Pre-Mississippian tectonic affinity across the Canada Basin–Arctic margins of Alaska and Canada

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ABSTRACT

New and reprocessed seismic reflection data on the Alaskan and Canadian Arctic margins of the Canada Basin, together with geologic constraints from exploration wells and outcrops, reveal structural and stratigraphic relationships in pre-Mississippian rocks that constrain models of Canada Basin opening. Lithostratigraphic age and acoustic character indicate that the Devonian and older passive-margin to foreland-basin succession in the Canadian M’Clure Strait is also found on the central Alaska margin. This succession also displays similar structural geometry and relief as well as deformational age on both margins. Moreover, Middle Devonian to Early Mississippian tectonic vergence—north directed on the central Alaska margin and east directed in the Canadian M’Clure Strait—indicates a common direction of tectonic transport if the two margins were conjugate. All of these observations demonstrate that pre-Mississippian rocks of the Alaskan and Canadian Arctic margins share a common tectonic history of uplift and exhumation and that the two margins were conjugates prior to opening of the Canada Basin.

INTRODUCTION

The origin and plate tectonic reconstruction of the Arctic Ocean Basin remains controversial, in part because of limited data from this remote and inaccessible ice-covered region of Earth. One of the contentious topics is the opening of the Canada Basin, part of which lies between high-standing continental crust of Canada, Alaska, and the Chukchi Borderland (Fig. 1A; Grantz et al., 2011). A popular model considers the Alaskan and Canadian Arctic margins to be conjugates separated by a Bay of Biscay-type (Vissers and Meijer, 2012) counterclockwise opening of the Canada Basin about a pole of rotation in the Mackenzie Delta region (Fig. 1A; Grantz et al., 2011). Geological and geophysical evidence pertinent to this model has been presented by numerous authors (e.g., Embry, 1990; Miller et al., 2010; Grantz et al., 2011; Strauss et al., 2013; Gottlieb et al., 2014; Chian et al., 2016).

Significantly, the conjugate relationship between the Alaskan and Canadian Arctic margins and the rotational-opening model have been challenged recently by Lane et al. (2016). Those authors cite the absence of evidence for Late Devonian tectonism in Arctic Alaska. Access to new and reprocessed seismic reflection data on the Alaskan and Canadian submerged margins of the Canada Basin (Fig. 1A) provides an unprecedented opportunity to interpret the crustal-scale structure and deep stratigraphy that support a conjugate relationship between the two margins.

PERTINENT DATA AND METHODS

The geology of the Canada Basin and its submerged margins is inferred mainly from geophysical data. Regional potential field grids, in combination with sonobuoy velocity and seismic reflection data, have been used to infer a relict spreading center in the Canada Basin and the crustal character across the Alaskan and Canadian margins (e.g., Grantz et al., 2011; Chian et al., 2016).

High-resolution seismic reflection data are limited mainly to shelf areas. Public-domain seismic reflection and refraction data that constrain shelf to deep-basin geology are sparse and of limited depth resolution (Grantz et al., 1990; Jackson et al., 1990). Newer seismic reflection and refraction data provide enhanced imaging (Chian et al., 2016), but are also sparse in coverage. Thus, current understanding of Canada Basin tectonics is based mainly on integration of onshore and nearshore geology with sparse data from the offshore.

We use two sets of two-dimensional seismic reflection data, integrated with well and outcrop data, to interpret stratigraphy and structure across the potentially conjugate Alaskan and Canadian margins. The first is a grid of A.D.
Pre-Mississippian rocks of the North Slope of Alaska are mainly acoustically transparent (Fig. 2B). In some areas, laterally continuous reflections of variable dip direction and magnitude define a stratigraphy that can be correlated across tens of kilometers. However, near the coast and continuing as far as 50 km offshore, stratification dips 30° to 45° to the north. This seismic facies has been penetrated by ~100 wells along the Barrow arch (Fig. 1B), where lithofacies are mainly argillite and chert with dips that exceed 60° in many cores (Dumoulin, 1999, 2001). These rocks are Neoproterozoic to Silurian in age based on a cosmopolitan fauna that is non-diagnostic regarding affinity to coeval shelf facies bearing both Siberian and Laurentian fauna in the Alaska Brooks Range and only Laurentian fauna in the Canadian Arctic Islands (Dumoulin et al., 2000; Dumoulin, 1999, 2001). In addition, a core from one well (Fig. 1B, well T) contains Lower to Middle Devonian nonmarine strata, and two nearby wells likely penetrated coeval strata (Dumoulin, 2001). We interpret these Devonian strata to be conformable with the older rocks and that both were deformed by a tectonic event that postdated deposition of the Lower to Middle Devonian rocks.

Significantly, the dipping fabric in pre-Mississippian rocks is overlain in angular unconformity by Lower to Middle Mississippian strata in extensional grabens (Wicks et al., 1991). This angular unconformity, which is confirmed by seismic observations and well penetrations across the region, demonstrates that contractional deformation of pre-Mississippian rocks is bracketed between Middle Devonian and Early Mississippian time and that the region was subjected to extension shortly thereafter.

The Cambrian to Silurian argillite and chert (Fig. 1B) along the Barrow arch likely were deposited in a deep-water basin, perhaps located between the Canadian Franklinian margin (Trettin et al., 1991) and the Arctic Alaska margin prior to accretion of the Arctic Alaska terrane to Laurentia (Dumoulin et al., 2000). We interpret the seismic geometries and steep dips in cores to indicate that these rocks are deformed by contraction and significantly more shortened, structurally elevated, and erosionally truncated onshore and nearshore (inferrd Paleozoic orogenic hinterland) compared to offshore (inferred Paleozoic foreland, see below). We infer that this Paleozoic structural domain is analogous to the Banks Island belt in the Canadian Arctic Islands. And, we suggest that the local occurrence of Lower to Middle Devonian nonmarine strata on the south flank of the Barrow arch is analogous to the faulted syncline interpreted as part of the Devonian clastic wedge on the back of the large M’Clure Strait structure (Fig. 2A).

Seismic data from the outer Beaufort shelf north of Prudhoe Bay, including the northern
Dinkum graben and Dinkum plateau (Fig. 1B; Hubbard et al., 1987; Grantz et al., 1990), image pre-Mississippian rocks of significantly different acoustic character. There, we interpret the top of pre-Mississippian rocks by the presence of an angular unconformity at the base of Mississippian or younger strata (Fig. 3).

The seismic geometries below the pre-Mississippian unconformity display discrete domains of parallel concordant strata (Fig. 3, label 1) bound by low-angle thrust faults (2) that sole into a deeper detachment below the base of the seismic record. Back-limb (3) and front-limb (4) cutoff geometries are consistent with imbricate fault-bend folding (Shaw et al., 2005). These relationships document the presence of a north-vergent fold-and-thrust belt. Furthermore, the reflective character and relief of the pre-Mississippian unconformity suggests preservation of an irregular paleotopography that clearly influenced accommodation in the Dinkum graben, as

Figure 3. Seismic line segment beneath outer Beaufort shelf of Alaska, displayed with approximately no vertical exaggeration. Inferred Middle to Upper Devonian strata are deformed in north-vergent fold-and-thrust belt. Black lines within Devonian strata show two correlative horizons that display back-limb and front-limb cutoff geometries. LCU—Lower Cretaceous unconformity. Numbers in italics refer to text descriptions of key features. Approximate line location is shown in Figure 1B. TWT—two-way traveltime; VE—vertical exaggeration.

Figure 2. Regional seismic lines. A: Long-offset, pre-stack, time-migrated reflection seismic line in M’Clure Strait of Canada illustrating inferred structure and stratigraphy of Devonian and older rocks. See text for additional explanation. Inset map shows approximate line location (yellow line) and nearby wells (yellow dots); wells are not posted on line as all are more than 45 km from line. Interpretation of stratigraphy and regional geologic elements is based mainly on Harrison and Brent (2005) and well data from Natural Resources Canada (Geological Survey of Canada) online BASIN database (http://basin.gdr.nrcan.gc.ca/index_e.php). BI—Banks Island; MI—Melville Island; PPI—Prince Patrick Island. Seismic image shown courtesy of ION Geophysical (Houston, Texas, USA). B: Composite seismic line from Alaska Brooks Range foothills to shelf edge of Beaufort Sea. Generalized stratigraphy is constrained by well penetrations and regional seismic interpretation. All thrust faults in foothills and in inferred Devonian fold-and-thrust belt are generally north vergent. Many normal faults on and north of Barrow arch display multiple phases of growth, including Mississippian, Jurassic, and Hauterivian. Younger growth faults sole near Lower Cretaceous unconformity. Approximate line location is shown in Figure 1B. TWT—two-way traveltime; VE—approximate vertical exaggeration.


Dumoulin, J.A., Harr, H.I., and Freitas, T.A., 2000, Facies patterns and conformable biogeography in Arctic Alaska and the Canadian Arctic Islands: Evidence against juxtaposition of these areas during Early Paleozoic time: Polar Forschung, v. 68, p. 257–266.


Manuscript received 7 March 2016
Revised manuscript received 2 May 2016
Manuscript accepted 5 May 2016
Printed in USA