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PRELIMINARY GEOLOGIC MAP OF THE BETHEL AND SOUTHERN RUSSIAN MISSION QUADRANGLES, SOUTHWESTERN ALASKA

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INTRODUCTION

This report presents a preliminary geologic map of the Bethel and southern Russian Missions 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.

The Bethel and southern Russian Mission quadrangles map area in southwestern Alaska 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.

The bedrock can be broadly divided into four units: (1) a complex assemblage of Early Cretaceous and older tectonostratigraphic terranes (Gemuk Group; Hoare and Coonrad, 1959a,b), (2) a thick, highly deformed sequence of Upper Cretaceous clastic sedimentary rocks (Kuskokwim Group; Cady and others, 1955), (3) gently deformed, Late Cretaceous and early Tertiary intermediate to felsic volcanic and plutonic rocks, and (4) a few Quaternary olivine basalt flows (fig. 1). Severe deformation occurred after deposition of each of units 1 and 2, and mild folding, tilting, and faulting followed deposition and emplacement of unit 3. Unit 4 is undeformed.

The Early Cretaceous and older tectonostratigraphic terranes include (from east to west) the Tikchik, Togiak, Goodnews, Kilbuck, and Nyac terranes (Jones and others, 1987). The Tikchik terrane is the most poorly understood, and consists of a structurally complex assemblage of volcanic rocks, chert, clastic rocks, argillite, and limestone whose ages range from early Paleozoic to Triassic. The Tikchik terrane is faulted against the Togiak terrane along the Cenozoic Togiak Fault in the map area; earlier relations between these two terranes are uncertain. The Togiak terrane consists of a coherent stratigraphic sequence of Upper Triassic through Lower Cretaceous volcaniclastic and minor volcanic rocks of volcanic arc affinity. The Togiak terrane is interpreted as part of an oceanic island-arc terrane emplaced against North America in Early Cretaceous time (Box, 1985). The Goodnews terrane consists of a structurally disrupted assemblage of basalt, chert, argillite, limestone, and minor clastic rocks, ranging from Ordovician to Early Cretaceous in age. These lithologies are locally overprinted by high-pressure/low-temperature regional metamorphism. The Goodnews terrane is interpreted as a forearc accretionary complex, which was progressively underthrust beneath and emplaced against the northwestern flank (present coordinates) of the island arc crust of the Togiak terrane from Early Jurassic through Early Cretaceous time (Box, 1985). The Kilbuck terrane consists of amphibolite-facies orthogneiss and minor paragneiss with Early Proterozoic protoliths (Box and others, 1990). This relatively narrow and thin crustal sliver is interpreted as a fragment of continental North America with which the amalgamated Togiak-Goodnews arc-forearc terrane collided in Early Cretaceous time. The Nyac terrane consists primarily of Jurassic and Cretaceous volcanic, volcaniclastic, and plutonic rocks of volcanic arc affinity. This terrane is interpreted as part of a Mesozoic volcanic arc terrane. Sedimentary rocks of the Kuskokwim Group overlap all the older terranes except the Nyac terrane, indicating these terranes were juxtaposed by earliest Late Cretaceous time (about 96 Ma). The Nyac terrane is separated from the other four terranes and their overlapping Kuskokwim Group by the Sawpit Fault. Late Cretaceous and (or) early Tertiary volcanic and plutonic rocks appear to overlap the Sawpit Fault, and indicate that the Nyac terrane was juxtaposed with the terranes to the east by that time.

The Late Cretaceous and early Tertiary volcanic and plutonic rocks in the map area are part of a broad belt of correlative rocks in western Alaska. This magmatic belt is interpreted as the product of subduction-related magmatism resulting from northward subduction of the Pacific plate beneath continental Alaska in roughly its present configuration (Moll-Stalcup, in press). Minor post-subduction, intraplate-affinity volcanic rocks were erupted during Eocene time. Minor Quaternary olivine basalt flows in the map area are part of the broadly distributed but volumetrically minor Bering Sea basalt province, a region of Pliocene to Holocene intraplate-affinity volcanism in western Alaska behind the late Neogene Aleutian-Alaska Peninsula volcanic arc (Moll-Stalcup, in press).

DESCRIPTION OF MAP UNITS

UNCONSOLIDATED DEPOSITS

Qa **Alluvium (Holocene and Pleistocene)** — Unconsolidated alluvial, colluvial, glacial outwash, lacustrine, and eolian conglomerate, sand, silt, and mudrock. Found as continuous blanket covering bedrock over western one-third of map area; elsewhere restricted to alluvial deposits in

stream valleys and thick colluvial deposits covering some unglaciated slopes. Age presumed to range from Pleistocene to Holocene

Qt **Glacial till (Pleistocene)**—Unconsolidated glacial till, including ground, lateral, and end moraines. End moraines of at least three distinct glacial advances are present, with oldest found farthest downvalley. Geomorphological expression of oldest deposits almost completely obscured. Oldest moraines contain basalt clasts derived from unit Qb, so are younger than 400 ka. As mapped, includes minor Holocene till in areas around small modern glaciers in southeastern part of map area

SUPERJACENT ROCKS

Consist of consolidated units which are present throughout entire map area. Rocks overlie all older terranes or were emplaced in or through them

VOLCANIC ROCKS

Qb **Basalt (Pleistocene)**—Unaltered olivine tholeiite basalt flows having diktytaxitic texture. Rock contains olivine, subophitic clinopyroxene, plagioclase and iron oxides with sparse interstitial volcanic glass. Exposed in south-central part of map area in cutbanks within a few meters of river level along Kwethluk River and Crooked Creek, and on west-sloping terrace as high as 70 m above river level along Kisaralik River above Upper Falls. Basaltic lavas flowed at least 45 km down pre-Wisconsin-age glacial valley now occupied by upper Kisaralik River, Crooked Creek, and Kwethluk River. Flows are essentially horizontal with total thickness of less than 30 m. Flows are typically 3 to 4 m thick with nonvesicular bases and highly vesicular to scoriaceous tops and are overlain by glacial till or glacial outwash gravels. Lava chemistry is similar to Hawaiian tholeiitic lavas, characteristic of magmas in intraplate, non-arc-related setting. Pleistocene age assignment based on whole-rock K/Ar age of 0.418±0.016 Ma (table 1, locality 1)

Nukluk Volcanic Field

Consists primarily of alkali rhyolite and lesser basalt exposed in low hills between Clear Creek and Otter Creek in central part of map area. Volcanic rocks crop out at tops of hills and are exposed as rubble along flanks. Main volcanic field, south of Fog River, has exposed thickness of at least 300 m and is estimated to be as thick as 2 km on the basis of gravity data (Robert Morin and others, unpublished data, 1993). At least 30 m of incipiently welded rhyolitic ash-flow tuff (Tnr) is exposed along Fog River and is overlain by basalt flows (unit Tnba). Field overlies sedimentary rocks (Kkcd) of Kuskokwim Group to east and is flanked on south and west sides by slightly older rocks (TKea, Tker) of Eek Volcanic Field. Volcanic rocks of Nukluk volcanic field are distinguished from latest Cretaceous to early Tertiary volcanic rocks by abundance of sanidine and presence of riebeckite in rhyolites and more strongly alkaline chemical composition in all lithologies. Nukluk lavas have lower La/Ta elemental ratios and higher TiO_2 contents than typical magmatic rocks from latest Cretaceous to early Tertiary magmatic province (Moll-Stalcup, in press). Their compositions are not typical of arc-related magmatism, and Nukluk lavas are presumed to represent postsubduction intraplate magmatism in this area. Divided into:

Tnr **Rhyolite (Eocene)**—Moderately altered rhyolite flows, domes, and ash-flow tuffs. Ash-flow tuffs are welded to nonwelded. Rhyolites of main volcanic field are characterized by phenocrysts of sanidine, riebeckitic amphibole, and rare quartz, and by groundmass of finely crystalline feldspar and oxides. Rhyolites north of Fog River have 0 to 15 percent very fine grained phenocrysts of plagioclase±sanidine±quartz±biotite +magnetite in groundmass of glass shards and pumice. Eocene age assignment based on riebeckite $^{40}Ar/^{39}Ar$ total-fusion age of 54.7±1.6 Ma from main volcanic field (table 2, locality 11)

Tnba **Basalt and andesite flows (Eocene)**—Massive to columnar-jointed basalt and subordinate andesite flows; minor latite and dacite. Basalts and andesites typically contain 1 to 5 percent phenocrysts of plagioclase+ clinopyroxene±olivine; clinopyroxene in basalt is pinkish brown and may be titanium rich. Basalt overlies rhyolitic ash-flow tuff (Tnr) along Fog River; elsewhere relations between rhyolite (unit Tnr) and basalts are uncertain, but units are presumed to be interbedded. Unit also includes compositionally similar basalt found north of Elbow Mountain in southwestern part of quadrangle. Age assigned on basis of age of interbedded rhyolite unit (Tnr)

Eek Volcanic Field

Consists of andesite, dacite, and rhyolite exposed in discontinuous low hills west of Golden Gate Fault from Kisaralik River south over 80 km to middle fork of Eek River in central and south-central parts of map area. Volcanic rocks appear to overlie sedimentary rocks (Kkcd) of Kuskokwim Group in northern and central parts of field and overlie rocks of Nyac terrane in west-

central part of field. In southern part of field, unit found in isolated hills surrounded by alluvium. Lavas are typical arc-related, calc-alkaline rocks. Data on low-silica rocks (less than 68 percent SiO_2) plot in medium-K field using classification of Gill (1981); data on high-silica rocks plot in high-K field. Divided into:

TKea **Andesite flows and porphyry (Paleocene and Cretaceous?)**—Andesite flows and subordinate altered andesite porphyry. Andesite flows found as small outcrops and columnar-jointed cliffs along ridges or along cutbanks of rivers. Flows have vesicular tops. Unit has estimated exposed thickness of 60 to 250 m but may be much thicker. Andesite flows have 1 to 30 percent fine- to coarse-grained phenocrysts of plagioclase+orthopyroxene±clinopyroxene; some in glomeroporphyritic clots. Groundmass has same mineralogy plus opaque oxides and as much as 40 percent glass. Subordinate, altered andesite porphyry found chiefly in northern part of volcanic field, north of Akulikutak River, and at Eluwaktak Mountain in southern part of volcanic field. Rock consists of coarse- to medium-grained phenocrysts of plagioclase±biotite±mafic minerals altered to chlorite+opaque oxides±calcite. Groundmass is only slightly finer grained and consists of plagioclase+quartz±biotite+altered mafic mineral. Unit also contains minor olivine basalt, andesite lithic tuff, and dacite. Age assignment based on plagioclase $^{40}Ar/^{39}Ar$ total-fusion age of 59.5±12.3 Ma (table 1, locality 20). Unit also possibly includes rocks as old as Late Cretaceous

TKer **Rhyolite (Paleocene and Cretaceous?)**—Rhyolite domes found as small knobs or large domical hills as large as 4 km in diameter and 300 to 500 m in relief, like those at Spein Mountain or Shining Dome. Domes are composed of moderately to deeply weathered pale-pink to orange, platy rhyolite. Rhyolites generally contain 2 to 3 percent phenocrysts of feldspar (plagioclase or sanidine; rare anorthoclase) and sparse biotite in finely crystalline groundmass of quartz+potassium feldspar +plagioclase+magnetite±biotite. Unit tentatively includes thin (25-75 m) highly altered rhyolite tuffs and flows that discontinuously overlie units Jab and Jvc of Nyac terrane north of Elbow Mountain in south-central part of map area. Poor exposure allows for possibility that these undated rhyolites north of Elbow Mountain may not be correlative but instead might be interbedded with unit Jvc of Nyac terrane. Statigraphic relation between rhyolites and andesites (unit TKea) is uncertain. Age assignment based on biotite and whole-rock K/Ar ages of 62.5±1.9 Ma and 59.3±1.8 Ma, respectively, from sample of rhyolite dome east of Kisaralik River (table 1, locality 8; Robinson and Decker, 1986). K/Ar and $^{40}Ar/^{39}Ar$ ages indicate Eek field is generally older than, and therefore underlies Nukluk Volcanic Field to east. Unit also possibly includes rocks as old as Late Cretaceous

Swift Creek Volcanic Field

Consists of thick pile of pyroclastic deposits and capping lava flows in area between Akoswift Creek and Kisaralik River in southeastern part of map area. Field is intruded and locally contact metamorphosed by Crooked Mountain pluton (Kick) on southeast side and unconformably overlies sedimentary rocks (Kkv) of Upper Cretaceous Kuskokwim Group. Main volcanic field is divided into two stratigraphic units. Lower unit (Ksl) forms broad semicircular stream-cut plateau composed of lithic tuff, lapilli tuff, ash, and lesser lava flows and breccias; upper unit (TKsa) consists of erosional remnants of andesite lava flows that cap small hills rising above plateau. Two additional units, small rhyolite dome (TKsr) exposed about 2 km south of main volcanic field, and rhyolite ash-flow tuff (TKst) located 8 to 10 km south, are also included in Swift Creek Volcanic Field. All of igneous rocks of field are arc-related, calc-alkaline rocks. Divided into:

TKst **Rhyolite ash-flow tuff (early Tertiary and (or) Late Cretaceous)**—Fresh to moderately altered, densely welded rhyolite ash-flow tuff exposed on ridges on both sides of Little Swift Creek. Chiefly black glassy vitrophyre; subordinate white to pink, partially devitrified rhyolite. Tuff contains 3 to 10 percent medium-grained phenocrysts of plagioclase, quartz, and sanidine and sparse fine-grained magnetite in groundmass of pale-brown glassy pumice and shards. Partially devitrified samples are oxidized. Rock contains abundant small (less than 1 cm) sandstone xenoliths. Unconformably overlies unit Kvs of Togiak terrane. Uncertain relation to main volcanic field. Age constrained only as younger than Valanginian (Early Cretaceous) biostratigraphic age of unit Kvs

TKsr **Rhyolite (early Tertiary and (or) Late Cretaceous)**—Frost-riven rubble from single rhyolite dome(?) exposed on ridge north of Akoswift Creek and west of Crooked Mountain pluton (Kick). Rhyolite contains 7 to 10 percent fine-grained phenocrysts of plagioclase, quartz, biotite, and garnet in groundmass of potassium feldspar, plagioclase, quartz, and sparse oxides. Overlies and (or) intrudes sedimentary rocks (Kkv) of Kuskokwim Group. Age constrained only as younger than Turonian (Late Cretaceous) biostratigraphic age of unit Kkv

TKsa **Andesite flows (early Tertiary and (or) Late Cretaceous)**—Columnar-jointed andesite

flows capping small hills that overlie unit Ksl. Flows consist of andesite containing 4 to 30 percent fine- to medium-grained phenocrysts of plagioclase, pyroxene, magnetite, and rare biotite. Brown amphibole is common in some flows. In parts of field, mafic minerals are altered to chlorite, calcite, or dark-brown opaque oxides. Plagioclase laths, granular pyroxene, magnetite, and ilmenite comprise groundmass in freshest andesites. Plagioclase laths, opaque oxides, and glass comprise groundmass in more altered andesite. Unit is about 50 to 70 m thick and conformably(?) overlies unit Ksl. Unit also includes prominent columnar-jointed andesite dike exposed about 2 km south of main volcanic field. Age constrained as younger than Campanian (Late Cretaceous) radiometric age of unit Ksl

Ksl **Lithic air-fall tuff (Late Cretaceous; Campanian)**—Moderately altered, andesitic lithic air-fall tuffs, tuff breccias, and altered andesite flows. Makes up extensive basal unit of Swift Creek Volcanic Field. Varies from very coarse-grained lithic tuff breccia containing dispersed clasts as large as 2 m in diameter to greenish-gray ash beds containing lithic fragments less than 0.6 cm in diameter. Most lithic clasts are 1 to 2 cm in diameter, angular, and poorly sorted and consist of maroon, green, or black aphanitic andesite clasts, set in finer andesitic tuff matrix. Rhyolitic breccias present in some areas. Clasts often have numerous veins or vesicles filled with calcite, chlorite and quartz. Unit appears to be more coarse-grained in basal part, grading into finer grained tuff in uppermost part. Coarse-grained parts of section appear to be more crudely bedded; finer grained parts are well bedded and display normal and, less commonly, reverse grading. Lower part of unit is probably vent breccia; upper bedded part of unit is interpreted as air-fall tuff. Unit is extensively cut by dikes presumed to be feeder vents for overlying flows (unit TKsa) in main part of volcanic field. Conformably(?) overlain by andesitic lava flows (unit TKsa). Appears to unconformably overlie sedimentary rocks (Kkv) of Kuskokwim Group along western and eastern flanks of field, but may be in fault contact locally. Exposed thickness is estimated to exceed 500 m in central part of field. The circular outcrop pattern of unit and its alteration suggest it may represent caldera fill. An interbedded andesite flow yielded whole-rock $^{40}Ar/^{39}Ar$ total-fusion age of 74.3±2.2 Ma (table 2, locality 17)

Tulip Volcanic Field

Located in east-central part of map area near headwaters of Kipchuk River, and consists chiefly of dacite flows and subordinate rhyolite bodies. Field is divided into 3 units, from oldest to youngest: (1) rhyolite domes and flows (Ktr), located chiefly around margin of field; (2) andesite and dacite flows (TKtd), which comprise main volume of field, locally underlain by a basal section of dacitic tuffs; and (3) single block and ash flow (TKtb). In eastern, southern, and northern parts of field, dacite tuffs unconformably overlie sedimentary rocks (Kkv) of Upper Cretaceous Kuskokwim Group. Along parts of west and east-central margins of field, dacite tuffs or flows overlie(?) large rhyolite domes as large as 1 km in diameter. Volcanic pile has minimum exposed thickness of 430 m in central part of field. All of lavas are typical arc-related, calc-alkaline rocks. Divided into:

TKtb **Block and ash flow (early Tertiary and (or) Late Cretaceous)**—Only one small block and ash flow was mapped and is exposed on steep slope on northwestern flank of volcanic field. Flow consists of long narrow tongue approximately 15 m thick and 100 m long of broken blocks of dacite in ashy matrix of same lithology. Interpreted to be hot avalanche deposit formed during dome collapse. Blocks are poorly sorted, angular to subrounded, and are either black and glassy, red and oxidized, or have banded streaks of red in black. One to three-m-thick sequence of red and black banded dacite flows found as a detached, folded sheet about 20 m long floating in ashy matrix. Matrix is red, and granulated fine ash contains broken crystals, bent biotite crystals, and chalcedony-filled pore space. Mineral assemblages in unit vary considerably, probably indicating that parent dome formed from inhomogeneous (or mixed) magma chamber. However, all parts are dacite and all are characterized by very coarse (as large as 14 mm) to fine-grained phenocrysts. Most mafic part consists of 20 percent coarse- to fine-grained phenocrysts of plagioclase+clinopyroxene+orthopyroxene (some in glomeroporphyritic clots) in groundmass of fine-grained feldspars. More felsic parts of flow contain 5 to 10 percent phenocrysts of plagioclase±quartz±sanidine+biotite+orthopyroxene±clinopyroxene+magnetite in brown to black glassy matrix. Gold-brown amphibole, anorthoclase, garnet, zircon, and apatite present in some parts of flow but are uncommon. Minerals in block and ash flow appear to be out of equilibrium: some feldspar is highly resorbed and garnet has thick reaction rims. Depositionally overlies unit TKtd. Age constrained only as younger than Turonian (Late Cretaceous) biostratigraphic age of unit Kkv

TKtd **Dacite and andesite flows and dacite tuff (early Tertiary and (or) Late Cretaceous)**—Dacite and subordinate andesite flows and underlying dacitic pyroclastic rocks. Flows crop out as

columnar-jointed cliffs throughout main part of Tulip Volcanic Field. Pyroclastic rocks include tuffs and breccias exposed in lower 50 m of unit. Dacite flows contain 7 to 10 percent medium- to fine-grained phenocrysts of plagioclase+orthopyroxene+magnetite± clinopyroxene±amphibole±biotite±quartz. Andesite flows consist of 10 percent fine- to medium-grained phenocrysts of plagioclase+ clinopyroxene+orthopyroxene+magnetite in groundmass of fibrous plagioclase needles, colorless glass, and tiny opaque-oxide dust; intergrown clots of plagioclase, orthopyroxene, and opaques appear to have replaced biotite. Dacitic tuffs generally consist of plagioclase+orthopyroxene+ amphibole+magnetite phenocrysts in vitroclastic groundmass. Lavas characteristically contain inclusions of orthopyroxene±clinopyroxene±plagioclase±magnetite (andesites) and plagioclase ±ilmenite± orthopyroxene±clinopyroxene±brown glass (dacite). Unit overlies sedimentary rocks (Kkv) of Kuskokwim Group or rhyolite (Ktr), and is locally overlain by unit TKtb. Age constrained only as younger than Turonian (Late Cretaceous) biostratigraphic age of unit Kkv

Ktr **Rhyolite domes and flows (Late Cretaceous)**—Rhyolite domes and flows found as small knobs or hills of orange to pink to white platy rhyolite. All are moderately to severely altered. Most rhyolite bodies appear to be overlain by dacite and andesite flows that comprise central part of volcanic field. Dacite flow just north of VABM Tulip has columnar joints that curve from near vertical to near horizontal at contact with rhyolite dome to north, indicating that the dacite cooled against a preexisting hill of cooled rhyolite. Rhyolites contain 3 to 5 percent fine-grained phenocrysts of plagioclase+biotite±quartz± magnetite±garnet, or less than 1 percent fine-grained plagioclase phenocrysts, in groundmass of glass or fine-grained crystalline potassium feldspar +quartz+spongy patches of opaque oxides. Altered samples contain as much as 10 to 15 percent secondary calcite. Unit overlies sedimentary rocks (Kkv) of Kuskokwim Group and is overlain by unit TKtd. Late Cretaceous age based on presumed correlation with unit Kvkr of Kipchuk Volcanic Field to north

Kipchuk Volcanic Field

Consists primarily of andesitic flows and tuffs and subordinate rhyolite domes exposed in area covering greater than 230 km^2 between Kipchuk and Aniak Rivers in east-central and northeastern part of map area. Rhyolite bodies found only at east and west edges of central part of field. Intermediate volcanic section is here divided into six units (given numbered subscripts starting with stratigraphically lowest). Lower part of section (units Kvk_1 through Kvk_4, inclusive) crops out in northwest-dipping homocline in southern part of field. Upper part of section (Kvk_5, Kvk_6) is exposed in broad north-northeast-trending syncline in northern part of field. Lower part of section only found on southeast side of syncline. Lavas and tuffs of Kipchuk Volcanic Field have chemical compositions typical of arc-related, calc-alkaline rocks. However, there are significant compositional differences between various units in Kipchuk Volcanic Field. Units in lower part of section have lower TiO_2, K_2O, and MgO content and higher Na_2O and Al_2O_3 content than rocks in upper part of section. Lower part of section also has lower incompatible trace-element contents (for example, Ba, Rb, Nb, Ta, La) than upper part of section at same silica content. Limited Sr and Nd isotopic data (Moll-Stalcup and others, 1989) indicate that rocks in lower part of section have higher initial $^{87}Sr/^{86}Sr$ and lower initial $^{143}Nd/^{144}Nd$ ratios than rocks in upper section. Many of lavas in upper part of section show disequilibrium mineral assemblages and large variations in mineralogy and incompatible element chemistry, suggestive of mixing of two very different magmas. Divided into:

Kvk_6 **Andesite and basalt flows (Late Cretaceous; Maestrichtian)**—Porphyritic plagioclase-pyroxene-olivine andesitic flows and flow breccias, minor interbedded flows of olivine basalt, and black andesite tuff. Flows exposed in broad syncline cut by Kipchuk River in north-central part of volcanic field. Unit is well exposed along ridges near Kipchuk River where flows are marked by columnar-jointed cliffs. Farther north, unit is covered with dense brush and exposure is limited to rubble and small outcrop. Lavas have between 51 and 63 percent SiO_2 and are characterized by high to very high Mg and Cr contents and large variations in potassium (K) content. Typical andesites contain 2 to 20 percent coarse- to fine-grained phenocrysts of plagioclase±olivine±clinopyroxene±orthopyroxene±opaque oxides. More K-rich andesites contain phenocrysts of plagioclase+ clinopyroxene+biotite±olivine±sanidine± orthopyroxene. Groundmasses vary from holocrystalline to intersertal glass to granular pyroxene, magnetite, and ilmenite enclosed in brown glass to sparse plagioclase microlites surrounded by abundant brown glass. Mafic glomeroporphyritic clots are common and consist of orthopyroxene (as many as 35 crystals in single clot) or plagioclase ±clinopyroxene±orthopyroxene. Some olivine appears xenocrystic. Orthopyroxene in some K-rich samples has exsolution

lamellae of clinopyroxene; clinopyroxene contains abundant inclusions of orthopyroxene. Many of K-rich samples appear to be out of equilibrium and probably formed by mixing of discrete magmas. Basalts contain 3 to 5 percent phenocrysts of olivine or clinopyroxene in holocrystalline groundmass of flow-oriented plagioclase, ilmenite, clinopyroxene, and magnetite. Black andesite tuffs contain approximately 15 percent phenocrysts of plagioclase. Thickness is estimated to be between 1,200 and 1,700 m. Conformably overlies unit Kvk_5 on east flank of syncline; unconformably overlies sedimentary rocks (Kkv) of Kuskokwim Group and is interbedded with lacustrine strata of unit Kvk_5 on west flank of syncline, indicating that these lavas were deposited in shallow lake. High-silica andesite flow from near top of sequence yielded biotite $^{40}Ar/^{39}Ar$ total-fusion age of 69.5±2.1 Ma (table 1, locality 12)

Kvk_5 Fine-grained tuff, crystal-vitric tuff, and tuffaceous sandstone (Late Cretaceous; Maestrichtian)—Water-lain (lacustrine and fluvial) and air-fall tuff. Exposed in northern part of field along west and east margins. Crops out primarily in cutbanks, in canyons, and on ridges. On west side of volcanic field, unit is estimated to be about 100 m thick. It consists of very fine grained to fine-grained tuffs that are finely laminated on millimeter to centimeter scale from greenish gray to white. Beds are interpreted to have been deposited in lacustrine environment. Coarsest samples are composed primarily of pumice and plagioclase, with subordinate clinopyroxene crystals and andesitic lithic fragments. On east side of field, unit is generally coarser grained. Along cutbank of Kipchuk River, unit consists of white air-fall tuff, stream-reworked tuff, and minor interbedded, finely laminated tuffaceous lacustrine deposits similar to those found on west side. Air-fall tuff is fine- to medium-grained crystal tuff and has well-developed bedding. It consists primarily of vesicular pumice (2 to 3 mm across), plagioclase (25 to 40 percent) partially replaced by calcite, and subordinate andesite lithic fragments. Farther north, tuff appears to be more reworked and, in places, more mafic, containing as great as 5 percent altered clinopyroxene or chloritic pseudomorphs after mafic minerals. Here, unit consists of coarse- to fine-grained tuffaceous sandstone and siltstone with well-defined beds, 0.5 cm to 1 m thick. Sparse andesite flows are interbedded with tuffs in some areas. Unit is estimated to be about 150 m thick on east side of field. It conformably overlies unit Kvk_4 and underlies unit Kvk_6 on east side of field; on west side of field, it is interbedded with lower flows of unit Kvk_6. Maestrichtian age is constrained by radiometric ages from overlying unit Kvk_6 and underlying unit Kvk_4

Kvk_4 Upper black andesitic lithic tuff (Late Cretaceous; Maestrichtian)—Black, densely welded andesite tuff exposed in low hills and ridges south and east of Kipchuk River. Rocks consist of fresh, broken crystals of plagioclase, orthopyroxene, and magnetite and lithic fragments of andesite and sandstone in groundmass of black, almost opaque glass. Some of plagioclase is strongly zoned and some is strongly resorbed. Flattened fiamme appear as dark lenses. Lithic fragments are commonly 0.2 to 0.7 mm, but some are several centimeters. Clasts include various lithologies of andesite and rarer felsic volcanic and sandstone fragments. Generally fresh, but where altered, clasts are replaced by epidote, calcite, and chlorite. Mafic minerals are altered to chlorite. Unit is estimated to be about 200 m thick at radiometric age sample locality (locality 7). Unit is petrographically similar to lower black andesite lithic tuff (Kvk_2) but much thinner; may be correlative with unit Kvk_2 (see below). Overlies andesite flows unit (Kvk_3) and is overlain by water-lain tuff unit (Kvk_5). Age assignment based on plagioclase and whole-rock K/Ar ages of 69.0±2.1 Ma and 71.4±2.1 Ma, respectively (table 1, locality 7; Robinson and Decker, 1986)

Kvk_3 Andesite flows (Late Cretaceous)—Porphyritic, propylitically altered, one- and two-pyroxene andesite lava flows; minor olivine basalt flows, dacite flows, and andesite tuff. Exposed as rubble and small outcrop in low hills, ridges, and canyons in south-central part of volcanic field. Andesite generally comtains 5 to 30 percent very coarse (as long as 1 cm) to fine-grained phenocrysts of plagioclase± orthopyroxene±clinopyroxene+magnitite±ilmenite. Mafic minerals often in glomeroporphyritic clots with plagioclase. Groundmasses vary from intersertal to hyaloophitic. Glass is colorless, brown, gold or gray black. Mafic minerals commonly altered to calcite, chlorite, and magnetite, less commonly replaced by colorless or blue-green amphibole. Some replacement by chalcedony and blue-green or blue-brown tourmaline. Some rocks have pore space lined with alteration products and vesicles filled with quartz, chlorite, and zeolites(?). Some rocks having black, glassy groundmass strongly resemble black lithic tuff but lack broken crystals, lithic fragments, and vitroclastic texture. Olivine basalt composed of very coarse grained olivine+orthopyroxene+ plagioclase±clinopyroxene phenocrysts in holocrystalline groundmass of chiefly plagioclase±orthopyroxene+opaque oxides. Dacite composed of 5 percent fine- to coarse-grained phenocrysts of wormy plagioclase, fine-grained fresh plagioclase, quartz,

orthopyroxene, and brown and black oxides in groundmass of quartz, plagioclase, and approximately 5 percent rusty oxides. Andesite tuff composed of 20 to 25 percent fine-grained broken crystals of altered plagioclase and mafic minerals (altered to fibrous chlorite), and lithic fragments of andesite and basalt in groundmass of plagioclase, opaque oxides, altered mafic minerals, and glass. Structure of unit is poorly known, but it is at least 300 m thick. May be as thick as 1,700 m if dip is consistent with single measured attitude near northwest margin of unit and with the attitude of unit Kvk_1 to southeast. Relations with adjacent units are uncertain; inferred to be sandwiched between glassy tuff units Kvk_4 and Kvk_2 in west-dipping homoclinal stack. However, an alternative interpretation, based on similarity and unaltered character of units Kvk_2 and Kvk_4 in contrast with consistently altered unit Kvk_3, is that unit Kvk_3 is older than both black tuff units (Kvk_2, Kvk_4), and that the black tuff units are correlative and were erupted through and onto previously altered unit Kvk_3. In this alternative model, unit Kvk_2 would be caldera-ponded ashflows, down faulted into unit Kvk_3 during caldera collapse, and thinner unit Kvk_4 would be outflow sheets. Late Cretaceous age constrained by Maestrichtian (radiometric) age of overlying unit Kvk_4 and Turonian (biostratigraphic) age of underlying unit Kkv

Kvk_2 Lower black andesitic lithic tuff (Late Cretaceous)—Massive, dark, fine-grained tuff having black opaque vitroclastic groundmass and abundant lithic fragments of volcanic rock and lesser sandstone and shale. Forms prominent ridge in southeastern part of Kipchuk Volcanic Field. Probably related to caldera-forming eruption and may be (tilted?) caldera-filling deposit. Andesite tuff consists of pumice, crystals, and lithic fragments, generally 0.3 to 5 cm in diameter. Typical tuff contains 10 to 15 percent crystals of plagioclase+orthopyroxene+clinopyroxene +opaque oxides±red-brown amphibole± brown secondary(?) biotite±garnet(?) xenocrysts. Crystals within pumice are well preserved but those in matrix are broken and range from very fine grained to medium-grained. One to two percent of plagioclase crystals are highly resorbed and have sponge-like appearance. Pumice lenses are generally black, almost opaque glass; rest of rock is more translucent black glass or lighter black, partially devitrified glass. Parts of unit are completely devitrified obscuring vitroclastic texture. Structure of unit is poorly known. If it is flat lying, it may be as little as 300 m thick; if its attitude is similar to that measured in upper part of unit and in underlying unit Kvk_1, it is at least 2.2 km thick. Appears to be conformable above unit Kvk_1 and below unit Kvk_3. Alternatively, may be younger than and faulted against unit Kvk_3 (see unit Kvk_3 description). Late Cretaceous age constrained by Maestrichtian (radiometric) age of overlying unit Kvk_4 and by Turonian (biostratigraphic) age of underlying unit Kkv

Kvk_1 Basal andesite flows (Late Cretaceous)—Light-gray to tan, sugary textured, fine-grained andesite flows with well-developed flow banding and irregular platy fracture. Black where glassy near base of unit. Consists of 1 to 3 percent fine-grained plagioclase phenocrysts in a very fine grained groundmass of aligned plagioclase laths, granular pyroxene (orthopyroxene and (or) clinopyroxene), and opaque oxides. Subordinate high-silica andesite has groundmass of felted feldspar and sparse quartz; groundmass ranges from holocrystalline to vitric with as much as 30 percent black interstitial glass. Rare xenocrysts of orthopyroxene in crystal clusters or brown amphibole crystals with thick oxidized rims. Altered samples have oxidized mafic minerals and glass(?) or contain calcite lenses along flow banding. Unit includes andesite dike cutting unit Kvkr at VABM Cap just west of volcanic field. Dike consists of sparse plagioclase phenocrsts in groundmass of stubby plagioclase laths, biotite, opaque oxides, and interstitial potassium feldspar. Unit is 1.6 km thick where it is exposed along west-dipping homocline in southeast part of Kipchuk Volcanic Field. Unit extends to south and west of main Kipchuk Volcanic Field as far as VABM Cone. Unconformably overlies sedimentary rocks (Kkv, Kkmf) of Kuskokwim Group and underlies unit Kvk_2. Intruded by rhyolite dome (Kvkr) at VABM Obvious. Late Cretaceous age constrained by Maestrichtian (radiometric) age of overlying unit Kvk_4 and Turonian (bio-stratigraphic) age of underlying unit Kkv

Kvkr Rhyolite domes and flows (Late Cretaceous)—Moderately to severely altered, white to orange, platy rhyolite domes and flows, and minor rhyolite breccia. Lithologically similar to unit Ktr. Includes prominent rhyolite domes at VABM Obvious and VABM Cap, large rhyolite body on west side of volcanic field in bend of Kipchuk River, and small dacite knob north of VABM Obvious. Rhyolite at VABM Obvious generally contains 1 to 2 percent fine-grained phenocrysts of plagioclase+quartz± sanidine± biotite±magnetite in very fine grained groundmass of plagioclase+quartz+ potassium feldspar+ magnetite. More altered samples contain secondary muscovite and 1 percent blue to brown tourmaline. Dacite north of VABM Obvious consists of ? percent medium-grained phenocrysts of embayed quartz and feldspar in groundmass of

plagioclase, abundant muscovite, and clusters of dark oxides. Body west of central part of volcanic field consists of highly altered rhyolite containing no remaining phenocrysts and is composed entirely of fine-grained quartz, feldspar, opaque oxides, and minor white mica. Unit is at least 500 m thick at VABM Obvious, where it includes basal tuff ring. Relation to surrounding units is uncertain; unit could be of several ages. At VABM Cap rhyolite dome is cut by dike of unit Kvk_1. At VABM Obvious unit appears to intrude and depositionally overlie unit Kvk_1. Ash flows of unit Kvk_2 probably flow around dome at VABM Obvious and are younger. Late Cretaceous age constrained by Maestrichtian (radiometric) age of stratigraphically overlying unit Kvk_4 and by Turonian (biostratigraphic) age of underlying sedimentary rocks (Kkv, Kkmf) of Kuskokwim Group

INTRUSIVE ROCKS

Intrusive rocks, undivided—With exception of diorite (nomenclature of Streckeisen, 1976) pluton (TKie) west of Shining Dome, all intrusive units described in this section crop out east of Sawpit Fault. Most common rock is coarse-grained porphyritic to seriate-textured hornblende-biotite granodiorite to biotite granite. Partial rims of two-pyroxene gabbro (locally quartz bearing) to hornblende diorite and biotite-augite or biotite-hornblende quartz diorite are present around some felsic plutons. Contacts between felsic and mafic bodies generally are poorly exposed, but most mafic bodies are sharply cut by adjacent felsic plutonic rocks where contacts are exposed. Hypidiomorphic granular texture is most common in diorites and quartz diorites. Coarse, mesocumulate textures are present in some mafic rocks. Geochemical character and isotopic ages of plutonic rocks indicate that they are product of arc-related magmatism roughly contemporaneous with early Tertiary and (or) Late Cretaceous volcanic fields. Plutons are elliptical, erosionally resistant [except Cripple Mountains pluton (Ticp), which is erosionally recessive], and in sharp contact with biotite- and cordierite-hornfels zones as wide as 1 km. Divided into:

Tial **Aniak Lake pluton (Paleocene)**—Coarse-grained, porphyritic to seriate leucocratic biotite granite pluton 10 km^2 in area supports prominent glacially carved ridges northwest of Aniak Lake in east-central part of map area. Color index (CI) = 2-7. Rock has distinctive speckled texture with randomly oriented feldspar phenocrysts. Subhedral white, patchy microperthite phenocrysts are 2 to 4 cm, commonly along with smaller euhedral plagioclase phenocrysts, in seriate matrix of orthoclase, quartz, plagioclase, and euhedral biotite. Muscovite is present in some samples; zircon with pleochroic haloes is prominent accessory. Partial replacement of biotite by chlorite is common in some samples. Porphyritic rhyolite dikes are common in uppermost parts of pluton and in surrounding biotite hornfels. Intrudes and contact-metamorphoses unit Kkv of Kuskokwim Group. Pluton-wallrock contact forms near-perfect hemisphere for its exposed uppermost 770 m. Age assignment based on biotite $^{40}Ar/^{39}Ar$ total-fusion age of 60.8±1.8 Ma (table 2, locality 14)

Ticp **Cripple Mountains pluton (Paleocene)**—Elliptical, erosionally recessive pluton, 40 km^2 in area in east-central part of map area. Coarse-grained, hypidiomorphic-granular hornblende-biotite granodiorite and granite are most common rock types, with lesser quartz monzodiorite and quartz monzonite. CI=2-12. Biotite forms euhderal books and typically is unaltered; hornblende is subhedral to euhedral and partially replaced by chlorite. Local poikilitic orthoclase contains euhedral biotite and plagioclase. Sphene and zircon are accessory minerals. Igneous-textured hornblende-biotite quartz diorite inclusions comprise as much as 5 percent of outcrop near pluton margin; abundance of inclusions decreases toward pluton core. Aplite dikes are common near pluton margin. Intrudes sedimentary rocks (Kksh, Kkmf, Kkmc) of Kuskokwim Group, with resistant biotite-cordierite hornfels zone 1 km wide. Sample of hornblende-biotite granite yielded biotite $^{40}Ar/^{39}Ar$ total-fusion age of 62.2±1.9 Ma (table 2, locality 13)

TKie **Eek River pluton and related plutonic rocks (early Tertiary and (or) Late Cretaceous)**—Sill 50 to 500 m thick crops out in discontinuous exposures over 10 km length cutting and contact-metamorphosing sedimentary rocks (Kkcd) of Kuskokwim Group north of Eek River in south-central part of map area; other small bodies exposed west and east of Shining Dome and north of mouth of Johnson Creek in central part of map area. Mass on west flank of Shining Dome may lie west of or intrude trace of Sawpit Fault. Rock is medium- to coarse-grained, porphyritic to diabasic (hornblende) augite diorite, quartz diorite, and mafic quartz monzodiorite. CI=15-35. Interstitial quartz and potassium feldspar are present in some samples; locally these phases are graphically intergrown. Similarities in major and trace-element chemistry suggest Eek River pluton and quartz diorite on west side of Shining Dome are comagmatic. Age is constrained only as younger than Turonian (Late Cretaceous) biostratigraphic age of unit Kkcd of Kuskokwim Group

TKif **Fisher Dome and Marvel Creek plutons, undivided (early Tertiary and (or) Late Cretaceous)**—Small intrusions of about 1 km^2 area exposed at Fisher Dome and in valley near headwaters of Marvel Creek in northeastern part of map area. Biotite hornfels zone 100 m wide developed in sedimentary rocks (Kkmf) of Kuskokwim Group around intrusions. Rocks are hornblende-biotite granite and granodiorite porphyry. Randomly oriented euhedral brown hornblende, brown biotite, plagioclase, and resorbed quartz phenocrysts as large as 3 mm comprise 20 to 40 percent of rock and are set in very fine grained aplitic matrix of quartz, plagioclase, potassium feldspar, and minor biotite and hornblende. CI= 5-7. Accessory minerals include opaque oxides, apatite, and zircon. Age constrained as younger than Turonian (Late Cretaceous) biostratigraphic age of unit Kkmf of Kuskokwim Group

TKig **Gemuk Mountain pluton (early Tertiary and (or) Late Cretaceous)**—Elongate, north-trending, erosionally resistant, mafic to intermediate quartz gabbro to mafic granodiorite pluton, 25 km^2 in area, that has cut and contact-metamorphosed sedimentary rocks (Kkv) of Kuskokwim Group and unit Kvs of Togiak terrane in northeastern part of map area. Varies from coarse-grained, cumulus-textured biotite-augite quartz diorite and quartz gabbro to intergranular-textured biotite-augite quartz diorite, quartz monzodiorite, and mafic granodiorite. Some samples contain intergranular micrographic quartz-potassium feldspar intergrowths. CI=15-35. Age is constrained as younger than Turonian (Late Cretaceous) biostratigraphic age of unit Kkv of Kuskokwim Group

TKik **Quartz monzodiorite of Kipchuk River (early Tertiary and (or) Late Cretaceous)**—Small (less than 1 km^2) quartz monzodiorite intrusion in sedimentary rocks (Kkcd) of Kuskokwim Group below unconformity, which is overlain by Kipchuk Volcanic Field. Found just east of Kipchuk River in northeastern part of map area. Sedimentary rocks of Kuskokwim Group are contact metamorphosed by pluton. Volcanic rocks of Kipchuk Volcanic Field do not appear to be metamorphosed, although extensive tourmaline-quartz replacement of volcaniclastic tuffs is present near base of volcanic section (Frost, 1990). Pluton consists of medium-grained, intergranular-textured biotite-augite quartz monzodiorite and quartz diorite. Quartz-potassium feldspar graphic intergrowths are common. Age constrained as younger than Turonian (Late Cretaceous) biostratigraphic age of unit Kkcd of Kuskokwim Group; age relative to adjacent Kipchuk Volcanic Field uncertain

TKin **North Fork pluton (early Tertiary and (or) Late Cretaceous)**—Mafic margin and eastern mafic sill shown by diagonal-line pattern. Two discrete phases mapped: (1) main felsic phase that forms bulk of pluton; and (2) mafic phase that crops out on south margin of pluton above North Fork Lakes, in large sill cutting sedimentary rocks (Kkv) of Kuskokwim Group east of main part of pluton, and in small outcrop north of main pluton. Located in east-central part of map area. Main felsic phase of pluton is seriate to hypidiomorphic granular (augite-) hornblende-biotite quartz monzodiorite, granodiorite, and minor biotite granite. CI=7-15. Hornblende is partially altered to chlorite. Aplite dikes are common. Mafic phase is characterized by coarse-grained, cumulus-textured augite quartz gabbro and quartz diorite. Augite is partially replaced by green amphibole. Euhedral opaque oxides along with interstitial brown biotite and green hornblende are ubiquitous. Sill cutting sedimentary rocks of Kuskokwim Group has similar mineralogy but intergranular texture. CI=20-30. Mafic phase is intruded by main felsic phase on south margin of pluton. Sample of biotite granite yielded biotite $^{40}Ar/^{39}Ar$ total-fusion age of 64.3±1.9 Ma (table 1, locality 15) on main felsic phase of pluton

TKip **Mt. Plummer pluton (early Tertiary and (or) Late Cretaceous)**—Erosionally resistant pluton in northeastern part of map area consisting of medium- to coarse-grained hypidiomorphic granular augite-biotite mafic granodiorite, quartz monzodiorite, and quartz diorite. Characterized by euhderal plagioclase, anhedral amoeboid deep-brownish-red biotite, and subhedral pinkish augite. Accessory minerals include euhedral opaque oxides and apatite. Minor chloritization of biotite. CI=15-25. Intruded into and has contact metamorphosed sedimentary rocks (Kkmf, Kksh, Kkcd) of Kuskokwim Group. Age assignment based on biotite K/Ar ages of 65.1±2.0 Ma and 66.6±2.0 Ma (table 2, localities 2 and 6, respectively)

Kick **Crooked Mountain pluton (Late Cretaceous)**—Large, composite pluton with thin gabbro and diorite margin that partially rims and is intruded by massive core of biotite-hornblende granodiorite and granite. Located in southeastern part of map area. Mafic margin is approximately 200 m wide on west side of pluton between Swift and Akoswift Creeks; elsewhere outcrop patterns suggest margin is thin or absent. Augite-biotite-hornblende and (augite-) hornblende-biotite granodiorite, quartz monzonite, and granite comprise main phase of pluton. CI=3-15. Augite is present both as discrete euhedral crystals and as cores of green hornblende prisms. Bulk of main phase has

hypidiomorphic granular to seriate texture. Igneous-textured quartz diorite inclusions are present in very low abundances throughout pluton. Mafic margin is composed of biotite-augite gabbro, quartz gabbro, and quartz diorite. CI=15-35. Euhedral unzoned plagioclase as large as 8 mm, subhedral pinkish augite as large as 3 mm, and opaques to 2 mm are cumulus phases. Subhedral olivine is present in some samples. Interstitial to subophitic dark-brown biotite is ubiquitous. In lithologies of intermediate composition, green hornblende joins augite as a cumulus phase; plagioclase retains unzoned cores with strongly zoned rims. Texture and mineralogy of most mafic parts of main phase are gradational to most silicic parts of mafic margin. Most samples without olivine contain quartz as interstital phase, in many cases graphically intergrown with potassium feldspar. Patches of secondary fibrous pale-green amphibole are common. Intruded into and has contact metamorphosed units Ksl, Kkv, Kvs, and KJc. Sample of hornblende-biotite granite yielded biotite $^{40}Ar/^{39}Ar$ total-fusion age of 69.8±2.1 Ma (table 2, locality 18)

Kicc **Canyon Creek pluton (Late Cretaceous)**—Small pluton about 1 km^2 in area, cutting hornfels of unit Kvs at headwaters of Canyon Creek in south-central part of map area. Map unit includes petrographically similar body cutting unit Kkv, 10 km to northwest. Rock is composed of medium- to coarse-grained, intergranular to hypidiomorphic granular augite-biotite quartz diorite to hornblende-biotite granodiorite. CI=15-25. Interstitial quartz is common. Iron-stained pyritiferous aplite dikes locally present cutting both pluton and unit Kvs. Age assignment based on biotite $^{40}Ar/^{39}Ar$ total-fusion age of 70.3±2.1 Ma (table 2, locality 19)

Kihd **Hornblende diorite stocks and dikes (Late Cretaceous)**—Small stocks and dikes scattered through Togiak terrane. All but two bodies are too small to show at map scale. Rock is composed of 15 to 35 percent unaltered, euhedral, dark-honey-brown hornblende prisms 1 to 4 mm long and lesser, pinkish subhedral augite, along with minor subhedral opaque oxides. Remainder of rock is extensively altered and is composed of relict euhedral plagioclase prisms partially to completely replaced by calcite, chlorite, and zeolites. Secondary quartz is common. Some examples are strongly foliated. Trace element chemistry is characterized by high chromium content (200-900 ppm). Age assignment based on hornblende $^{40}Ar/^{39}Ar$ total-fusion age of 68.0±2.0 Ma (table 2, locality 16) from small intrusive body in east-central part of map area

Ksp **Serpentinite (Late Cretaceous)**—Small, pervasively slickensided bodies of serpentinite, serpentinite-matrix melange, and silica-carbonate altered serpentinite, found just west and east of Golden Gate Fault in northeastern and central part of map area. Bodies just north of Nukluk Creek are serpentinite melange with 0.1- to 5.0-m blocks of massive, layered and pegmatitic gabbro, unserpentinized peridotite, and dunite with chromitite layers; bodies west of Golden Gate Fault have been extensively altered to silica-carbonate rock by replacement of serpentine minerals by iron-rich carbonate and quartz, and were subsequently brecciated and extensively veined by quartz (Frost, 1990). Apparently intruded as cold serpentinite diapirs along faults cutting rocks as young as middle Late Cretaceous (Turonian), probably during Late Cretaceous tectonism. Protolith age uncertain

ROCKS WEST OF SAWPIT FAULT

VOLCANIC AND SEDIMENTARY ROCKS

Nyac terrane

Consists of four-part stratigraphic sequence of volcanic and subordinate volcaniclastic rocks of primarily Middle and Late Jurassic and Early(?) Cretaceous age. Located in central, north-central, and northeastern parts of map area along west side of area of bedrock exposure. Lavas exhibit weak to moderate light rare-earth-element (REE) enrichment and high La/Nb elemental ratios characteristic of arc-related magmatism. Aeromagnetic data (Jeff Phillips and others, unpublished data, 1993) indicate terrane extends to northwest for distance of about 30 to 50 km beneath alluvial deposits. Terrane nowhere overlain depositionally by sedimentary rocks of Kuskokwim Group. Separated from Kuskokwim Group exposures by Sawpit Fault, which is overlapped by Late Cretaceous(?) and early Tertiary volcanic (TKer, TKea) and Late Cretaceous and(or) early Tertiary plutonic (TKie) rocks. Late Cretaceous displacement on Sawpit Fault is inferred to have been about 250 km in right-lateral sense (Box and others, 1990). Intrusive rocks of known mid-Cretaceous age (Kinc, Kis) and of inferred mid-Cretaceous (in part, at least) age (TJih, TJim, TJik, TJis) found only within Nyac terrane and are also cut by Sawpit Fault

TJwl **Whitefish Lake Volcanic Field (early Tertiary?, Cretaceous, and Jurassic?)**—Chiefly highly altered basaltic flows, subordinate altered andesite, dacite, rhyolite, and gabbro. Crops out in low hills along north edge of map area. Basalt contains 50 percent plagioclase phenocrysts in groundmass of clinopyroxene, ilmenite, magnetite, chlorite, calcite, trace potassium feldspar, apatite and amphibole. Andesite consists of 2 to 30 percent phenocrysts of plagioclase ±clinopyroxene

altered to calcite, sericite, or cryptocrystalline quartz; mafic minerals are altered to calcite, chlorite, epidote, and opaque oxides. Groundmass consists of plagioclase laths, chlorite, calcite, opaque oxides, potassium feldspar, and trace quartz. Some samples contain secondary biotite and (or) amphibole. Dacites contain 3 to 15 percent phenocryst of plagioclase, amphibole, and biotite in groundmass of plagioclase, potassium feldspar, quartz, chlorite, and opaque oxides. Plagioclase is often replaced by sericite; mafic minerals are altered to calcite and opaque oxides in dacites. Most of gabbros are medium-grained plutonic rocks; some contain coarse-grained plagioclase phenocrysts as long as 5 mm. Gabbros consist of plagioclase laths (partially altered to sericite) ±orthopyroxene±clinopyroxene±sphene±epidote±amphibole±biotite±chlorite+magnetite +apatite+trace quartz+potassium feldspar. Extrusive rhyolites contain 1 to 2 percent phenocrysts; shallow intrusive rhyolites contain 40 percent phenocrysts. Extrusive rhyolites contain phenocrysts of plagioclase, partially replaced by calcite in groundmass of partially altered feldspar laths, polygonal quartz, and rusty brown oxides. Shallow intrusive rhyolite contains phenocrysts of sanidine and plagioclase rimmed by potassium feldspar. Interstices are filled with polycrystalline quartz, potassium feldspar, magnetite, biotite, chlorite, and zircon. Lavas are strongly magnetic, and aeromagnetic data (Jeff Phillips and others, unpublished data, 1993) indicate this unit continues as far as 50 km to west and southwest under thin surficial deposits. Map relations suggest unit is unconformable on units Jvc and KJba of Nyac terrane. Lavas are inferred to be extrusive equivalent of parts of diorites and gabbros (TJim) of Nyac terrane, on the basis of their close similarity in major and trace-element contents. Regional constraints suggest unit could be as old as Jurassic or as young as Tertiary

KJba **Basaltic and andesitic lava flows (Early Cretaceous and (or) Late Jurassic)**—Basaltic and andesitic lava flows; poorly to moderately exposed in low hills. Flow rocks are variably altered basalts and andesites(?) containing phenocrysts of plagioclase ±clinopyroxene with secondary chlorite and calcite and are chemically similar to flow rocks (unit Jab). Thickness is uncertain. Conformably(?) overlies unit Jvc, and is unconformably(?) overlain by unit TJwl. Stratigraphic relations indicate latest Jurassic or Early Cretaceous age

Jvc **Volcaniclastic conglomerate, sandstone, and shale (Late and Middle Jurassic)**—Mostly epiclastic sequence of tuffaceous marine sandstones, shales, and conglomerates with minor interbedded basaltic and andesitic lava flows. Poorly to moderately exposed in low hills. Sandstones and conglomerates composed primarily of rounded clasts of andesitic and basaltic lavas with minor component of mafic to intermediate plutonic rock fragments. Estimated thickness is approximately 1 to 2 km in central part of map area. Felsic pyroclastic rocks found locally near base of sequence in northern outcrop belt and in middle part of sequence in southern outcrop belt. Rests conformably(?) on unit Jab and is conformably(?) overlain by unit KJba. In north-central part of map area, unit is unconformably(?) overlain by unit TJwl and intruded by known mid-Cretaceous (Kinc) and presumed mid-Cretaceous (in part, at least) (TJih, TJim, TJik) plutonic rocks. Bajocian (early Middle Jurassic) marine pelecypods found locally west of Shining Dome in central part of map area in shallow-marine deposits near base of sequence; Tithonian (late Late Jurassic) marine pelecypods found in upper part of sequence above felsic pyroclastic rocks in north-central part of map area (Stephen Box and others, unpublished data, 1993)

Jab **Andesitic and basaltic lava flows and marine epiclastic rocks (Middle Jurassic)**—Andesitic and basaltic lava flows, flow breccias, and tuffaceous marine sedimentary rocks. Poorly to moderately exposed in low hills. Andesite flows contain phenocryts of plagioclase±clinopyroxene±hornblende; lesser basalt flows contain plagioclase±clinopyroxene phenocrysts. Tuffaceous sedimentary rocks consist of lithic sandstones and conglomerates, and contain similar volcanic rock fragments and minor component of mafic to intermediate plutonic rock fragments. Altered to static greenschist-facies metamorphic-mineral assemblages with variable replacement by chlorite, calcite, epidote, albite, and quartz. Thickness is uncertain. Conformably(?) underlies clastic rocks of unit Jvc; intruded by known mid-Cretaceous (Kinc, Kis) and inferred mid-Cretaceous (in part, at least) (TJim, TJih, TJik, TJis) plutonic rocks. Interbedded volcaniclastic strata have yielded marine pelecypods of Bajocian (early Middle Jurassic) age (Stephen Box and others, unpublished data, 1993)

INTRUSIVE ROCKS
(Intrusive into Nyac terrane)

Intrusive rocks, undivided—Elliptical plutons of hornblende-biotite granodiorite to granite and biotite granite that weather recessively and are rimmed by erosionally resistant biotite±cordierite hornfels zones. Mafic plutons include small bodies of coarse-grained cumulate- and static-textured augite gabbro and diorite; minor hornblende quartz diorite

is present locally. Plutons found exclusively west of Sawpit Fault, intruding Jurassic to Lower Cretaceous andesitic and volcaniclastic sedimentary rocks of Nyac terrane. Radiometric ages of felsic intrusive rocks range from 120 to 101 Ma. Mafic intrusive rocks are thought to be cogenetic with dated felsic intrusive rocks, but ages are uncertain and may range from Jurassic through Tertiary. Hypabyssal rhyolite porphyries (TJih) appear to cut some of mafic plutonic rocks but have chemical affinites with them. All plutonic rocks have chemical characteristics typical of arc-related magmatism. Divided into:

TJik **Little Kasigluk River pluton (early Tertiary?, Cretaceous, and Jurassic?)**—Forms several small masses, each less than 6 km^2 in area, intruding andesitic wall rocks (Jab, Jvc) of Nyac terrane at headwaters of Little Kasigluk River in central part of map area. Medium-grained, hypidiomorphic granular hornblende diorite and gabbro. CI=20-30. Composed of euhedral plagioclase, subhedral to interstitial green hornblende, and opaque oxides. Patchy color zoning and locally fibrous nature of amphibole indicates much of it is replacing clinopyroxene. Contact metamorphism adjacent to these bodies is weak. Age is uncertain; maximum age constrained by Jurassic age of wall rock units Jab and Jvc

TJim **Altered mafic plutonic rocks (early Tertiary?, Cretaceous, and Jurassic?)**—Small, erosionally neutral, texturally and compositionally diverse, partially to extensively altered diorite and gabbro bodies cutting andesitic wall rocks (Jab, Jvc) of Nyac terrane north of Fog River in northeastern part of map area. Contact metamorphism adjacent to these bodies is weak. Largest mass is in Fox Creek drainage area and consists of massive and cumulus-textured augite and augite-amphibole gabbro and diorite along with hypidiomorphic-textured gabbro, diorite, and quartz diorite. Plagioclase is most commonly euhedral; augite and amphibole are subophitic to interstitial. Most amphibole is secondary after augite; in many cases amphibole is fibrous. Interstitial opaque oxides are ubiquitous; interstitial biotite and quartz are present in some samples. Other masses are lithologically similar, but most lack cumulus-textured gabbros. CI=20-40. Gabbro bodies northwest of the Nyac pluton (Kinc, part) exhibit major and trace-element similarities to rocks of Whitefish Lake Volcanic Field (TJwl), suggesting that they may represent intrusive equivalents of some of the volcanic rocks. Northwesternmost body, west of large Nyac pluton (Kinc, part), appears to be cut by unit TJih . Ages are uncertain; maximum age constrained by Jurassic age of units Jab and Jvc

TJis **Slate Creek pluton (early Tertiary?, Cretaceous, and Jurassic?)**—Erosionally neutral, mafic hornblende tonalite and granodiorite pluton, less than 2 km^2 in area, cutting andesitic wall rocks (Jab) of Nyac terrane north of Slate Creek in northeast part of map area. No prominent hornfels zone developed. Medium-grained, hypidiomorphic-granular hornblende tonalite and granodiorite. CI=15-30. Euhedral, randomly oriented, twinned green hornblende prisms, euhedral zoned plagioclase, and opaque oxides. Quartz is abundant, comprising 20 to 25 percent of rock, and forms anhedral interstital crystals to subophitic pools enclosing other minerals. Distinguished from other quartz-rich plutons by low potassium feldspar content, lack of biotite, and chemically by low potassium and flatter chondrite-normalized rare earth element (REE) patterns. Trace-element signatures similar to those of bodies of unit TJih south of Slate Creek. Age uncertain; maximum age constrained by Jurassic age of wall rock unit Jab

TJih **Hypabyssal felsic intrusive rocks (early Tertiary?, Cretaceous, and Jurassic?)**—Highly altered rhyolite and dacite porphyries. Included in map unit are porphyries of Fox Creek, Dry Creek, and large unnamed body west of the Nyac pluton (Kinc, part) in northeastern part of map area. Found as rubble and small outcrop. Rhyolite consists of orange-weathering, highly altered rock containing as much as 10 percent phenocrysts of resorbed quartz, plagioclase, and altered mafic minerals replaced by opaque oxides and chlorite. Groundmass in rhyolites is composed of quartz, potassium feldspar, and plagioclase, locally with graphic intergrowths. In most samples, groundmass is altered to granular aggregate of quartz, sericite, zeolites, and calcite. Some rhyolites contain lithic fragments of andesite and may be tuffs, but alteration has obscured their original texture. Dacites contain as much as 5 percent plagioclase and biotite phenocrysts in groundmass of chiefly plagioclase, quartz, and opaque oxides. Alteration with partial replacement by chlorite, calcite, and zeolites is common. Bodies south of Slate Creek have trace-element signatures similar to Slate Creek pluton (TJis). Unit appears to cut coarse-grained diorite (TJim) west of Nyac pluton (Kinc, part). Age uncertain; maximum age constrained by Jurassic age of wallrock units Jab and Jvc

Kinc **Nyac, Bonanza Creek, and Columbia Creek plutons, undivided (Early Cretaceous)**—Nyac pluton, west of mining camp of Nyac in north-central part of map area, is largest in region and underlies approximately 200 km^2. Bonanza Creek pluton underlies 2 km^2. and crops out east of Nyac pluton as resistant ridge

centered on VABM Bonanza. Columbia Creek pluton, 22 km^2 in area, is exposed in low hills west of headwaters of Columbia Creek in central part of map area. Most plutons form recessive, smooth-weathering hills with scattered resistant tors, rimmed by resistant fine-grained biotite hornfels of andesitic wall rocks (Jab, Jvc) of Nyac terrane. Rock is pale-pink-weathering, light-gray, coarse-grained porphyritic to seriate hornblende-biotite and biotite-hornblende granite, quartz monzonite, and lesser granodiorite and quartz monzodiorite. Nyac pluton is crudely concentrically zoned from hornblende-biotite granodiorite and granite at margin to hornblende-biotite granite at core; somewhat more porphyritic at core. Biotite and hornblende are euhedral, plagioclase is subhedral, and perthitic microcline most commonly present as anhedral phenocrysts containing small included plagioclase and mafic minerals; quartz is anhedral and interstitial. Nyac and Columbia Creek plutons CI=5-12; Bonanza Creek pluton CI=10-15. Common accessory minerals include monazite, sphene, zircon, and apatite. Igneous-textured mafic inclusions are common in Nyac pluton near its margin; pink aplite and pegmatite dikes are abundant throughout all three plutons and in adjacent wall rocks. Distinguished from Sawpit pluton by presence of hornblende and lower silica content (62 to 72 percent). Radiometric ages include: Nyac pluton: 101.1±3.0 Ma (K/Ar, hornblende; table 1, locality 4), 108.5±3.3 Ma (K/Ar, biotite; table 1, locality 4), 120.0±3.6 Ma (K/Ar biotite; table 1, locality 5), and 104 to 129 Ma (U/Pb, zircon; table 3, locality 21); Bonanza Creek pluton: 110±3.3 Ma ($^{40}Ar/^{39}Ar$ total-fusion , biotite; table 2, locality 10). Columbia Creek pluton: 115.0±3.5 Ma (K/Ar biotite; table 1, locality 3)

Kis **Sawpit pluton (Early Cretaceous)**—Recessively weathering, pink-colored, leucocratic biotite granite pluton underlying 35 km^2 northwest of Sawpit Creek in northeastern part of map area. Coarse-grained seriate texture with subhedral andesine, perthitic microcline, subhedral to euhedral biotite, and anhedral interstital quartz. Opaque oxides and sphene are common accessories. CI=2-4. As mapped, unit includes small, chemically and petrographically similar pluton near mouth of Cale Creek. Probably related to Nyac and correlative plutons but distinguished from them by lack of hornblende, greater compositional and textural homogeneity, and higher silica content (74.3 to 75.0 percent SiO2). Age constrained only as younger than Jurassic age of wallrock unit Jab, but chemistry and field relations suggest that Sawpit pluton is similar in age to dated plutons comprising unit Kinc

ROCKS EAST OF SAWPIT FAULT
SEDIMENTARY AND VOLCANIC ROCKS

Kuskokwim Group—Kuskokwim Group (Cady and others, 1955) in map area consists of Upper Cretaceous (Cenomanian and Turonian) clastic sedimentary rocks that unconformably overlie three older terranes (Togiak, Goodnews, and Kilbuck terranes) and that are unconformably overlain by Upper Cretaceous and lower Tertiary volcanic rocks. Lower part of Kuskokwim Group consists of basal marine conglomerate (Kkbc) overlain by marine shale (Kksh). Upper part of Kuskokwim Group consists of five broadly time-equivalent facies (Kkcd, Kkcf, Kkmf, Kkmc, Kkv), subdivided using clastic composition (c, chert-clast dominant; m, significant metamorphic-clast component; and v, volcanic-clast dominant) and depositional facies (d, deltaic; f, submarine fan; and c, turbidite channel). Divided into:

Chert-clast provenance rocks (Late Cretaceous; Turonian)

Kkcd **Deltaic facies**—Thick-bedded quartzose sandstone, pebbly sandstone, and subordinate siltstone and shale. Exposed as north-northeast-trending belt in western foothills of Kilbuck Mountains in south-central, central, and northeastern parts of the map area and as smaller areas of exposures to east in northeastern part of map area. Unit is well exposed on ridges in southern part of exposure belt (for example, Great Ridge); elsewhere exposed in sporadic stream cuts and on ridges as frost-heaved sandstone rubble. Characteristic sandstones are composed of clasts of monocrystalline quartz, foliated and unfoliated polycrystalline vein quartz, radiolarian chert and argillaceous chert, minor graphic granite, and rare recrystallized quartz-rich sandstone, with rare interbeds of volcanic provenance rocks. Sandstone at northern Little Crow Hills near Kisaralik River in central part of map area contains abundant clasts of phyllitic siltstone and metachert. Great Ridge exposures consist of lower section of shaley prodelta deposits, a middle section composed of a deltaic sequence of thick-bedded marine sandstones, and upper section of fluvial meandering stream deposits with minor coaly interbeds. Stream cuts on Kisaralik River expose highly bioturbated prodelta shaley turbidites with rare conglomeratic channels, presumably equivalent to prodelta sequence of lower section at Great Ridge; elsewhere exposures generally consist of rubbly outcrops of medium to coarse sandstone. Paleocurrents in marine and nonmarine sandstones at Great Ridge indicate paleoflow to east-southeast (Box and Elder, 1992), and trending north-northeast/south-southwest in prodelta facies

at Kisaralik River. Rocks deformed into tight, upright to overturned (to northwest) folds lacking penetrative slaty cleavage. On west, unit is separated by Sawpit Fault from volcanic rocks of Nyac terrane, which are not compositionally appropriate source rocks for clastic rocks of unit Kkcd. Golden Gate Fault forms much of east boundary of unit. However, in northeastern part of map area, unit found depositionally above unit Kkv along lower Kipchuk River, and depositionally(?) above Kkmf north of Dominion Creek. Intruded by Late Cretaceous and (or) early Tertiary plutons and unconformably overlain by volcanic rocks of Eek River, Nukluk, and Kipchuk Volcanic Fields. Age considered to be Turonian (Late Cretaceous) on the basis of several megafossil occurrences (Elder and Box, 1992)

Kkcf **Outer-fan turbidite facies**—Thin-bedded, fine-grained quartzose sandstone and slate with lesser thin- and thick-bedded medium-grained sandstone. Exposed in north-northeast-trending belt along 900 m ridge north from north end of Greenstone Ridge to Bear Creek in central and northeastern parts of map area. Characteristic sandstones composed of clasts of monocrystalline and polycrystalline quartz, radiolarian chert, and minor graphic granite; plagioclase and volcanic rock fragments are rare to absent. Sandstone-shale interbeds exhibit turbidite features, with thickening and coarsening-upward bedding cycles noted in a few places, suggesting mid or outer submarine-fan depositional enivronment. Similarity in sandstone composition suggests this unit is a deep-water facies equivalent of deltaic unit Kkcd. Strata folded into tight, overturned folds (to northwest) and pervasively overprinted by strong slaty cleavage in both shales and sandstones. Unit depositionally overlies unit Kksh. Age considered to be Turonian (Late Cretaceous) on the basis of three megafossil collections (Elder and Box, 1992)

Mixed provenance rocks (Late Cretaceous; Turonian)

Kkmf **Outer-fan turbidite facies**—Shale-rich sequence with lesser thin- to thick-bedded, medium-grained sandstone sections. Widely exposed in east-central and northeastern parts of map area. Sandstone compositions are variable: western exposures (upper Salmon River and Fisher Dome ridge) composed of clasts of monocrystalline and polycrystalline quartz, chert, quartz-mica schist, and muscovite and plagioclase crystals; eastern exposures composed of clasts of volcanic rock, quartz-mica schist, and felsic plutonic rock, and detrital grains of plagioclase, muscovite, and monocrystalline quartz. Sandstone-shale interbeds exhibit turbidite features, with thickening- and coarsening-upward cycles relatively common, suggesting mid to outer submarine-fan depositional environments. Bed-bottom paleocurrent features (for example, flutes, grooves, tool marks) indicate generally northeast-directed paleocurrents (Box and Elder, 1992). Depositionally overlies unit Kksh and apparently interfingers with unit Kkmc to south in area around and south of Cripple Mountains pluton (Ticp) Overlain by or faulted against unit Kkcd north of Dominion Creek. Strata are tightly folded into west-verging overturned folds with weak slaty cleavage in western exposures and into east-verging overturned folds (no slaty cleavage) in eastern exposures. Age considered to be Turonian (Late Cretaceous) on the basis of two megafossil occurrences (Elder and Box, 1992)

Kkmc **Inner-fan-channel facies**—Mixed shale-rich and sandstone-rich sections, with coarse sandstone and pebbly sandstone in thick-bedded, amalgamated sequences with minor interbedded shales. Exposed in stream cuts and rubbly ridges in east-central part of map area south of Cripple Mountains pluton (Ticp) and north of Crooked Creek. Characteristic sandstones composed of phyllitic and schistose metasedimentary and metaplutonic rock fragments with minor component of unfoliated volcanic and plutonic rock fragments. Base of sequence is prominent 20-m-thick, coarse to pebbly sandstone with sharp conglomeratic base on underlying shale of unit Kksh. Above basal sandstone, section is variable from shale-rich sections with thin discontinuous sandstone beds (facies E of Mutti and Ricchi-Lucchi, 1972) to channelized sandstone or pebbly conglomerate sections that fine and thin upward (facies B of Mutti and Ricchi-Lucchi, 1972). Preserves turbidite and other mass-flow depositional features. Bed-bottom features indicate northeast-directed paleocurrents (Box and Elder, 1992). Sedimentary features suggest deposition as inner to middle submarine fan channel-and-levee complex. Depositionally overlies and probably interfingers with upper part of unit Kksh; apparently interfingers northward with unit Kkmf. Age based on stratigraphic position and apparent interfingering with unit Kkmf. Recovered fossils are nondiagnostic Cretaceous forms (Stephen Box and others, unpublished data, 1993)

Kkv **Volcanic provenance rocks (Late Cretaceous; Turonian)**—Interbedded shale, siltstone, sandstone, and conglomerate composed of rounded clasts of volcanic, volcaniclastic, and plutonic rocks. Found along east side of Kuskokwim Group outcrop area flanking west margin of older rocks (Kvs) of Togiak terrane in eastern part of map area. Prominent coarse clastic horizons, typically tens of

meters thick, found sporadically in predominantly shale-rich section. Coarse horizons typically consist of amalgamated sandstone and conglomerate beds with no intervening shales; conglomerates range from clast-supported to sand matrix and mud-matrix supported. Slump folding at outcrop scale is relatively common; one 20-m-thick slump-folded section well exposed in prominent rivercut on east bank of lowermost Kipchuk River. Paleocurrents are generally westerly directed (Box and Elder, 1992). Depositional environment interpreted as slope and inner submarine fan, fringing an eastern source area. Relatively sharp west contact with units Kksh and Kkmf may be fault. Conformably(?) overlain by unit Kkcd along lower Kipchuk River. Eastern contact with unit Kvs is locally an unconformity (for example, east of North Fork of Kisaralik River), but is typically faulted. Age constrained by megafossil occurrences of Turonian (Late Cretaceous) age (Elder and Box, 1992)

Kksh **Shale and siltstone (Late Cretaceous; early Turonian and (or) late Cenomanian)**—Dark-gray to black, finely laminated shale, siltstone and thin-bedded, very fine grained sandstone. Sandstone beds generally cross-laminated (interval T_{cde} of Bouma, 1964) and pinch and swell in thickness, which are generally 1 to 2 cm but locally as thick as 50 cm. Slump folding on scales from 5 cm to 2 m locally common. Weak to strong slaty cleavage often makes recognition of bedding difficult. Interpreted to represent several sand-poor depositional environments, including slope, interchannel areas on inner part of submarine fan, and distal basin-plain environments. Depositionally overlies unit Kkbc and gradationally underlies units Kkcf, Kkmf, and Kkmc. Age constrained by megafossil occurences of late Cenomanian and (or) early Turonian age low in section and by overlying units of Turonian age (Elder and Box, 1992)

Kkbc **Basal conglomerate (Late Cretaceous; Cenomanian?)**—Pebble to boulder conglomerate, coarse sandstone, and minor interbedded medium-grained sandstone, siltstone, and shale. Conglomerate composition is variable with basal strata dominated by clasts of underlying lithology and with higher strata consisting of mixture of clasts of quartz-mica schist, quartzite, dioritic to granitic gneiss, phyllitic metavolcanic and metasedimentary rocks, and unfoliated volcanic and plutonic rocks. Conglomerate is typically clast supported with moderately rounded to well-rounded clasts, or poorly sorted with sandy matrix. Meter-scale crossbedding, flat-pebble imbrication, and large, oversized, locally derived clasts in channelized basal few meters suggest nearshore-marine deposition on profound erosional surface along east side of Greenstone Ridge in central part of map area, around anticlinorium of older rocks on ridge immediately east of Greenstone Ridge (Box and Murphy, 1987), and on unit Xo of Kilbuck terrane west of Eek Mountains in south-central part of map area. Interbedded turbiditic sandstones above basal few meters indicate most of conglomerate was deposited in deeper water below effect of surface waves. Murphy (1987, 1989) interprets thick conglomerate in Eek Mountains to be fill of submarine canyon cutting into older rocks, with no basal shallow-marine deposits. Cross-bedding and pebble imbrication indicate easterly directed paleocurrents (Box and Elder, 1992). Age constrained by occurrence of late Cenomanian to early Turonian fossils from basal part of overlying unit Kksh unit and Valanginian fossils from unit Kts immediately below unconformity in Eek Mountains (Stephen Box and others, unpublished data, 1993)

PRE-LATE CRETACEOUS TERRANES EAST OF SAWPIT FAULT

Four pre-Late Cretaceous tectonostratigraphic terranes are defined east of the Sawpit Fault (from west to east): the Kilbuck, Goodnews, Togiak, and Tikchik terranes (Jones and others, 1987). These terranes are interpreted to have experienced significantly different geologic histories prior to overlap by the Upper Cretaceous Kuskokwim Group. Faults or inferred faults separate the exposures of these terranes, and we infer that these terranes haved moved an unspecified distance relative to each other prior to Late Cretaceous juxtaposition

Kilbuck terrane

Xo **Amphibolite-facies orthogneiss and amphibolite with minor intercalated pelitic schist (Early Proterozoic)**—Strongly lineated and foliated, muscovite, biotite-muscovite, or amphibole orthogneiss with granite to tonalite to diorite protoliths. Unit is more extensively exposed to south in Goodnews Bay quadrangle, where it also includes amphibolite and minor pelitic schist and marble (Hoare and Coonrad, 1979). Exposed as rubble and small outcrops in southern part of map area: in low hills east of Great Ridge, on a small knob north of Kwethluk River, and as small exposure low on the west side of Greenstone Ridge. Granitic and tonalitic gneiss consist of large strained and recrystallized quartz crystals and granulated plagioclase and potassium feldspar crystals, with undulating biotite-rich and (or) muscovite-rich seams. Mafic minerals

comprise as much as 25 percent of gneisses and include biotite, chlorite, opaque oxides, and zoisite in felsic rocks, and green to yellow to blue-green amphibole, epidote, and sphene in intermediate and mafic rocks. Tourmaline or garnet is present is some rocks. Depositionally overlain by conglomeratic rocks (Kkbc) of Kuskokwim Group near south boundary of map area; nature of contact to east with fine-grained sedimentary rocks (Kksh) of Kuskokwim Group is uncertain. Inferred to structurally overlie sedimentary rocks (Kkcd) of Kuskokwim Group to west along southern extension of Golden Gate Fault, on the basis of relationships to north and south. Smaller exposures to north are structurally overlain by unit MzPzb along strands of Golden Gate Fault, and at least the northern exposure structurally overlies sedimentary rocks (Kkcd) of Kuskokwim Group along another strand of same fault. Two U/Pb zircon ages indicate igneous protolith is about 2.06 Ga (table 3, localities 22, 23); neodymium-samarium isotopic systematics interpreted to indicate that rocks formed from depleted mantle source in arc-related environment at about 2 Ga (Box and others, 1990). Early Proterozoic age of amphibolite-facies metamorphism indicated by U-Pb sphene age of 1.78 Ga (Turner and others, 1983). Cretaceous overprinting of most K/Ar ages suggests thermal or dynamothermal event between 120 to 150 Ma (Turner and others, 1983)

Goodnews terrane

Consists of structurally disrupted assemblage of deep-marine sedimentary and mafic volcanic rocks of diverse origin. In map area, Goodnews terrane is exposed in cores of thrust-related anticlines, which fold unconformably overlying strata of Kuskokwim Group, in three areas in central and south-central parts of map area. Each area is distinct in structural style and metamorphic grade, but shares common association of protolith types. In southern area (Eek Mountains), shale-matrix melange (MzPza) of prehnite-pumpelleyite metamorphic grade is depositionally overlain by and structurally imbricated with Lower Cretaceous clastic sedimentary rocks (Kts). On Greenstone Ridge in central part of map area, greenschist facies, foliated metabasalt and minor metachert (MzPzb) bear northeast-trending mineral lineation and are internally imbricated. On ridge immediately east of Greenstone Ridge is antiformally folded structural sequence, informally referred to as Kisaralik anticlinorium. South half of anticlinorium (south of Swift Creek) consists of five lithologic units (units MzPzp, MDm, MzPzm, MzPzs, and MzPzv, in structurally descending order), which are interpreted to be separated by antiformally folded low-angle faults. Metamorphic grade decreases structurally downward in structural stack from strongly foliated and crenulated greenschist facies (MzPzp, MzPzm) and transitional greenschist-blueschist facies (unit MDm) rocks to prehnite-pumpelleyite facies rocks (MzPzs, MzPzv) with weak to strong slaty cleavage. North half of anticlinorium consists of two units of prehnite-pumpelleyite metamorphic grade (MzPzs, MzPzc), which are imbricated along southeast-dipping faults. South half of anticlinorium structurally overlies north half along low-angle(?) fault south of Swift Creek. Divided into:

Kts **Turbiditic sandstone, conglomerate, and phyllite (Early Cretaceous)**—Sandstone, sandy conglomerate, pebbly mudstone, siltstone, and shale with phyllitic fabric. Exposed only in Eek Mountains in south-central part of map area. Sandstone compositions range from entirely volcanogenic to polymictic, with clasts derived from adjacent Togiak, Goodnews, and Kilbuck terranes (Murphy, 1989). Thickness is uncertain. Depositionally overlies and imbricately faulted with unit MzPza. Unconformably overlain by conglomeratic strata (Kkbc) of Kuskokwim Group on northwest; faulted over unit Kkbc to west near south boundary of map area. Depositionally or structurally overlain by sedimentary rocks (Kkv) of Kuskokwim Group on east. Age assignment based on several pelecypod fossil collections of Valanginian, and of Late Jurassic and (or) Early Cretaceous, age (Murphy, 1989; Stephen Box and others, unpublished data, 1993)

MDm **Marble with metabasaltic dikes (Early Mississippian and (or) Late Devonian)**—Light-gray to white calcitic and dolomitic marble cut by premetamorphic basaltic dikes. Only found in small area east of Greenstone Ridge in central part of map area. Locally contains as much as 20 percent clastic grains of feldspar, quartz, and plutonic rock fragments. Rare metamorphic blue amphiboles (magnesioriebeckite) in metabasaltic dikes indicate relatively high-pressure, low-temperature metamorphism (Sarah Roeske, written commun., 1988). Ranges from 100 to 300 m thick. Unit found structurally above unit MzPzm and structurally below unit MzPzp; original depositional relations are uncertain. Age constrained by conodonts of latest Devonian to earliest Mississippian age (Stephen Box and others, unpublished data, 1993)

MzPzb **Metabasalt and minor metachert (Mesozoic and (or) Paleozoic)**—Weakly to strongly foliated metabasalt with variable recrystallization to greenschist-facies assemblage of albite-epidote-chlorite-actinolite; several inter-

bedded sequences (to 50 m thick) of thin-bedded, white or green metachert with white mica-rich laminae. Found only on Greenstone Ridge in central part of map area. Typical protolith lithology is plagioclase-clinopyroxene diabase but rarely basalt containing plagioclase phenocrysts. Whole-rock trace-element chemical compositions of lavas are similar to modern mid-ocean ridge basalts and range from light REE-depleted to slightly light REE-enriched varieties. Age of protolith is unknown. Age of metamorphic cooling constrained to Late Jurassic or Early Cretaceous time on the basis of actinolite K/Ar age of 146.0±15.0 Ma (table 1, locality 9)

MzPzs **Arkosic sandstone and slate (Mesozoic and (or) Paleozoic)**—Strongly cleaved, medium-grained, generally thin-bedded, arkosic sandstone and slate. Exposed on prominent ridge east of Greenstone Ridge in central part of map area. Detrital grains in sandstones include monocrystalline quartz (30 to 50 percent), plagioclase (10 percent), and potassium feldspar (5 percent), and minor mica, slate, and volcanic rock fragments. Alteration products include secondary prehnite, calcite, quartz, and white mica. Turbidite depositional features locally preserved. Thickness is uncertain. Intercalated (structurally?) over 100-m-thick zones with thin-bedded chert-argillite sections (MzPzm); unconformably overlain by conglomeratic rocks (Kkbc) of Kuskokwim Group. Age is uncertain, but older than Late Cretaceous age of unit Kkbc

MzPzc **Chert and argillite (Mesozoic and (or) Paleozoic)**—White, gray-green, and blue-green recrystallized chert in 2- to 5-cm-thick beds interbedded with black to dark-green phyllite or slate beds of similar thickness. Exposed on prominent ridge east of Greenstone Ridge in central part of map area. Structurally(?) intercalated with unit MzPzs; unconformably overlain by conglomeratic rocks (Kkbc) of Kuskokwim Group. Age constrained by presence of recrystallized radiolarians (Phanerozoic) and Late Cretaceous age of overlying unit Kkbc

MzPzv **Volcaniclastic sandstone and argillite (Mesozoic and (or) Paleozoic)**—Turbiditic, thin-bedded, medium- to fine-grained, volcaniclastic sandstones, and dark-green to black argillites with weak to nonexistent slaty cleavage. Exposed along prominent ridge east of Greenstone Ridge in central part of map area. Detrital grains include volcanic rock fragments containing plagioclase phenocrysts, plagioclase, and minor potassium feldspar, clinopyroxene, and quartz. Thickness is uncertain. Structurally overlain and underlain by unit MzPzs; structurally overlain by unit MzPzm along Kisaralik River; unconformably overlain by conglomeratic strata (Kkbc) of Kuskokwim Group north of Kisaralik River. Age is uncertain, but older than Late Cretaceous age of unit Kkbc

MzPzm **Metachert and phyllitic metachert (Mesozoic and (or) Paleozoic)**—Finely crystalline, thin-bedded quartzites (metachert) and finely interlayered quartzite and black phyllite. Found east of southern part of Greenstone Ridge in central part of map area. Composed of fine aggregates of quartz with seams to centimeter-thick bands rich in fine-grained white mica. Recrystallized radiolarian tests present in some horizons. Thickness is uncertain. Structurally overlies units MzPzs and MzPzv on north and is structurally overlain by unit MDm on south. Unconformably overlain by conglomeratic rocks (Kkbc) of Kuskokwim Group along Kisaralik River. Age constrained by presence of radiolarians (Phanerozoic) and by Late Cretaceous age of overlying unit Kkbc

MzPzp **Chloritic phyllite (Mesozoic and (or) Paleozoic)**—Relatively homogenous unit of finely foliated and crenulated phyllite composed of chlorite+albite+white mica+epidote+quartz. Found east of southern part of Greenstone Ridge in south-central part of map area. Protolith was probably fine-grained tuffaceous sediment of uncertain age. Whole-rock major- and trace-element chemical compositions are similar to those of modern mid-ocean ridge basalts and strikingly similar to those of lavas from unit MzPzb. Structurally overlies unit MDm and is intruded by serpentinite body (Ksp). Depositionally overlain by conglomeratic rocks (Kkbc) of Kuskokwim Group. Age is uncertain, but older than Late Cretaceous age of unit Kkbc

MzPza **Argillaceous melange with blocks of limestone, basalt, and chert (Mesozoic and (or) Paleozoic)**—Argillaceous melange of black to green, weakly to intensely fracture foliated argillite with discontinuous phacoids of recrystallized radiolarian chert and limey siltstone. Larger phacoidal blocks of massive to subphyllitic, amygdaloidal basalt with interbedded clastic limestone are surrounded by deformed argillite-chert matrix (Murphy, 1989). Found only in Eek Mountains in south-central part of map area. Basalt has diabasic texture of plagioclase and clinopyroxene and has trace-element chemistry ranging from arc-like to ocean-island-basalt-like. Faulted against and locally depositionally overlain by unit Kts. Unconformably overlain by conglomeratic sedimentary rocks (Kkbc) of Kuskokwim Group to northwest. Nature of contact with sedimentary rocks (Kkv) of Kuskokwim Group to east is uncertain. Age range based on range of fossil ages (Ordovician through Late Jurassic) in unit south of map area (Hoare and Coonrad, 1978). In map area,

Permian pelecypods were recovered from basalt-limestone block (Murphy, 1989), and Permian conodonts were recovered from limey siltstones in argillaceous matrix (Stephen Box and others, unpublished data, 1993)

Togiak terrane

Consists of stratigraphic sequence ranging from Late Triassic to Early Cretaceous in age, cropping out in southeastern part of map area. Consists primarily of deep-marine basinal strata deposited adjacent to intermittently active, subaerially eroding, andesitic volcanic highland. Late Triassic pillow basalts (Trb) with chemical characteristics of island arc tholeiitic magmas form base of exposed section. Divided into:

Kvs **Marine volcaniclastic sandstone, conglomerate, shale, and interbedded tuff (Early Cretaceous)**—Thin- to thick-bedded, green tuffaceous sandstone, siltstone, argillite, conglomerate, tuff and tuffaceous chert. Clastic rocks are almost entirely volcanogenic containing dominantly pyroclastic components (glass shards, broken crystals) in lower part of section with increasing epiclastic component upward. Unit is at least a few kilometers thick. Distinctive white dacitic to rhyolitic crystal tuff beds as thick as tens of meters are interbedded with turbiditic sandstones and argillite. Unconformably overlain by sedimentary rocks (Kkv) of Kuskokwim Group; relations with older units obscured by complex folding and faulting. Age assignment based on Early Cretaceous pelecypods and radiolarians from the upper part of section (Hoare and Coonrad, 1978; Stephen Box and others, unpublished data, 1993)

KJc **Argillite and tuffaceous chert (Early Cretaceous and (or) Late Jurassic)**—Thin-bedded green to brown argillite with occasional 1- to 4-cm-thick tuffaceous chert, siltstone, and fine-grained tuff interbeds. Thickness is uncertain due to complex structure but probably at least a few kilometers thick. Appears to be conformable above unit Jvs south of Kisaralik Lake. Pillow basalts (KJb) found within unit KJc section south of Heart Lake. Apparently faulted over unit Kvs southwest of Heart Lake. Unconformably overlain by sedimentary rocks (Kkv) of Kuskokwim Group west of Kisaralik Lake. Late Jurassic and (or) Early Cretaceous age given by range of poorly preserved radiolarians (Stephen Box and others, unpublished data, 1993)

KJb **Pillow basalt (Early Cretaceous and (or) Late Jurassic)**—Very altered pillow basalt sequence. Exposed along narrow trend for about 10 km of strike south of Heart Lake near south margin of map area. Original ophitic texture of clinopyroxene and plagioclase is barely discernible through extensive alteration assemblage of chlorite, calcite, quartz, epidote and iron oxides. Thickness is about 300 to 500 m. Interbedded with argillite and thin-bedded chert of unit KJc. Chemically characterized by slight light REE enrichment and low La/Nb ratios, suggesting a change from earlier arc setting (backarc? intra-arc rift?). Superficially similar to unit Trb, but distinguished from that unit by its stratigraphic position—enclosed within unit KJc—and by its distinct trace-element chemistry. Age given by range of radiolarian fauna in interbedded unit KJc (Stephen Box and others, unpublished data, 1993)

Jvs **Marine volcaniclastic sandstone, conglomerate, and argillite (Jurassic)**—Turbidite facies volcaniclastic strata, locally as coarse as fine-grained pebble conglomerate. Sandstone composed predominantly of intermediate volcanic lithic fragments and detrital grains of plagioclase, clinopyroxene, and hornblende, but contains persistent minor component of plutonic rock fragments, felsic volcanic and hypabyssal plutonic rock fragments, sandy and argillaceous (some radiolarian-bearing) sedimentary rock fragments, and low-greenschist facies, foliated, finely micaceous quartzite (metachert?), phyllite, and rare foliated epidote-actinolite-chlorite metabasalt; cut by secondary prehnite veins. Thickness uncertain due to complex structure but may reach at least a few kilometers. Interfingers with unit Ja along strike to north. Maximum age given by stratigraphic position above Upper Triassic(?) and Lower Jurassic unit JTRp east of Kisaralik Lake; minimum age of given by Late Jurassic and (or) Early Cretaceous age of overlying unit KJc

Ja **Marine arkosic sandstone and argillite (Jurassic)**—Turbidite-facies arkosic sandstone and shale. Sandstone composed predominantly of detrital grains of plagioclase, quartz, and potassium feldspar with lesser hornblende, biotite and clinopyroxene of plutonic origin, less than 10 percent felsic and subordinate intermediate volcanic rock fragments, and trace amounts of clasts of low-greenschist-facies phyllite and metachert, and of detrital grains of epidote. Cut by secondary prehnite veins. Sandstones within unit are unfoliated except east of north-striking, east-dipping low-angle thrust(?) fault that trends from south arm of Chikuminuk Lake to just east of Aniak Lake. Age inferred from its stratigraphic position above Upper Triassic(?) and Lower Jurassic unit JTRp; found along strike with and is presumably correlative with Jvs east of Milk Creek Fault

JTRp **Phyllite and chert (Early Jurassic and Late Triassic?)**—Gray, green, and black phyllite,

fine-grained tuff, and tuffaceous chert. Thickness is uncertain. Depositionally underlies unit Jvs south of Milk Creek and unit Ja north of Milk Creek; depositionally overlies unit TRb near Aniak and Upnuk Lakes. Late Triassic(?) and Early Jurassic age constrained by age of underlying unit TRb and by single radiolarian collection of Early Jurassic(?) age (Stephen Box and others, unpublished data, 1993)

TRb **Pillow basalt and minor interbedded chert (Late Triassic)**—Massive and pillow basalt and basaltic breccia interbedded with thin-bedded tuffaceous chert and shale. Subophitic and fine-grained plagioclase porphyritic protolithic textures overprinted by unoriented secondary chlorite, quartz, and calcite west of Milk Creek Fault; strong foliation and recrystallization east of Milk Creek Fault produced fine-grained schist or phyllite composed of chlorite, epidote, calcite, and pumpellyite. Whole-rock trace-element chemistry characterized by flat to light REE-depleted chondrite-normalized REE pattern, and by high La/Nb elemental ratios, characteristic of island-arc tholeiitic basalts. Interbedded shale has yielded Late Triassic pelecypods just east of Aniak Lake in map area (Stephen Box and others, unpublished data, 1993) and in two places in Taylor Mountain quadrangle just east of map area (W.L. Coonrad, unpublished data, 1991). Unit TRb is identified on east side of Milk Creek Fault on the basis of similar stratigraphic position and trace-element chemistry

Tikchik terrane

Consists of structurally disrupted assemblage of sedimentary and volcanic rocks exposed only east of Togiak Fault in southeasternmost part of map area. Broadly, terrane can be divided into two assemblages separated by low-angle(?) fault: (1) upper plate of volcanic rocks (MDv), depositionally overlain by clastic marine section (TRDs), and (2) lower plate of structurally disrupted melange (TRPzm). However our mapping of this area is woefully insufficient, and our interpretations of relations within and between units are highly uncertain. Divided into:

TRDs **Marine sandstone, shale, limestone, and conglomerate (Middle? Triassic to Late Devonian)**—Well-bedded, cleaved sandstone, shale, thin limestone interbeds, and cobble conglomerate exposed both north and south of head of Upnuk Lake. Well-bedded sandstone and conglomerates are composed predominantly of chert clasts (containing radiolarian ghosts and internal quartz veins) and minor phyllite and porphyritic volcanic clasts; shale-rich sections have thin limestone turbidite beds and thin sand to gravel beds of volcaniclastic composition. Thickness is uncertain. Unit appears to depositionally overlie unit MDv except at north end, where unit MDv is faulted over it. Faulted against rocks (TRb, JTRp, and Ja) of Togiak terrane along Togiak Fault to west. Age assignment based on conodont collections near top and bottom of section that give Middle(?) Triassic and Late Devonian to Early Mississippian ages, respectively (Stephen Box and others, unpublished data, 1993)

MDv **Massive volcanic and volcaniclastic rocks (Early Mississippian and (or) Late Devonian)**—Weakly to moderately foliated and flattened pillowed and massive basalt, andesite, dacite, and rhyolite flows and breccia with greenschist-facies metamorphic-mineral assemblages. Flow rocks are compositionally variable from diabasic basalt, to andesites and dacites containing phenocrysts of plagioclase and clinopyroxene, and to quartz-plagioclase porphyritic dacites and rhyolites. Whole-rock trace-element chemical compositions indicate calc-alkaline arc affinities. Depositionally overlain by unit TRDs to west and faulted against structurally complex melange (TRPzm) with Upper Triassic limestone blocks on east. Juxtaposed against rocks (Ja, Jvs, JTRp) of Togiak terrane along Togiak Fault on west. Minimum age from Late Devonian to Early Mississippian fossils near base of depositionally overlying unit TRDs, which is interbedded with flow rocks near its base

TRPzm **Melange (Triassic and Paleozoic)**—Structurally complex assemblage of intercalated chert, limestone, basalt, and graywacke, dismembered along anastomosing cleavage into argillite matrix. Clastic rocks are composed of volcanic and chert lithic fragments. Apparently faulted beneath unit MDv to northwest across low-angle(?) fault; separated from rocks (Jvs) of Togiak terrane to southwest by subvertical Togiak Fault. Fossils recovered from limestones are of Permian and Late Triassic age (Hoare and Coonrad, 1978; Stephen Box and others, unpublished data, 1993) radiolarian fossils from cherts are of Paleozoic(?), pre-Late Devonian, Devonian(?), and Triassic ages (Hoare and Jones, 1981)

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