STRATIGRAPHY, STRUCTURE, AND ORIGIN OF THE FRANKLINIAN, NORTHEAST CHUKCHI BASIN, ARCTIC ALASKA PLATE

K. W. Sherwood, Minerals Management Service, 949 E. 36th Ave., Anchorage, Alaska 99508, USA

ABSTRACT

The fault-bounded Northeast Chukchi basin preserves at least 9 km of mildly deformed Franklinian strata. The basin is juxtaposed on three flanks against highly deformed, acoustically incoherent Franklinian rocks. The basin is inferred to contain a 4.5-km-thick carbonate succession. Carbonates are not found among the slaty metamorphic rocks that characterize the Franklinian assemblage in western Arctic Alaska and, perhaps, other Franklinian terranes flanking the basin. The carbonate-bearing Northeast Chukchi basin is truncated on the northeast at the (Cretaceous) Beaufort rift margin and probably extended into the terrane once opposite the rift.

Geological comparisons and tectonic models support the notion that Northeast Chukchi basin is a fragment of the carbonate-bearing part of the Franklinian basin of the Canadian Arctic Islands that was isolated into the Arctic Alaska plate by Cretaceous rifting and formation of the oceanic Canada Basin.

INTRODUCTION

Northeast Chukchi basin is known only from seismic surveys and occupies part of the northeastern Chukchi shelf offshore of the northwest coast of Alaska (Fig.1). Previous investigations of this area and the adjoining continental shelves of the Beaufort and Chukchi Seas were carried out primarily by Arthur Grantz and colleagues of the U.S. Geological Survey (select publications cited below). Contributions by Craig et al. (1985), Thurston and Theiss (1987), and Hubbard et al. (1987) also have improved our understanding of the region.

The geological evolution of the Canadian Arctic and Arctic Alaska can be organized into three major sedimentary cycles, represented by the Franklinian (Precambrian(?) to Middle or Late Devonian), Ellesmerian (Early Mississippian to Early Cretaceous), and Brookian (Early Cretaceous to Present) sequences (Lerand, 1973; Grantz et al., 1975). In many parts of the Arctic, Franklinian rocks, the focus of this work, were strongly deformed in the Ellesmerian orogeny (Late Devonian to Early Mississippian) that preceded formation of Ellesmerian-cycle basins.

THE NORTHEAST CHUKCHI BASIN ENIGMA

Northeast Chukchi basin is a fault-bounded crustal block roughly 140 km wide and 225 km long (Figs.1,2). On the southeast, southwest, and northwest, undisturbed seismic reflections of the basin are faulted against

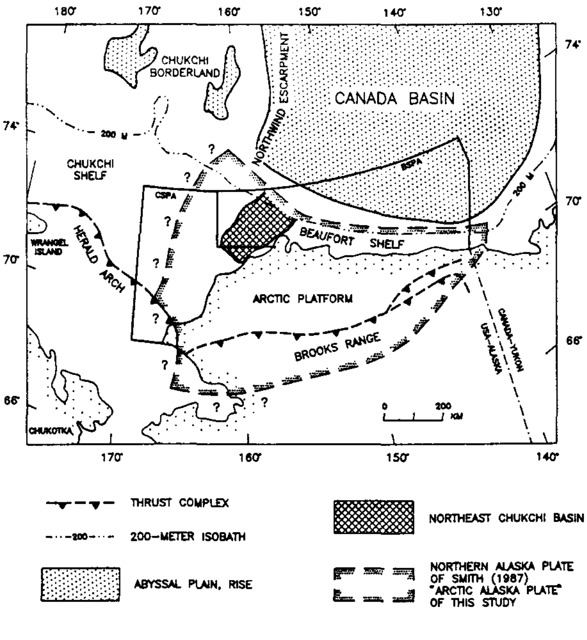


Fig.1. Location of Northeast Chukchi basin and conservative outline of Arctic Alaska plate. The Arctic Alaska plate may extend westward to include northeast Chukotka and parts of the East Siberian shelf (Jackson and Gunnarsson, 1990).

acoustically incoherent, presumably highly deformed, Franklinian rocks. To the northeast, all of these Franklinian terranes are truncated at the Cretaceous rift margin of the Arctic Alaska lithospheric plate (Fig.2) (Grantz and May, 1982).

Because Northeast Chukchi basin is truncated at the rift margin and because it is geologically quite unlike correlative, flanking Franklinian terranes, it may provide a unique clue to the identity of the larger plate to which the Arctic Alaska plate was joined prior to Cretaceous rifting. The stratigraphy of Northeast Chukchi basin guides the search for the correlative basin opposite the rift, while the structural fabric helps document structural continuity and constrain tectonic reconstructions.

SEISMIC STRATIGRAPHY OF NORTHEAST CHUKCHI BASIN

Grantz et al. (1990) and Craig et al. (1985) recognize two seismic-stratigraphic units in the Northeast Chukchi basin. The "Carbonate" unit of this study corresponds to the "carbonate unit" of Craig et al. (1985) and unit "PzpC" of Grantz et al. (1990). The present study and that of Sherwood (1990) differ from previous work in recognizing two structural units within the post-Carbonate sequence (lumped as the "Clastic Wedge/Lower Ellesmerian Sequence" by Craig et al. and unit "Pzf" by Grantz et al.).

The Carbonate unit floors Northeast Chukchi basin; is at minimum 4.5 km thick; and is characterized by parallel, continuous-amplitude reflections that persist to great depths in seismic records (Fig.3). Grantz and May (1982) report seismic velocities ranging from 5.35 to 7.30 km/s, which together with style of stratification suggest a succession dominated by carbonates.

The post-Carbonate basin fill is separated here into two units on the basis of structural and acoustic character. In the western part of the basin, the "Clinoformal Clastic" unit features reflections that converge and downlap the top of the Carbonate unit towards the southeast. When the top of the underlying Carbonate unit is restored to horizontal, the clinoformal reflections dip from 1° to 7° southeast (Craig et al., 1985; Grantz et al., 1990), suggesting that the Clinoformal Clastic unit prograded into the basin from present-day northwest. Interval velocities obtained by Craig et al. (1985) range from 4.0 to 4.6 km/s, consistent with a shale-sandstone sequence. The maximum preserved stratigraphic thickness in areas unaffected by thrusts is approximately 4.5 km.

The Clinoformal Clastic unit tapers southeast beneath a southeast-thickening wedge (up to 8 km near Barrow fault) of mostly acoustically incoherent rocks here termed the "Deformed Clastic" unit (Fig.3). Grantz et al. (1990) interpreted the contact between these overlapping wedges as a facies boundary between a foreset facies (Clinoformal Clastic unit of this paper) and equivalent basinal shales to the southeast. However, high-quality reflection seismic surveys reveal folds within the Deformed Clastic unit above the undisturbed Clinoformal Clastic unit (Fig.3). Also, individual reflections in both the Clinoformal Clastic unit and the overlying folds appear to be truncated at a southeast-inclined (12°) surface that defines their mutual contact. This contact is interpreted here as a ramp on a thrust fault that superposed a detached fold belt on the Clinoformal Clastic unit (Fig.3).

Grantz et al. (1979, Fig.8) report seismic velocities ranging from 4.4 to 5.6 km/s in rocks corresponding to the Deformed Clastic unit of this study, significantly higher than the 4.0 to 4.6 km/s obtained for the Clinoformal Clastic unit by Craig et al. (1985). Deformed Clastic unit velocities are, however, comparable to the 4.3 to 5.4 km/s velocities measured in well surveys of the Franklinian basement complex of the Arctic platform (Fig.3).

The high-interval velocities of the Deformed Clastic unit suggest a high degree of induration, probably a consequence of greater burial and tectonic deformation. The widespread absence of coherent reflections east of the thrust ramp is likewise consistent with severe tectonic deformation. In both aspects, the Deformed Clastic unit most resembles acoustic basement beneath the Arctic platform.

BASIN STRUCTURE AND BOUNDING FAULTS

The Carbonate unit is undeformed and homoclinally dips 7° to the southeast to a truncation at the Barrow fault. The thrust ramp that floors the Deformed Clastic

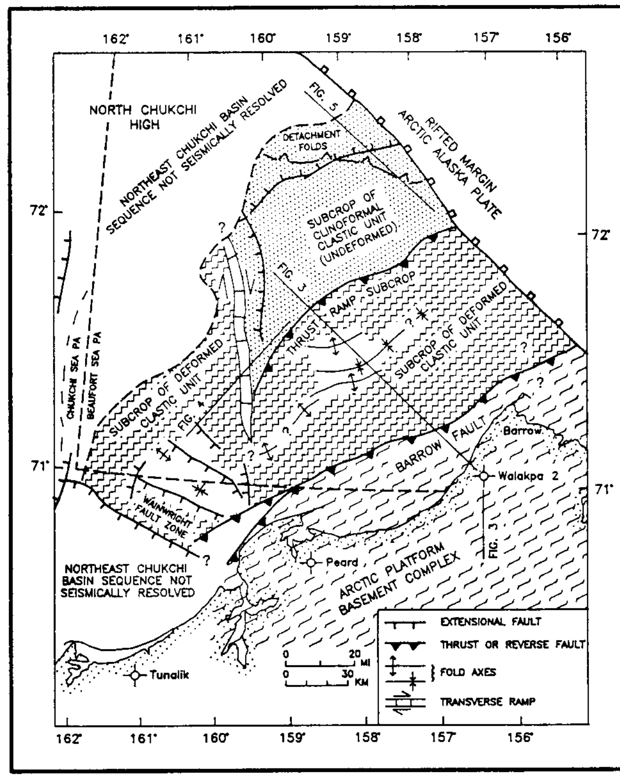


Fig.2. Geologic map of Franklinian rocks of Northeast Chukchi basin and Arctic Alaska at subcrop at base of overlap sequences (Mississippian and younger).

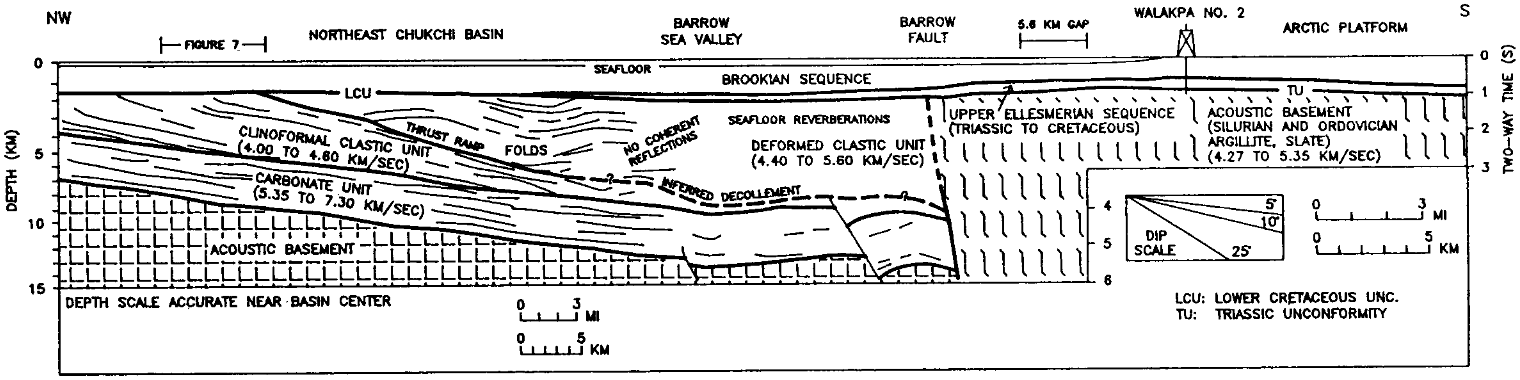
unit is interpreted to curve downdip into a decollement at or near the top of the Carbonate unit (Fig.3). This decollement may ultimately be rooted in the Barrow fault or, alternatively, it may be truncated by the fault. Seismic data indicate that the Barrow fault is inclined 70° to 80° southeast at the level of the Carbonate unit.

A belt of discontinuously mappable folds 30 km wide and 100 km long lies southeast of the thrust ramp in the Deformed Clastic unit (Fig.2). These folds pass southeast into acoustically incoherent rocks west of Barrow fault. Individual fold axes trend east to northeast, parallel to Barrow fault, the thrust ramp, and the fold belt as a whole (Fig.2). In cross section, folds are weakly asymmetric and northwest vergent (Fig.3).

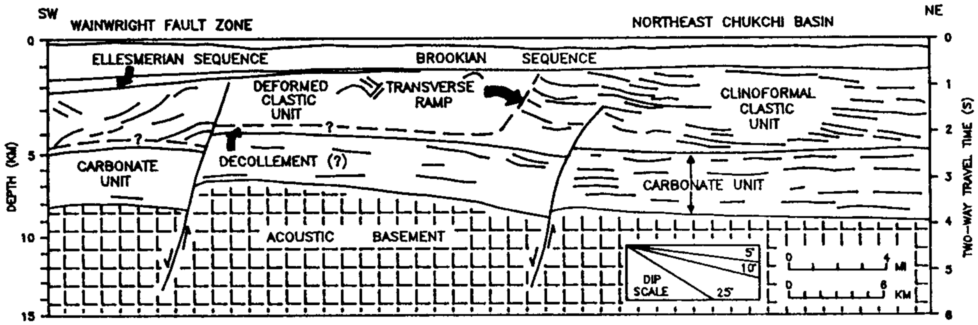
The thrust ramp terminates on the southwest at a "transverse ramp" (Fig.2), which appears in Fig.4 as a steeply inclined fault that juxtaposes the Clinoformal Clastic unit against acoustically incoherent rocks, assigned to the Deformed Clastic unit, on the west. The Carbonate unit passes undisturbed beneath the fault, which apparently flattens westward into a decollement (Fig.4). The transverse ramp mechanically linked the shallower thrust ramp on the east to the deeper decollement on-strike to the west, as schematically illustrated in Fig.6.

West and south of the transverse ramp, Carbonate unit reflections can be traced southwestward 100 km to the southernmost fault in the Wainwright fault zone, where they are down-faulted beneath the bases of seismic records (Thurston and Theiss, 1987). The Wainwright fault zone (partly illustrated in Fig.4) consists of several

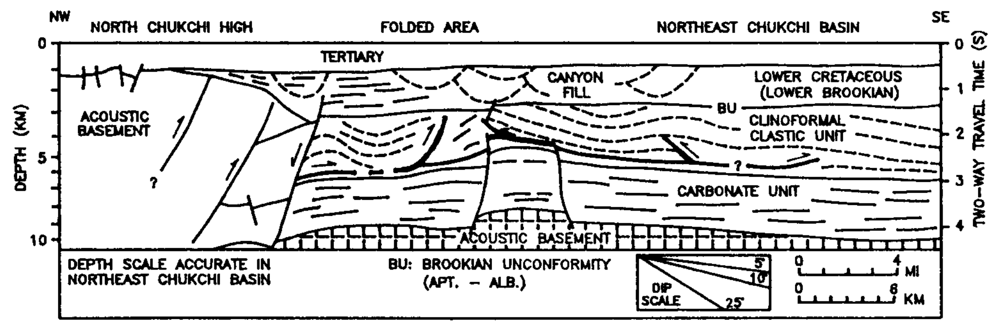
3



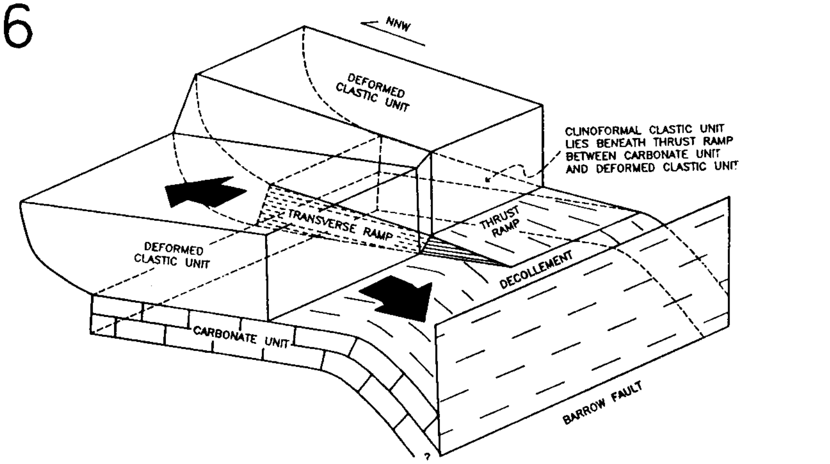
4



5



6



Figs.3,4,5. Line drawings of selected seismic-reflection profiles showing geological structures and seismic stratigraphy of Northeast Chukchi basin and fault systems that bound the basin. Profile locations shown in Fig.2.

Fig.6. Block diagram showing mechanical relationship of major structures in Northeast Chukchi basin.

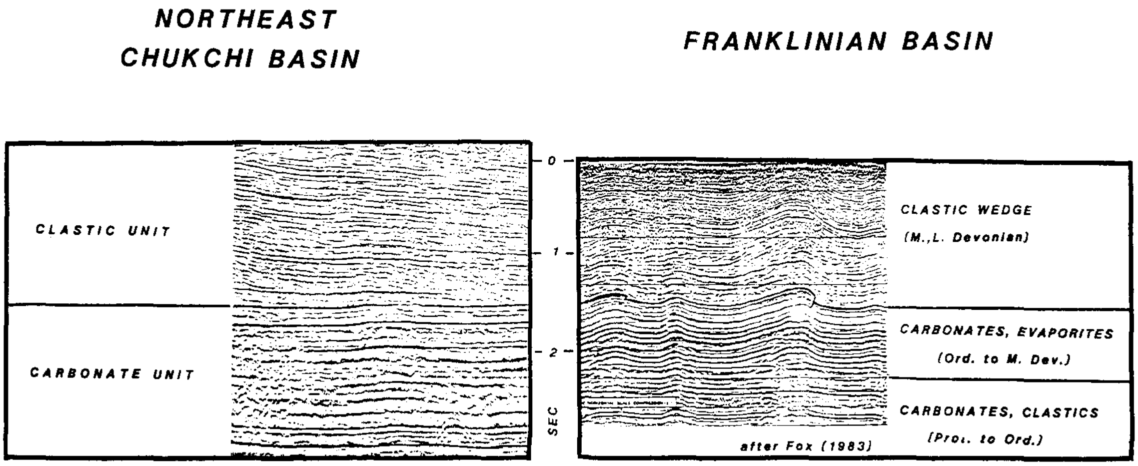


Fig.7. Comparison of seismic stratigraphy of Northeast Chukchi basin and carbonate-bearing part of Franklinian basin. See Fig.3 for location of Northeast Chukchi basin line. The Franklinian basin line is from eastern Melville Island (Fox, 1983, Fig.4).

large down-to-the-southwest faults that predate overlapping Mississippian rocks.

To the northwest, reflections from the Clinoformal Clastic and Carbonate units are lost in a broad zone of faults along the southeast flank of North Chukchi high (Figs.2,5). In an area adjacent to the fault zone, seismic data reveal detached folds within the Clinoformal Clastic unit (Fig.5). Seismic coverage is too sparse to determine the map orientations of these folds, but they clearly attenuate to the south, suggesting south or southeast vergence. These structures predate the overlying Lower Brookian sequence (Aptian-Albian) and may be contemporary with pre-Mississippian thrusting in southeast parts of the basin. Alternatively, the folds could form part of a much younger belt of Early Cretaceous folds mapped discontinuously around the south margin of North Chukchi high (Johnson, 1990).

AGE AND CORRELATION OF THE ARCTIC PLATFORM AND NORTHEAST CHUKCHI BASIN

Franklinian rocks (basement complex) on the Arctic platform consist mostly of steeply inclined argillites, slates, and phyllites of diverse ages. Phyllites in the Cape Simpson and Staines River areas along the Barrow arch yielded K-Ar ages ranging from 547 to 592 Ma (Brosge and Dutro, 1973; Drummond, 1974). Ordovician and Silurian fossils were recovered from argillites at two wells in the Barrow area and at a third well near Prudhoe Bay (Carter and Laufield, 1975). Elsewhere, steeply dipping coal-bearing shales and sandstones encountered in several wells yielded fossils of Early or Middle Devonian age (Collins, 1958; Husky, 1982). A granite that intrudes the basement complex in the East Teshekpuk No. 1 well yielded a minimum K-Ar age of 332 Ma (Bird et al., 1978). Significantly, carbonates are virtually absent. Much of this assemblage apparently formed in a deep-water clastic basin quite unlike the carbonate-bearing Northeast Chukchi basin.

The Northeast Chukchi basin succession is unconformably overlain by Triassic and younger seismic units in the north (Fig.3). To the south, in the vicinity of the Wainwright fault zone (Fig.2), the basin is unconformably onlapped by seismic reflections directly traceable to carbonates reported as Pennsylvanian in age at the base of the Tunalik No.1 well (Molenaar et al., 1986). Up to 1 km of unsampled, probably Mississippian, strata are observed in seismic data beneath Tunalik well. Reflections associated with these inferred Mississippian rocks also onlap Northeast Chukchi basin rocks offshore near the Wainwright fault zone. A pre-Mississippian age is consistent with a Franklinian association for Northeast Chukchi basin.

The Parry Islands fold belt and Franklinian basin of the Canadian Arctic Islands feature Paleozoic assemblages that compare favorably in age, lithologic succession, and thickness with Northeast Chukchi basin. In the Parry Islands fold belt, two gross sequences are recognized: (1) basal carbonates, evaporites, and clastics up to 7 km(?) in total thickness, ranging from Proterozoic(?) to early Middle Devonian in age (Fox, 1983), and (2) an overlying foreland basin sequence roughly 4 km in total thickness, clinoformal in its lower parts, and ranging in age from late Middle Devonian through Late Devonian (Embry, 1988).

Fig.7 compares the seismic stratigraphy of the Franklinian and Northeast Chukchi basins. In both basins, we observe a lower, carbonate-dominated sequence characterized by continuous, parallel, high-amplitude reflections, overlain by a clastic sequence characterized by relatively discontinuous reflections with clinoformal or wedge-like geometries. A similar comparison (different seismic lines) was published earlier by Embry (1990).

Sedimentation in the Franklinian basin was terminated by the Ellesmerian orogeny (latest Famennian to Tournaisian; Embry, 1988), which created the paired Parry Islands and Canrobert Hills fold belts. The Parry Islands fold belt is detached above Ordovician evaporites within the upper part of the carbonate assemblage. Fold trains are sharply cuspate in profile, and anticlines are upright and cored by opposing thrusts originating in evaporites and shallower detachment horizons. Westward, evaporites pinch out, and the style of

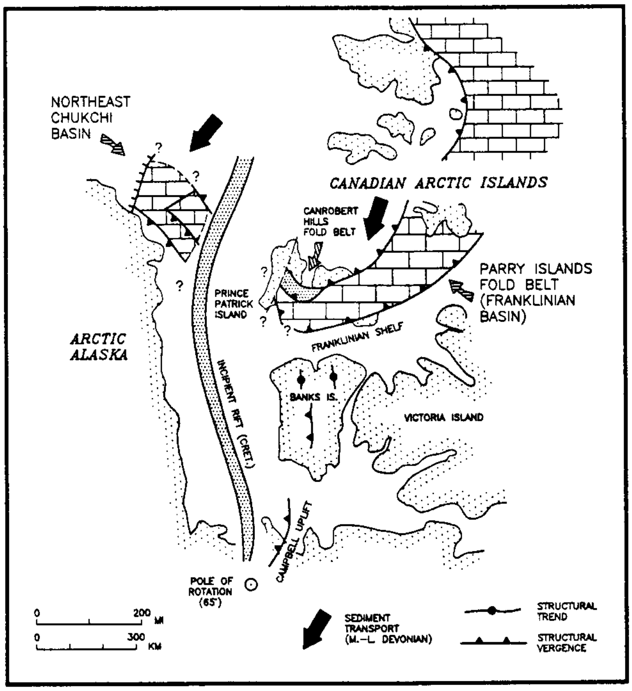


Fig.8. Pre-rift (125 Ma) reconstruction based on rotation model for opening of Canada basin. Brick pattern locates carbonate-floored Northeast Chukchi basin and carbonate-dominated part of Franklinian basin (Parry Islands fold belt). Reconstruction after Boucher (1978). Sediment transport arrow (Canada) from Embry (1988). Prince Patrick Island structural trends from Harrison and Trent (1991). Banks Island trends from Embry (1990; pers. commun., 1990). Campbell uplift structure from Coflin et al. (1990).

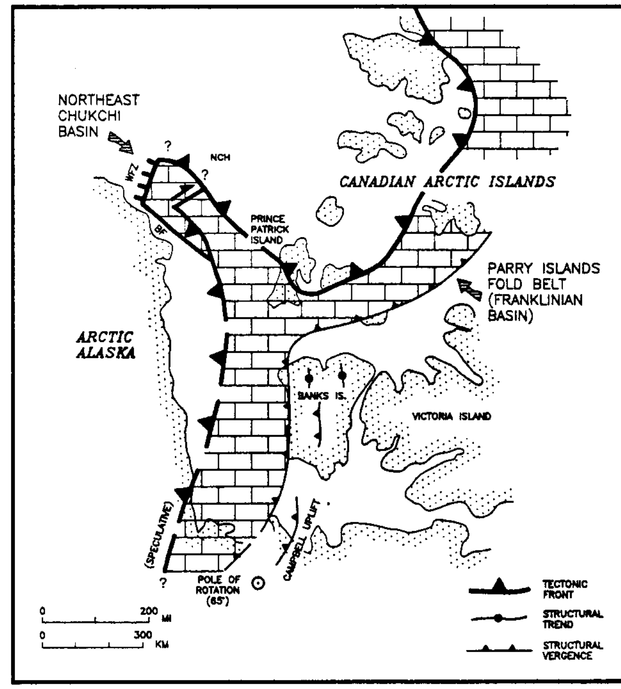


Fig.9. Speculative reconstruction of Late Devonian Ellesmerian orogenic belt. Tectonic front separates highly deformed, predominantly deep-water clastic rocks from mildly deformed, carbonate-floored part of Franklinian basin (brick pattern). BF: Barrow fault; WFZ: Wainwright fault zone; NCH: North Chukchi high.

deformation changes to folding and reverse faulting (Harrison et al., 1991). Northward, fold amplitudes and overall structural complexity increase markedly into the synkinematic, south-vergent Canrobert Hills fold belt (Fig.8).

The Canrobert Hills fold belt formed in a northern part of the Franklinian basin that received mainly deep-water clastics rather than the carbonates that floor the southern part of Franklinian basin and the Parry Islands fold belt (Harrison et al., 1991). The deep-water clastic part of the basin experienced the earliest phases of the Ellesmerian orogeny and became a hinterland provenance that shed the thick Middle to Late Devonian clastic wedge southward into a foredeep superposed on the earlier carbonate basin. The transition from highly deformed deep-water clastic basin (Canrobert Hills) to mildly deformed carbonate/foreland basin (Parry Islands) within the collective Franklinian basin resembles the transition from fine-grained metamorphites of the Alaska Arctic platform basement to the thick, undeformed carbonate/clinoformal wedge succession of Northeast Chukchi basin.

DISCUSSION

A long-popular model for the opening of the Canada basin invokes a wedge-like rift with a pole of relative rotation located near the modern Mackenzie Delta (Tailleur, 1973; Rickwood, 1970; Boucher, 1978; Grantz et al., 1979; Harland et al., 1984). The phase of rifting that led to seafloor spreading and formation of Canada basin began 125 or 128 Ma (Grantz and May, 1982; Hubbard et al., 1987) and ultimately produced a 60° to 70° counterclockwise rotation of the Arctic Alaska plate away from an initial position against the Canadian Arctic margin.

A speculative pre-rift restoration of Franklinian elements based upon the removal of 65° of opening about the rotation pole of Boucher (1978) is presented in Fig.8. The Northeast Chukchi basin neatly restores to a position opposite the northwesternmost exposures of the Franklinian basin on Prince Patrick Island. Also, inferred directions of sediment dispersal for Middle and Late Devonian clastic wedges (Fig.8) in the Northeast Chukchi and Franklinian (Embry, 1988) basins project toward a common source. Lastly, the trends of thrust faults and folds form a continuous arc between Prince Patrick Island and Northeast Chukchi basin. Pre-rift continuity between basins seems likely.

The opposing structural vergences in Northeast Chukchi basin are not observed in the Franklinian basin. The opposing vergences could indicate that Northeast Chukchi basin is not a simple extension of the Franklinian basin but once lay within a syntaxis between the Ellesmerian orogenic belts of Alaska and Canada. This hypothesis is attractive because it helps explain the abrupt boundaries and very limited extent of Northeast Chukchi basin in the Arctic Alaska plate.

Fig.9 speculatively reconstructs the shape of the Ellesmerian orogenic belt. This reconstruction maps the transition from the Middle Devonian and older carbonate-bearing (southern) part of Franklinian basin to the equivalent deep-water clastics basin on the north. The transition is closely mimicked by the tectonic front bounding the area of "Highly deformed Lower Paleozoic strata" mapped by Embry (1988) in a similar reconstruction. The carbonate-bearing part of the Franklinian basin, like Northeast Chukchi basin, is only mildly deformed, probably reflecting a structural buttressing role for the carbonate substrate during the Ellesmerian orogeny. As noted, the tectonic front appears to encroach Northeast Chukchi basin from two flanks. On the southeast (present-day) flank, the Deformed Clastic unit (Arctic platform basement?) was overthrust on Northeast Chukchi basin fill. Thrust encroachment from the northwest is suggested by southeast-vergent detachment folding on that flank and the northwesterly provenance of the Clinoformal Clastic unit (indicating a tectonic uplift to the northwest). The enigmatic system of normal faults (Wainwright fault zone) along the present southwest margin of the basin may have accommodated subsidence beneath large thrust-imposed vertical loads in the cusp of the syntaxis where flanking thrust systems converged. In any case, these data suggest that prior to Cretaceous rifting, Northeast Chukchi basin was a syntaxis or reentrant in a probably continuous Ellesmerian orogenic belt passing from Canada into Alaska.

Reentrants and salients in orogenic belts are thought to mimic promontories and embayments, respectively, in precollisional continental margins (Thomas, 1983), and Northeast Chukchi basin may have thus originated as a promontory on the early Paleozoic Franklinian continental margin of North America. Although reentrants are common features of orogenic belts, that inferred to host Northeast Chukchi basin seems quite "deep" (600 km) by most comparisons. However, the depth of the reentrant in Fig.9 is partly an artifact of the reconstruction (that of Harland et al. [1984] brings Northeast Chukchi basin 200 km closer to Prince Patrick Island). It is also possible that strike-slip movements along the flanks of the reentrant (for example, Barrow fault) during thrusting may have deepened the reentrant.

ACKNOWLEDGEMENTS

The Minerals Management Service (MMS), U.S. Department of the Interior, supported this work and allowed its publication. Discussions with Ashton Embry, Chris Harrison, and James Craig provided valuable insights into the Northeast Chukchi basin enigma. This study draws upon unpublished seismic mapping by James Scherr and James Craig of the MMS. This manuscript was improved by the technical reviews of James Craig and Ashton Embry. Cartographic support was provided by Beverly Lothamer and Ida Menge.

REFERENCES CITED

Bird, K.J., Connor, C.L., Tailleur, I.L., Silberman, M.L. and Christie, J.L., 1978. Granite on the Barrow arch, northeast NPRA. U.S. Geological Survey Circular 772-B, pp. B24-B25.

Boucher, G., 1978. Rotation of Alaska and the opening of the Canada basin. U.S. Geological Survey Open-File Report 78-96, 19 pp.

Brosge, W.P. and Dutro, J.T., Jr., 1973. Paleozoic rocks of northern and central Alaska. In: M.G. Pitcher (Editor), Arctic Geology. Amer. Assoc. Petrol. Geol., Memoir 19, pp. 361-375.

Carter, C. and Laufield, S., 1975. Ordovician and Silurian fossils in well cores from the North Slope of Alaska. Amer. Assoc. Petrol. Geol. Bull., 59: 457-464.

Coflin, K.C., Cook, F.A. and Geis, W.T., 1990. Evidence for Ellesmerian convergence in the subsurface east of the Mackenzie Delta. Marine Geology, 93: 289-301.

Collins, F.R., 1958. Test wells, Topogoruk area, Alaska. U.S. Geological Survey Professional Paper 305-D, pp. 265-316.

Craig, J.D., Sherwood, K.W. and Johnson, P.P., 1985. Geologic report for the Beaufort Sea Planning Area, Alaska. U.S. Minerals Management Service OCS Report 85-0111, 192 p.

Drummond, K.J., 1974. Paleozoic Arctic margins of North America. In: C.A. Burk and C.L. Drake (Editors), The Geology of Continental Margins. Springer-Verlag, New York, pp. 797-810.

Embry, A.F., 1988. Middle-Upper Devonian sedimentation in the Canadian Arctic Islands and the Ellesmerian orogeny. In: N.J. McMillan, A.F. Embry, and D.J. Glass (Editors), Devonian of the World. Can. Soc. Pet. Geol. Memoir 14, pp. 15-28.

Embry, A.F., 1990. Geological and geophysical evidence in support of the hypothesis of anticlockwise rotation of northern Alaska. Marine Geology, 93: 317-329.

Fox, F.G., 1983. Structure sections across Parry Islands foldbelt and Vesey Hamilton salt wall, Arctic archipelago, Canada. In: A.W. Bally (Editor), Seismic Expression of Structural Styles. Amer. Assoc. Petrol. Geol., Studies in Geology Series No. 15, pp. 3.4.1-54 - 3.4.1-72.

Grantz, A., Eittreim, S. and Dinter, D.A., 1979. Geology and tectonic development of the continental margin north of Alaska. Tectonophysics, 59: 263-291.

Grantz, A., Holmes, M.L. and Kososki, B.A., 1975. Geologic framework of the Alaskan continental terrace in the Chukchi and Beaufort Seas. Canadian Society of Petroleum Geologists Memoir 4, pp. 669-700.

Grantz, A. and May, S.D., 1982. Rifting history and structural development of the continental margin north of Alaska. Amer. Assoc. Petrol. Geol. Memoir 34, pp. 77-102.

Grantz, A., May, S.D. and Hart, P.E., 1990. Geology of the Arctic continental margin of Alaska. In: A. Grantz, L. Johnson, and J.F. Sweeney (Editors), The Arctic Ocean Region. Geological Society of America, The Geology of North America, L, pp. 257-288.

Harland, W.B., Gaskell, B.A., Heafford, A.P., Lind, E.K. and Perkins, P.J., 1984. Outline of Arctic post-Silurian continental displacements. In: A.M. Spencer (Editor), Petroleum Geology of the North European Margin. Norw. Pet. Soc. and Graham and Trotman, London, pp. 137-148.

Harrison, J.C., Fox, F.G. and Okulitch, A.V., 1991. Late Devonian - Early Carboniferous deformation of the Parry Islands and Canrobert Hills fold belts, Bathurst and Melville Islands. In: H.P. Trettin (Editor), Chapter 12 of Geology of the Innuitian Orogen and Arctic Platform of Canada and Greenland, Geological Survey of Canada, Geology of Canada, No. 3, pp. 321-333.

Harrison, J.C. and Trent, T.A., 1991. Late Devonian - Early Carboniferous deformation, Prince Patrick and Banks Islands. In: H.P. Trettin (Editor), Chapter 12 of Geology of the Innuitian Orogen and Arctic Platform of Canada and Greenland, Geological Survey of Canada, Geology of Canada, No. 3, pp. 334-336.

Hubbard, R.J., Edrich, S.P. and Rattey, R.P., 1987. Geological evolution and hydrocarbon habitat of the 'Arctic Alaska Microplate'. Marine and Petroleum Geology, 4: 2-34.

Husky (Oil NPR Operations, Inc.), 1982. Geological report, South Meade test well no. 1, National Petroleum Reserve in Alaska. Prepared for the U.S. Geological Survey, Office of the National Petroleum Reserve in Alaska, Anchorage, Alaska.

Jackson, H.R. and Gunnarsson, K., 1990. Reconstructions of the Arctic; Mesozoic to Present. Tectonophysics, 172: 303-322.

Johnson, P.P., 1990. Multiple stage deformation along the southern flank of the North Chukchi high, Chukchi Sea, Alaska (abs). Am. Assoc. Petrol. Geologists Bull., 74: 687.

Lerand, M., 1973. Beaufort Sea. In: R.G. McCrossmam (Editor), The Future Petroleum Provinces of Canada--Their Geology and Potential, Canadian Society of Petroleum Geologists Memoir 1, pp. 315-386.

Molenaar, C.M., Bird, K.J. and Collett, T.S., 1986. Regional correlation sections across the North Slope of Alaska. U.S. Geological Survey Miscellaneous Field Studies MF-1907, 1 sheet.

Rickwood, F.K., 1970. The Prudhoe Bay Field. In: W.L. Adkinson and W.P. Brosge (Editors), Proceedings of the Geological Seminar on the North Slope of Alaska, Pacific Section, Amer. Assoc. Petrol. Geol., Los Angeles, pp. L1-L11.

Sherwood, K.W., 1990. Seismic stratigraphy and structural geology of the Northeast Chukchi basin. In: G.S. Stubbs (Editor), Proceedings, Second Symposium on Studies Related to Continental Margins, Bureau of Economic Geology of Texas, pp. 9-17.

Smith, D.G., 1987. Late Paleozoic to Cenozoic reconstructions of the Arctic. In: I. Tailleur and P. Weimer (Editors), Alaska North Slope Geology. Soc. Econom. Geol. and Paleontologists, Pacific Sec., and Alaska Geol. Soc., Book 50, pp. 785-796.

Tailleur, I.L., 1973. Probable rift origin of Canada Basin. In: M.G. Pitcher (Editor), Arctic Geology. Amer. Assoc. Petrol. Geol. Memoir 19, pp. 526-535.

Thomas, W.A., 1983. Continental margins, orogenic belts, and intracratonic structures. Geology, 11: 270-272.

Thurston, D.K. and Theiss, L.A., 1987. Geologic report for the Chukchi Sea Planning Area, Alaska. U.S. Minerals Management Service, OCS Report MMS 87-0046, 193 pp.