Early Paleozoic paleogeography and accretionary history of the Newfoundland Appalachians

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ABSTRACT

New paleomagnetic results were obtained from several units in the Central Mobile belt of the north-central Newfoundland Appalachians. Combined with recently published data, the results place important limits on interpretations of early Paleozoic paleogeography and evolution of the Appalachian-Caledonian orogen. The Ordovician Appalachian margin of North America, located at low paleolatitudes and facing roughly south, was separated from the southern margin of Iapetus (Avalon-Armorica) by ~3500 km. Primary directions in pillowed volcanic rocks of the Moreton's Harbour Group that are part of an Early Ordovician island arc show that these rocks were formed near the North American margin, at a paleolatitude of 12°S. Early to Middle Ordovician volcanic rocks of the Roberts Arm, Chanceport, and Summerford groups, on the other hand, were extruded at paleolatitudes of 30°–40°S. Unconformably overlying volcanics of the Silurian Botwood Group were extruded subaerially at a paleolatitude of 24°S. Combined with tectonostratigraphic data, these results suggest the following tectonic history. In Early Ordovician time, northerly subduction of the main Iapetus basin was accompanied by the formation of a volcanic arc and a back-arc basin near the North American margin. Middle Ordovician emplacement of ophiolites on the North American margin reflects the closure of this back-arc basin (Iapetus I), and continued northerly subduction in Silurian time closed the main basin (Iapetus II).

INTRODUCTION

The existence of a wide Iapetus Ocean between Laurentia (North America, Greenland, and northern Great Britain) and western Gondwana (South America and Africa) during the early Paleozoic has been well documented, and its history is preserved in the Appalachian-Caledonian orogen (Wilson, 1966; Dewey, 1969; Harland and Gayer, 1972). In more than 20 years of lively discussion, a plethora of tectonic models have been proposed; in particular, the location of island arc(s), subduction zones, and subduction polarities have been debated. However, in the absence of quantitative data on the distribution and timing of accretion of such characteristic tectonic elements as the bordering continental blocks, volcanic arcs, ocean islands, and microcontinents, these models remain speculative.

New paleomagnetic results were obtained from several Ordovician units in north-central Newfoundland. The Newfoundland Appalachians are subdivided into the Humber zone, the Central Mobile belt, and the Avalon terrane (Fig. 1A; van der Pluijm and van Staal, 1988; Williams et al., 1988). The Humber zone represents the North American continental margin (miogeocline) and characterizes the northern margin of Iapetus; the Central Mobile belt contains various tectonic elements associated with the formation and destruction of Iapetus; the Avalon terrane is a continental block that bordered Iapetus on its southern side. On the basis of new and recently published results, this paper discusses the paleogeography of the bordering continental blocks and several characteristic elements of the intervening Central Mobile belt.

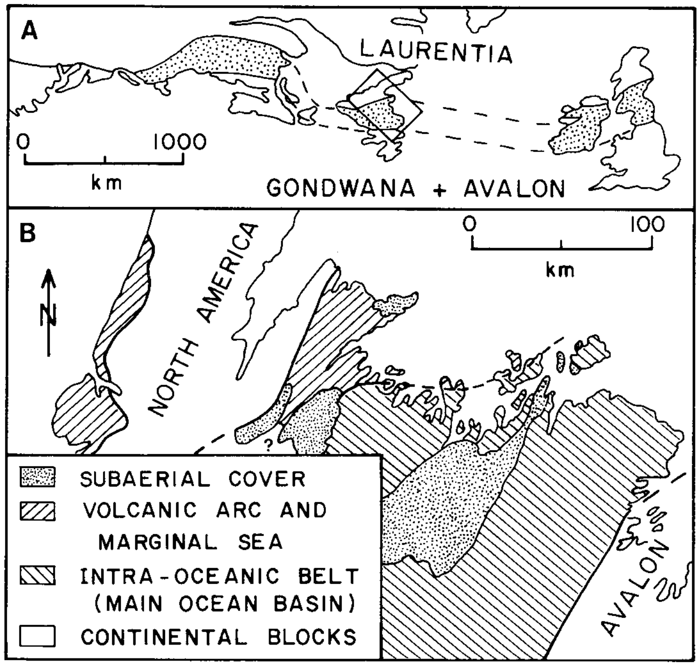

Figure 1. A: Subdivision of Appalachian-Caledonian chain; stippled area between Laurentia and Gondwana + Avalon is Central Mobile belt. B: Paleogeographic domains of northern Newfoundland. Heavy dashed line that separates arc and marginal sea from main basin is Lobster Cove–Chanceport fault; subaerial cover unconformably overlies these two domains.

PALEOMAGNETIC DATA

During Ordovician time, the Appalachian margin of North America was oriented approximately east-west and located at 10°–20°S paleolatitude, while the northern margin of western Gondwana was located at about 50°S or more (Briden et al., 1988; Van der Voo, 1988). Paleomagnetic results from the Avalon terrane (Johnson and Van der Voo, 1986) give paleolatitudes similar to those of northern Gondwana, implying that this terrane was located along the southern margin of Iapetus. These paleomagnetic data are in excellent agreement with biogeographic data (Cocks and Fortey, 1982; Neuman, 1984; Fortey and Cocks, 1988; Van der Voo, 1988).

We have studied key units of the Central Mobile belt of north-central Newfoundland (Fig. 1B), which we group into two early Paleozoic domains that represent (1) a volcanic arc with a back-arc basin (minor ophiolite) and (2) an intra-oceanic domain. These two domains are currently juxtaposed along the steeply dipping Lobster Cove–Chanceport fault. Our subdivision refines the recently proposed subdivision of central Newfoundland (Williams et al., 1988) that separates the Notre Dame subzone from the Exploits subzone along the Red Indian line. In addition to marked lithologic and geochemical contrasts between our domains

TABLE 1. PALEOPOLES AND PALEOLATITUDES FOR AVALON, CENTRAL MOBILE BELT, AND LAURENTIA

Rock unit/time interval (Ma)	Pole position	Paleolatitude (°S)	k/K	α95/A95
LAURENTIA				
UD, MD/UD (366-378)	29S, 291E	10	24	9
MD, LD (379-397)	23S, 290E	16	40	8
US/LD (398-414)	3S, 277E	32	26	7
US, MS (415-429)	19S, 304E	21	52	6
UO/LS, UO, MO (430-467)	16S, 324E	22	19	8
L/MO, LO (468-505)	15S, 344E	17	50	18
UC, MC, C (506-542)	9S, 338E	25	25	12
LC (543-575)	5S, 350E	23	22	15
CENTRAL MOBILE BELT				
Botwood, U/LS	16S, 313E	24	54	7
King George IV Lake, LS[1]	36S, 265E	0	19	11
Roberts Arm, M/LO**	0N, 328E	38	25	12
Chanceport, M/LO**	9S, 316E	31	74	8
Summerford, M/LO**	3S, 328E	34	47	11
Moreton's Harbour, LO*	29S, 307E	12	31	6
AVALON				
Dunn Point, LS/UO	2N, 316E	42	79	4
Dunn Point, LS/UO*	2S, 310E	41	69	4
Stapeley (U.K.), U/MO[2]	27N, 036E	51	89	5

Note: U=upper, M=middle, L=Lower; D=Devonian, S=Silurian, O=Ordovician, C=Cambrian; K and A95 are statistical parameters associated with the Laurentian poles; k, α95 are statistical parameters associated with the mean direction of individual studies.

*New result; **New result, preliminary; (1) Buchan and Hodych (1989); (2) McCabe and Channell (1990).

(Williams, 1979; Bostock, 1988), the paleomagnetic and faunal evidence (see below) indicates that the Lobster Cove–Chanceport fault marks a fundamental boundary in the Central Mobile belt.

We sampled Ordovician and Silurian volcanic units to determine by paleomagnetic techniques the paleogeographic history of the two domains; our results and an updated Laurentian paleopole list are summarized in Table 1. Pillow lavas from the Moreton's Harbour Group are part of an Early Ordovician volcanic arc that was built onto oceanic crust (Kean and Strong, 1975; Williams and Payne, 1975). Stepwise thermal demagnetization of samples from 20 sites revealed a characteristic magnetization that is carried by magnetite. In Figure 2, the mean direction for each site is plotted in field coordinates and after structural correction. A statistically significant, positive fold test and the presence of dual-polarity directions support a primary age for the magnetization. The mean paleomagnetic direction of 178°/22° (declination/inclination [D/I]) corresponds to a paleolatitude of 12°S, which indicates that these volcanic rocks were formed at or near the margin of North America. This result agrees with a paleomagnetic study of this unit listed in Deutsch and Rao (1977), but these authors did not report a fold test for the age of magnetization. In contrast, Lower to Middle Ordovician volcanic rocks of the Roberts Arm Group that form part of a laterally extensive volcanic belt with a characteristic geochemical signature give a mean direction of 150°/57° (D/I). A primary age for this magnetization is indicated by a positive fold test and a remanent magnetization of dual polarity that is carried by magnetite. The intermediate inclination implies that these rocks were formed at a paleolatitude of 38°S, i.e., separate from both North America and Avalon-Gondwana. Similar intermediate paleolatitudes were obtained from our preliminary studies of the Chanceport and Summerford groups (Table 1) of northeastern Newfoundland, which we correlate with the Roberts Arm Group. The separation of this volcanic belt from both continental margins is supported by the presence of distinct benthic faunas of the Celtic province to the south of the Lobster Cove–Chanceport fault in the Summerford Group (Neuman, 1984).

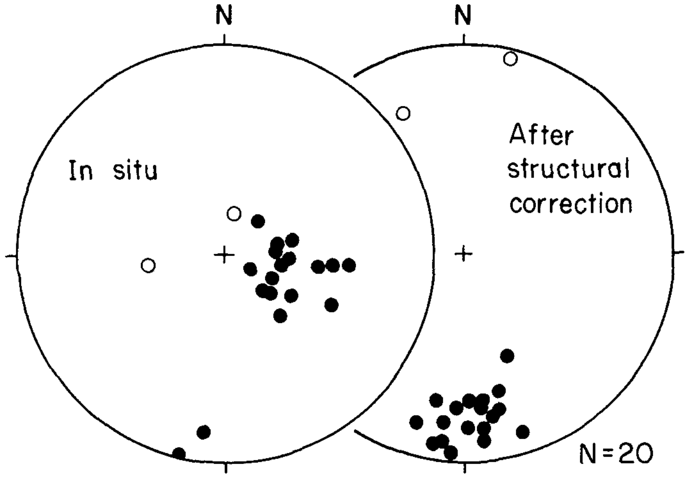

Figure 2. Equal-area projections of characteristic components of 20 sites in Moreton's Harbour Group volcanic rocks. Directions are plotted in field coordinates (in situ) and after structural correction, with corresponding mean values of 107°/65° (α_{95} = 12°; *k* = 9) and 178°/22° (α_{95} = 6°; *k* = 31), respectively. Open circles plot in upper hemisphere, solid circles in lower hemisphere.

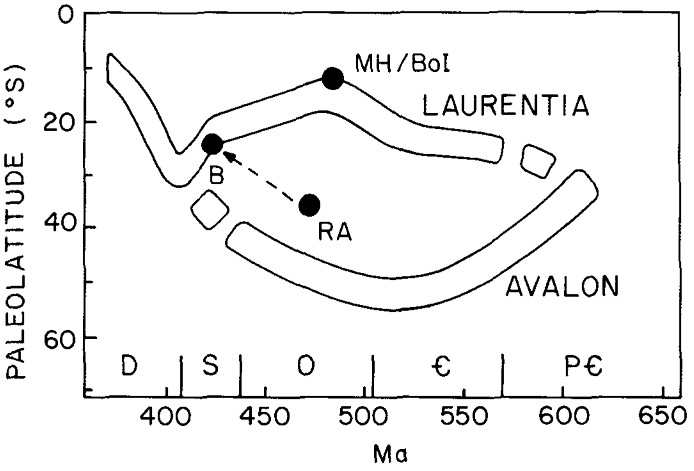

Figure 3. Paleolatitudes of Laurentia, Avalon, and parts of Iapetus from late Precambrian to Devonian time. Based on data listed in Table 1 and Van der Voo (1988). B = Botwood Group, BoI = Bay of Islands (Skinner Cove), MH = Moreton's Harbour Group, RA = Roberts Arm Group; D = Devonian, S = Silurian, O = Ordovician, € = Cambrian, P€ = Precambrian.

Paleomagnetic results from subaerial units of the Botwood Group that unconformably overlie units of the intra-oceanic belt (van der Pluijm et al., 1989) show that by Middle Silurian time a large part of the marine belt had accreted to North America and had become exposed to surface weathering. Volcanic rocks of the Botwood Group give a direction of 175°/43° (D/I) and a corresponding paleolatitude of 24°S, which is indistinguishable from the Middle Silurian position of the Laurentian margin at ~25°S (Gales et al., 1989). The significance of the proposed equatorial position of a coeval unit in the King George IV Lake area in southwestern Newfoundland remains unclear (Table 1; Buchan and Hodych, 1989).

Paleomagnetic analysis does not provide longitudinal information, but latitudinal (north-south) separations are readily obtained. In Figure 3, we have plotted the observed paleolatitudes of several tectonic elements from Iapetus and its bordering continents as a function of time. The paleopoles for Laurentia and Avalon have been used to calculate the paleolatitudes of these blocks as they occur in Newfoundland. The plot shows that the Avalonian and Laurentian continents were separated by an ocean basin with a maximum *latitudinal* width of 30°–40° (Table 1; Van der Voo and Johnson, 1985; McCabe and Channell, 1990; Johnson and Van der Voo, 1990). Given that the North American margin was oriented approximately east-west in Ordovician time, this latitudinal width establishes a separation of ~3500 km. Furthermore, the proximity of the volcanic arc to North America dictates that the major tract of Iapetus was located between the arc and Avalon. This geometry also restricts interpretations of the paleogeography of Early Ordovician age ophiolitic slices that were emplaced on the North American margin in Middle Ordovician time (Church and Stevens, 1971; Williams, 1979). Unless these ocean-floor sequences were transported over and across the volcanic arc, they must have been derived from a basin that was bounded by North America and the arc. The width of this basin was within the limits of paleomagnetic resolution (±5° latitude) and thus had a north-south width of <600 km. Paleomagnetic data from the Humber Arm allochthon of western Newfoundland that give a paleolatitude of 12°S (Table 1; Beaubouef et al., 1988) appear to confirm this near-Laurentian margin position (Fig. 3).

TECTONIC MODEL

A tectonic model for the evolution of Iapetus that is consistent with the paleogeographic data presented in this paper, tectonostratigraphic data (e.g., Keppie, 1989), and palinspastic reconstructions (e.g., Stockmal et al., 1990) is illustrated in Figure 4. Because of the absence of longitudinal control (east-west motion) in paleomagnetic data, we will present our interpretation of the events in a series of north-south sections. Obviously, such diagrams cannot reflect strike-slip motion (e.g., Currie and Piasecki, 1989; Keppie, 1989) along the roughly south facing Appalachian margin. Information about the evolution of the southern margin of Iapetus is obscured in Newfoundland by the steeply dipping Dover fault, which separates Avalon from the Central Mobile belt (Fig. 1; Kennedy et al., 1982; Keen et al., 1986). The northern part of Iapetus was characterized by a small ocean basin (marginal sea) with relatively young (Early Ordovician) oceanic crust that separated the craton from the volcanic arc. This marginal sea and arc were likely formed in response to northward subduction in the main basin (Fig. 4). In van der Pluijm and van Staal (1988), the terms "Iapetus I" and "Iapetus II" were introduced for the basins to the north and south of the arc, respectively. Subsequent collision of the arc with North America, possibly as a result of plate-boundary evolution (Dewey and Shackleton, 1984), resulted in closure of Iapetus I and northerly obduction of ophiolite associated with minor southward underplating (Fig. 4). The short time interval that separates ophiolite formation and obduction (10–20 m.y.; Dewey and Shackleton, 1984; Dunning and Krogh, 1985) is explained by the opening of this marginal basin rapidly followed by its closure.

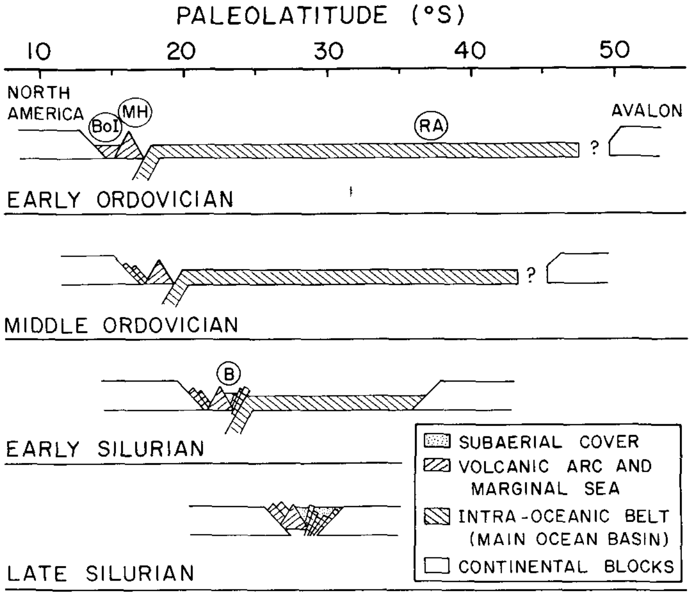

Figure 4. Schematic illustration of paleolatitudinal progression of Iapetus-bordering continents and selected tectonic elements. See Figure 3 for abbreviations.

The Early Ordovician paleogeography of northern Iapetus appears analogous to the late Cenozoic history of the Japan region of the western Pacific. Subduction of the Pacific plate formed a volcanic arc (Japan) that in late Oligocene time (30 Ma) rifted from the Eurasian continent until the early Miocene (15 Ma) to form the ~800-km-wide Japan Sea back-arc basin in ca. 15 m.y. (Kimura and Tamaki, 1986). Recent (<5 Ma) tectonic activity in the Japan Sea reflects the initiation of an eastward-dipping subduction zone under Japan while westward subduction of the Pacific plate continues (Tamaki and Honza, 1985). If this represents the onset of closure of the Japan Sea, the duration of this basin would be comparable to the time interval of Appalachian ophiolite formation and obduction.

Units of the intra-oceanic belt that were formed in the main part of Iapetus (Iapetus II) did not reach the margin of North America until Late Ordovician(?)–Silurian time (Fig. 4). Accretion of these elements during continued northerly subduction at the margin of North America is recorded by the presence of a Silurian accretionary wedge (van der Pluijm, 1986) and arc magmatism (Whalen, 1989) in the Central Mobile belt. By Late Silurian–Early Devonian time, final convergence between Avalon and North America (Fig. 4) resulted in an abrupt change in plate motion of Laurentia from a southerly to a northerly direction (Fig. 3).

CONCLUSIONS

The paleogeography of several elements in the Central Mobile belt of the Newfoundland Appalachians implies that Iapetus closed as a result of major subduction along its northern margin underneath Laurentia in Silurian time. Iapetus consisted of more than one basin and contained several geographically distinct tectonic elements (e.g., arc, seamount). Deformation events in the Appalachians recorded the successive outboard accretion of these elements to Laurentia.

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ACKNOWLEDGMENTS

Supported by National Science Foundation Grant EAR 89-05811. We thank Alex Halliday, Peter Plumley, Henry Pollack, Peter Vrolijk, and Hank Williams for review and discussion. We apologize to those who are uncited because of space limitations.

Manuscript received February 12, 1990
Revised manuscript received April 13, 1990
Manuscript accepted April 23, 1990

Printed in U.S.A.