Peary (1898-1912), was in part so located to take advantage of adjacent mineable Tertiary coal (West, 1977).

[1]Department of Geological Sciences, University of British Columbia, Vancouver, B.C.

Although the geological framework and gross distribution of the coal measures have been documented by the Geological Survey of Canada, the coal resources have received no study.

As part of a stratigraphic and sedimentological study on Axel Heiberg and Ellesmere Islands in the northeastern Arctic Archipelago, coal of the Eureka Sound Formation was examined at numerous localities and the rank of the coal was determined by the reflectance method (Bustin, 1977; Bustin *et al.*, 1977). The purpose of this paper is to document some of the major coal occurrences, the rank and character of the coal, and to provide some preliminary estimates of the coal resources within the area of study.

AREA OF STUDY

The study area encompasses parts of eastern Axel Heiberg Island and the Fosheim Peninsula area on west central Ellesmere Island (Fig. 1). The physiography of the area which has been described by Roots *(in* Fortier *et al.*, 1963) includes rugged mountain topography on east-central Axel Heiberg Island and more subdued plateau and lowland areas on eastern Axel Heiberg and west-central Ellesmere Island.

Access to the study area is exclusively by light aircraft. The only permanent establishment is a weather station at Eureka, Ellesmere Island.

REGIONAL GEOLOGY

Troelsen (1950, p. 78) proposed the name Eureka Sound Group for deposits of Tertiary sandstone, shale and coal cropping out on Ellesmere Island. Tozer (1963, p. 97) redefined the Eureka Sound Group as a formation and Souther

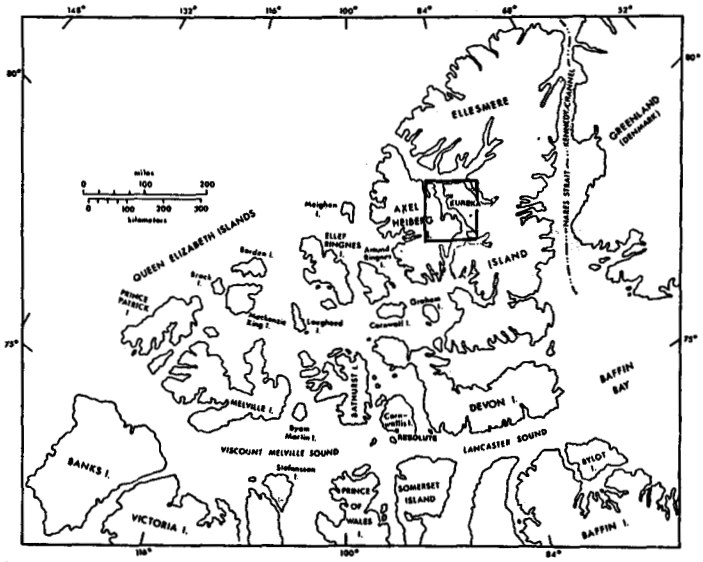


FIG. 1. Map of the Canadian Arctic Archipelago showing the location of the study area.

(*in* Fortier *et al.*, 1963, p. 444-445) proposed as the type section 2700 m of interbedded sandstone, shale, mudstone and coal which conformably overlies Upper Cretaceous shales on western Axel Heiberg Island.

The Eureka Sound Formation as so defined is a complex deposit ranging in age from Maastrichtian (latest Cretaceous) to Middle Eocene (c.f. Hills and Wallace, 1969). Although in part a syntectonic deposit, it is older than the last major phase of orogenesis in the eastern Arctic Archielago (Tozer, 1970; Balkwill *et al.*, 1975). As originally deposited, the Eureka Sound Formation probably enveloped most of the Canadian Arctic Archipelago. It presently occurs as erosional outliers on Banks, Devon, Somerset, Bathurst, Melville, Ellef Ringnes, Lougheed, Cornwall, Axel Heiberg and Ellesmere Islands. It also occurs in the subsurface of Banks, Ellef Ringnes and Meighen Islands and is also likely present in the interisland seaways and off the northern margin of the Archipelago. The formation is highly variable in thickness ranging from a maximum of 3300 m at Fosheim Peninsula, Ellesmere Island to thin erosional edges at many localities. In the central and southern parts of the Archipelago it conformably overlies Upper Cretaceous shales of the Kanguk Formation, whereas on the northern margin it rests unconformably on older Mesozoic strata and on the eastern margin lies unconformably on Mesozoic, Paleozoic or Proterozoic rocks. The Eureka Sound Formation is unconformably overlain by Quaternary deposits or locally by the Miocene-Pliocene Beaufort Formation.

The lithologies of the Eureka Sound Formation are remarkably uniform throughout the Canadian Arctic Archipelago. The formation consists of rhythmically interbedded dark grey shale, mudstone and siltstone, buff to light grey quartzose sandstone, minor conglomerate and coal. Coal seams have been reported from almost all known localities. The seams are commonly between 0.5 and 1.0 m thick, but in some locations attain thicknesses of several metres.

With the exception of the present study, there has been no systematic determination of rank or quality of the coal. The coal has been generally assumed to be lignite (Latour, 1972); however, the results of this study indicate that in addition to lignite considerable resources of sub-bituminous and high-volatile bituminous coal are present in some areas.

COAL MEASURES - AREA OF STUDY

The distribution of the coal measures in the area of study is shown in Figure 2. Table 1 summarizes the general stratigraphic succession and correlation at several localities. Throughout the area of study the coal measures are composed of alternating sandstone, siltstone, shale, mudstone and coal ranging in age from Maastrichtian (latest Cretaceous) to Middle Eocene. The coal measures range in thickness from thin erosional outliers on parts of easternmost Axel Heiberg Island to a maximum thickness of 3300 m at Fosheim Peninsula, Ellesmere Island.

The variation in thickness of the coal measures is considered to be the result of differential subsidence rates, syntectonic deposition and erosion, and

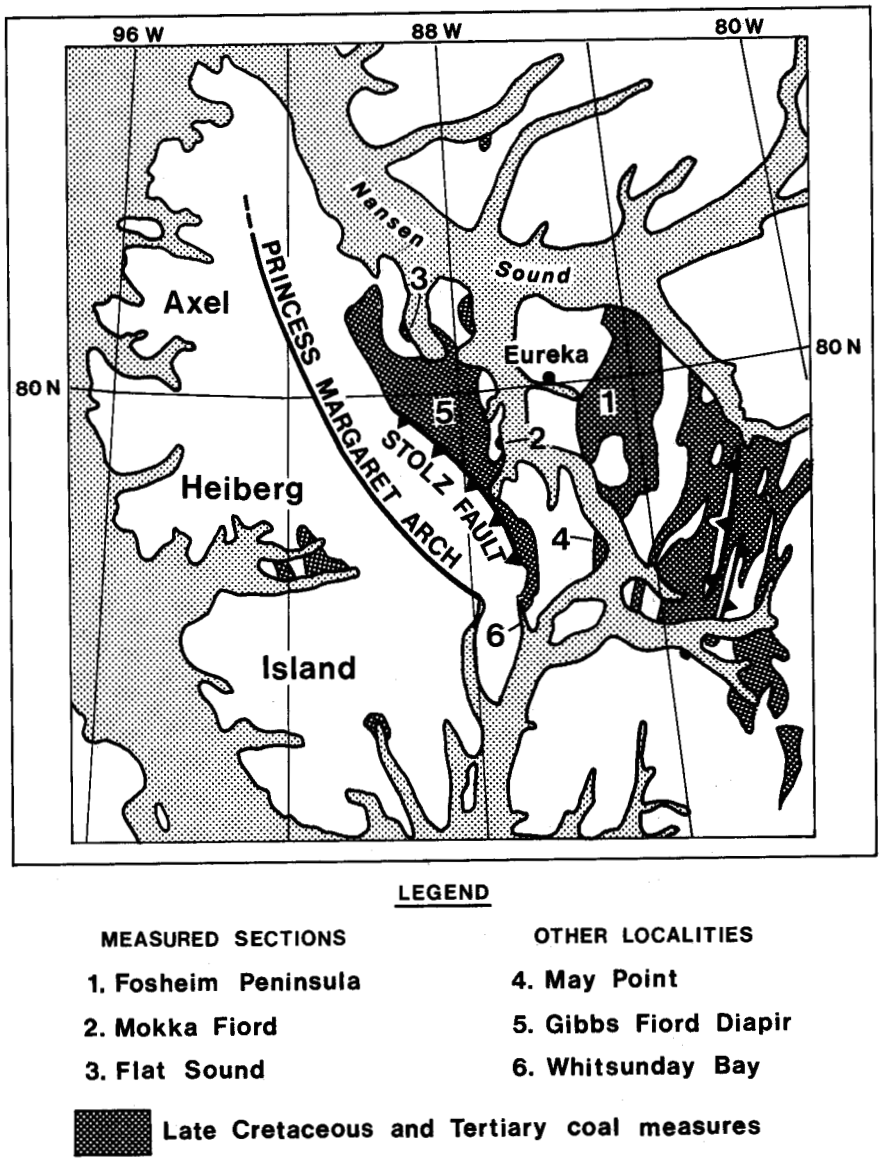
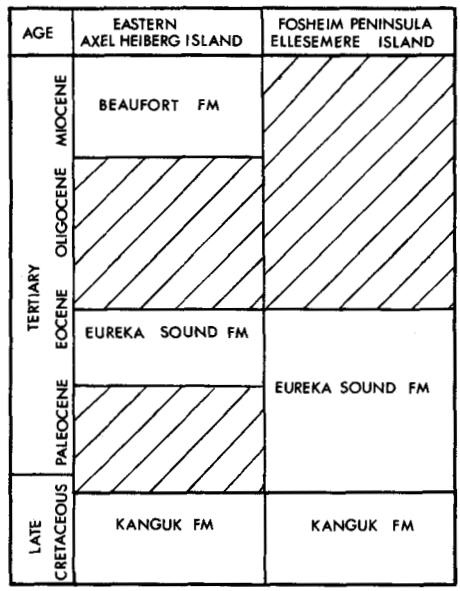


FIG. 2. Generalized geological map of the study area and adjacent regions showing the distribution of Late Cretaceous and Tertiary coal measures (shaded).

younger tectonism and erosion. During the Late Cretaceous, arch-like uplift of the northern margin of the Archipelago resulted in a southward progradation of deltaic and fluvial deltaic sediments resulting in progressive withdrawal of the Late Cretaceous Sea. In the early Paleocene uplift of a southerly plunging structural high on east-central Axel Heiberg Island resulted in the formation of an isolated basin with its depo-centre located in the Fosheim Peninsula area (Bustin, 1977). This basin, referred to as the Remus

TABLE 1. Upper Cretaceous and Tertiary stratigraphy, eastern Arctic Archipelago.



Basin, was bounded to the east by the uplift on east-central Axel Heiberg Island and to the west by the stable Paleozoic-Proterozoic platform of eastern Ellesmere Island (Bustin, 1977). From the Late Cretaceous through to the Middle Eocene a thick succession of deltaic and fluvial deltaic sediments accumulated in the Remus Basin. The only evidence for marine sedimentation is south of the Fosheim Peninsula area where probable Eocene marine fossils occur (West *et al.*, 1975). The last major phase of orogenesis in the eastern Arctic Archipelago occurred between the Middle Eocene and Miocene resulting in uplift, folding and faulting of the coal measures throughout the study area (Bustin, 1977). The oldest deposits post-dating this orogenic event are nearly flat-lying Miocene sediments assigned to the Beaufort Formation (Balkwill *et al.*, 1975; Bustin, 1977).

From the depo-centre of the Remus Basin at Fosheim Peninsula to the western flank of the basin on Eastern Axel Heiberg Island, there is a marked reduction in the thickness of the coal measures, a deterioration in quality of the coal and a decrease in the coal rank. In the following discussion these two areas are discussed separately.

Fosheim Peninsula

In the area of Fosheim Peninsula the coal measures outcrop over an area of about 2500 km^2 (Fig. 2). The regional structure is that of a broad northerly-trending synclinorium (Thorsteinsson, 1971). The structure of the synclinorium is relatively simple — broad, gentle northerly-plunging anticlines

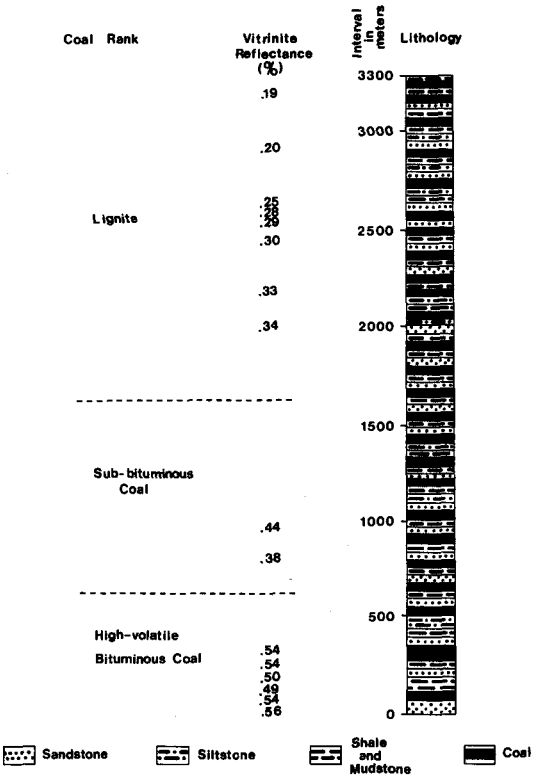


FIG. 3. Schematic lithologic log, variation in mean maximum vitrinite reflectance and coal rank at Fosheim Peninsula, Ellesmere Island.

and synclines and northerly-striking normal faults with throws which probably do not exceed 100 to 200 m. The coal measures conformably overlie Upper Cretaceous shales of the Kanguk Formation along the east and west limbs of the synclinorium. Quaternary gravels and sands ranging from 0.5 to 10 m thick mantle the coal measures throughout the Fosheim Peninsula area.

A section 3300 m thick was measured through the coal measures along Remus Creek on the west flank of the synclinorium. Although the section includes a number of major covered intervals, relatively good exposures are present which are considered representative of the coal measures (Fig. 3). Throughout the measured section the coal measures are composed of rhythmically interbedded shale, mudstone, siltstone, sandstone and coal. The lithologies have been described in detail by Bustin (1977). The shales are medium to dark grey, variably carbonaceous and thin- to thick-bedded. Mudstones are medium to dark grey, silty, carbonaceous, thin- to very thick-bedded, and predominantly unconsolidated. The siltstones are light grey to dark red, variably argillaceous and carbonaceous, generally thin-bedded and well indurated with a platy- to flaggy-splitting. Sandstones are white to

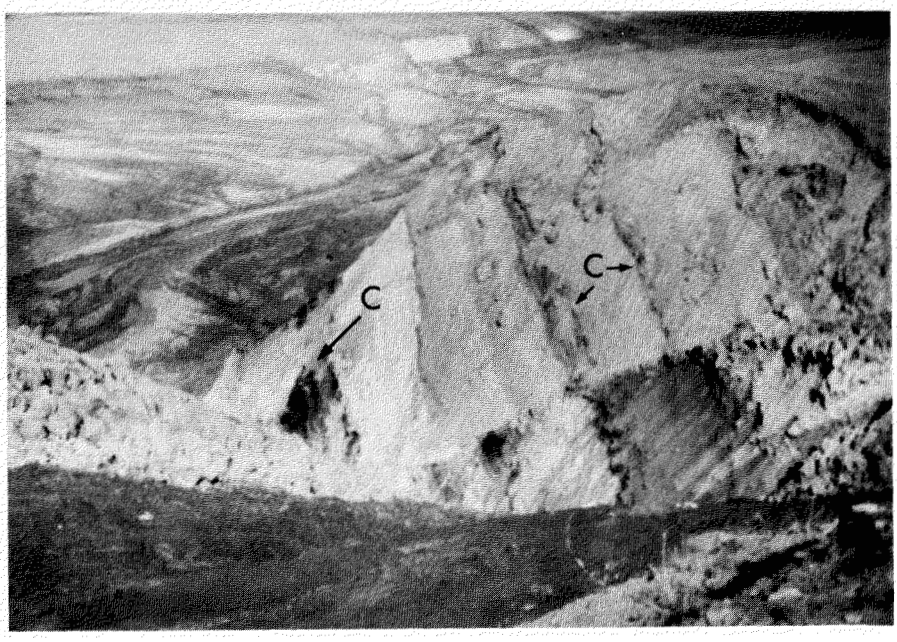


FIG. 4. **Coal seams (c) in the basal part of the Eureka Sound Formation, Fosheim Peninsula, Ellesmere Island.**

medium grey, highly quartzose and thin-bedded to massive with most being fine-to medium-grained and friable to completely unconsolidated. The coal is described in detail below.

Coal seams. In contrast to most coal measures, coal seams in the Eureka Sound Formation are one of the most competent rocks and commonly form low ridges. Coal seams occur throughout the measured section at Remus Creek although they are more abundant in the basal 1500 m of the section (Fig. 3). In the better exposed intervals of the measured section (45% of the total section) 86 coal seams were measured of which 48 seams are less than one metre thick and 28 seams are greater than one metre thick. The thickest measured seam was 10 m.

In general the thickness and quality of the coal seam deteriorated from the base to the top of the section. Coal seams at the base of the coal measures are clean, massive with little finely divided argillaceous material and few discreet rock bands (Fig. 4). Towards the top of the coal measures, particularly in the upper 1000 m, the coal is commonly argillaceous and granular, and in some areas gradational to carbonaceous mudstones and shales. The lateral continuity of individual seams is difficult to evaluate because of the recessive character of the coal measures. Where outcrop permits, however, individual seams were traced for distances in excess of one kilometre with little discernible variation in quality and thickness. Most analysed seams contain in the order of 70-80% vitrinite, 5-10% exinite and 5% fusinite. Semifusinite,

which is common in many western Canadian coals (Cameron, 1974), is present in only minor amounts. The dominant lithotypes are vitrain, followed by clarain and fusain.

Coal rank. The rank of the coal has been determined using the reflectance method following the procedures outlined by the American Society of Testing Materials (1970) and the correlation between reflectance and coal rank summarized by Teichmuller and Teichmuller (1966). Bustin *et al.* (1977) have summarized the equipment and techniques used in this study.

The coal rank ranges systematically from the base to the top of the section at Remus Creek (Fig. 3). The range in coal rank is from high volatile bituminous coal (0-600 m) to sub-bituminous coal (600 m to 1625 m) to lignite (1625 m to 3300 m). Such a systematic variation in coal rank with depth of burial is to be expected in areas where the present coal rank was established prior to orogenesis or structural complications. Consequently, the coal rank obtained from surface observation and in lieu of other data, may be extrapolated to the subsurface with some degree of confidence for reserve calculations.

Eastern Axel Heiberg Island

The area of outcrop of the Eureka Sound Formation on eastern Axel Heiberg Island is approximately 1500 km² (Fig. 2). The coal measures at most localities paraconformably overlie Cretaceous, Jurassic or Triassic strata except at May Point where the coal measures conformably overlie the Upper Cretaceous Kanguk Formation. The coal measures are unconformably overlain and mantled by Quaternary gravels and sands.

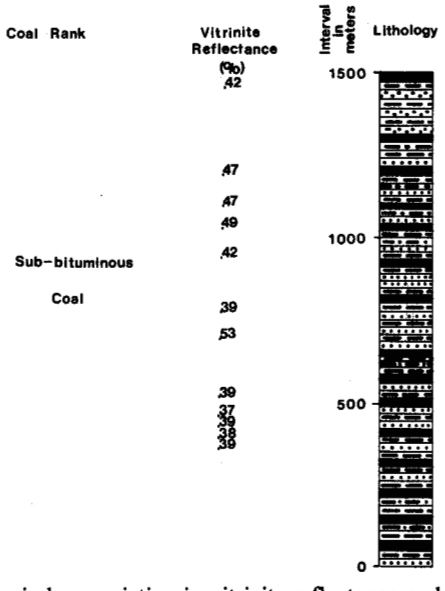


FIG. 5. Schematic lithologic log, variation in vitrinite reflectance and coal rank at Flat Sound, eastern Axel Heiberg Island (see legend on Fig. 3)

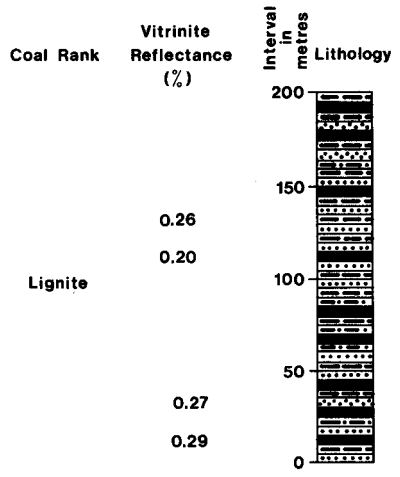


FIG. 6. Schematic lithologic log, variation in vitrinite reflectance and coal rank at Flat Sound, eastern Axel Heiberg Island (see legend on Fig. 3)

The regional structure of eastern Axel Heiberg Island is highly varied. On the easternmost parts of the island the coal measures are deformed into broad, generally gentle, north-plunging anticlines and synclines (Thorsteinsson, 1971; Thorsteinsson and Trettin, 1972). To the west, the coal measures are in part overthrust by the Stolz Fault and locally intruded by evaporite diapirs (Thorsteinsson, 1971).

The coal measures on eastern Axel Heiberg Island range in age from Late Paleocene to Middle Eocene (Table 1). Maastrichtian and early Paleocene strata are not represented with the exception of the May Point area. The coal measures are highly variable in thickness, ranging from a maximum measured thickness of 1500 m adjacent to Mokka Fiord to thin erosional outliers along parts of easternmost Axel Heiberg Island.

Measured sections of the coal measures adjacent to Mokka Fiord (Fig. 5) and Flat Sound (Fig. 6) show the general lithologies and rank of the coal. The lithologies are similar to those described at Fosheim Peninsula with the following exceptions; the sandstones are generally thicker and more massive, rare thin beds of conglomerate are present, the shales and mudstones are highly carbonaceous, and the coal is generally of poorer quality.

Coal seams. Coal is present in the Eureka Sound Formation at all examined localities on eastern Axel Heiberg Island. Adjacent to Mokka Fiord where the thickest succession of the coal measures are exposed, a total of 40 seams were measured through a 1500 m interval with about 70% exposure. Of the 40 seams, 22 are less than one metre thick and 18 are greater than one metre thick. The thickest seam is six metres thick, but contains a high percentage of argillaceous material. At Flat Sound, 10 seams were measured through a well exposed section 195 m thick (Fig. 6). Of the ten seams, nine are less than one metre thick and one seam was two metres thick. Additional areas where

FIG. 7. **Highly argillaceous coal seams (c) in the Eureka Sound Formation adjacent Mokka Fiord.**

particularly thick seams were observed are as follows; in the May Point area a five metre thick seam occurs near the base of the coal measures, east of Gibbs Fiord Diapir a four metre thick seam is exposed, and north of Whitsunday Bay several three to four metre thick seams crop out.

In many of the examined areas the coal is granular and highly argillaceous or arenaceous (Fig. 7). Some seams contain an estimated 20 to 30% ash and others are gradational to carbonaceous shales and mudstones. Distinct rock bands are absent from almost all seams. The recessive character of the coal measures does not enable prediction of the lateral continuity of the coal seams. A noteworthy exception is the five metre thick seam near the base of the coal measures in the May Point area which can be traced for 16 km.

Only the cleaner coal seams were selected for reflectance analysis; therefore, the petrography of the examined samples is not considered representative. Macroscopic examinations of the coal seams, however, indicated that the major lithotypes are vitrain followed by clarain and fusain.

Coal rank. The rank of the coal seams at Mokka Fiord and Flat Sound are summarized in Figures 5 and 6. At these localities the coal rank ranges between lignite and sub-bituminous B coal. Additional rank determinations indicate the presence of sub-bituminous C coal in the May Point area, high volatile bituminous C coal adjacent to Whitsunday Bay and sub-bituminous C and B coal between Whitsunday Bay and Mokka Fiord.

The variations in coal rank on eastern Axel Heiberg Island do not form a consistent trend with estimated depths of burial or age of the strata (Bustin *et*

al., 1977). Such variations in coal rank have been considered a function of anomalous heat flows possibly resulting from overthrusting of the Stolz Fault or intrusion of evaporite diapirs (Bustin *et al.*, 1977). Whatever the cause of the observed variations, any extrapolation of observed coal rank to the subsurface can only be made with caution.

COAL RESOURCES

Resource calculations presented in this study belong primarily to the 'inferred resources' category of Latour (1972). That is, the resource estimates are based on a broad knowledge of the character of the coal measures and on assumed continuity of the coal seams in areas remote from outcrops. In this paper, it is not considered justifiable to differentiate between the 'inferred' and 'indicated' resource categories. The calculations presented here were obtained by considering those seams which are equal to or greater than one metre thick and extrapolating their thickness over the area of outcrop to a depth of 200 m. In calculating coal resources it is customary to introduce a reduction factor in the total estimates in areas where the continuity of seams cannot be demonstrated. With the calculations presented here no such reduction figure was introduced. The calculations must only be considered approximate within orders of magnitude.

Coal resources in the Fosheim Peninsula area are estimated to be in the order of 21 000 million tonnes. Of the total resource estimate, 4000 million tonnes is considered to be high volatile bituminous coal, 7000 million tonnes sub-bituminous coal and 10 000 million tonnes are lignite.

Coal resources of the Eastern Axel Heiberg area are estimated to be in the order of 9000 million tonnes. Of these resources 4000 million tonnes are sub-bituminous coal, 5000 million tonnes are lignite and 300 million tonnes are high volatile bituminous coal.

CONCLUSIONS AND SUMMARY

Preliminary investigation indicates that substantial resources of high volatile bituminous coal, sub-bituminous coal and lignite occur in the eastern Arctic Archipelago. In the area considered the coal resources are estimated to be in the order of 30 000 million tonnes of which 4000 million tonnes is high volatile bituminous coal, 11 000 million tonnes is sub-bituminous coal and 15 000 million tonnes is lignite. The area of study encompasses only a small portion of the known outcrop area of Tertiary coal measures in the Arctic Archipelago, which strongly suggests that considerable additional coal resources are present. Although coal resources located in such remote areas as the Canadian Arctic Archipelago are not presently attributed any economic significance, recent advances in coal mining, processing and transportation technology may enable future exploitation of the coal if sizable resources can be shown to exist.

ACKNOWLEDGEMENTS

I am grateful to J.D. Hale of John D. Hale Consulting Ltd., Calgary for suggesting that the paper be written, and to Drs. D.G. Perry and W.H. Mathews of the University of British Columbia and L.V. Hills of the University of Calgary who provided many useful suggestions on earlier drafts. The study was financially supported by the Geological Survey of Canada and a Natural Science and Engineering Research Council (Canada) grant to L. V. Hills.

REFERENCES

American Society of Testing Materials. 1970. Book of A.S.T.M. Standards. Part 19, Gaseous fuels, coal and coke. Philadephia, Pa. p. 502.

BALKWILL, H.R., BUSTIN, R.M., and HOPKINS, W.S. Jr. 1975. Eureka Sound Formation at Flat Sound, Axel Heiberg Island and chronology of the Eurekan Orogeny. In: Report of Activities, Part B. Geological Survey of Canada Paper 75-1B. 205-207.

BUSTIN, R.M. 1977. Eureka Sound and Beaufort Formation, Axel Heiberg and west central Ellesmere Island, District of Franklin. M.Sc. Thesis, University of Calgary. 208 p.

———, HILLS, L.V., and GUNTHER, P.R. 1977. Implications of coalification levels, Eureka Sound Formation, northeastern Arctic Canada. Canadian Journal of Earth Sciences 14(7): 1588-1597.

CAMERON, A.E. 1974. Petrography of Kootenay coals in the upper Elk River and Crowsnest areas, British Columbia and Alberta. In: Mellon, G.B., Kramers, J.W., and Seagel, E.J. (eds.), Proceedings First Geological Conference on western Canadian coal. Research Council of Alberta, Information Series No. 60: 31-46.

FORTIER, Y.O., BLACKADAR, R.G., GLENISTER, B.F., GREINER, H.R., McLAREN, D.J., McMILLAN, N.J., NORRIS, A.W., ROOTS, E.F., SOUTHER, J.G., THORSTEINSSON, R., and TOZER, E.T. 1963. Geology of the north-central part of the Arctic Archipelago, Northwest Territories (Operation Franklin). Geological Survey of Canada Memoir 320.

HILLS, L.V. and WALLACE, S. 1969. Paraalnipollenites, a new form genus from uppermost Cretaceous and Paleocene rocks of Arctic Canada and Russia. Geological Survey of Canada Bulletin 182: 139-145.

LATOUR, B.A. 1972. Coal deposits of western and North America. In: Mellon, G.B., Kramers, J.W. and Seagel, E.J. (eds.), Proceedings, First Geological Conference on western Canadian coal. Research Council of Alberta, Information Series No. 60: 1-8.

TEICHMULLER, M. and TEICHMULLER, R. 1966. Geological causes of coalification. Coal Sciences. Advances in Chemistry Series. 55: 133-135.

THORSTEINSSON, R. 1971. Geology, Slidre Fiord, District of Franklin. Geological Survey of Canada. Map 1298A.

——— and TRETTIN, H.P. 1972. Geology, Bukken Fiord, District of Franklin. Geological Survey of Canada. Map 1310A.

TOZER, E.T. 1963. Mesozoic and Tertiary stratigraphy, western Ellesmere Island and Axel Heiberg Island, District of Franklin. Geological Survey of Canada. Paper 63-30. 38 p.

———. 1970. Mesozoic and Cenozoic. In: Thorsteinsson, R. and Tozer, E.T., Geology of the Arctic Archipelago. In: Douglas, R.J.W. (ed.), Geology and economic minerals of Canada: Geological Survey of Canada. Economic Geology. Report No. 1, 5th ed. p. 574-589.

TRETTIN, H.P., (Coord.). 1972. The Innuitian Province. In: Price, R.A. and Douglas, R.JW. (eds.), Variations in tectonic styles in Canada. Geological Association of Canada: Special Paper 11. p. 83-179.

TROELSEN, J.C. 1950. Contribution to the geology of northwest Greenland, Ellesmere and Axel Heiberg Islands. Meddelelser om Grønland 147: 85 p.

WEST, R.M. 1977. Warm-climate life on ancient Ellesmere Island. Geoscience, Winter 1977: p. 9-11.

———, DAWSON, M. R., HUTCHINSON, J.H. and RAMAEKERS, R. 1975. Paleontologic evidence of marine sediments in the Eureka Sound Formation of Ellesmere Island, Arctic Archipelago, N.W.T., Canada. Canadian Journal of Earth Sciences 12: 574-579.