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THE GRAVITY FIELD OF NORTHEASTERN ELLESMERE ISLAND, PART OF NORTHERN GREENLAND AND LINCOLN SEA

with map: No. 114 – Lincoln Sea

L. W. Sobczak and L. E. Stephens

DEPARTMENT OF ENERGY, MINES AND RESOURCES

OTTAWA, CANADA 1974

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CONTENTS

THE GRAVITY FIELD OF NORTHEASTERN ELLESMERE ISLAND, PART OF NORTHERN GREENLAND AND LINCOLN SEA

L. W. Sobczak and L. E. Stephens

ABSTRACT - More than 700 gravity stations have been established in northern Ellesmere Island, in part of northern Greenland and on Lincoln Sea during the period 1957-1967. These measurements are presented in the form of a Bouguer anomaly map at a scale of 1:500,000. Primary gravity anomaly trends are parallel to major northeasterly structural trends. The most significant anomaly is an extensive low with a minimum value of -120 mgal over Ellesmere Island which is attributed to the combined effect of ice caps, thick sequences of low-density sediments and a thickening of the crust below the mountains of the United States Range. A northeasterly extension of this low over Lincoln Sea suggests that the Franklinian geosyncline and Sverdrup Basin continue beyond the northeastern tip of Ellesmere Island. A prominent northeasterly trending high (maximum anomaly 50 mgal) over the Hazen Plateau and Lincoln Sea and a parallel low (minimum anomaly -95 mgal) to the southeast over Judge Daly Promontory and Greenland are separated by a steep horizontal gradient (max. -3.68 mgal/km). This change in anomaly may be explained by an abrupt step-like thickening of the crust of 10 km or more from the northwest to the southeast and may be related to an ancient plate boundary.

RÉSUMÉ - De 1957 à 1967, plus de 700 stations de mesure de la gravité ont été installées dans le nord de l'île Ellesmere, dans une partie du Nord du Groenland et dans la mer de Lincoln. Les mesures sont présentées sous forme d'une carte des anomalies de Bouguer à l'échelle de 1:500,000. Les directions d'anomalie gravitationnelles primaires sont parallèles aux principales directions structurelles orientées nord-est. L'anomalie la plus importante est une longue dépression à travers l'île Ellesmere, d'une valeur minimale de -120 mgals, et attribuée à l'action combinée de la calotte glaciaire, à d'épaisses successions de sédiments de faible densité et à un épaississement de la croûte sous les montagnes de la chaîne États-Unis. L'extension nord-est de cette dépression, à travers la mer de Lincoln, porte à croire que le géosynclinal franklinien et le bassin Sverdrup s'étendent au-delà de la pointe nord-est de l'île Ellesmere. Une élévation importante, à direction nord-est (anomalie maximale 50 mgals), par le plateau Hazen et la mer de Lincoln, et une dépression parallèle (anomalie minimale -95 mgals), orientée sud-est à travers le promontoire Juge-Daly et le Groenland, sont séparées par un gradient horizontal élevé (maximum -3.68 mgals/km). Ce changement d'anomalie peut s'expliquer par un épaississement abrupt en gradins de la croûte de 10 km ou plus, depuis le nord-ouest jusqu'au sud-est, et peut être relié à une ancienne limite de plateau.

INTRODUCTION

In 1957 the Gravity Division of the Earth Physics Branch established a gravity control tie from Resolute Bay to Alert using North American gravimeter No. 137 (Bancroft, 1958). This base network was extended to Lake Hazen in 1958 and about 300 gravity measurements were made by the Canadian Defence Research Board to investigate ice cap thicknesses on a traverse from Clements Markham Inlet across the United States Range to Lake Hazen (Weber, Sandstrom and Arnold, 1960; Weber, 1961). Another 50 observations were made in 1962 along two profiles to further investigate an area of interesting geomagnetic variations at Alert, Northwest Territories (Law, DeLaurier, Anderson and Whitham, 1963). One profile was measured along the northern coast of Ellesmere Island to Greenland and the other extended southeastward from Lake Hazen to Greenland. The strong correlation between gravity and geomagnetic anomalies along these profiles necessitated a regional gravity survey in order to delineate the gravity expression of this geomagnetic feature. Thus, in 1964 and 1966, additional control stations were established (Winter and Perrier, 1968) and a regional gravity survey of northeastern Ellesmere Island and Greenland was completed by helicopter in 1966 but a proposed survey of the Lincoln Sea was abandoned because of DECCA (Hi-Fix chain) transmission failure. In the following year a more powerful DECCA system (Polar Continental Shelf Project Lambda 6F system) was employed and 235 gravity measurements were made on the sea ice using helicopters in a joint operation with hydrographers of the Polar Continental Shelf Project.

During the period 1957 to 1967 a total of more than 700 gravity stations was established in the Lincoln Sea region (Figure 1). With the exception of measurements made in 1958, all measurements were made by personnel of the Earth Physics Branch supported by the Polar Continental Shelf Project (both of the Department of Energy, Mines and Resources, Ottawa). Table I lists by year of operation, the names of the observers, the instruments used, the number of gravity observations and the areas surveyed. Stations were spaced at 10 to 15 km intervals, except over the ice caps of the United States Range where the station density is greater (Weber *et al.*, 1960).

TABLE I

Summary of Gravity Surveys

Year	Personnel	Instruments	Number of Stations	Area of Survey
1958	J.R. Weber N. Sandstrom	W 10 W 44	300	United States Range and Ruggles River
1962	A. Spector	W 573	50	Ellesmere Island and Greenland
1964	P.J. Winter	G7, G9	4	Alert (Control)
1966	A.W.J. Berkhout L.E. Stephens	G25A W 573	139	Northern Ellesmere Island and Northern Greenland
1967	L.E. Stephens D. Picklyk	H 2G G 139 W 573	235	Lincoln Sea
		Total	728	

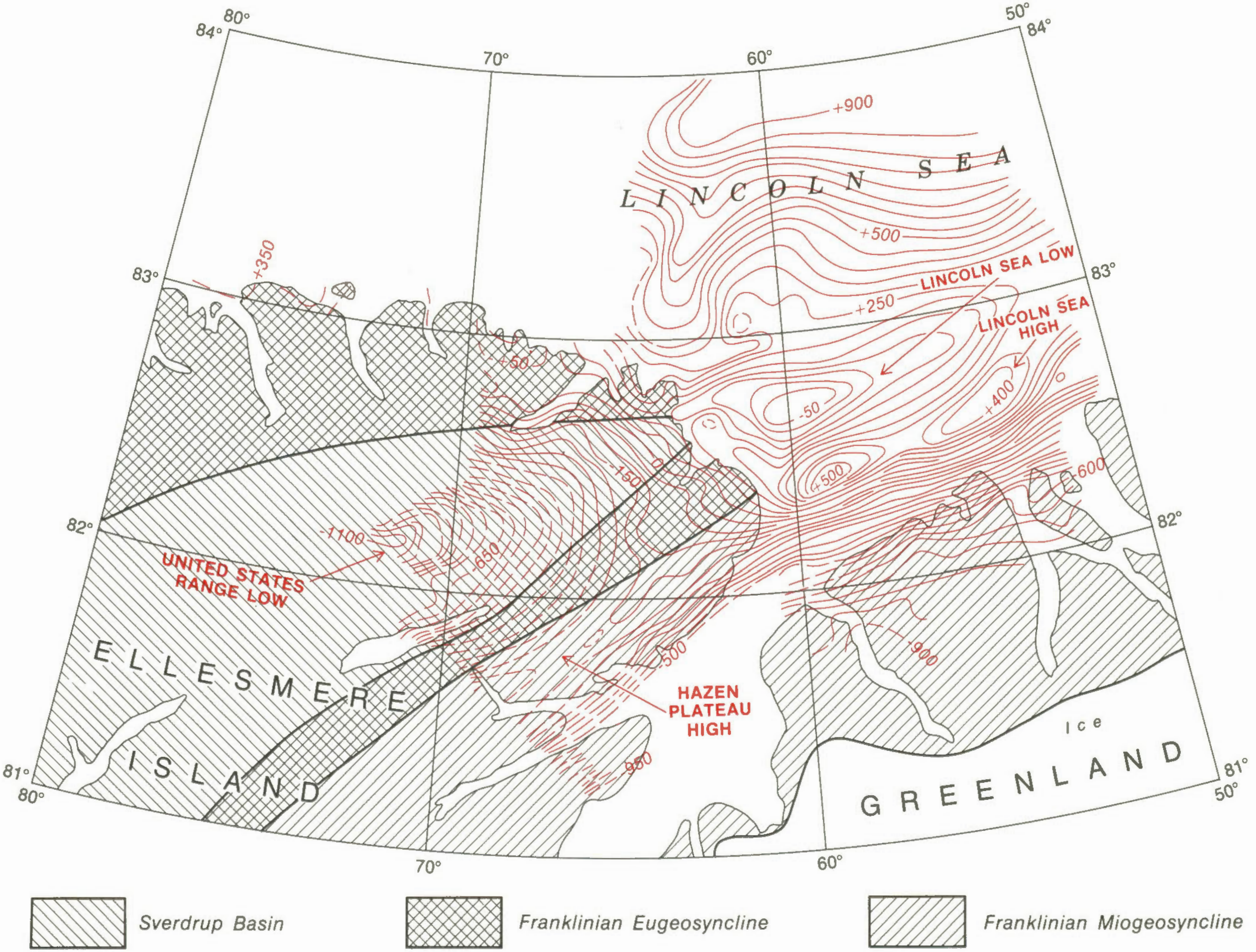

Figure 1. Location map showing the geology (black) and gravity (Bouguer anomalies in red) over the north-eastern part of the Sverdrup Basin and Franklinian geosyncline. Gravity contours are at 5 mgal intervals.

Survey procedures and the accuracy of the gravity measurements over land and sea ice were similar to those described by Sobczak and Weber (1970) and the reader is referred to that publication for details. In this area the average accuracy of the Bouguer anomaly values, which were calculated using a density of 2.67 g/cm^3 according to the method described by Tanner and Buck (1964), is estimated to be about ±3 mgal. Terrain corrections and errors in water depths and elevations may be large. To assess the magnitude of the terrain effect, corrections were calculated for 13 stations at various locations in very rugged topography. The ring graticule method described by Bible (1962) and adapted for the computer, was used out to zone M (about 22 km from the station); the terrain corrections vary from 1.6 to 15.5 mgal the average being 6.4 mgal. In general, much smaller corrections would apply for most of the stations. Uncertainties in elevation and water depth which are estimated to be about 6 and 15 m, respectively, contributed errors to the Bouguer anomalies of about 1 mgal.

GEOLOGY

The survey area covers the northeastern end of the Innuition Orogenic System (Thorsteinsson and Tozer, 1960) which is divided into two structural provinces the Sverdrup Basin to the north of Lake Hazen, and the Franklinian geosyncline to the north and southeast of the United States Range (Figure 1). This basin contains folded and unfolded beds of late Paleozoic, Mesozoic and Cenozoic age which unconformably overlie and partly conceal the structures of the geosyncline. The geosyncline contains tightly folded early and middle Paleozoic beds with recognizable eugeosynclinal and miogeosynclinal facies. The boundaries of the eugeosyncline were modified by Kerr (1967). Geological evidence reported by Trettin (1970), shows that the area east of Lake Hazen is not a eugeosyncline as indicated in Figure 1 but an axial trough crossing the Hazen Plateau with a eugeosyncline and shelf northwest of the trough and a miogeosyncline and shelf southwest of the trough. The eugeosyncl-inal rocks are exposed to the north of the Sverdrup Basin and the miogeosyncl-inal rocks are exposed on the Hazen Plateau, on Judge Daly Promontory and in northern Greenland. The predominant structural trends are northeasterly, with prominent folds over the Hazen Plateau and, faults north of Lake Hazen and on Judge Daly Promontory. These structures parallel the straight coastline of Polaris Promontory and Nyeboe Land of northern Greenland.

Rock groups of Precambrian, Paleozoic, Mesozoic and Cenozoic ages are discussed in detail by Christie (1964) and Trettin (1971). Gneiss, migmatite and granite exposed along the northern side of Ellesmere Island may form the basement rocks of the Franklinian geosyncline. Carbonate rocks, sandstone, quartzite and slate of the miogeosyncline grade northwesterly into greywacke, impure limestone, volcanic flows, breccia, tuff and related sedimentary rocks of the eugeosyncline. Limestone, sandstone, shale and conglomerate of the Sverdrup Basin are partly exposed northeast of Lake Hazen but these rocks are generally covered by ice caps. Dioritic and basaltic dykes and sills are widespread and intrude all formations older than Cenozoic.

ROCK DENSITIES

Rock densities have been determined for many areas of the Queen Elizabeth Islands (Sobczak, 1963; Berkhout and Sobczak, 1967; Picklyk, 1969; Sobczak, Weber and Roots, 1970). These densities are also representative of similar rock types in northern Ellesmere Island and Greenland.

Very few samples were collected for density measurements in the surveyed area; 20 samples were obtained from Dr. R.L. Christie of the Geological Survey of Canada and only 12 samples were collected during the gravity survey of 1966. Of the latter samples, four came from Greenland. Table II summarizes the density results.

TABLE II

Density Measurements

Rock Type	Number of Samples	Range of Density g/cm^3	Mean Density g/cm^3
Greywacke	12	2.64 - 2.87	2.72
Quartzite	3	2.63 - 2.72	2.67
Phyllite	3	2.63 - 2.82	2.71
Shale	3	2.56 - 2.72	2.65
Slate	2	2.76 - 2.94	2.85
Sandstone	3	2.27 - 2.37	2.31
Arkose	1		2.83
Limestone	3	2.61 - 2.81	2.71
Dolomite	1		2.84
Soapstone	1		2.74

BOUGUER ANOMALY MAP

The Bouguer anomaly map (Figure 1) reveals an uneven gravity field with anomalies varying from -120 mgal over the central part of Ellesmere Island to +90 mgal over the northern part of the Lincoln Sea. It outlines four prominent anomalies: an extensive low (minimum -120 mgal) over the United States Range of central Ellesmere Island named herein the *United States Range Low*, a low (minimum -5 mgal) over the central part of Lincoln Sea named the *Lincoln Sea Low*, a relative high (maximum -15 mgal) over the Hazen Plateau named the *Hazen Plateau High* and a belt of highs (maximum +50 mgal) over the Lincoln Sea just north of Greenland, called the *Lincoln Sea High*. The southeastern part of the gravity field is negative, and decreases southeastwards to -95 mgal over Judge Daly Promontory on Ellesmere Island and to -90 mgal on Greenland. This horizontal gradient (maximum -3.68 mgal/km) is continuous across Robeson Channel and trends parallel to the structural trends over the Hazen Plateau and the straight coastline of northern Greenland.

DISCUSSION

Some general characteristics of the gravity field are as follows:

(1) The gravity field becomes more negative towards the glaciated areas of central Greenland and Ellesmere Island suggesting some relationship between glacial loading and gravity anomalies.

(2) Over the land as the terrain becomes higher, the anomalies become more negative while over the sea, as the water gets deeper, the anomalies become more positive. Qualitatively, this inverse relationship suggests seaward crustal thinning as noted elsewhere along the continental margin (Weber, 1963; Wold, Woodzick and Ostenso, 1970; Sobczak and Weber, 1973; Berry and Barr, 1971).

(3) Negative gravity anomalies occur over the Sverdrup Basin and these anomalies in part probably correlate with sediment thicknesses, the greatest thickness being where the anomaly is lowest. Although very little deep seismic control exists, the gravity data suggest the following interpretations:

The *United States Range Low* which is underlain by ice caps, the Sverdrup Basin and the United States Range mountains may be explained by a combination of the following factors. Firstly Weber *et al.* (1960) recorded ice thicknesses of up to 800 m over the Gilman and Clements Markham Glacier; this ice thickness would account for only about -60 mgal of the United States Range Low. Secondly both Christie (1964) and Petryk (1969) estimate about 1930 m (6,000 ft) downward displacement of Mesozoic clastic sediments on the southeastern side of the Lake Hazen fault. These sediments which have a density contrast of -0.33 g/cm^3 with the Paleozoic sediments (Sobczak *et al.*, 1970) can account for a residual gravity anomaly of about -20 mgal north of Lake Hazen. Thirdly ice caps and low density sediments are insufficient to entirely account for the United States Range Low. If one neglects horizontal density changes such as low density Paleozoic sediments below the Sverdrup Basin, a low density granitic core below the mountains or a decrease in density in the mantle, for which there is no evidence, the regional low over the United States Range may be interpreted as a thickening of the crust below the mountains. A 5-km-thick root system with density contrast of -0.44 g/cm^3 between crustal and mantle rocks below the mountains would account for a regional low of about -90 mgal. This root system would essentially support the loads of the mountains and ice caps.

The *Lincoln Sea Low* (minimum -5 mgal), a relative anomaly low of about -30 mgal, covers an extensive area (45 x 125 km) over the Lincoln Sea and is continuous with the Sverdrup Basin to the southwest. The gravity lows over the continental margin generally correlate with deposits of low density sediments (Wold, Woodzick and Ostenso, 1970; Sobczak and Weber, 1973). If this were the case and we assume a density contrast of -0.33 g/cm^3 as used for the Lake Hazen Mesozoic sediments, then a sedimentary basin, 2 km thick, could account for the anomaly low. The gravity effect caused by thick deposits of low density sediments is usually regionally removed by some form of isostatic compensation as in the western part of the Sverdrup Basin (Sobczak and Weber, 1973) and in the Mackenzie Delta (Sobczak, in preparation). If this were the case then much greater sedimentary thicknesses could be expected and would make this area an attractive hydrocarbon prospect.

The northeasterly trending *Hazen Plateau High*, a relative high of about 110 mgal with a peak anomaly of about -15 mgal, follows structural trends of the Hazen Plateau region and appears to be unrelated to the surface rocks in which no apparent density contrast exists. This high occurs in a region where an axial trough has been proposed by Trettin (1970). It lies between the Alert geomagnetic anomaly (Law, DeLaurier, Anderson and Whitham, 1963) and a proposed edge of an ancient stable craton or an ancient plate boundary (Law and Riddihough, 1971; Riddihough, Haines and Hannaford, 1972). Law *et al.* (1963) interpreted the geomagnetic anomaly as due to deep-seated cylindrical conducting body (100 km in diameter and 10 km below the surface) but their model produced an unsatisfactory magnetic vertical field response and yielded a questionable gravity anomaly. Praus, DeLaurier, and Law (1970) suggested another alternative, namely, a broad subterranean structure, possibly a horizontal slab, to explain the geomagnetic data. The Hazen Plateau High may be explained by crustal thinning consisting of a horizontal slab with a density contrast of 0.44 g/cm^3 between the crustal and mantle rocks. This structure would have a southeast trending 9 km step which would be below Judge Daly Promontory and would be between the proposed plate boundary (i.e. the crust is 9 km thicker southeast towards the craton) and a 4.5 km step southeast of Lake Hazen lying below the Alert geomagnetic anomaly. Although there is good correlation between the northwestern side of the slab and the Alert geomagnetic anomaly on Ellesmere Island, there is no correlation over Lincoln Sea where the Alert geomagnetic anomaly trends northeast across the Lincoln Sea Low and has no apparent relationship with any gravity anomalies. The southeastern side of the slab appears to be continuous across Robeson Channel and along the southern flank of the Lincoln Sea High on the north coast of Greenland.

The *Lincoln Sea High* appears to be a seaward extension of the Hazen Plateau High but at the northeastern end of Ellesmere Island the belt of highs trends northwestwards and parallels the northern coastline of Ellesmere Island. Although the southeastern flank of the Lincoln Sea High may readily be explained by a 10-km step in the crust-mantle boundary, the small but intense anomaly closures suggest mass excesses which are closer to the surface than 10 km. More information is needed to interpret this anomaly.

SUMMARY

The thickness of the crust has been estimated at 23 ±3 km from a study of the P wave spectra of an Alaskan earthquake which was recorded at Alert (Utsu, 1966). If this estimate is valid then the gravity data would suggest that the thickness of the crust for northern Greenland and the south side of Judge Daly Promontory is 33 ±3 km, for central Ellesmere Island is 27 ±3 km, and for the continental shelf is about 18 to 20 km. The gravity low over Lincoln Sea suggests at least 2 km of low density sediments possibly similar to the Mesozoic sediments found in the Lake Hazen area. The crust-mantle boundary of the stable craton proposed by Riddihough *et al.*(1972) may fall along the proposed step which trends from the central part of Judge Daly Promontory, along the central part of Robeson Channel and to the northern side of Greenland.

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REFERENCES

Bancroft, A.M., 1958. Gravity measurements in the Queen Elizabeth Islands of Arctic Canada. *Trans. Amer. Geophys. Un.* 39(4), pp. 615-619.

Bible, J.L., 1962. Terrain correction tables for gravity. *Geophys.* 27, pp. 715-718.

Berkhout, A.W.J., and L.W. Sobczak, 1967. A preliminary investigation of gravity observations in the Somerset and Prince of Wales Islands, Arctic Canada, with map. *Gravity Map Series, Dom. Obs.* No. 81.

Berry, M.J., and K.G. Barr, 1971. A seismic refraction profile across the Polar Continental Shelf of the Queen Elizabeth Islands. *Can. J. Earth Sci.* 8(3), pp. 347-360.

Christie, R.L., 1964. Geological reconnaissance of northeastern Ellesmere Island, District of Franklin (120, 340, parts of). *Geol. Surv. Can.*, Mem. 331.

Kerr, J.W., 1967. Stratigraphy of Central and Eastern Ellesmere Island, Arctic Canada, Part II. *Geol. Surv. Can.*, Paper 67-27.

Law, L.K., J. DeLaurier, F. Anderson, and K. Whitham, 1963. Investigations during 1962 of the Alert anomaly in geomagnetic variations. *Can. J. Phys.* 41, pp. 1868-1882.

Law, L.K., and R.P. Riddihough, 1971. A geographical relation between geomagnetic variation anomalies and tectonics. *Can. J. Earth Sci.* 8(9), pp. 1094-1106.

Picklyk, D.D., 1969. A regional gravity survey of Devon and Southern Ellesmere Islands, Canadian Arctic Archipelago, with map. *Gravity Map Series, Dom. Obs.* No. 87.

Petryk, A.A., 1969. Mesozoic and Tertiary stratigraphy at Lake Hazen, northern Ellesmere Island, District of Franklin. *Geol. Surv. Can.*, Paper 68-17.

Praus, O., J.M. DeLaurier, and L.K. Law, 1970. The extension of the Alert geomagnetic anomaly through Ellesmere Island, Canada. *Can. J. Earth Sci.* 8(1), pp. 50-64.

Riddihough, R.P., G.V. Haines, and W. Hannaford, 1972. Regional magnetic anomalies of the Canadian Arctic. *Can. J. Earth Sci.* 10(2) pp. 157-163.

Sobczak, L.W., 1963. Regional gravity survey of the Sverdrup Islands and vicinity with map. *Gravity Map Series, Dom. Obs.* No. 11.

Sobczak, L.W., J.R. Weber, and E.F. Roots, 1970. Rock densities in the Queen Elizabeth Islands, Northwest Territories. *Proc. Geol. Assoc. Can.* 21, pp. 5-14.

Sobczak, L.W., and J.R. Weber, 1970. Gravity measurements over the Queen Elizabeth Islands and Polar Continental Margin with maps. *Gravity Map Series, Earth Physics Branch* Nos. 115 and 116.

Sobczak, L.W., and J.R. Weber, 1973. Crustal structure of Queen Elizabeth Islands and Polar Continental Margin. 2nd Intern Sym. on Arctic Geol., San Francisco. Arctic Geol. Mem. 19, *Amer. Assoc. Petrol. Geol.* pp. 517-525.

Tanner, J.G., and R.J. Buck, 1964. A computer-oriented system for the reduction of gravity data. *Pub. Dom. Obs.* 31(3), pp. 57-65.

Thorsteinsson, R., and E.T. Tozer, 1960. Summary account of the structural history of the Canadian Archipelago since Precambrian time. *Geol. Surv. Can.*, Paper 60-7.

Trettin, H.P., 1970. Ordovician-Silurian flysch sedimentation in the axial trough of the Franklinian Geosyncline, northeastern Ellesmere Island, Arctic Canada. *Geol. Assoc. of Can.*, Special Paper No. 7, pp. 13-35.

Trettin, H.P., 1971. Geology of Lower Paleozoic formations, Hazen Plateau and the southern Grant Land Mountains, Ellesmere Island, Arctic Archipelago. *Geol. Surv. Can.*, Bull. 203.

Utsu, T., 1966. Variations in spectra of P-waves recorded at Canadian Arctic seismograph stations. *Can. J. Earth Sci.* 3(5) pp. 597-622.

Weber, J.R., N. Sandstrom, and K.C. Arnold, 1960. Geophysical surveys on Gilman Glacier, northern Ellesmere Island. *Int. Assoc. Snow and Hydrology* (54), pp. 500-511.

Weber, J.R., 1961. Comparison of gravitational and seismic depth determinations on the Gilman Glacier and adjoining ice cap in northern Ellesmere Island. Geology of the Arctic, *Univ. of Toronto Press*, pp. 781-790.

Weber, J.R., 1963. Gravity anomalies over the Polar Continental Shelf. *Contr. Dom. Obs.* 4(17), pp. 1-10.

Winter, P.J., and J.A. Perrier, 1968. Descriptions of Gravity Control Stations Arctic Islands. Unpub. Gravity Division, Earth Physics Branch.

Wold, R.J., T.L. Woodzick, and N.A. Ostenso, 1970. Structure of the Beaufort Sea continental margin. *Geophys.* 35(5), pp. 849-861.