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Gravity and magnetic character of south-central Alaska: Constraints on geologic and tectonic interpretations, and implications for mineral exploration

Jonathan M.G. Glen
U.S. Geological Survey, 345 Middlefield Road, Menlo Park, California 94025, USA

Jeanine Schmidt
U.S. Geological Survey, 4200 University Drive, Anchorage, Alaska 99508, USA

Robert Morin
U.S. Geological Survey, 345 Middlefield Road, Menlo Park, California 94025, USA

ABSTRACT

Recent gravity and aeromagnetic investigations of the Talkeetna Mountains of south-central Alaska (61.5–63.75°N, 145–151°W) were undertaken to study the region's framework geophysics and to reinterpret crustal structures and composition. Aeromagnetic data for this study were compiled from 13 available regional- and local-scale surveys. Over 400 new gravity stations were collected along 12 profiles in the study area and combined with 3286 existing regional data.

These data are brought together here with current stratigraphic, lithogeochemical, structural, isotopic, and paleontologic findings to bear on the tectonics and metallogeny of south-central Alaska, and in particular to: (1) help understand the regional tectonic character of south-central Alaska, especially related to the development of the southern Alaska orocline; (2) to determine the structural relationships between tectonostratigraphic terranes (including Kahiltna, Wrangellia, and Peninsular terranes, as well as smaller terranes such as Susitna, Broad Pass, and Maclaren); (3) to understand the character of major faults; and (4) to develop a geophysically based regional mineral assessment for the Talkeetna Mountains and surrounding region that identifies the locations, size, and depth of buried sources of important potential mineral targets such as ultramafic units associated with feeder zones to the Triassic Nikolai Greenstone flood basalt.

Within the Talkeetna Mountains region, we interpret four regional-scale domains, with internally consistent geophysical character, that mostly correspond with previously defined tectonostratigraphic terranes. These include a Wrangellia domain, a restricted Peninsular domain, and two domains within the Mesozoic overlap assemblage north of Wrangellia. At the broadest scale, potential field data suggest that a large block of the Talkeetna Mountains consists of relatively dense magnetic crust, likely of oceanic-crustal composition (corresponding with Wrangellia and Peninsular terranes) that may also have been underplated by mafic material during early to

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middle Tertiary volcanism. At the NW edge of this block lies a prominent gravity and magnetic gradient (~3.25 mGal/km, ~100 nT/km) that forms a NE-trending first-order crustal discontinuity between dense late Paleozoic to Cretaceous Wrangellia crust and low-density Jurassic to Cretaceous flysch to the northwest.

Potential field models indicate this crustal break is a deep (>10 km), steeply dipping structure—not a shallow-dipping thrust as previously thought. Confined to a narrow zone of a few tens of kilometers situated along this boundary is a belt of Nikolai Greenstone and related rocks that carry a distinct geophysical signature that allows for assessing their size and distribution.

A zone of transitional crust, located between Wrangellia and North America, is cut by several northeast-trending structures that may have been reactivated in Tertiary time, perhaps accommodating combined thrust and dextral strike-slip motion due to the westward escape of crust during and since Tertiary oroclinal bending.

Due to the geophysical contrast of continental North American crust and Wrangellia's oceanic crust, slivers of Wrangellia's margin can be seen offset, along the Talkeetna fault zone, from interior Wrangellia, perhaps allowing an estimate of the magnitude of strike-slip displacement.

The Mesozoic flysch northwest of this crustal break is distributed over two distinct geophysical domains that we interpret as a southeast domain underlain by transitional crust and a northwest domain rooted by continental crust. We infer this to reflect two different depositional basins, consistent with recent sediment provenance studies that demonstrate that two distinct subbasins, one to the northwest and one to the southeast, received their sediments from continental North America's Mesozoic margin and from Wrangellia, respectively.

Keywords: south-central Alaska, crustal structure, mineral resources, geophysics, gravity, magnetics, terrane.

INTRODUCTION

Nature and Purpose of Study

Although the Talkeetna Mountains (Fig. 1) are one of Alaska's most promising areas for mineral exploration because they are surrounded by major transportation corridors, they have remained relatively inaccessible and their mineral potential underexplored. Existing geologic mapping (Csejtey, 1974; Csejtey et al., 1978, 1992; Fig. 2) has been mainly reconnaissance in nature, leaving large tracts of terrain unmapped at scales appropriate for mineral resource evaluation.

New gravity (Fig. 3A) and aeromagnetic (Fig. 3B; GSA Data Repository, Table DR1[1]) data from the Talkeetna Mountains and surrounding regions provide an opportunity to address several fundamental mineral resource, geologic, and infrastructure (such as routing and hazard issues for pipelines, rail extensions, and roads) issues. These data significantly improve the regional potential field database of this remote area and provide a basis for reevaluating the regional structural framework. We use these data to (1) define and assess the geophysical character of crustal terranes; (2) constrain the geometry of first-order, terrane-bounding structures; and (3) identify major second-order structures internal to terranes. These crustal interpretations in turn affect our understanding of Late Triassic to Holocene plate interactions throughout the region and suggest modifications to the currently accepted tectonostratigraphic terrane nomenclature. These interpretations improve our understanding of the suturing of Wrangellia to the continental margin, the development of the southern Alaska orocline, and the distribution of Tertiary plutonism and volcanism.

Evaluating the area's mineral potential depends on understanding this geologic and tectonic history, as well as the distribution of tectonostratigraphic terranes and their internal and bounding faults that influence the distribution of mineral occurrences. Because many potentially ore-bearing magmatic rocks have distinct geophysical expressions, gravity and magnetic data can be used to determine the subsurface extent of known bodies and to identify buried sources. As a result, these new geophysical data provide an improved metallogenic framework for an updated mineral assessment for south-central Alaska.

Regional Setting

Physiography

The Talkeetna Mountains form an elevated topographic block situated between the Alaska Range and Clearwater Mountains to the north and Chugach Mountains in south-central Alaska (Fig. 1).

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[1] GSA Data Repository Item 2007113, Tables DR1–DR3, is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140, USA, or editing@geosociety.org, at www.geosociety.org/pubs/ft2007.htm.

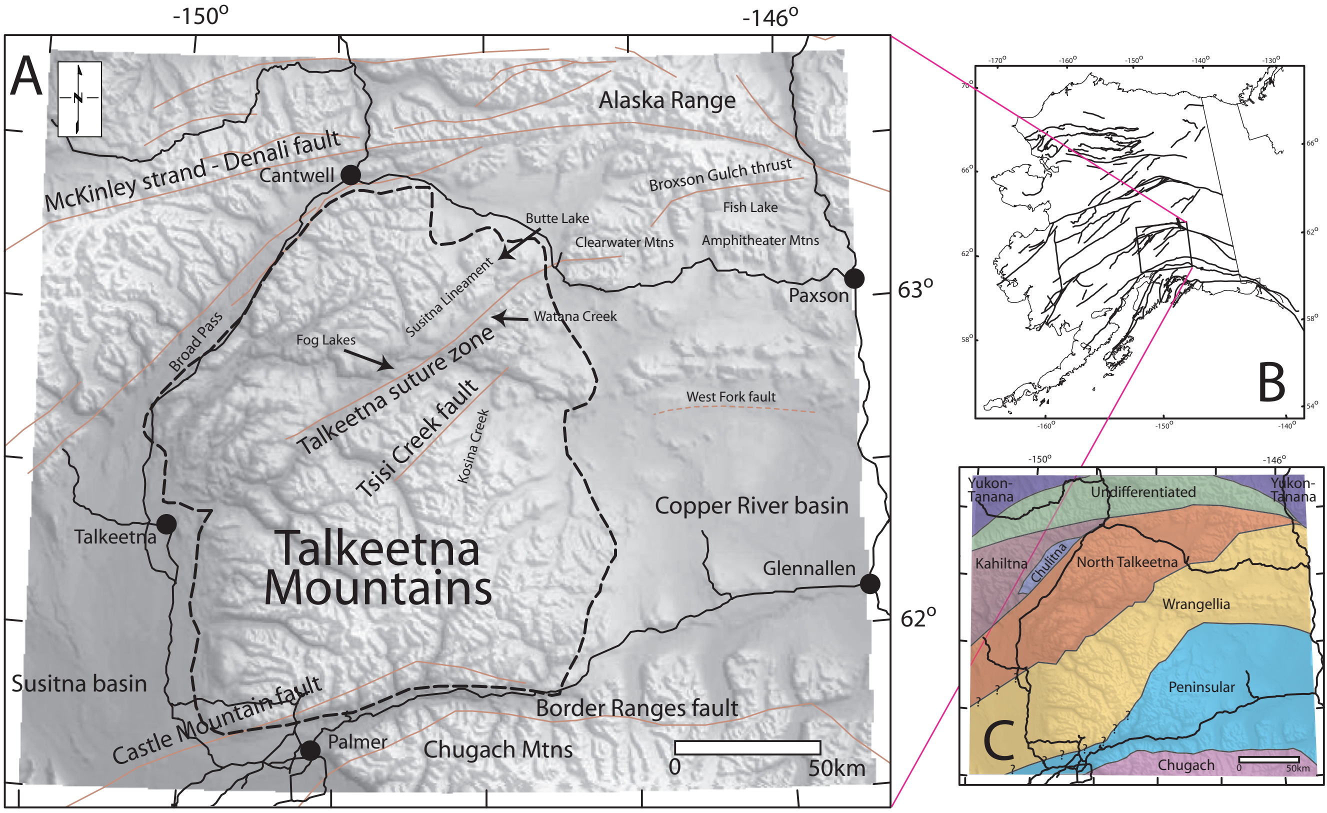

Figure 1. (A) Digital shaded relief map of south-central Alaska showing physiographic provinces, major roads, towns, outline of Talkeetna Mountains (dashed line), and major faults (red lines); (B) regional locality map with faults; (C) major lithotectonic/tectonostratigraphic terranes as defined in this study.

Two prominent river basins bound the Talkeetna Mountains—the Susitna to the west and the Copper River to the east (Fig. 1). The Talkeetna Mountains vary from rugged glaciated terrain with summit peaks between 2000 and 2700 m to benches at 600–700 m elevation along the deeply incised Susitna River.

The physiography of the Talkeetna Mountains, including the orientation of the drainage network, ridges, and valleys, is strongly influenced by geologic structures. A pervasive N20–40°E structural fabric is defined by prominent physiographic features such as Broad Pass, the Fog Lakes lowland, and Watana and Tsisi Creeks. Conjugate fracture patterns forming a network of intersecting lineations result in polygonal topographic blocks observed in aerial photos and satellite imagery throughout much of the northern and central Talkeetna Mountains.

Regional Geologic Framework

South-central Alaska (Figs. 1C, 2) is an assemblage of Paleozoic and Mesozoic tectonostratigraphic terranes, including intraoceanic and possible continental arcs, accretionary prisms, flysch basins, oceanic plateaus, and large blocks of oceanic crustal rocks that represent the remnants of Devonian to Jurassic continental marginal basins (Berg et al., 1972; Jones et al., 1972; Berg et al., 1978; Plafker and Berg, 1994). After having accreted to the North American continent, oblique subduction drove these terranes northwestward along the continental margin via dextral strike-slip fault systems like the ancestral Denali and Castle Mountain fault zones. During Late Cretaceous to early Tertiary time, widely distributed but discontinuous volcanism and plutonism stitched together the assemblage of southern Alaska terranes.

Prior to Eocene volcanism, oblique subduction and transpression of southern Alaska terranes toward a North American plate backstop within and north of the Alaska Range produced the distinctive curvature of southern Alaska commonly referred to as the southern Alaska orocline (Plafker and Berg, 1994).

The Talkeetna Mountains study area is uniquely situated within the axis of the orocline, a region presently undergoing convergence, experiencing abundant shallow seismicity, and situated on an active upper crustal plate above the Aleutian Benioff zone (Eberhart-Phillips et al., 2003; Glen, 2004). Therefore, insights developed from this geophysical study concerning the crustal character of, and structures within, the Talkeetna Mountains bear on our understanding of the framework of current tectonic activity.

Dextral Shear Zones. Among the most prominent physiographic features of southern Alaska are a series of nested arcuate lineations that parallel the convex-southward coastline of the state. These features are generally interpreted as major dextral fault zones that developed in response to stresses imposed on the western edge of North America by transcurrent motion and by the oblique

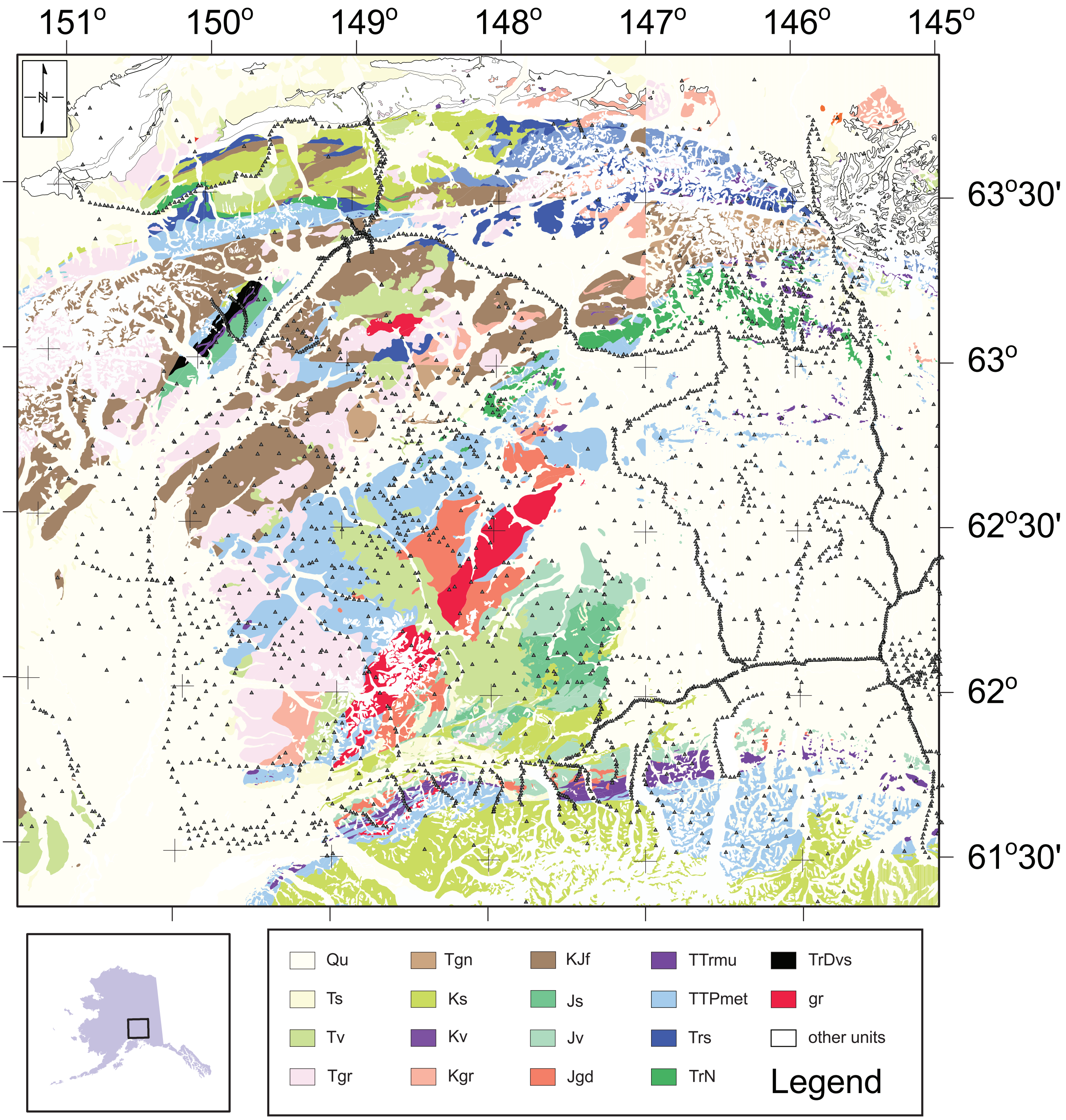

Figure 2. Regional geologic map of the Talkeetna Mountains and surrounding region (simplified from Wilson et al., 1998). Gravity stations are shown by triangles. Qu = Quaternary sediments, undifferentiated; Ts = Tertiary nonmarine clastic sedimentary rocks; Tv = Tertiary volcanic rocks; Tgr = Tertiary granitoid intrusive rocks; Tgn = Tertiary gneiss and granitoid intrusive rocks, undifferentiated; Ks = Cretaceous sedimentary rocks; Kv = Cretaceous volcanic rocks; Kgr = Cretaceous granitoid intrusive rocks; KJf = Jurassic to Cretaceous flysch, shale, sandstone, and conglomerate; Js = Jurassic sedimentary rocks; Jv = Jurassic volcanic and volcaniclastic rocks; Jgd = Jurassic granodiorite; TTrmu = Tertiary(?) to Triassic mafic and ultramafic rocks; TPmet = Tertiary to Permian metamorphic rocks and mélange, undifferentiated; Trs = Triassic sedimentary rocks; TrN = Triassic Nikolai Greenstone and gabbros; TrDvs = Triassic to Devonian Chulitna terrane volcanic and sedimentary rocks; gr = granitoid rocks, undifferentiated.

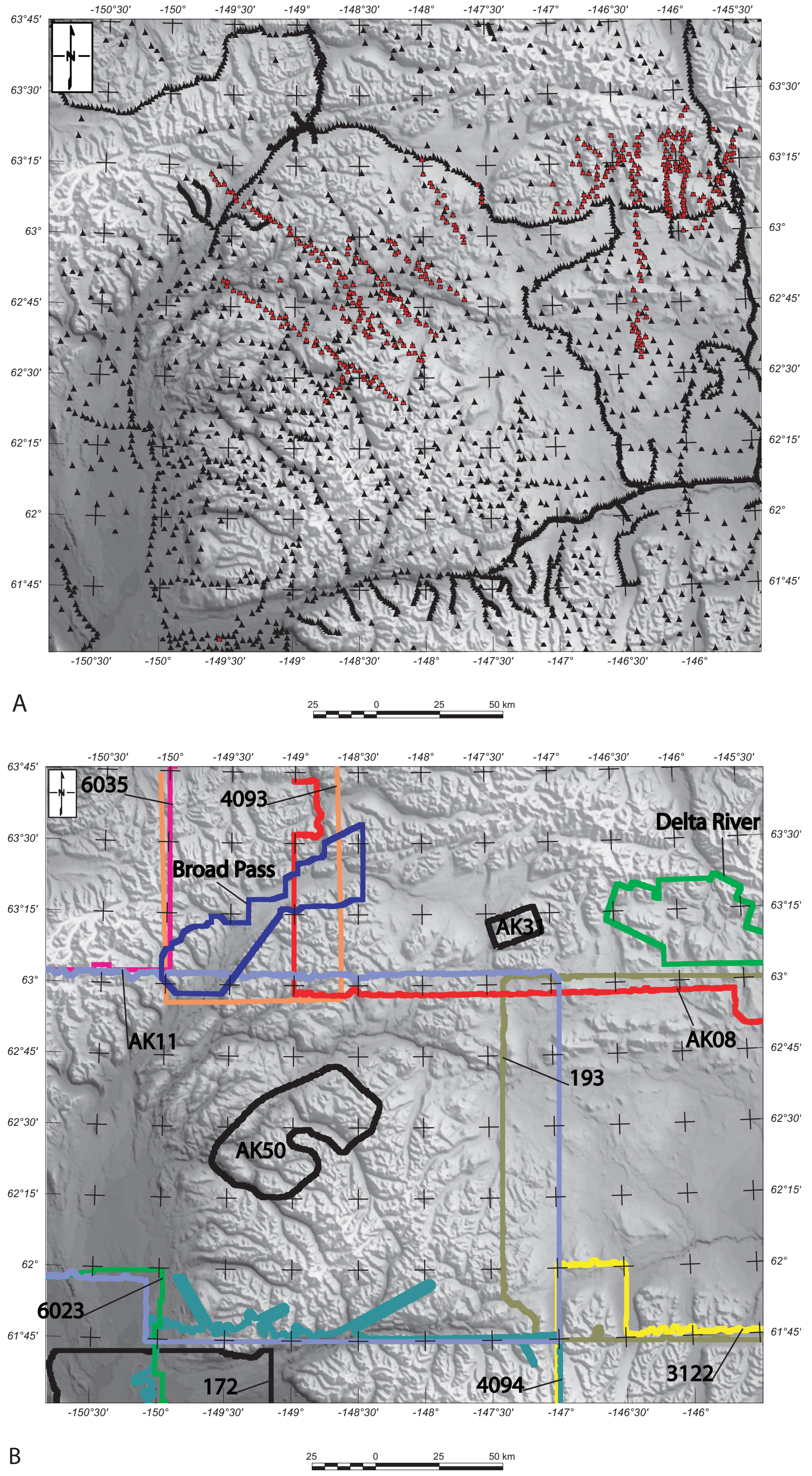

Figure 3. Index of (A) new (red squares) and existing (black triangles) gravity stations, and (B) aeromagnetic surveys within the Talkeetna Mountains study area (refer to Table DR1 [see footnote 1]). Note that interpretations are more tentative in areas of low station density, or low resolution data.

subduction of the Pacific plate beneath the North American plate. From north to south, these major structural boundaries are the Denali fault zone (including the Hines Creek, McKinley, Totschunda, Susitna Glacier, and related fault splays; Eberhart-Phillips et al., 2003) the Castle Mountain fault zone, and the Border Ranges fault.

Northeast-trending faults. Although arcuate dextral strike-slip faults, which bound the Talkeetna Mountains to the north and south (Denali and Castle Mountain fault zones, respectively), are oriented dominantly east-west, many of the prominent faults in the Talkeetna Mountains region are oriented N 20–40°E and parallel the northeast trend of geologic units within the area. It is speculated that many of these northeasterly structures are part of a system of oblique-slip faults that accommodate shortening within the hinge of the Alaska orocline as crust is transported westward through the bend (Glen, 2004). Some of these northeasterly structures and their relationship to bulk shear within the Talkeetna Mountains were described by O'Neill et al. (2005).

Broxson Gulch thrust. The Broxson Gulch thrust fault was first recognized by Stout (1965, 1972) in the Delta River region. It was subsequently extended southwestward by Smith (1974). Csejtey (1976) and Csejtey et al. (1978) mapped it into the Talkeetna Mountains to merge with the Talkeetna thrust, lengthening it to nearly 200 km. Where it was recognized in the Delta River region, the fault is manifest as a narrow zone of northwest-dipping (5–40°) imbricate thrusts and shows evidence of Tertiary movement. Stout and Chase (1980) suggested that the Broxson Gulch thrust may have been responsible for mitigating compressional stress between what they considered distinct plates north and south of the thrust.

Talkeetna thrust. The northeast-trending Talkeetna fault was originally mapped by Csejtey et al. (1978) as a single, southeastward-dipping shallow thrust fault interpreted to place rocks of Wrangellia terrane in the upper plate tens of kilometers northwestward over continental margin sedimentary rocks in the lower plate. Most of the length of the Talkeetna thrust fault as mapped was covered by Quaternary sediments in the lowlands along the Fog Lakes and Watana Creek in the Talkeetna Mountains. Csejtey et al. (1978) interpreted several splays of the Talkeetna thrust in the Butte Creek area (Talkeetna D-2 and Healy A-2 quadrangles). The basal thrust exposed at Butte Creek, however, has been documented to have both minor offset and little deformation (O'Neill et al., 2003a, 2003b). Exposures of the Talkeetna thrust at its southern end (TK B-5 quadrangle) dip 75° W with small-scale structures suggesting local reverse motion.

Because of these inconsistencies, we do not use the term *Talkeetna thrust fault,* but refer to the deep crustal structure bounding the Wrangellia terrane as the Talkeetna Suture Zone, which will be described later in this paper. Surface structures near and overlying the Talkeetna suture zone are identified separately (Watana Creek fault, Butte Creek thrust, and the Susitna Lineament).

West Fork fault. The West Fork fault is defined as the boundary between the Wrangellia terrane (Gulkana River metamorphic complex) to the north and unmetamorphosed Talkeetna arc rocks of the Peninsular terrane to the south (Nokleberg et al., 1994). This fault is marked along its southern edge by prominent east-trending magnetic highs (including the Sourdough high of Andreasen et al., 1964, and Nokleberg et al., 1994, and our regional magnetic domain 13; Table DR2 [see footnote 1]) that reflect a subvertical structure marking the northern edge of the Wrangellia-Peninsular terrane boundary as herein defined. Westward, however, the magnetic high dies out near the Oshetna River, and the fault has not been mapped in the Talkeetna Mountains quadrangle. No sense of offset has been suggested for the West Fork fault.

Tsisi Creek fault. A major shear zone along Tsisi Creek (Fig. 1) was first mapped by Csejtey et al. (1978), who suggested that it may mark a thrust zone up to 25 km wide with significant displacement. The Tsisi Creek fault as defined by recent geologic mapping and geophysical modeling, however, is a relatively narrow, near-vertical north-30°-east trending structure (Glen et al., this volume) that locally coincides with prominent gravity and magnetic gradients. Up-to-the-east displacement on the Tsisi Creek fault places Middle Jurassic granitoid batholiths and their gneissic wall rocks in contact with Nikolai Greenstone and its basement rocks to the west. Vertical offset of several kilometers is suggested by the presence of andesitic dikes and course-grained intrusions of the same age, at the same elevations on either side of the fault. No strike-slip motion has been documented along the fault. At its northeastern end, the Tsisi Creek fault coalesces with the Kosina Creek fault but has not been traced north of the Susitna River.

Susitna Lineament. The Susitna Lineament of Smith et al. (1988), a prominent physiographic break along the edge of Butte Lake, was extended southward through the northern Talkeetna Mountains by Clautice (1990). It is defined primarily by elongate lakes and aligned drainages and forms the western edge of the Fog Lakes and Watana lowlands. Although clearly visible in aerial and satellite imagery as a single through-going feature, the Susitna Lineament is comprised of segments, some of which have complex or subdued surface expressions. In detail the lineament consists of a series of 10–20-km-long en echelon segments stepping eastward as it is traced northward. Motion on the Susitna Lineament is in part east-side down, with Eocene volcanic rocks and Miocene and Oligocene sedimentary rocks exposed in the Fog Lakes and Watana basins (Hardy, 1987; Schmidt et al., 2002). The en echelon offsets and associated fracture zones suggest that the Susitna Lineament also has a component of dextral strike-slip offset (O'Neill et al., 2005).

Tectonostratigraphic Terranes

Subsequent to having accreted to the continent, south-central Alaskan terranes were significantly modified from their original spatial extent by faulting and shearing imposed by oblique subduction (Plafker and Berg, 1994). In the Talkeetna Mountains, terranes are presently arranged with a dominantly northeast orientation that changes to an easterly trend in the eastern portion of the study area. Three major lithostratigraphic terranes and overlap assemblages have been previously defined in this region (Berg et al., 1978): the Jurassic-Cretaceous Kahiltna Flysch, the late Paleozoic–early Mesozoic Wrangellia terrane, and the middle Mesozoic Peninsular terrane.

Wrangellia. The Wrangellia terrane in the northern Talkeetna Mountains consists of a sequence of Mississippian to Middle Triassic metasedimentary rocks including siliceous siltstones, chert, sandstones, and fossiliferous limestone (Nokleberg et al., 1994). These are overlain by flood basalts of the Middle to Late Triassic Nikolai Greenstone and related gabbro and dolerite sills and by minor Triassic and Jurassic shallow marine sedimentary rocks.

Peninsular. The Peninsular terrane as defined in the southeast portion of the study area consists of Paleozoic(?) and Mesozoic metasedimentary rocks, the distinctive Late Triassic(?) to Early Jurassic (205–190 Ma) Talkeetna volcanic arc rocks, and Early and Middle Jurassic granitoid batholiths (Nokleberg et al., 1994).

Kahiltna overlap assemblage. The Jurassic-Cretaceous Kahiltna Flysch was defined as deformed flysch and basinal clastic sedimentary rocks intruded by Late Cretaceous and Tertiary plutons that lie northwest (inboard) of the Wrangellia terrane (Nokleberg et al., 1994). The flysch has recently been recognized to have been deposited in two separate basins (Ridgway et al., 2002). The Kahiltna flysch basin that lies to the northwest of Broad Pass contains middle Jurassic to Late Cretaceous continental material derived from North America (near present-day western Alaska) that was shed to the southeast. The North Talkeetna flysch basin, located to the southeast of Broad Pass includes Late(?) Triassic to Early Cretaceous clastic material derived from Wrangellia that was shed to the northwest.

GEOPHYSICS

Potential Field Geophysics

Geophysical surveys, which image the subsurface, are particularly important to geologic interpretation in areas such as Alaska where much of the land surface is covered by Quaternary deposits, where bedrock is degraded by extreme weathering conditions, and where many bedrock exposures are inaccessible. Gravity and magnetic data can be obtained relatively quickly over large tracts of land making them particularly useful for regional studies of crustal structures. Spatial variations in gravity and magnetics result from lateral contrasts in rock-density and rock-magnetic properties (induced and remanent magnetizations), respectively. These rock-property contrasts may occur across geologic structures such as faults or folds, across contacts between lithologic or stratigraphic units, or within a single lithostratigraphic unit, such as variations resulting from facies changes.

The size, geometry, and depth to a potential field source; the character of the geomagnetic field; and the rock properties of a source and its surroundings all determine the character of a source's anomaly. Despite this complexity, and the inherent nonunique nature of potential field model solutions, potential field data can provide concrete constraints on the geometry and, inferentially, the origin of anomaly sources, particularly when combined with other geologic constraints such as the regional tectonic framework, surface geology, and seismic or electrical data.

Some general conclusions can be drawn from the character of geophysical anomalies and their likely sources. The shallower the depth to a potential field source body, the higher the amplitude, the shorter the wavelength, and the steeper the gradients of its potential field anomaly. As a result, high-amplitude, short-wavelength anomalies, which often have steep gradients, are produced by sources at shallow depths in the crust. In contrast, long-wavelength anomalies having smooth gradients commonly reflect deep sources. Anomalies with wavelengths of hundreds of kilometers, for example, most likely arise from sources in the lower crust. Although wide, shallow, thin sources with gently sloping sides can produce similar anomalies, such cases can usually be recognized with regional geologic mapping. For the purposes of this paper, we define deep as >10–15 km, midcrustal as 3–10 km, and shallow as any source <3 km below the surface.

Gravity maps indicate anomalies that arise from lateral density contrasts that may arise from deviations from isostatic equilibrium, density contrasts between rock bodies, or lateral variations in temperature within the crust. On the one hand, contrasts in rock density may be due to lithologic or structural contacts between rock units, partial melting, or phase transitions. Magnetic anomalies, on the other hand, reflect variations in the magnetization of the crust (including induced and remanent magnetizations), which, to a large extent (i.e., in rocks with small remanent components) reflect variations in the magnetic susceptibility of rocks caused by changes in the concentration and mineralogy of magnetic minerals within the crust. It is often assumed that the induced component need only be considered because of present field remanent overprints that are parallel to the induced component or low intensity remanence components. Although this is generally a reasonable assumption, it may not hold true in strongly magnetic terrain such as over mafic volcanic or intrusive rocks.

Generally, gravity and magnetic highs arise from mafic and ultramafic igneous and crystalline basement rocks, whereas lows arise from felsic igneous, sedimentary, or altered basement rocks. Metamorphism and alteration can strongly affect the susceptibility of an originally homogeneous rock body by leading to the nonuniform production or destruction of magnetic minerals. Igneous outcrops not associated with magnetic anomalies might be thin or contain low concentrations of primary magnetic minerals or might have lost them due to alteration. In south-central Alaska, many of the most prominent aeromagnetic anomalies arise from volcanic, gabbroic, and ultramafic rocks associated with the Wrangellia and Peninsular (and Chugach) terranes.

In contrast to gravity data, magnetic data highlight shallow and midcrustal features as opposed to deep sources. This is due in part to the more rapid attenuation of magnetic fields with distance to their source than gravity. The fact, too, that there are significantly fewer gravity data, limits the ability of gravity data to resolve small-scale features, rendering the gravity method most effective at resolving broad, deep crustal structures. In addition, unlike gravity, crustal remanent magnetism has a depth limit set by the Curie temperature isotherm, the temperature above which remanent magnetization does not exist.

Previous Geophysical Work

Results from previous geophysical studies overlapping all or part of the current study area (e.g., Barnes and Csejtey, 1985; Csejtey and Griscom, 1978; Burns, 1982; Cady, 1989; Campbell, 1987; Campbell and Barnes, 1985; Campbell and Nokleberg, 1984, 1985, 1986, 1997; Case, 1985; Fisher and von Huene, 1984; Grantz et al., 1963; Griscom, 1979; Griscom and Case, 1983; Hackett, 1978a, 1978b, 1979a, 1979b; Saltus et al., 1997, 2003; Wescott and Witte, 1982) were incorporated in our interpretations. At the regional scale, Saltus et al. (1997) defined several tectono-geophysical domains that correspond closely to the regional-scale geophysical domains described here. Notable differences, however, are discussed below and in the adjoining geophysical tables.

Potential Field Data

Gravity data collected at 399 gravity stations from across the Talkeetna Mountains study area (Fig. 3A) during 1999–2002 were compiled along with previously published data (Morin and Glen, 2002, 2003; Sanger and Glen, 2003).

In order to produce gravity maps reflecting lateral variations in the density of the crust, raw gravity measurements were reduced using standard gravity reduction methods (Dobrin and Savit, 1988; Blakely, 1995). These reductions remove the effects of elevation, topography, and the total mass, rotation, and ellipsoidal shape of the Earth and yield the complete Bouguer gravity anomaly (CBA). Although the CBA reveals lateral density variations at short wavelength scales, it does a poor job isolating longer wavelength features because these are often masked by broad anomalies due to deep crustal roots that isostatically compensate topographic loads. The isostatic correction accounts for the effects of these compensating masses (Fig. 4), and yields isostatic maps that typically indicate anomalies arising solely from density inhomogeneities in the crust. Both the new and existing data were reduced and gridded to produce the various gravity and derivative maps shown in this report. Barnes (1976) suggests that much of southern Alaska, including the present study area, is not in isostatic balance due to effects of the subducting Pacific plate. Lack of isostatic balance could bias some of the residual anomalies, particularly in the southern portion of the study area, such as the Cook Inlet. Nonetheless, this is a relatively broad wavelength phenomenon and should not influence the domain analysis discussed below, which is concerned with domain fabric dominated by relatively high frequencies and with domain boundaries that are defined by sharp magnetic horizontal gradients.

Magnetic data used in this report (Fig. 3B, Table DR1 [see footnote 1]) were derived from a statewide compilation (Saltus et al., 1999a, 1999b; Saltus and Simmons, 1997) and from several more recently flown surveys (Pritchard, 1997, 1998; Burns, 2002, 2003). These surveys were gridded and merged to produce the various filtered and derivative maps discussed below.

Rock Property Data

Because gravity and magnetic field anomalies reflect variations in the density and magnetic susceptibility of the underlying lithology, these rock properties are essential components to potential field modeling. A compilation of 306 density and 706 susceptibility measurements (Sanger and Glen, 2003), collected to constrain potential field models, were used in this report.

In general, the average grain density of rocks in the study region increases from sedimentary, felsic, and intermediate igneous rocks, to mafic igneous and metamorphic rocks. Magnetic susceptibility measurements performed on rock outcrops and hand samples from the study area also reveal lower magnetic susceptibilities for sedimentary and felsic intrusive rocks; moderate susceptibility values for metamorphic, felsic extrusive, and intermediate igneous rocks; and higher susceptibility values for mafic igneous rocks. The density and magnetic properties of rocks in the study area are generally consistent with general trends expected for these rock types.

The magnetization of a rock depends largely on its magnetic mineral content. Mafic rocks generally have higher magnetic susceptibilities than felsic rocks because mafic rocks typically contain more strongly magnetic minerals such as magnetite (Carmichael, 1982). Rocks from the study area reflect this trend—the highest average magnetic susceptibilities come from mafic igneous rocks, whereas the lowest calculated averages come from sedimentary as well as felsic and unidentified igneous rocks.

Density values for rocks from the study area are also consistent with general trends (Olhoeft and Johnson, 1989) and show highest average grain densities for both extrusive and intrusive mafic igneous rocks and lowest mean grain density values for felsic intrusive rocks. Because grain density is affected largely by a rock's mineral composition and porosity, rocks rich in felsic minerals tend to have lower densities than rocks rich in mafic minerals. Igneous and metamorphic rocks tend to be denser than sedimentary rocks, in part because of their composition but also because they are generally less porous than sedimentary rocks.

Filtering and Derivative Methods

Magnetic Potential (Pseudogravity)

Crustal magnetism varies because of changes in both the concentration and type of magnetic minerals within the crust (analogous to the relation between density and gravity) and differences in remanent magnetization. In addition, crustal magnetization is seldom vertical except at the magnetic poles, creating magnetic anomalies that are asymmetric and not centered over their sources.

Because of these complexities, magnetic anomalies are typically difficult to interpret. As a result, the magnetic potential, or pseudogravity transformation (Baranov, 1957; Blakely, 1995), is often employed because it removes the asymmetry of magnetic anomalies and leads to anomalies that more effectively lie centered over their sources. In addition, it helps highlight regional magnetic features masked by high-frequency anomalies.

The magnetic and gravity potentials are related by a directional derivative; thus, the total magnetic field can be transformed mathematically into an equivalent gravity field. Magnetic potential, or pseudogravity, maps are produced by the transformation of the magnetic field into the equivalent gravity field assuming a density distribution equal to the magnetization distribution (Bara-

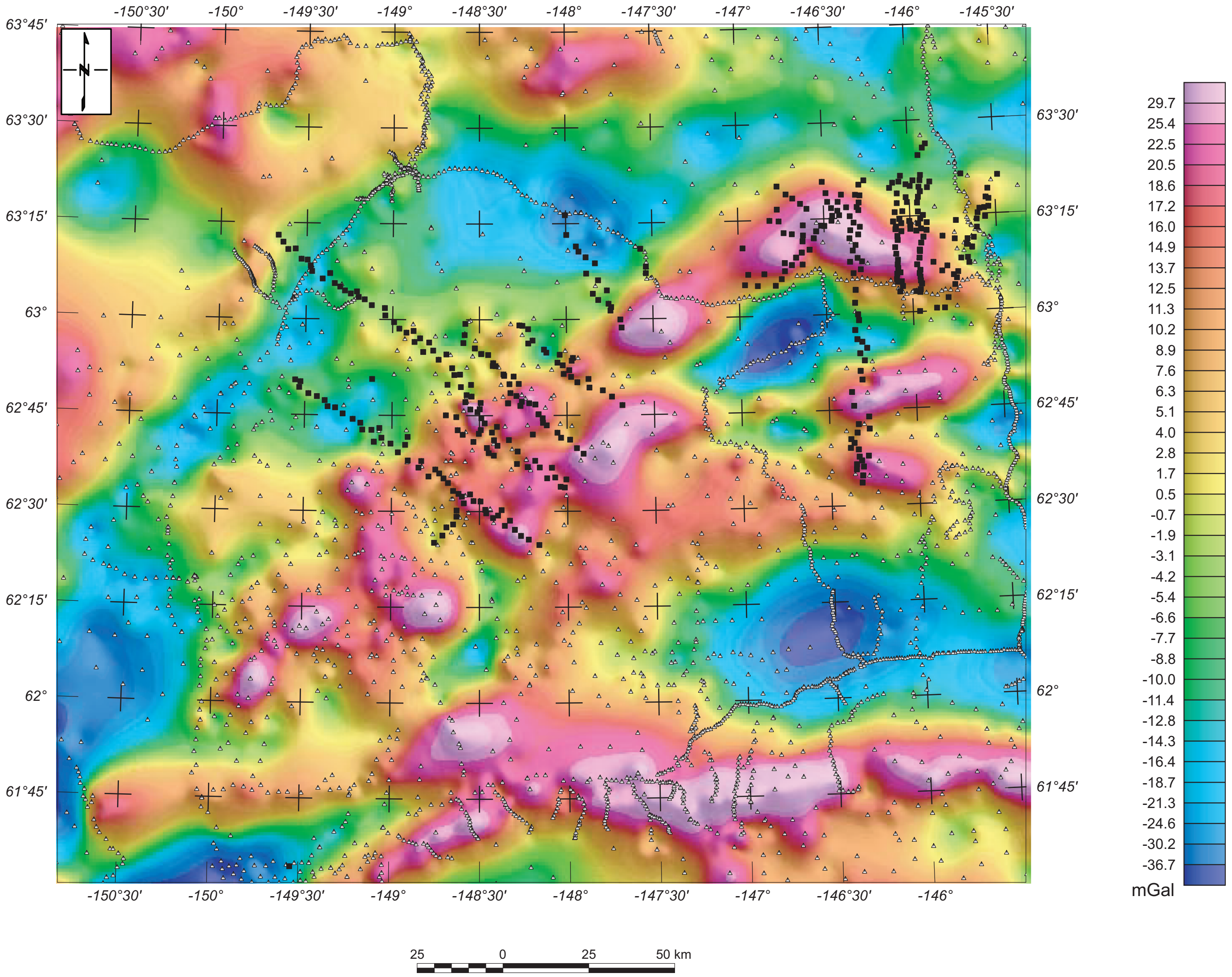

Figure 4. Isostatic gravity shaded relief map showing regional gravity stations (triangles) and newly collected data (squares). Note that color scale is nonlinear.

nov, 1957). The ratio between magnetization and density is held constant (in this application, the ratio is a magnetization contrast of 0.001 cgs-units [0.0126 SI] to a density contrast of 0.10 g/cm^3 [100 kg/m^3]), and remanent magnetization is assumed to be either negligible or in the same direction as the Earth's magnetic field. This process amplifies long wavelengths (deeper sources) at the expense of short wavelengths (shallow sources). The pseudogravity transformation is a useful tool for interpreting magnetic data because it allows for a more direct comparison with gravity anomalies. Furthermore, it generates anomalies with gradient maxima that lie approximately over the edges of their causative sources (especially for shallow sources), providing the means to approximate the extent of magnetic sources (Blakely, 1995). A residual magnetic potential map highlighting the shallow crustal features of pseudogravity for the study area is shown in Figure 5.

Maximum Horizontal Gradients

To better define the edges of geophysical sources and to help derive geophysical lineaments and terranes, the maximum horizontal gradients of both gravity and magnetic (magnetic potential) data were computer generated (Figs. 6 and 7, respectively). A technique described by Blakely and Simpson (1986) was used to calculate the maximum horizontal gradients that represent discrete maxima in the horizontal gradient field. Because these maxima reflect abrupt lateral changes in the density or magnetization of the underlying rocks and tend to lie over the edges of bodies with near vertical boundaries (Cordell and McCafferty, 1989; Grauch and Cordell, 1987), they can be used to estimate the extent of buried sources and to define the boundaries of geophysical terranes and internal terrane structures, such as folds and faults, which appear as an alignment of maximum horizontal gradients.

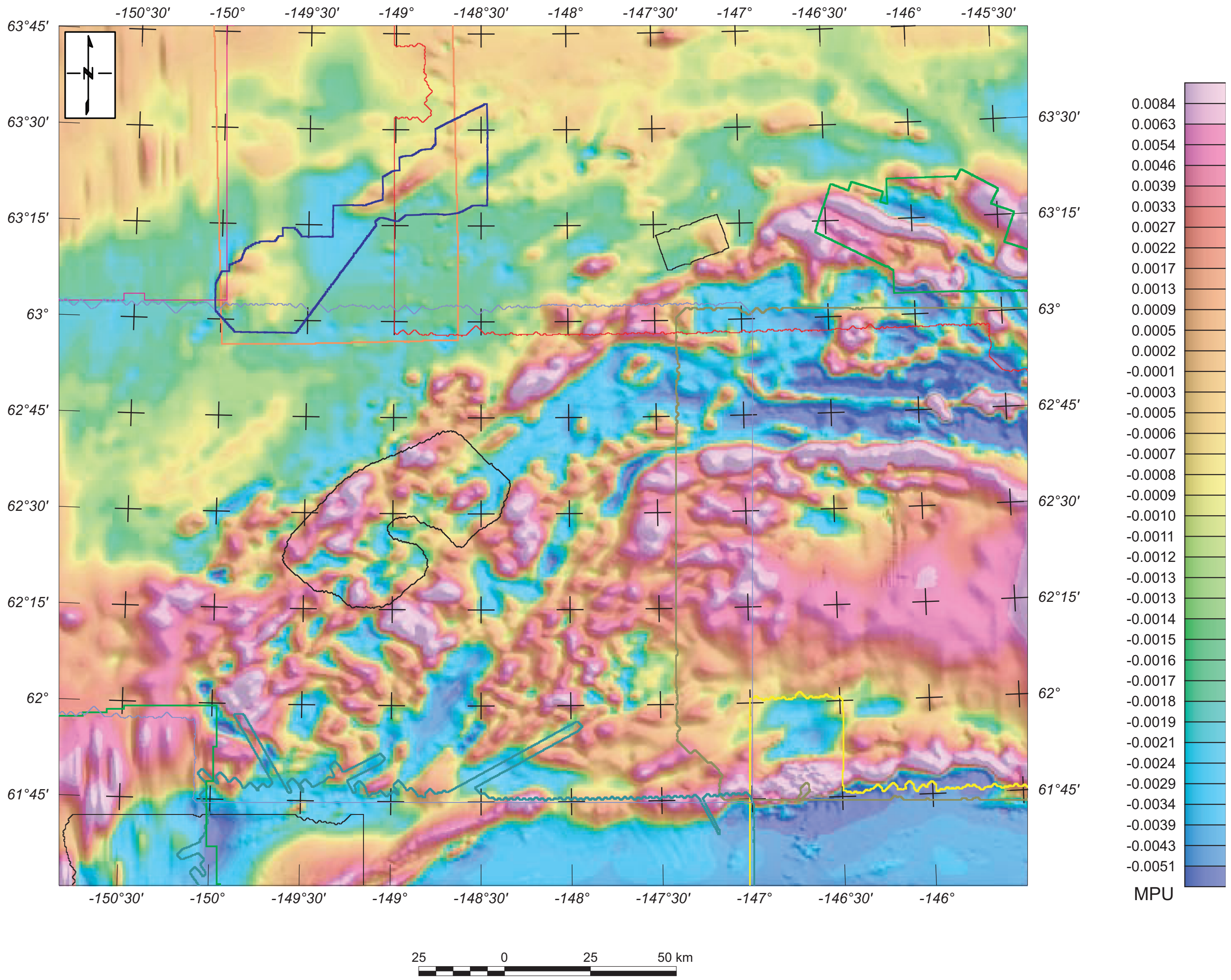

Figure 5. Residual magnetic potential shaded relief map of the study area. Colored lines outline individual aeromagnetic surveys shown in Figure 3B. Note that color scale is nonlinear.

Geophysical domains are defined in part with the maximum horizontal gradient method but also with other filtering and derivative methods that aid in highlighting the regional structural grain. Regions with a consistent anomaly trend, amplitude, or frequency content are defined as distinct geophysical terranes and are assumed to represent discrete crustal blocks with similar physical properties or sources.

Matched Filtering

Another filtering technique we have applied involves application of a matched-filtering algorithm (Syberg, 1972; Phillips, 2001). Generally, shallow potential field sources tend to produce shorter wavelength anomalies than deep sources. As a result, the frequency spectrum of the potential field can be filtered in a way that effectively isolates anomalies arising from different crustal levels, provided that the depths of anomaly sources are sufficiently distinct. In the study area, gravity and magnetic spectra were fit with three layers representing shallow, intermediate, and deep crustal layers. A map of each matched-filter layer should, therefore, approximate variations in the properties of rocks within that layer. Because it is unlikely, however, that sources throughout the entire study area fall neatly into one of these three layers, some of the anomalies may also partly reflect variations in the depth to sources, which might explain some of the coherency of features between adjacent layers.

The longest wavelength band, representing the deepest sources, probably reflects variations in magnetization of crystalline basement. The intermediate bandpass layers represent sources from intermediate to shallow depths that may outcrop at the surface. The shallowest layer, resulting from the highpass filter and reflecting the shortest wavelength anomalies, is due to sources at the surface or in the shallow subsurface. It is likely that some anomalies in this layer also result from noise in the data. Despite this, even the shallowest layer appears to resolve coherent fabrics that may be used to distinguish regional geophysical domains.

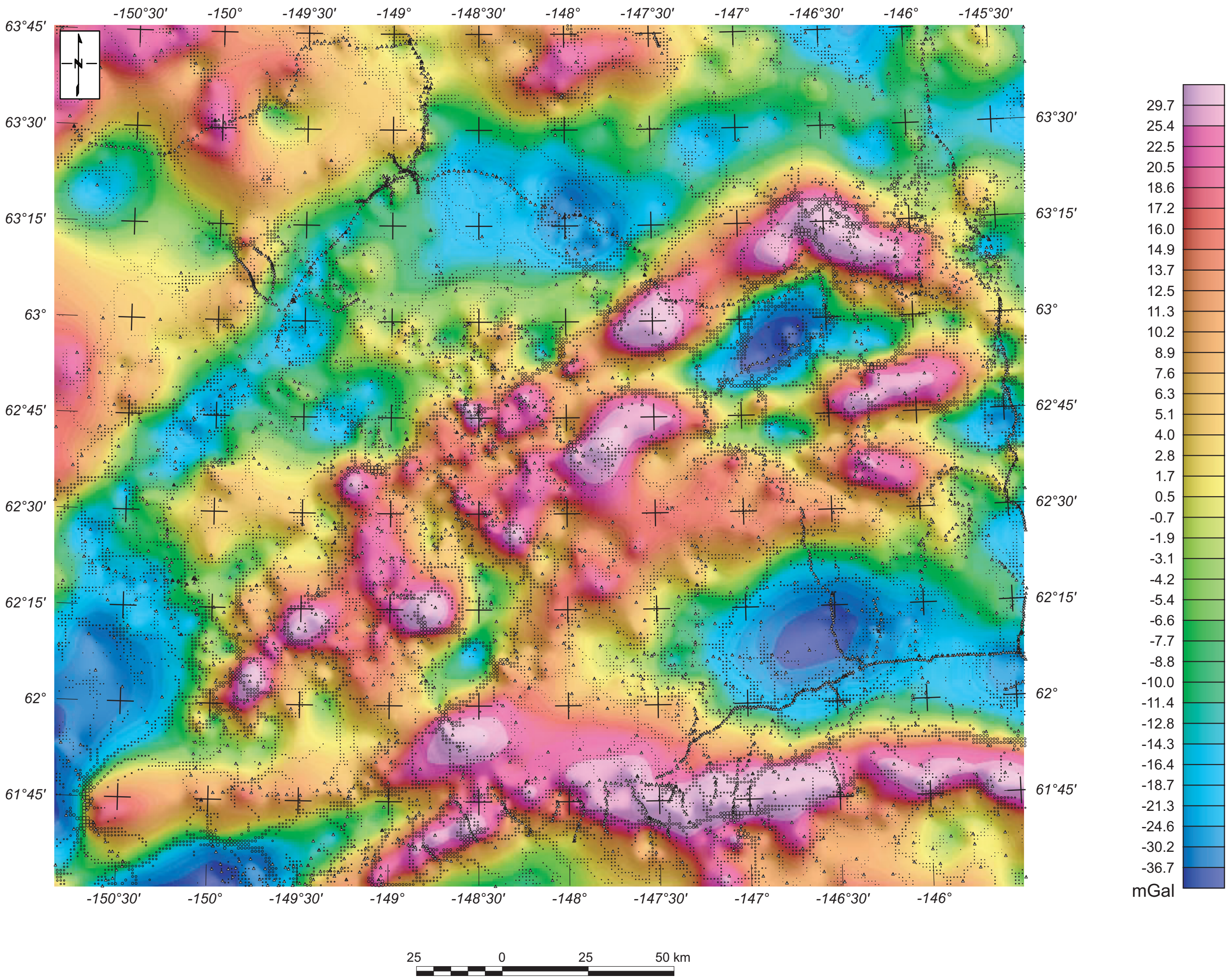

Figure 6. Isostatic gravity map with points of maximum horizontal gradient (dots) sized proportionally to their magnitude. Also shown are gravity stations (triangles).

GEOPHYSICAL MAPS

Gravity Field

A map of residual isostatic gravity of the study area (Fig. 4) shows relatively high gravity values over much of the Talkeetna Mountains and along the Talkeetna, West Fork, and Border Ranges faults and relatively low values over the Kahiltna Flysch and Susitna and Copper River basins. Much of the Talkeetna Mountains forms a prominent gravity high. The Talkeetna suture zone is expressed as a prominent step from high gravity over the Wrangellia terrane to low gravity values over much of the Kahiltna Flysch.

The gravity contrast across the Talkeetna suture zone is also reflected in a map of rock densities of samples taken from the surface (Fig. 8). Higher rock densities south of the Talkeetna suture zone indicate that some of the gravity anomaly across the suture zone is produced by rocks exposed in the shallow crust. Shallow crustal rocks, however, cannot entirely explain the gravity anomaly. Forward and inverse potential field models across the suture zone (Glen et al., this volume) demonstrate that a strong contrast in density and magnetic susceptibility extending into the deep crust is required to account for the observed anomalies associated with the fault zone, indicating that the Talkeetna suture zone is a profound crustal discontinuity. Matched-filtering of gravity data also indicates that the suture zone forms a prominent, deep-seated crustal discontinuity that is present at all crustal levels (Fig. 9).

Magnetic Field

Caution was taken in interpreting anomalies near survey boundaries that may represent artifacts of the grid merging process. Features, therefore, were not interpreted where they fell along flight-line directions (e.g., southern part of study area, survey 4094, Table DR1 [see footnote 1]) or along survey margins

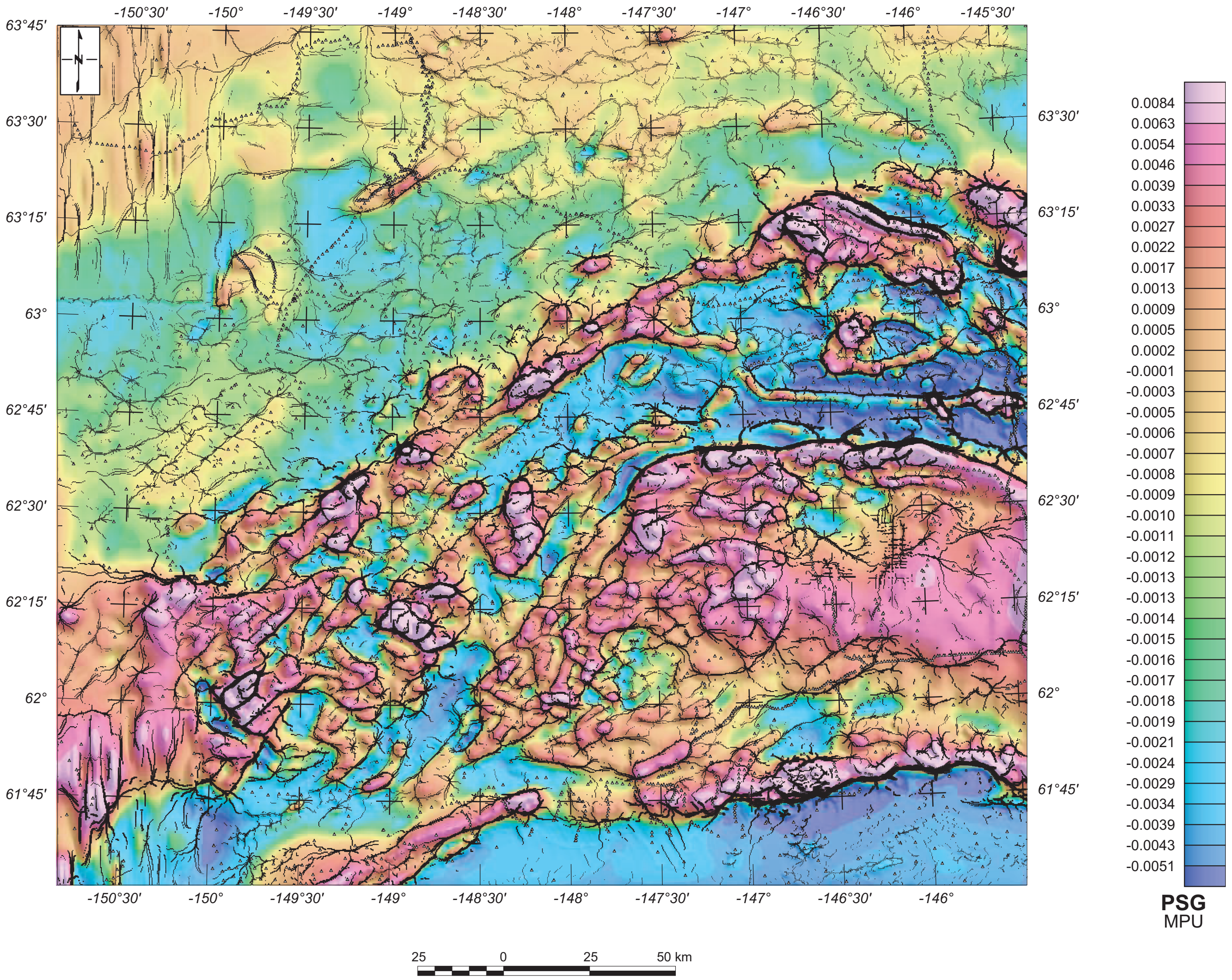

Figure 7. Residual magnetic potential map with points of maximum horizontal gradient (dots) sized proportionally to their magnitude.

where there are commonly slight mismatches between surveys (e.g., northwest part of study area, southern margin of survey 6035, Table DR1) that can produce spurious artifacts. In addition, we generally avoided detailed interpretations in regions where data are poor (i.e., low resolution or widely spaced, e.g., northwest and southwest corners of the study area, surveys 6035 and 6023, see Table DR1). Magnetic variations can also arise from departures of the aircraft from the designated draped or fixed elevation. This is a potential problem in interpreting older surveys where aircraft elevations were not available. The effect is most significant in widely varying terrain and can result in accentuating anomalies over ridge crests and smoothing anomalies over valleys.

The residual magnetic potential map (Fig. 5), which shows high values along the Talkeetna and Border Ranges faults and over the Copper River and southern Susitna basins and low values over the flysch basins, reflects variations in rock magnetic susceptibility. One of the most striking features in this map is the contrast across the Talkeetna Suture Zone between the weakly magnetic flysch basin to the north and the intensely and variably magnetic rocks of Wrangellia to the south. Equally impressive are a series of prominent narrow magnetic highs in the vicinity of the Talkeetna, West Fork, and Border Ranges faults that correspond to major terrane bounding sutures and are probably due to strongly magnetic remnants of island arc and oceanic crustal rocks that were sandwiched between the accreting terranes and the edge of the margin to which they were accreting.

Similar to the gravity data, match-filtered magnetic maps (Fig. 10) indicate that the Talkeetna suture zone is apparent throughout the crustal cross section and forms a prominent deep-seated structure.

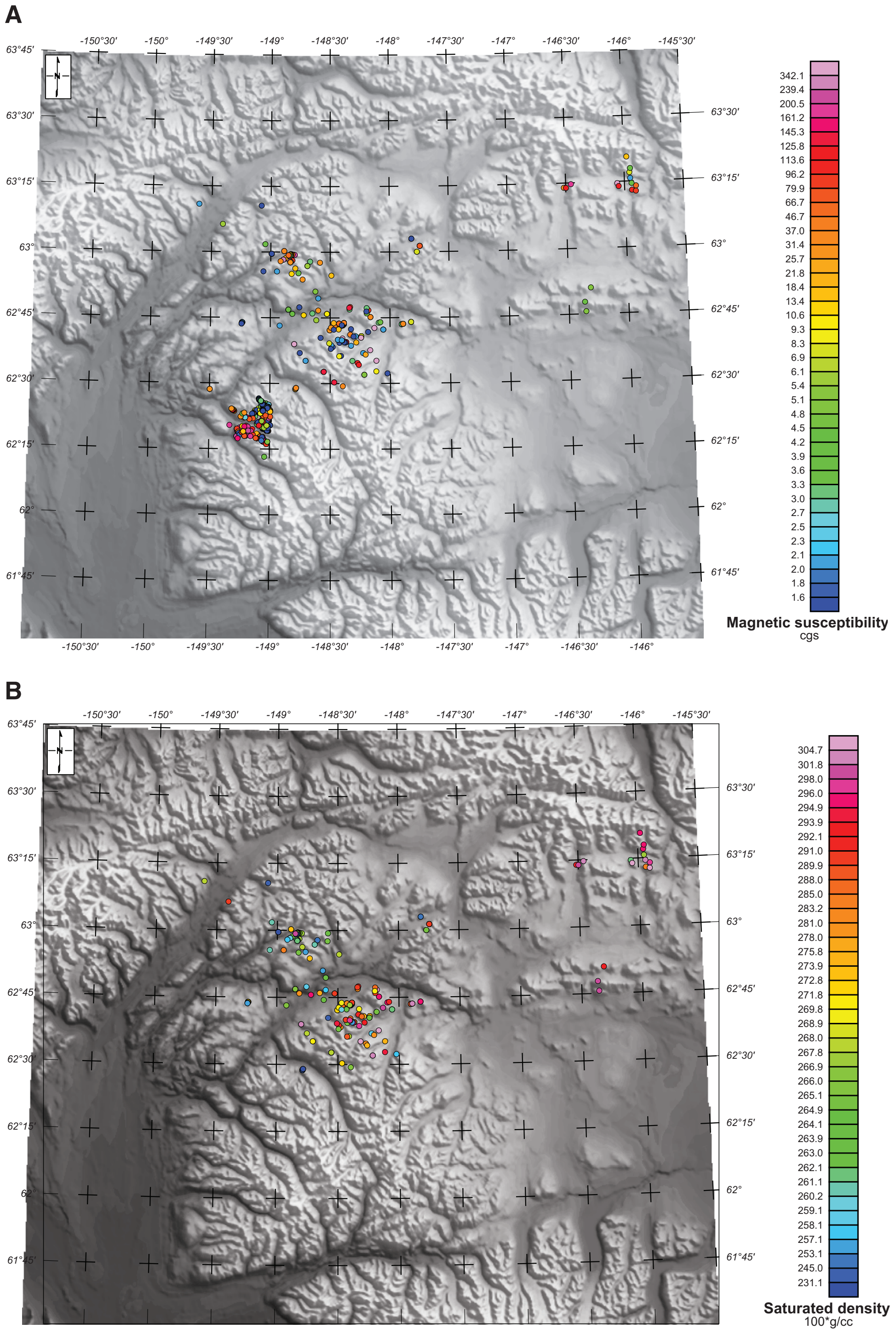

Figure 8. Maps showing rock property data: (A) magnetic susceptibility sample localities colored proportionally to their magnitude and (B) rock-density sample localities superimposed on a color grid of density values.

GEOPHYSICAL FEATURES

Geophysical domains are regions with internally consistent geophysical (gravity or magnetic) fabric that are typically bound by discrete gradients in magnetization or gravity (Glen et al., 2004). In defining domains, we have taken into account the overall amplitude and fabric of the domain (in contrast to surrounding areas), the nature of internal anomalies, as well as gradients and structural features (such as contacts, faults or fault zones, and lineaments) that define their boundaries. In general, the delineation of geophysical domains is intended to aid understanding of their underlying causes, to relate them to

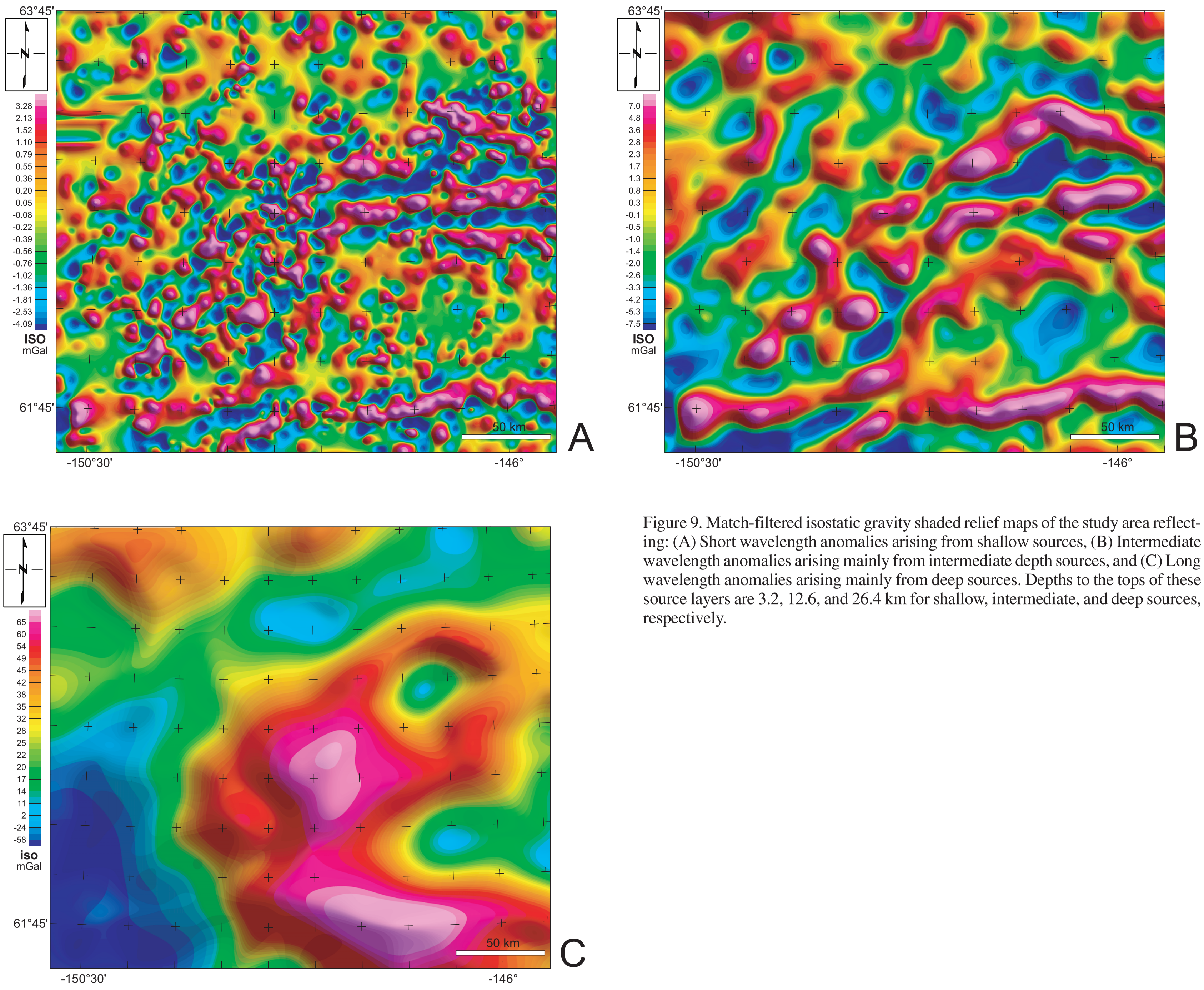

Figure 9. Match-filtered isostatic gravity shaded relief maps of the study area reflecting: (A) Short wavelength anomalies arising from shallow sources, (B) Intermediate wavelength anomalies arising mainly from intermediate depth sources, and (C) Long wavelength anomalies arising mainly from deep sources. Depths to the tops of these source layers are 3.2, 12.6, and 26.4 km for shallow, intermediate, and deep sources, respectively.

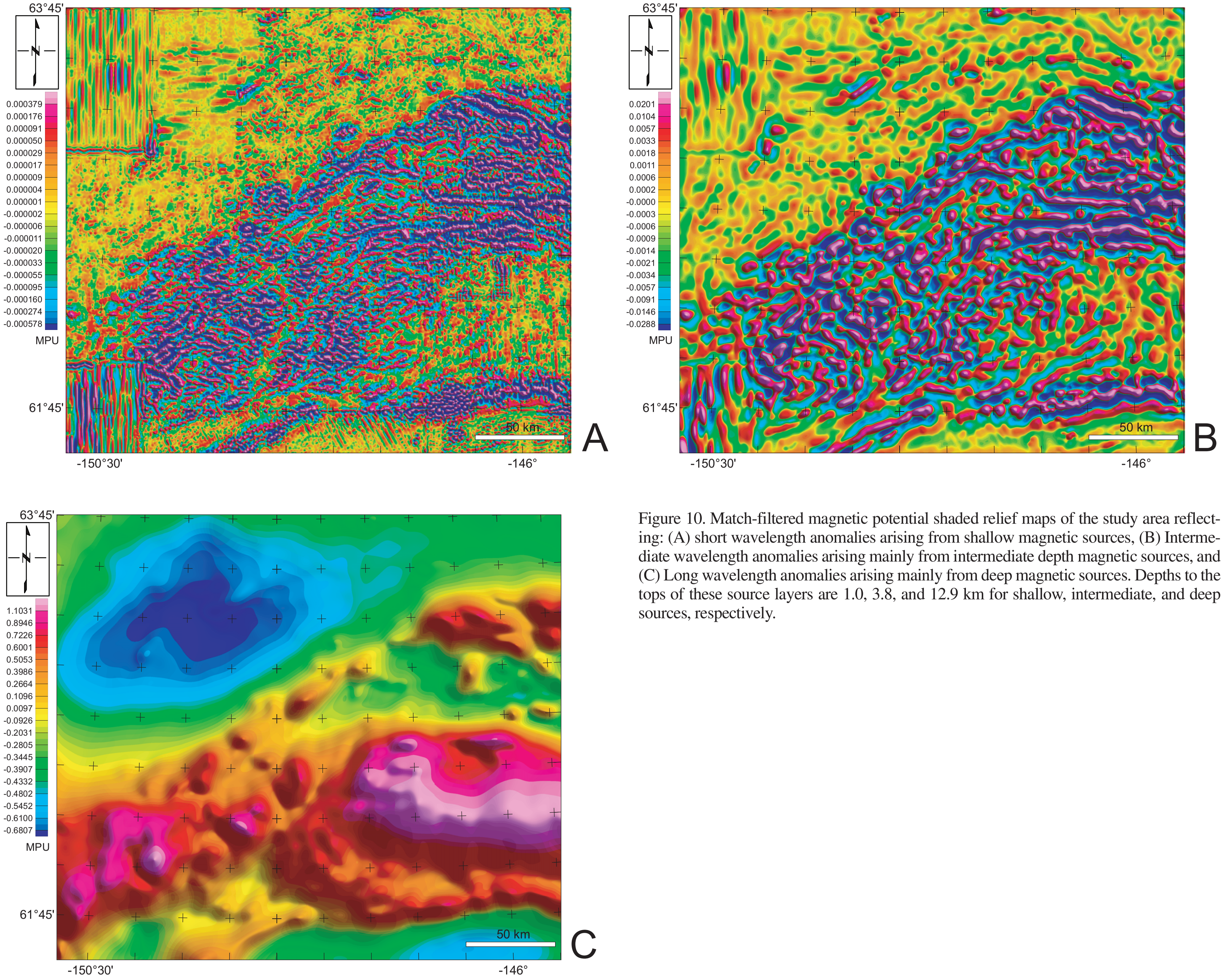

Figure 10. Match-filtered magnetic potential shaded relief maps of the study area reflecting: (A) short wavelength anomalies arising from shallow magnetic sources, (B) Intermediate wavelength anomalies arising mainly from intermediate depth magnetic sources, and (C) Long wavelength anomalies arising mainly from deep magnetic sources. Depths to the tops of these source layers are 1.0, 3.8, and 12.9 km for shallow, intermediate, and deep sources, respectively.

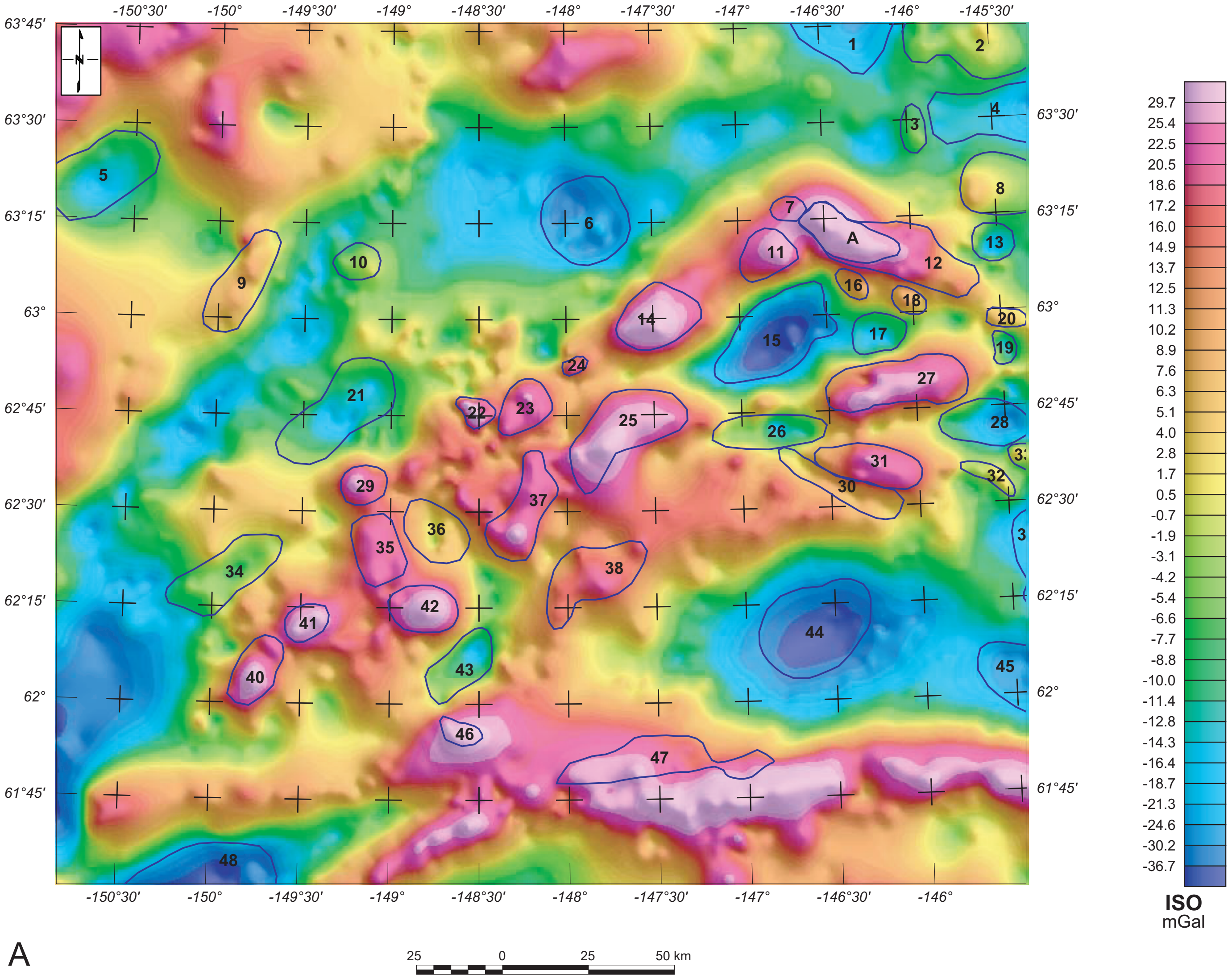

Figure 11 (*on this and the following two pages*). (A) Isostatic gravity field domains and lineations superimposed on a map of isostatic gravity: local- to intermediate-scale domains.

their geologic counterparts, and to resolve the nature of transitions between domains.

A number of techniques have been employed to define geophysical domains. Gravity and magnetic domain maps (Figs. 11 and 12) were created by visual inspection of gravity, magnetic, and derivative geophysical maps and by drawing polygons around similar geophysical areas and using geophysical lineaments as a guide to locating domain boundaries. The maximum horizontal gradient method described above was used to derive gravity and magnetic lineations (Figs. 11 and 12) that often mark the edges of geophysical domains.

The extent of geophysical domains is derived in part from these maximum horizontal gradient-delineated boundaries and also by using filtering and derivative methods that aid in highlighting regional fabric. A shaded relief filter, for example, of the potential field maps aids in highlighting the regional structural grain. As a result, shaded relief with varying illumination azimuths and angles can be useful in revealing various sets of geophysical fabrics. Areas that carry a consistent regional amplitude, anomaly trend, or frequency content in contrast to their surroundings were defined as distinct geophysical domains and considered to represent discrete crustal blocks having similar physical properties or sources (note, however, that some anomalies appear as continuous and uniform features but may arise from several different, geophysically indistinguishable sources).

Geophysically defined boundaries may take several forms, such as: (1) a stepped anomaly that forms along an edge of a large crustal block with relatively uniform density or magnetic properties (e.g., dip-slip fault or edge of a batholith); (2) a long, narrow, linear anomaly generated over a source whose vertical extent is much greater that its width (e.g., a dike or alteration zone along a

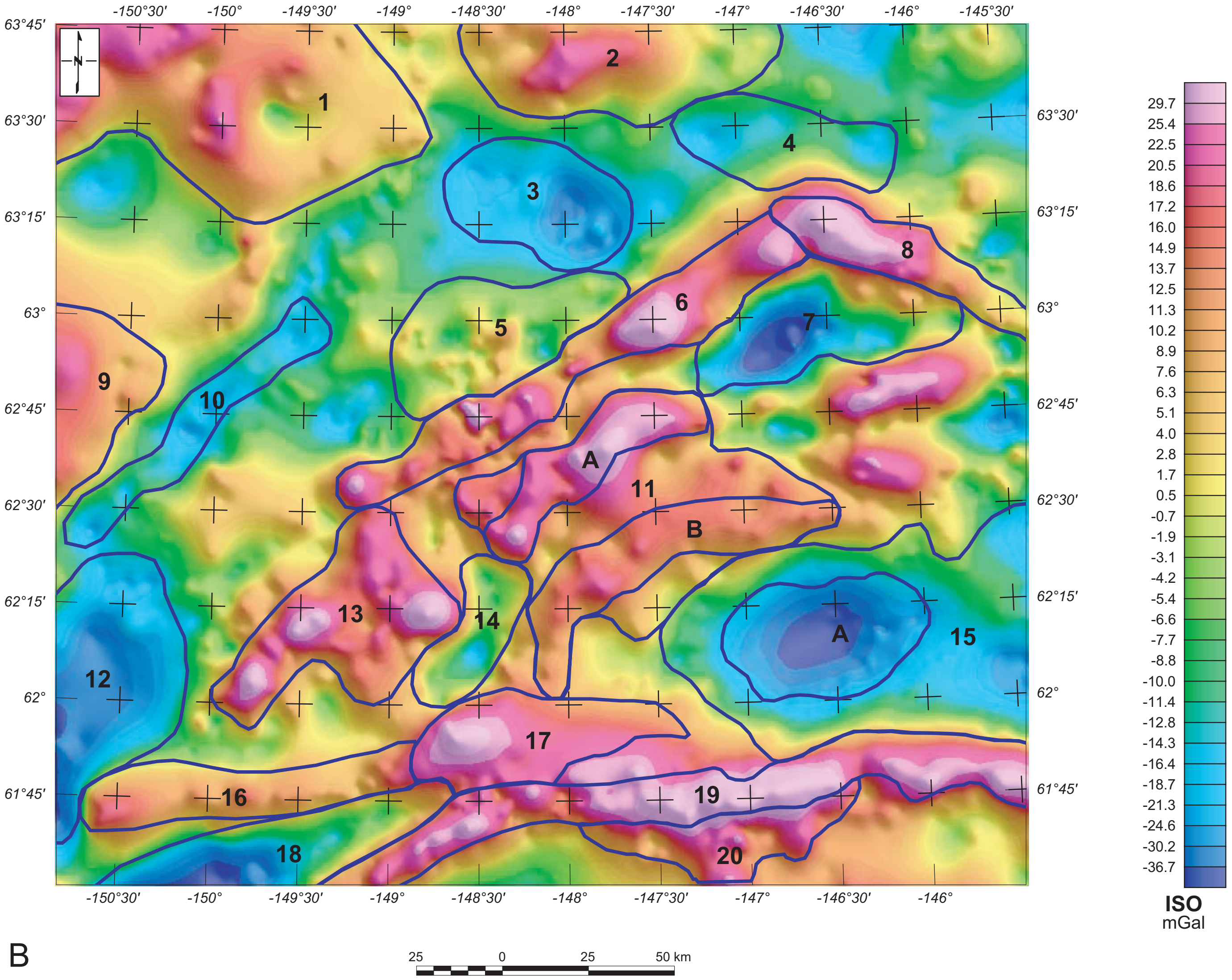

Figure 11 (*continued*). (B) Isostatic gravity field domains and lineations superimposed on a map of isostatic gravity: regional-scale domains.

fault); or (3) a linear feature observed as the abrupt termination and/or alignment of numerous high and low anomalies of different sizes and intensities (e.g., lateral fault).

The majority of geophysical domains whose sources are relatively well constrained occur in the Talkeetna Mountains, where most of the geologic mapping has been concentrated (particularly along the Talkeetna transect, Glen et al., this volume). Much less is known about possible anomaly sources elsewhere, for instance in the Copper and Susitna River basins or the Alaska Range, where map coverage is poor or where source rocks and related units do not outcrop.

Geophysical Domains Table

A table of geophysical domains (Table DR2, [see footnote 1]) is keyed to features outlined on the gravity and magnetic domain maps (Figs. 11 and 12). The table includes local-scale anomalies up to tens of kilometers in extent (e.g., individual plutons or faults) that arise from discrete source bodies in the shallow and midcrust. The table also includes regional-scale features (hundreds of kilometers in extent) that may be sourced in the deep crust. The focus of this work is on intermediate- to regional-scale features, with the aim of relating geophysical domains to their geologic counterparts and understanding their origin and relation to crustal structures and composition. At the broadest scale, this work is intended to define the geophysical character of tectonostratigraphic terranes (Table DR3), estimate their extent, and resolve the nature of transitions between terranes.

Regional Geophysical Domains

Regional-scale domains are defined here as areas from tens to hundreds of kilometers in extent that share a common character in contrast to surrounding regions (e.g., a domain may define

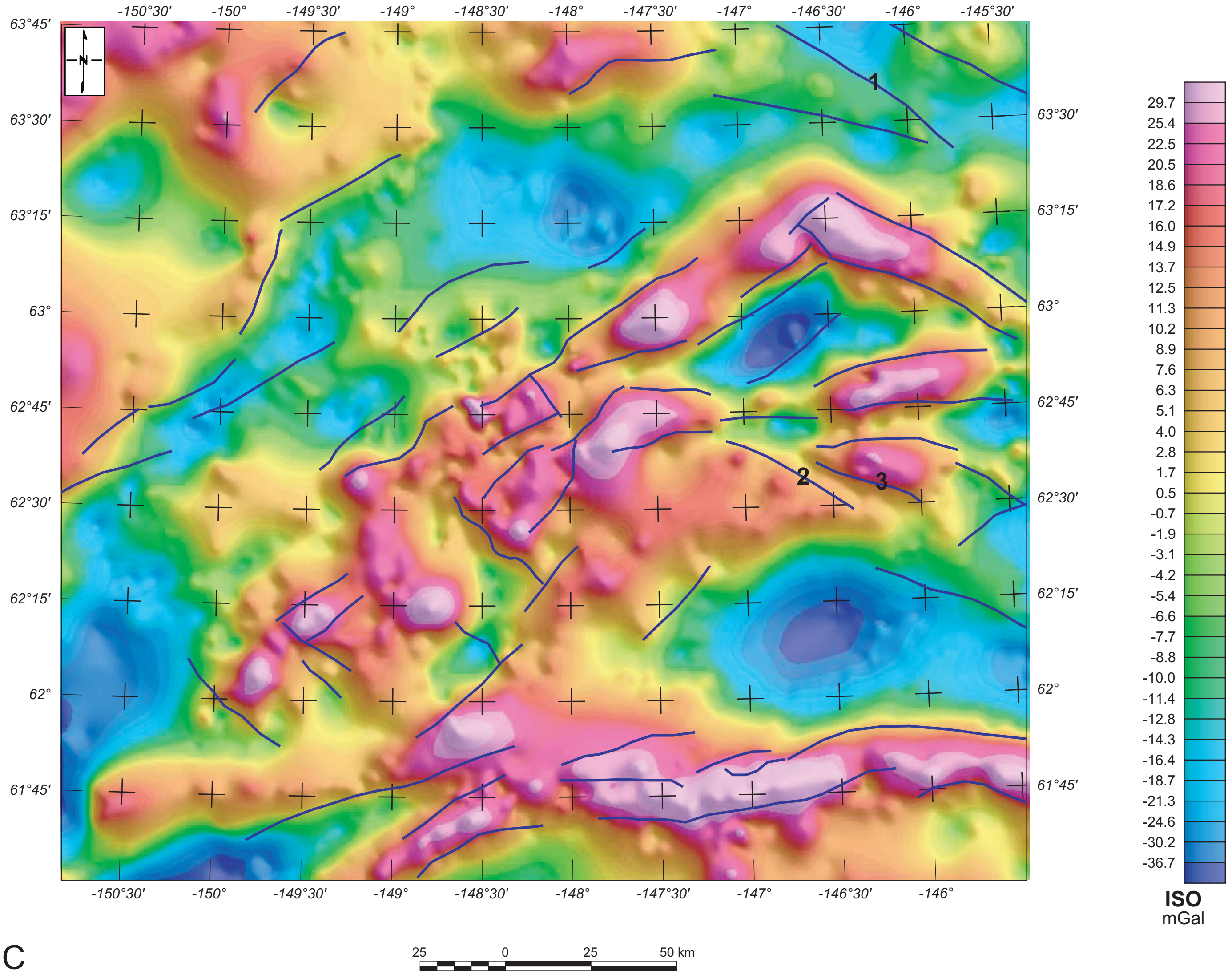

Figure 11 (*continued*). (C) Isostatic gravity field domains and lineations superimposed on a map of isostatic gravity: regional lineations.

a zone of consistent fabric). Some regional domains comprise assemblages of smaller domains of similar character. Identification of regional-scale features is aided by standard- and long-wavelength geophysical maps, fabric analysis, contrasts of dominant frequencies, and contrasts in mean values.

A regional-scale geophysical feature or domain may reflect a region of common geologic, tectonic, or magmatic history, and it may be bounded by deep crustal to subcrustal faults. In the study area, regional geophysical domains typically correspond to all or parts of previously identified tectonostratigraphic terranes as defined by Silberling et al. (1994). Unlike tectonostratigraphic terranes, however, which are fault-bounded packages of crust that have distinctly different geologic histories from neighboring rocks, geophysical domains are distinguished solely by their crustal rock properties. For this reason, interpreting geologic units, structures, or assemblages based on geophysical grounds in the absence of other information, should be done with caution.

An assessment of the regional geophysical domains we have defined in this study and a comparison of them with previously defined tectonostratigraphic terranes, overlap assemblages (Nokleberg et al., 1994; Silberling et al., 1994), and tectonogeophysical domains (Saltus et al., 1997, 1999c) is given in Table DR2 and discussed below. Based on the geophysics, we have redefined the extent of tectonostratigraphic terranes. Figure 13 shows the boundaries for our modified terrane designations.

Wrangellia

Wrangellia's northwestern margin, which borders on a Jurassic and Cretaceous flysch basin, is particularly well defined geophysically because it is marked by a series of narrow gravity and magnetic highs similar to the contact between Peninsular

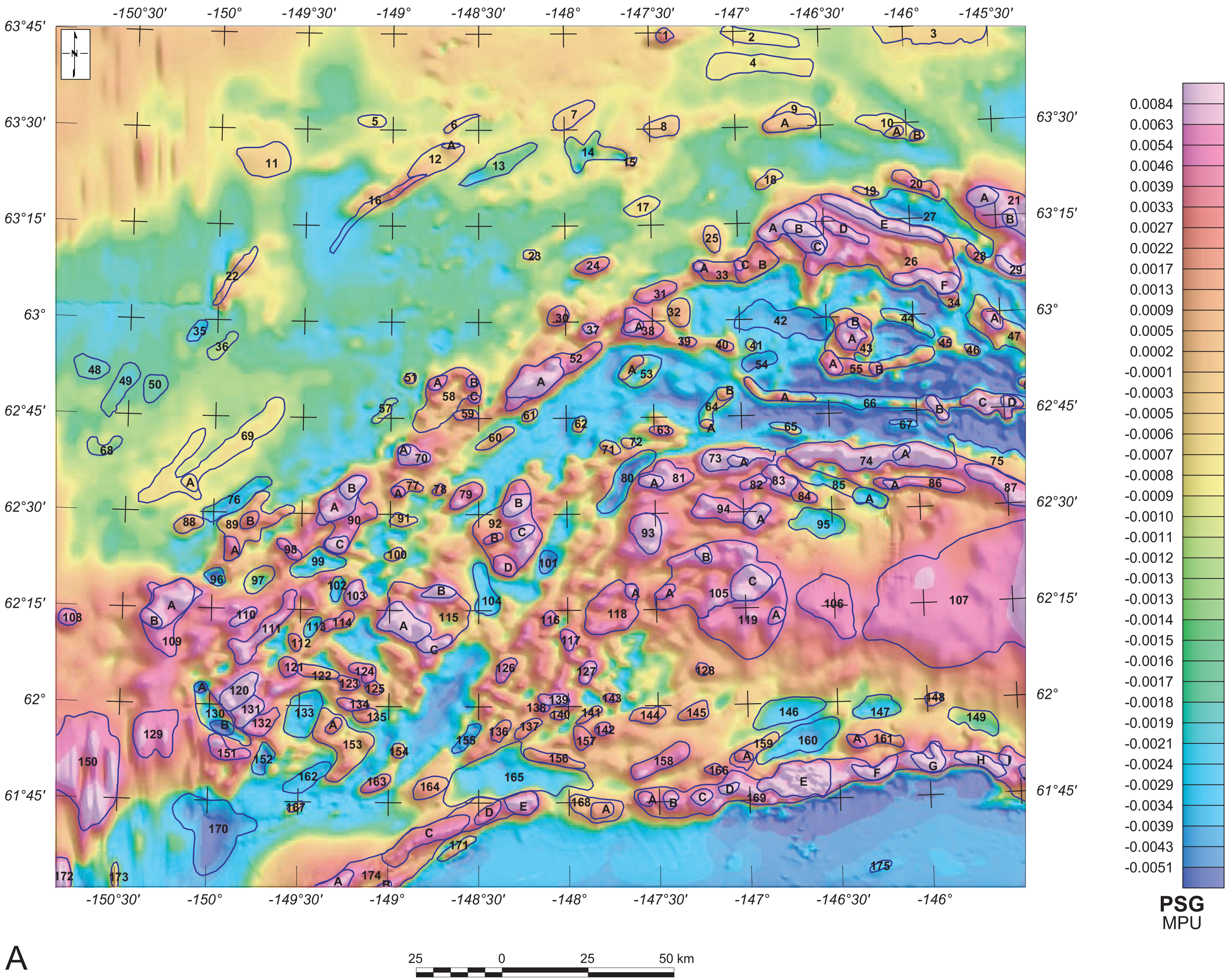

Figure 12 (*continued on the following three pages*). (A) Magnetic potential domains and lineations superimposed on a map of residual magnetic potential: local- to intermediate-scale domains.

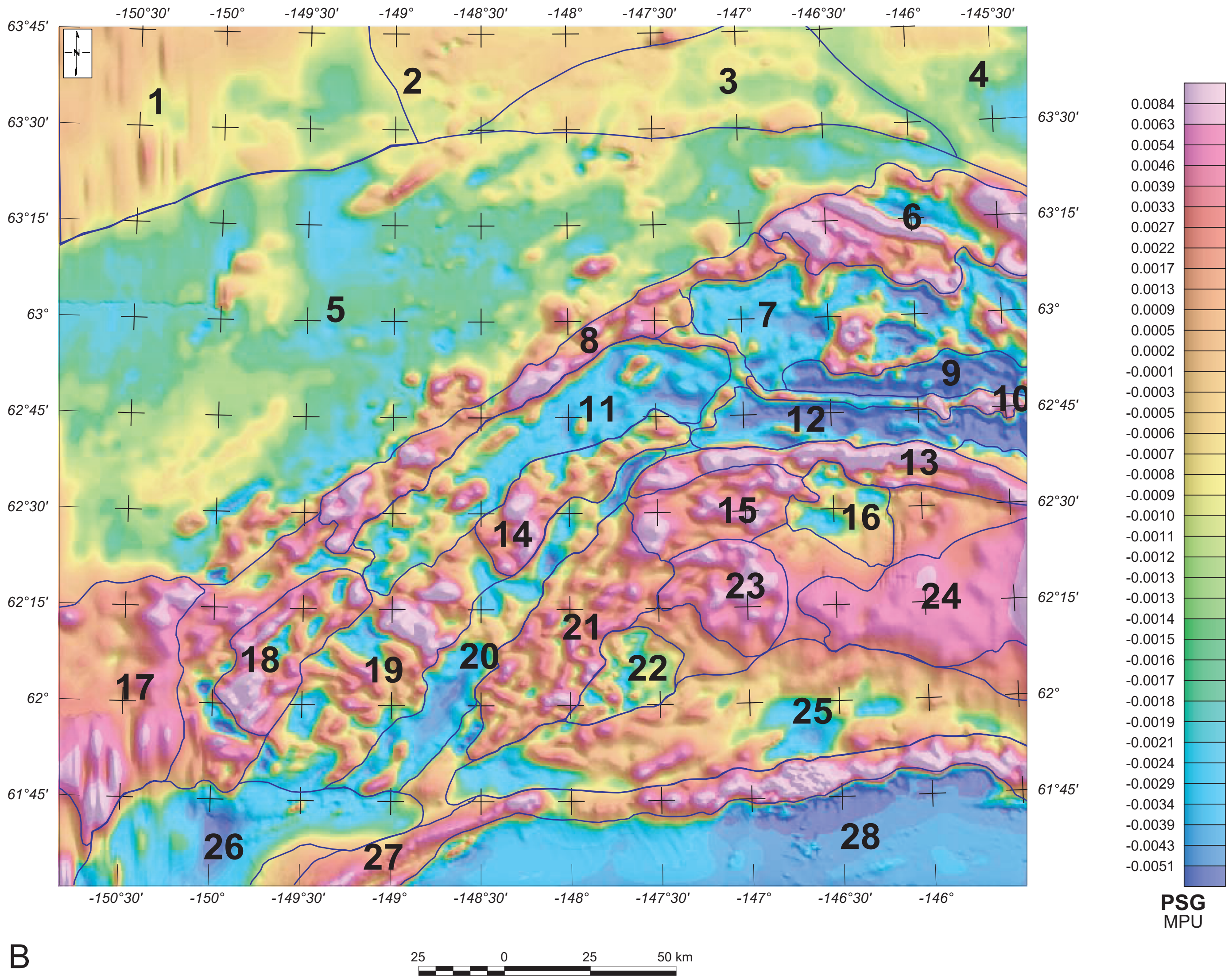

Figure 12 (*continued*). (B) Magnetic potential domains and lineations superimposed on a map of residual magnetic potential: regional-scale domains.

and Chugach terranes. In contrast, the position of Wrangellia's southern boundary (Fig. 13A) as defined by Jones et al. (1987) does not correspond with any distinguishable geophysical feature. This boundary was originally tied to intrusive rocks within the Talkeetna Mountains that were thought, based largely on their age, to be part of the Talkeetna arc—a distinctive component of the Peninsular terrane. New isotopic data reveal the previously obtained ages are not reliable, a fact that weakens a possible link between the intrusive rocks and the Peninsular terrane.

We suggest, instead, that a prominent narrow dense and magnetic zone (best seen in the filtered data that reflect intermediate- to deep-sourced anomalies, Figures 9 and 10) located several tens of kilometers to the southeast along the western Copper River basin, is a better candidate for the Wrangellia and Peninsular terrane boundary (Fig. 13B).

Moving the contact to the southeast results in a consistent character among all three major terrane boundaries in the Talkeetna Mountains region (Wrangellia/Peninsular, Wrangellia/Kahiltna, and Peninsular/Chugach) and ensures that all the terranes have internally uniform geophysical fabrics, well-defined geophysical gradients at their margins, and prominent narrow magnetic and gravity highs between them. With these newly defined boundaries, the Wrangellia terrane is characterized by short-wavelength and high-amplitude magnetic highs and lows due largely to numerous volcanic and ultramafic bodies associated with the Nikolai Greenstone.

Peninsular

This newly defined Peninsular-Wrangellia terrane boundary results in a relatively coherent character for the Peninsular terrane that consists of variable intensity and high-frequency magnetic

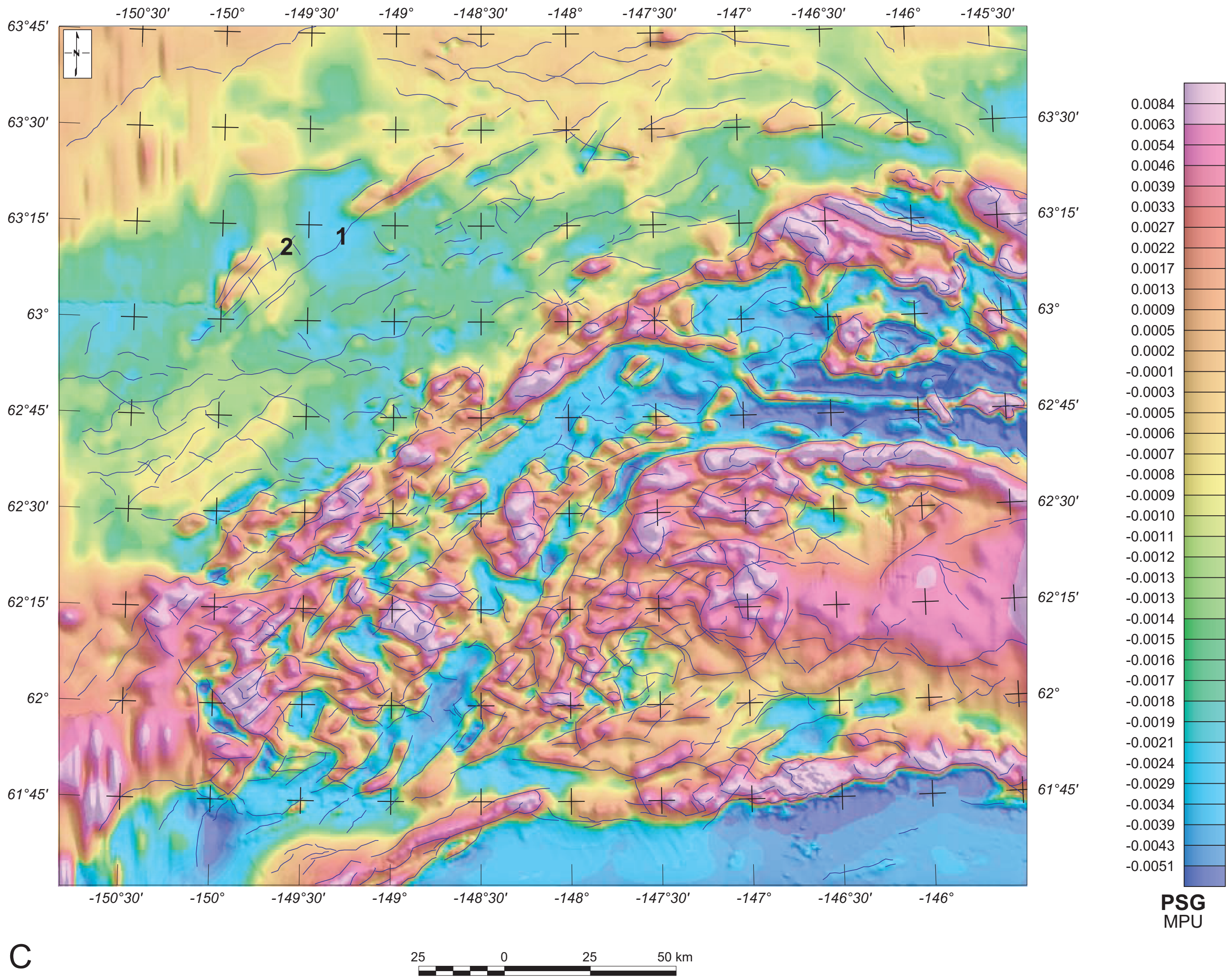

Figure 12 (*continued*). (C) Magnetic potential domains and lineations superimposed on a map of residual magnetic potential: lineations.

fabric dominated by the broad Copper River basin magnetic-high/gravity-low anomaly and is enclosed by narrow bands of magnetic and gravity highs. Furthermore, it eliminates the need to characterize two distinct Peninsular geophysical domains as Saltus et al. (1997) had done in order to satisfy the previously held belief that the Peninsular/Wrangellia boundary lay farther to the west (see discussion above).

Similar to the northern edge of Wrangellia, the bounding highs surrounding the Peninsular terrane mark the terrane's contact with its neighboring terranes—highs north and west of the Copper River basin represent the Peninsular/Wrangellia terrane boundary, whereas highs south of the Copper River basin define the Peninsular/Chugach boundary.

In the case of Wrangellia's northern boundary, however, gravity and magnetic highs were included as part of Wrangellia because they are attributed to mafic and ultramafic rocks associated with the Nikolai flood basalts—a defining unit of the Wrangellia terrane (Fig. 13B). It is less clear, in the case of the Peninsular terrane, whether its surrounding narrow highs should be included as part of the Peninsular terrane, as part of its neighboring terranes, or as entirely separate terranes. We have adopted the view of Case et al. (1986) and Burns (1985), who consider the Tazlina mafic-ultramafic belt as part of the Talkeetna arc and, therefore, assign the magnetic highs of the Northern Chugach Mountains as part of the Peninsular terrane. In addition, we have included the band of anomaly highs at Peninsular's northern and western edges as also part of the Peninsular terrane.

North Talkeetna and Kahiltna Flysch Basins

Jurassic and Cretaceous flysch is located over a region of subdued crustal gravity and magnetic fields that end abruptly at the Talkeetna suture zone in contact with a strip of narrow gravity and

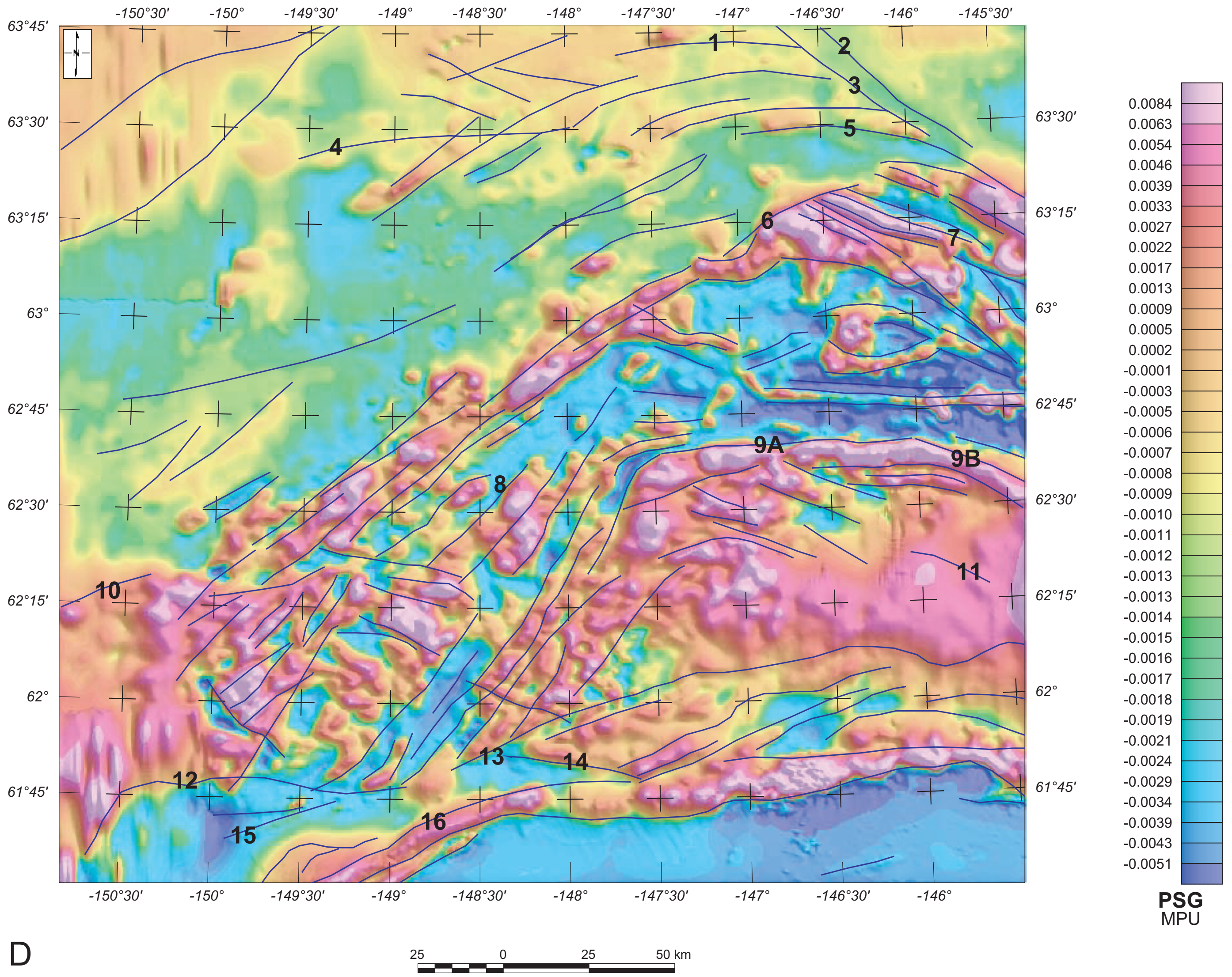

Figure 12 (*continued*). (D) Magnetic potential domains and lineations superimposed on a map of residual magnetic potential: regional lineations.

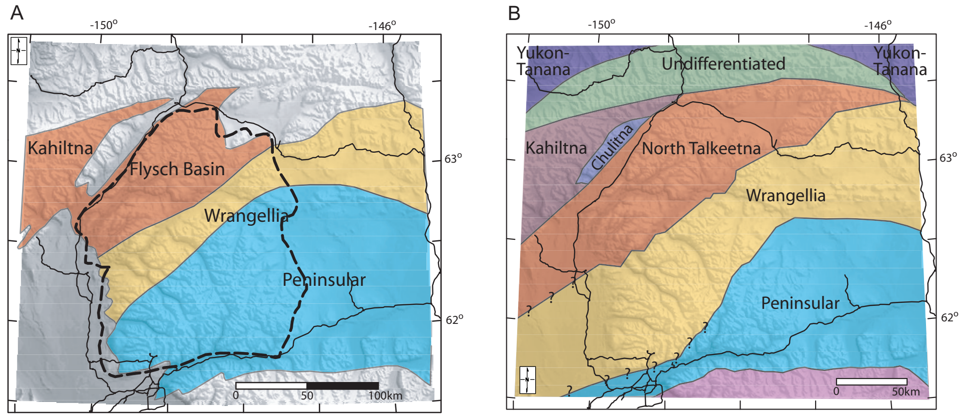

Figure 13. (A) Tectonostratigraphic terrane map after Jones et al. (1987), and (B) revised tectonostratigraphic terrane map (based on geophysical character of terranes).

magnetic highs at Wrangellia's northern margin. Flysch is distributed across two subtly distinct geophysical domains, however, which suggests the two regions may reflect two distinct tectonic terranes (Fig. 13B). This interpretation is consistent with recent sediment provenance mapping of the flysch that reveals two distinct sedimentary basins (Ridgway et al., 2002). Sediments within the northwestern domain in the Alaska Range were derived from a continental source and were shed southward. Sediments from the southeastern domain were derived from Wrangellia and shed to the northwest. Although both basins are characterized by subdued gravity and magnetic anomalies, Kahiltna sedimentary rocks lie over a terrace in the gravity characterized by a slightly higher mean isostatic gravity field that is separated from the North Talkeetna basin sedimentary rocks by a northeast-trending gravity gradient aligned with the Broad Pass graben.

Local- to Intermediate-Scale Geophysical Domains

Intermediate- to local-scale geophysical domains are defined here as typically constituting large (order of several tens of kilometers—e.g., reflecting crustal rifts or sutures, structural basins or ranges, or batholiths) to moderately sized (order of a few to tens of kilometers—e.g., reflecting individual plutons or faults) coherent anomalies arising from discrete source bodies that reside in the shallow to midcrust. Identification of these features is aided by standard geophysical maps, long- and short-wavelength maps, and maximum horizontal gradients maps. Intermediate- to local-scale geophysical domains discussed in this report are shown in Figure 12 and discussed in Table DR2 (see footnote 1). Although a few local-scale anomalies are described here, a detailed assessment of local-scale anomalies is beyond the scope of this study.

Geophysical Character of Faults

Although the McKinley strand of the Denali fault zone is one of the most prominent physiographic features in Alaska (Fig. 1), its geophysical expression is subdued in the study area. This is in strong contrast to the Border Ranges fault, which crosscuts the Chugach Mountains to the south. The lack of any prominent geophysical expression of the Denali fault is due to the fact that the fault juxtaposes geophysically similar low-density, weakly magnetic continental rocks, whereas the Border Ranges fault, marking the suture between the Peninsular and Chugach terranes, is marked by dense, strongly magnetic oceanic crustal rocks incorporated during closure of the intervening basin.

Between the Denali and Border Ranges fault zones (Fig. 1), the dominant northeast trend of faults and of geophysical lineaments parallels the overall trend and internal fabric of tectonostratigraphic terranes. Several linear geophysical features (e.g., geophysical gradients, the alignment of anomalous highs and lows, or the truncation of anomalies) southeast and subparallel to the Talkeetna suture zone are interpreted as faults. In addition to identifying previously unmapped faults, the geophysical signatures can be used to extend faults into areas where they are covered and can potentially be used to make estimates of fault dip or estimate fault offsets.

Many of the northeast-trending shallow crustal faults (including the East Broad Pass and Watana Creek faults and the Susitna Lineament [Smith et al., 1988], etc.) were active in Tertiary time and may have accommodated crustal escape and deformation related to the transport of crust through the Alaska orocline due to slip along major dextral shear zones like the Denali and Border Ranges faults (Glen, 2004). Many faults within the Talkeetna Mountains have experienced several episodes of movement, although the ages of primary motion and reactivation are often unknown (O'Neill et al., 2003b). Most faults exposed at the surface with documented Tertiary movement, such as the Broad Pass and Watana Creek fault, occur in moderately wide physiographic zones (5–15 km wide) overlying deeper structures. No direct connection is known between the relatively young faults in the shallow to middle crust and any single deep crustal fault that represents the original terrane suture. Surface features like the Fog Lakes and Broad Pass grabens, which generally coincide with major tectonostratigraphic terrane boundaries, are not themselves the primary structures, nor are the surface faults necessarily of the same character, offset, or orientation as those involved in the initial suturing.

Talkeetna Suture Zone

The Talkeetna suture zone includes a 2–12-km-wide zone of complex structure in the shallow subsurface ($\leq$3 km). It overlies a first-order geophysical and structural discontinuity between dense, strongly magnetic, oceanic Wrangellia crust and the less dense, weakly magnetic transitional crust beneath the flysch basins; the discontinuity is manifest as a prominent gravity and magnetic gradient between the flysch and Wrangellia. The potential field data indicate that this structure extends into the middle to deep crust. Surface traces within the fault zone indicate a complex, long-lived history as young as Tertiary in age involving both strike-slip and dip-slip motion. This suggests that the feature has reactivated since its inception during Mesozoic terrane collision and has influenced the location of overlying Tertiary faulting. It is important to note that although we consider that the Talkeetna suture zone corresponds with the Wrangellia terrane boundary, the shape and orientation of the fault zone does not reflect the original shape of the northern margin of Wrangellia. The original crustal boundary was likely much more complex but, like many sutures, has evolved into a relatively straight structure during collision. In addition, because sutures form natural zones of weakness, this effect is probably accentuated by episodes of subsequent faulting and reactivation.

The sense of dip of the structure in the shallow to midcrust has been inferred from modeling the dense, magnetic bodies located along the northwest edge of the Wrangellia terrane (Glen et al., 2003). Although this analysis is hampered by superimposing anomalies from different sources on opposing sides of the fault, there are several places along the fault zone where relatively isolated anomalies associated with Wrangellia are juxtaposed with relatively weakly magnetized and less dense flysch. Where well-defined magnetic anomalies occur, dip estimates for the Talkeetna suture zone structure indicate that it is steeply dipping (Glen et al., this volume). Model inversions based on gravity data across the Talkeetna transect indicate that the structure dips to the northwest (Glen et al., 2003). This is consistent with potential field model dip estimates from a segment of the fault located a couple of hundred kilometers to the southwest of the transect (Griscom, 1979) that suggest the fault dips to the northwest. However, models of prominent isolated magnetic anomalies located just north and south of the transect suggest that the fault dips steeply to the southeast. This discrepancy may indicate that either the fault changes dip along its length or that entirely different faults with different dips bound each of the modeled anomalies, as might occur if the fault zone represents a flower structure over the suture. In either case, the suture zone represents a steeply dipping, major crustal boundary that extends throughout upper crust.

Because surface features above the Talkeetna suture zone are relatively young and localized by older (presumably late Mesozoic) structures, the original terrane boundaries have been significantly modified. If a primary suture between two terranes, for example, was a complex, interdigitating margin, subsequent faults would straighten and simplify that margin, offsetting fragments of both terranes in a complex central zone (Brew, 2001). As a result, parts of adjoining tectonostratigraphic terranes overlap mapped surface faults, resulting in a broad zone of apparent microterranes extending to both sides from the original suture. For example, fragments of Wrangellia-related crust may be found northwest of the Talkeetna suture zone, offset from equivalent rocks to the southeast. One place that the potential field data suggest this possibility is in the center of the study area, northwest of the Fog Lakes Lowland. Although gravity values drop steeply westward across the suture zone along most of its length (stepping from Wrangellia to the Northern Talkeetna flysch basin), there is an ~40 km × 70 km long area northwest of the Susitna Lineament where gravity values are distinctly higher than elsewhere within the flysch basin. This elevated gravity may reflect the presence of a fragment of denser oceanic crust originally associated with Wrangellia, now stranded north of the Susitna Lineament and Talkeetna suture zone. An alternative explanation may be that the transitional crust in this area has been underplated with dense mafic material of unknown origin but possibly related to Eocene volcanism in the central Talkeetna Mountains (Fig. 2).

Geophysical Framework of Mineral Occurrences

Evaluating a region's mineral potential depends mostly on understanding its magmatic and metamorphic history and knowing how mineral occurrences relate to the distribution of lithologic units and structures. Gravity and magnetic methods are often useful in mineral resource investigations because many ore minerals have, or are associated with, other minerals that have distinctive density and/or magnetic properties relative to their host rocks. In addition to identifying ore-bearing bodies or structures key to the development of ore deposits, potential field techniques are frequently employed to assess the size and depth of buried mineral targets.

Each of the three major terranes and overlap assemblages in the Talkeetna Mountains has potential for mineral resources that include a variety of deposit types. For example, some granitoid plutons that intrude the Kahiltna flysch assemblage and that locally host Au-Cu or Ag-Sn-W porphyry and vein deposits are distinct in density and magnetic susceptibility from their host rock, whereas others can be distinguished by magnetic anomalies produced by strongly magnetic minerals like pyrrhotite formed during contact metamorphism. Magmatic Ni-Cu-PGE deposits are associated with mafic-ultramafic feeder zones to the Triassic Nikolai Greenstone flood basalts within Wrangellia (Fig. 14A, 14B) that are typically easily identified because of their distinctive high density and magnetic susceptibility (Sanger et al., 2002). The metallogeny and mineral potential of the Wrangellia terrane are discussed in greater detail in Schmidt and Rogers (this volume).

The Peninsular terrane has potential for volcanic-hosted massive sulfide deposits associated with the Talkeetna Formation volcanic arc and for porphyry and vein deposits of base metals associated with Early and Middle Jurassic granitoids (USGS, 2000). Both these intrusive and extrusive host rocks are often distinguished geophysically from surrounding units, as is true for many of the postaccretionary volcanic fields and associated hypabyssal intrusions that have potential for epithermal precious metal mineralization. In such cases, geophysical maps are useful in defining the size of host rock units beyond their mapped extent.

Gravity over small postaccretionary sedimentary basins such as those in Broad Pass and along Watana creek, that contain coal and, perhaps, some metallic mineral potential is particularly useful in estimating basin size and depth. There is, therefore, great potential for focused geophysical studies that support mineral-resource assessment in the Talkeetna Mountains and surrounding areas using potential field techniques. The primary aim of the geophysical domain analysis given here is to provide improved regional geologic, tectonic, and metallogenic framework of the area and to highlight potential metallogenetic locations that would be of interest for future, more detailed geologic and geophysical investigations.

Ultramafic Complexes

Key mineral targets in the Talkeetna Mountains are mafic and ultramafic rocks that occur in narrow elongate belts characterized by coincident gravity and magnetic highs. Several belts of such anomalies occur within the study area (e.g., at North Talkeetna Flysch-Wrangellia, Peninsular-Wrangellia, and Peninsular-Chugach terrane boundaries, Fig. 15).

Because these anomalies form narrow bodies (<25km) that tend to occur at terrane margins, they most likely represent remnants of oceanic crust, roots to accreted volcanic island arcs, and/or volcanic plateau rocks trapped between autochthonous intra-oceanic terranes as they were accreted to the continental margin.

Nikolai flood basalts. One of the best examples of these mafic-ultramafic belts is located along the northwestern edge of the Wrangellia terrane and includes lavas and feeders to the Triassic Nikolai Greenstone flood basalts province (Fig. 14A). Due to a long history of oblique subduction, the Wrangellia terrane has been dissected into a number of blocks that are now widely distributed along the west coast of North America extending from south-central Alaska to southern British Columbia (Fig. 14B; Jones

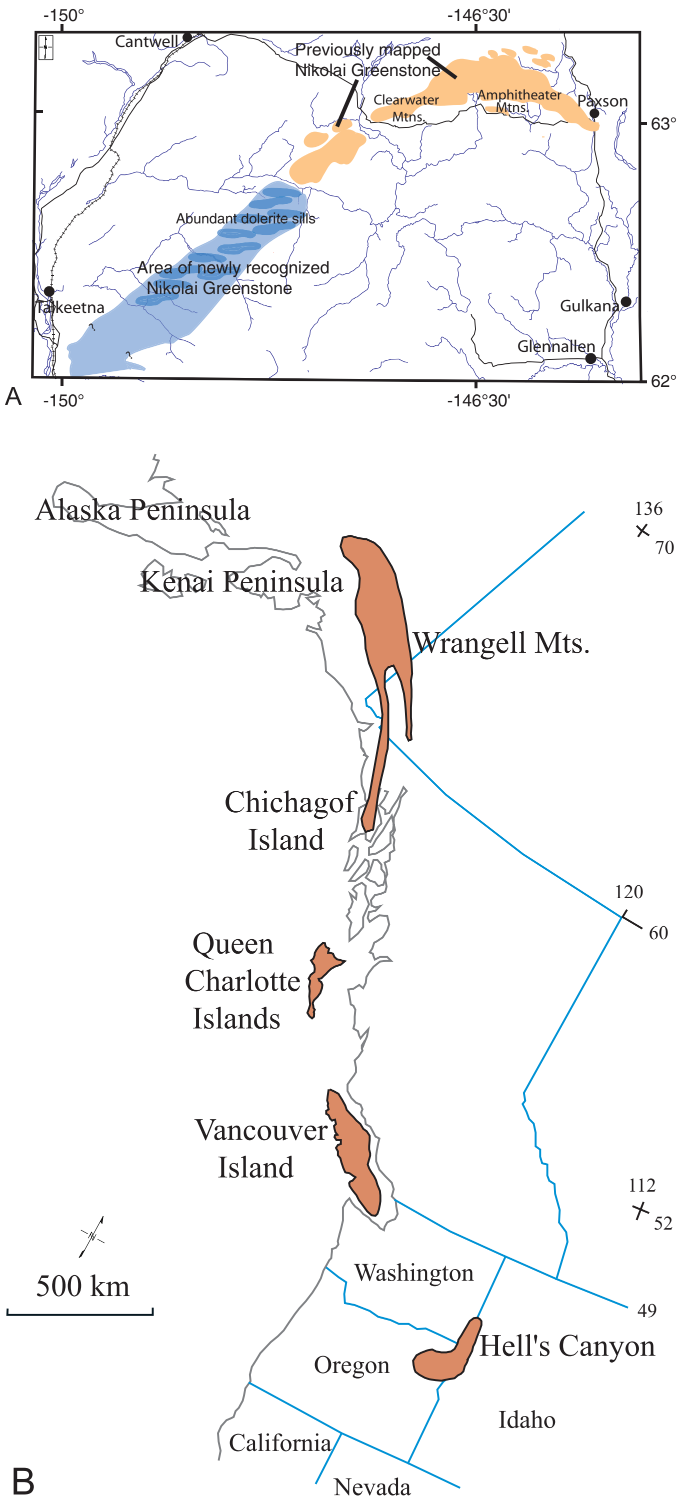

Figure 14. (A) Extent of Nikolai Greenstone and associated intrusives in south-central Alaska. (B) Extent of Wrangellia rocks in North America (adapted from Jones et al., 1977).

et al., 1977). The original shape of this flood basalt province is difficult to determine because its present ribbon-shaped form of outcrops in southern Alaska is likely due in part to the effects of accretion and subsequent strike-slip faulting (Jones et al., 1977). Nonetheless, the province contains some primary vent and rift features that parallel its present elongated axis, suggesting that its original shape may have resembled, to some degree, its present elongate form in the Talkeetna Mountains, with its magmatic axis lying roughly parallel to the accreting margin (Hulbert, 1997).

One of the more impressive anomalies in the study area corresponds with the Fish Lake layered ultramafic complex located in the Amphitheater Mountains. The Fish Lake complex, which includes pillow and subaereal lavas and related mafic-ultramafic rocks, represents a major feeder of the Nikolai magmatic system and is the only known exposure of Nikolai multiphased layered intrusives. It is of particular interest because it carries significant mineral potential—ranking perhaps among the highest of unmined PGE-bearing layered ultramafic complexes in the world (Ellis, 2000). Mineral deposits of the Nikolai and related feeder gabbros and intrusions include Cu-Ni deposits; PGE (e.g., Pd, Pt); and Co and Cr magmatic sulfides (Hulbert, 1997).

The geophysical character of these intrusives (i.e., given by distinctively strong magnetic and gravity anomalies) guides exploration of related intrusive bodies elsewhere in Wrangellia. The geophysical maps reveal several similar anomalies occurring far west and south of the Nikolai's previously mapped extent and provide a means for predicting the locations and geometry of potentially important mineral occurrences (Fig. 15). These prospective ultramafic (and perhaps Nikolai-related) intrusive bodies occur within a northeast-east–trending band across the northern edge of the Wrangellia terrane.

DISCUSSION

Major Crustal Belts

South-central Alaska is characterized by a dominant northeast-trending geophysical fabric. This is reflected in a series of narrow bands of magnetic and gravity highs that have been used here to refine the extent of major tectonostratigraphic terranes in the region. Although these geophysically distinct belts typically occur at terrane margins, one resides internal to the Wrangellia terrane (Fig. 15). This zone, which could be roots of a flood volcanic province or rift zone or remnants of an ocean basin, might represent a new terrane boundary subdividing the Wrangellia terrane and likely represents a potentially important target for ultramafic-related mineral resources (including PGE, Cu-Ni deposits, and a variety of metal-bearing magmatic sulfides).

Crustal Types

At the broadest scale, geophysical data reveal that the Talkeetna Mountains, comprising a series of Mesozoic and Paleozoic accreted terranes, form part of the South Alaska Magnetic

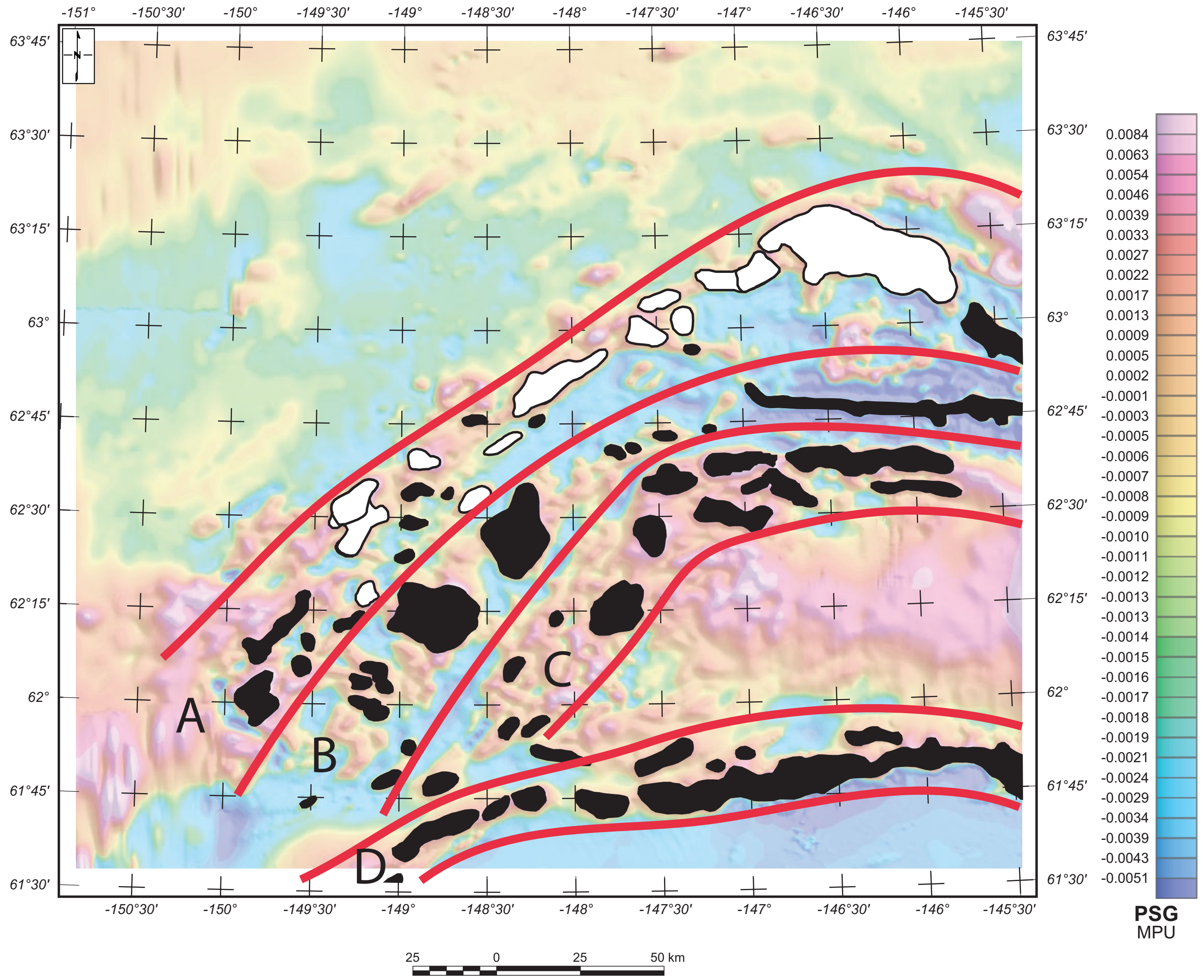

Figure 15. Belts (A–D) of geophysically inferred ultramafic bodies (white and black polygons) outlined in red and superimposed on a map of residual magnetic potential. White polygons represent anomalies associated with mapped outcrops of Nikolai-related rocks.

High (Saltus et al., 1999c) and a coincident regional gravity high. The geophysical expression of these terranes contrasts sharply with that of the dense, more weakly magnetic crust composed of Paleozoic continental North America lying north of the Denali fault zone. The strongest contrast, a prominent gravity gradient over the Talkeetna suture zone, most likely reflects the contrast between dense magnetic oceanic crust upon which Wrangellia rests and less dense, less magnetic transitional to continental crust that underlies the flysch basins. This interpretation is consistent with conclusions based on the compositional and isotopic character of granitic and intermediate-to-silicic volcanic rocks produced largely within the deep crust (Arth, 1994) that are used to infer the nature and origin of the crust. Because magmas commonly inherit the isotopic signature of the crust within which they formed, one can infer whether that crust is fundamentally oceanic, continental, or transitional in chemistry. Plutons with initial $^{87}Sr/^{86}Sr$ ratios of 0.702–0.705 are interpreted to have formed from rocks with oceanic affinities, such as island arcs or ocean crust (Arth, 1994). All areas that we include within the Wrangellia and Peninsular terranes overlie oceanic crust. Initial Sr-ratios greater than 0.708 indicate plutons formed mainly from older continental lithosphere (Arth, 1994); these rocks are confined to the north side of the Denali fault zone (e.g., Yukon Tanana terrane). Plutons yielding initial $^{87}Sr/^{86}Sr$ ratios between 0.705 and 0.708 likely formed either by melting of Phanerozoic flysch or from transitional or mixed oceanic and continental crust sources. These intermediate Sr values underlie the Talkeetna and Kahiltna flysch basins. Although Arth (1994) interpreted this area as underlain by "Detritia"—crust of transitional character—we suggest that these intermediate initial Sr ratios could also result from melting of Mesozoic flysch of combined oceanic and continental provenance.

A similar strong combined gravity and isotopic gradient is observed in other oceanic-continental sutures (e.g., Jachens and Griscom, 1985). In the Sierra Nevada, the western part of the range has gravity values—40–60 mGal higher than the eastern part of the range. Most of this gravity relief occurs over a 20-km-wide zone and persists over a strike length of 750 km along the batholith and across a complex distribution of ages of Mesozoic plutons. Profile modeling across the Sierra Nevada anomaly suggests that the density differences seen at the surface extend to depths of 10–15 km and correlate with Sr isotopic data. Jachens and Griscom (1985) suggested that plutons of the western batholith inherited character of the dense accreted oceanic crust they passed through as they ascended, whereas eastern plutons passed through less dense, primarily continental crust. A similar situation is suggested for the Talkeetna Mountains, where smaller magmatic bodies inherited different isotopic signatures on either side of the prominent gravity gradient.

Reactivated Structures

As early as the 1920s, it was conjectured that ancient structural features, such as "the grain of the continents, the trend of folds and foliation produced by older deformations" influence and are inherited by later deformations (Ruedemann, 1923). More recently, it has been recognized that features such as the trend of orogenic fabric can guide rift propagation (e.g., Tommasi and Vauchez, 2001), and that deep-seated crustal faults localize igneous and hydrothermal activity. These features, which form weak crustal zones, are susceptible to reactivation (Hildenbrand et al., 2000).

Many of the structures in the study area represent important crustal discontinuities that form natural zones of weakness that can influence later development (e.g., fluid migration, mineralization, seismicity, volcanism, plutonism, faulting, and basin formation). As a result, these structures may have a complex kinematic history and manifestation, having accommodated slip associated with a number of different tectonic episodes. Their present-day surface expressions include splays or parallel strands (e.g., flower structures, rhombic zones, grabens, and series of parallel blocks) that reflect very different slip histories. In south-central Alaska, many of these structures, like the Talkeetna suture zone, were likely reactivated during the Cenozoic, accommodating transcurrent crustal transport, the continued collision of terranes at Alaska's southern margin, and the southwest escape and CCW rotation of crust required by oroclinal bending (Glen, 2004).

The combined gravity and magnetic gradient corresponding to the Talkeetna suture zone is one of the most prominent geophysical features in south-central Alaska. We interpret this prominent northeast-trending feature as the suture between dense oceanic crust of the Wrangellia terrane and the low-density Jurassic to Cretaceous flysch. We further infer that Cenozoic faulting along the suture zone has been influenced by the deeper, more pronounced Mesozoic crustal discontinuity.

Like many suture zones, such as the Anatolia fault and Coast Megalineament, the original terrane boundaries are generally geometrically more complex prior to suturing (Brew, 2001). Subsequent faulting that exploits the suture tends to straighten the boundary as it crosscuts the same zone of weakness. As a result of repeated reactivation of the suture, the form of the original crustal boundary (including both the incoming oceanic crust and the continental mass it was approaching) is lost. In addition, remnants of crust from either side of the suture can be offset or even stranded from their primary crustal blocks.

CONCLUSIONS

Gravity and aeromagnetic data, combined with stratigraphic, structural, isotopic, geochronological information, provide new insights into the crustal structure beneath south-central Alaska. We have defined unique and internally consistent geophysical domains at regional (100s of kilometers; Tables DR2D and DR2G [see footnote 1]) and intermediate to local (10s of kilometers; Tables DR2A, DR2E) scales. We have also identified gravity and magnetic lineations at the regional (Tables DR2C, DR2F) and intermediate (Table DR2B) scales.

At the regional scale, these data characterize tectonic terranes and define the location and orientation of intraterrane and terrane-bounding structures, which in turn control the metallogeny and mineral potential of an area. At the local scale, the combined potential field domain and lineation data constrain the location, geometry, and depth of individual buried sources, such as plutons or ultramafic bodies that are direct controls on mineralization.

At the broadest scale, potential field data suggest that the southeastern portion of the Talkeetna Mountains is underlain by relatively dense magnetic crust, likely of oceanic-composition. This region, corresponding with Wrangellia and Peninsular terranes, may also have been underplated by mafic material during early to mid-Tertiary volcanism.

The Wrangellia terrane is characterized by short-wavelength and high-amplitude magnetic highs and lows due largely to numerous mafic volcanic and ultramafic bodies associated with the Nikolai Greenstone. Based on both potential field and geologic data, we redefine the boundary between Wrangellia and Peninsular terranes to lie along a prominent northeast trending geophysical gradient ~40 km southeast of its previously proposed location.

The Peninsular terrane, although containing a variable intensity and high-frequency magnetic fabric, is dominated by the broad Copper River basin magnetic-high/gravity-low anomaly and is enclosed by a narrow band of magnetic and gravity highs at its borders with Wrangellia and Chugach terranes to the north and south, respectively.

The most prominent geophysical gradient in the Talkeetna Mountains is the northeast-trending Talkeetna suture zone. It is a profound crustal discontinuity between oceanic crust to the southeast and crust of transitional to partly continental character to the northwest. The Talkeetna suture zone itself is deep and steeply dipping and is overlain by a wide zone (1–20 km) of surface structures of Tertiary and younger age localized by the crustal discontinuity.

Northwest of the Talkeetna suture zone, Mesozoic flysch, deposited on transitional crust between Wrangellia and continental North America, is characterized by subdued gravity and magnetic anomalies. The flysch is distributed across two distinct geophysical domains separated by a modest northeast-trending gravity gradient aligned with the Broad Pass graben. These two domains support the suggestion of separate flysch basins with different ages and provenances as identified by Ridgway et al. (2002).

Using these modified designations, all major terranes in the Talkeetna Mountains have internally uniform geophysical fabrics, well-defined geophysical gradients at their margins, and prominent narrow magnetic and gravity highs between them.

Coincident magnetic and gravity anomalies identify domains underlain by mafic/ultramafic rocks. Many of these lie in narrow belts that delineate sutures between allochthonous intraoceanic terranes accreted to the continental margin. Those within the Wrangellia terrane may identify previously unknown ultramafic intrusions related to emplacement of the Nikolai flood basalts. Their geophysical character is consistent with that of exposed layered ultramafic intrusions, which have significant potential for magmatic sulfide deposits of Ni-Cu ± PGEs.

The largest and most extensive geophysical domains in the Talkeetna Mountains correspond with tectonostratigraphic terranes and their boundaries. Major potential field lineations and domain boundaries map out the distribution of large crustal discontinuities. Although the age of formation of many of the deep or major structures forming these discontinuities is unknown, the crustal boundaries are zones of tectonic weakness that strongly influence the subsequent accretionary and structural history of the region.

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