72. SUBSURFACE STRATIGRAPHY, CONODONT ZONATION, AND ORGANIC METAMORPHISM OF THE LOWER PALEOZOIC SUCCESSION, BJORNE PENINSULA, ELLESMERE ISLAND, DISTRICT OF FRANKLIN

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Abstract

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Strata penetrated by two wells (Panarctic Tenneco et al. CSP Eids M-66 and Panarctic ARCO et al. Blue Fiord E-46), located at southern Bjorne Peninsula in southwestern Ellesmere Island, range in age from late Early Devonian to Early Ordovician (Eids to Copes Bay formations). In terms of conodont zonation, this span is from Faunas 7-8 of Klapper et al. (1971) to Fauna D of Ethington Clark (1971). An organic metamorphism study, based on conodonts, has been initiated only in the Canadian Arctic Islands, and no firm conclusions can be drawn at this time. The study does suggest, however, that in a rock that has been assessed as a mature hydrocarbon source by geochemical analyses, the values of the conodont colour alteration index (CAI) may be higher in terrigenous sediments than in carbonates.

Introduction

Two wells, Panarctic Tenneco et al. CSP Eids M-66 and Panarctic ARCO et al. Blue Fiord E-46, located in the southern part of Bjorne Peninsula in southwestern Ellesmere Island (Fig. 72.1), are under study. The rocks encountered in these wells were deposited in a marginal zone of a Siluro-Ordovician carbonate platform. The wells penetrated a sequence ranging from the Lower Devonian to Lower Ordovician, from the Eids to Copes Bay formations (Fig. 72.2).

In this account, description of formations and discussion of their stratigraphic relationships are by Mayr; biostratigraphic and colour alteration studies of the Siluro-Devonian conodonts are by Uyeno, and of the Ordovician conodonts by Barnes. The final part on organic metamorphism and source rock potential is a joint responsibility of the three authors.

We are grateful to Anita G. Harris of the U.S. Geological Survey, Washington, for providing a set of standards of conodonts of different CAI values. R. Thorsteinsson and T.G. Powell, both of I.S.P.G., provided us with graptolite identifications, and geochemical analyses, respectively. Three of the participants of the wells, Panarctic Oils Ltd., Petro-Canada Exploration Inc., and Tenneco Oil and Minerals, Ltd., provided us with bulk samples for conodont sudy.

Stratigraphy

Both wells were spudded in the Eids Formation, which consists of calcareous, dolomitic, and micaceous siltstone. A gradient in grain size appears to be present between the two wells, because the siltstone in the Eids M-66 well is interbedded with subordinate very fine grained sandstone, whereas the siltstone in the Blue Fiord E-46 well is generally argillaceous. The contact with the underlying Cape Phillips Formation is gradational and was drawn at a colour change from light to dark grey.

Only the Blue Fiord E-46 well [in the interval 60-1300 ft (18.3-396.2 m)] yielded stratigraphically useful conodonts from the Eids Formation; a form transitional between **Pandorinellina exigua philipi** (Klapper) and **P. exigua exigua** (Philip). Such a form was reported previously from the Road River Formation at Royal Creek, Yukon Territory (Klapper, 1969, p. 17, Pl. 5, figs. 1-7). The Royal Creek occurrence suggests an assignment of this form to Faunas 7 and 8 of Klapper et al. (1971, Fig. 1), or the **Polygnathus dehiscens** Fauna of Weddige and Ziegler (1977, p. 70), of late Early Devonian (Emsian) age. The informal faunal units of Klapper et al. (1971) are currently being given zonal terms (see Klapper and Johnson, 1977, p. 1051). This transitional form of **Pandorinellina exigua**, together with **P.** cf. **P. expansa** Uyeno and Mason, are present in a sample collected by R. Thorsteinsson from the Eids Formation at its type area (GSC loc. 57730; McLaren, 1963, p. 317; see Collins, 1969, p. 32, 33, 36 for locality details). **Pandorinellina exigua** (Philip) and **Polygnathus inversus** Klapper and Johnson were reported by Weyant (1975) from the lower member of the Blue Fiord Formation at its type area (McLaren, 1963, p. 319), and may be assigned to Fauna 9 of Klapper et al. (1971, Fig. 1) or the **Polygnathus latiscostatus** Fauna of Weddige and Ziegler (1977, p. 71).

At Sör Fiord, to the southeast of the study-area **Polygnathus dehiscens** was reported from the Eids Formation (Klapper and Johnson, 1975, Fig. 4) and, therefore, is of similar age to the Eids Formation in the E-46 well.

The stratigraphic relationship between the Eids and Cape Phillips formations is not known, but may be resolved by palynomorph identifications in progress.

The Cape Phillips Formation [top at 271 ft (82.6 m), M-66; 1576 ft (480.4 m), E-46] overlies and laterally replaces the Siluro-Ordovician carbonates of the Read Bay and Allen Bay formations. It is in the order of 500 m (1500 ft) thick and consists of calcareous and silty, very dark grey shale. Interbeds of dark brown lime mudstone and skeletal wackestone are present in the lower part of the formation in the Eids M-66 well.

Graptolites at a depth of 1720 feet (524.3 m) in the Eids M-66 well (?**Stromatograptus** sp. indet. and **Monograptus** sp. indet., R. Thorsteinsson, pers. comm., 1977) indicate a latest Llandoverian or earliest Wenlockian age for the lower part of the formation in the northern part of the study-area. The age assignment based on graptolites is corroborated by conodont dating. **Pterospathodus celloni** (Walliser) and **Astropentagnathus irregularis** Mostler in the 1740 to 1860 foot (530.4-566.9 m) interval indicate the P. **celloni** Zone of Walliser (1964) [=**Icriodella inconstans** Zone of Aldridge (1972)]. This zone correlates with the C_5 subdivision of the Upper Llandovery Series (Aldridge, 1972, p. 153, Tables 1-4; Klapper and Murphy, 1975, p. 7), and constitutes a part of the Telychian stage of Cocks et al. (1970). **"Neoprioniodus" planus** Walliser occurs in the interval from 1830 to 1980 feet (557.8-603.5 m) and suggests an early Silurian age (Fig. 72.2).

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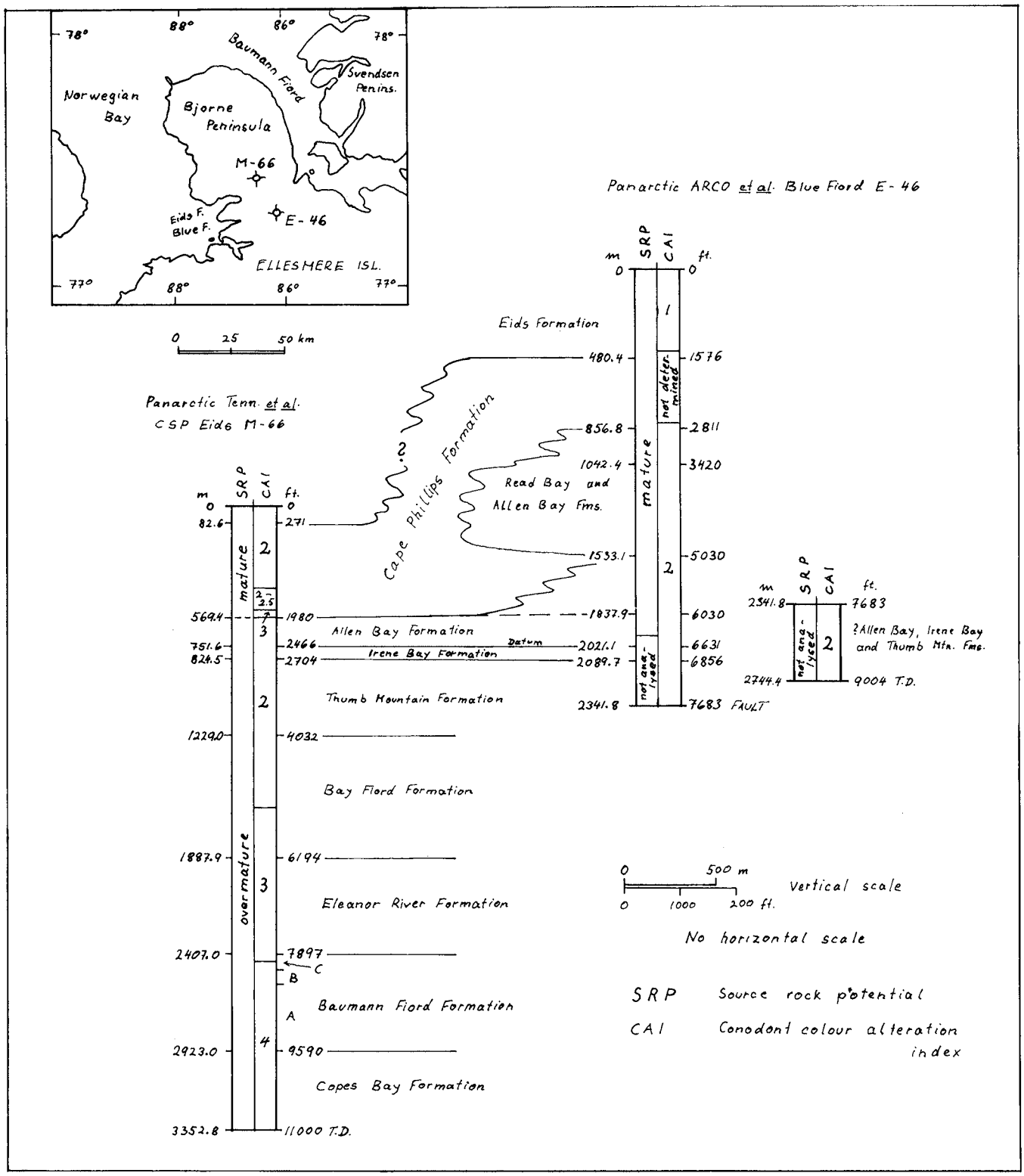

Figure 72.1. Correlation, conodont colour alteration index (CAI) values, and hydrocarbon maturity of Panarctic Tenneco et al. CSP Eids M-66 and Panarctic ARCO et a. Blue Fiord E-46 wells.

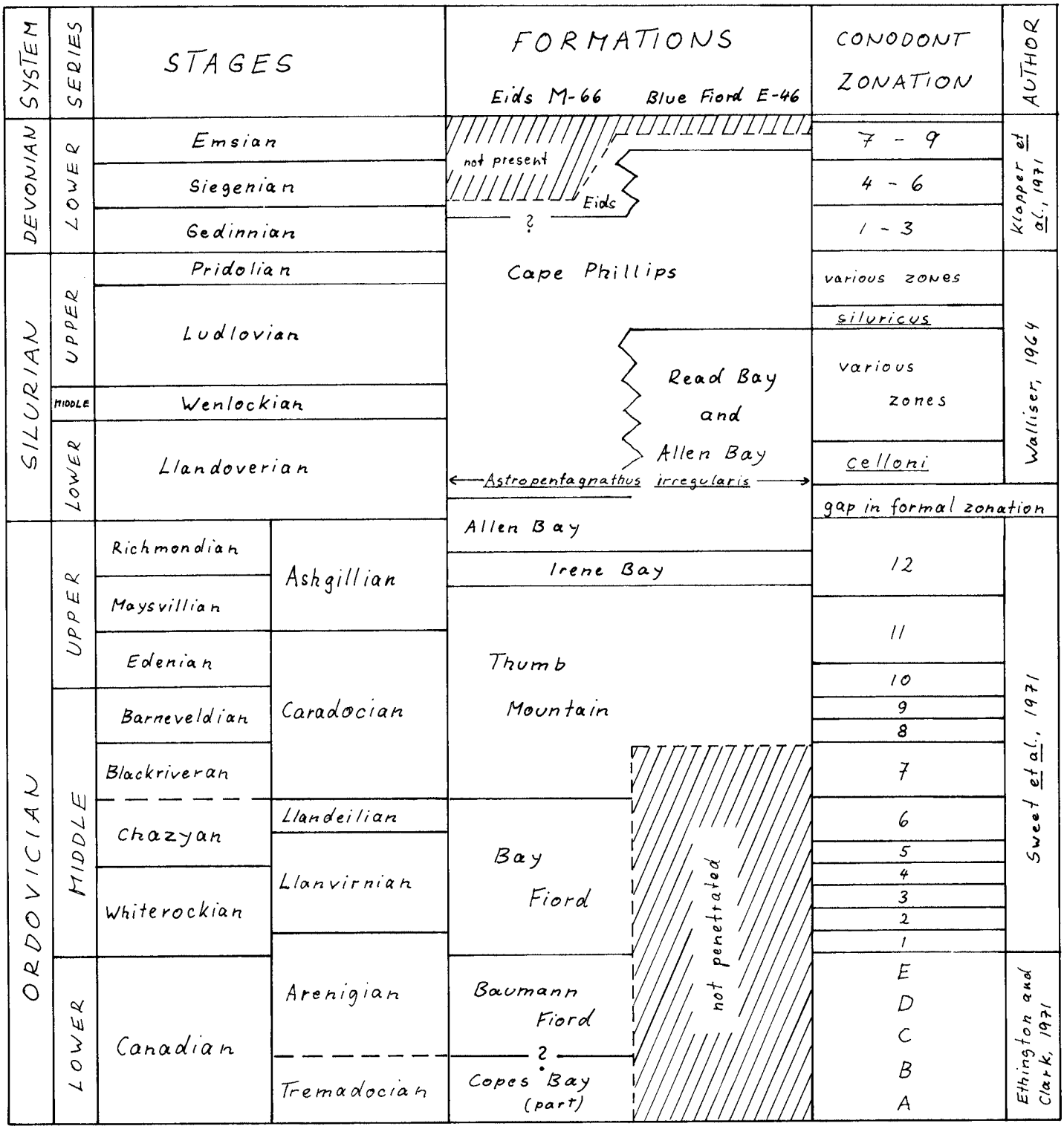

Figure 72.2. Conodont zonation of the strata encountered in the two wells studied herein.

A single conodont fragment was obtained from the Cape Phillips Formation in the Blue Fiord E-46 well, but was unidentifiable.

In the Eids M-66 well, the Allen Bay Formation is 148.1 m (486 ft) thick [top at 1980 ft (569.4 m)]. In the Blue Fiord E-46 well, the Siluro-Ordovician carbonates are 1164.3 m (3820 ft) thick [top at 2811 ft (856 m)] and include the Allen Bay and Read Bay formations. The Allen Bay Formation in the Eids M-66 well comprises carbonates of relatively deep water origin. They consist of dark brown-grey lime mudstone and very finely crystalline dolomite with abundant fragments of **Pseudogygites** sp. A similar very dark unit, although completely dolomitized and silicified, forms the lower part of the carbonates in the Blue Fiord E-46 well [top at 6030 ft (1837.9 m)]. This unit is overlain by carbonates, consisting of interbedded bioclastic limestone and dark coloured calcareous shale and argillaceous lime mudstone [top at 5030 ft (1533.1 m)]. These probable slope carbonates are overlain by 490.7 m (1610 ft) of very pale coloured, medium and finely crystalline dolomite [top at 3420 ft (1042.4 m)]. The extensive dolomitization of this unit hinders facies interpretation, but it is possible that the unit represents a reefoidal platform margin. Reefs are known from outcrops on Svendsen Peninsula (Mayr, 1974; McGill, 1975). The uppermost unit of the Silurian carbonates forms a transition zone to the overlying Cape Phillips Formation and consists of dolomitic, silty and argillaceous lime mudstone.

Ozarkodina excavata excavata (Branson and Mehl) in the Read Bay-Allen Bay unit of the Blue Fiord well [2700-2900 ft (823.0-883.9 m) interval] is a long-ranging form, extending from Middle Silurian (**Kockelella patula** Zone) through Lower Devonian (Klapper in Ziegler, 1973, p. 226). In the interval from 3300 to 3400 feet (1005.8-1036.3) is **Ozarkodina** cf. **O.** n. sp. B of Klapper (in Klapper and Murphy, 1975), a form identical to that illustrated by Uyeno (1977, p. 214, Pl. 41.1, figs. 7, 8) from the upper part of the Cape Storm Formation at eastern Cornwallis Island. There it cannot be dated precisely, but occurs just below an interval carrying conodonts of probable **Polygnathoides siluricus** Zone (about mid-Ludlow; Walliser, 1971, Text-fig. 1). **Astropentagnathus irregularis** occurs in the 5800 to 5900 foot (1767.8-1798.3 m) interval, indicating the **P. celloni** Zone (see discussion under Cape Phillips Formation), and is correlated with the 1740 to 1860 foot (530.4-566.9 m) interval of the Eids M-66 well (Fig. 72.2). **"Neoprioniodus" planus** ranges from 5600 to 6400 feet (1706.9-1950.7 m) in the E-46 well and suggests an early Silurian age.

Below the 2030-foot (618.7 m) level in the Eids M-66 well are conodonts assignable to Fauna 12 of Sweet et al. (1971) of Late Ordovician age [late Maysvillian to Richmondian; Barnes (1974)].

The Irene Bay Formation top at 2466 ft (751.6 m), M-66; 6631 ft (2021.1 m), E-46 is about 70 m (230 ft) thick and its lithology is variable. It is typical in the Eids M-66 well, where it consists of variably argillaceous lime mudstone and calcareous shale. In the Blue Fiord E-46 well, however, the formation consists of coarsely and medium crystalline, euhedral, white dolomite. The argillaceous material is preserved as green intercrystalline matrix. The upper boundary in the Blue Fiord well is based on a colour change from dark to light in the cuttings samples and a very small deflection in the gamma ray log.

Conodonts from the upper part of the formation in the Eids M-66 well [above 2570 ft (783.3 m)] are assignable to Fauna 12, as in the overlying Allen Bay Formation (Fig. 72.2).

The Thumb Mountain Formation [top at 2704 ft (824.5 m), M-66; 6856 ft (2089.7 m), E-46] is 404.5 m (1328 ft) thick in the Eids M-66 well. The lower part consists of lime mudstone with dolomitic mottling (Core 1 of Eids M-66 well), whereas the upper part consists of ?cryptalgal lime mudstone in the Eids well and of medium and coarsely crystalline dolomite in the Blue Fiord well.

Several intervals in the Eids M-66 well yielded conodonts. The interval from 3110 to 3430 feet (947.9-1045.5 m) contained conodonts belonging to Fauna 8 (Sweet et al., 1971), whereas in the lower part of the formation at 3910 feet (1191.8 m), the conodonts are assignable to Fauna 6 or 7. This faunal range is well within the age range of the Thumb Mountain Formation (Fig. 72.2) which is from Fauna 7 to 11, Blackriveran to early Maysvillian (Caradocian to early Ashgillian) according to Nowlan (1976).

Also assigned tentatively to the Thumb Mountain Formation, on the basis of similarity in lithology, is the upper part of the interval below 7683 feet (2341.8 m) in the Blue Fiord E-46 well. The interval between 8410 and 8900 feet (2563.4 and 2712.7 m), however, contains elements of Fauna 12 which suggest correlation of this interval with the Allen Bay and Irene Bay formations. At present, the true stratigraphic position of the sequence below the 7683-foot (2341.8 m) level in the E-46 well is not known. It probably is a complexly faulted and folded, perhaps even overturned, unit, which contains slices of Thumb Mountain, Irene Bay and, possibly, Allen Bay formations.

The Bay Fiord Formation [top at 4032 ft (1229.0 m), M-66] is 658.9 m (2162 ft) thick. The lower part comprises aphanocrystalline dolomite interbedded with shale and anhydrite. The thin middle part [4700-4845 ft (1432.6-1476.8 m)] contains dolomitic, probably mottled, lime mudstone with abundant fossil fragments. The upper part consists of dolomite and minor limestone and anhydrite.

Conodonts were obtained from several levels within the Bay Fiord Formation in the Eids M-66 well, ranging from 4540 feet (1383.8 m) at its highest part [with conodonts of Fauna 6 or 7 of Sweet et al. (1971)] to 6160 feet (1877.6 m) at the lowest (with Fauna 2 or 3). The lowest level is only a short distance above the lower formational boundary. The age of the formation, therefore, is from early Blackriveran (early Caradocian, late Middle Ordovician) to late Whiterockian (early Llanvirnian, early Middle Ordovician) (Fig. 72.2). This range is identical with that reported by Nowlan (1976) based on outcrop sections.

The Eleanor River Formation [top at 6195 ft (1887.9 m), M-66] is 519.1 m (1703 ft) thick and consists of dolomite and limestone. The middle part of the formation is argillaceous and contains subordinate interbedded shale and anhydrite.

In terms of conodonts, the formation has a slightly different age range than has been recorded from elsewhere in the Arctic Islands (Barnes, 1974; Nowlan, 1976) on Grinnell Peninsula and central eastern Ellesmere Island. In the Eids M-66 well, the range is from Fauna 2 or 3 [6210 ft (1892.8 m)] to Fauna E or 1 [(7900 ft (2407.9 m)] (Ethington and Clark, 1971; Sweet et al., 1971). This is a range from about late Whiterockian (early Llanvirnian, early Middle Ordovician) to late Canadian (late Arenigian) (Fig. 72.2).

On comparing the age span of the Eleanor River Formation in the Eids M-66 well with that reported from outcrops, it is noted that the upper limit is approximately the same. However, conodonts of Fauna D (Ethington and Clark, 1971) (about middle Arenigian or middle Early Ordovician) have been reported in the oldest part of the formation in outcrops (Nowlan, 1976).

The Baumann Fiord Formation [top at 7897 ft (2407.0 m), M-66] is 516.0 m (1693 ft) thick and its three members (Kerr, 1967) can be distinguished by the anhydrite content of the formation. Member A [top at 8402 ft (2560.9 m)] consists of very finely crystalline dolomite, interbedded with anhydrite and various types of limestone, including pelletoidal grainstone. Member B [top at 8146 ft (2482.9 m)] comprises lime mudstone, whereas member C is similar to member A, but appears to contain more argillaceous material.

Member B yielded conodonts belonging to Ethington and Clark's (1971) Fauna D which is of middle Arenigian (about middle Early Ordovician) age (Fig. 72.2).

The Copes Bay Formation is present below 9590 feet (2923.0 m) in the M-66 well and is more than 429.8 m (1410 ft) thick. The lower part consists of variable limestone with subordinate beds of calcareous sandstone and siltstone, whereas the upper part comprises finely crystalline or aphanocrystalline dolomite and lime mudstone. Cored intervals show ripple cross-beds, bioturbation and possibly mudcracks. No conodonts were found in the Copes Bay Formation.

Organic metamorphism study (conodont colour alteration)

Epstein et al. (1977) arranged the conodonts of different colours in an order of increasing darkness, grouped them according to similarity in darkness, and then assigned each set a value of colour alteration index (CAI). They demonstrated that the colour changes are time and temperature dependent, and that the different colours of conodonts, therefore, can be used as a tool to assess organic metamorphism. The conodont CAI values were correlated with vitrinite reflectance and fixed carbon ranges. Using the Appalachian basin as their test model, they found that a CAI value of 1.5 coincides with that level of organic metamorphism above which there is no known commercial oil and condensate production.

The relationship between the CAI and the degree of organic metamorphism may be related aside from being dependent on temperature, to variations in the host rock and the history of burial. For these reasons, Epstein et al. (1977, p. 15) limited their study to one rock type, namely limestone, in order to eliminate the unknown effect of host rock texture and composition on the colour alteration of conodonts.

It should be noted, also, that Epstein et al. (1977, p. 24) have stressed that the upper thermal limits, inferred from conodont CAI values, for oil production for different stratigraphic intervals, are not the same everywhere. This factor, in addition to the lack of information concerning the relationship between CAI and the source rock potential resulting from organic hydrocarbon analyses, have led the authors to a study, now in progress, to investigate what these relationships may be, if there are any, in the lower Paleozoic rocks of the Arctic Islands.

In the Eids M-66 well, the interval from 30 to 1410 feet (9.1-429.8 m) (Eids and the upper part of Cape Phillips formations) has yielded conodonts with a CAI value of 2 (Fig. 72.1). The interval from 1480 to 1860 feet (451.1-566.9 m) yielded conodonts with a CAI value of 2-2.5 and the interval from 1890 to 1980 feet (576.1-603.6 m), CAI value of 3. The change from terrigenous sediments to carbonates at 1980 feet (603.5 m) coincides approximately with a reversal of the CAI value to 2, but below that it increases gradually to 3 at 5300 feet (1615.4 m) and to 4 at 8000 feet (2438.4 m).

In the Blue Fiord E-46 well, conodonts from the Eids Formation [60-1300 ft (18.3-396.2 m) interval] have a CAI value of 1. Conodonts from the Cape Phillips Formation [2700-2800 ft (823.0-853.4 m)] and the Read Bay-Allen Bay formations [2800-6400 ft (853.4-1950.7 m)] have a CAI value of 2. From there the same CAI value continues downward through the Cornwallis Group to the bottom of the well (Fig. 72.1).

The organic source rock potential, based on the yield of liquid hydrocarbons as a percentage of the total organic carbon (T.G. Powell, pers. comm., 1977), has been plotted on Figure 72.1. One notes that there is no obvious direct relationship between the CAI and source rock potential. Differences in the characteristics of the host rock appear to affect, in varying amount, the degree of conodont colour alteration. In the terrigenous sediments of the Cape Phillips Formation, for example, the CAI value may go as high as 3 in the mature zone.

In carbonates, the correlation between the CAI and source rock potential is also variable. In the dominantly limestone sequence of the Eids M-66 well, a CAI value of 2 falls into the overmature zone, corroborating the conclusions of Epstein et al. (1977), but in the dolomite sequence of the Blue Biord E-46 well, a CAI value of 2 is present in an interval which has been assessed as mature.

In summary, an organic metamorphism study, based on conodont CAI values, has been initiated only in the Canadian Arctic Islands, so no firm conclusions can be drawn. It appears, however, that in a rock that has been assessed as a mature hydrocarbon source by geochemical analyses, the values of the conodont CAI may be higher in terrigenous sediments than in carbonates.

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