STATE OF ALASKA

DEPARTMENT OF NATURAL RESOURCES

DIVISION OF GEOLOGICAL AND GEOPHYSICAL SURVEYS

STATE OF ALASKA

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Report of Investigation 84-30

STRATIGRAPHY, PETROLOGY, AND GEOCHEMISTRY OF UPPER TRIASSIC ROCKS FROM THE PINGSTON AND McKINLEY TERRANES, CENTRAL ALASKA RANGE

By
W.G. Gilbert, C.J. Nye, and K.W. Sherwood

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CONTENTS

FIGURES

TABLE

METRIC CONVERSION FACTORS

To convert feet to meters, multiply by 0.3048. To convert inches to centimeters, multiply by 2.54. To convert miles to kilometers, multiply by 1.61.

STRATIGRAPHY, PETROLOGY, AND GEOCHEMISTRY OF UPPER TRIASSIC ROCKS FROM THE PINGSTON AND McKINLEY TERRANES

By
W.G. Gilbert,[1] C.J. Nye,[2] and K.W. Sherwood[3]

INTRODUCTION

Recent geologic studies suggest that central and southern Alaska is made up of numerous distinct geologic terranes that accreted to the northwestern North American continental margin during Mesozoic and early Cenozoic time (Plafker and others, 1977; Jones and others, 1977; and Coney and others, 1980). The terranes are distinguished by their contrasting internal stratigraphies and geologic histories. In the central Alaska Range, nine possible tectonostratigraphic terranes have been identified (Jones and others, 1982). This paper describes the Upper Triassic sequences that form the basis for comparison and separation of two of these terranes, the Pingston and McKinley terranes. These terranes are adjacent to one another and extend in a broad arc for 175 km southwest of Mount McKinley as fault slivers (Gilbert and others, 1985; Kline and others, 1985) and 175 km east of Mount McKinley (Sherwood and Craddock, 1979) into the Yanert Fork drainage, where they appear to merge into a single structural unit (Sherwood and others, 1984) (fig. 1).

UPPER TRIASSIC FLYSCH OF THE PINGSTON TERRANE

For most of its length, the Hines Creek strand of the Denali fault system juxtaposes a polymetamorphic sequence of Proterozoic(?) and Paleozoic metapelites and metavolcanic rocks to the north (the Yukon-Tanana terrane) and a sequence of thin- to thick-bedded rhythmic intercalations of black graywacke, calcarenite, and thinly laminated calcareous slate to the south (Gilbert and Bundtzen, 1979; Sherwood and Craddock, 1979; Jones and others, 1983). This sequence has been named the Pingston terrane by Jones and others (1982) because of its excellent exposures along Pingston Creek 100 km southwest of Mount McKinley. Conodont microfossils indicate that the Pingston sequence is of Late Triassic (Karnian-Norian) age (Hickman, 1974, p. 273; Cota, 1975, p. 195; Sherwood, 1979, plate IV, app. 5; Jones and others, 1983; Umhoefer, 1979). No pre-Cenozoic rocks are known to lie stratigraphically above the Upper Triassic sequence, but locally the Pingston sequence overlies upper Paleozoic pillowed and fragmented greenstones or fine-grained, quartzose metavolcanic and metapelitic rocks (Sherwood and Craddock, 1979; Sherwood and others, 1985; Kline and others, 1985). Numerous east- and northeast-trending intrusions of dark-gray-green, fine- to coarse-grained gabbro and minor diorite cut both the Pingston and McKinley sequences (Gilbert and Redman, 1977; Sherwood and Craddock, 1979; Kline and others, 1985).

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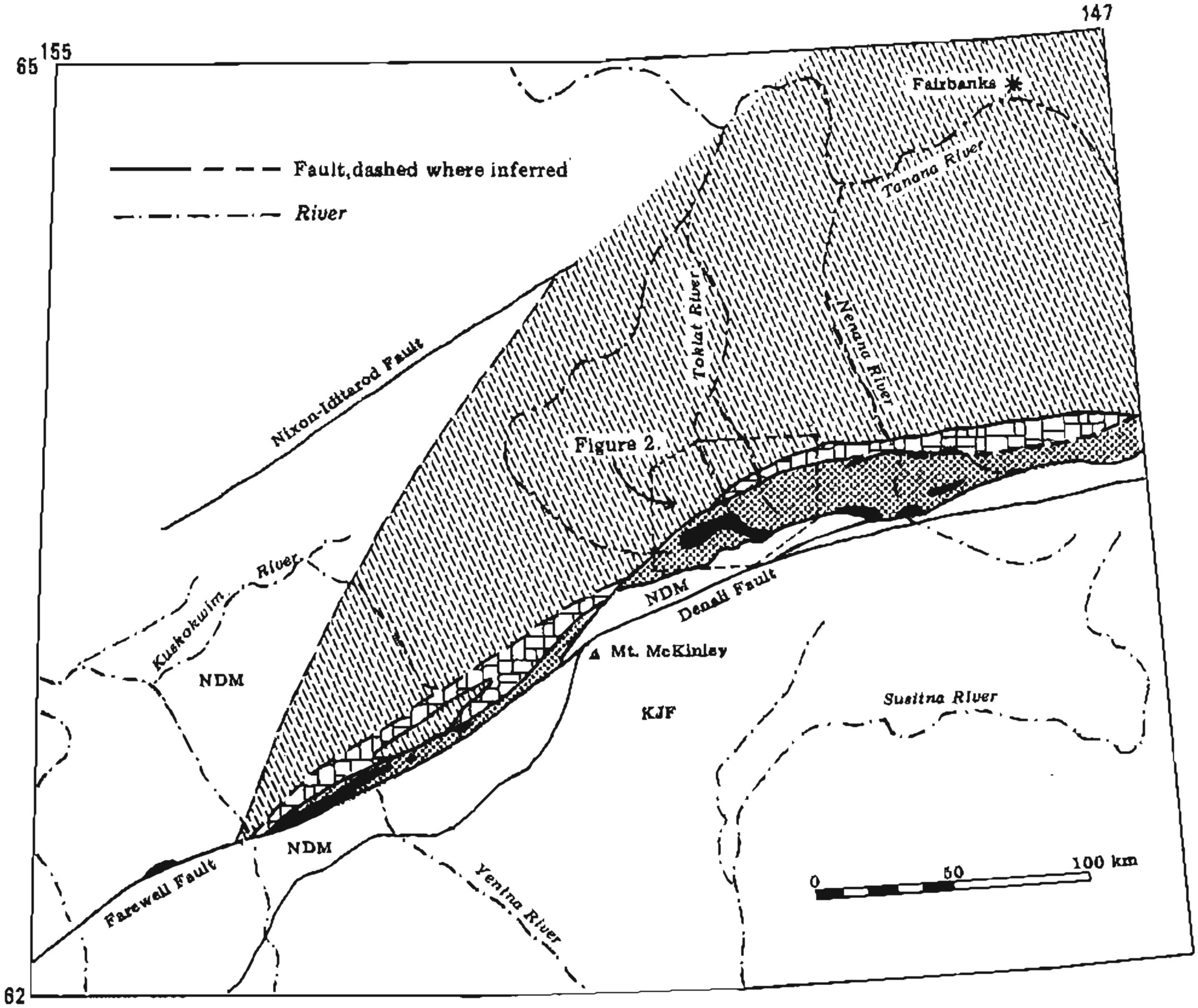

Figure 1. Tectonstratigraphic terranes of west-central Alaska Range. [pattern] = Yukon-Tanana terrane, [pattern] = Pingston terrane, [pattern] = McKinley terrane (black is greenstone), NDM = Nixon Fork/Dillinger/-Mystic superterrane, KJF = Jurassic and Cretaceous flysch.

Individual beds within the Upper Triassic flysch of the Pingston terrane are commonly planar and maintain thicknesses for at least tens of meters across exposures. Sandstone beds typically possess sharp lower contacts and grade upward into cleaved slaty rocks. Ripple cross-lamination (Bouma Tc interval) is locally developed in the central parts of these arenaceous beds, while parallel laminations are developed near the upper (Td) and lower (Ta) surfaces. Sole markings are only rarely found on the bottom surfaces of arenaceous beds. Load casts and penecontemporaneous deformational structures are commonly developed in laminated slates. Massive lenses of structureless quartzite up to 30 m or more in thickness and traceable for up to 2 km along strike are locally prominent in the headwater regions of the Wood River.

Cota (1975, p. 90) has also described quartzite from exposures of these rocks south of the Yanert Fork. Reticulated veins of milky quartz and carbonate occupy fractures prominently developed in the hinge areas of folds and are commonly injected along cleavage and bedding in argillaceous rocks.

In thin section, calcarenite east of the Nenana River consists of up to 90 percent fine-sand-sized grains of carbonate with accessory quartz, epidote, zircon, and tourmaline. Limonite, pyrite, and black carbonaceous material are present as trace constituents.

Calc-arenite is relatively well-sorted, and much of the carbonate appears to be fragments of biotic material---principally crinoid ossicles and algal material. Angular grains of monocrystalline quartz up to 0.1 mm in average diameter form the most abundant (6 to 10 percent) accessory constituent. Tourmaline and epidote occur as angular grains up to 0.05 mm in diameter. Zircon grains 0.5 to 0.01 mm in diameter are typically well-rounded. Pyrite, partly pseudomorphed by limonite, forms small cubes 0.1 mm along an edge. Black carbonaceous material is scattered throughout specimens and imparts the characteristic dark color to these rocks. Carbonate forms the principal cementing agent.

Quartzite and graywacke are typically composed of up to 90 percent very coarse sand- to silt-sized detrital grains of monocrystalline quartz. Opaques, carbonate, zircon, microcline, plagioclase, muscovite, and rock fragments of quartz schist, murky cryptocrystalline chert, quartz-mica phyllite and metasiltstone or metachert occur as accessory or trace constituents. Sorting is generally very poor. Large quartz grains (up to 2 mm in diameter) are commonly equant and well-rounded, whereas fine-sand- to silt-sized quartz grains are angular. Schistose rock fragments are discoidal and subrounded. Carbonate and quartz are the principal cementing agents.

Microcline and plagioclase (An_{35}) occur as subrounded to subangular detrital grains up to 0.1 mm in diameter. Muscovite occurs in schistose rock fragments and as single detrital flakes up to 0.1 mm long. Zircon and rare opaque grains occur as rounded grains up to 0.1 mm in average diameter.

Petrographic investigations and X-ray diffraction scans (Cota, 1975, p. 87) of slate and phyllite reveal that they are composed of silt-sized and finer mineral grains of quartz, chlorite, muscovite, and opaque carbonaceous material. These rocks typically exhibit a fine lamination defined by nearly opaque concentrations of carbonaceous material intercalated on a fine scale with calcareous or silty layers.

At most exposures, these rocks are tightly folded and east of the Nenana River appear virtually unmetamorphosed. The mineralogical assemblages observed in most specimens, however, are stable throughout the zeolite to greenschist facies. Near felsic intrusions, silicates and carbonate have reacted to produce diopside-, garnet-, and wollastonite-bearing assemblages of the pyroxene-hornfels facies. East of the Toklat River, gabbros that intrude the Upper Triassic flysch are metamorphosed within the prehnite-pumpellyite facies (Sherwood, 1979). Between the Nenana River and Stoney Creek, Pingston sedimentary rocks have been weakly metamorphosed and upgraded to siliceous marble, phyllitic marble, and carbonaceous slate (Decker, 1975; Gilbert and Redman, 1977; fig. 2). Here individual fine-grained marble beds weather to a yellowish-brown rough surface and display fine laminations. Black chert nodules are scattered throughout the marble. Whereas the marble is resistant and stands out in bold relief, the phyllitic marble is highly fissile and weathers to loose debris. In some areas, concordant quartz layers form up to 40 percent of the section, and crosscutting sparry calcite veins and veinlets are common.

The siliceous marble is composed of calcite crystals (53 to 83 percent) and quartz grains (5 to 29 percent) and lesser amounts of carbonaceous material (2 to 20 percent) and sericite (0 to 3 percent). Feldspar grains and metamorphic biotite are present in trace amounts. Quartz grains exhibit angular to subangular detrital outlines and occasionally very incipient recrystallization, whereas calcite is xenoblastic. The texture of the rock varies from a mosaic of equidimensional calcite and quartz in siliceous marble, which locally exhibits fine bedding laminations marked by concentrations of heavy minerals, to phyllitic marble. Fissility increases as quartz and carbonaceous material increase and calcite decreases, and the rock has a prominent cleavage where carbonaceous material and sericite are concentrated.

The most conspicuous structural-fabric element of the Pingston rocks is a single slaty cleavage developed in argillaceous rocks and oriented at a substantial angle to bedding. Cleavage parallels the axial planes of mesoscopic folds. Mesoscopic folds were produced by a single episode of folding and vary from upright isoclinal to overturned concentric folds with northward or northwestward vergence (Gilbert and Redman, 1977; Sherwood, 1979). Local intrafolial recumbent isoclinal folds may signal the presence of large-scale isoclinal folding or may locally represent 'drag' folds along bedding-plane thrust faults. Restorations of structures to pre-Paleocene attitudes by 'unfolding' overlying Paleocene beds generally yields subhorizontal attitudes for cleavage and axial surfaces of isoclinal folds, suggesting original recumbancy of those structures prior to Eocene folding.

The sedimentary structures and bedding style of the calcarenite and graywacke within the Upper Triassic sequence suggest that they originated as coarse bioclastic and siliciclastic sediments introduced by turbidity currents into relatively deep water characterized by accumulation of pelagic muds and marls. The massive, apparently structureless, quartzite beds may represent proximal turbidites. The presence of detrital carbonate grains derived from the skeletal parts of shallow-water marine fauna suggests proximity to a shallow marine shelf. The overall compositional maturity, the high degree of rounding of large detrital grains, and the nature of the accessory constituents of slate, quartzite, and graywacke collectively suggest a provenance best characterized as cratonic and metamorphic/igneous. Siliceous polymetamorphic schists and metavolcanic rocks widely exposed within the Yukon-Tanana terrane north and west of the Denali fault system form a potential source for the detrital constituents of the Upper Triassic quartzite and graywacke, and the Upper Triassic flysch of the Pingston terrane may represent oceanic rocks that were once deposited along the passive continental margin of the Yukon-Tanana terrane before its late Mesozoic accretion with northern Alaska (Gilbert and Bundtzen, 1983).

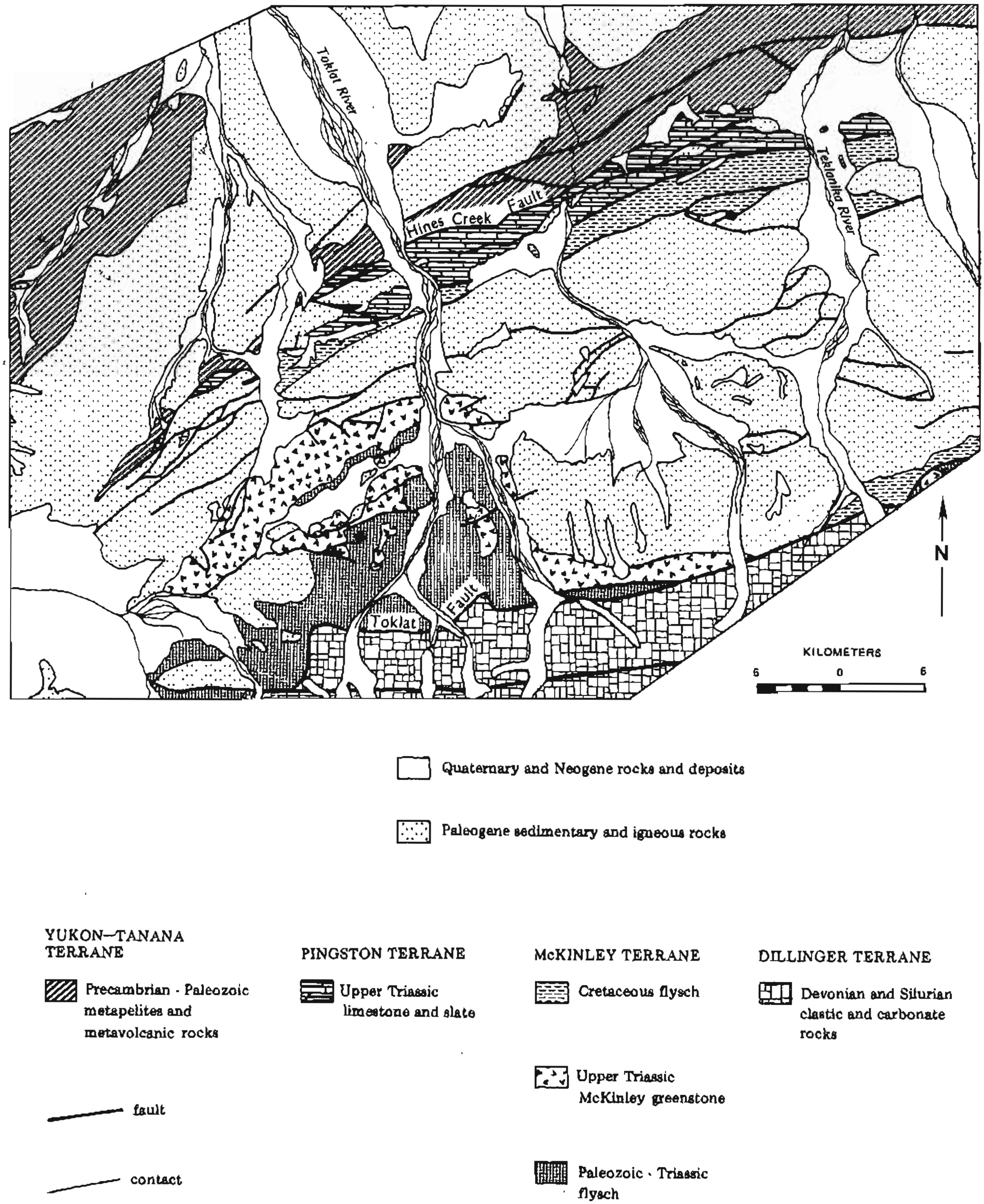

Figure 2. Geologic framework of the Toklat River area. Modified from Gilbert (1979) and Jones and others (1983).

GREENSTONE OF McKINLEY TERRANE

West of the Nenana River, the McKinley terrane lies immediately south and southeast of and in apparent fault contact with the Pingston terrane (Jones and others, 1982; 1983). East of the Nenana River, essential elements of both the McKinley and Pingston terranes appear to be intercalated in a single tectostratigraphic package. McKinley terrane strata include a sequence of Paleozoic-Triassic flysch, Upper Triassic basalt, and Cretaceous flysch (Jones and others, 1982), but this paper describes only the Upper Triassic basaltic greenstone (hereafter informally called the McKinley greenstone) in the Toklat and Thorofare river drainages northeast of Mount McKinley. McKinley greenstone crops out discontinuously from just south of the Hines Creek strand of the Denali fault in the Gillam Glacier region (PT gs of Sherwood and Craddock, 1979) southwest to the area between the Jones and Dillinger Rivers immediately northwest of the Farewell fault (Kline and others, 1985) (fig. 1). Field observations and chemical data from widely separate localities suggest that the greenstone in the Toklat River exposures is representative of Upper Triassic greenstone elsewhere in the McKinley terrane.

In the Toklat River area, a 5-km-wide, fault-bounded sequence of upper Mesozoic flysch and Tertiary continental rocks lies between the Pingston marble and slate and the McKinley greenstone (fig. 2). The McKinley greenstone overlies a sequence of Paleozoic-Triassic flysch, chert, and minor limestone (Gilbert, 1979). A flat clam collected by Gilbert and Dennis Trainor from a clastic interbed in pillowed greenstone was identified by N.J. Silberling as an Upper Triassic <u>Halobia</u>, with a likely age range of late Karnian to early Norian. Chert beds sampled by Gilbert and N.J. Silberling immediately beneath the lowest McKinley terrane basalt in the upper Toklat River drainage yielded Upper Triassic radiolaria (Jones and others, 1983).

The McKinley greenstone is composed of clinopyroxene-olivine-plagioclase-magnetite-bearing basalt and related hypabyssal rocks and forms a section 600 to 1,700 m thick. The 5- to 30-m-thick basalt flows are dark green to gray, weather to reddish brown, and usually have a blocky fracture, although columnar jointing, pillows, fragmental greenstone, and massive flows with vesicular tops are locally conspicuous. Individual flows are commonly diabasic and locally have porphyritic, quenched margins. Discontinuous beds of fine-grained clastic sedimentary rocks are locally intercalated with the basalt. The unit is intruded by dikes and sills that appear to be subvolcanic equivalents of the surrounding rocks.

Petrography

Clinopyroxene forms 10 to 55 percent of the mode of McKinley greenstone samples. It is clear to pleochroic and in some samples displays hourglass zoning or normal and oscillatory zoning. Spongy textures indicative of resorption are common, and small, spongy and embayed crystals commonly form cores of larger, inclusion-free phenocrysts. Individual crystals occur as phenocrysts, either alone or as glomeroporphyritic clots, as intersertal grains, or as large crystals ophitically intergrown with plagioclase. Radiating bundles of intergrown pyroxene needles are common. Relicts of original radiating bundles are sometimes preserved as radiating cleavages in larger crystals. Pleochroic titanaugite commonly rims clear augite but also occurs as discrete grains. Crystallization of titanaugite rather than uncolored augite is not related to FeO*(total iron as FeO)/MgO (the degree of fractionation) or the TiO_2 content of the sample, but does have a vague inverse correlation with the appearance of well-crystallized magnetite euhedra.

Bowlingite pseudomorphs after olivine make up as much as 15 percent of the rock. Rare unaltered olivine crystals have an optically estimated composition of about Fo_{85}. Bowlingite is formed of microcrystalline fibers and platelets that are arranged in an irregular fringe along grain margins and along lines that may have been fractures through the parent olivine crystals. In the center of pseudomorphs, bowlingite particles are optically coherent. The bowlingite pseudomorphs commonly contain trains of magnetite octahedra 10 to 15 microns in diameter and, rarely, trains of rutile(?) crystals.

Plagioclase is generally the most abundant phase in the rock, making up over half the mode, but is subordinate to clinopyroxene in the most mafic samples. Plagioclase forms independent laths or clumped phenocrysts set in a fine-grained groundmass, independent crystals supported by ophitic or intersertal pyroxene, or interlocking networks that support pyroxene crystals. The plagioclase is usually altered, either to a dense brown-gray opaque mass of unidentifiable microlites (saussurite) or to a very fine grained, low-relief, birefringent clay mineral. The saussuritization is commonly incomplete, preserving small portions of clear labradorite. Partially unaltered plagioclase appears unzoned with simple albite twinning, although the tendency of the cores to become sausseritized first indicates that they are more calcic.

Opaque phases are common minor constituents of the rock and make up as much as 10 percent of the mode. The opaque minerals are most commonly euhedral magnetite crystals that range up to half the size of the largest phenocrysts in the rock. The magnetite crystals are either massive with exsolved triangular lamellae of leucoxene or are skeletal. Scattered, irregular, elongate opaque crystals appear to be secondary.

Accessory and minor constituents of the rocks consist of amphibole, biotite, myrmekite, chlorite, apatite, and calcite. Amphibole forms phenocrysts in one sample and is coarse, euhedral, and pleochroic from light brown to brownish green. Secondary amphibole(?) occurs in a few samples as small, green, birefringent, pleochroic fibers. Fine-grained, reddish-brown biotite occurs along with secondary amphibole in a few samples. The absence of low-grade metamorphic minerals such as prehnite and pumpellyite suggests that the secondary amphibole and biotite are deuteric rather than post-magmatic. Myrmekitic intergrowths of quartz and plagioclase rim plagioclase specimens in some specimens. Chlorite forms patches of green, low-relief platelets that occur either in the groundmass or, rarely, in amygdules. Chlorite never makes up more than a few percent of the rock. Calcite is rare in the analyzed rocks, with the exception of a sample that contains calcite and calcite-zeolite(?) amygdules. Apatite is a common trace accessory phase that forms slender needles and elongate prisms, commonly incorporated in any of the major primary silicate phases or in the groundmass.

Geochemistry and Tectonic Setting

The McKinley greenstone is dominantly composed of basalt, although rare andesites exist (table 1). The rocks span a wide range of FeO*/MgO at relatively constant SiO_2 and are thus tholeiitic (fig. 3). Chemical variations between samples result from a number of processes, including fractional crystallization, alteration, and crystal accumulation. Low concentrations of immobile, incompatible trace elements such as Nb and Zr in some evolved rocks (fig. 3) may reflect exclusion of residual liquid from cumulate diabases. Alkali- and alkaline-earth-element concentrations have changed during metamorphism and weathering.

Relative concentrations of elements that are immobile during weathering and low-grade metamorphism suggest that the McKinley greenstone did not erupt at a plate boundary (fig. 4). Low Nb/Y and high Zr/P ratios (fig. 5), lack of abundant normative nepheline (table 1), and moderate concentrations of incompatible trace elements in the least fractionated samples (fig. 3) suggest that the McKinley greenstone is not alkaline. Lack of abundant silicic or fragmental rocks and the steady increase of TiO_2 with fractionation and relatively high concentration at TiO_2 (fig. 3) preclude association of the McKinley greenstone with a volcanic arc. Concentrations of incompatible trace elements are higher than abyssal MORB (for example, Sun and others, 1979) and provide ample chemical evidence that the greenstone was not generated at a divergent plate margin.

Chemical evidence suggests that the McKinley greenstone represents a fragment of one or more Upper Triassic seamounts, a conclusion substantiated by interbedding of the greenstone with deep-marine sedimentary rocks, the existence of the greenstone as discontinuous bodies within the McKinley terrane (which suggests discrete volcanic centers), and the absence of continental basement in the McKinley terrane (Jones and others, 1982). The presence of sedimentary rocks under the greenstone also argues against eruption at a mid-ocean ridge. The discontinuous nature and relative low volume of the McKinley greenstone suggest that the greenstone is neither a fragment of a volcanic arc nor of an oceanic plateau.

The conclusion that the McKinley greenstone is of ocean-island origin does not mean that it is far-traveled with respect to neighboring terranes, because ocean islands are not necessarily formed in deep parts of ocean basins and may even erupt through continental shelves. The absence of anatectic silicic rocks in the McKinley terrane, however, suggests that any continental crust beneath the McKinley greenstone is thin.

CONCLUSIONS

The Upper Triassic sequences in the Pingston and McKinley terranes represent coeval oceanic environments that appear to interfinger in the eastern part of the study area. The close spatial relationship between the terranes and their likely cratonic provenance suggest that the Upper Triassic

Table 1. Major, minor, and trace-element geochemistry and CIPW norms from the McKinley greenstone in the Toklat River area. Rb, Sr, Zr, Nb, and Y by X-ray diffraction at University of California - Santa Cruz. Estimated precision is ±3 percent relative. Other trace elements by semiquantitative emission spectroscopy at DGGS.

Analyses recalculated to 100% anhydrous. Original totals and volatile contents preserved.												
SiO_2	56.59	47.87	50.70	48.42	48.79	48.68	48.64	49.99	51.62	48.48	50.19	51.53
TiO_2	1.60	1.76	1.95	2.24	1.47	1.76	1.78	1.94	2.22	1.94	2.12	0.14
Al_2O_3	14.33	14.32	16.31	15.27	8.54	18.14	15.51	17.52	13.09	14.93	14.03	20.69
Fe_2O_3	1.32	2.05	2.17	1.80	2.47	1.68	1.96	2.85	3.40	1.56	2.05	2.69
FeO	10.26	9.09	9.81	11.82	10.48	7.25	8.60	7.67	10.92	8.82	11.78	8.45
MnO	0.18	0.16	0.18	0.23	0.21	0.15	0.17	0.15	0.22	0.20	0.22	0.14
MgO	4.55	10.39	5.93	5.82	15.41	4.84	8.89	5.26	5.78	5.93	4.82	3.60
CaO	6.17	11.50	7.63	10.46	10.99	12.83	10.69	11.47	9.83	14.41	10.45	11.68
Na_2O	3.51	2.10	4.32	2.32	1.23	3.50	3.31	2.76	2.57	2.57	2.64	2.66
K_2O	1.37	0.71	0.89	1.39	0.32	1.00	0.27	0.28	0.19	0.93	1.45	0.29
P_2O_5	0.12	0.06	0.11	0.24	0.11	0.18	0.18	0.11	0.18	0.24	0.24	0.11
H_2O+	3.23	3.63	3.60	3.07	2.75	3.15	3.97	1.92	1.86	2.03	2.60	2.03
CO_2	0.82	0.33	0.50	0.01	0.31	1.48	0.10	0.34	0.53	1.70	0.07	0.73
H_2O-	0.21	0.41	0.14	0.21	0.29	0.17	0.31	0.14	0.27	0.21	0.28	0.29
Total	99.86	100.05	99.90	98.92	100.71	99.09	99.78	100.01	99.71	99.03	100.57	100.66
FeO*/MgO	2.5	1.1	2.0	2.3	0.8	1.8	1.2	2.0	2.5	1.7	2.9	2.6
Rb	41	12	16	36	9	19	3	2	0	15	42	2
Sr	292	378	355	592	234	604	368	247	157	418	476	261
Ni	10	150	15	15	500	15	100	50	3	50	5	10
Co	20	50	30	50	70	30	30	50	30	30	30	50
Cr	0	1,000	20	0	1,000	100	500	200	20	200	20	50
V	500	700	700	300	500	300	500	1,000	1,000	500	500	1,000
Cu	100	200	300	200	150	200	150	700	200	200	200	300
Zr	125	126	138	208	104	142	131	131	147	160	209	120
Nb	10	15	13	35	14	18	17	12	12	21	39	12
B	20	15	15	20	20	50	20	5	5	20	20	10
Y	35	22	29	31	20	23	22	28	33	27	39	28
CIPW Norms												
Q	6.5	0.0	0.0	0.0	0.0	0.0	1.4	5.6	0.0	0.0	0.0	3.4
Or	8.1	4.2	5.3	8.2	1.9	5.9	1.6	1.6	1.1	5.5	8.6	1.7
Ab	29.7	17.8	36.5	19.6	10.4	19.2	26.7	23.3	21.7	15.9	22.4	22.6
An	19.3	27.5	22.5	27.1	16.8	30.8	26.7	34.6	33.6	26.5	22.1	43.7
Ne	0.0	0.0	0.0	0.0	5.7	0.7	0.0	0.0	0.0	3.2	0.0	0.0
Di	8.9	23.5	12.0	19.3	29.7	26.0	20.4	17.6	19.8	35.7	23.6	11.2
Hy	22.3	3.8	1.1	8.3	22.3	0.0	0.0	13.3	18.6	0.0	12.2	13.0
Ol	0.0	16.7	15.5	10.0	12.2	6.3	17.2	0.0	0.0	6.8	3.6	0.0
Im	3.0	3.3	3.7	4.3	2.8	3.3	3.4	3.7	4.2	3.7	4.0	0.3
Mt	1.9	3.0	3.2	2.6	3.6	2.4	2.8	4.1	4.9	2.3	3.0	3.9
Ap	0.3	0.1	0.3	0.6	0.3	0.4	0.4	0.3	0.4	0.6	0.5	0.3
Pg & An	39.3	60.8	38.1	50.0	61.7	61.7	50.0	59.7	52.1	62.5	49.7	66.0

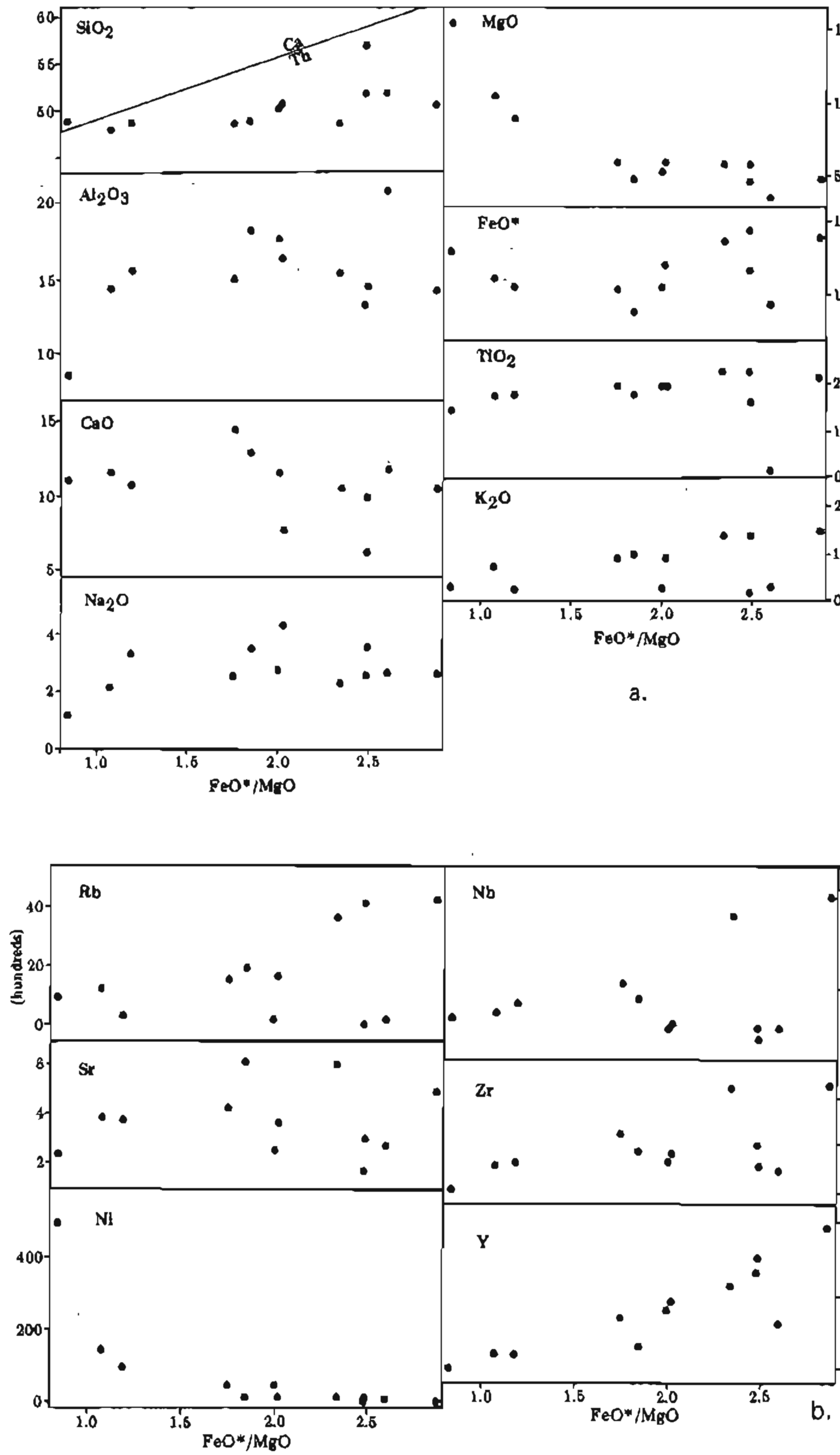

Figure 3. FeO*(total iron as FeO)/MgO variation diagrams of major (fig. 3a) and trace (fig. 3b) elements from McKinley greenstone samples in the Toklat River area. The calc-alkaline-tholeiitic boundary line is from Miyashiro (1974).

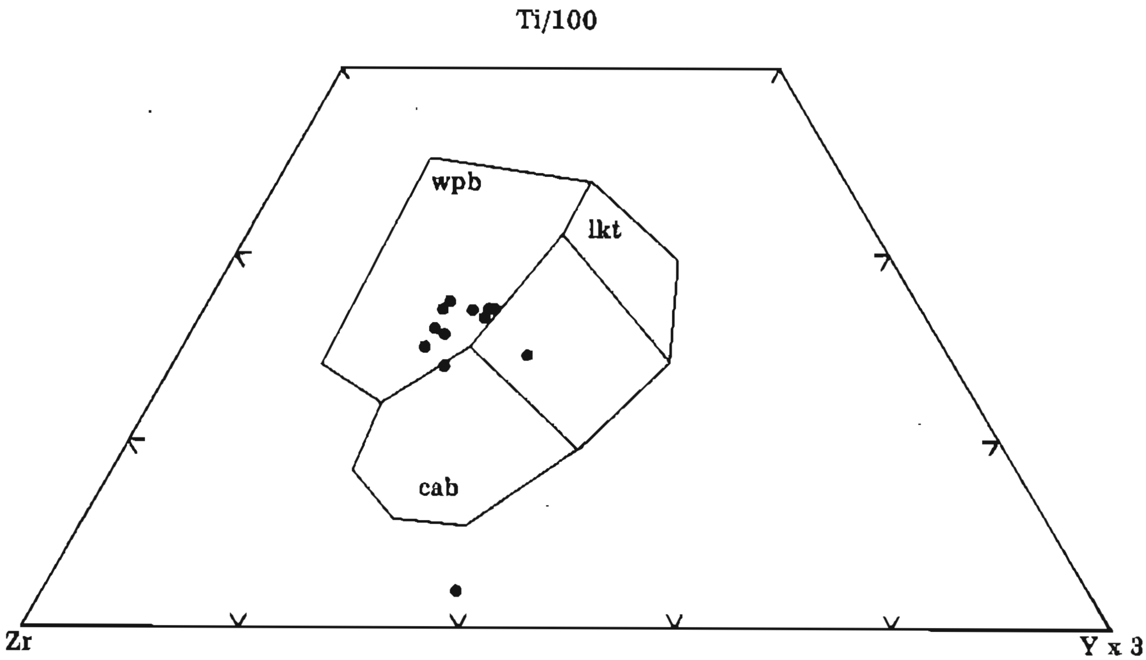

Figure 4. Ti/100 vs. Zr vs. Yx3 discriminant diagram (Pearce and Cann, 1973). Fields of within plate basalt (wpb), calc-alkaline basalt (cab) and low-k tholeiite (MORB, lkt) are shown. The unlabeled field is a zone of overlap.

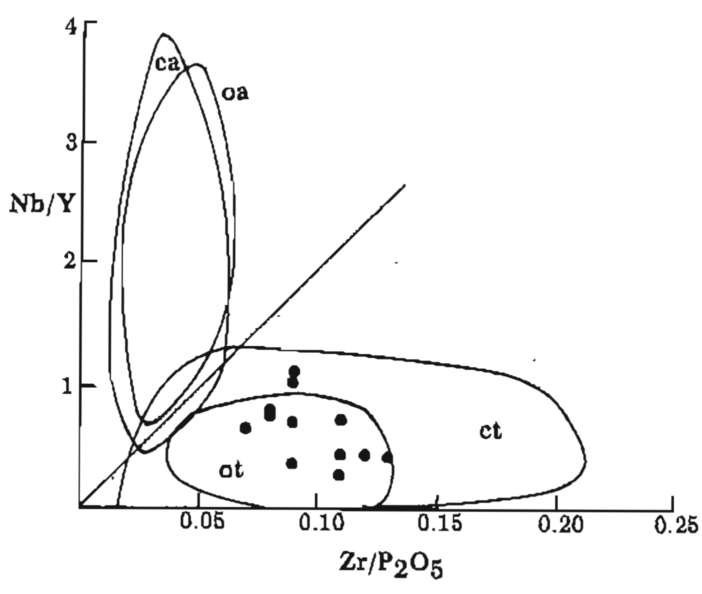

Figure 5. Nb/Y vs. Zr/P_2O_5 with fields for continental and oceanic alkaline rocks (ca and oa) and continental and oceanic tholeiitic rocks (ct and ot) (from Floyd and Winchester, 1975). The diagonal line divides alkaline from tholeiitic basalts (Winchester and Floyd, 1976).

flysch and basalt formed near the continental margin of the Yukon-Tanana block (Gilbert and Bundtzen, 1983). If the Upper Triassic flysch of the Pingston terrane originated as an apron flanking the Yukon-Tanana terrane, foreshortening of the Yukon-Tanana/Pingston/McKinley sequences may have occurred in response to the collision of the Yukon-Tanana block with North America to the north and west or with unknown terranes to the south during Late Jurassic-Early Cretaceous time (Templeman-Kluit, 1979; Csejety and others, 1982; Gilbert and Bundtzen, 1983). Structural evidence indicates that the Pingston rocks and mid-Cretaceous McKinley flysch of the Toklat-Teklanika River areas suffered the same Late Cretaceous deformation (Gilbert and Redman, 1977). Lack of known upper Mesozoic flysch overlying the Pingston rocks suggests that accretion of the Pingston and McKinley terranes may have occurred in stages, with the Pingston rocks displaced against the Yukon-Tanana terrane during Late Jurassic time, and then both the Yukon-Tanana and Pingston terranes shedding debris into a nearby McKinley basin during Early and mid-Cretaceous time. East of the Nenana River, final juxtaposition of the Pingston/McKinley structural package against the Yukon-Tanana terrane occurred by strike-slip displacement along the Hines Creek fault prior to 95 m.y. B.P. (Wahrhaftig and others, 1975; Sherwood, 1979). In any case, the Pingston and McKinley rocks were severely deformed and amalgamated with the Yukon-Tanana terrane by the beginning of Cenozoic time, because all the terranes are overlapped by continental clastic rocks of the Paleocene Cantwell Formation (Gilbert and Redman, 1975; Sherwood and Craddock, 1979). Folds in the Cantwell Formation, however, indicate that shortening within the two terranes continued during early Cenozoic time (Gilbert, 1976).

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