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Global Stratotype Section and Point for base of the Ordovician System

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The Global Stratotype Section and Point for base of the Ordovician System and base of the lowest Ordovician stage (Tremadocian) is exposed in the coastal platform at Green Point, western Newfoundland, at the 101.8 m level, within Bed 23, in the measured section (Lower Broom Point Member, Green Point Formation), coinciding with the first appearance of the conodont Iapetognathus fluctivagus Nicoll, Miller, Nowlan, Repetski and Ethington, 1999, and 4.8 m below the earliest planktic graptolites.

Introduction

The Ordovician is the last of the Paleozoic Periods (and Systems) to have its lower boundary formally designated. The International Working Group on the Cambrian-Ordovician Boundary (COBWG) reached a decision on its choice of Global Stratotype Section and Point (GSSP) for base of the Ordovician System in January 1999, 25 years after its inauguration. The decision was approved by the International Subcommittee on Ordovician Stratigraphy (ISOS) in September 1999, by the Commission on Stratigraphy in November 1999, and by the International Union of Geological Sciences in January 2000.

The COBWG visited and examined candidate sections in Kazakhstan, China, Australia, Scandinavia, Britain and North America. Two volumes of papers on candidate boundary sections were published (Bassett and Dean, 1982, and a special 1988 issue of Geological Magazine v. 125, no. 4). In addition, two volumes of papers on the Dayangcha section alone have been published (Chen et al., 1985; 1986).

The Green Point section

In western Newfoundland, a Cambrian to Ordovician sequence of shale and carbonates (Cow Head Group) is preserved in several allochthonous thrust sheets (Humber Arm Allochthon) that represent a transect across the continental slope (James and Stevens, 1986; Figure 1a, 1b). The conodont sequence in stratigraphic sections through the boundary interval in the Cow Head Group has been described by Fähræus and Nowlan (1978), Bagnoli et al. (1987), Barnes (1988) and Pohler (1994) and includes the Cow Head, Broom Point north, Broom Point south, St Paul's Inlet Quarry, Martin Point and Green Point sections (representing proximal to distal sites across the continental slope). Debris flow conglomerates become increas-

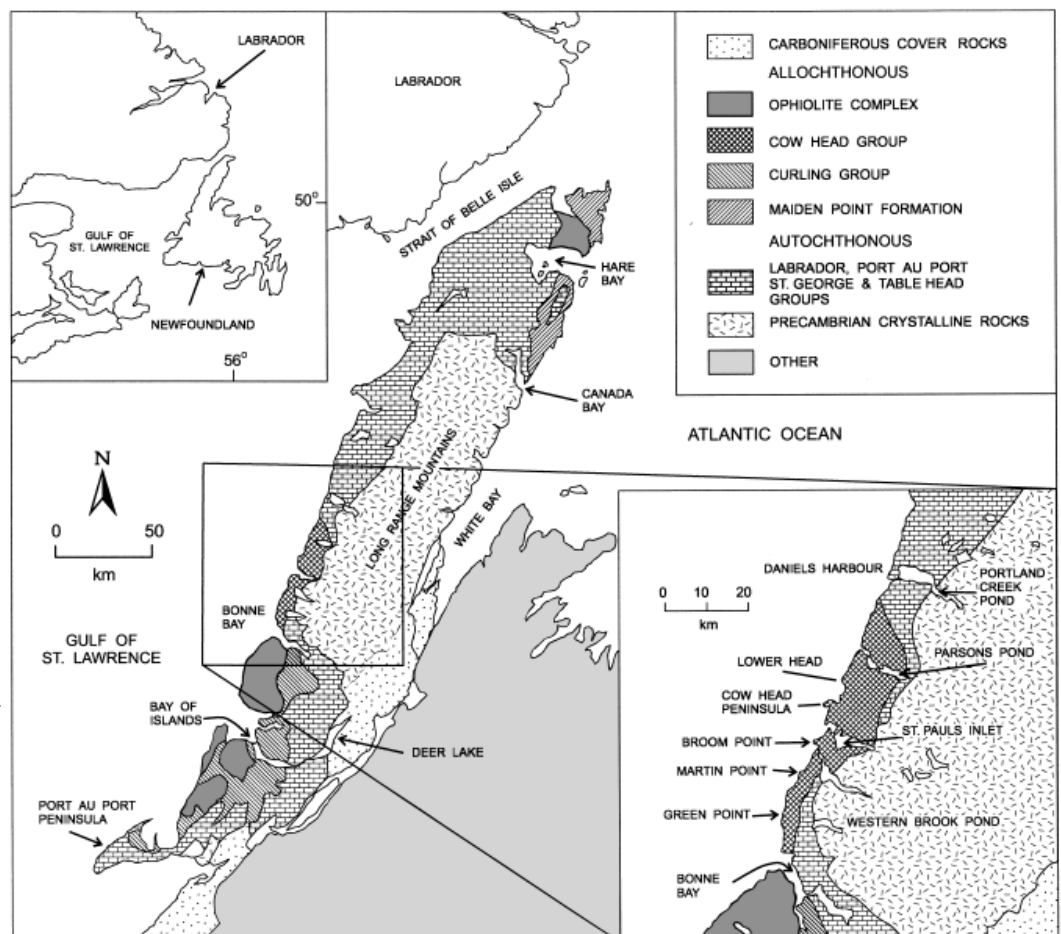


Figure 1a Location of Cow Head Group and Green Point in western Newfoundland (after Barnes, 1988).

ingly common in proximal sections. The Green Point section is the most distal and represents a base-of-slope depositional environment. It is comprised of alternating black, grey and green shale, micritic nodular and ribbon limestone and grainstone (Figures 2, 3). Limestone conglomerate is largely confined to one bed (Bed 19) and a lenticular bed within Bed 25.

The section, which is free from unconformities, ranges from Trempealeau Series (Late Cambrian) or older to Arenig (Early Ordovician) and is over 400 m thick. The boundary interval discussed here is 60 m thick. Beds dip uniformly to the southeast at 60–70° and are overturned. A few faults offset the sequence but displacements are small and readily detectable. The beds are unmetamorphosed; the conodont colour alteration index (CAI) is 1.5. Preservation of conodonts, graptolites and other fossils is excellent. Conodonts were collected from 77 levels and yielded over 9,400 elements (Barnes, 1988) while graptolites were collected from numerous bedding planes grouped into 25 main levels (Cooper et al., 1998) yielding specimens in the thousands. The conodont succession has been faithfully reproduced in several reiterative sampling sessions, mainly by Barnes (1988 and later) and most recently by Nowlan (1997). The graptolite succession is one of the most complete and well represented early Tremadoc sequences in the world, providing an exceptional 'profile' through the rapidly evolving *Rhabdinopora flabelliformis* complex (Erdtmann, 1988, Cooper et al., 1998).

The chosen level is based on a distinctive, pandemic conodont species about which there is little or no taxonomic controversy. At Green Point it lies just 4.8 m (not 4.7 m as reported in Cooper & Nowlan, 1999) below the first appearance of planktic graptolites (base of the *Rhabdinopora praeparabola* Zone) so that, in shale successions, the FAD of planktic graptolites can be taken as a reasonable proxy for the boundary and, therefore, both conodonts and graptolites can be used in its correlation. It can thus readily be correlated directly among both carbonate and shale successions.

Other microfossil groups present are acritarchs, chitinozoans and scolecodonts (Williams, 1997), and brachiopods and radiolaria have been reported by Barnes (1988). The stratigraphic utility of these groups has yet to be determined. Shelly fossils are rare and largely uninvestigated at Green Point, however, trilobites and other shelly fossils are known from adjacent, more upslope sections (e.g. Fortey et al., 1982).

Wide coastal platform and cliff-base exposures (Figure 5) provide plenty of outcrops for studying the lithological and faunal sequence and sedimentology and for collection of samples for biostratigraphy, magnetostratigraphy and other purposes. The boundary horizon itself is exposed in the platform for over 100 m along strike.

The section is reached via Highway 430 and lies about 70 km from Deer Lake Airport and about 10 kilometres north of the village of Rocky Harbour which has hotel accommodation. The section is not in danger of deterioration or destruction from natural processes and it lies within the Gros Morne National Park (a World Heritage

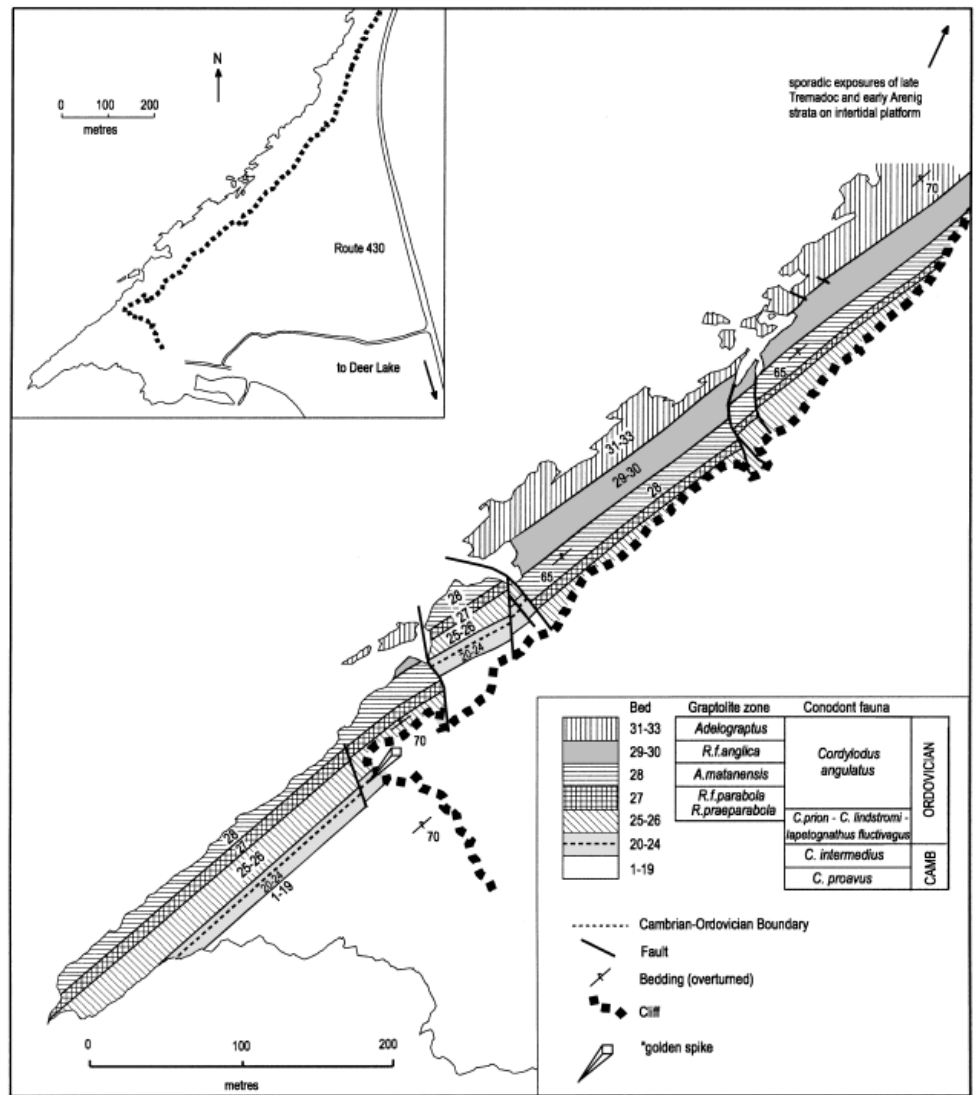


Figure 1b Green Point, showing distribution of Beds 19-33. The Beds were sampled for graptolites and conodonts in the south-west facing cliff face and the shore platform immediately in front of, and to the west of, the cliff face. Position of the GSSP spike in this sampled profile is indicated by the spike symbol.

site) so that appropriate protection and preservation are assured. Further research on the section can be undertaken with the Park authority's approval. With the cooperation of Parks Canada, a permanent marker is currently being installed.

The Green Point section satisfies the requirements for a GSSP set out in the revised Guidelines for the establishment of global chronostratigraphic standards (Remane et al., 1996):

Geological requirements

- exposure over an adequate thickness
- continuous sedimentation
- sufficiently rapid sedimentation rate
- absence of metamorphism and strong diagenesis

Biological requirements

- abundance and diversity of well preserved fossils
- absence of vertical facies changes
- favourable facies for long-range correlation

Other requirements and desirable attributes

- suitability for radio-isotope dating, magnetostratigraphy, chemostratigraphy, sequence stratigraphy is desirable
- indication by a permanently fixed marker
- avoidance of very remote locations
- free access by researchers regardless of nationality

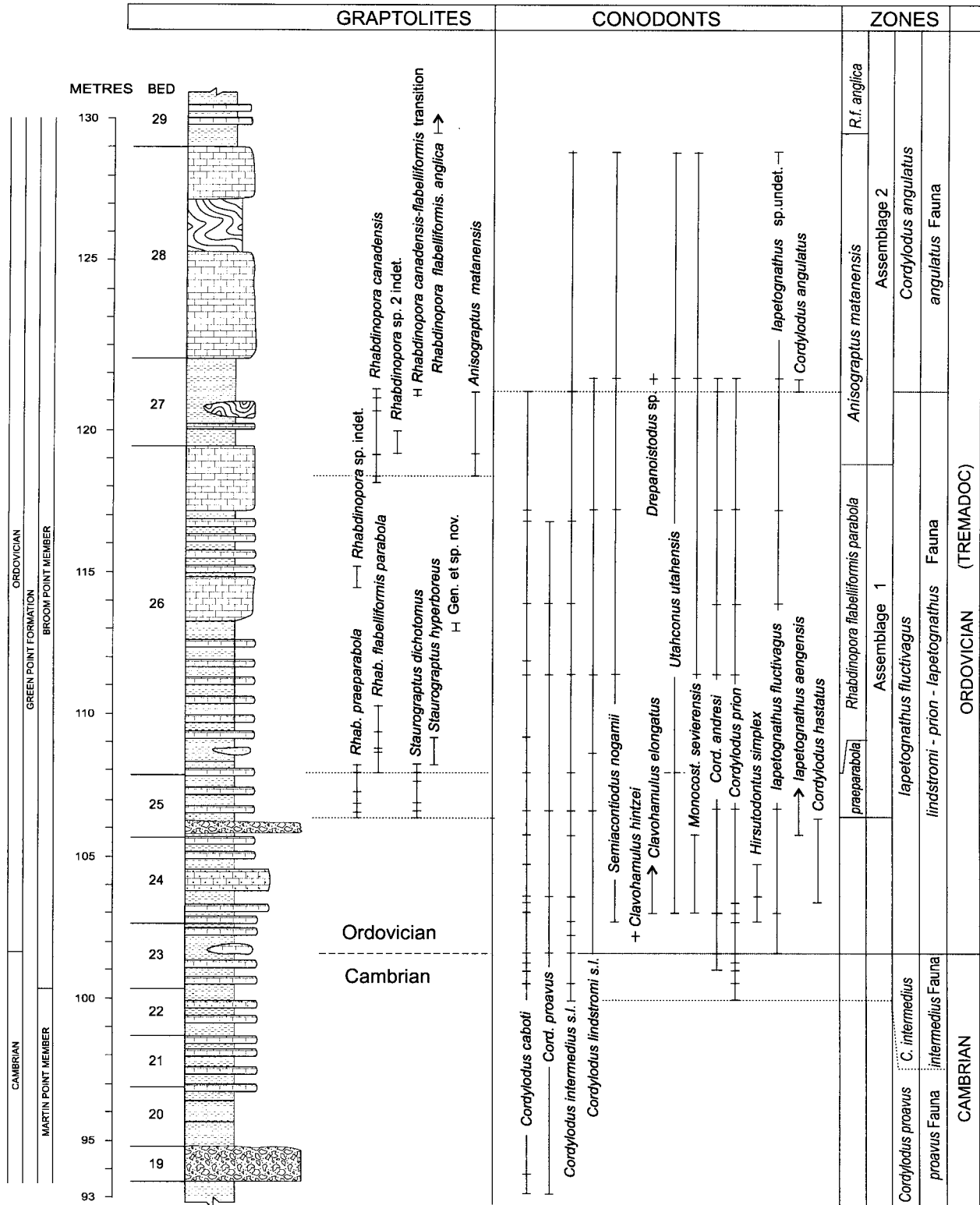


Figure 2 Stratigraphic column for the Green Point section. Graptolite ranges from Cooper et al. (1998) and Erdtmann (1985). Conodont ranges from Barnes (1988) and Nowlan and Barnes (1996), and Nowlan (1997); selected taxa and levels shown. Lithology from Erdtmann, 1985 and S.H. Williams (unpublished). Meterage used in this column is that of Erdtmann (1986) and Cooper et al. (1998).

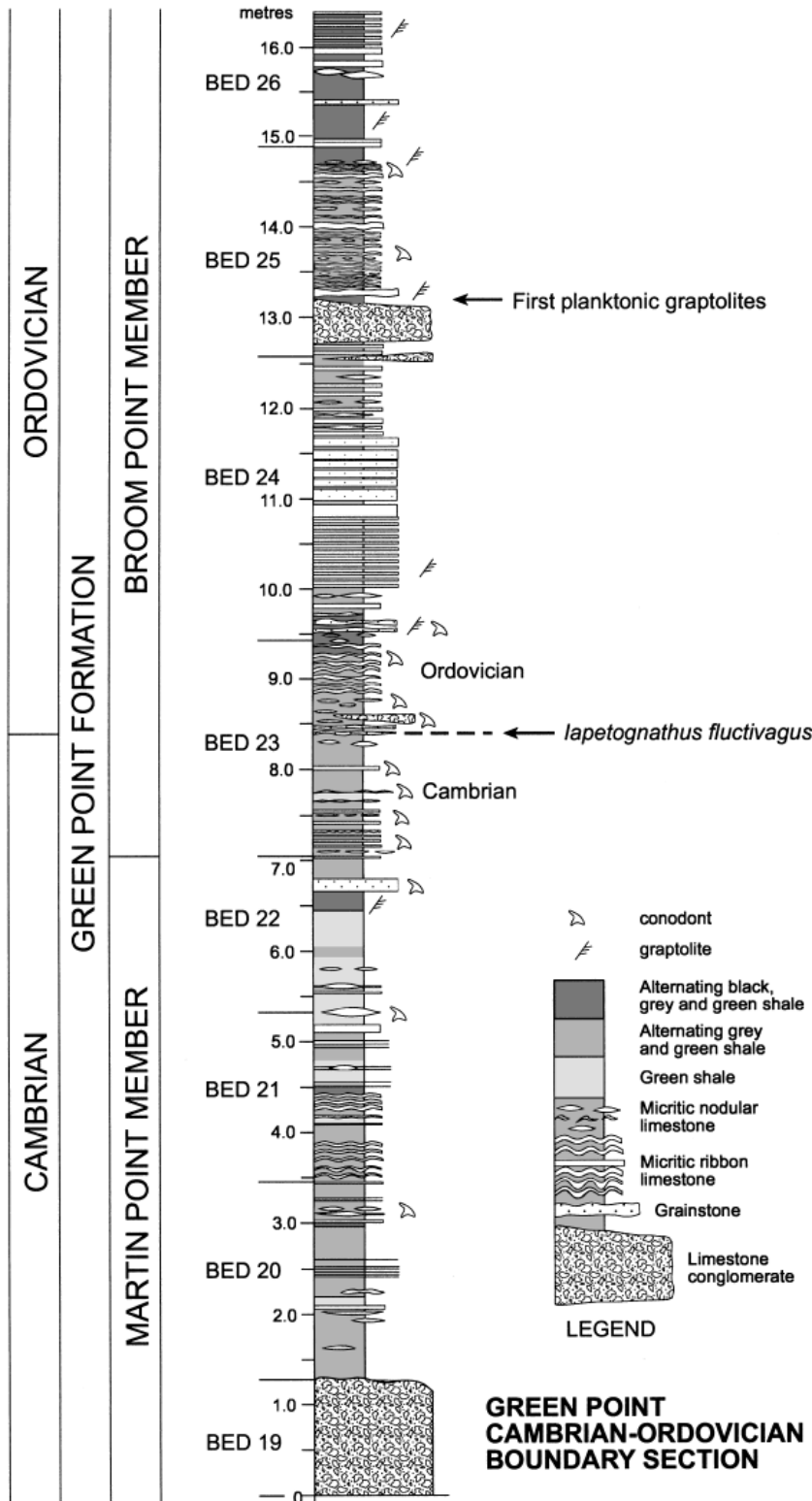


Figure 3 Detailed stratigraphic column of the boundary interval prepared by S. H. Williams, showing position of graptolite occurrences and the conodont samples collected by S. H. Williams and examined by Nowlan (1997).

– free access for research, permanent protection of site

The chemostratigraphy of the section, based on a $\delta^{13}\text{C}$ profile, appears to have most of the features seen in other sections across the Cambrian-Ordovician boundary, but there is extreme scatter in some of the data, possibly due to contamination from organic-rich shale units (Ripperdan, 1995). A marked negative excursion in the data near the base of the section (i.e. below the proposed boundary) correlates well with excursions found elsewhere and thus provides a firm correlation in this interval in which conodonts are only locally abundant. The section appears to be suitable for directly establishing a magnetic reversal stratigraphy across the boundary (Barnes, 1988) but as yet there are no published studies. Volcanogenic deposits suitable for direct radio-isotope dating are not yet known in the section. The sequence stratigraphy of the section has yet to be analyzed.

The Green Point section was one of 3 investigated in detail, the others being Dayangcha (northwest China) and Lawson Cove (western USA). Apart from the general problems in selection of a GSSP outlined below, all three candidates considered by COBWG since 1994 had specific disadvantages of various sorts. Although the Green Point section provides a sound GSSP, one disadvantage is the lack of diversity in conodont faunas below Bed 23. However, the most contentious issue probably is the question of whether or not the conodont biostratigraphy has been significantly altered by sedimentary reworking at Green Point. Critics point to the presence of trilobites in pebbles in the conglomerate beds at several of the western Newfoundland sections as clear indication of fossil reworking, and Miller (1997a; 1997b) has claimed that the difference between Green Point and shallow shelf sections like Lawson Cove, in stratigraphic range of conodont species, is *prima facie* evidence for reworking, at least of the shallow water species.

The presence of rare specimens of conodonts such as *Clavohamulus* and *Hirsutodontus*, considered to be shallow water genera, in the deep water Green Point environment, may well indicate reworking of shallow water species and these taxa should be used only with caution when correlating the section. But the plexus of species that has been focussed on for definition of the boundary — the denticulate conodonts including *Cordylodus* and *Iapetognathus* — was inhabitants of both shallow and deep water environments and are thought to have evolved in deep water. Rather than having been reworked into higher stratigraphic levels, these taxa may well, as thought by Bagnoli and Stouge (1997), appear earlier in deep water sequences than those of the shelf. The difference in stratigraphic range may therefore be due to facies control on distribution in the shallow water facies rather than to reworking in the deep water facies.

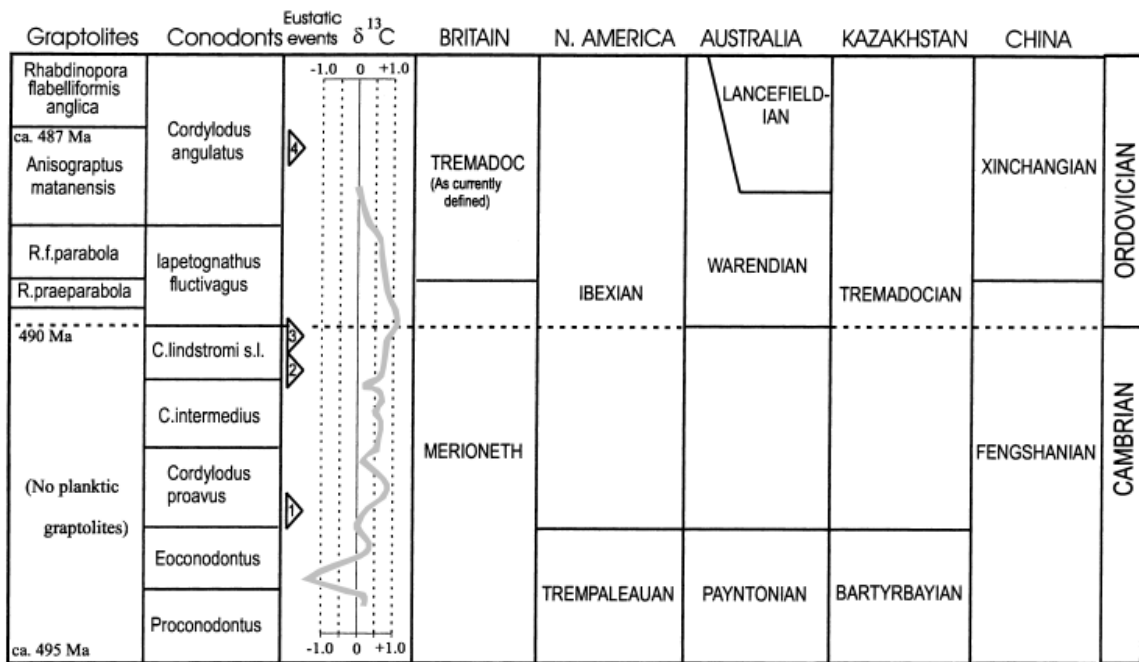


Figure 4 Correlation of proposed boundary for the base of the Ordovician System. Eustatic events are numbered: 1. Lange Ranch Eustatic Event (multiple event); 2-3. Acerocare Regressive Event (multiple event); 4. Black Mountain Regressive Event. Generalized $\delta^{13}C$ curve based on data in Ripperdan et al. 1992, 1993, and Ripperdan and Miller, 1995.

Further, biostratigraphic correlations tied to first appearance events (range bases) will not normally be affected by reworking and first appearance events should therefore be preferred for correlation. Also, in the Ordovician part of the section, a check on sediment reworking is provided by graptolites with delicate rhabdosomes that can not be reworked without at least partial, and obvious, destruction. There is no question that the numerous beds with well preserved graptolites have not been reworked at Green Point.

Key fossil groups — Conodonts

For international biostratigraphic correlation of rocks in the boundary interval, the two most important fossil groups have proved to be conodonts and graptolites. Conodonts (Figure 6) have proved reliable for global correlation of carbonate sequences and span the boundary interval. Although there are difficulties yet to be overcome (see below), they also provide the best means of correlating from shelf to deep water sequences, particularly in the late Cambrian. However, they are easily reworked by sedimentary processes.

Iapetognathus fluctivagus The conodont group identified as having best potential for use as primary guide in boundary definition by COBWG I (i.e. up to 1993) was the denticulate conodont group, the cordylodans. Although this group is still regarded by many as one of the best for correlation (e.g. Nicoll, 1990; 1992), it soon became apparent that considerable taxonomic clarification was required before the group could be utilized unambiguously. For this reason COBWG II focused on a different, but related denticulate group, including the genus *Iapetognathus*.

A full review of the genus *Iapetognathus* Landing and related forms (Nicoll et al., 1999) has established one new genus (*Iapetonudus*) and three new species of *Iapetognathus* (*Ig. fluctivagus*, *Ig. jilinen-*

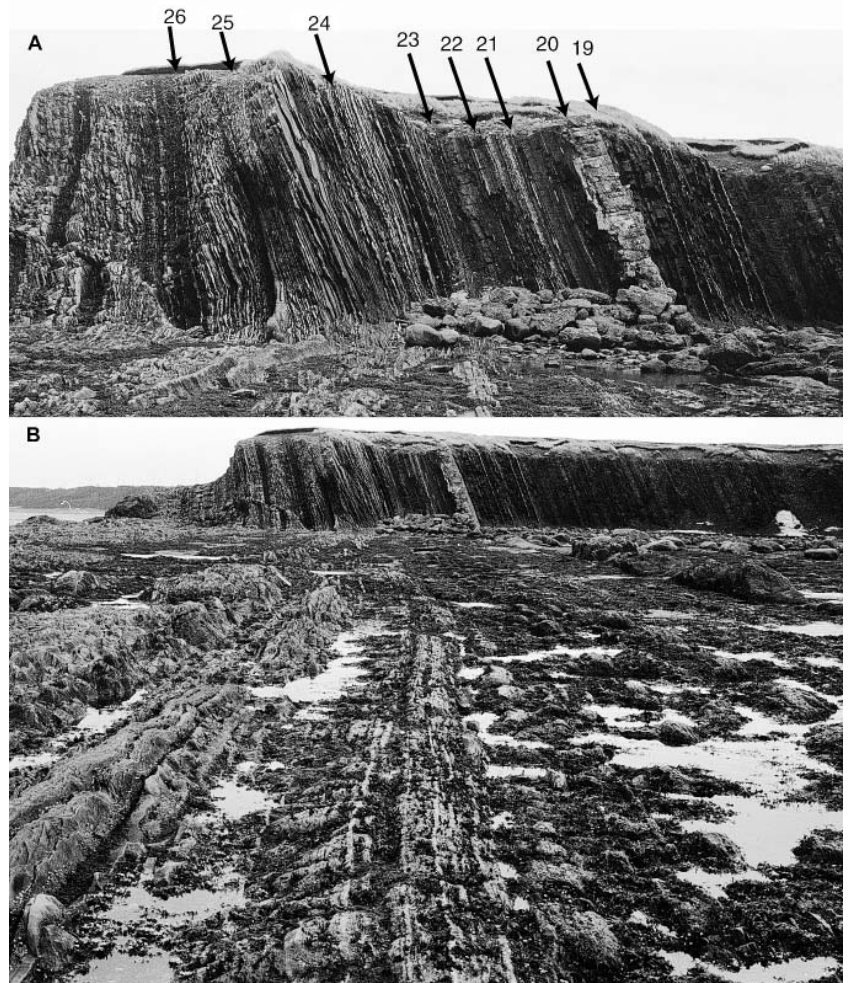


Figure 5 Photos of outcrop at Green Point. A, Close-up of critical interval with bases of units marked; B, broader view showing wide extent of outcrops in cliff and wave-cut platform.

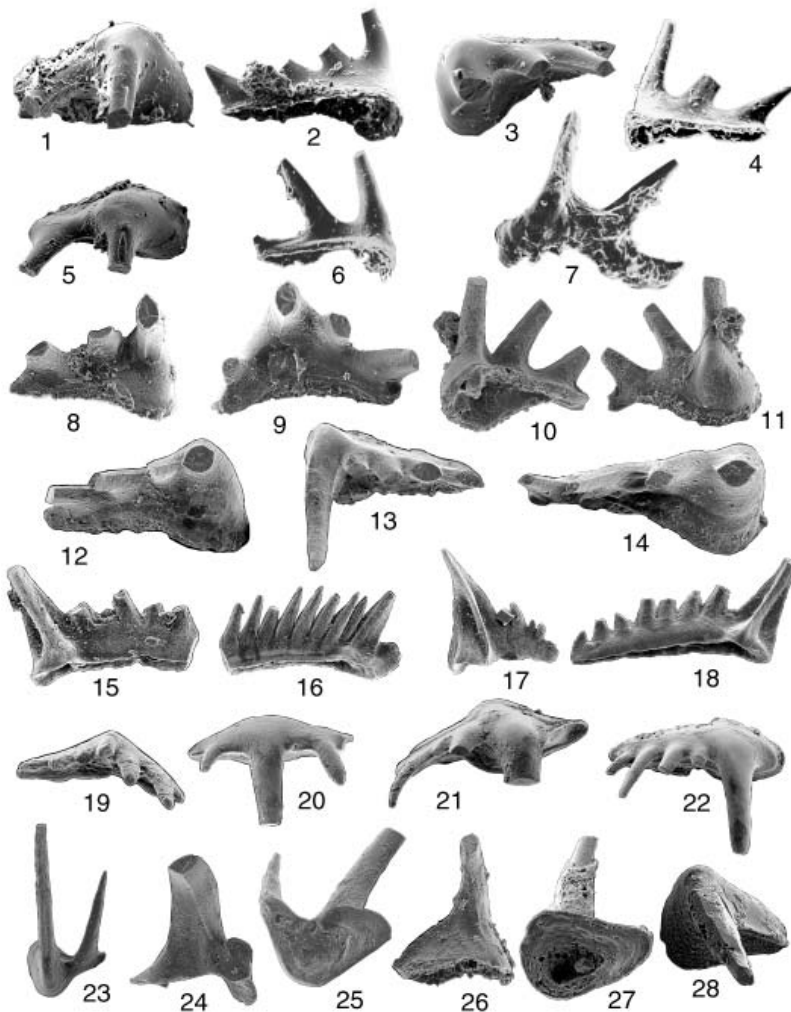


Figure 6 Plate illustrating a variety of forms of *Iapetognathus* Landing and *Iapetonudus* Nicoll, Miller, Nowlan, Repetski and Ethington n. gen. Specimens are deposited with the Geological Survey of Canada (GSC) and the United States National Museum (USNM).

1–4, 6, 7 *Iapetognathus fluctivagus* n. sp. from the Green Point section, Newfoundland, Canada. 1, Sc element, oral view, $\times 89$, Bed 23, sample 34 of Barnes (1988), GSC 117142; 2, Sc element, posterior view, $\times 61$, Bed 23, sample 34 of Barnes (1988), GSC 117143; 3, Sc? element, oral view, $\times 70$, Bed 23, sample 34 of Barnes (1988), GSC 117144; 4, Sc element, posterior view, $\times 83$, Bed 23, GSC 117145; 6, Sc element, posterior view, $\times 66$, Bed 23, GSC 117146; 7, anterior view, Sd? element, $\times 83$, Bed 23, GSC 117147.

5, 8–11 *Iapetognathus fluctivagus* n. sp. from the 438 foot level of the Lawson Cove section, Utah, U.S.A. (Miller and Taylor, 1995). 5, Sc element, oral view, X185, USNM 498933; 8, Pb element, posterior view, X78, USNM 498951; 9, Sd element, posterior view, $\times 75$, USNM 498943; 10, 11, Sc element, posterior and anterior views, $\times 72$, USNM 498937.

12–14 *Iapetognathus jilinensis* n. sp. from sample HDA 14-2 in the Xiaoyangqiao section, Dayangcha, Jilin Province, China (Chen and Gong, 1986, Table 17). 12, Sc element, oblique oral-posterior view, $\times 48$, USNM 498965; 13, Sb element, oral view, $\times 33$, USNM 498967; 14, Pb element, oral view, $\times 89$, USNM 498971.

15–18 *Iapetognathus landingi* n. sp. from Bed 6 of the Manitou Formation, Missouri Gulch Section, Colorado, U.S.A. (Berg and Ross, 1959; Seo and Ethington, 1993). 15, Sb element, inner lateral view, $\times 69$, USNM 498978; 16, Xa element, inner lateral view, $\times 53$, USNM 498986; 17, Sd element, inner lateral view, $\times 48$, USNM 498982; 18, Sc element, inner lateral view, $\times 72$, USNM 498977.

19–22 *Iapetognathus aengensis* (Lindström) from the Ceratopyge Limestone at the Ånga Quarry, Stora Backar, Västergötland, south central Sweden, Bed 5 of Lindström, 1955). 19, Pa element, oral view, $\times 46$, USNM 498932; 20, Pb element, oral view, $\times 41$, USNM 498929; 21, Sd element, oral view, $\times 33$, USNM 498925; 22, Sc element, oral view, $\times 33$, USNM 498914.

23–25 *Iapetognathus sprakersi* Landing from sample TC-1404 in the Wilberns Formation, Threadgill Creek Section, Llano Uplift, Texas, U.S.A. (Miller et al., 1982). 23, Sc element, oblique anterior-oral view, $\times 77$, USNM 498998; 24, Sd element, oblique outer lateral view, $\times 48$, USNM 499002; 25, Sc element, basal view, $\times 66$, USNM 499000.

26–28 *Iapetonudus ibexensis* gen. & sp. nov. from the Lawson Cove Section, Ibex area, Utah, U.S.A. 26, Sb element, posterior view, $\times 58$, 438 ft. level, USNM 499006; 27, 28, Pa element, aboral and oral views, $\times 110$, 435 ft. level, USNM 499009.

sis and *Ig. landingi*). Other species include *Ig. sprakersi* Landing and *Ig. aengensis* (Lindström), type species. The genus *Iapetognathus* is one of the earliest denticulate conodont genera known. It has a ramiform-ramiform apparatus structure and is readily distinguished from coeval denticulate multi-element genera (*Eodentatus*, *Cordylodus*) by the lateral orientation of the major denticulate process. It is believed to have evolved from the coniform-coniform apparatus *Iapetonudus ibexensis* Nicoll et al. The genus is global in its distribution and a succession of species first appearances seems to hold in areas with the most diverse species representation, although not all species are represented in all regions (Nicoll et al., 1999).

The species chosen for boundary definition is *Iapetognathus fluctivagus* (Figure 6). As known at present, its first appearance lies below other species of the genus. It is known from many sections in the western USA (Utah, Nevada, Idaho, Colorado, Oklahoma, Texas, New Mexico), western Newfoundland and British Columbia in Canada, Bartyrbay (Kazakhstan), and Wushan section, Hebei Province, China. It is found in a variety of facies and depositional environments ranging from shallow shelf to lower continental slope, in middle to low paleolatitude regions. Because species of the genus

have been little studied to date, it is likely that the full geographic range of this species will prove to be considerably greater than is presently known.

Graptolites

Planktic graptolites appear 4.8 m. above the boundary in the Green Point section. This stratigraphic interval, which contains no significant stratigraphic breaks, can be estimated as equivalent to less than 1% of Tremadoc time (Cooper, 1991). Therefore, for most practical purposes, the first appearance level of planktic graptolites can be taken as a proxy for the boundary in shale sequences devoid of conodonts. Graptolites (Figures 7, 8) are reliable for global correlation of shale sequences, can not be readily reworked and, in favourable facies, can be used for correlation between shelf and deep water sequences. However, they are confined to the Ordovician side of the boundary.

The earliest planktic graptolite species, *Staurograptus dichotomus* and *Rhabdinopora praeparabola*, are both present in the Green

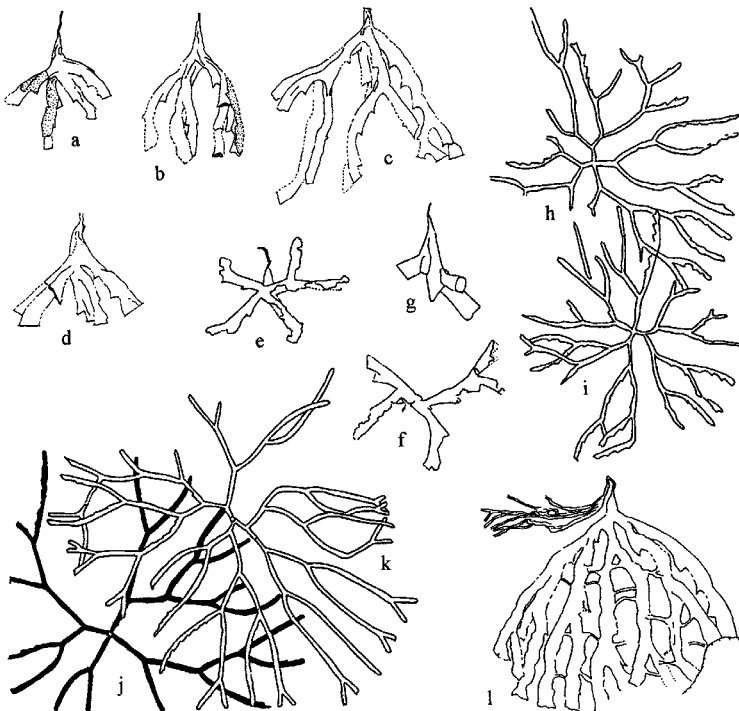


Figure 7 Earliest planktic graptolites. a–d), *Rhabdinopora praeparabola* Bruton, Erdtmann and Koch 1982, immature rhabdosomes showing proximal details; a) GSC 115800, b) GSC 115801, c) GSC 115802, d) PMO 155.447; e–k), *Staurogaptus dichotomus* Emmons, growth stages (e–g) and mature rhabdosomes (h–k); e) GSC 115834, f) GSC 115835, g) GSC 115831, h) GSC 115837, i) GSC 115838, j) GSC 115847, k) GSC 115846, l) *Rhabdinopora flabelliformis parabola*, incompletely grown specimen with divided nema, PMO 155.450. a–d) $\times 4.1$; e–f) $\times 4$; g) $\times 7.3$; h–k) $\times 1.8$; l) $\times 6$. All specimens are from Green Point except for 7d and 7l which are from Digermul Peninsula, northern Finnmark. All figures from Cooper et al. (1998).

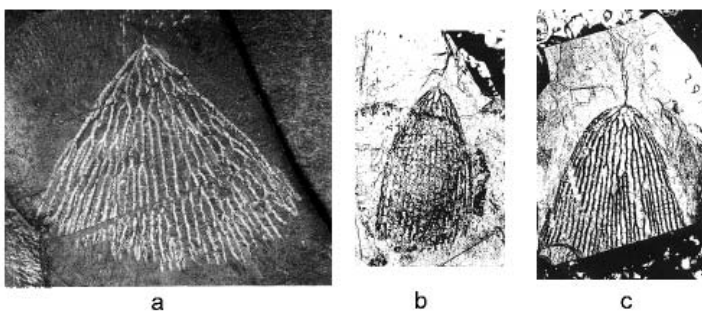


Figure 8 a) *Rhabdinopora flabelliformis flabelliformis* (Eichwald 1840), immature specimen, LO7511 from Öland, Sweden, $\times 0.9$; b–c), *Rhabdinopora flabelliformis parabola* (Bulman 1954), mature specimens from Dayangcha, China (NIGPAS 92667 and NIGPAS 92662 respectively), $\times 1.2$.

Point section. The following succession of *Rhabdinopora* species and subspecies represents an evolutionary complex with global distribution. The genus is diverse, composed of intergrading populations, each characteristic of a particular horizon (stratigraphic subspecies) or ecological zone (ecological subspecies). Four biostratigraphic zones are recognized in the Early Tremadoc, the Zones of *Rhabdinopora praeparabola*, *R. flabelliformis parabola*, *Anisograptus matanensis*, *Rhabdinopora flabelliformis anglica*, in upward sequence. Within each of the upper 3 zones, subspecies are partitioned into shelf, upper slope, lower slope and ocean floor assem-

blages. The succession of subspecies preserved at any one site in the shelf and upper slope environments reflects the interplay of evolutionary change and migrating biofacies with sea level change. The biostratigraphic/ecological scheme enables fine correlation of the earliest Ordovician (Cooper, 1999).

Other fossil groups

Trilobites enable fine subdivision and correlation of platform sequences, and olenid trilobites enable correlation with deeper water successions. The boundary closely coincides with the first appearance of the trilobites *Jujuyaspis borealis* and *Symphysurina bulbosa* at the base of the *S. bulbosa* Subzone of North America (Miller and Stitt, 1995). Brachiopods and other shelly groups are most useful for intra-regional correlation. Correlation based on organic walled microfossils is still largely undeveloped but one group that shows promise is acritarchs (Martin, 1982).

The most difficult problem in biostratigraphic correlation of the boundary interval is not due to regional provincialism but to strong facies differentiation. Working Group papers presented in the two volumes on the boundary mentioned above, and Cooper (1999), show that relatively precise correlation of the boundary interval, at the zonal level, can now be achieved between continents within shelf carbonate successions using conodonts and trilobites, or within slope-basin successions using graptolites and conodonts. But correlating between shelf and basin sequences, even when they lie adjacent to each other on the one continent, remains difficult. The key fossil group for pan-facies correlation of the boundary is conodonts but deep water (slope and basin) conodont successions are relatively poorly known, the best by far being the Green Point sequence. It is therefore uncertain whether observed differences in the succession of some species between the Green Point sequence and shallow shelf sequences such as the Lawson Cove sequence are due to a sedimentological cause such as reworking or to facies control on stratigraphic range. Considerably more research is required to resolve this question. The problem is greater in the Late Cambrian than in the early Ordovician where graptolites evolved rapidly and invaded the shelf environment providing an additional, precise, correlation tool.

Correlation of the boundary

Correlation of the proposed boundary is shown in Figure 4. The boundary lies just below the base of the Tremadoc Series as traditionally defined (Rushton 1982). It lies in the lower Ibx Series of North America (Ross et al., 1997), at the base of the Warendian Stage of north Australia (Shergold and Nicoll, 1992), in the lower Tremadoc as used in Kazakhstan (Apollonov et al., 1988), and in the late Fengshanian of north China. In terms of conodont zones (Miller 1988, Miller and Stitt 1995, Nicoll et al., 1999) the boundary coincides with the base of the *Iapetognathus* Zone.

Numerical age of the boundary

Until recently, numerical dates in latest Cambrian and earliest Ordovician rocks were lacking and age of chronostratigraphic boundaries was poorly constrained (Tucker and McKerrow, 1995). A recent U-Pb zircon date of 491 ± 1 Ma gives a maximum age for detrital zircon in volcanoclastic sandstone of *Peltura scarabaeoides* Zone age at Ogof-ddŷ near Criccieth in north Wales (Davidek et al.,

1998) and provides a maximum age constraint on the boundary. Together with the other Cambrian and Ordovician zircon dates (Tucker and McKerrow, 1995; Perkins and Walshe, 1993; Encarnación et al., 1999; Landing et al., 1997) the new dates suggest an age for base of the Ordovician no older than, and close to, 490 Ma*.

Carbon isotopes

Among the more promising physical tools for boundary correlation among carbonate-bearing sections is carbon isotope ($\delta^{13}\text{C}$) chemostratigraphy. Unlike most chemostratigraphic markers, $\delta^{13}\text{C}$ values are relatively insensitive to many post-depositional processes because of the extremely low abundance of carbon in water relative to carbonate rock (Magaritz 1983; Banner and Hanson 1990). Work by R. Ripperdan and colleagues shows that remarkably comparable curves reflecting shifts in $\delta^{13}\text{C}$ can be obtained for carbonate sequences spanning the boundary interval on different continents (Ripperdan, 1995; Ripperdan and Miller, 1995; Ripperdan et al., 1992, 1993). Curves have been established for carbonate sections at Bartyrbay Ravine (Kazakhstan), Black Mountain (Australia), Lange Ranch (Texas), Lawson Cove (Utah), Dayangcha (China). At Green Point, the data are more scattered, possibly due to isotopic contamination from organic-rich shales during immediate post depositional diagenesis. As a result, the curve is less well established, but some of the main $\delta^{13}\text{C}$ excursions are identifiable.

In general, the global trend shows minimum values near the base of the *Cambroostodus minutus* Zone after which values rise sharply, representing a shift of 1–2‰. Two main positive cycles are present between the base of the *Cordylodus proavus* Zone and base of the *C. lindstromi* sensu lato Zone in many sections. In the *Iapetognathus* Zone, $\delta^{13}\text{C}$ rises rapidly to reach its highest value in the boundary interval, before dropping rapidly, and continuing to fall through the *C. angulatus* Zone.

The chosen boundary level therefore coincides closely with the peak of a positive cycle in $\delta^{13}\text{C}$ (‰ vs. PDB), representing the highest value reached in the boundary interval. This should be a useful correlation datum.

Magnetostratigraphy

As yet there is no standardized magnetostratigraphy through the boundary interval, (i.e. verified in several sections). Magnetostratigraphic reversal stratigraphy has been obtained from several sections, including Black Mountain, Dayangcha, several sections in western Newfoundland including Green Point, Bartyrbay, and Texas (Ripperdan and Kirschvink, 1992; Kirschvink et al., unpublished). In general, the geomagnetic field had predominantly reversed polarity throughout the boundary interval. In the Late Cambrian, short intervals of normal polarity are present in the late *Proconodontus* and late *Eoconodontus* Zones and appear to have good value for correlation. In the Early Ordovician, short intervals of normal polarity are present but are currently difficult to correlate. The low conodont colour alteration index (CAI) values for some western Newfoundland rocks, including those of Green Point (Nowlan and Barnes, 1987), and the preliminary work done so far, suggest that these rocks are Early Tremadoc graptolitic bioevents and sea level events is discussed by Cooper (1999).

* Since submission of this MS, an age for the lower boundary of the Ordovician System close to 490 Ma has been supported by Landing, et al. (2000) who have dated zircons in two thin volcanoclastic bands immediately underlying the base of the Ordovician in the Bryn-Illn farw section, North Wales, indicating that the base is no old than 489 ± 0.6 Ma. (Landing, E. S. A., Bowring, K. L., Davidek, K. L., Rushton, A. W. A., Fortey, R. A. and Wimbledon, A. P., 2000. Cambrian-Ordovician boundary age and duration of the lowest Ordovician Tremadoc series based on U-Pb zircon dates from Avalonian Wales. *Geological Magazine* 137:485–494).

Name of earliest Ordovician stage

The International Subcommittee on Ordovician Stratigraphy voted in 2000 to approve the name, Tremadocian, for the earliest Ordovician stage. The stage extends from the level of the first appearance of the conodont, *Iapetognathus fluctivagus*, in the Green Point section of western Newfoundland (base of the Ordovician) up to the level of the first appearance of the graptolite, *Tetragraptus approximatus*, in which ever section is chosen as GSSP for the base of the second Ordovician stage.

International boundary working groups (COBWG I, COBWG II)

The International Working Group on the Cambrian-Ordovician Boundary (COBWG I) was established in 1974, with 14 voting members and more than 50 corresponding members, under the Chairmanship of G. Henningsmoen (Norway). Over the following 19 years the Working Group issued 31 Circulars with description and discussion of candidate sections and levels, and debate on boundary definition issues, principles and procedures. The Group visited candidate sections in Kazakhstan, China, Australia, Scandinavia, Britain and North America. Two volumes of papers on candidate boundary sections were published (Bassett and Dean, 1982 and a special 1988 issue of *Geological Magazine*, v. 125 no. 4). In addition, two volumes of papers on the Dayangcha section alone have been published (Chen et al., 1985; 1986). In 1976 W.T. Dean (United Kingdom) succeeded Henningsmoen as Chairman; in 1980 he in turn was succeeded by B.S. Norford (Canada) and the number of titular members was increased to 17. The executive and voting members of this first Working Group (COBWG I) retired in 1993.

Later in 1993 a new group of 13 titular members (COBWG II) was formed, and in December of that year the group elected R.A. Cooper (New Zealand) as Chairman and G.S. Nowlan (Canada) as Secretary. From 1994 to 1998 the new Group issued 6 Circulars and a number of information letters and undertook detailed investigations into the Dayangcha, Green Point and Lawson Cove candidate sections. Altogether, 15 formal ballots have been held by the two Groups. A full summary of the activities, deliberations and formal decisions of the two Groups is given in Appendix 1 of the report submitted to the Subcommittee on Ordovician Stratigraphy in March 1999. The decision to recommend the Green Point section and point or GSSP for base of the Ordovician System was approved by 77% of Voting Members.

Voting members, 1974

J.W. Cowie	B.S. Norford
R.A. Cooper	R.J. Ross
W.T. Dean	K. Szdzy
E.C. Druce	J.H. Shergold
G. Henningsmoen (Chairman)	D. Skevington
D.E. Jackson	M.E. Taylor
J.F. Miller	H.B. Whittington

Voting members, 1989

M.K. Apollonov	Lu Yanhao
Chen Jun-yuan	J.F. Miller (Secretary)
R.A. Cooper	B.S. Norford (Chairman)
J.W. Cowie	R.J. Ross
W.T. Dean	J.H. Shergold
B-D. Erdtmann	D. Skevington
G. Henningsmoen	M.E. Taylor
D. Kaljo	H.B. Whittington

Voting members, 1993-98

Chen Jun-yuan	R.S. Nicoll
R.A. Cooper (Chairman)	G.S. Nowlan (Secretary)
S.V. Dubinina	R. Ripperdan
B.-D. Erdtmann	A.W.A. Rushton
R.L. Ethington	J.H. Shergold
R.A. Fortey	J.F. Taylor
D. Kaljo	

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Dr. S. Henry Williams has been closely involved with the work of the Ordovician Subcommittee since completion of his PhD thesis in 1983, the data of which was used in defining the Ordovician-Silurian boundary GSSP at Dob's Linn, southern Scotland. He was Secretary of the Ordovician Subcommittee for eight years and has been a Professor at Memorial University of Newfoundland since 1987.

