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Notes

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ABSTRACT

Recent paleomagnetic data and existing paleontological evidence show that Baltica occupied temperate southern latitudes during Cambrian and Early Ordovician time, but was inverted with reference to its present orientation. Hence the currently opposed margins of the Baltic and Laurentian shield were not conterminous in the early Paleozoic. Laurentian and Baltic late Precambrian rifting episodes may therefore have occurred along unrelated continental margins. Closure of the Tornquist sea was accompanied by the counterclockwise rotation of Baltica relative to Avalonia in Early to Middle Ordovician time. This rotation, initiated in Late Cambrian–Early Ordovician time, was coeval with the Finnmarkian orogeny in the northern Scandinavian Caledonides.

INTRODUCTION

Geologic and geophysical evidence supports the existence of a major ocean separating Laurentia (North America, Greenland, western Newfoundland, and northern Britain), Baltica, and Avalonia (southern Britain, eastern Newfoundland, and eastern Maritime provinces) during the Ordovician. Whereas the position of Laurentia is now reasonably constrained by paleomagnetic data, the positions of Baltica and Avalonia are less

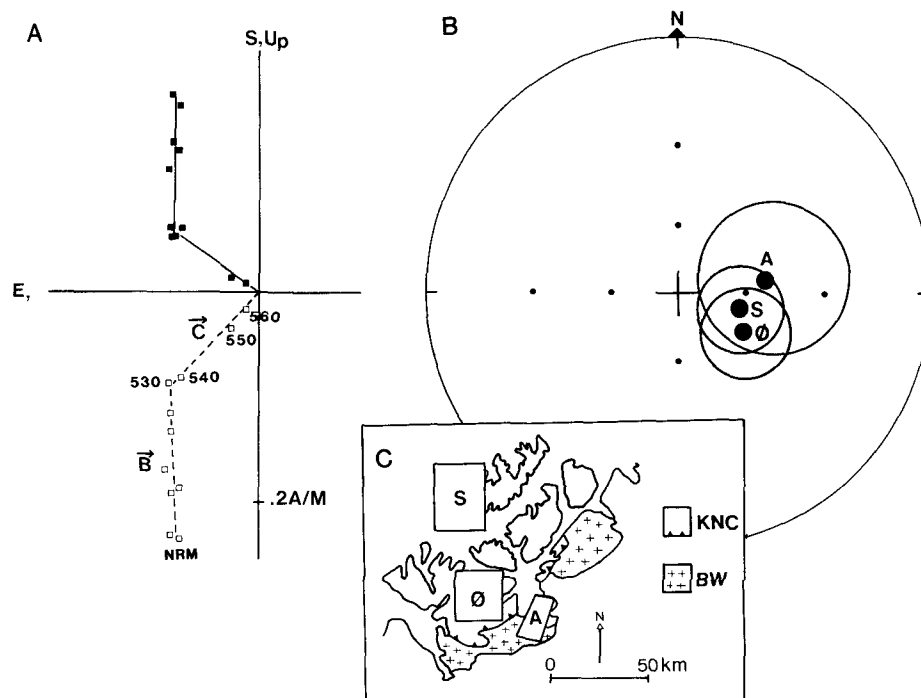
certain; this has led to a number of contrasting paleogeographic models (e.g., Cocks and Fortey, 1982; Scotese and McKerrrow, 1990; Torsvik et al., 1990a). New paleomagnetic results from the Caledonides of Finnmark, northern Norway, delimit new apparent polar wander (APW) paths for Baltica that have profound consequences for paleogeographic and tectonic reconstructions. The Caledonides of northern Norway comprise a series of nappe complexes (Gaissa, Laksefjord, and Kalak) consisting of rocks of probable Precambrian origin, and a higher nappe (Magerøy) of lower Paleozoic rocks emplaced onto Baltica (Ramsay et al., 1985; Townsend and Gayer, 1989). Evidence suggests that the Gaissa, Laksefjord, and Magerøy nappes underwent only one major tectonometamorphic episode, 430–400 Ma (Scandian), whereas the Kalak nappe has yielded isotopic dates for at least three phases (>800 and 510–490 Ma [Finnmarkian], and 430–400 Ma; Andersen et al., 1982; Aitchison et al., 1989; Dallmeyer, 1988).

NEW PALEOMAGNETIC DATA

The samples used in our investigation were collected from basic igneous rocks of the Seiland igneous province within the Kalak nappe complex, and from Precambrian intrusions within tectonic windows of Precambrian rock in the Kalak nappe complex.

Three remanence components, A, B, and C, were reported by Tors-

Figure 1. A: Example of thermal demagnetization of layered gabbroic sample, Øksnes area. C component is identified above 530 °C after randomizing southward- and downward-dipping component (component B). NRM = Natural remanent magnetization. Intensity scale in amps per metre (A/m). S = south, E = east. Viscous behavior ensued above 560 °C. In orthogonal vector projection, solid symbols represent points in horizontal plane and open symbols refer to vertical plane. B: C component area means (downward-dipping inclinations in equal-angle stereoplot) and their associated 95% confidence circles. A = Altnes-Alta basement window (Precambrian metabasalts and metagabbros); S = Sørøy (gabbros, Kalak nappe complex); Ø = Øksnes (layered gabbros, Kalak nappe complex). C: Location of sampling areas, northern Norway (also see Fig. 2A). Letters as in B. KNC = Kalak nappe complex; BW = basement windows.



vik et al. (1990b) and discussed in relation to Ordovician-Devonian paleomagnetic data from Europe. Here, we specifically address the importance of the C component and its bearing on Cambrian-Ordovician reconstructions. The C component has the following remanence properties and structural characteristics.

1. Single polarity, magnetite-bearing remanence typically unblocked between 500 and 580 °C (declination = 104, inclination = +57, α_{95} = 10.6, number of sites [N] = 10 [82 samples]).

2. The C component commonly coexists at sample level with the B component (Fig. 1A).

3. The C component postdates complex regional folding of igneous layering, and hence is inferred to be secondary.

4. The identification of C within Precambrian autochthonous basement windows (Altenes-Alta; Fig. 1, B and C) rules out major rotations linked to subsequent thrusting. This is confirmed by the directional consistency of component C over an area of ~3500 km².

5. The C pole (N31, E086, dp/dm [semiaxes of 95% confidence about the pole] = 11/15) is close to late Precambrian-Cambrian poles from Scandinavia (Fig. 2B), which Pesonen et al. (1989) believed to be reliable (see geographic locations in Fig. 2A).

Isotopic data (³⁹Ar/⁴⁰Ar hornblende; Dallmeyer, 1988) indicate that C was acquired during postmetamorphic cooling in the Early Ordovician, ca. 490 Ma. The component may therefore date the accumulation of the Finnmark nappes on the western margin of Baltica. A paleomagnetic pole reported from the Båtsfjord dikes, northern Norway (BD in Fig. 2B; Kjode et al., 1978), earlier taken to be late Precambrian on the basis of K/Ar biotite isotopic ages, is similar to the C pole. The Caledonian tectonothermal history of the Båtsfjord area, the fact that these dikes are situated immediately beneath the Kalak nappe complex, and the new isotopic data suggest to us that both poles record Early Ordovician cooling.

If the APW path for Baltica was as shown in Figure 2C, then the pole reported from the Swedish Orthoceras Limestones (Claesson, 1978) furnishes a lower age limit to the C pole (pole SL in Fig. 2C). We assign a primary late Arenigian-early Llanvirnian age (480–470 Ma) to this pole because it shows no resemblance to poles of younger age. The directional results of Claesson (1978) have recently been confirmed by Perroud et al. (1990).

POLAR WANDER PATHS

Two new smoothed APW paths (X and Y) for Baltica, calculated by using the spherical spline method (Jupp and Kent, 1987) and based on the new paleomagnetic data, are portrayed in Figure 2C. The path segments are similar for most of Cambrian-Ordovician time, but because Silurian poles from Baltica are ambiguous (Torsvik et al., 1990b), the two paths subsequently diverge. Here we address the tectonic significance of the Cambrian-Ordovician part of the postulated paths.

The APW paths for northern Britain (Scotland), southern Britain, and North America are characterized by a Silurian-Devonian (Middle Silurian to Middle Devonian) corner where they converge to produce a common path (Fig. 2C), indicating the assembly of Euramerica. However, a minor discordance exists in the Ordovician-Lower Silurian section of the Scottish and North American paths. Despite this, we have positioned North America and Scotland as a coherent unit in our reconstruction (fit of Bullard et al., 1965).

CAMBRIAN-ORDOVICIAN RECONSTRUCTION

Gondwana occupied high southern latitudes during the Early Ordovician; Avalonia was marginal to northwestern Africa (Van der Voo, 1988). The positioning of Avalonia relies on paleontological linkage and on the interpolation of paleomagnetic data, because there are no reliable Early Ordovician paleomagnetic data. Laurentia occupied equatorial to tropical latitudes (Fig. 3). Pole C and the two smoothed paths imply that Baltica was inverted with reference to its present orientation in Cambrian and Early Ordovician time. Pesonen et al. (1989), however, argued that

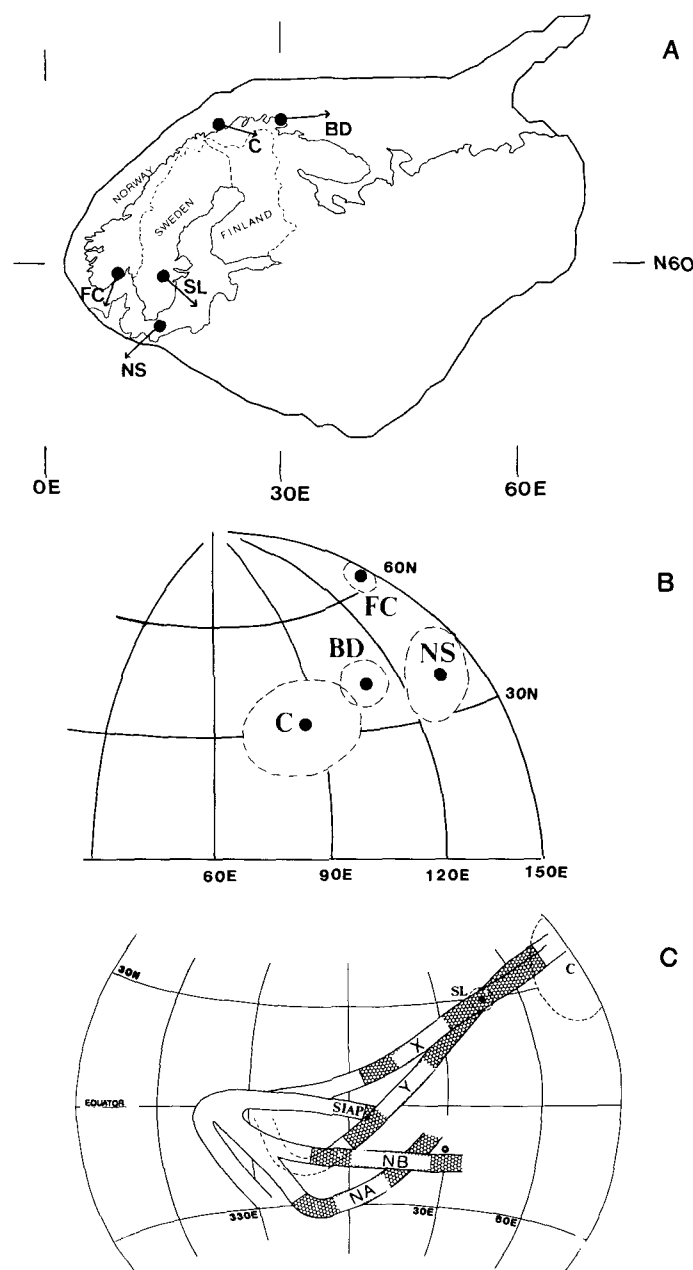


Figure 2. A: Geographic locations for poles shown in B and C. Arrows represent declination vectors. C = Area discussed in text (component C); BD = Båtsfjord dikes (Kjode et al., 1978); FC = Fen complex (late Precambrian-Early Cambrian; Poorter, 1972; declination and inclination inverted in pole calculation); NS = Nexø Sandstone (Lower Cambrian; Prasad and Sharma, 1978; declination and inclination inverted in pole calculation); SL = Swedish Limestones (Arenigian-Llanvirnian; Claesson, 1978). B: Late Precambrian-Cambrian poles compared with C pole (see text). Note that NS pole has been recalculated because originally reported pole is erroneous. Equal-area projection. C: British (Torsvik et al., 1990a) and North American APW paths (detailed in Torsvik et al., 1990b) and two alternative paths for Baltica (X and Y). C pole and Swedish Limestone pole (SL) are indicated. APW paths: SIAP = south of Iapetus suture (eastern Avalonia); NB = north of Iapetus suture (Scotland); NA = North America (including Greenland) in Bullard et al. (1965) fit. Pattern indicates Ordovician segments of paths. EQ = Equator. Equal-area projection. Reconstruction poles used in Figure 3: Laurentia positioned using intersection of paths NB and NA. Baltica is positioned according to pole C.

Baltica was oriented "the right-way-up" (i.e., similar to its present-day configuration) in northerly latitudes in late Precambrian–Cambrian time. We prefer our interpretation because of the revision of the magnetic age of the Båtsfjord dikes and the high crustal drift rates that a northern position would require relative to both Ordovician–Silurian and Sveconorwegian (850 Ma) reconstructions. It follows from our reconstruction that the Uralian margin of the Russian platform faced Avalonia–Gondwana, and the Lower Ordovician limestones in southern Scandinavia faced the equator, rather than the South Pole, as portrayed in conventional reconstructions. This scenario implies that the closure of the Tornquist sea was accompanied by continental-scale rotation of Baltica. Counterclockwise rotation relative to Avalonia must have begun by Arenigian–Llanvirnian

time (ca. 478 Ma; pole SL in Fig. 2C), and probably ceased by the Late Ordovician. We estimate northward latitudinal drift rates for Baltica, based on path X, of less than 6 cm/yr (Fig. 4A), and rotational velocities of less than 20°/10 m.y. (Fig. 4B).

EARLY ORDOVICIAN PALEONTOLOGICAL CONSTRAINTS

During the Early Ordovician (Arenigian–Llanvirnian), when provincialism was particularly marked, there existed three platform provinces associated with Gondwana, Baltica, and Laurentia (Havlicek, 1989, and references therein). Nevertheless, there is evidence for a chain of faunas quite different from those of the platforms along the length of the

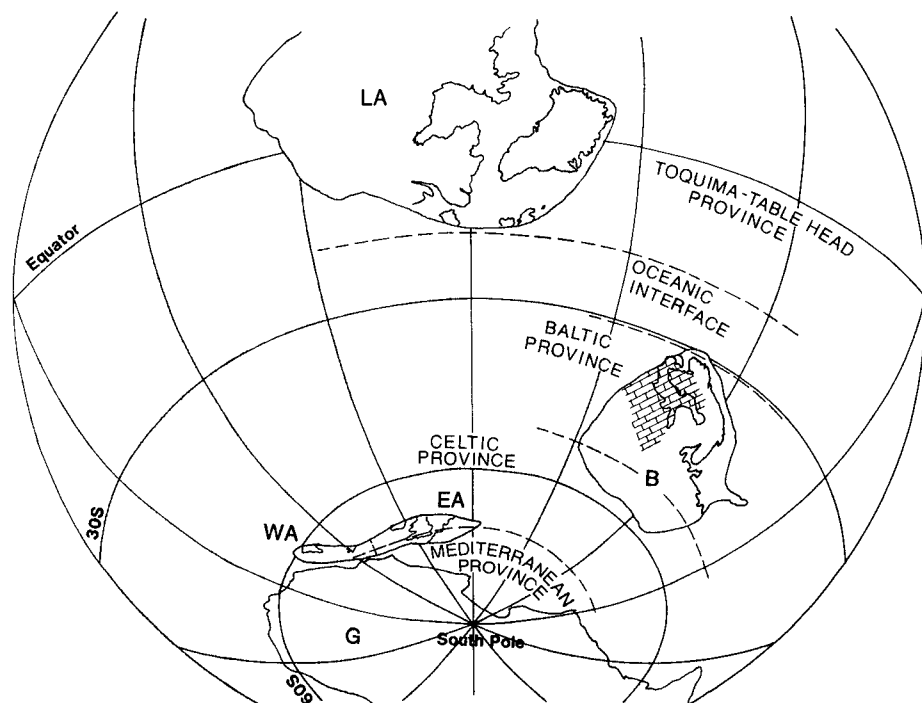


Figure 3. Cambrian-Ordovician to Early Ordovician paleoreconstruction. Brick pattern = Lower Ordovician limestones in Baltica. LA = Laurentia, B = Baltica, G = Gondwana, WA = Western Avalonia, EA = Eastern Avalonia. Dashed lines represent tentative provincial boundaries in late Arenigian–early Llanvirnian time. Oceanic interface includes provenance area of sedimentary rocks at Otta, central Norway (see text).

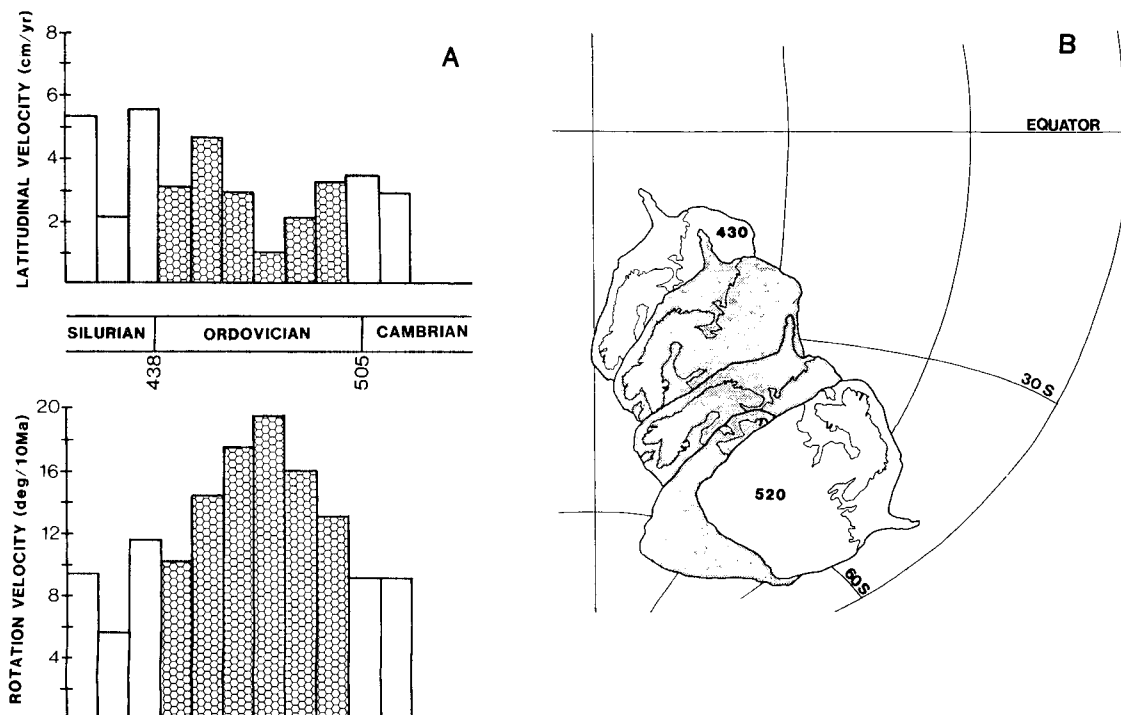


Figure 4. A: Predicted Cambrian to Silurian latitudinal (cm/yr) and rotational velocities (degrees/10 m.y.) derived from path X (reference locality: Oslo, N59°55', and E10°45'). Average values of 10 m.y. are plotted from ca. 410 to 520 Ma. B: Late Cambrian to Early Silurian drift history of Baltica using path X. Shading indicates Ordovician reconstructions. Dates (Ma) are approximations.

Appalachian-Caledonian orogen. Such intra-Iapetus assemblages have been assigned oceanic (Bruton and Harper, 1985) or marginal sites (Cocks and Fortey, 1988) associated with island habitats (Neuman, 1984). Arenigian-Llanvirnian brachiopod-dominated faunas from localities within eastern and western Avalonia, at high latitudes, have been assigned to the Celtic province (Fig. 3), whereas those associated with the margins of Laurentia, at low latitudes, belong to the Toquima-Table Head realm (Ross and Ingham, 1970). Other examples of such external faunas outside the Iapetus area (R. B. Neuman, 1990, written commun. to Harper) confirm the strong latitudinal constraints on their relative distributions.

The autochthonous Ordovician successions of Baltica were provincially coherent during the Early Ordovician, although the brachiopod faunas of the Moscow basin show some links with those of Gondwana (Hints, 1971). Along the predicted polar-facing margin of Baltica (Fig. 3), the Arenig fauna from the Kuragen stage of the southern Urals (Andreeva, 1972) possesses many of the characteristics of the Celtic province, whereas the Otta fauna from the lower part of the Upper allochthon, central Norway, is intermediate between both the Celtic and Baltic provinces and the Toquima-Table Head provinces (Bruton and Harper, 1981). Thus, the proposed reconstruction in Figure 3 provides a better paleogeographic framework for the currently known biogeographical patterns.

CONCLUSIONS

New paleomagnetic data from Finnmark, coupled with existing paleomagnetic data and paleontological arguments, suggest that during the Early Ordovician Baltica was in southern latitudes and was inverted with reference to its present-day geography. This has several profound implications for paleotectonic reconstructions. First, there is no need for late Precambrian rifting along the Baltic margin to be in any way related to that along the Laurentian margin, as has been implied in previous geologic models. Second, the rapid rotation initiated in the Late Cambrian-Early Ordovician, which is implicit in our model, was coeval with the Finnmarkian orogeny. This was followed by the closure of the Tornquist sea in Late Ordovician time (Cocks and Fortey, 1982). Third, our model implies that different margins of Baltica faced Iapetus (the ocean that separated it from Laurentia) at different times, suggesting that the concept of a single Iapetus Ocean throughout the entire period of Caledonide evolution may require modification.

REFERENCES CITED

- Aitcheson, S.J., Daly, J.S., and Cliff, R.A., 1989, A Late Proterozoic orogen in the North Norwegian Caledonides: *Terra Abstracts*, v. 1, p. 15.
- Andersen, T.B., Austreim, H., Sturt, B.A., Pedersen, S., and Kjaersrud, K., 1982, Rb-Sr whole rock ages from Magerøy, North Norwegian Caledonides: *Norsk Geologisk Tidsskrift*, v. 62, p. 79-85.
- Andreeva, O.N., 1972, Brachiopods of the Ordovician Kuranga suite of the South Urals: *Palaeontological Journal*, v. 6, p. 39-49 (in English, translated from Russian).
- Bruton, D.L., and Harper, D.A.T., 1981, Brachiopods and trilobites from the Early Ordovician serpentine Otta Conglomerate, south-central Norway: *Norsk Geologisk Tidsskrift*, v. 61, p. 153-181.
- , 1985, Early Ordovician (Arenig-Llanvirn) faunas from oceanic islands in the Appalachian-Caledonian orogen, in Gee, D.G., and Sturt, B.A., eds., *The Caledonide orogen—Scandinavia and related areas*: Chichester, England, Wiley, p. 359-368.
- Bullard, E.C., Everett, J.E., and Smith, A.G., 1965, The fit of continents around the Atlantic: *Royal Society of London Philosophical Transactions*, ser. A, v. 258, p. 41-51.
- Claesson, C., 1978, Swedish Ordovician limestones: Problems in clarifying their directions of magnetizations: *Physics of the Earth and Planetary Interiors*, v. 16, p. 65-72.
- Cocks, L.R.M., and Fortey, R.A., 1982, Faunal evidence for oceanic separation in the Palaeozoic of Britain: *Geological Society of London Journal*, v. 139, p. 465-478.
- , 1988, Lower Palaeozoic facies and faunas around Gondwana, in Audley-Charles, M.G., and Hallam, A., eds., *Gondwana and Tethys*: Geological Society of London Special Publication 37, p. 183-200.
- Dallmeyer, R.D., 1988, Polyorogenic $^{40}\text{Ar}/^{39}\text{Ar}$ mineral age record within the Kalak Nappe Complex, Northern Scandinavian Caledonides: *Geological Society of London Journal*, v. 145, p. 705-716.
- Havlicek, V., 1989, Climatic changes and the development of benthic communities through the Mediterranean Ordovician: *Sbornik Geologických Ved Palaeontologie*, v. 44, p. 79-116.
- Hints, L., 1971, A new genus of rhipidomellid brachiopod from the Middle Ordovician of the Moscow syncline: *Eesti NSV Teaduste Akadeemia Toimetised Keemia Geoloogia*, v. 22, p. 248-256.
- Jupp, P. E., and Kent, J.T., 1987, Fitting smooth paths to spherical data: *Applied Statistics*, v. 36, p. 34-46.
- Kjode, J.K., Storetvedt, K.M., Roberts, D., and Gidskehaug, A., 1978, Palaeomagnetism of late Precambrian dolerite dykes from Varanger Peninsula, North Norway: *Physics of the Earth and Planetary Interiors*, v. 21, p. 38-49.
- Neuman, R.B., 1984, Geology and paleobiology of islands in the Ordovician Iapetus Ocean: Review and implications: *Geological Society of America Bulletin*, v. 95, p. 1188-1201.
- Perroud, H., Robardet, M., and Bruton, D.L., 1990, The position of Baltica during the Ordovician [abs.]: *Annales Geophysicae*, Special Issue (XV General Assembly Copenhagen 1990), p. 46.
- Pesonen, L.J., Torsvik, T.H., Elming, S.-Å., and Bylund, G., 1989, Crustal evolution of Fennoscandia—Palaeomagnetic constraints: *Tectonophysics*, v. 162, p. 27-49.
- Poorter, R.P.E., 1972, Preliminary palaeomagnetic results from the Fen Carbonate Complex, Southern Norway: *Earth and Planetary Science Letters*, v. 17, p. 194-198.
- Prasad, S.N., and Sharma, P.V., 1978, Palaeomagnetism of the Nexø sandstone from Bornholm Island, Denmark: *Royal Astronomical Society Geophysical Journal*, v. 54, p. 669-680.
- Ramsay, D.M., Sturt, B.A., Zwann, K.B., and Roberts, D., 1985, Caledonides of northern Norway, in Gee, D.G., and Sturt, B.A., eds., *The Caledonide orogen—Scandinavia and related areas*: Chichester, England, Wiley, p. 163-184.
- Ross, R.J., Jr., and Ingham, J.K., 1970, Distribution of the Toquima-Table Head (Middle Ordovician Whiterock) faunal realm in the Northern Hemisphere: *Geological Society of America Bulletin*, v. 81, p. 393-408.
- Scotese, C.R., and McKerrow, W.S., 1990, Palaeozoic symposium introduction, in McKerrow, W.S., and Scotese, C.R., eds., *Palaeozoic palaeogeography and biogeography*: Geological Society of London Memoir 12, p. 1-21.
- Torsvik, T.H., Smethurst, M.A., Briden, J.C., and Sturt, B.A., 1990a, A review of Palaeozoic palaeomagnetic data from Europe and their geographical implications, in McKerrow, W.S., and Scotese, C.R., eds., *Palaeozoic palaeogeography and biogeography*: Geological Society of London Memoir 12, p. 25-41.
- Torsvik, T.H., Olesen, O., Ryan, P., and Trench, A., 1990b, On the palaeogeography of Baltica during the Palaeozoic: New palaeomagnetic data from the Scandinavian Caledonides: *Geophysical Journal International*, v. 103.
- Townsend, C., and Gayer, R.A., 1989, The timing of orogenesis in northern Norway: Did the Finnmarkian Orogeny occur?, in Gayer, R.A., ed., *The Caledonide geology of Scandinavia*: London, Graham & Trotman, p. 63-65.
- Van der Voo, R., 1988, Paleozoic paleogeography of North America, Gondwana, and intervening displaced terranes: Comparisons of paleomagnetism with paleoclimatology and biogeographical patterns: *Geological Society of America Bulletin*, v. 100, p. 311-324.

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Reviewer's comment

Results fill a critical gap in our paleogeographic knowledge about Baltica and provide an exciting scenario for early Paleozoic plate evolution of Iapetus.

Rob Van der Voo