Carboniferous age for the East Greenland "Devonian" basin: Paleomagnetic and isotopic constraints on age, stratigraphy, and plate reconstructions

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**Notes**
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“Devonian” basin: Paleomagnetic and isotopic constraints on age, stratigraphy, and plate reconstructions

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ABSTRACT

New paleomagnetic and isotopic data from East Greenland indicate that this classical “Devonian” basin was partly formed in Carboniferous. The basin preserves a stratigraphically linked magnetic reversal pattern of primary character. Paleomagnetic data indicate that the two stratigraphically lowermost intrabasinal angular unconformities, identified on each side of the basin, in fact correlate as one unconformity. This implies a 2 km reduction of the estimated basin thickness, and thus that the unconformity represents a major depositional hiatus. Successions below the unconformity are taken to be Devonian (Givetian) in age, on the basis of correlation with paleomagnetic reference poles. However, we argue that the overlying strata are Carboniferous, rather than Devonian, in age, on the basis of a ca. 336 Ma 40Ar/39Ar extrusive age for a basalt flow and paleomagnetic data. A Carboniferous age for the strata has significant implications for vertebrate evolution; fossils of a terrestrial tetrapod, Ichthyostega, are found above the unconformity. Ichthyostega is regarded as the earliest fossil of an animal known to walk on land; however, our data suggest that these dry footsteps are much younger than previously believed. Our results are also significant for plate reconstructions. Paleomagnetic data indicate that the lower part of the basin was deposited at low southerly latitudes. Sediments above our Early Carboniferous unconformity were deposited approximately at lat 4°N, indicating that the continent had drifted northward. A minor pole-longitude misfit between Devonian and Carboniferous poles from East Greenland and North America implies (1) a closer pre–Labrador Sea Greenland–North America fit; (2) counterclockwise block rotations (10°–15°) of the study area; or (3) a combination of both. The East Greenland “Devonian” basin formed along the Caledonian spine of Euramerica, and counterclockwise block rotation may have occurred between sinistral faults resulting from continued relative movement between Baltica and Laurentia during Devonian and Carboniferous time.

INTRODUCTION

The East Greenland “Devonian” basin formed as an intramontane supradetachment basin (Hartz and Andresen, 1995) within the Caledonian orogen (Bütler, 1959; Haller, 1971). Devonian deposits generally are in large north-south–trending grabens, most recently suggested to be controlled by major left-lateral faults (Larsen and Bengaard, 1991). Herein we report the first paleomagnetic data from the East Greenland Devonian deposits. These data cast doubts on the proposed Devonian age of the entire basin sedimentary succession and challenge traditional facies correlations across the basin.

GEOLOGIC SETTING AND PALEOMAGNETIC SAMPLING

Devonian deposits unconformably overlie Late Proterozoic to Ordovician sedimentary rocks and, in some localities, overlie Precambrian gneiss (Fig. 1A; Bütler, 1959). Basin fill is estimated to be >8 km thick and consists mainly of coarse terrestrial clastics and minor fine-grained lacustrine deposits (Olsen and Larsen, 1993). Bütler (1959) reported that the stratigraphy of the basin can be divided into the following four series: the Basis, series, suggested to be late-Middle Devonian (Givetian); the late Givetian to Frasnian Kap Koltthoff series; the early Famennian Kap Graah series; and the Famennian Celsius Bjerg series. Each series is separated by angular unconformities, and the ages are identified on the basis of vertebrate fossils (Jarvik, 1961; Friend et al., 1983).

In a reexamination of the lithostratigraphy of the basin, Olsen and Larsen (1993) divided the deposits into four new groups based on sedimentary facies correlations. Their revised stratigraphy combines rocks across marked angular unconformities, however, which we find awkward. We therefore favor the stratigraphic subdivision proposed by Bütler (1959). Our studies have focused on paleomagnetic and isotopic sampling of the Basis, Kap Koltthoff, and Kap Graah series in two
Sections across two previously defined intra-basinal unconformities (Fig. 1, A and B).

Section I

The Basis series represents the oldest Devonian deposits in East Greenland (Fig. 1B; Büttler, 1959). The unit is only exposed in west-central Moskusoksefjord (Fig. 1A) and consists of conglomerates interfingered with red sandstones which dip 35° to 70° eastward (sites G1, 43, and G2). The Kap Kolthoff series is between the first and second intra-basinal unconformities, and the lowermost part of this series was sampled in east-central Moskusoksefjord (Fig. 1A, sites H, 18, and 19). The stratigraphically highest of these sites (site 19) was sampled directly below a 10-m-thick basalt flow (sites 20 and 21). A second basalt flow located 250 m stratigraphically above the first was also sampled in two sites (sites 1 and 50). In the upper part of the Kap Kolthoff series, a red conglomeratic sandstone, the Snehvide Formation of Olsen and Larsen (1993), was sampled at two localities at east-central Dybendal (Fig. 1A, site 13).

Section II

In eastern Moskusoksefjord, the Basis and Kap Kolthoff series are mapped as conformable and are separated from the Kap Graah series by an angular unconformity (Fig. 1B; Büttler, 1959). Sandstone and basalts of the Kap Kolthoff series were sampled in three sites (Fig. 1B; sites 31, 32, and 35). Basalts within the lowermost Kap Graah

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**TABLE 1. MEAN DIRECTIONS OF EAST GREENLAND "DEVONIAN" BASIN (LAT. 73.7°N, LONG. 23.7°W)**

<table>
<thead>
<tr>
<th>S/P</th>
<th>Dec</th>
<th>Inc</th>
<th>N</th>
<th>α95</th>
<th>k</th>
<th>Dec</th>
<th>Inc</th>
<th>α95</th>
<th>k</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above unconformity:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I/N</td>
<td>353.1</td>
<td>-1.4</td>
<td>5</td>
<td>16.9</td>
<td>21.5</td>
<td>352.6</td>
<td>-2.4</td>
<td>11.7</td>
<td>43.4</td>
</tr>
<tr>
<td>I/R</td>
<td>193.5</td>
<td>-21.9</td>
<td>4</td>
<td>21.8</td>
<td>18.7</td>
<td>192.4</td>
<td>-20.6</td>
<td>21.3</td>
<td>19.6</td>
</tr>
<tr>
<td>II/N</td>
<td>333.9</td>
<td>3.8</td>
<td>33°</td>
<td>1.7</td>
<td>213.3</td>
<td>333.5</td>
<td>4.8</td>
<td>1.7</td>
<td>213.3</td>
</tr>
<tr>
<td>C/M</td>
<td>358.8</td>
<td>8.6</td>
<td>10</td>
<td>14.6</td>
<td>11.9</td>
<td>358.1</td>
<td>7.6</td>
<td>13.4</td>
<td>14.0</td>
</tr>
<tr>
<td>Paleomagnetic south-pole:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Latitude = 20.1°S, Longitude = 338.3°E, dp/dm = 6.8°/13.5°</td>
<td></td>
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</tr>
</tbody>
</table>

Below unconformity:

| I/N   | 020.4 | 6.1 | 11° | 9.7 | 23.3 | 019.1 | -10.5 | 9.7 | 23.3 |
| I/R   | 194.7 | -3.0 | 4  | 28.0 | 11.7 | 197.7 | 6.1 | 24.6 | 14.9 |
| II/R  | 176.3 | 13.5 | 3  | 6.4 | 377 | 190.5 | 22.5 | 7.7 | 256.6 |
| C/M   | 188.5 | 3.0 | 8  | 14.6 | 15.4 | 195.2 | 13.0 | 11.6 | 23.9 |
| Paleomagnetic south-pole: |     |     |    |     |    |     |     |     |    |
| Latitude = 9.1°S, Longitude = 321°E, dp/dm = 6°/11.8° |

Anomalous basalt sites:

Combined I (44), II (20 and 21) baked sandstone 19); cf. Figs. 2 & 3 and text

| 244.1 | 40.8 | 3  | 13.3 | 87.5 | 243.7 | 42.0 | 11.7 | 111.5 |

**Note:** S/P = Section and polarity (C/M = Combined/ Mixed)

Dec/Inc = mean declination/inclination.

N = number of sites (or samples *) (total number of samples included in statistics = 374).

α95 = 95% confidence circle.

k = precision parameter.

dp/dm = semi-axis of the 95% confidence ovals.
series were sampled directly above this locality (Fig. 1B, site 34). The lowest basalt horizon in the Kap Graah series was also sampled 10 km farther northwest (site 44). Within the ~10-m-thick basalt horizon, thin (<5 cm) layers of sand are discernible, indicating that some basalt horizons may include more than one flow.

PALEOMAGNETIC RESULTS

The natural remanence magnetization (NRM) was measured with a JR5A (Trondheim) and a 2G Squid (Ann Arbor) magnetometer. The NRM stability of 430 samples was tested by stepwise thermal demagnetization (MMDT60 furnace), and ancient remanence components were isolated using a least square algorithm.

In section I, at least four polarity transitions are identified, and in two red sandstone units (G2 and 13) both polarities occasionally were identified in individual samples (Fig. 2, site G2A). Characteristic remanence components in red sandstones are carried by hematite; this is also identified, and ancient remanence components were rotated into Greenland coordinates (Labrador Sea closed) using fit of Roest and Srivastava (1989). Reference poles 410–320 Ma were listed in Torsvik et al. (1996) (except entry 20 in Table 1). a: As in a, but using Bullard et al. (1965) fit for Labrador Sea reconstruction (Euler pole and rotation angle calculated from their Greenland-Europe–North America fits). For diagram simplicity, only Laurentia error ellipses and smooth spline path derived from Laurentia and Baltica data (smoothing parameter = 200; graded according to Q-factor; cf. procedure in Torsvik et al., 1996) are shown. In both fits, Greenland poles plot to east but overlap with Devonian and Carboniferous poles. Misfit is best reduced with original Bullard et al. (1965) fit. Misfit can also be reduced by invoking local block rotations on vertical axes for poles B (below unconformity) and A (above unconformity). Black circles indicate effect of compensating for local counterclockwise rotations about vertical axis in 10° and 20° steps. Note that pole A is in much better correspondence with Early Carboniferous poles than previously claimed Devonian (Frasnian) age.

40Ar/39Ar RESULTS

Plagioclase from the basalt flow at site 44 was dated by 40Ar/39Ar furnace step heating at the Massachusetts Institute of Technology (MIT) argon laboratory. The release spectrum yields a near-plateau age of 335.6 ± 3.1 Ma (Fig. 3). Analytical and statistical details follow those in Hodges and Bowring (1995), except that a newer version (3.1.3) of the MIT Ar isotopic analysis program was used. The plagioclase cooling age is interpreted to date the time of extrusion of the basaltic lava.

DISCUSSION

The paleomagnetic signatures across the Basis–Kap Kolthoff and Kap Kolthoff–Kap Graah unconformities in the eastern and western side of the Devonian basin are broadly similar. Therefore, we argue that they are time correlative and do not represent two different unconformities within the basin. This implies that the cumulative stratigraphic thickness of the basin actually is <6 km, rather than the earlier reported >8 km. A stratigraphic link between the two unconformities at each side of the basin is not depicted in existing maps or profiles (Bütler, 1959; Olsen and Larsen, 1993). Additional mapping is needed to evaluate the validity of the new proposed stratigraphic model of the basin.

Paleomagnetic poles from below (B, Fig. 4) and above (A, Fig. 4) the first Devonian unconformity are significantly different.
Laurentian (North America and Scotland) and Baltic poles, pole B partly overlaps Middle to Late Devonian poles (Givetian and Frasnian), whereas pole A plots within the Early Carboniferous (Fig. 3B). The latter relation is at clear variance with the previously postulated Late Devonian, or Frasnian, age (ca. 377–367 Ma; Harland et al., 1990). The paleomagnetic reference poles for this time interval are not well constrained (Fig. 4). Pole A, however, clearly plots in the vicinity of Carboniferous reference poles, and within the 345–329 Ma segment of a combined Laurentia-Baltica apparent polar wander path (Fig. 4B). A Carboniferous age is further confirmed by the ca. 336 Ma ⁴⁰Ar/³⁹Ar age from the lowermost basalt (site 44) in the Kap Graah series.

If this Carboniferous age is representative, it has serious paleontological and evolutionary implications. The tetrapod Ichthyostega (Jarvik, 1961), regarded as the earliest well-preserved fossil of animals that walked on land, occurs in the deposits above our sampling sites. Ichthyostega, found in the Celsius Bjerg series, had been regarded as having evolved during the mid–Late Devonian (Famennian) (Jarvik, 1961; Friend et al., 1983).

The East Greenland poles overlap with the Laurentia and Baltic poles after reconstructing the Labrador Sea, and the collective data imply a near-equatorial position of Greenland (Fig. 5) during Late Devonian and Early Carboniferous time. A minor, systematic, easterly offset of both Greenland poles is indicated by our data when compared with published reference poles (Fig. 4); the overall misfit of these poles is, however, minimized in a Bullard et al. (1965) fit. This may indicate that the amount of pre-drift, Labrador Sea extension previously has been underestimated. Alternatively, the fits can be improved by invoking Late Devonian to Early Carboniferous, local, counterclockwise block rotation of the basin. Because Baltica had docked obliquely against Laurentia from the south (Torsvik et al., 1996), the resulting sinistral transpression could have caused strain partitioning between local rotations, folding, and left-lateral faulting. Although we envision the “Devonian” basin of East Greenland as a supradetachment basin (Hartz and Andresen, 1995), rather than a basin controlled by strike-slip faults (Larsen and Bengaard, 1991), such local block rotations are compatible with a link to well-known left-lateral faults within the Caledonian orogen, such as the Great Glen fault in Scotland and/or the Møre-Trøndelag fault zone in west-central Norway (Fig. 5).

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