DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
STATE OF ALASKA DEPARTMENT OF NATURAL RESOURCES,
DIVISION OF GEOLOGICAL AND GEOPHYSICAL SURVEYS

GEOPHYSICAL INVESTIGATIONS
MAP GP-913

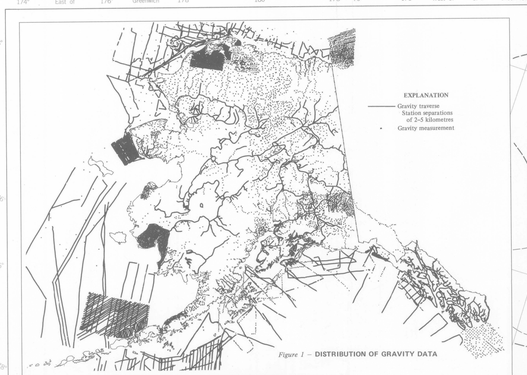

Figure 1 — **DISTRIBUTION OF GRAVITY DATA**

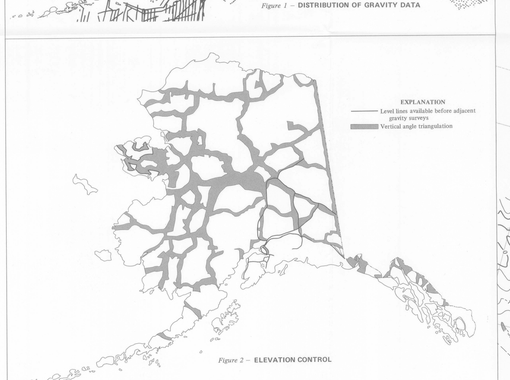

Figure 2 — **ELEVATION CONTROL**

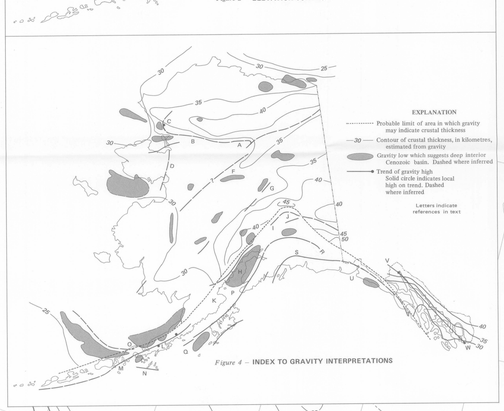

Figure 4 — **INDEX TO GRAVITY INTERPRETATIONS**

BOUGUER GRAVITY MAP OF ALASKA

By

David F. Barnes

1977

INTRODUCTION

The Bouguer gravity map of Alaska has been compiled from about 30,000 Alaska land gravity measurements plus approximately 40,000 km of surface-ship gravimeter traverses over the bordering continental shelves. The compilation thus represents nearly three times as much land data and ten times as much marine data as were available for one previous Alaskan gravity map (Barnes, 1963b) and a fifty-fold increase since the original compilation of Alaskan land gravity data (Woollard and others, 1960). However, data from many parts of the State are still too scattered (fig. 1) for accurate contouring; such deficiencies are most serious in the southwestern part of the State and in the Bering Sea.

The map shows the variation of the simple Bouguer anomaly field and the generalized regional gravity fields over the land areas and the continental-margin areas of Alaska (Woollard and Joesting, 1964). On land the Bouguer anomaly contours reflect the regional variations of gravity better than free-air anomaly contours, which are not very widely separated topographically. However, in oceanic areas the free-air anomaly is less sensitive to bottom topography than is the Bouguer anomaly. Accordingly, the map coverage includes available data from the continental shelves where the bottom relief is small, but it has not been extended to cover the continental slope, the deep ocean, or the islands of the Aleutian arc, where the free-air anomaly would be a better indicator of the regional variation of gravity, and where Bouguer data are only available for a few small areas (Miller and Bath, 1965; Hasegawa and Kibblewhite, 1976a, b).

The basic data for the map are provided by a network of approximately 1,500 gravity stations established mainly by the U.S. Geological Survey between 1958 and 1974. Small-loop traverses along rivers and shorelines provided more than two-thirds of these measurements, so that much of the station distribution resembles a skeletal network of widely spaced traverses along which stations are separated by distances of 2 to 5 km. Additional measurements were made along with Geological Survey's data by other commercial surveys only contour maps were available; these contours have been adjusted to the map datum by comparisons with Geological Survey stations within the surveyed areas. The contours of such maps are generalized to permit portrayal at a scale of 1:2,500,000. Where discrepancies occur between government data and commercial data, average corrections are used but datum adjustment. None of these discrepancies exceed 5 mgal, or half the contour interval of this map.

Marine data come from a variety of sources and of significant differences in both instrumentation and navigation. The largest single source of data is the 40,000 km of gravity traverses made mainly by NOAA (National Oceanic and Atmospheric Administration) (U.S. Environmental Science Services Adm., 1969, and U.S. Natl. Oceanic and Atmos. Adm., 1972a and b, 1973) and Oregon State University (Couch and Gemperle, 1972). For many of these traverses the ships were equipped with gimbal-suspended LaCoste and Romberg surface-ship gravimeters, and Loran A and C, ship color/rail and radar fixes were used for navigation. Some of these data contained errors greater than 10 mgal, many of which were undetected because of inconsistencies between intersecting or nearby traverses. The east-meets-square uncertainty of the remaining data has been estimated to be 5–7 mgal on the Dehlinger and others, 1972; R. W. Couch, written commun., 1975). However, the data from some areas, such as the Gulf of Alaska, are of considerably greater accuracy than this. Other major data contributing to the compilation are in the Gulf of Alaska and Bering Sea are a few submarine pendulum measurements (Worzel, 1965) and more recent NOAA and Canadian data obtained with stabilized-platform gravimeters, and satellite navigation. Both types of data are probably more accurate than the data obtained with gimbal-suspended meters, but the number of these data used in the compilation is very limited.

In the Arctic Ocean, a stabilized-platform gravimeter operated by the U.S. Geological Survey on Coast Guard icebreakers equipped with satellite navigation provided most of the data (Cady and others, 1972; Hanna and others, 1973; Kuppel and McHendrie, 1976); however, two problems caused by Arctic operating conditions tended to reduce the accuracy that the modern instrumentation-aboard Hanna was achieved. First, floating ice caused many small course changes in the northern part of the map area and thus introduced errors into the Eötvös correction. Second, a lack of control over the surveyed ice-island tracks made the detection of the presence of cross tares, at least one of which caused a discrepancy of 8 to 10 mgal. Thus the east-meets-square uncertainty of these data is a correction for apparent tares is also approximately 5 mgal, or half a contour interval. A final source of gravity data for the Arctic Ocean is the airplane landings made on ice by the University of Wisconsin, which obtained measurements accurate to better than 1 mgal (Weal and others, 1959). However, possible location errors for these stations may be as large as 15 km and thus cause errors of more than 5 mgal.

This map and the compilation of the gravity surveys resulted primarily from the support of the State of Alaska Department of Natural Resources through its Division of Geological and Geophysical Surveys. The surveys in the southeastern Alaska were supported by the National Science Foundation; those in the southwestern Alaska were supported by the U.S. Army Topographic Command. Some of the data were provided by the Department of Defense Gravity Library, both of which are now part of the Defense Mapping Agency. The Office of Naval Research provided logistic support for most of the surveys in Arctic Alaska through the Arctic Research Laboratory at Point Barrow. The U.S. Atomic Energy Commission supported surveys in southwestern Alaska, and many other groups and agencies provided various types of support to individual field parties.

The Geological Survey's Alaskan gravity data were collected by many small field parties supervised either by myself or at various times by the following individuals who are listed in alphabetical order: R. V. Ankeny, H. F. Bennett, J. E. Case, K. D. Hedden, R. C. Jachens, W. T. Kinoshita, R. L. Kirschner, R. W. Kleinkopf, R. L. Miller, J. D. Mollenhauer, R. L. Morris, W. L. Rankin, and S. L. Robbins. Additional data contributing to the map were collected by field parties of the State of Alaska Division of Geological and Geophysical Surveys, also under the supervision of various individuals listed above.

The agencies contributing marine data were all mentioned in the previous section, and need not to be repeated. Much of the marine data was generalized from maps published by the National Oceanic and Atmospheric Administration (NOAA) (1969, 1972, 1973). Data for extending some contours across the international boundary came from Canadian maps (Haines and others, 1972) and Soviet maps (Bulin and others, 1973). Unpublished data were also generously provided by H. B. Stewart and B. J. Grant of NOAA and R. W. Couch of Oregon State University. M. W. Mendenhall, A. G. McHendrie, and R. W. Kuppel provided compilations of much marine data.

Finally, the compilation of this map spread years ago and has involved much assistance from M. J. Erwin, J. B. Fonseca, M. V. MacKenzie, R. L. Morris, and R. C. Olsen.

Elevation Control. The accuracy of Bouguer gravity anomalies in Alaska is primarily limited by that of the elevations used for calculating the anomalies. Level lines available before the collection of the gravity data (fig. 2) cross only the small part of the state covered by the highway network. Tidal level along the extensive coast line provides good control for the part of the map that is within a few miles of the shore or of navigable rivers. Another fairly good source of elevation control are the vertical angles measured along the first- and second-order triangulation nets that cross the interior (fig. 2).

Between these vertical control networks, the accuracy of available elevations control is variable and difficult to evaluate. Almost the whole state is now covered by modern 1:250,000-scale maps with either 100- or 200-foot contour intervals, and 1:63,360-scale maps are available for about two-thirds of the State. However, these maps do not conform to national map accuracy standards, and they probably are influenced both by errors in fourth-order control and by photogrammetric bridging between control points. Consequently, they probably have errors in some areas of vertical control errors of the order of 15 m (50 ft). Furthermore, many of the roads maps had not yet become available during much of the gravity survey. For these reasons the government surveys have involved a large amount of altimetry, most of which was controlled from loops whose elevation could be established from either the leveling or the first-order triangulation network. Because the possibilities of errors in both mapping or altimetry increase with distance from primary control, the accuracy of Bouguer anomalies drowns with distance from the elevation control networks shown in figure 2.

Many types of elevation control have been used in reducing the data, and a statistical analysis of the various accuracy was not attempted. It is made from the available data. On most coastal traverses the maximum errors are less than 3 m. Most of the data in areas of good control are estimated for stations along the level lines. A large proportion of the Geological Survey data comes from traverses along the major rivers, many of which are close to the first-order triangulation network. Along these rivers the error in gradient determined from the modern topographic maps was used for elevation control, and the elevation have a probable accuracy of 3 m (1 mgal). On a few rivers the choice of a river gradient was influenced by altimetry, and altimetry plus a few spot elevations have been used for determining the elevations of most of the reconnaissance stations obtained with aircraft support and not located at vertical-angle bench marks. A preliminary analysis of the altimetry indicates that 90 percent of measurements have less than 15 m uncertainty (50 ft or 2 mgal), but extensive weather conditions that affected 1 or 2 percent of fieldwork can cause errors as large as 55 m or some anomalies.

For the marine data, the Eötvös corrections in progressing some of the gravity measurements in the Gulf of Alaska, in the Bering Sea could be made by computer. However, in the Bering Sea and Arctic Ocean separate records were kept of bathymetry. Here the Bouguer corrections were contoured on the best available bathymetric maps and then applied to free-air plots or contour maps. By limiting the extent of the contouring to approximately the limits of the continental shelves, the magnitudes of the Bouguer corrections were kept below 20 mgal except for some generalized contours of high positive magnitude. The errors caused by Bouguer corrections to the marine data are thus believed to be small in comparison with the errors and navigation errors.

Data reduction and conversion to absolute gravity system. — Bouguer anomalies were calculated with the 1967 Geodetic Reference System and lower densities had been used for the land areas. Because the land data were based on many more data for small parts of the map, that base data had low elevation and topographical relief, so the change in density factor does not significantly influence the contouring. Most anomalies were not corrected for effects of local terrain, but some anomalies that were obviously influenced by local terrain were either used with estimated corrections or ignored in the contouring.

Datum control for the gravity values was provided by the Alaskan gravity base station network of the Geological Survey (Barnes, 1968 and 1972a), which has now been adjusted to the new absolute datum of the International Gravity Standardization Net 1971 (Morelli and others, 1974). This worldwide network includes one first-order station at Fairbanks and stations at four other Alaskan towns. The new datum is lower than the previous Alaskan gravity datum by 14.61 mgal (±0.10 mgal depending on the part of the world considered).

Calculation of this Bouguer anomalies included a latitude correction obtained from a new ellipsoid defined by the Geodetic Reference System of 1967 (Bomford, 1971; Moritz, 1973). Alaskan gravity maps prepared before 1975 had all been based on the 1930 ellipsoid. However, the new system was used for the most recent map of Canada (Canada Earth Physics Branch, 1974), and will be used for most future Geological Survey Alaskan gravity maps. When the change in latitude correction is combined with the change in gravity datum, the anomalies are changed by 6 to 10 mgal depending on latitude and longitude; the relation shown in figure 3, which shows the correction that should be applied to older maps.

For the Gulf of Alaska, the Bering Sea, and the Arctic Ocean, gravity and oldmetry reductions were performed on a hand calculator. However, a digital program has been used for the past 10 years, and the standard methods of reduction were described by Barnes (1972b).

MAP COMPILATION AND INTERPRETIVE FEATURES

The map was prepared by hand contouring at a scale of 1:250,000 on a series of 45 overlapping plots of the available gravity stations and their anomalies. These maps were later reduced to a scale 1:2,500,000, which was used for adjusting the contouring to the base map (by now, 1973, edition of U.S. Geol. Survey Alaska Map E) and for some necessary smoothing and generalization required at the smaller scale. The 1:250,000 scale for the initial contouring was chosen because it is the largest scale for geologic, geophysical, and resource maps on supplementary data and at a scale that can be shown on single-sheet areas of widely scattered gravity stations. However, both the quantity of available data and the use of supplementary information from other types of mapping naturally make the map in part a product of judgment and interpretation.

Some of the principles that controlled these interpretations should be briefly mentioned to prevent misuse of the map. Perhaps the most obvious principle was that contours should be as simple as possible and avoid unnecessary closures. Thus two areas of high or low gravity were connected even if there was a wide area of no data between the two areas; provided that the contours did not cross well-defined belts of different geologic units. A second principle was the acceptance of tectonic and the geologic trends as indicated by mountain ranges, belts of folds, belts of low or lower density rocks) over a distance of many miles. However, this principle was not followed where gravity contours did not the values of contours; where lower gravities were assumed in mountainous areas, the contours representing this lower gravity were drawn parallel to generalized mountain ranges, even though data could not be obtained in the highest part of a range and lower gravity may be measured in the future. A third principle was that if high or low gravities were associated with a particular geologic unit, the contours should parallel the outcrop of that rock unit within these was contradictory data. Some unrecognizable pattern were used in a similar way as a guide to the distribution of certain geologic units. In spite of all of these such guides, measurements, however, a few gravity contours are based on the assumptions that they were probably erroneous.

Figure 4 shows some of the interpretive features of the map and provides a key to this discussion. First, for much of the state, the contours of crustal thickness estimated from gravity may indicate some of the effects of topography. The crustal thickness contours were obtained from the gravity contours with the aid of the empirical relation derived by Woollard and Rose (1963), which has been corrected for the effects of the new datum and ellipsoid. Both these authors and I (Barnes, 1965a, 1971) have shown that these empirical correlations are not accurate in areas where active tectonic processes predominate over processes of isostatic adjustment. Such processes include the formation of mountains by folding and faulting at plate convergence such as the coastal region of the Gulf of Alaska. The free-air gravity (fig. 4) represents a rather arbitrary northern boundary of the gravitational effects of this tectonic activity and the northern limit of the possible usefulness of an empirical relation between gravity and crustal thickness. This boundary is undoubtedly gradational and cannot be estimated until the completion of many new Alaskan seismic studies. Even north of this boundary the contours could be changed by use of other empirical relations such as the one described by Dzeniszkiewicz (1959). However, the consistency and general simplicity of the new gravity low gravity measurements suggest crustal thickening.

The map also includes other gravity lows, which are not in mountainous areas and which are interpreted as small relatively deep Cenozoic basins (fig. 4). Some of these basins are associated with volcanic rocks, but a few other lows are better interpreted as low-density sedimentary basins. The gravity lows are near large faults and are within larger topographic basins. The structural basins along the continental margin and those that are filled primarily by pre-Cenozoic and some early or this Cenozoic rocks are better adjusted isostatically and are less well defined by gravity lows. Examples of such basins usually require more detailed gravity data and the analysis of anomaly patterns and gradients. Thus I have not attempted to draw the boundaries of these coastal or older sedimentary basins on figure 4, although some anomalies associated with such basins are shown.

Much of the map compilation involved the recognition of several linear or arcuate gravity highs, indicated either by adequate gravity data or a few gravity measurements suggesting characteristic association of high gravity anomalies with either elongate rock outcrops or elongate aeromagnetic anomaly patterns. These highs are conspicuous features on this Alaskan gravity map, but users should be aware of the limited evidence defining some of the highs. Therefore each of the features is briefly discussed in sequence from northwest to southeast.

A pronounced gravity high along much of the south flank of the Brooks Range (A) parallels a belt of late Paleozoic mafic volcanic rocks that crops out on the north edge of the high and that has been interpreted as the cause of this high. A large number of measurements along this belt are higher than those in adjacent areas, but the continuity of the belt along the entire south edge of the range is not established by the available data. At the west end of the range the strikes of most geologic units curve southward, but evidence for parallel flexure of the gravity anomaly is not clear. Part of the gravity high does bend southward (B) towards the east end of the Seward Peninsula. However, high gravity values were also measured westward of this bend and thus suggest a possible bifurcation of the anomaly. Such a westward extension through an area of poor gravity coverage may connect the Brooks Range high with a very high anomaly near the Noatak River (C) (Barnes, 1970; Barnes and Tailleur, 1970). Another high gravity anomaly bends abruptly northeastward (D). The probable southwestward branch of the Brooks Range high is also interpreted as bifurcated near the northeast corner of the Seward Peninsula, where gravity stations are very widely separated. On the southern flank of the high (E) there are only four gravity measurements, but they are near outcrops of igneous rocks that have been mapped in a continuous belt across the east end of the Seward Peninsula. The continuity of this gravity high is thus based primarily on geologic evidence.

South of the central Brooks Range, the gravity high reaches its maximum amplitude (A) near Bettles and then makes a sharp curve to the south and southwest. Throughout this bend it parallels both the outcrop of the mafic volcanic rocks and also the associated aeromagnetic anomalies (U.S. Geol. Survey, 1973), which were a valuable aid in the compilation. However, other high gravity anomalies were measured eastward along the entire south flank of the Brooks Range up to the Canadian border, so the bend again represents a branching of the anomaly. A short distance southwest of the bend the gravity high is abruptly offset to the southeast (G) along a fault. Southwest of this offset the gravity high is broad, but the high extends further southwest (F) into areas where the gravity stations are widely separated. Here, but where a few high gravity values were measured along the same trend. Geologic mapping (Patton and Hoare, 1968) suggests that the volcanic rocks are offset by the Kaltag fault near the Yukon River, but that south of this Yukon on the same trend there are other mafic rocks that could cause another gravity high. The gravity stations are too widely spaced to indicate any possible offset or change in cause of the anomaly.

The gravity low interpreted as Cenozoic fill in the Tanana Valley near Minto is flanked by a small gravity high along its northwest side near Nenana (G) (Barnes, 1961). No mafic rocks have been found in this area, but a belt of mafic rocks crops out on the south side of the valley and has been recognized for 15 years. Newer data suggest that the high may not be continuous with the Brooks Range high. However, the high gravity that is only locally bordered on the northwest by the small lows that suggest Cenozoic structural basins. Gravity stations are so widely spaced along this belt that both the continuity and the cause of the high remain uncertain.

An almost parallel and better developed gravity high is located near the southwest shore of Cook Inlet (H), where it seems to be associated (S. W. Hackett, 1975, and written commun., 1975) with the outcrops of the Jurassic gravity base station network of the Geological Survey (Barnes, 1968 and 1972a), which has now been adjusted to the new absolute datum of the International Gravity Standardization Net 1971 (Morelli and others, 1974). This worldwide network includes one first-order station at Fairbanks and stations at four other Alaskan towns. The new datum is lower than the previous Alaskan gravity datum by 14.61 mgal (±0.10 mgal depending on the part of the world considered).

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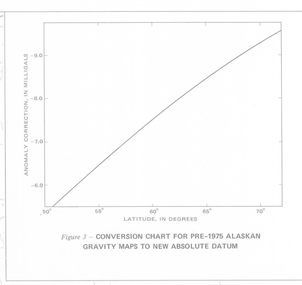

Figure 3 — **CONVERSION CHART FOR PRE-1975 ALASKAN GRAVITY MAPS TO NEW ABSOLUTE DATUM**

Base from U.S. Geological Survey
Alaska Map E, 1973

Interior—Geological Survey, Reston, Va.—1977—G76207

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