Incomplete isostatic gravity map of Alaska

by

David F. Barnes, John Mariano, Robert L. Morin,
Carter W. Roberts, and Robert C. Jachens

MAP PREPARATION

INTRODUCTION

This map is largely derived from an earlier Bouguer gravity map of Alaska (Barnes, 1977) but includes some new data and uses computer enhancements designed to emphasize anomalies caused by geologic units and to deemphasize the anomalies associated with crustal thickness and topographic relief. These computer enhancements are made possible by digital files of terrain and bathymetry that have become available since the preparation of the earlier map. Two types of data improvement are permitted by the use of computer enhancement. The more significant of these corrections is an isostatic reduction by the methods of Jachens and Roberts (1981) and Simpson and others (1986a, b); this method was applied to all data on the map to emphasize the anomalies caused by density variations of rock units in the upper crust. The second correction is a terrain correction that has thus far been applied to the northern and southeastern parts of the state (fig. 1). The 1977 map did not include terrain corrections and thus was considered a map of "simple Bouguer" anomalies in contrast to "complete Bouguer anomaly" maps, which include terrain and are the usual products of detailed surveys designed for mineral and petroleum prospecting. Much of the 1977 map was compiled from hand-reduced data files, and the process of converting those files to digital data files and then calculating the terrain and isostatic corrections is not finished in many parts of Alaska. The present map could be described as "partly a complete isostatic anomaly map and partly a simple isostatic anomaly map". However, the phrase "incomplete isostatic anomaly map" is simpler and is fully consistent with the map content and data processing. The map is an interim product prepared especially for this volume.

GRAVITY DATA

The distribution of data used in the map preparation and the boundaries (on land) between the terrain-corrected data sets in the north and southeast and the non-terrain-corrected data sets in the central part of the state and in all offshore areas are shown in figure 1. The data distributions for the non-terrain-corrected parts of the map are the same as those used for the 1977 map. In the central and offshore areas some new data were obtained in the past ten years, but the new data are not incorporated in this map. Publication lists of the U.S. Geological Survey, Alaska Division of Geological and Geophysical Surveys, and the Geophysical Institute at the University of Alaska, Fairbanks, can provide references to these newer data. In particular, the U.S. Geological Survey has released several maps of free-air anomalies offshore since 1977 (for example, Burkhard and others, 1980a, b; Bruns and others, 1981a, b; Fisher and others, 1982, 1983; Childs and others, 1985; May, 1985), but the data files for these maps do not include bathymetry and are difficult to convert to Bouguer and isostatic anomalies.

The northern and southeastern parts of Alaska contain the largest number of new measurements made by the U.S. Geological Survey since the completion of the 1977 map and were the areas where greatest effort was expended to assemble the digital data sets. The largest single new data set contains 53,393 measurements made along the seismic profiles that were used to evaluate the National Petroleum Reserve in Alaska (NPRA) (Gutman, 1980). Collection of these data also led to the development of U.S. Geological Survey digital terrain corrections for Alaska (Barnes, 1984b). These new data replace older data collected in part of the same area during the exploration of Naval Petroleum Reserve No. 4 (Woolson, 1962). The older data contain elevation problems and are not in a digital format. Southwest of the National Petroleum Reserve, the U.S. Geological Survey has also collected much new data in the Delong Mountains, Mishaguk Mountain, Howard Pass, Noatak, Baird Mountains, and Selawik 1:250,000- scale quadrangles (fig 2). Other data were collected by the State of Alaska Division of Geological and Geophysical Surveys as part of the cooperative Alaska Mineral Resource Appraisal Program (AMRAP) mineral assessments in Baird Mountains, Ambler River, Survey Pass, and Wiseman quadrangles (G.H. Pessel, written commun., 1974, 1975; S.W. Hackett, written commun., 1980, 1981, 1985; J.T. Dillon, written commun., 1981), and these data were later processed and terrain corrected by the U.S. Geological Survey. In the Wiseman quadrangle, additional processing assistance, interpretation, and modeling were provided by Smith and others (1987). Their paper also includes a preliminary interpretation of part of a gravity traverse made by the National Oceanic and Atmospheric Administration (NOAA) along the Alaska Pipeline first order level line (W.E. Strange, written commun., 1980). In the eastern Brooks Range, the U.S. Geological Survey also collected new data in the Philip Smith Mountain quadrangle (D.F. Barnes, unpub. data), Bettles, Tanana, Hughes, Melozitna, and adjacent quadrangles (J.C. Cady, written commun., 1985) and northern part of the Arctic National Wildlife Range (Robbins, 1987). A final source of Arctic data collected since the preparation of the 1977 map is a data set collected on the Seward Peninsula by the University of Alaska (Lockhart, 1984).

In southeastern Alaska, the data obtained since the preparation of the 1977 map were collected by the U.S. Geological Survey as part of either Wilderness Studies or AMRAP mineral assessments. The principal Wilderness Studies were those in Glacier Bay National Monument (Barnes and others, 1978) and the Chugach National Forest (Barnes and Morin, 1990). Mineral assessment data were also collected in Petersburg and parts of adjacent quadrangles (Barnes and others, 1989) and in the Ketchikan and Juneau quadrangles (Barnes, unpub. data 1977, 1984).

Much of the 1977 map was prepared from hand-calculated data that were hand-contoured using available geologic, aeromagnetic, and topographic data for supplementary guides. These hand-calculated and hand-contoured data were used to prepare the central part of this map. The data for the northern and southeastern parts of the map were entirely calculated and contoured by digital methods. The basic reduction system used to calculate the simple Bouguer anomalies was described by Barnes (1972b). All the data were converted by computer algorithm to the 1967 Reference Ellipsoid and the IGSN -71 datum (International Association of Geodesy, 1971; Morelli and others, 1974; Woollard, 1979). Most of the base station control for the map was reported by Barnes (1968) and Barnes (1972a) in reports that used the Woollard and Rose (1963) datum. Terrain corrections for these data were calculated by the program of Plouff (1977), which was modified slightly to use the Alaskan digital terrain files (Barnes, 1984b).

ELEVATION DATA AND DIGITAL TERRAIN FILES

The reduction of gravity data requires good elevation control, and both terrain and isostatic corrections require knowledge of the topography near the measurement points. Most of Alaska is a wilderness area in which good elevation control is as scarce that topographic mapping is severely handicapped. Only the most recent 1:24,000-scale maps near the few larger cities conform to national map accuracy standards. Photogrammetric mapping of much of the Alaska Pipeline right-of-way did not begin until 1947, but now covers a large part of the state at scales of 1:63,360 and 1:250,000. Most of the latter small-scale maps were prepared from the larger scale maps and thus may be among the best in the United States (Brooks and O'Brien, 1966). Most of the available digital elevation model (DEM) terrain data files were prepared from the 1:250,000 maps.

However, it is important to realize that the vertical survey control for this mapping and for the gravity surveys is very limited. The previous state gravity map (Barnes, 1977) contained an index showing that first order level lines were available only along the highways, and that first and second order horizontal triangulation control was limited to a few widely spaced nets across the State's interior. The only overall first order control obtained since the preparation of that map is a level line along the Dalton Highway (Alaska Pipeline) from Fairbanks to the north coast (fig. 2). However, newer mapping in the Brooks Range also benefited from various types of satellite control. Between these level lines and networks of first order triangulation, the accuracy of topographic contouring and elevation control decreases with increasing distance from the control.

The primary gravity control is a skeletal network of traverses along the highways and major rivers. On most of the highways, surveyed elevations were available. River gradients were used along the major rivers, many of which also served as transportation routes for the triangulation parties. Sea level, corrected for tidal variations, was also used for elevation control along much of the southern coastline and especially in the inland passages of southeastern Alaska and Prince William Sound. In the large set of data collected along the National Petroleum Reserve in Alaska seismic lines, elevation control was provided by vertical angle theodolite traverses between control points established by a Litton autosurveyor system. This helicopter-borne inertial guidance system set the control points at intervals of about 7 km (4 mi) and tied the resulting control net to the first order vertical triangulation control used for the topographic mapping. Altimetry was used for elevation control of most of the gravity measurements that were not made along these highway, river, coastline, and seismic traverses, although a few benchmarks and other types of control were also used. A preliminary analysis of the altimetry indicates that 90 percent of the measurements have less than 15 m uncertainty (50 ft or 3 mGal), but unusual weather conditions that affected 1 to 2 percent of the fieldwork can cause errors as large as 50 m or one contour interval (Barnes, 1977).

Station elevations were universally used for the infinite-slab part of the Bouguer correction, but the terrain corrections should show the effect of topographic slopes near the gravity station, and the station elevation differs significantly from the elevation shown by topographic mapping at that location the terrain correction will be enlarged or distorted. In Alaska the altimetry elevation often differs significantly from that indicated by the topographic mapping so the U.S. Geological Survey Alaska gravity file has routinely included two types of elevations, the altimetry elevation and the map elevation. When files of digital topography became available they were based on the available 1:250,000-scale maps, which had usually been prepared by reducing and simplifying previously compiled 1:63,360-scale mapping. Thus the map elevation produces a better terrain correction and was used to calculate the terrain part of the Bouguer correction.

Compilation of the map involved the use of a large variety of digital terrain data as shown in figure 2. The primary sources of terrain data were the digital elevation model (DEM) tapes (Elassal and Caruso, 1983), which provide a 3" by 6" grid of metric elevations. Data from these tapes were compiled into computer files of 1/4 by 1/2', 1 by 2', and 3" by 6" mean elevations arranged in map unit blocks (Barnes, 1984b) suitable for use by a modified version of the gravity terrain correction program of Plouff (1977). The DEM data do not include any lake or ocean bathymetric information; elevations in such areas are either the lake surface elevation or 0 m in ocean covered areas. Although some 1/4' mean bathymetry data are available for Alaska, the file is so incomplete that no attempt has been made to incorporate bathymetric data in the 1/4 by 1/2' or 1' by 2' data files. Thus, inner zone terrain corrections did not include bathymetric or hydrologic data.

The 3' by 6' terrain files were used both for outer zone terrain corrections and for isostatic corrections and had to be augmented both to cover areas not included in the DEM files and to provide ocean bathymetric data. Initially, the additional data were collected by, visually estimating mean depths, elevations, and proportions of sea level coverage from charts of the Arctic Ocean and from Canadian topographic maps. The estimates of sea level proportion were used to combine the DEM land data with the offshore bathymetric data. This "hand" compilation of bathymetric and land terrain data was already completed for the shoreline part of the Arctic Ocean and for the Canadian quadrangles adjacent to the 141° meridian International Boundary where a new world topographic and bathymetric data set became available (National Geophysical Data Center, 1986). This set of 5' by 5' mean elevations and water depths was regridded by R.C. Jachens to obtain a large area of 3' by 6' data to extend and merge with the Alaskan terrain files. However, examination of the data set suggests that the regridding process caused some errors and also that much of the data had been derived from older maps and charts. Preference was thus given to the data from the digital elevation model (DEM) data set, but where this data set indicated a sea level elevation, a bathymetric depth from the regridded world data set was substituted. Furthermore, the world data set was used for all oceans, and land data were used only in lakes.

These files of digital terrain are a valuable aid to the reduction of Alaskan gravity data. However, their routine usage has revealed some problems that were not obvious until the data were carefully examined and perhaps contoured on an individual quadrangle basis and compared with the best available maps. Errors already encountered include (1) use of old or outdated maps as source materials, (2) multiple conversion from feet to meters, (3) erroneous projection routines, (4) elevations and water depths missing over large areas, (5) tape errors causing extremely high or low elevations. Routine data processing included checks of maximum and minimum elevations, checks for out-of-range elevations, and checks of colored contour maps of regional topography. Judging from the number of errors already detected, the presence of other undetected errors seems certain; they will probably not be revealed until all of the regional data are carefully examined on a local (quadrangle or smaller) basis.

©1994 The Geological Society of America, Inc.

ISOSTATIC REDUCTION AND MAP COMPILATION

The data for the northern and southeastern parts of Alaska were reduced by standard Alaskan gravity procedures (Barnes, 1972b). Terrain corrections were calculated by the program of Plouff (1977) using the 1/4' by 1/2', 1' by 2', and 3' by 6' terrain files derived from the DEM tapes, and the isostatic correction was applied according to the procedure of Jachens and Roberts (1981) using only the 3' by 6' terrain files. These data were initially compiled as individual 1:250,000-scale quadrangles, a scale that was used for detecting and eliminating location and other types of errors. The combined quadrangles were also computer gridded and contoured at scales of 1:500,000 and 1:1,000,000 for interim regional maps. Both data sets were then regridded using an 8-km grid interval.

The data in the central part of Alaska and in offshore Alaska were derived directly from the earlier state map (Barnes, 1977); the contours of that map were digitized by R.H. Godson (digital commun., 1985). These digitized contours were then converted to a geographically gridded data set that was not terrain corrected, but which was isostatically corrected by the method of Simpson and others (1986a), using the 3' by 6' terrain file. This file was also reduced to an 8-km grid.

The isostatic anomaly calculation programs of Jachens and Roberts (1981) and Simpson and others (1986a, b) assume an Airy-Heiskanen system of isostatic compensation (Heiskanen and Vening Meinesz, 1958). Simpson and others (1986a, b) discuss this system and show that the resulting isostatic anomalies do not differ significantly when the parameters of the isostatic model are varied within the range of crustal models suggested by available seismic data for the conterminous United States. For the Alaskan isostatic calculations the assumed parameters were a crustal density of 2.67 g/cm³ (the same as used in the Bouguer reduction), a density contrast at the base of the isostatic root of 0.4 g/cm³, and a root thickness at sea level of 30 km. The choice of these parameters was arbitrary and was not influenced by the limited amount of seismic crustal information now available for Alaska. A better choice of parameters may be possible when more results become available from the Trans-Alaska Crustal Transect (TACT) seismic refraction profiles (Page and others, 1986).

The three 8-km grids (northern, southeastern, and central with offshore) were then merged into a single geographic grid. However, all data in two 24-km wide boundary or buffer zones between the three data sets were omitted (fig. 1). This buffer zone helped to smooth the contours in the transition between the terrain corrected and non-terrain-corrected data. Although some available data were lost in this transition zone, the contouring of only one significant anomaly was detrackly altered. This anomaly is a gravity low caused by Tertiary and (or) Quaternary sedimentary deposits in the Ruby-Rampart structural trough along the Yukon River west of its junction with the Tanana River. The map shows this anomaly as three small separate lows, but the omitted data would connect these lows and transform them into a more linear feature of greater amplitude (see Barnes, 1977).

This combined 8-km grid was then projected and computer contoured to produce the contour lines shown on the map. Color-separation plates to define the anomaly level were computer generated by the SCITEX mapping system. Throughout a large part of Alaska, the isostatic anomaly varies between −50 and +30 mGal; a range for which pale colors were chosen so that the geographic base could be easily distinguished. The important high and low anomalies are shown by the darker, brighter colors.

INTERPRETATION

Simpson and others (1986a, b) assumed that some form of isostatic adjustment prevails throughout most of the conterminous United States and that the principal isostatic anomalies result primarily from density variations of rock units in the upper part of the crust. The distribution of pale colors in the map suggest that the same adjustment also prevails in Alaska. However, dark and bright colors in the southern part of the state suggest that this is a region in which there may be significant departure from isostatic adjustment. Barnes (1966, 1969) suggested that tectonic processes such as the 1964 earthquake increased the amplitudes of these anomalies. Barnes (1969, 1970) also speculated that the gravity high off the north coast of Alaska might be the result of rapid sedimentation exceeding the rate of isostatic adjustment along the ice-covered continental margin in the Arctic Ocean.

Most of the other anomalies can be interpreted as variations in crustal density. These anomalies were generally present on the earlier Bouguer map (Barnes, 1977), although the new isostatic correction has modified the shapes and amplitudes of the anomalies. A brief discussion and interpretive index figure on that earlier map provide a preliminary review of the primary features of the Alaskan gravity field. That interpretive index figure showed long lines indicating the axes of gravity highs that are important features of the Alaskan map. The linearity of these features may be less obvious on the present map due to computer contouring. The computer contouring algorithm involves a minimum curvature routine that in areas of limited and scattered data tends to draw circles, whereas the earlier map was subjectively hand contoured to emphasize probable linear trends. Thus the linear features on the 1977 map tend to become bead-like chains of circles on the newer map. A few gravity lows also result from the lack of terrain correction, where the isostatic correction was applied to simple Bouguer anomalies. Thus, gravity lows in the Alaska Range and other mountainous areas may in part reflect this lack of terrain correction.

Two principal types of Alaskan gravity anomalies were identified by Barnes (1977, fig. 3): (1) small lows caused by Cenozoic sedimentary rocks in interior structural basins, and (2) linear belts of gravity highs associated with mafic and ultramafic rocks. In this volume, Kirschner discusses both Mesozoic and Cenozoic interior basins, and Patton and others discuss mafic-ultramafic rocks. Accordingly, the previous interpretation index (fig. 3 of Barnes, 1977) is somewhat revised here (fig. 3) and is better keyed to Kirschner's and Patton and others' discussions; four Mesozoic basins and additional mafic anomalies are also shown. Gravity anomalies associated with the Cenozoic basins are listed in table 1 in the order of Kirschner's discussion (see fig. 3 for locations). Similarly, gravity highs that correspond to mafic-ultramafic complexes discussed by Patton and others are listed in table 1 in the order of their discussion (see fig. 3 for locations). Basins and mafic-ultramafic complexes with anomalies too small to be obvious on the map are omitted from the table and figure. Some anomalies not reported in those chapters are shown on figure 3 (loc. 30-35, 44-48). Kirschner and Patton and others provide adequate geological references for each anomaly, but some additional geophysical references are available for specific anomalies and these are also listed in table 1.

Kirschner's text (Kirschner, this volume) is confined to a discussion of the interior basins, but his map (plate 7; Kirschner, this volume) shows interior, coastal, and offshore basins. All the Cenozoic basins (delineated on plate 7) have at least a small associated gravity anomaly, and at least three other gravity lows mapped here (fig. 3, loc. 30-32) probably represent Cenozoic basins. Many of the basins were originally named for topographic basins which are usually more extensive than their gravity lows. The gravitational expression of Mesozoic basins is much less distinct, probably because of higher density sedimentary rocks and better isostatic adjustment. Although plate 7 shows many Mesozoic basins and flysch deposits in Alaska, only four have sufficiently distinct gravity expression to be shown in figure 3 (loc. 33-36). Some of this Mesozoic basin gravitational expression is emphasized by adjacent or overlying Cenozoic basins and low density intrusions. The gravitational expression of basins close to the continental margin is usually marked by the large gradients associated with this crustal transition, so coastal basins are not shown on figure 3. Ehm (1983) provides much additional information about Alaskan sedimentary basins, and his map is a supplemental reference for all basins for which he shows either structure contours, structure sections, or seismic profiles.

Patton and others (this volume) give a good discussion of Alaska's ophiolites and mafic-ultramafic rock bodies and provide a useful aid for interpreting of the gravity highs shown on the map. However, some of the geologic units discussed by Patton and others are not evident on the gravity map, and their discussion also omits some mafic volcanic units lacking ultramafic components, but which cause significant gravity highs.

Furthermore, the geologic discussion implies some correlations between mafic-ultramafic units that locally conflict with continuity suggested by the gravity data. Accordingly, table 1 does not exactly parallel the order of discussion by Patton and others, and two additional groups of gravity highs that reflect mafic volcanic rocks are added to the table and to figure 3 (loc. 44-49). Some of the discrepancies result from the fact that many gravity anomalies caused by ultramafic rock bodies are so small that they cannot be shown on a map at a scale of 1:2,500,000, especially when it was compiled from a 8-km grid.

In the western part of the Brooks Range, no gravity anomaly was detected at the Iylikovik Mountain peridotite body of Beuk and others (1987), but a chain of high gravity connects the Misheguk and Avik Mountain anomalies, and an additional large anomaly was measured at Deviation Peak. The amplitude of some of these gravity highs is considerably higher than any of the anomalies measured along the Angayucham trend, which geologists (Mayfield and others, 1983; Roeder and Mull, 1978; Patton and others, 1977) consider to be the root zone of these mafic-ultramafic allochthons. Gravity data are still too limited to define the anomalies near the south end of the Angayucham trend and their relation to the few anomalies observed in the Tozitna-Ivisinik mafic bodies. The ultramafic bodies in southwestern Alaska described by Patton and others are very small. Although one of these bodies was indicated by a small contour closure on the Barnes (1977) map, the anomaly was eliminated in the digital process of converting that map to this isostatic anomaly map. On this map only a broader and more regional high associated with the outcrop of Hagemeister Island volcanic rocks is shown (fig. 3, loc. 44). Similarly, any gravity anomalies associated with the mafic-ultramafic complexes in the Livengood, Salcha, Seventymile, and Alaska Range areas (Patton and others, this volume) do not seem to be present on this map. However, all these areas show more regional anomalies associated with the nearby Circle ultramafic and Nikolai mafic volcanic rock (fig. 3, loc. 45, 46).

In southern and southeastern Alaska, the alignment of gravity highs (Barnes, 1977, fig. 3 and map) differs from the geologic correlation of Patton and others, whose Baranof-Chugach-Kodiak mafic-ultramafic belt is distinct from their Prince William Sound mafic-ultramafic rocks, but partly overlaps the Fairweather complex of Himmelberg and Loney (1981). In contrast, the gravity data suggest a nearly continuous belt of gravity highs that extends from south of Kodiak Island in Prince William Sound eastward across the Bering Glacier quadrangle and then southeastward through the St. Elias and Yakutat quadrangles to merge with the Fairweather gravity highs at Mt. Fairweather and Mt. La Perouse. The anomaly also extends onto Baranof Island, although most of the mafic and ultramafic bodies on that island cause small and isolated gravity highs. The gravity data also suggest that a separate and more northerly belt of gravity highs follows the mafic-ultramafic rocks on the northern edge of the Chugach Mountains westward from their Tonsina outcrop along the Border Ranges fault (Nelchina and Eklutna districts), and then southwestward through the Kenai Peninsula, Seldovia, northern Kodiak Island and perhaps to the Shumagin Islands. Although these rocks follow the boundary between the Chugach and Peninsular terranes (Silberling and others, this volume) gravity models and petrologic data by Burns (1982) suggest that they are part of the Peninsular terrane. Patton and others (this volume) discuss a belt of zoned ultra-mafic complexes in southeastern Alaska that causes a distinct chain of gravity highs with the largest anomalies at Duke Island and Haines, the south and north ends of the chain. Calculations by Barnes (1966) suggest that the Haines anomaly represents a mafic plug that penetrates a significant thickness of crust. Another belt of gravity highs extends along the Aleutian Arc; on the map the high is reflected by three separate segments. Mafic rocks are present in all three segments, but the lack of ultramafic components exempts these bodies from discussion by Patton and others. Along the Aleutian Island's part of the arc (fig. 3, loc. 47), the highest gravity is measured near the shelf break and could result from the rise of isostatic uplift exceeding the rate of isostatic adjustment (Barnes, 1969), although it can also be satisfactorily modeled on the basis of available seismic and density data (Grow, 1973). Along the Alaska Peninsula segment, the axis of high gravity follows the volcanic arc and may represent both a structural high and the densities of these mafic volcanic rocks (Case and others, 1981). In the southern part of the Alaska Range the gravity high also follows the axis of active volcanism, but seems to be better explained by the densities of the underlying granitic-to-mafic plutonic rocks.

REFERENCES CITED

Andreasson, G.E., Granitz, Arthur, Zietz, Isidore, and Barnes, D.F., 1964, Geologic interpretation of magnetic and gravity data in the Copper River Basin, Alaska: U.S. Geological Survey Professional Paper 316-H, p. 133-153.

Barnes, D.F., 1961, Gravity low at Metro Flats, Alaska: U.S. Geological Survey Professional Paper 424-D, p. 254-257.

———1966, Gravity changes during the Alaska earthquake: Journal of Geophysical Research, v. 71, no. 2, p. 451-456.

———1968, Alaskan gravity base station network: U.S. Geological Survey Open-File Report 68-41, 21 p.

———1969, Lack of isostatic adjustment on two Alaskan continental margins [abs.]: Geological Society of America Abstracts with Programs for 1969, pt. 7, p. 254-256.

———1970, Gravity and other geophysical data from northern Alaska, in Adkinson, W.L., and Brosge, W.M., eds., Proceedings of the Geological Seminar on the North Slope of Alaska: American Association of Petroleum Geologists Pacific Section, Los Angeles, Calif., p. H-119.

———1972a, Southeast Alaska gravity base station network: U.S. Geological Survey Open-File Report 72-18, 40 p.

———1972b, Notes on the processing and presentation of U.S. Geological Survey Alaskan gravity data: U.S. Geological Survey Open-File Report 72-162, 25 p.

———1977, Bouguer gravity map of Alaska: U.S. Geological Survey Geophysical Investigations Map GP-913, 1 sheet, scale 1:2,500,000.

———1984a, Interpretation of available gravity data, in U.S. Geological Survey and U.S. Bureau of Mines, Mineral resources of the Tracy Arm-Fords Terror Wilderness Study Area and vicinity, Alaska: U.S. Geological Survey Bulletin 1525, p. 63-72.

———1984b, Digital elevation models improve processing of Alaskan gravity data, *in* Coonrad, W.L., and Elliott, R.L., eds., U.S. Geological Survey in Alaska: Accomplishments during 1981: U.S. Geological Survey Circular 868, p. 5-7.

———1986, Gravity data indicate large mass and depth of the gabbro body at Haines, in Bartsch-Winkler, Susan, and Reed, K.M., eds., Geologic studies in Alaska during 1985: U.S. Geological Survey Circular 978, p. 88-92

———1987, Gravity anomaly at a Pleistocene lake bed in NW Alaska interpreted by analogy with Greenland's Lake Tasersuaq and its floating ice tongue: Journal of Geophysical Research, v. 92, no. B9, p. 8976-8984.

Barnes, D.F., and Morin, R.L., 1968, Results of a gravity survey of McCarthy's Marsh, Seward Peninsula, Alaska: U.S. Geological Survey Open-File Report 68-546, 9 p., 2 plates.

Barnes, D.F., and Morin, R.L., 1990, Gravity contour map and interpretation of gravity data for the Chugach National Forest, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1645-F, 1 sheet, scale 1:250,000, 6 p.

Barnes, D.F., and Tailleur, I.L., 1970, Preliminary interpretation of geophysical data from the lower Noatak River basin, Alaska: U.S. Geological Survey Open-File Report 70-181, 15 p.

Barnes, D.F., Brew, D. A., and Morin, R.L., 1989, Bouguer gravity map of the Petersburg quadrangle and parts of the Port Alexander, Sitka, and Sumdum quadrangles, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1970-A, 1 sheet, scale 1:250,000.

Barnes, D.F., Morin, R.L., and Watts, R.D., 1978, Interpretation of gravity and ice thickness data, in Brew, D.A., Johnson, B.R., Grybeck, Donald, Grissom, Andrew, Barnes, D.F., Kimball, A.L., Still, J.C., and Rataj, J.L., Mineral Resources of the Glacier Bay National Monument Wilderness Study Area, Alaska: U.S. Geological Survey Open-File Report 78-494, p. B-51-B-75.

Beak, J.M., Turner, D.L., Henry, D.J., Moore, T.E., Wallace, W.K. 1987, Petrology and K-Ar ages of the Misheguk igneous sequence—an allochthonous mafic and ultramafic complex—and its metamorphic aureole, Western Brooks Range, Alaska, *in* Tailleur, I.L., and Werner, Paul, eds., Alaskan North Slope Geology: Society of Economic Paleontologists and Mineralogists, Pacific Section, Bakersfield, Calif., v. 2, p. 737-745.

Brooks, P.D., and O'Brien, T.J., 1966, The evolving Alaska mapping program: Photogrammetric Engineering and Remote Sensing, v. 32, no. 6, p. 769-777.

Bruns, T.R., Atwood, T.J., and Childs, J.R., 1981a, Free-air gravity anomaly map, Cross Sound to Icy Bay, northern Gulf of Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1306, scale 1:500,000.

Bruns, T.R., Childs, J.R., and Atwood, T.J., 1981b, Free-air gravity anomaly map, Dixon Entrance to Cross Sound, northern Gulf of Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1307, scale 1:500,000.

Burkhard, Nardia, Bruns, T.R., McHendrie, Craig, and Ruppel, B.D., 1980a, Free-air gravity map, eastern Gulf of Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1172, 1 sheet, scale 1:500,000.

Burkhard, Nardia, Von Huene, Roland, Childs, Craig, Ruppel, B.D., and Bruns, T.R., 1980b, Free-air gravity map, western Gulf of Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1173, 1 sheet, scale 1:500,000.

Burns, L.E., 1982, Gravity and aeromagnetic modeling of a large gabbroic body near the Border Ranges fault, southern Alaska: U.S. Geological Survey Open-File Report 82-460, 66 p., 3 sheets.

Cady, J.W., 1969, Geologic implications of topographic, gravity, and aeromagnetic data in the northern Yukon Koyukuk province and its borderlands: Journal of Geophysical Research, v. 94, no. B11, p. 15821-15841.

Cady, J.W., and Wolfe, F.R., 1983, Aeromagnetic map and interpretation of magnetic and gravity data, Circle quadrangle, Alaska: U.S. Geological Survey Open-File Report 83-170-C, scale 1:250,000.

Campbell, D.L., and Barnes, D.F., 1985, Gravity and magnetic model of a part of the 1984 TACT line, Chugach Mountains and southern Copper River Basin, in Bartsch-Winkler, Susan, The United States Geological Survey in Alaska: Accomplishments during 1984: U.S. Geological Survey Circular 967, p. 52-55.

Case, J.E., Sikora, R.F., Tysdal, R.G., Barnes, D.F., and Morin, R.L., 1979, Geologic interpretation of the gravity anomaly map of the Seward and Blying Sound quadrangles, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map, MF-890-C, 1 sheet, scale 1:250,000.

Case, J.E., Barnes, D.F., Detterman, R.L., Morin, R.L., and Sikora, R.F., 1981, Gravity anomaly and interpretation map of the Chignik and Sutwik Island quadrangles, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1053-J, 5 p., 1 plate, scale 1:250,000.

Childs, J.R., Magistrale, H. W., and Cooper, A.K., 1985, Free air gravity anomaly map of the Bering Sea: U.S. Geological Survey Miscellaneous Field Studies Map MF-1728, 1 sheet, scale 1:250,000.

Ehm, Arlen, 1983, Oil and gas basins map of Alaska: Alaska Division of Geological and Geophysical Surveys Report 82, 1 sheet, scale 1:2,500,000.

Elassal, A. A., and Caruso, V.M., 1983, Digital elevation models: U.S. Geological Survey Circular 895-B,40 p.

Fisher, M.A., Childs, J.R., and Magistrale, H.W., 1982, Free-air gravity map, Norton basin, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1460, scale 1:250,000.

Fisher, M.A., Von Huene, Roland, and Steele, W.C., 1983, Marine free-air gravity map of the western Gulf of Alaska, Lower Cook Inlet, and Shelikof Strait, Alaska: U.S. Geological Survey Open-File Report 83-52, 2 sheets, scale 1:500,000.

Grantz , Arthur, Zietz, Isidore, and Andreasen, G.E., 1963, An aeromagnetic reconnaissance of the Cook Inlet area, Alaska: U.S. Geological Survey Professional Paper 316-C, p. 117-134, 5 plates.

Grow, J.A., 1973, Crustal and upper mantle structure of the central Aleutian arc: Geological Society of America Bulletin, v. 84, no. 7, p. 2169-2192.

Gutman, S.I., 1980, Regional gravity survey of the National Petroleum Reserve in Alaska: National Geophysical Data Center Report TGR-0010, 36 p.

Heiskanen, W.A., and Vening Meinesz, F.A., 1958, The Earth and its Gravity Field: New York City, N.Y., McGraw Hill, 470 p.

Himmelberg, G.R., and Loney, R.A., 1981, Petrology of the ultramafic and gabbroic rocks of the Burwash Glacier nickel-copper deposit, Fairweather Range, southeastern Alaska: U.S. Geological Survey Professional Paper 1195, 25 p.

International Association of Geodesy, 1971, Geodetic Reference System, 1967: Paris Bureau Central de l'Association Internationale de Geodesie, Special Publication 3, 116 p.

Jachens, R.C., and Roberts, C.W., 1981, Documentation for a FORTRAN program, 'isocomp', for computing isostatic residual gravity: U.S. Geological Survey Open File Report 81-574, 26p.

Lockhart, A.B., 1984, Gravity survey of the central Seward Peninsula: M.S. thesis, Fairbanks, University of Alaska, 83 p.

May, S.D., 1985, Free air gravity anomaly map of the Chukchi and Alaskan Beaufort Seas, Arctic Ocean: U.S. Geological Survey Miscellaneous Investigations Series Map I-1182-E, 1 sheet, scale 1:1,000,000.

Mayfield, C.F., Tailleur, I.L., and Ellersieck, Inyo, 1988, Stratigraphy, structure, and paltinpastic synthesis of the western Brooks Range, northwestern Alaska: *in* Gryc, George, ed., Geology and exploration of the National Petroleum Reserve in Alaska, 1974 to 1982: U.S. Geological Survey Professional Paper 1399, p. 143-186, pl. 7,1-7.4.

Meyer, J.F., and Kroskop, D.L., 1984, Preliminary gravity data, Holitna basin, south central Alaska: Alaska Division of Geological and Geophysical Surveys Report of Investigations 84-25, 6 p., 2 plates, scale 1:500,000.

———1986, Preliminary gravity data of the Minchumina basin, south central Alaska: Alaska Division of Geological and Geophysical Surveys Report of Investigations 86-1, 14 p., 2 plates, scale 1:500,000.

Morelli, Carlo, Gantar, C., Honkasalo, Tauno, McConnell, R.K., Tanner, J.G., Szabo, Bela, Uotila,U.A., and Whalen, C.T., 1974, The international gravity standardization net 1971 (I.G.S.N. 71): Paris Bureau Central de l'Association Internationale de Geodesie Special Publication 4, 174p.

National Geophysical Data Center, 1986, Digital relief of the surface of the Earth, 5-min x 5-min gridded data: National Geophysical Data Center magnetic tape ETOPO-5, 1 reel.

Page, R.A., Plafker, George, Fuis, G.S., Nokleberg, W.J., Ambos, E.L., Mooney, W.D., Campbell, D.L., 1986, Accretion and subduction tectonics in the Chugach Mountains and Copper River Basin, Alaska: Initial results of the Trans-Alaska Crustal Transect: Geology, v. 14, no. 6, p. 501-506.

Patton, W.W., Jr., Tailleur, I.L., Brosge, W.P., and Lanphere, M.A., 1977, Preliminary report on the ophiolites of northern and western Alaska, *in* Coleman, R.G., and Irwin, W.P., eds., North American ophiolites: Oregon Department of Geology and Mineral Industries Bulletin 95, p. 51-57.

Plouff, Donald, 1977, Preliminary documentation for a FORTRAN program to compute gravity terrain corrections based on topography digitized on a geographic grid: U.S. Geological Survey Open-File Report 77-535, 44 p.

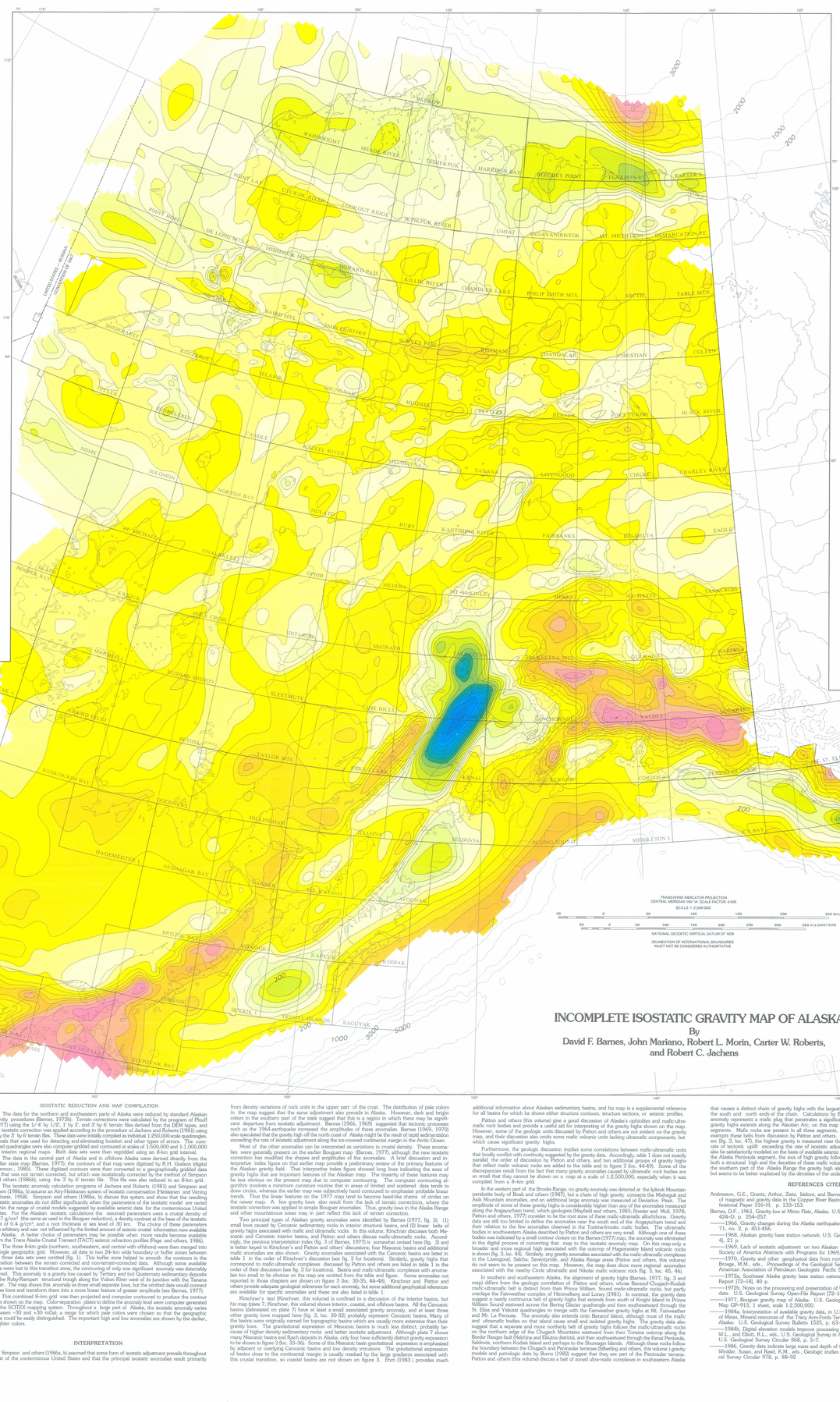
Roeder, Dietrich, and Mull, C.G., 1978, Tectonics of Brooks Range ophiolites (Alaska): American Association of Petroleum Geologists Bulletin, v. 62, no. 9, p. 1696-1713.

Simpson, R.W., Jachens, R.C., Saltus, R.W., and Blakely, R.J., 1986a, Isostatic residual gravity, topographic, and first vertical derivative gravity maps of the conterminous United States: U.S. Geological Survey Geophysical Investigations Map GP-975, 2 sheets, scale 1:7,500,000.

Simpson, R.W., Jachens, R.C., Blakely, R.J., and Saltus, R.W., 1986b, A new isostatic residual gravity map of the conterminous United States with a discussion on the significance of the isostatic residual anomalies: Journal of Geophysical Research, v. 91, no. B8, p. 8348-8372.

Smith, D.T., Stone, D.B., and Dillon, J.T., 1987, Bouguer gravity data and a north-south gravity and magnetic profile from the Wiseman area, Brooks Range, Alaska, *in* Tailleur, I.L., and Weimer, Paul, eds. Alaskan North Slope Geology: Society of Economic Paleontologists and Mineralogists Pacific Section, Bakersfield, Calif., v. 2, p. 725-734.

Woollard, G.P., 1979, The new gravity system — changes in international gravity base values and anomaly values: Geophysics, v. 44, no. 8, p. 1352-1366.

Woollard, G.P., and Rose, J.C., 1963, International Gravity Measurements: Society of Exploration Geophysicists, Tulsa, Okla., 518 p.

Woolson, J.R., 1962, Seismic and gravity surveys of the Naval Petroleum Reserve no. 4 and adjoining areas, Alaska: U.S. Geological Survey Professional Paper 304-A, 25 p., 19 pl.