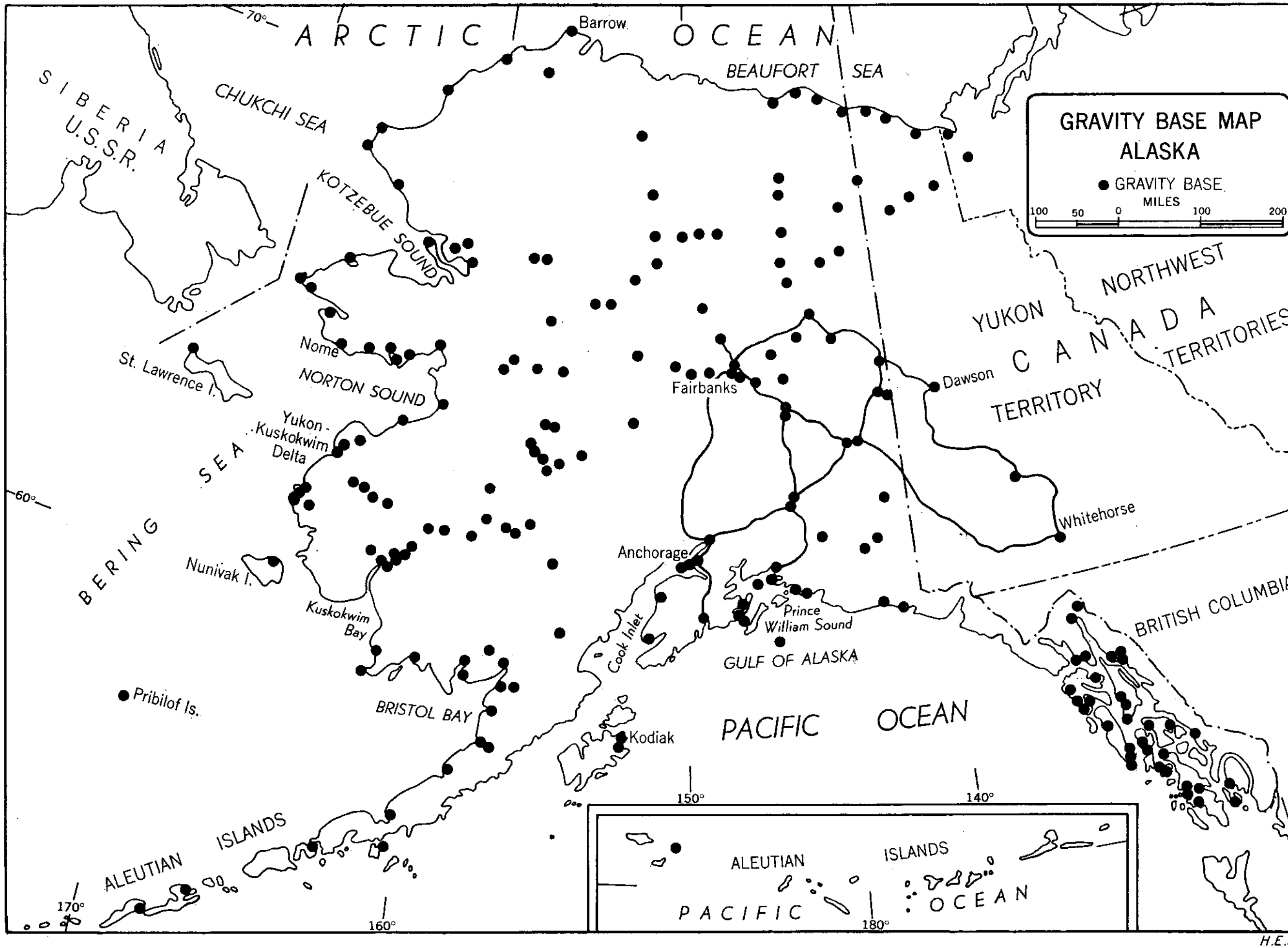

Fig. 1. Gravity stations and traverses.

GRAVITY MEASUREMENTS IN ALASKA

E. Thiel*, N. A. Ostenso*, W. E. Bonini†, and G. P. Woollard**

THE mapping of the earth's gravity field is important for several branches of scientific endeavour. In geodesy, gravity measurements furnish a basis for determining the overall shape of the geoid and its undulations. In studying the earth's crust gravity measurements provide a quick and reliable method of determining variations in crustal structure. In the study of the crystalline basement rock complex gravity values used in conjunction with seismic and well data have immeasurably broadened our knowledge of both the lithology and configuration of this buried surface. Finally, such measurement have proved of great value in the search for mineral resources. The ultimate use made of gravity measurements depends on the method of analysis employed. The basic data for all uses are the same — the gravity observations themselves.

The present report outlines the extent of a gravity observation program in Alaska, carried out by the authors. Although the areal gravity mapping in this area will take many years to complete, sufficient work has been done to furnish a nucleus for integrating past and future studies into a unified network covering most of the state. Five hundred and thirteen gravity stations have been established to date distributed throughout Alaska as shown in Fig. 1. Approximately one-third are located at airports and the balance constitute traverses with a 5- to 10-mile station spacing following the highway system, the Alaska Railroad, and part of the Yukon River. Station descriptions and principal facts for the 513 gravity stations are presented in a mimeographed report (Thiel *et al.* 1958) of which the present paper is an abstract.

Field procedure

In 1950 when the authors began their program of gravity measurements in Alaska little previous work was available. The U.S. Coast and Geodetic Survey had established only widely scattered pendulum stations and the limited oil exploration data were restricted to company use and based on an arbitrary datum.

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In beginning work in this new area it was necessary to establish base stations from which gravity-meter surveys could be carried, and to establish a uniform calibration standard for all gravity-meters to be employed in the work. To this end a line of precise gravity bases extending from Mexico City to Fairbanks was established by the University of Wisconsin with quartz-pendulum apparatus developed by the Gulf Research and Development Company. This work provided a gravity-meter calibration range of 4300 milligals and the necessary base stations in Alaska and the Yukon (Rose and Woollard 1956).

The second step in the program called for the establishment of subsidiary base stations throughout the state carefully tied to the primary bases (see Table 1). These subsidiary bases were established by air travel using long-range Worden geodetic gravity-meters calibrated against the Gulf pendulum standard. Financial considerations precluded chartering aircraft for this work. However, it was found that by using scheduled commercial flights and mail runs by Alaskan bush pilots to outlying Eskimo and Indian villages the cost of this phase of the program was not prohibitive. Since only 5 minutes are required to read a Worden gravity-meter, there was sufficient time at every stop to make the gravity observation while the pilot unloaded supplies. The only problem encountered was the occasional

Table 1. Primary base stations.

Place	*Location*	*Latitude N.*	*Longitude W.*	*Altitude ft.*	*Observed gravity*
Ladd Air Force Base, Fairbanks	South side of hangar No. 1, at base of control tower, adjacent to USCGC benchmark in face of tower and stamped "F 60 1951"	64°50.7′	147°36.2′	444	982.2437
Area surveyed from base: Alaska north of the Alaskan Range and Yukon north of 65°N.					
Elmendorf Air Force Base, Anchorage	Field entrance to MATS terminal (gate 2), on concrete platform level with the field.	61°15.0′	149°47.7′	212	981.9377
Area surveyed from base: Alaska south of the Alaska Range and west of 141°W.					
Juneau	Airport, at field entrance to passenger terminal, on left-hand concrete sidewalk (as one faces terminal), at the end of sidewalk, nearest runway.	58°21.7′	134°35.3′	26	981.7672
Area surveyed from base: Southwest Alaska.					
Whitehorse	Airport, in the basement of emergency pumping station of Dept. of Transport, about 100 ft. east of C.P.A. hangar.	60°43.0′	135°03.4′	2281	981.7487
Area surveyed from base: Yukon south of 65°N.					

difficulty in finding a suitable site that could be adequately described for reoccupation by later observers. Approximately 12,000 miles were flown in single-engine aircraft in carrying out this phase of the program. This constituted about 90 per cent of the mail runs scheduled by the Civil Aeronautics Authority at the time.

Phase three involved gravity observations at 5- to 10-mile intervals on the ground by whatever means of transportation were available. Gravity observations were taken during travel along the Alaska, Richardson, Anchorage-Palmer, Glenn, Slana-Tok, Elliot, Steese, and Taylor highways. The Department of the Interior provided a track sedan for travel along the Alaska Railroad between Fairbanks and Seward. The U.S. Army Arctic Center provided boats and manpower for an 800-mile river trip down the Lewes and Yukon rivers from Whitehorse to Circle. In Table 2 are listed the observers, the instruments employed and their calibration, and the year of completion of these various aspects of the program.

Table 2. Establishment of stations.

Observer	*Gravity-meter*	*Calibration*	*Year*
J. C. Rose	Gulf pendulums	———	1953
W. E. Bonini	North American 113a	0.21289 mgls./dial unit	1950
C. Muckenfuss	Worden 10-e	0.02296 mgls./vernier unit	1950
E. Thiel	Worden 14-c	0.10326 mgls./vernier unit	1954
N. A. Ostenso	Worden 14-d	0.12599 mgls./vernier unit	1955
E. Thiel	Worden 14-d	0.12599 mgls./vernier unit	1955
E. Thiel	Worden 147	0.010456 mgls./vernier unit	1956

Reduction of data

Observed gravity values are on the Potsdam standard, which gives a value of 980.1190 gals for the United States national gravity base at floor level in the gravity vault of the U.S. Coast and Geodetic Survey in the Department of Commerce Building, Washington, D.C. (Woollard 1958). Station latitudes and longitudes were taken from the U.S.G.S. Alaska Reconnaissance Topographic Map Series, scale 1:250,000. Altitude control has been derived from a multitude of sources of varying accuracy (Table 3).

The three values of observed gravity, latitude, and altitude are the data from which various gravity anomalies can be computed. In the present study only Free Air and Bouguer anomalies have been determined. This was done at the University of Wisconsin using the IBM 650 computer in the Numerical Analysis Laboratory. The 1930 International Gravity Formula has been used as the basis for computing theoretical sea-level gravity. In order to obtain the maximum geological value from the data Bouguer anomalies were computed for densities of 1.77, 2.00, 2.20, 2.40, 2.50, 2.67, 2.80, and 2.90 at each station. No corrections for terrain or gravity tidal

Table 3. Sources of altitude control.

Estimated accuracy	*Source of control*
± 1 foot	Benchmark or levelling from that
± 2 feet	Altitude given for U.S. weather station mercury barometer
± 3 feet	Estimated from mean sea-level with tidal correction from tide tables
± 5 feet	Altimeter
± 25 feet	C.A.A. altitude for runway
± 25 feet	Based on computed river gradient between points of known altitude
± 100 feet	U.S.G.S. Alaska Reconnaissance Topographic Maps, scale 1:250,000

effects have been made, since the magnitude of these corrections is no larger than possible altitude errors. Because of the questionable altitudes of some stations the observed gravity values are of a higher order of accuracy than the anomaly values.

Results

Areal gravity coverage. The gravity coverage in Alaska at the present time does not permit a realistic anomaly map to be constructed for the state as a whole. However, for two areas reasonably accurate regional anomaly maps are presented. Fig. 2 is a map of the Naval Petroleum Reserve No. 4 in northwestern Alaska. This area was originally mapped in detail by United

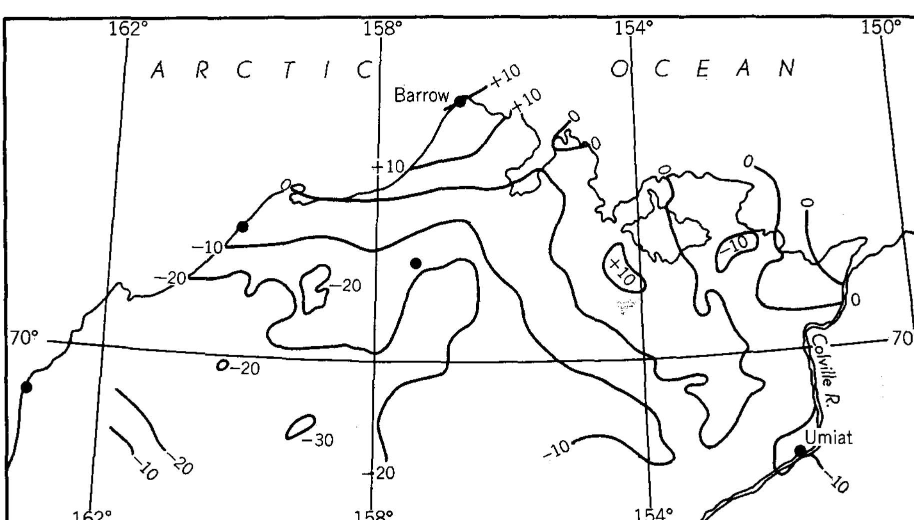

Fig. 2. Bouguer anomaly map (density = 2.67) of Naval Petroleum Reserve No. 4, Northwestern Alaska.

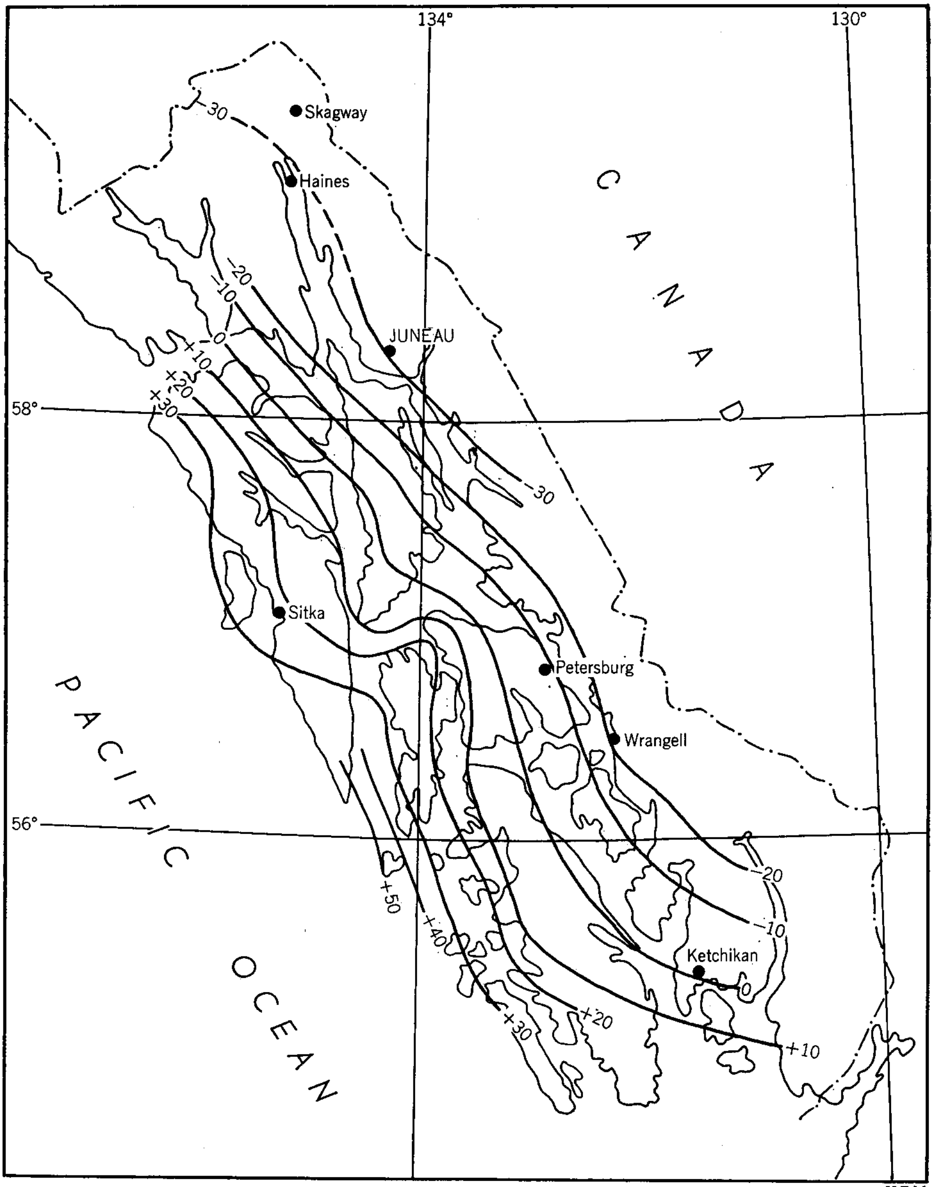

Fig. 3. Bouguer anomaly map (density = 2.67) of southeastern Alaska.

Geophysical Company under contract to the U.S. Navy on an arbitrary datum. Values have been adjusted to conform to the Potsdam datum.

Fig. 3 is a regional gravity map of southeastern Alaska. The prominent decrease in anomaly as one proceeds inland perpendicular to the coast is immediately evident. The magnitude of the gradient suggests a thickening of the earth's crustal layer, or, in seismic terms, a downward dip of the Mohorovicic discontinuity as one proceeds from ocean to continent. Superimposed on this regional trend between Sitka and Petersburg is a more local

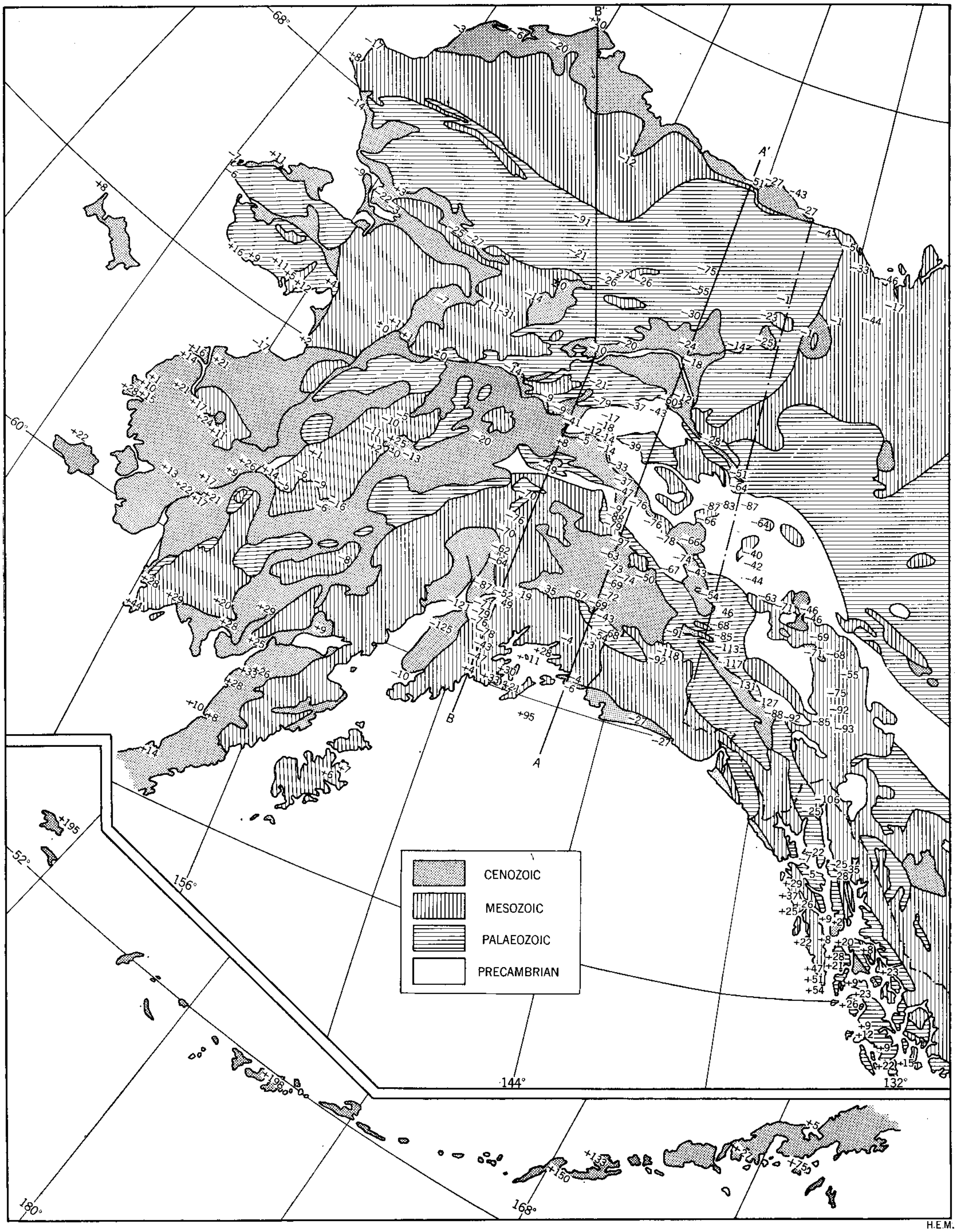

Fig. 4. Generalized geological map of Alaska with superimposed Bouguer anomalies (density = 2.67).

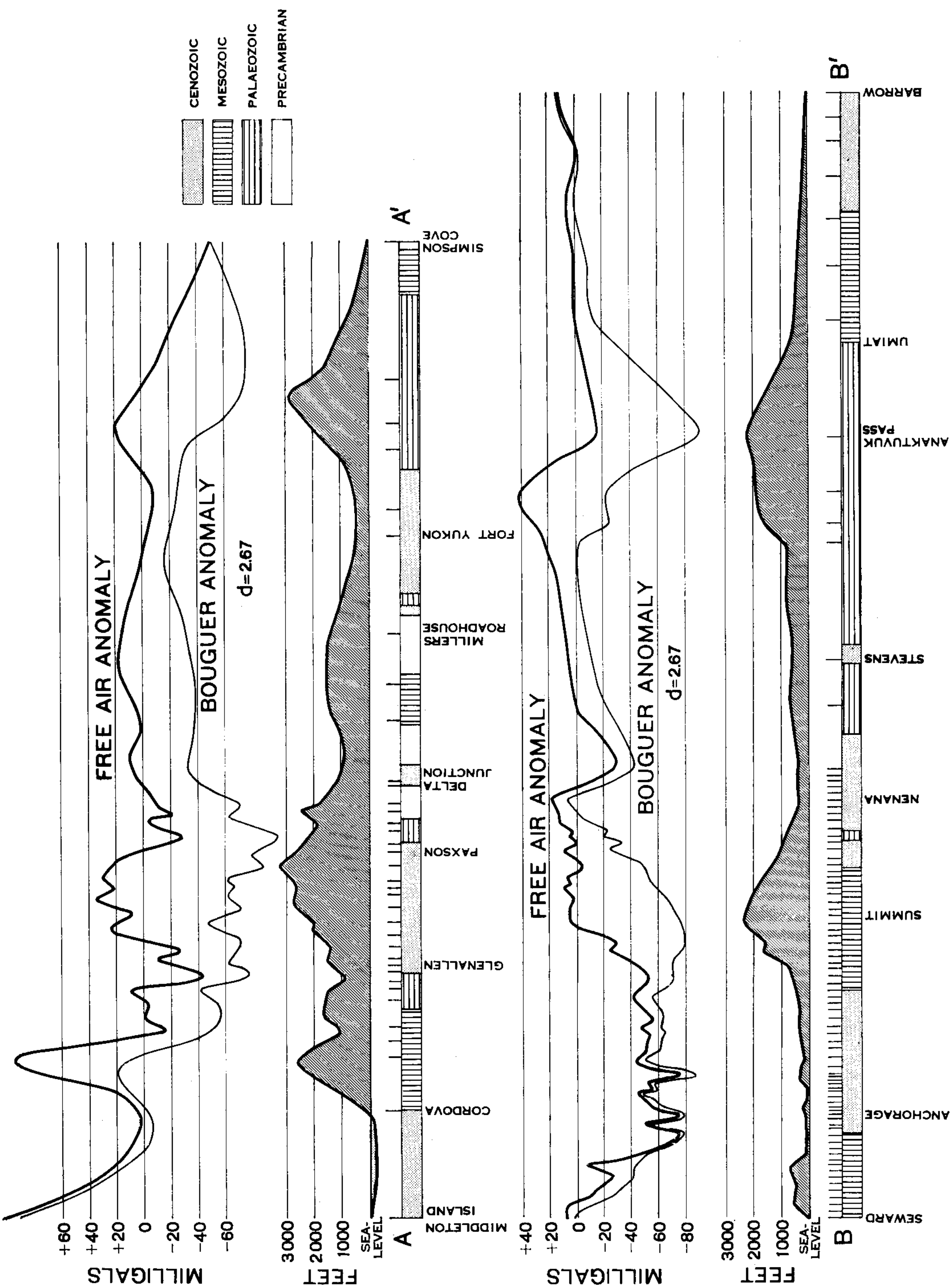

Fig. 5. Free air and Bouguer anomaly profiles in relation to topography and geology.

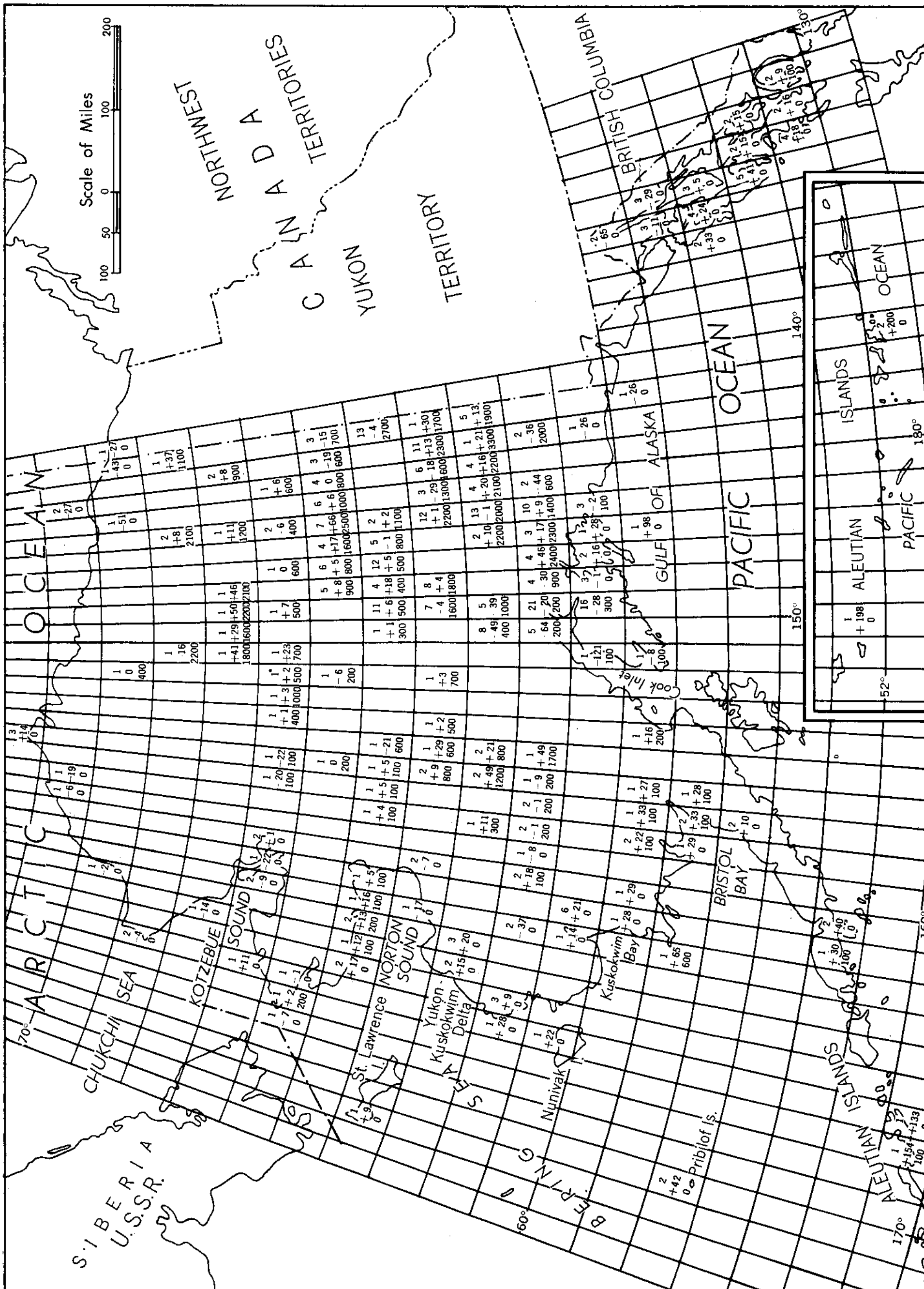

Fig. 6. Free air anomalies in 1° by 1° rectangles. Figures give (a) number of gravity observations per rectangle, (b) mean free air anomaly, (c) mean altitude of gravity stations.

anomaly of near surface origin. The anomaly gradient from Haines northward through Skagway is particularly steep.

Geology. Fig. 4 is a generalized geological map of Alaska with Bouguer anomalies (density = 2.67) superimposed. The most pronounced features are the following:

(1) A great gravity low occupies Cook Inlet, with anomalies for sea-level stations of —125 milligals. By contrast, other coastal embayments are either positive (for example, Prince William Sound and Bristol Bay) or nearly zero (Norton Sound and Kotzebue Sound). The Cook Inlet low is the most striking anomaly on the Alaska gravity map and calls for a thorough study by both the geophysicist and the structural geologist.

(2) Positive Bouguer anomalies of nearly 200 milligals occur over the Aleutian Chain. Such large positive anomalies are not the rule, although positive anomalies of 100 milligals are found on some recent volcanic islands. Isostatic theory requires the gradual sinking of the islands once the volcanic outpouring is complete.

(3) An average positive anomaly of 17 milligals occurs on the Yukon-Kuskokwim delta. If the earth's crust were rigid and capable of supporting great loads, large positive anomalies would be expected in areas of recent deposition. The lack of such anomalies would indicate that isostatic adjustment is proceeding concomitantly with deposition.

(4) An anomaly of +7 milligals centres on Nenana. Positive Bouguer anomalies are not common in the continental interior and are usually associated with the presence of high density rock at or near the surface.

Fig. 5 presents a graphic comparison of gravity, topography, and geology along two north-south sections perpendicular to structural strike. The vertical lines above the geology indicate gravity stations; control for the northern half of each profile is scanty. The two profiles exhibit negative Bouguer anomalies over the Alaska and Brooks ranges in accord with isostatic theory. The Cook Inlet low and the Nenana high are both evident on profile B — B′.

Geodesy. For the determination of the undulations of the geoid the geodesist would like to know the mean value of the free air anomaly for each 1° by 1° rectangle on the earth's surface. These basic data for Alaska are still incomplete, but all present knowledge is included in Fig. 6. The empty rectangles are mute evidence of the need for additional gravity observations.

Acknowledgements and request

The gravity work reported in this paper was supported in part by the Cambridge Research Center of the U.S. Air Force. However, much of the field work was a "labour of love" and resulted from individual initiative in securing transportation and a willingness to work for expenses only or entirely gratis.

The authors would appreciate receiving additional Alaska gravity data as they become available through commercial exploration ventures, academic research projects, and other work. It is their hope to gather these data as they accumulate, with the objective of finally compiling an accurate gravity map of Alaska. The present paper is only the first step.

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