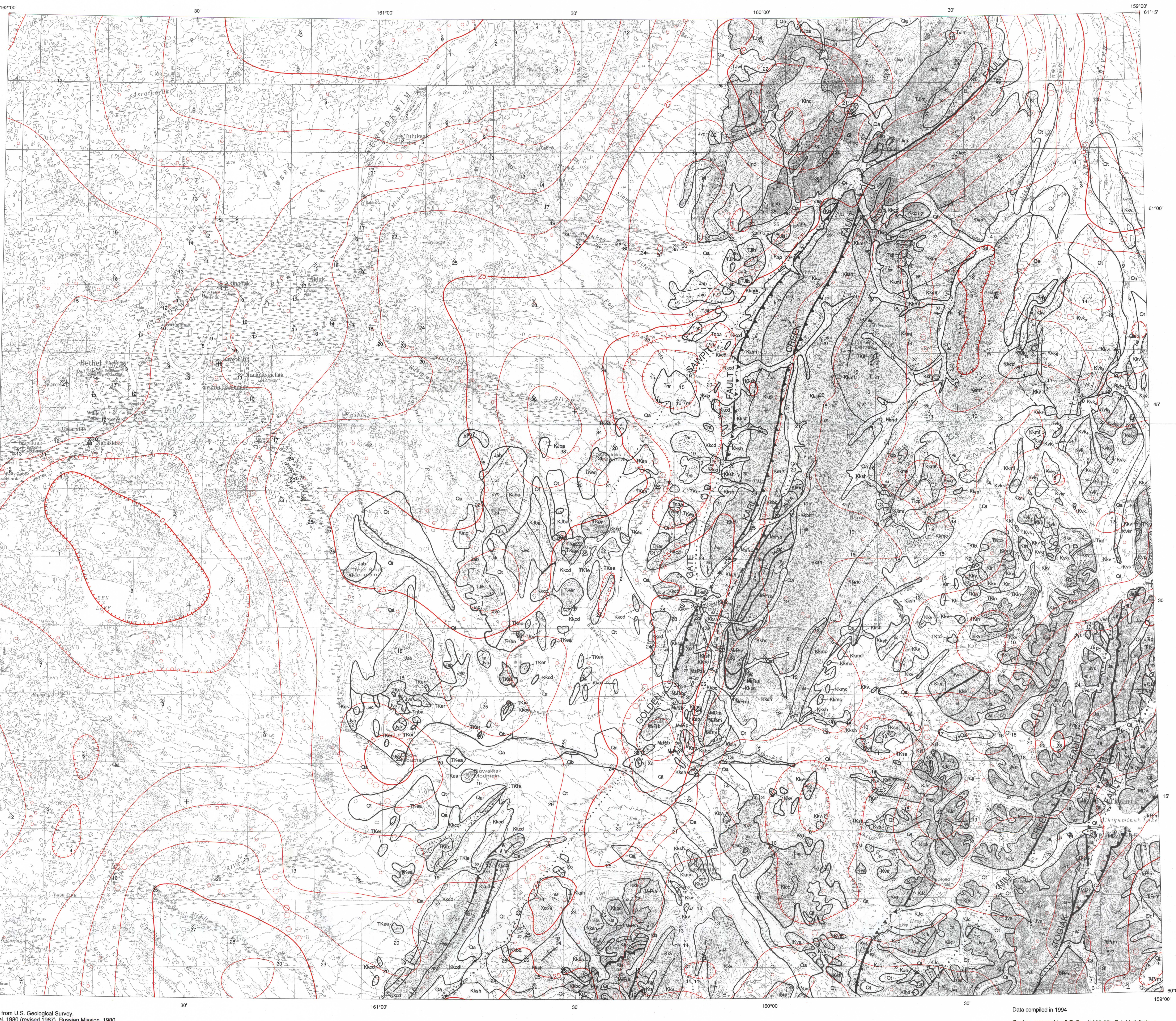


Base from U.S. Geological Survey,
Bethel, 1980 (revised 1987), Russian Mission, 1980
Universal Transverse Mercator projection

SCALE 1:250 000

CONTOUR INTERVAL 200 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Data compiled in 1994

Geology mapped by S.E. Box (1986-89), E.J. Moll-Stalcup (1988-89), T.P. Frost (1987-89), J.M. Murphy (1984, 1986-89), J.P. Calzia (1987-89), Greg Grimsich (1989), T.E. Moore (1987), M.W. Mullen (1987-88), W.W. Patton, Jr. (1987), S.M. Roeske (1987), and M.E. Yount (1987).

Edited by Dale Russell

Manuscript approved for publication May 25, 1995

EXPLANATION

Isostatic gravity anomaly contour—Reduction density 2.67 g/cm³. Terrain corrections from 0.39 km to 166.7 km. Assumed thickness of normal crust 25 km. Assumed density contrast of crust with upper mantle 0.4 g/cm³. Contour interval 5-mGal. Hachures indicate gravity low. Contours were generated based on a 2-km grid derived from scattered gravity data

Gravity station—Showing anomaly value

Maximum horizontal gradients

0.23 to 1.3 mGal/km

1.3 to 3.7 mGal/km

INTRODUCTION

This report presents a complete Bouguer and an isostatic gravity map of the Bethel and southern part of the Russian Mission quadrangles in southwestern Alaska. This report is one part of a folio on the geological, geochemical, geophysical, and mineral resource assessment studies of this area prepared as part of the Alaskan Mineral Resource Assessment Program (AMRAP) of the U.S. Geological Survey (USGS).

These quadrangles are near the mouth of the Kuskokwim River and are bounded by 60° to 61°15' north latitude and by 159° to 162° west longitude. Most all of the data used in producing these maps were collected as part of a regional mineral assessment of the area.

The Bethel and southern part of the Russian Mission quadrangles map area is divisible into three physiographically distinct areas. The west half of the map area consists of a low-relief alluvial plain underlain entirely by unconsolidated Quaternary deposits. The southeastern one-ninth of the map area consists of steep, glaciated mountainous terrain with up to 1,525 m of relief and with nearly 100 percent bedrock exposure, dissected by broad, flat-bottomed glacial valleys. The intervening area consists of hilly to mountainous terrain with low to moderate relief and with a semicontinuous colluvial or frost-shattered bedrock cover, variably dissected by broad glacial, glacial outwash, and alluvial valleys. Bedrock in this central area is exposed as isolated knobs on ridges, on locally glaciated valley or cirque walls, and in present-day stream cutbanks (Box and others, 1993).

GRAVITY DATA

Approximately 419 gravity measurements were made in the study area as part of AMRAP during 1987, 1988, and 1989. These data were added to data from 138 gravity stations that were previously in the area.

The majority of the gravity stations were accessed with the use of a helicopter, but some were accessed with a fixed-wing aircraft on skis, and some with watercraft. Gravity base-station control was established with LaCoste and Romberg gravity meters as were most of the data points. Field gravity bases were established with ties to one or more bases in Aniak, Anchorage, Bethel, Dillingham, and Fairbanks, and the observed gravities of these field bases are probably good to within ±0.1 mGal. About 25 stations were measured with a Worden gravity meter, which drifts much more than LaCoste and Romberg meters, but the data appear to be reliable. Drift control was calculated assuming linear drift between successive base readings. The accuracy of the observed gravities at individual gravity stations are generally good to within ±0.2 mGal for 90 percent of the data.

Elevation control, for the most part, was done with altimetry with backup control of map elevations either from bench marks, spot elevations, lake elevations, river gradients, or contour interpolations. The use of a recording barometer and incorporation of barometric variations in the altimetry processing improved the accuracy of altimeter elevations. Using barometry is a better technique than presuming linear drift between known elevations. Altimeter elevations are probably accurate to within 15 m for 80 percent of the stations, which would correlate to ±3.0 mGal in the anomaly. Locations of gravity stations were plotted on 1:63,360-scale USGS topographic maps in the field.

Data used to make these maps (Morin, 1994) are based on the 1971 datum (IGSN71), (Morelli, 1974, p. 18) with data reduced according to the Geodetic Reference System 1967 (GRS 67), (International Association of Geodesy, 1971, p. 58) with a density of 2.67 g/cm³. Terrain corrections (Plouff, 1977) were computed for the area from 0.39 km to a radial distance of 166.7 km from each gravity station using a digital terrain model. Map elevations at the station locations were used for calculating the terrain corrections. Most digital terrain data for Alaska are taken from manuscript 1:250,000-scale USGS topographic maps made from 1:63,360-scale USGS topographic maps. At the time of the production of these terrain files, in the 1970's, several of the 1:63,360-scale topographic maps in the mountainous areas of the study area were not available. These areas were filled in with the best mapping available at the time, which were the 1:250,000-scale USGS reconnaissance topographic maps published in the 1940's and 1950's and the, then current, aeronautical charts. The 1:63,360-scale USGS topographic maps have since been published, however, major discrepancies with the digital terrain are apparent. To improve the quality of the terrain and, thus, the terrain corrections, much of the study area with poor terrain quality was redigitized by hand using present-day 1:63,360-scale USGS topographic maps (Morin, 1993). This involved estimating the average elevations of over 19,000 1/4-minute by 1/2-minute compartments. Isostatic corrections were made with a modified version of a FORTRAN program (Jachens and Roberts, 1981) that assumes an Airy-Heiskanen model with the following parameters: density of topographic load, 2.67 g/cm³; crustal thickness at sea level, 25 km; density contrast across the base of the model crust, 0.4 g/cm³. Taking into account the accuracy of the terrain corrections, which are estimated to be ±1.0 mGal and the elevation accuracy, anomaly values are probably good to within ±4.0 mGal for 80 percent of the data, which would justify using a 4-mGal or greater contour interval.

GRAVITY MAPS

Complete Bouguer and isostatic gravity maps were produced by gridding the data using surface display with a 2-km spacing and contouring these grids with a 5-mGal contour interval (Briggs, 1974). A 15-minute border of data to the north and south and a 30-minute border to the east and west were used in the gridding to control contours near the edge of the maps. About 800 data points were used to produce the grids. The gravity anomaly values are shown below the station location on the maps.

The isostatic gravity map is a derivative of the complete Bouguer gravity map. Isostatic corrections are added to remove the buoyancy effect of rocks below a certain depth. The Alaska gravity data set uses a depth of 25 km below sea level as the arbitrary bottom of the crust. Generally, the isostatic correction increases with elevation. The western part of the study area is near sea level so the isostatic corrections are very small, thus the western part of both maps look very similar. Much of the eastern part of the study area is well above sea level, thus a positive isostatic correction is added. Because the complete Bouguer anomaly values are negative in this area, the isostatic values become more positive, producing a map with a much flatter gravity field in the mountainous areas.

MAXIMUM HORIZONTAL GRADIENTS

Maximum horizontal gradients shown on maps as hexagons and are called max spots. They are derived from the grids used to produce the gravity contours. Blakely and Simpson's technique (1986) calculates horizontal gradients of the gridded data. Maximum gradients generally trace the boundaries of different density bodies. These maps show two different size hexagons, each represents the gradients in milligals per kilometer (mGal/km) of the gravity field. The smaller hexagons represent gradients less than the average gradient, which usually indicate edges of bodies of similar densities or variations of densities within a body. The larger hexagons represent gradients larger than the average gradients, which show larger density differences in adjoining bodies. Many of these gradients are good indicators of faults with major offsets. The Golden Gate, Karl Creek, and Sawpit Faults or combinations of parts of each can be traced fairly closely to their mapped surface locations with hexagons representing maximum horizontal gradients. Near the center of both maps is a closed gravity low. The max spots on both maps, but with larger hexagons on the isostatic map, generally outline the Nukluk volcanic field indicating that these rocks have a lower density than the surrounding rock units. Northeast of the Nukluk volcanic field near the north edge of the map is a gravity low associated with the Nyac pluton. The max spots encircle the northern part of the pluton, north of the Tuluksak River. This suggests that this part of the pluton is much thicker than the southern part. Generally, the pattern of max spots are very similar on the two maps, but because the complete Bouguer gravity map has steeper gradients in the mountainous areas and the average gradient for both maps is 1.3 mGal/km, the larger hexagons appear in several places on the complete Bouguer map that are shown as small hexagons on the isostatic map.

ACKNOWLEDGMENTS

I thank S. Box, J. Case, and R. Jachens for helping to digitize topography and T. Frost and K. Kelley for sharing the helicopter used for geochemical sampling. Without the use of a helicopter, much of the gravity data used to produce these maps could not have been collected. I also thank M. Mullen and G. Grimsich for their assistance in the boating operations used to access gravity stations.

REFERENCES CITED

Box, S.E., Moll-Stalcup, E.J., Frost, T.P., and Murphy, John M., 1993, Preliminary geologic map of the Bethel and southern Russian Mission quadrangles, southwestern Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-2226-A, scale 1:250,000.

Blakely, R.J., and Simpson, R.W., 1986, Approximating edges of source bodies from magnetic or gravity anomalies: Geophysics, v. 51, no. 7, p. 1494-1498.

Briggs, I.C., 1974, Machine contouring using minimum curvature: Geophysics, v. 39, p. 39-48.

International Association of Geodesy, 1971, Geodetic reference system 1967: International Association of Geodesy Special Publication no. 3, 116 p.

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

Morelli, C., editor, 1974, The international gravity standardization net 1971: International Association of Geodesy Special Publication no. 4, 194 p.

Morin, R.L., 1993, Digital terrain in the Bethel, Russian Mission, and Goodnews Bay 1°X3° quadrangles, Alaska, including improved terrain for parts of these quadrangles: U.S. Geological Survey Open-File Report 93-702-A, documentation, 9 p. and 93-702-B, diskette of data.

———1994, Principal facts for gravity data in the Bethel and Russian Mission 1°X3° quadrangles, Alaska: U.S. Geological Survey Open-File Report 94-14-A, documentation, 6 p. and 94-14-B, diskette of data.

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, 45 p.

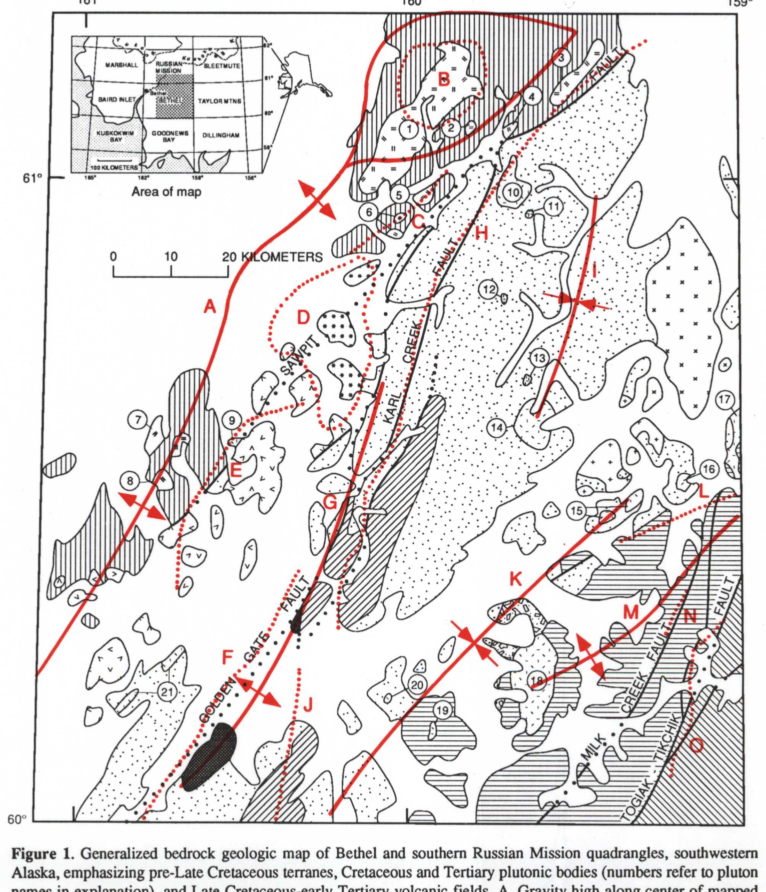


Figure 1. Generalized bedrock geologic map of Bethel and southern Russian Mission quadrangles, southwestern Alaska, emphasizing pre-Late Cretaceous terranes, Cretaceous and Tertiary plutonic bodies (numbers refer to pluton names in explanation), and Late Cretaceous-early Tertiary volcanic fields. A, Gravity high along center of mapped Nyac terrane which suggests that terrane is continuous beneath alluvial cover. B, A closed circle of max spots that outlines part of Nyac pluton suggesting location of its stock. C, Segment of max spots near an unexposed segment of Sawpit Fault. D, Max spots surrounding approximate mapped boundary of Nukluk volcanic field. E, Max spots that occur along part of mapped and inferred southwestern end of Sawpit Fault. F, Max spots correlate well with inferred southwest part of Golden Gate Fault. G, Axis of gravity high through Kilbuck terrane and western edge of much of Goodnews terrane. H, Max spots with good alignment along mapped location of Karl Creek Fault and northeastern end of Sawpit Fault. I, Axis of gravity low through the center of Kuskokwim Group. J, A linear group of max spots that project toward an inferred fault. K, Axis of gravity low that falls near much of boundary between Kuskokwim Group and Togiak terrane. L, Alinement of max spots that fall near northeastern contact between Kuskokwim group and Togiak terrane. M, Axis of gravity high through center of mapped Togiak terrane. N, Max spots that align with part of Milk Creek Fault. O, Max spots that fall along part of Togiak-Tikchik Fault.

EXPLANATION

A — Axis of gravity ridge

K — Axis of gravity trough

C — Selected maximum horizontal gradients

Surficial deposits (Quaternary) undivided

PLUTONIC ROCKS

Early Cretaceous plutons (some units may be Jurassic or Late Cretaceous) (west of Sawpit fault)

Plutons indicated by number:
1. Nyac, 2. Bonanza Creek, 3. Sawpit , 4. Fox Creek, 5. Slate Creek, 6. Dry Creek, 7. Columbia Creek, 8. Little Kasigluk River

Late Cretaceous to early Tertiary plutons (mostly east of Sawpit fault)

Plutons indicated by number:
9. Shining Dome, 10. Mt. Plummer, 11. Marvel Creek, 12. Fisher Dome, 13. Loco Creek, 14. Cripple Mountains, 15. North Fork, 16. Aniak Lake, 17. Gemuk Mountain, 18. Crooked Mountains, 19. Canyon Creek, 20. West Canyon Creek, 21. Eek River

VOLCANIC FIELDS

Nukluk volcanic field (Eocene)—Alkalic rhyolite and basalt flows, and rhyolitic ash-flow tuffs

Eek volcanic field (Paleocene and Late Cretaceous?)—Calc-alkaline andesite and dacite flows; subordinate rhyolite domes

Kipchuk volcanic field (Late Cretaceous)—Calc-alkaline andesite flows and tuff; subordinate rhyolite domes

Tulip volcanic field (early Tertiary and (or) Late Cretaceous)—Calc-alkaline dacite and andesite flows, pyroclastic rocks, and rhyolite domes

Swift Creek volcanic field (early Tertiary and (or) Late Cretaceous)—Calc-alkaline andesite flows and breccias and rhyolite ash-flow tuffs

SEDIMENTARY ROCKS

Kuskokwim Group (Late Cretaceous)—Shallow- to deep-marine sandstone, shale, and minor conglomerate

TERRANES

Nyac terrane (Early Cretaceous? and Jurassic)—Volcanic, volcaniclastic, and plutonic rocks of volcanic arc affinity

Goodnews terrane (Mesozoic and Paleozoic)—Structurally disrupted assemblage of metabasalt, argillite, chert, marble, and minor clastic rocks

Togiak terrane (Early Cretaceous to Late Triassic)—Volcaniclastic and minor volcanic rocks of volcanic arc affinity

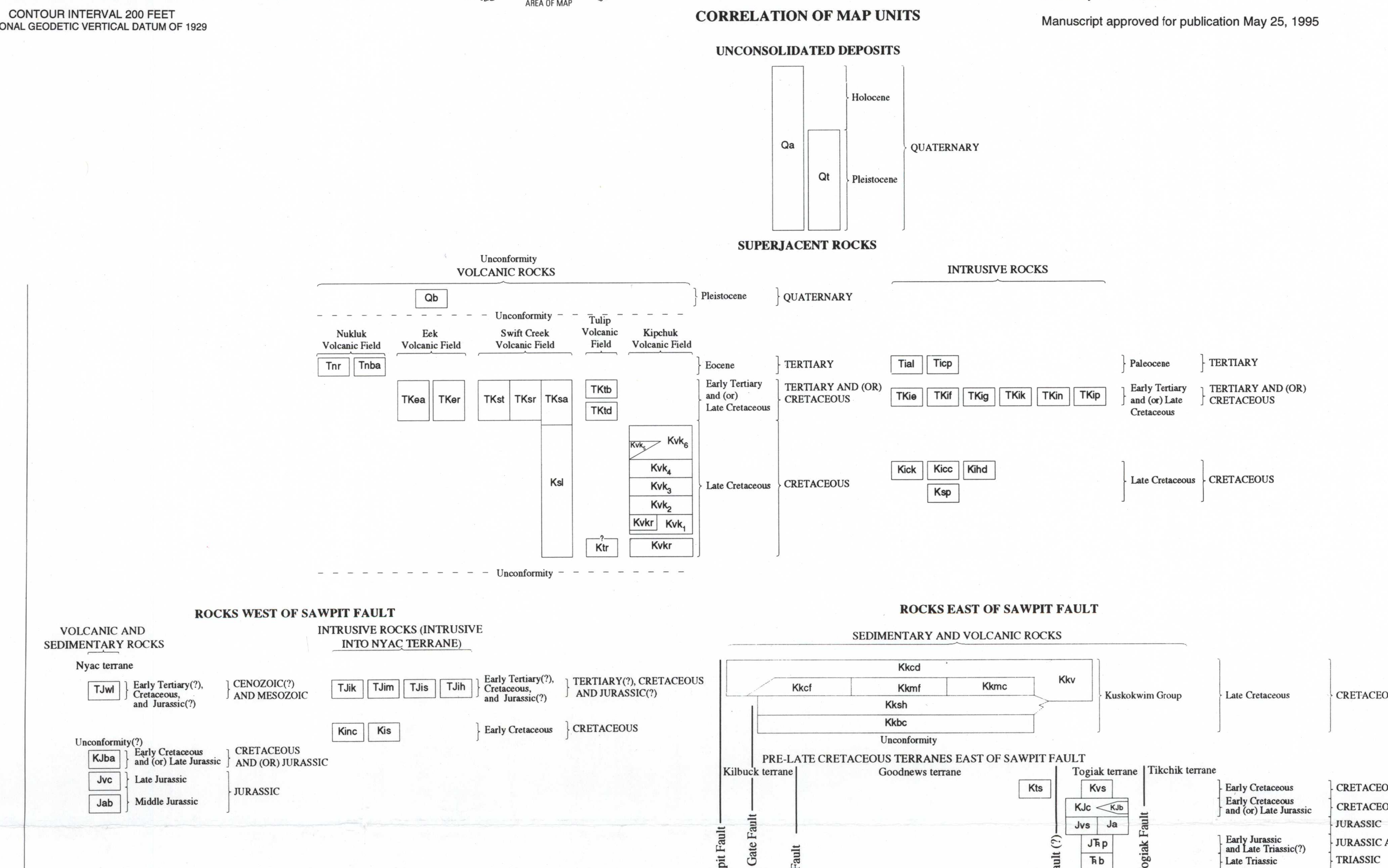
Tikchik terrane (Mesozoic and Paleozoic)—Structurally disrupted assemblage of volcanic rocks, chert, clastic rocks, argillite, and marble

Kilbuck terrane (Early Proterozoic)—Amphibolite-facies orthogneiss and paragneiss

Contact

Fault, dotted where inferred

CORRELATION OF MAP UNITS



LIST OF MAP UNITS

UNCONSOLIDATED DEPOSITS

Qa — Alluvium (Holocene and Pleistocene)
Qt — Glacial till (Pleistocene)

SUPERJACENT ROCKS

VOLCANIC ROCKS

Qb — Basalt (Pleistocene)

Nukluk Volcanic Field

Tnr — Rhyolite (Eocene)
Tnba — Basalt and andesite lava flows (Eocene)

Eek Volcanic Field

TKea — Andesite lava flows and porphyry (Paleocene and Cretaceous?)
TKer — Rhyolite (Paleocene and Cretaceous?)

Swift Creek Volcanic Field

TKst — Rhyolite ash-flow tuff (early Tertiary and (or) Late Cretaceous)
TKsr — Rhyolite (early Tertiary and (or) Late Cretaceous)
TKsa — Andesite flows (early Tertiary and (or) Late Cretaceous)
Ksl — Lithic air-fall tuff (Late Cretaceous; Campanian)

Tulip Volcanic Field

TKtb — Block and ash flow (early Tertiary and (or) Late Cretaceous)
TKtd — Dacite and andesite flows and dacite tuff (early Tertiary and (or) Late Cretaceous)
Ktr — Rhyolite domes and flows (Late Cretaceous)

Kipchuk Volcanic Field

Kvk₄ — Andesite and basalt flows (Late Cretaceous; Maastrichtian)
Kvk₃ — Fine-grained tuff, crystal-vitric tuff, and tuffaceous sandstone (Late Cretaceous; Maastrichtian)
Kvk₂ — Upper black andesitic lithic tuff (Late Cretaceous; Maastrichtian)
Kvk₁ — Andesite flows (Late Cretaceous)
Kvk₀ — Lower black andesitic lithic tuff (Late Cretaceous)
Kvkb — Basal andesite flows (Late Cretaceous)
Kvkr — Rhyolite domes and flows (Late Cretaceous)

INTRUSIVE ROCKS

Intrusive rocks, undivided—Divided into:
Tial — Aniak Lake pluton (Paleocene)
Ticp — Cripple Mountains pluton (Paleocene)
TKie — Eek River pluton and related plutonic rocks (early Tertiary and (or) Late Cretaceous)
TKif — Fisher Dome and Marvel Creek plutons, undivided (early Tertiary and (or) Late Cretaceous)
TKig — Gemuk Mountain pluton (early Tertiary and (or) Late Cretaceous)
TKik — Quartz monzodiorite of Kipchuk River (early Tertiary and (or) Late Cretaceous)
TKin — North Fork pluton (early Tertiary and (or) Late Cretaceous)
TKip — Mt. Plummer pluton (early Tertiary and (or) Late Cretaceous)
Kick — Crooked Mountain pluton (Late Cretaceous)
Kicc — Canyon Creek pluton (Late Cretaceous)
Kihd — Hornblende diorite stocks and dikes (Late Cretaceous)
Ksp — Serpentinite (Late Cretaceous)

ROCKS WEST OF SAWPIT FAULT

VOLCANIC AND SEDIMENTARY ROCKS

Nyac terrane

TJwl — Whitefish Lake Volcanic Field (early Tertiary?, Cretaceous, and Jurassic?)
KJba — Basaltic and andesitic lava flows (Early Cretaceous and (or) Late Jurassic)
Jvc — Volcaniclastic conglomerate, sandstone, and shale (Late and Middle Jurassic)
Jab — Andesitic and basaltic lava flows and marine epiclastic rocks (Middle Jurassic)

INTRUSIVE ROCKS
(Intrusive into Nyac terrane)

Intrusive rocks, undivided—Divided into
TJlk — Little Kasigluk River pluton (early Tertiary?, Cretaceous, and Jurassic?)
TJlm — Altered mafic plutonic rocks (early Tertiary?, Cretaceous, and Jurassic?)
TJls — Slate Creek pluton (early Tertiary?, Cretaceous, and Jurassic?)
TJlh — Hypabyssal felsic intrusive rocks (early Tertiary?, Cretaceous, and Jurassic?)
Kinc — Nyac, Bonanza Creek, and Columbia Creek plutons, undivided (Early Cretaceous)
Kis — Sawpit pluton (Early Cretaceous)

ROCKS EAST OF SAWPIT FAULT

SEDIMENTARY AND VOLCANIC ROCKS

Kuskokwim Group—Divided into:
Kkcd — Chert-clast provenance rocks (Late Cretaceous; Turonian)
Kkcf — Deltaic facies; Outer-fan turbidite facies
Kkmf — Mixed provenance rocks (Late Cretaceous; Turonian); Outer-fan turbidite facies
Kkmc — Inner-fan-channel facies
Kkv — Volcanic provenance rocks (Late Cretaceous; Turonian)
Kksh — Shale and siltstone (Late Cretaceous; early Turonian and (or) late Cenomanian)
Kkbc — Basal conglomerate (Late Cretaceous; Cenomanian?)

PRE-LATE CRETACEOUS TERRANES EAST OF SAWPIT FAULT

Kilbuck terrane

Xo — Amphibolite-facies orthogneiss and amphibolite with minor intercalated pelitic schist (Early Proterozoic)

Goodnews terrane

Kts — Turbiditic sandstone, conglomerate, and argillite (Early Cretaceous)
MDm — Marble with metabasaltic dikes (Early Mississippian and (or) Late Devonian)
MzPzb — Metabasalt and minor metachert (Mesozoic and (or) Paleozoic)
MzPzs — Arkosic sandstone and slate (Mesozoic and (or) Paleozoic)
MzPzc — Chert and argillite (Mesozoic and (or) Paleozoic)
MzPzv — Volcaniclastic sandstone and argillite (Mesozoic and (or) Paleozoic)
MzPzm — Metachert and phyllitic metachert (Mesozoic and (or) Paleozoic)
MzPzp — Chloritic phyllite (Mesozoic and (or) Paleozoic)
MzPza — Argillaceous melange with blocks of limestone, basalt, and chert (Mesozoic and (or) Paleozoic)

Togiak terrane

Kvs — Marine volcaniclastic sandstone, conglomerate, shale, and interbedded tuff (Early Cretaceous)
KJc — Argillite and tuffaceous chert (Early Cretaceous and (or) Late Jurassic)
KJp — Pillow basalt (Early Cretaceous and (or) Late Jurassic)
Jvs — Marine volcaniclastic sandstone, conglomerate, and argillite (Jurassic)
Js — Marine arkosic sandstone and argillite (Jurassic)
J℞p — Phyllite and chert (Early Jurassic and Late Triassic?)
℞b — Pillow basalt and minor interbedded chert (Late Triassic)

Tikchik terrane

℞Ds — Marine sandstone, shale, limestone, and conglomerate (Middle? Triassic to Late Devonian)
MDv — Massive volcanic and volcaniclastic rocks (Early Mississippian and (or) Late Devonian)
℞Pzm — Melange (Triassic and Paleozoic)

Contact—Dashed where approximately located dotted where concealed

Fault—Dashed where inferred, dotted where concealed. U, upthrown block; D, downthrown block

Thrust fault—Sawteeth of upper plate. Dashed where inferred, dotted where concealed

Folds—Showing trace of axial plane, arrowhead indicates direction of plunge. Dashed where inferred, dotted where concealed

Anticline

Syncline

Overturned anticline

Overturned syncline

Axial trend of fold—Too small to show individually at scale of map

Strike and dip of bedding or flows

Inclined

Vertical

Overturned

Strike and dip of foliation—Arrow indicates plunge of mineral lineation

Strike and dip of cleavage

Hornfels

Mafic phase of felsic pluton

ISOSTATIC GRAVITY MAP

COMPLETE BOUGUER AND ISOSTATIC GRAVITY MAPS OF THE BETHEL AND SOUTHERN PART OF THE RUSSIAN MISSION QUADRANGLES, SOUTHWESTERN ALASKA

By
Robert L. Morin

1996

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA—1996
For sale by U.S. Geological Survey
Information Services
Box 25286, Federal Center
Denver, CO 80225