Early Ordovician eustatic events in Canada

By CHRISTOPHER R. BARNES

Four areas are discussed for which the Lower Ordovician and lower Middle Ordovician stratigraphy, sedimentology and paleontology are well documented: southern Rocky Mountains, Mackenzie Mountains, Arctic Canada, western Newfoundland. For each area a curve is developed representing major regional facies shifts through this time interval. The four areas are widely separated around the outer passive continental margin and slope of the ancient Canadan (Laurentian) craton. In comparing these areas, similar changes in the curves suggest that these are the result of eustatic changes in sea level. A generalized curve of transgressions and regressions is developed for the craton with transgressions in the early and late Tremadoc, mid to late Arenig and late Whiterock; regressive phases occur in the early Arenig and early Whiterock with a brief regressive pulse in the late Arenig. Paleogeographic maps for the Canadian craton during the Tremadoc, Arenig and Whiterock stages illustrate the major facies belts and the changing patterns of epeiric seas on the craton.

C. R. Barnes, Department of Earth Sciences, Memorial University of Newfoundland, St. John's, Newfoundland, A1B 3X5, Canada.

Several attempts have been made in recent years to document eustatic sea level changes from Lower Paleozoic successions (e. g. Benedict & Walker 1978; McKerrow 1979; Johnson & Campbell 1980; Johnson *et al.* 1981; Leggett *et al.* 1981; Lenz 1982). Most of these studies have used a combination of stratigraphical, sedimentological, and paleontological data to establish local apparent changes in sea level. Such apparent changes can, however, be induced by a variety of factors including eustacy, progradation, epeirogeny, tectonism which may operate individually or in combination. Space does not permit a review of this problem (see e.g. Pitman 1978). For the discrimination of unequivocal eustatic events the widespread (preferably global) occurrence of specific sea level changes must be established. It is the purpose of this paper to demonstrate that such widespread eustatic events can be recognized in Lower Ordovician strata in Canada, across distances of several thousand kilometers. Such events will need to be further tested by comparative analysis of data from outer cratonic areas (e. g. Australian and Siberian platforms).

As Lenz (1982) has noted, there is usually a larger data base available for cratonic platform facies than for abyssal facies in terms of stratigraphical, sedimentological and paleontological information. Further, the less deformed platformal sequences allow greater precision in applying the various criteria available to determine eustatic change (Benedict & Walker 1982). This paper will, therefore, only consider the platformal and slope facies of the Lower Ordovician in Canada. There are only a few major regions in Canada where most of this stratigraphic interval is well exposed, and has been studied in terms of its stratigraphy, sedimentology and paleontology to a degree that allows interpretation of eustatic changes. These areas are confined to the outer margins of the craton because Early Ordovician seas did not transgress across the interior region of the Canadian Shield as shown by paleogeographic reconstructions presented below. The areas selected for detailed review and for the interpretation of eustatic change are the southern Rocky Mountains, Mackenzie Montains, Arctic Canada and western Newfoundland. All were located on or adjacent to passive continental margins during the Lower Ordovician; only in western Newfoundland was the margin influenced by an adjacent subduction zone and in this area it did not significantly affect the margin until Middle Ordovician time (mar-

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gin collapse and ophiolite obduction). Discussion of the biostratigraphy and stratigraphical correlation of most of these areas, together with detailed references, has been presented by Barnes *et al.* (1976; 1981). Together, these areas allow an analysis of eustatic events experienced by the northern half of Laurentia (ancient North American craton) during the Early Ordovician. The object is to identify first order events and to filter out local second or third order eustatic events; these events are interpreted, and then compared, through a series of figures showing the stratigraphy and interpreted depositional environments for each region (Figs. 1–4).

Southern Rocky Mountains

The Lower Ordovician formations for western and eastern parts of the southern Rocky Mountain Fold Belt are shown in Figure 1, together with a general indication of the horizons with accurate biostratigraphic control based on conodonts (c), graptolites (g) and shelly fossils (s). The two areas represent stable platform environments with the western sections (Kicking Horse River, North White River areas) being located near the ancieng platform margin. The sections in the Main Ranges of the Rocky Mountains are the best documented, with the Survey Peak, Outram, Tipperary and Skoki formations being approximately 515, 440, 175, and 185 m in thickness, respectively. These formations are predominantly, carbonate with some shale; the Tipperary is a quartzite (Aitken *et al.* 1972).

The Survey Peak Formation overlies with sharp lithologic change the massive stromatolitic limestones and dolomites of the upward shallowing Mistaya Formation (Trempealeauan). The four informal members of the Survey Peak, in ascending order, are the basal silty, putty shale, middle and upper massive members. Aitken & Norford (1967) and Aitken 1966, 1978) considered the formation to represent a single "Grand Cycle" with the lower two members comprising a predominantly clastic, inner (?) detrital facies and the upper two members representing an upward shallowing, prograding, middle carbonate facies. Both the carbonates and clastics display a variety of shallow water sedimentary structures and a rather sparse fauna of trilobites, brachiopods, gastropods, sponges and conodonts, with thrombolites common in the upper member.

The Outram Formation is predominantly limestone, with calcareous quartzose siltstone and brown shale. The limestones are of variable lithology, but thick bedded, clotted-nodular limestone and thin beds of trilobite-brachiopod-pelmatozoan-gastropod grainstone are common; chert nodules occur throughout. The grainstones become widespread toward the top of the formation. There are no sedimentary structures indicative of intertidal environments. The formation grades westwards into the graptolitic Glenogle Shale.

Locally developed on top of the Outram Formation, or within the Glenogle Shale, the Tipperary Quartzite is thick bedded, unfossiliferous and in places dolomitic. It pinches out depositionally to the north and west.

The Skoki Formation is composed of dolomitized limestone typically pelmatozoan grainstone in the lower part passing upward into packstone and wackestone and near the top into oncolitic packstone with abundant gastropods (*Maclurites, Palliseria*). An interdigitating, diachronous contact with the underlying Outram Formation has been established. The formation spans the Lower-Middle Ordovician boundary.

Figure 1 includes an interpretative curve for the changing depositional environments within this sequence expressed in terms of intertidal, shallow subtidal and deep subtidal environments. These changes in environment may be interpreted as being produced by eustatic change. The intertidal stromatolitic facies of the upper Mistaya is replaced abruptly by open circulation conditions, but still relatively shallow, of the lower Survey Peak clastic members. The carbonate facies of the upper Survey Peak represents a shallowing event climaxing at the top with the massive thrombolitic limestone. The Outram Formation is clearly a deep subtidal facies and the change at the lower formational boundary is relatively abrupt. In the Main Ranges area, the influx of the Tipperary Quartzite marks a brief return to nearshore or intertidal conditions. The overlying Skoki Formation represents a complex of shallow subtidal environments with a relative shallowing up-

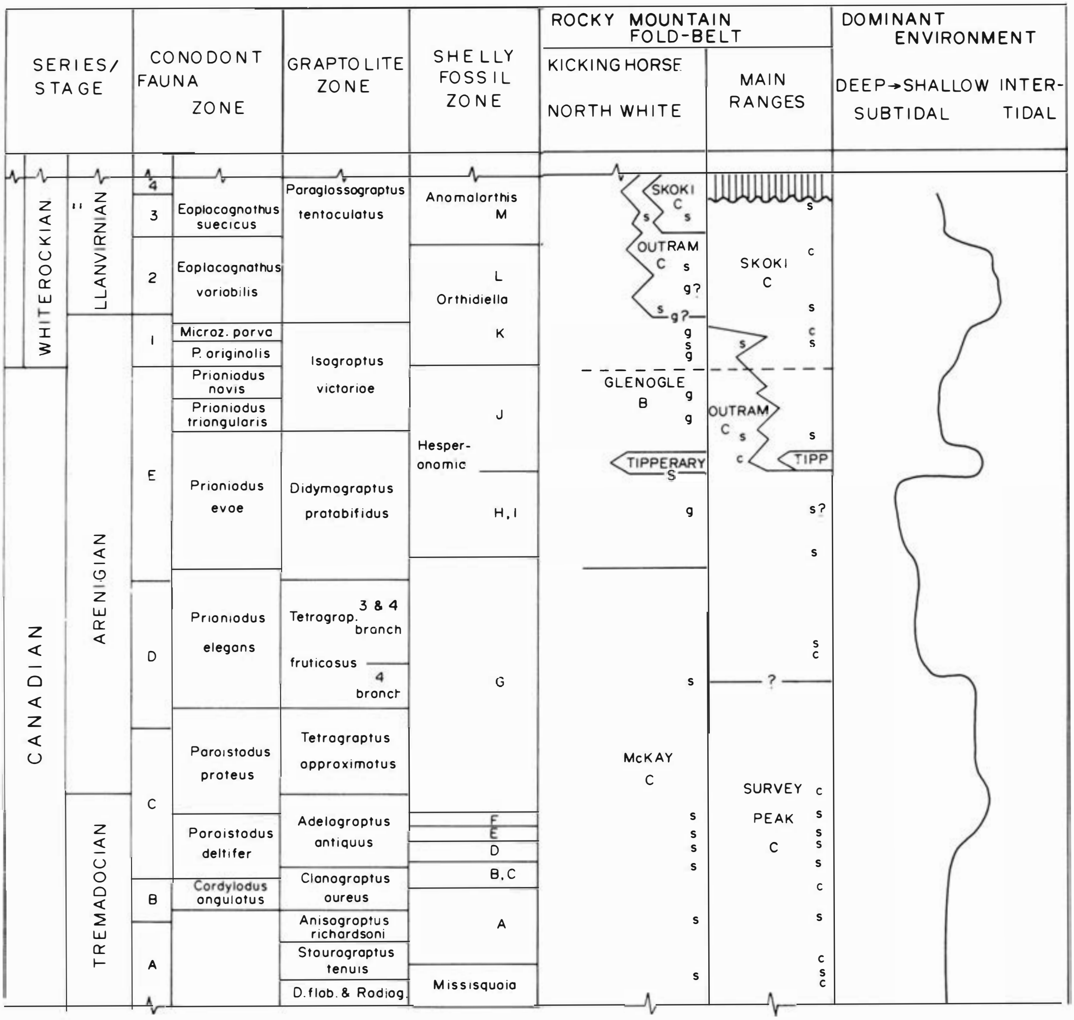

Fig. 1 – Stratigraphy, biostratigraphical control levels, and curve showing major changes in depositional environment for southern Rocky Mountains (c = conodont, g = graptolite, s = shelly, fossil, as control levels). Chronostratigraphy from Barnes et al. 1981.

wards marked by the oncolitic and gastropod limestones.

Mackenzie Mountains

In the northwestern part of Canada, Lower Ordovician strata are well exposed in the Selwyn and Mackenzie Fold Belts (Fig. 1). The central Mackenzie Mountains preserve a carbonate platform facies and part of a transitional slope facies. Further west, basinal shales are preserved in the Selwyn Basin and Misty Creek Embayent. The stratigraphy and paleontology of these areas has been detailed by Gabrielse *et al.* 1973; Ludvigsen 1975; 1978; 1979; 1982; Copeland 1977; Tipnis *et al.* 1978; Gordey 1980; Landing *et al.* 1980; and Cecile 1982.

The Broken Skull Formation consists of a thick sequence of dolostones and limestones, commonly sandy. It is correlative in part with the dolostones of the Franklin Mountain Formation (760 m thick) of the Mackenzie Moun-

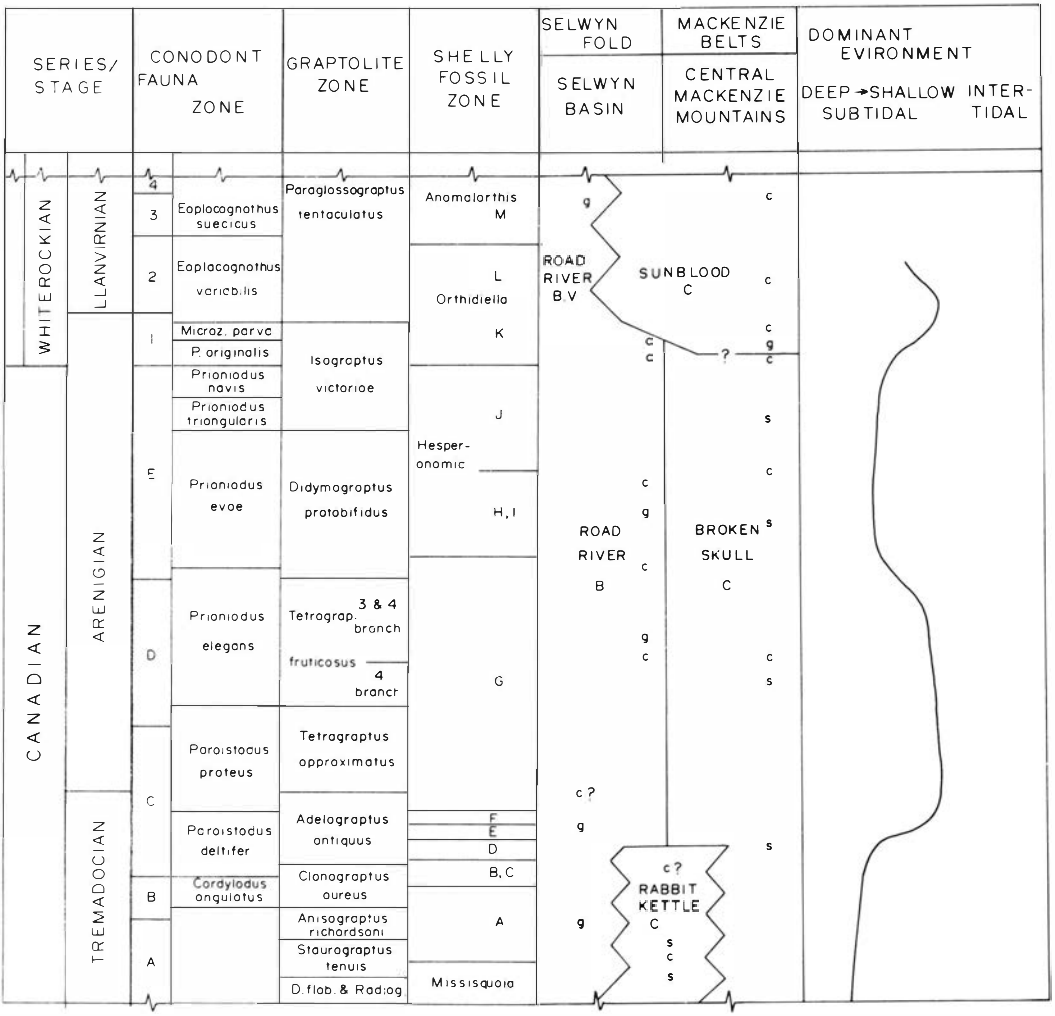

Fig. 2 – Stratigraphy, biostratigraphical control levels, and curve showing major changes in depositional environment for Mackenzie Mountains.

tains and Franklin Mountains to the east (Norford & Macqueen 1975). Shelly fossils allow correlation with the Ross-Hintze zones of the Great Basin sequence in Utah-Nevada but more detailed study is needed to better document minor facies changes as reflected by the cyclic, rhythmic, and cherty units.

The Broken Skull Formation passes westwards into the transitional slope facies of the Rabbitkettle Formation. Both formations were initiated in the Late Cambrian. The Rabbitkettle Formation (up to 750 m thick) consists of thin bedded silty limestone with shaly partings. Ludvigsen (1982) has shown subtle but important petrographic differences within the formation with some of the limestones being black laminated lime mudstones whereas others below are burrowed lime wackestones. He attributed the change to a deepening phase at the base of the *Corbinia apopsis* Subzone of the *Saukia* Zone coincident to the base of the "Hystricurid" Biomere and a Grand Cycle. The Rabbitkettle Formation extends into the Late Tremadoc in some areas (e.g. western District of Mackenzie; Ludvigsen 1982) and then is overlain by a black barren dolostone member of

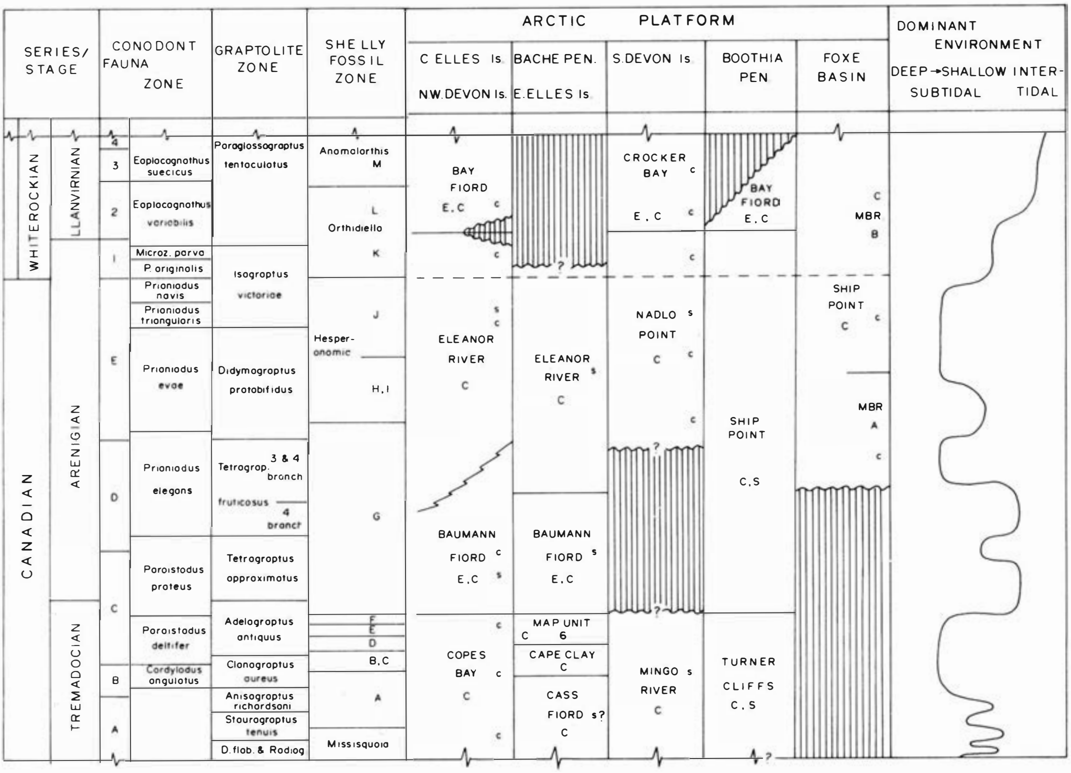

Fig. 3 – Stratigraphy, biostratigraphical control levels, and curve showing major changes in depositional environment for Arctic Canada.

the Road River Formation probably reflecting a brief relative shallowing. In other areas (e.g. southwest Mackenzie Arch; Cecile 1982), the Rabbitkettle Formation persists to approximately the base of the Whiterock before being overstepped by the basal Sunblood Formation as a result of another relative shallowing event.

The Sunblood Formation (up to 1400 thick) consists of dark grey dolostone, alternating dark and light grey dolostone overlain by limestone, locally with interbedded sandstone, and finally by grey limestone and dolostone, locally bioclastic (stratigraphy revised by Ludvigsen 1975). The formation is characterized by vivid weathering colours due to a high silt content. Ludvigsen (1975) advocated a shallow sublittoral, occasionally littoral environment for the Sunblood.

In terms of depositional environments, a generalized curve for the Mackenzie Mountains area is shown on Figure 2. It must be emphasized that this reflects changes in the areas of carbonate platform edge to transitional slope facies and is based largely in Ludvigsen's recent studies. He has demonstrated, in applying the Grand Cycle concept to the Rabbitkettle Formation, that a marked relative deepening in the slope facies occurs at the base of the *Corbinia apopsis* Subzone (late Trempealeauan). The black dolostone member, basal Road River Formation, and the nature of the middle Broken Skull Formation indicates an overall shallowing phase in both slope and platform facies. The more diverse faunas of the upper Broken Skull Formation and the development of more anoxic conditions in the laterally equivalent part of the Road River Formation suggests a relative deepening. The basal Sunblood Formation and its overstepping relationship to the slope facies indicates a fairly abrupt shallowing phase in early Whiterockian time. These changes are reflected in shifts in trilobite and conodont biofacies (Ludvigsen 1975, 1978; Tipnis *et al.* 1978; Landing *et al.* 1980).

Arctic Canada

In Arctic Canada, Lower Ordovician rocks are widely exposed in many areas of the Arctic Islands and northern mainland, together comprising the Arctic Platform (Fig. 3). Formational names change across this vast territory but the basic lithological successions are remarkably similar. Details of the Lower Ordovician stratigraphy and paleontology provides a basis for review comments have been published by several authors including Kerr 1968; Mossop 1979; Barnes 1974; Morrow & Kerr 1977; Mayr 1978; Miall & Kerr 1980.

The lower and late Middle Ordovician succession, where complete, typically consists of an alternation of two major facies: shallow subtidal carbonate, and evaporite. The Copes Bay and Eleanor River formations represent the former and the Baumann Fiord and Bay Fiord formations represent the latter.

The Copes Bay Formation (commonly 300–500 m in thickness) has a lower and upper part that consists of thick to massive bedded, mottled, limestone with a variety of sedimentary structures indicating a shallow subtidal environment. In many localities, an interval within the formation consists of thin bedded dolostones with desiccation cracks indicative of regional shallowing.

The overlying Bay Fiord Formation (300–350 m thick) is siminar in lithology to the evaporitic Baumann Fiord and both are recessive in outcrop. Limestones and shales predominate toward the top of the formation. As with the Baumann Fiord Formation, the unit is locally thin or absent and marked by an hiatus.

The Lower Ordovician succession in the Arctic Platform thus represents an oscillation of shallow subtidal and evaporitic intertidal-supratidal environments. The facies persist for significant periods of time. A curve representing these shifts through time is included in Figure 3; the oscillations at the base of the chart are diagrammatic, representing the stromatolitic cycles in the lower Copes Bay Formation.

Western Newfoundland

This area contains excellent exposures of Lower Ordovician strata of the carbonate platform facies (St. George Group) and also in the continental slope facies of the Cow Head Group preserved in adjacent allochthonous sheets. These two facies belts have long been studied in detail and much recent work has also been completed or is in progress. The review below is based on many of these detailed studies including Kindle & Whittington 1958; 1959; Whittington 1968; Hubert *et al.* 1977; Knight 1977 a, b, 1978; Fåhraeus & Nowlan 1978; Fortey 1979; Fortey & Skevington 1980; Stouge 1980, 1981, in press; Fortey *et al.* 1982; Stouge & Godfrey 1982.

The St. George Group (about 500 m thick) consists of four formations, in ascending order the Watts Bight, Boat Harbour, Catoche and Port au Choix formations. It is overlain, commonly disconformably, by the Table Head Group. The St. George Group consists of dolostones and limestones, commonly stromatolitic or bioturbated, and with chert at some horizons. There are a few brecciated horizons produced during karst formation following regressive phases. The pattern of shifts between exposure, intertidal and shallow subtidal facies has been detailed by Stouge (in press, Fig. 6) who has interpreted these changes in terms of major and minor eustatic events and the major ones are incorporated into the curve shown on Figure 4. Important lead-zinc deposits (e.g. Daniels Harbour) are associated with these paleokarst horizons.

The Cow Head Group (Ordovician part being about 160 m thick) is a sequence of thin bedded ribbon limestone and graptolitic shale that are interbedded with carbonate conglomerate and breccia with clasts or blocks up to many tens of metres in diameter. The breccias were derived through down-slope slumps or flows carrying carbonate blocks from the shelf margin (James 1981). The thin bedded limestones and graptolitic shales represent slow deposition on the continental slope whereas the thick breccia units represent sudden brief influxes of carbonate debris. There are major faunal differences between the two carbonate facies. It has been proposed (Stouge, in press;

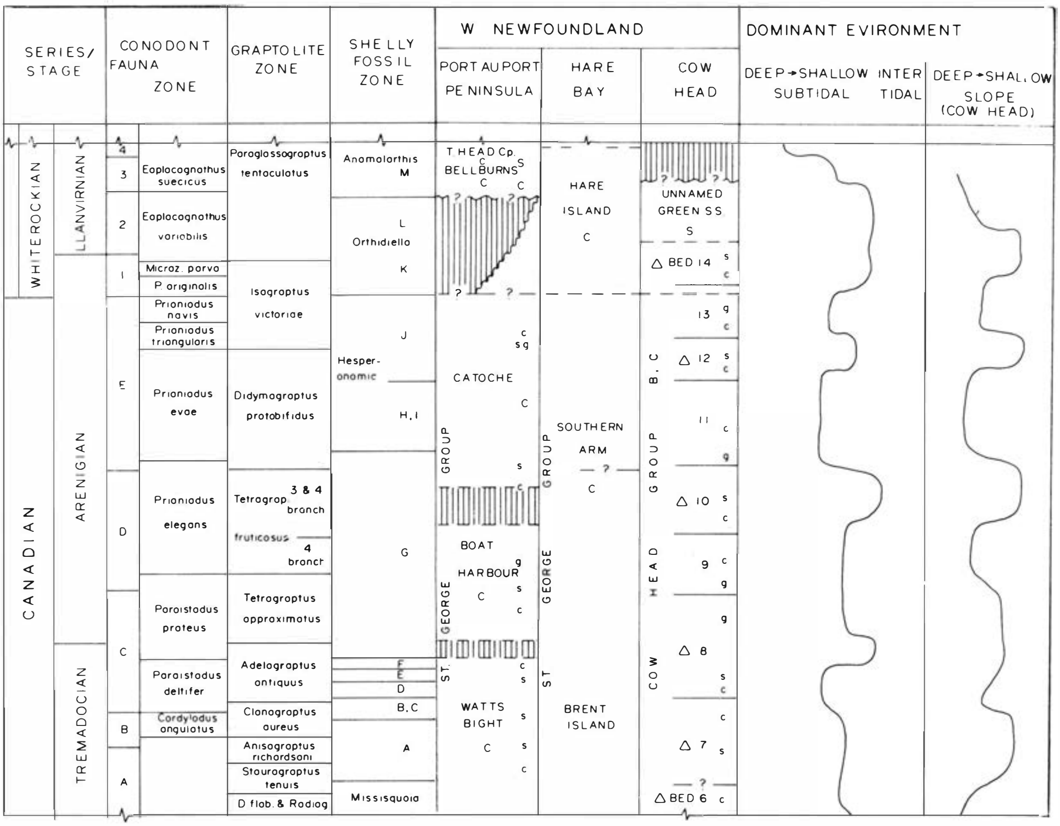

Fig. 4 – Stratigraphy, biostratigraphical control levels, and curves showing major changes in depositional environment for western Newfoundland. Open triangles show location of main megabreccias within numbered units (Beds) of Cow Head Group.

N. P. James and R. K. Stevens, pers. comm. 1981) that the megabreccias were generated during regressive phases when the carbonate platform margin was exposed and brecciated with the formation of karst surfaces. In Figure 4, the formal beds numbered within the Cow Head Group that contain the large megabreccias are shown with an open triangle. Several, but not all, seem to correlate well with the hiatuses demonstrated by stratigraphic studies and conodont biostratigraphy (e.g. Stouge, in press) in the St. George Group strata of the carbonate platform facies. Work in progress to try to refine further these events and correlations.

The carbonate platform suffered a major collapse in early Middle Ordovician time with the shallow water carbonates of the lower Table Head Group passing up into graptolitic shales in the upper Table Head. These shales are overlain by a flysch sequence and by obducted ophiolites. The continental margin is interpreted as being drawn down into an easterly dipping subduction zone. Some of the late Early Ordovician hiatuses may have resulted from a temporarily upwarped margin prior to collapse. However, as shown below, they do correlate with other apparent eustatic events elsewhere in Canada.

Summary

In four areas of Canada, the Lower Ordovician and lower Middle Ordovician stratigraphic record is remarkably complete and has been well documented in terms of its stratigraphy, sedimentology and paleontology: the southern

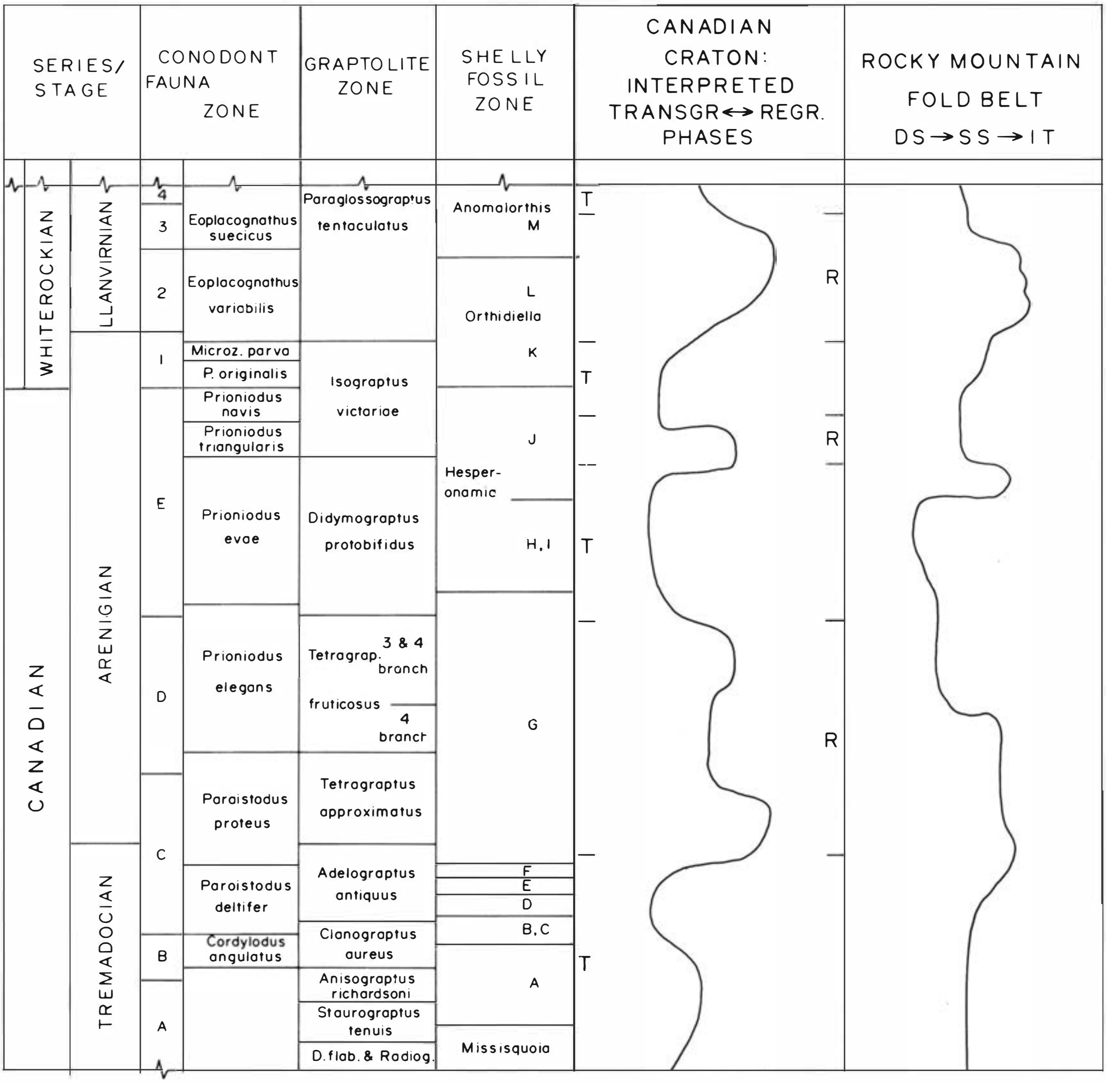

Fig. 5 – Interpreted transgressive–regressive phases for the Canadian craton during the Early and early Middle Ordovician, constructed by comparison of curves developed from southern Rocky Mountains, Mackenzie Mountains, Arctic Canada, and western Newfoundland.

Rocky Mountains, the Mackenzie Mountains, Arctic Canada, and western Newfoundland. Published data, not fully repeated herein because of space constraints, allows a curve to be developed for each area that plots the changing depositional environments. First order facies shifts are recognized and correlated against the chronostratigraphy and zonations adopted by Barnes, Norford and Skevington (1981).

In any particular region such major regional facies changes may be a result of various factors such as eustacy, progradation, epeirogeny, tectonism, or any combination of such factors. In this review paper, it is suggested that if major facies changes occur at the same time in the four widely separated areas around the margin of the ancient Laurentian craton then these are likely caused by eustatic sea level changes. This will need to be further checked against similar data from other cratons.

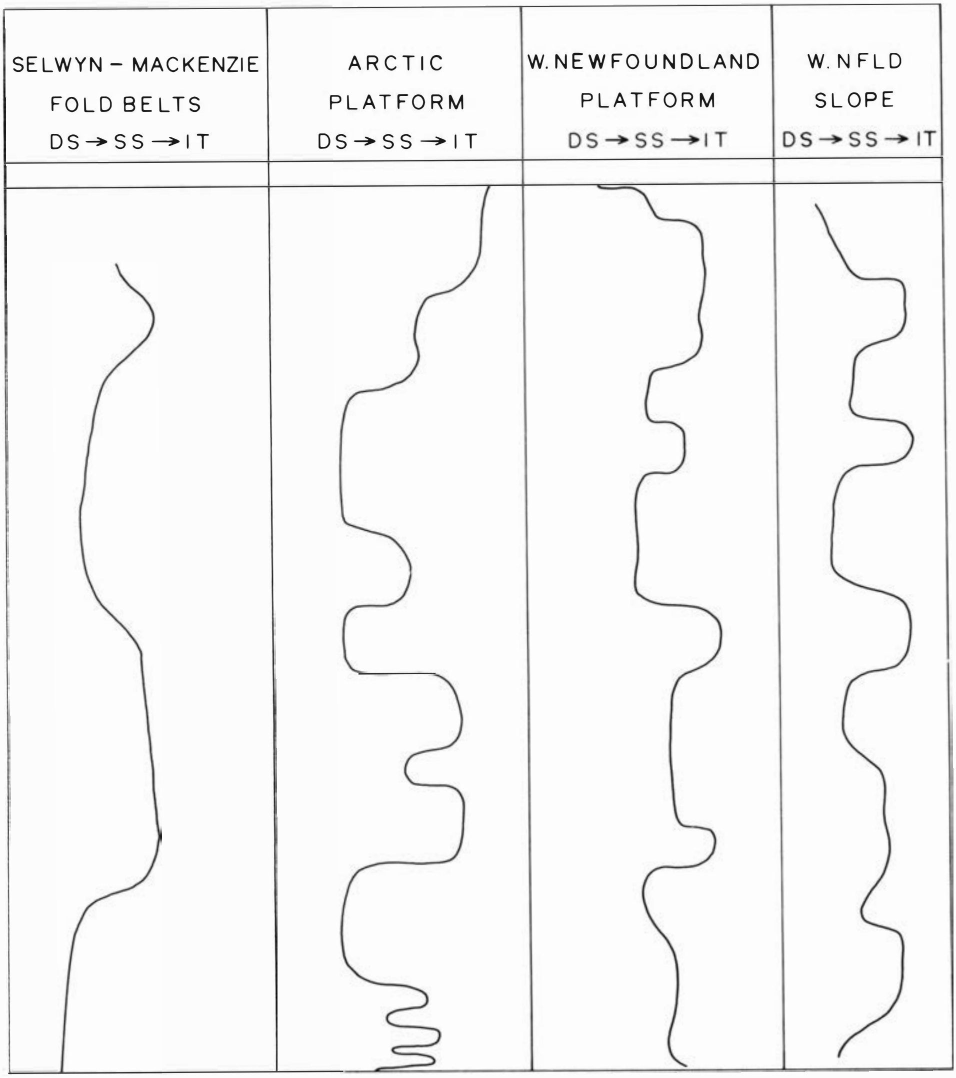

Figure 5 provides a comparison of the curves developed in the four areas. From these, a subjective generalized curve is derived which identifies major transgressive-regressive eustatic changes that affected the Canadian craton during the Early and early Middle Ordovician. Transgressive phases are recognized for the early and late Tremadoc, the mid to late Arenig and the late Whiterock. Major regressive phases occur during the early Arenig and the early Whiterock with a brief regressive phase in the late Arenig. These changes are portrayed as paleogeographic maps for the Tremadoc, Arenig, and Whiterock stages for the Canadian craton (Figs. 6–8), although such divisions cannot express the several eustatic changes that occur within each stage or series and must be viewed as generalized reconstructions. Although developed independently these results compare closely with the conclusions reached by

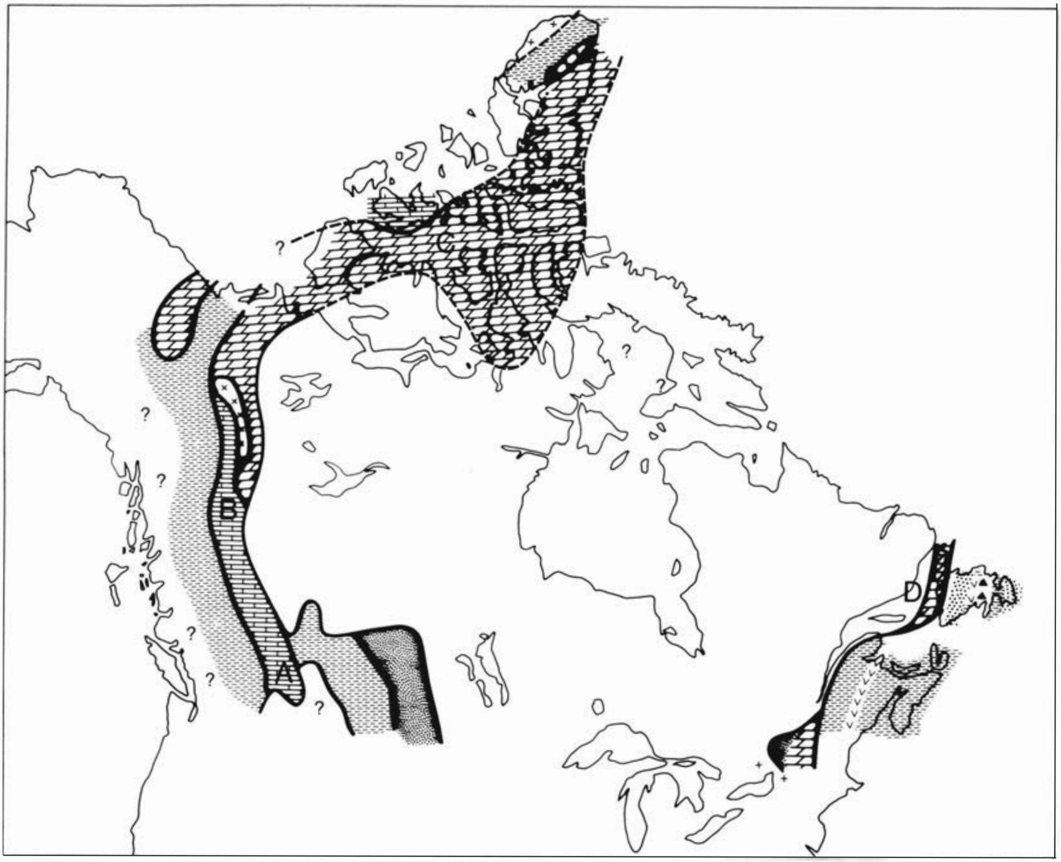

Fig. 6 – Paleogeographic recounstruction for the Canadian craton during the Tremadoc. General areas of southern Rocky Mountains, Mackenzie Mountains, Arctic Canada, and Western Newfoundland marked by letters, A, B, C and D, respectively.

Fortey's analysis (this volume) of Early Ordovician eustatic events from orther areas.

It is stressed that while full documentation could not be included here, it seems evident that eustatic events can be recognized for the Early and early Middle Ordovician in Canada. Similar unpublished data show that more detailed curves can be generated for the Middle and Late Ordovician. Although imperfect, it would be extremely valuable to see such curves generated for many other areas of the world in order that global coverage be attained to properly test the hypothesis that the curves do truly reflect eustatic events.

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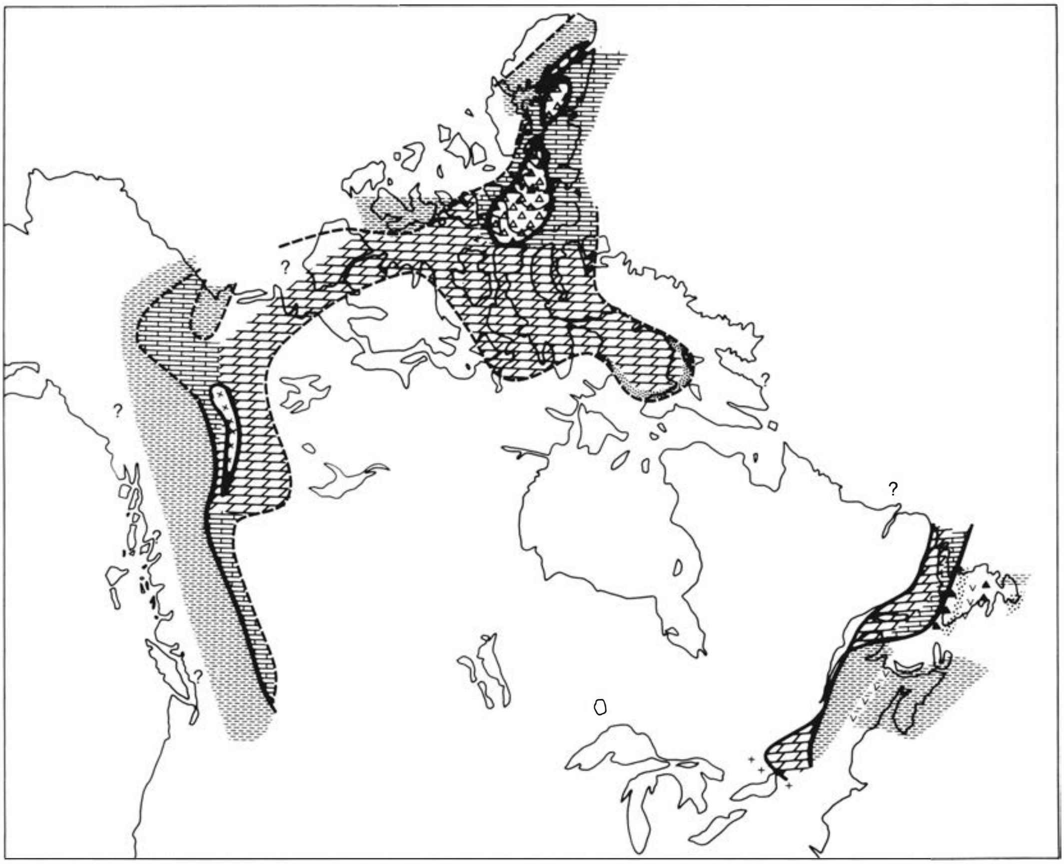

Fig. 7 – Palaeogeographic reconstruction for the Canadian craton during the early to middle Arenig. Open triangles indicate evaporite facies, crosses indicate local land areas.

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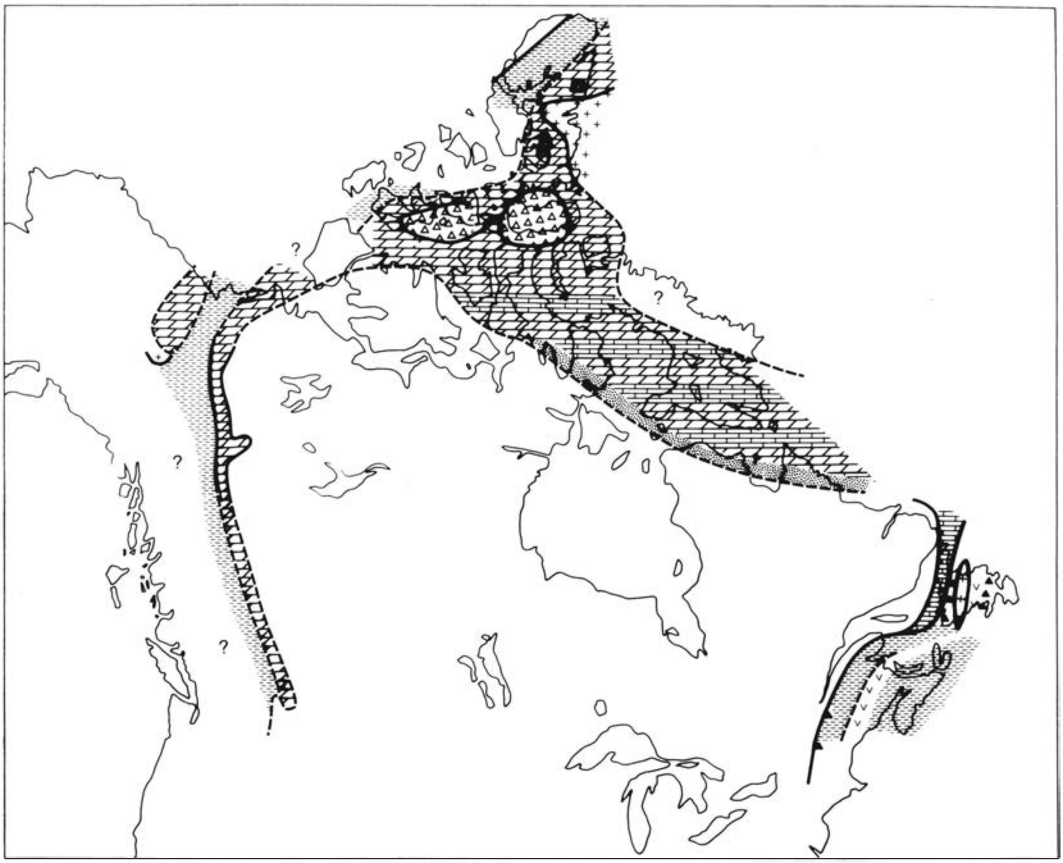

Fig. 8 – Paleogeographic reconstruction for the Canadian craton during Whiterock. Open triangles indicate evaporited facies.

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