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STRATIGRAPHIC AND STRUCTURAL STUDIES ON MELVILLE ISLAND, DISTRICT OF FRANKLIN

Project 840048

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Abstract

Melville Island is a key area in the Arctic Islands for understanding the Middle to Upper Devonian clastic wedge, the Ellesmerian Orogeny, the Melvillian Disturbance, and the evolution of Carboniferous to Tertiary tectonics and sedimentation of the Sverdrup Basin margin.

A mapping project to produce new 1:250 000 scale maps and cross-sections of Melville Island was begun in 1984, and some preliminary stratigraphic and structural results are presented in this paper. Various refinements to the stratigraphy proposed by Embry, Nassichuk, Kerr and others were found to be useful in the current studies. Middle Devonian shales have acted as a regionally significant décollement horizon during the Upper Devonian Ellesmerian Orogeny; we also suggest that the Permian Melvillian Disturbance, previously interpreted as a mild orogenic pulse on northwestern Melville Island, was a period during which drape folding and extensional tectonics related to the development of the margin of Sverdrup Basin occurred.

Résumé

Pour une meilleur compréhension du prisme clastique d'âge dévonien moyen à supérieur, de l'orogenèse de l'Ellesmérien, de l'accident du Melvillien, de l'évolution tectonique des roches carbonifères à tertiaires, et de la sédimentation de la marge du bassin de Sverdrup, l'île Melville représente une région clé dans l'étude de l'archipel Arctique.

En 1984, a été entrepris un projet de cartographie consistant à produire de nouvelles cartes à 1/250 000 et des coupes de l'île Melville; certains résultats préliminaires des études tectoniques et stratigraphiques sont donnés dans la présente étude. On a constaté que dans les études en cours, diverses améliorations de la stratigraphie proposées par Embry, Nassichuk, Kerr et d'autres auteurs se sont avérées utiles. Les schistes argileux du Dévonien moyen ont agi à titre d'horizon de décollement important à l'échelle régionale pendant l'orogenèse de l'Ellesmérien au Dévonien supérieur; les auteurs suggérent aussi que l'accident du Melvillien survenu au Permien et autrefois interprété comme une phase modérée d'orogenèse dans le nord-ouest de l'île Melville, a correspondu à une période de plissement moulant et de tectonique d'extension liée au développement de la marge du bassin de Sverdrup.

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Introduction

Melville Island and the nearby offshore region has been the site of considerable petroleum exploration since the early 1960s. Both seismic exploration and drilling have been carried out, with a well spudded as recently as 1983. The aim of the present project, a restudy of the geology of the island, is to obtain an improved understanding of the stratigraphy and structure. Further field work will be carried out in 1985. This report is a brief 'update' of the surface stratigraphy of Melville Island. Included are some notes on highlights of the 1984 field season.

Earlier geological work

Tozer and Thorsteinsson (1964, p. 2-17) provided a full account of both early geographical and geological exploration of the Melville Island region. Up until 1964, what was known of the geology of Melville Island was mainly due to the work of McMillan (1910), geologist on Captain J.E. Bernier's 1908-09 expedition in the D.G.S. Arctic, and Tozer (1956, 1963). Tozer and Thorsteinsson's (1964) account and reconnaissance mapping of Melville and other islands of the western Queen Elizabeth Islands has provided a basic stratigraphic and structural framework for the present studies.

Geological and geophysical exploration of Melville Island continued throughout the 1960s and 1970s. In 1964, H.P. Trettin studied the tar sands of Sproule Peninsula (Trettin and Hills, 1966, 1967) and W.W. Nassichuk studied and collected ammonoids from Permian beds. Nassichuk (1975) made further collections in 1967 at Barrow Dome, a site from which a large collection had earlier been obtained by B.P. Exploration Limited. Stratigraphic sections of Middle Devonian beds were measured in 1968 by D.C. McGregor and T.T. Uyeno, and samples for miospore studies were collected. The results of this study (see McGregor and Camfield, 1982) completed one phase of a broader study, by these and other authors, aimed at both interfacies correlation and correlation of marine and nonmarine biozones. Seismic exploration began on Melville Island in 1968, a year that also saw the announcement of the giant oil strike at Prudhoe Bay, Alaska (see Jones, 1981).

Five wells were drilled on Melville Island in 1969 and 1970. Two wells were completed in Ordovician and three in Pennsylvanian-Permian units. In 1970 the first successful well was completed, by Panarctic Oils Limited, in Triassic sandstone. This well, Panarctic Drake Point L-67, blew out of control (control was later recovered by drilling a relief hole). Panarctic Oils has since outlined the Drake Point gas field, one of the largest in Canada (Jones, 1981). About 45 exploratory wells have been drilled on Melville Island and in the nearby offshore area since 1960.

Seismic surveys were extended to offshore areas in the early 1970s. A considerably improved picture of the subsurface structure has been obtained from the seismic data, and is reported on and illustrated by Fox (1983) and Texaco Canada Resources Limited (1983).

Stratigraphic sections of Lower Paleozoic beds on Melville Island formed a major component of a wide-ranging study by Embry and Klovan (1976) of the Middle and Upper Devonian 'clastic wedge' of the Arctic Islands. This study, carried out between 1972 and 1975, resulted in refinements of the nomenclatural framework and understanding of the sedimentary environments of the several Middle and Upper Devonian facies. More recently, Embry (1983; 1984a, b, c) erected new stratigraphic divisions for the Middle Triassic to Middle Jurassic beds, based on the extensive subsurface information now available.

The surficial deposits and glacial features of Melville Island have been studied and reported on by several field parties. In 1980, D.A. Hodgson, J-S. Vincent, and S.A. Edlund carried out an airphoto and ground mapping study of Dundas Peninsula and central parts of the island (see Hodgson et al., 1984; Edlund, 1982, in press). These authors note that uplands of the island sustained local ice caps, but that the south coast and parts of the coasts of Liddon Gulf were impinged upon by continental ice approaching from the south. Evidence has been found for at least three advances of continental ice over parts of Dundas Peninsula, the southernmost extension of Melville Island.

Fieldwork in 1984

The field program of 1984 was carried out between late June and mid-August by a party of 13, with air support by Bell 206B Jet Ranger helicopter (Quasar Helicopters) and by de Havilland Twin Otter (Bradley Air Services), both provided by the Polar Continental Shelf Project (PCSP). Fuel and other support was obtained from the Panarctic Oils Limited camp at Rea Point, eastern Melville Island, and through the PCSP at Resolute, Cornwallis Island.

Stratigraphic studies were carried out by M. Jennifer Robson, University of Western Ontario, Q.H. Goodbody, University of Alberta, and R.L. Christie. J.C. Harrison was responsible for structural-stratigraphic mapping, and Sylvia Edlund (Ottawa), for geobotanical studies. Other fieldwork supported by the project included: Jurassic biostratigraphy, T. Poulton; Pennsylvanian-Permian biostratigraphy, J. Utting, A.C. Higgins, and P. Von Bitter (Royal Ontario Museum). Louise Journault and David Christensen, cook and camp manager, respectively, contributed considerably to the morale of the party by keeping both base and 'fly' camps well supplied. Able and cheerful field assistance was provided by Jane Bracken, Sabine Fuelgen, Kathi Higgins, and Todd Cross. The helicopter was skilfully piloted, frequently in trying conditions, by G. Dionne; engineering support by K. Mahoney, S. Long, and D. Tranelis also was appreciated.

Revisions to surface stratigraphic nomenclature since 1964

Significant revisions to the surface stratigraphic nomenclature of Melville Island have occurred since the 1:500 000 scale reconnaissance mapping in the area by Tozer and Thorsteinsson (1964). These changes have resulted from regional stratigraphic refinements introduced by A.F. Embry, W.W. Nassichuk, J.Wm. Kerr, H.R. Balkwill and others of the Geological Survey of Canada, working on Melville Island and throughout the Arctic Islands over the last twenty years.

All accepted modifications to the surface stratigraphy of Melville Island are shown in Tables 74.1 and 74.2. Selective comments on these changes follow.

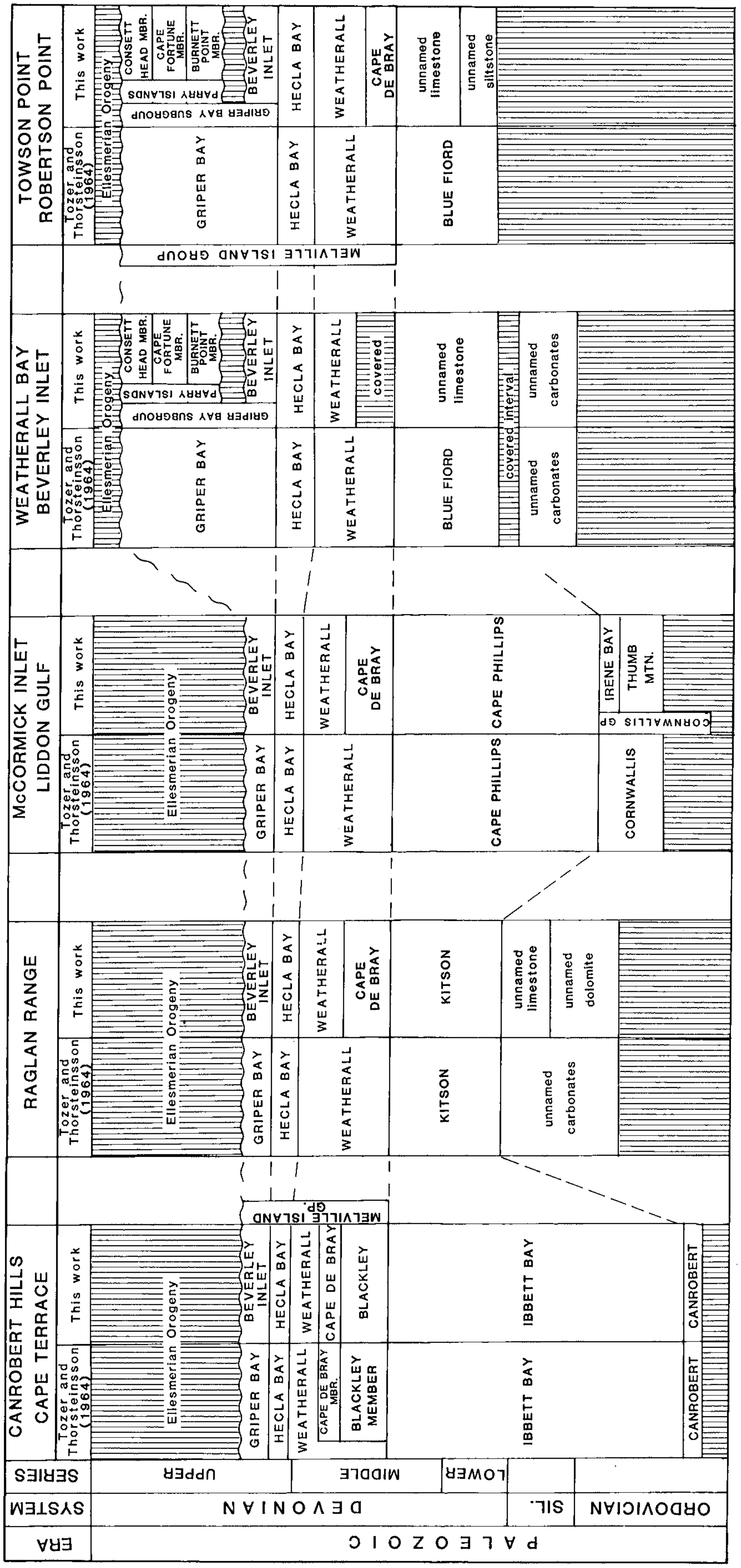
1. Thumb Mountain and Irene Bay formations

   Tozer and Thorsteinsson (1964) assigned the Middle Ordovician limestone, argillaceous limestone and dolomite unit underlying the Cape Phillips Formation on McCormick Inlet to the upper two members of the Cornwallis Formation. [The Cornwallis Formation was later (Kerr, 1967) raised to group status to include the Bay Fiord, Thumb Mountain and Irene Bay formations]. The Thumb and Irene Bay formations are both exposed around McCormick Inlet, and evaporites of the underlying Bay Fiord Formation were intersected below 3270 m in the Panarctic et al. Sabine Bay A-07 wildcat well, drilled on central Melville Island.

Table 74.1. Nomenclature of Carboniferous to Quaternary surface formations, Melville Island, District of Franklin. Sources: Tozer and Thorsteinsson (1964), Nassichuk, (1956), Balkwill et al. (1977), Embry (1984a), Thorsteinsson (1974), Balkwill (1983), and Tozer (1970).

ERA	SYSTEM	SERIES	SPROULE PENINSULA: T. and T. (1964)	SPROULE PENINSULA: This work	CAPE GRASSY: T. and T.(1964)	CAPE GRASSY: This work	SABINE PENINSULA: T. and T.(1964)	SABINE PENINSULA: This work	S.E. MELVILLE ISLAND: T. and T.(1964)	S.E. MELVILLE ISLAND: This work	SPENCER RANGE: T and T(1964)	SPENCER RANGE: This work
CENOZOIC	QUATERNARY	HOL.	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium		
		HOL.	Beach deposits	Beach deposits	Beach deposits	Beach deposits	Beach deposits	Beach deposits	Beach deposits	Beach deposits		
		PLEIST.	Till	Till	Till	Till	Till	Till	Till	Till		
	TERTIARY								BEAUFORT			
MESOZOIC	CRETACEOUS	UPPER					EUREKA SOUND KANGUK HASSEL	EUREKA SOUND KANGUK HASSEL				
		LOWER	CHRISTOPHER ISACHSEN	CHRISTOPHER ISACHSEN	CHRISTOPHER ISACHSEN	CHRISTOPHER ISACHSEN	CHRISTOPHER ISACHSEN	CHRISTOPHER ISACHSEN gabbro	CHRISTOPHER ISACHSEN	CHRISTOPHER ISACHSEN		
	JURASSIC	UPPER	MOULD BAY	DEER BAY RINGNES	MOULD BAY	DEER BAY RINGNES	MOULD BAY	AWINGAK RINGNES				
		MIDDLE	WILKIE POINT	WILKIE POINT GP.: HICCLES COVE McCONNELL IS. SANDY POINT JAMESON BAY	WILKIE POINT	WILKIE POINT GP.: HICCLES COVE SANDY POINT JAMESON BAY	WILKIE POINT	W.P. GP.: SANDY POINT JAMESON BAY				
		L	BORDEN IS.	HEIBERG GP.								
	TRIASSIC	U										
		M										
		L	BJORNE	BJORNE	BJORNE	BJORNE	BJORNE	BJORNE				
PALEOZOIC	PERMIAN	UPPER	ASSISTANCE	TROLD FIORD	ASSISTANCE	TROLD FIORD	ASSISTANCE	TROLD FIORD 'UNIT A' ASSISTANCE			SABINE BAY	TROLD FIORD ASSISTANCE
		LOWER	Melvillian Disturbance	Melvillian Disturbance	Melvillian Disturbance	Melvillian Disturbance	SABINE BAY BELCHER CH.	SABINE BAY BELCHER CHANNEL				
	CARBONIFEROUS	UPPER	CANYON FIORD	CANYON FIORD	CANYON FIORD	CANYON FIORD	CANYON FIORD unnamed	OTTO FIORD (in diapirs) CANYON FIORD			CANYON FIORD	CANYON FIORD

Table 74.2. Nomenclature of Lower Ordovician to Upper Devonian surface formations, Melville Island, District of Franklin. Sources: Tozer and Thorsteinsson (1964), Embry and Klovan (1976), and Kerr (1967).



2. Silurian and Devonian carbonate units

Silurian and Lower Devonian limestones, dolomite and minor siltstone units are exposed at four widely scattered localities on Melville Island. These units can not be correlated with equivalent strata in the eastern Arctic Islands. Stratigraphic revisions based on combined outcrop and drillhole information are being planned.

3. Subdivision of the Weatherall Formation

Tozer and Thorsteinsson (1964) recognized two distinct units at the base of the Weatherall Formation in Canrobert Hills and called them the Blackley and Cape de Bray members. These members were later raised to formational status by Embry and Klovan (1976). While the Blackley Formation is only exposed in the Canrobert Hills, the overlying Cape de Bray Formation is exposed in the cores of anticlines as far east as Weatherall Bay, and is suspected to gradationally underlie the Weatherall Formation everywhere in the subsurface of Melville Island. East of the Canrobert Hills, the Cape de Bray Formation lies conformably on the Kitson, Cape Phillips or Devonian carbonate formations (Embry and Klovan, 1976, Fig. 20).

4. Facies changes in the Middle and Upper Devonian clastic wedge

Stratigraphic studies of the Weatherall and Hecla Bay formations confirm the westward change of massive Hecla Bay Formation sandstone across Melville Island, as was suggested by Embry and Klovan (1976). On eastern Melville Island, two informal members of the Hecla Bay Formation are distinguished: (1) a thin, lower unit of white quartzose sandstone and interbedded green lithic siltstone and shale, and (2) a massively bedded, white quartzose sandstone that dominates the formation. The upper member becomes progessively thinner westwards and is entirely missing above a proportionately thicker lower member in the vicinity of Murray Inlet and the head of Purchase Bay. Marine to brackish conditions of sedimentation within the lower member of the Hecla Bay Formation are indicated by the occurrence of lingulid brachiopods.

5. Griper Bay Subgroup

Embry and Klovan (1976) demonstrated that a disconformity exists within the Griper Bay Formation and raised it to the status of a subgroup. On eastern

Melville Island, the Griper Bay Subgroup includes the Beverley Inlet Formation and three formal members of the Parry Islands Formation. All these units are mappable and can even be distinguished on 1:1 000 000 scale Landsat imagery (see Fig. 74.1).

On central Melville Island the Beverley Inlet Formation comprises three members, which are indicative of alternating marine and nonmarine conditions.

6. Otto Fiord Formation

Tozer and Thorsteinsson (1964) mapped Pennsylvanian anhydrite and limestone in two piercement diapirs on northern Sabine Peninsula. Based on the ammonoid collections of Nassichuk (1968), Thorsteinsson (1974) assigned the diapiric evaporite rocks to the Otto Fiord Formation.

7. Permian formations

Tozer and Thorsteinsson (1964) mapped two Permian formations in the Tingmisut Lake area, but recognized three: the Belcher Channel, Sabine Bay, and Assistance formations. Later, Nassichuk (1965) observed that the Assistance Formation of Tozer and Thorsteinsson included three readily mappable units. He restricted the name Assistance Formation to the lowest unit, and the upper two he called Unit A and Unit B. Thorsteinsson and Tozer (1970) eventually correlated Unit B with the Trold Fiord Formation.

8. Wilkie Point Group

Embry (1984b) raised the Wilkie Point Formation to group status and proposed four new formations: the Jameson Bay, Sandy Point, McConnell Island and Hiccles Cove formations. These new formations are defined in well sections and can also be recognized in surface exposures.

The Jameson Bay Formation consists of recessive, grey to light green weathering siltstone, and is gradationally overlain by the glauconitic sandstone of the Sandy Point Formation. These two formations have an aggregate thick-ness of about 100 m, and are not easily distinguishable at the scale of mapping. Castellate weathering, quartzose sandstone of the Hiccles Cove Formation is mappable across northwestern Melville Island, and brown shale of the underlying McConnell Island Formation appears to be present only north of Marie Bay. Skeletal remains of a Middle Jurassic vertebrate were found in the upper Hiccles Cove Formation south of Cape Grassy on northwestern Melville Island. They have been tentatively identified (from photographs) to be those of a plesiosaur (D. Russell, personal communication, 1984).

Locally, the Wilkie Point Group is unconformably underlain by Pleinsbachian and possible Sinemurian sandstone, which Tozer and Thorsteinsson (1964) assigned to the Borden Island Formation. These strata correlate with the Heiberg Group of Embry (1983).

9. Deer Bay, Awingak and Ringnes formations

Regional mapping and stratigraphic studies throughout central and western Sverdrup Basin by Balkwill (1983), A.F. Embry and others indicate that the Mould Bay Formation of Melville Island includes the Ringnes, Awingak and Deer Bay formations. On Sproule Peninsula, the Ringnes Formation is composed of black shale containing large, calcareous, siltstone concretions. The formation also includes underlying, non-concretionary, black shale strata above the Hiccles Cove Formation. The Ringnes is gradationally overlain by pale green siltstone and grey shale of the Deer Bay Formation. The Ringnes Formation thins eastward and lacks its distinctive concretions in the Cape Grassy area. Poorly exposed sandstone overlying a thin Ringnes shale on southern Sabine Peninsula is assigned to the Awingak Formation (Embry, personal communication, 1984).

10. Beaufort Formation

Poorly consolidated gravels containing uncompressed wood are exposed on hilltops in the Bridport Inlet area. These gravels were assigned to the Beaufort Formation by Tozer and Thorsteinsson (1964) and later were mapped by Hodgson and Vincent (1980) (and see Barnett et al., 1975). Fieldwork this year revealed that uncompressed wood is rare and that marine shell fragments are ubiquitous in these conglomeratic deposits. We believe that this is consistent with a glacial or glaciomarine origin. The unit is therefore probably Pleistocene in age and not assignable to the Beaufort Formation. Age determinations and palynological studies on these deposits are planned.

Highlights of regional mapping

1. A detachment in Middle Devonian shale

The convincing observations put forth by Workum (1965), and more recently, the evidence from seismic profiles published by Fox (1983), indicate that anticlines in the Parry Islands Foldbelt are the result of flexural flow deformation of evaporites in the Middle Ordovician Bay Fiord Formation and coincident thrust faulting in overlying Ordovician to Devonian strata. Tozer and Thorsteinsson (1964) suggested that the absence of the Bay Fiord Formation in the Lower Paleozoic strata of Canrobert Hills required the presence of a second (Cambrian or Precambrian) detachment level somewhere in the subsurface.

From the 1984 fieldwork it appears that a third detachment, in Middle Devonian shale, may be present. Below the Cape de Bray Formation, the radii of curvature of folds increase upward in anticlines and decrease upward in synclines. In contrast, folded beds above the Cape de Bray Formation have radii that decrease upward in anticlines and increase upward in synclines. Rare, resistent beds in the Cape de Bray Formation display brittle failure, and the dominant, clay-rich, micaceous mudstone lacks primary bedding and appears to have deformed in a semi-viscous fashion. Mesoscopic, and in many cases disharmonic, folds are common in the overlying Weatherall Formation and underlying Blackley Formation. These observations are consistent with a zone of flexural flow within the Cape de Bray Formation.

Flexural flow deformation in the Cape de Bray shale would explain the rarity of thrust faults and listric reverse faults at the surface on southeastern Melville Island. The appearance of fold-parallel reverse faults east of Sabine Bay could result from northward thinning of the Cape de Bray shale (as indicated on the seismic sections of Fox, 1983).

2. Observations on the Melvillian Disturbance

Thorsteinsson and Tozer (1964) observed that compressional fold structures in Ordovician to Devonian strata in the Canrobert Hills could be traced into the unconformably overlying Carboniferous strata, and interpreted these tectonic features as refolded folds. This post-Ellesmerian deformation, which they named

Figure 74.1. *Vertical satellite image of the Parry Islands Foldbelt on eastern Melville Island (part of C.C.R.S. image 415-45-7, 6 Aug., 1974). 1. unnamed Devonian limestone, 2. Weatherall Formation, 3. Hecla Bay Formation, 4. Beverley Inlet Formation, 5, 6, 7. Parry Islands Formation (5. Burnett Point Member, 6. Cape Fortune Member, 7. Consett Head Member), 8. Canyon Fiord Formation, 9. Permian formations (undivided), 10. Bjorne Formation.*

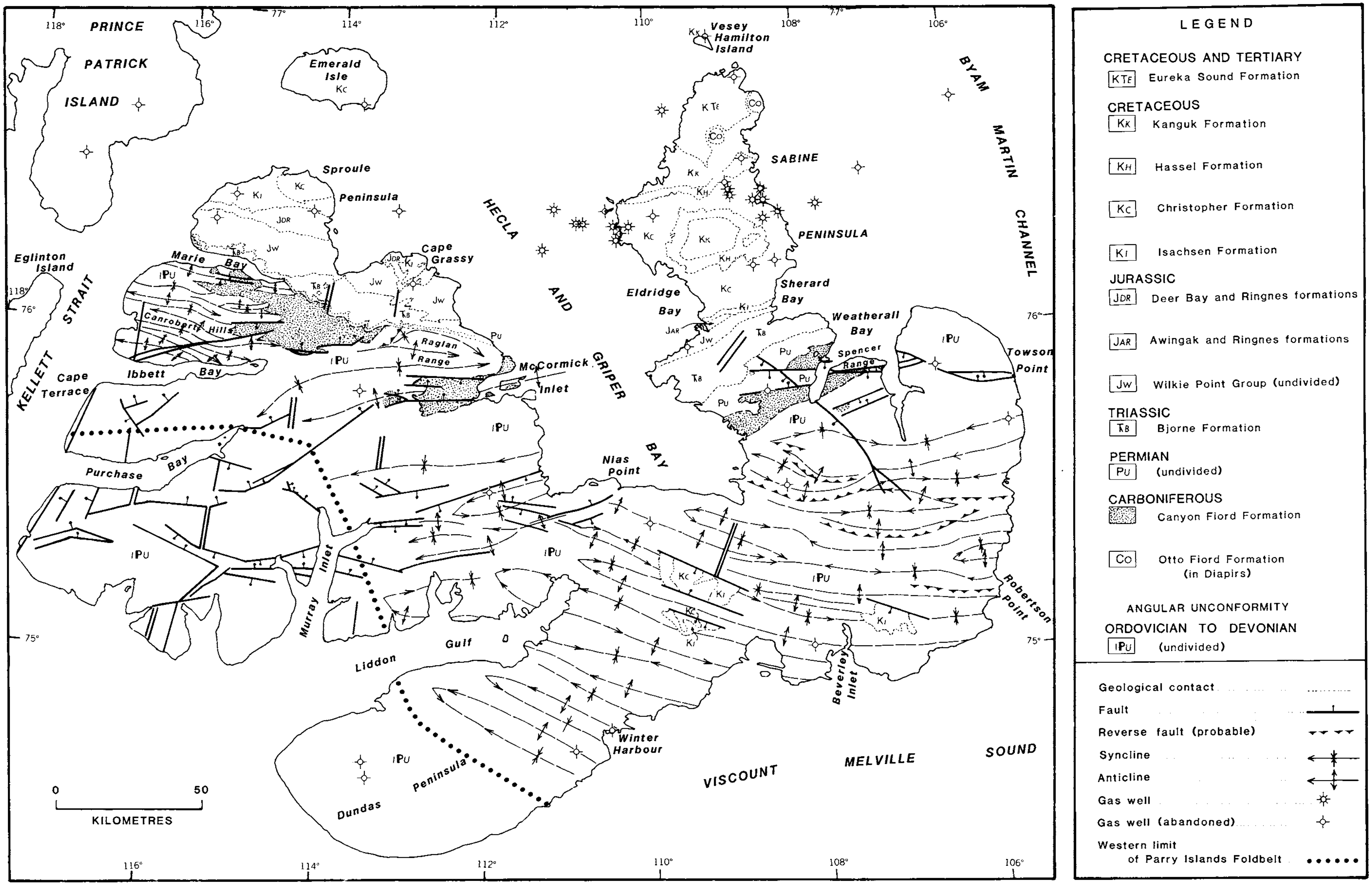


Figure 74.2. *Simplified geology of Melville Island. Information compiled from unpublished field observations and air photo interpretation by Balkwill (1976, 1978) on Sabine Peninsula, Harrison (1984), and from Tozer and Thorsteinsson (1964; Map 1142A).*

the Melvillian Disturbance, was observed to predate unconformably overlying Upper Permian strata (Thorsteinsson and Tozer, 1970).

We have confirmed that the Melvillian folds are broad, gently-dipping structures. The fold axes of both anticlines and synclines are short and tend to be associated with the termination of fault segments. Some Melvillian synclines can be described as small, circular, basin-like structures, and anticlines are asymmetric, with one limb gently dipping to flat.

Normal faults, cutting Carboniferous and older strata, strike mainly east-northeast. Oblique faults strike east and northeast. Across northwestern Melville Island, where Canyon Fiord Formation lies unconformably on shale of the Cape de Bray Formation, the unconformity is often marked by a moderate- to shallow-dipping normal fault that is probably listric in the subsurface. These faults, like most east-northeast striking faults in this area, apparently do not cut the Upper Permian strata, and are therefore probably Melvillian in age.

We suggest that the deformation style within Carboniferous strata on northwestern Melville Island is representative of horst and graben tectonics. The Melvillian 'folds' could be due to the drape of beds over normal faulted blocks in Lower Paleozoic "basement". Local angular unconformities beneath the Trold Fiord Formation could be accounted for by pre-Trold Fiord erosional truncation following the development of horst and graben structures.

3. Permian faults and drape folds

On southern Sabine Peninsula, en echelon, curvilinear, normal faults striking east are particularly common in the Lower Permian formations, and tend to die out upsection below the Bjorne Formation. Reverse drag of bedding is common in the hanging walls of these faults, suggesting that the faults are listric in the subsurface. Stratigraphic offset at the surface ranges from a few tens of metres to about 100 m.

An important en echelon fault system (on southern Sabine Peninsula) is exposed along the main southern boundary of outcrop of Permian strata. These north-dipping normal faults can be traced from western Spencer Range to the southwest across the west arm of Weatherall Bay as far as the lowlands east of Sabine Bay. A condensed Permian section is exposed in flat-lying outliers south of this fault system. A reflection seismic survey line crosses this fault in the vicinity of the Dome Panarctic Texex Weatherall O-10 wildcat well, and interpretation indicates a rapid thickening of the Canyon Fiord Formation on the north side. This structure may have been an important boundary fault on the southern margin of Sverdrup Basin.

It seems likely that many of the east- to east-northeast striking faults, related oblique faults, and drape structures that offset the Canyon Fiord Formation on northwest Melville Island, and the Permo-Carboniferous formations on southern Sabine Peninsula, represent a rifting event that affected the margin of the Sverdrup Basin prior to the Late Permian or Early Triassic.

4. Northeast-striking faults

North-northeast to northeast-striking faults and keystone grabens occur throughout Melville Island. Faults and other linear tectonic elements of this orientation are particularly common in the Blue Hills of southwestern Melville Island, along Kellet Strait, along a line joining Cape Grassy and western Dundas Peninsula, and throughout southern Sabine Peninsula. A prominent keystone graben cuts Hecla Bay Formation north of Bridport Inlet and apparently does not offset outliers of the Isachsen and Christopher formations in this area.

Average displacement on northeast-striking faults ranges up to to a few tens of metres. The faults are subparallel to Hauterivian gabbro dykes near Tingmisut Lake (Balkwill and Haimila, 1978) and in some cases are exactly coincident with linear magnetic anomalies as described by Balkwill and Fox (1982, see Fig. 2). These authors suggested that the northeast striking fault array resulted from the emplacement of gabbro sills in the subsurface and from simultaneous doming and fracturing of overlying strata. Although isotopic ages on the intrusive rocks range from 190 Ma to 86 Ma (Early Jurassic to Late Cretaceous; Balkwill and Fox, 1982), our observation that associated faults fail to penetrate the Isachsen Formation indicates that the most active period of northwest-southeast extension in the Melville Island area was complete by mid-Early Cretaceous time.

5. Post-Lower Cretaceous faults

Normal faults striking west-northwest offset Christopher Formation (Albian) and older strata on Sproule Peninsula, and in the Bridport Inlet area.

Outliers of the Isachsen and Christopher formations near Bridport Inlet are bounded by faults, the offsets on which must be at least 65 m, or the thickness of Lower Cretaceous strata preserved within the outliers. The regional extent of these post-Lower Cretaceous structures is unknown. It seems likely that some faults in the Blue Hills were active during this period, as was suggested by Tozer and Thorsteinsson (1964, p. 188).

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