GEOLOGY, GEOCHEMISTRY, AND REGIONAL IMPLICATIONS OF MAFIC IGNEOUS ROCKS IN THE CARBONIFEROUS LISBURNE GROUP, IVISHAK RIVER AREA, BROOKS RANGE, ALASKA

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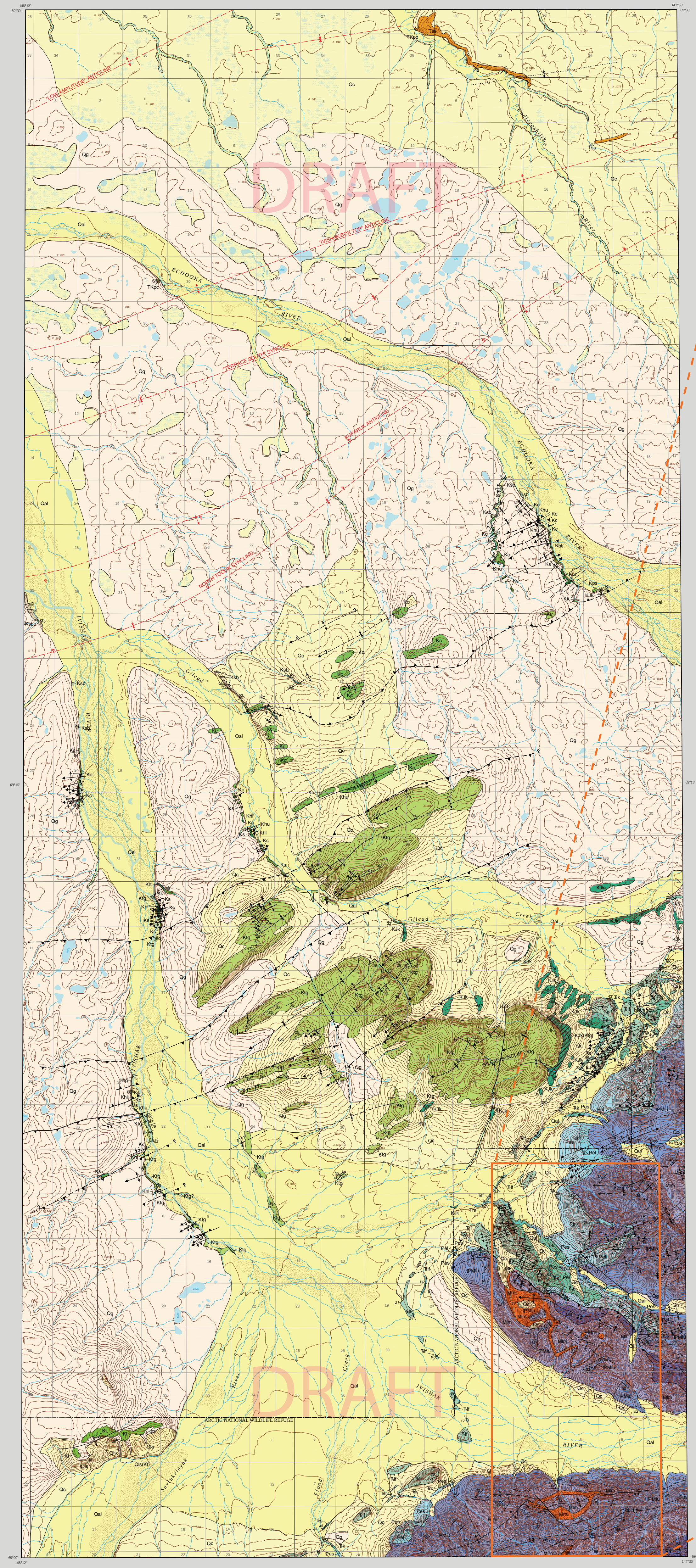
The data, maps, figures, and interpretations presented herein are preliminary and have not yet undergone rigorous technical or peer review. We will formally publish this work (Herriott et al., in preparation) through the Alaska Department of Natural Resources, Division of Geological & Geophysical Surveys' publications group. Please contact Trystan Herriott (trystan.herriott@alaska.gov) for further information regarding this poster.


DRAFT
ECHOOKA RIVER
IVISHAK RIVER
Gilead Creek
ARCTIC NATIONAL WILDLIFE REFUGE
148°12'
147°36'
69°30'
69°15'
69°00'

Topographic base vectorized from United States Geological Survey Sagavanirktok A-2 and B-2 quadrangles (1971).

Universal Transverse Mercator projection, zone 6.
1927 North American Datum

Geologic field investigations by: J.G. Clough (1989), P.L. Decker (2007-2009), R.J. Gillis (2007, 2009), T.M. Herriott (2009), T.A. Imm (1989), R. Kirkham (2001), D.L. LePain (2001), C.G. Mull (1989), M.D. Myers (1989), G.H. Pessel (1989), R.R. Reifenstuhl (1989, 1990, 2004, 2009), M.S. Robinson (1989), T.J. Ryherd (1989), G. Speeter (2008), W.K. Wallace (2007-2009), M.A. Wartes (2007-2009), C.F. Waythomas (1990)

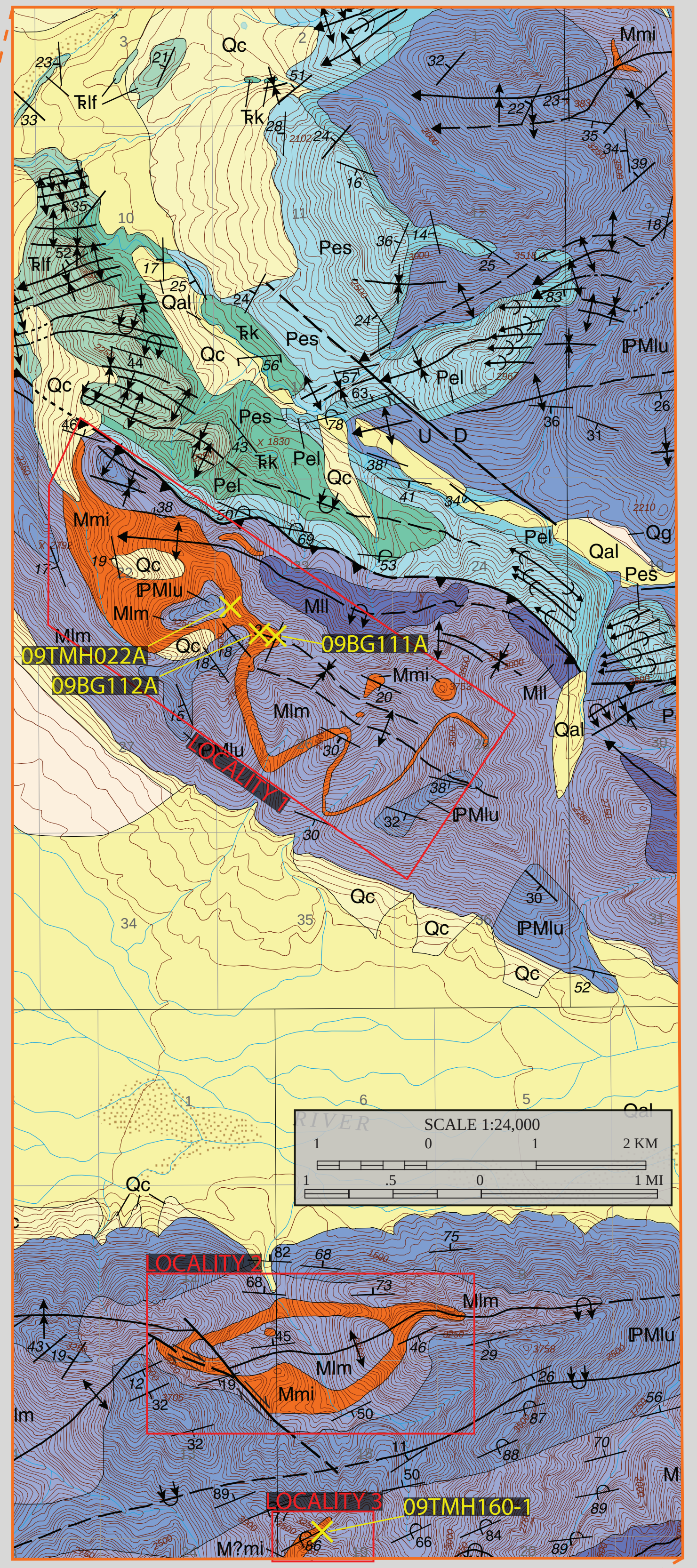
Quaternary mapping largely simplified after Waythomas (1991). The current authors thank C.F. Waythomas for allowing us to simplify his original surficial mapping and present it here.

Digital cartography by: T.M. Herriott

TRUE NORTH
MAGNETIC NORTH
23°
ESTIMATED DECLINATION, 2009
SCALE 1:63,360
KILOMETERS
MILES
CONTOUR INTERVAL 50 FEET
ALASKA
Sagavanirktok Quadrangle
MAP LOCATION
LOCATION INDEX
Harrison Bay
Beechey Point
Flaxman Island
Umiat
Sagavanirktok
Mount Michelson
Chandler Lake
Philip Smith Mountains
Arctic

GEOLOGIC MAPPING AND LOCAL CONTEXT

MAGNIFIED (1:24,000-SCALE) GEOLOGIC MAP HIGHLIGHTING LISBURNE GROUP MAFIC ROCKS


LOCALITY 1
LOCALITY 2
LOCALITY 3
09TMH022A
09BG111A
09BG112A
09TMH160-1
SCALE 1:24,000
2 KM
1 MI
Mmi
Mlm
Mll
IPMlu
Pes
Pel
Qc
Qal
Qg

LIST OF MAP UNITS

SURFICIAL DEPOSITS
(Quaternary mapping largely simplified after Waythomas, 1991)

Symbol	Unit
Qal	Alluvium, (Quaternary)
Qc	Colluvium, (Quaternary)
Qg	Glacial deposits, (Quaternary)
Qls	Landslide, (Quaternary)

BROOKIAN SEQUENCE
(stratigraphic nomenclature after Mull et al., 2003)

Symbol	Unit
Tss	Sagavanirktok Formation, Sagwon Member (Paleocene)
TKpc	Prince Creek Formation (Upper Cretaceous to Paleocene)
Ksbu	Schrader Bluff Formation, upper part (Upper Cretaceous)
Ksb	Schrader Bluff, undifferentiated (Upper Cretaceous)
Kc	Canning Formation (Upper Cretaceous)
Khu	Hue Shale, upper part (Upper Cretaceous)
Ks	Seabee Formation (Upper Cretaceous)
Ktg	Torok Formation, Gilead succession (informal name) (Lower to Upper Cretaceous)
Kt	Torok Formation (Lower to Upper Cretaceous)
Khl	Hue Shale, lower part (Lower to Upper Cretaceous)

BEAUFORTIAN SEQUENCE

Symbol	Unit
Kps	Pebble shale (Lower Cretaceous)
Kk	Kemik Sandstone (Lower Cretaceous)
KJk	Kingak Shale (Jurassic to Lower Cretaceous)

ELLESMERIAN SEQUENCE

Symbol	Unit
T̄Rs	Shublik Formation (Middle to Upper Triassic)
T̄Rif	Ivishak Formation, Fire Creek Siltstone and Ledge Sandstone members (Lower Triassic)
T̄Rk	Ivishak Formation, Kavik Member (Lower Triassic)
Pes	Echooka Formation, siliceous facies (Permian)
Pel	Echooka Formation, limy facies (Permian)
IPMlu	Lisburne Group, upper part (Upper Mississippian to Lower(?) Pennsylvanian)
Mlm	Lisburne Group, middle part (Mississippian)
Mmi	Lisburne Group, mafic igneous rocks (Mississippian and younger(?))
Mll	Lisburne Group, lower part (Mississippian)

MAP SYMBOLS

[For all line symbols: dashed where location is approximate; dotted where location is concealed; queried where identity or existence may be questionable]

Contact

Faults

Thrust fault—sawteeth on hanging wall

Strike-slip fault—arrows show relative motion

High-angle fault—U on upthrown side; D on downthrown side

Folds—showing trace of axial surface; direction of plunge indicated where appropriate; symbols in red where projected from seismic interpretation

Anticline

Syncline

Overturned anticline

Overturned syncline

Asymmetric anticline—shorter arrow on steeper limb

Asymmetric syncline—shorter arrow on steeper limb

Anticlinal bend—shorter arrow on steeper limb

Synclinal bend—shorter arrow on steeper limb

Small fold—showing down plunge profile view

Bedding—showing strike and dip where known or estimated

Inclined bedding

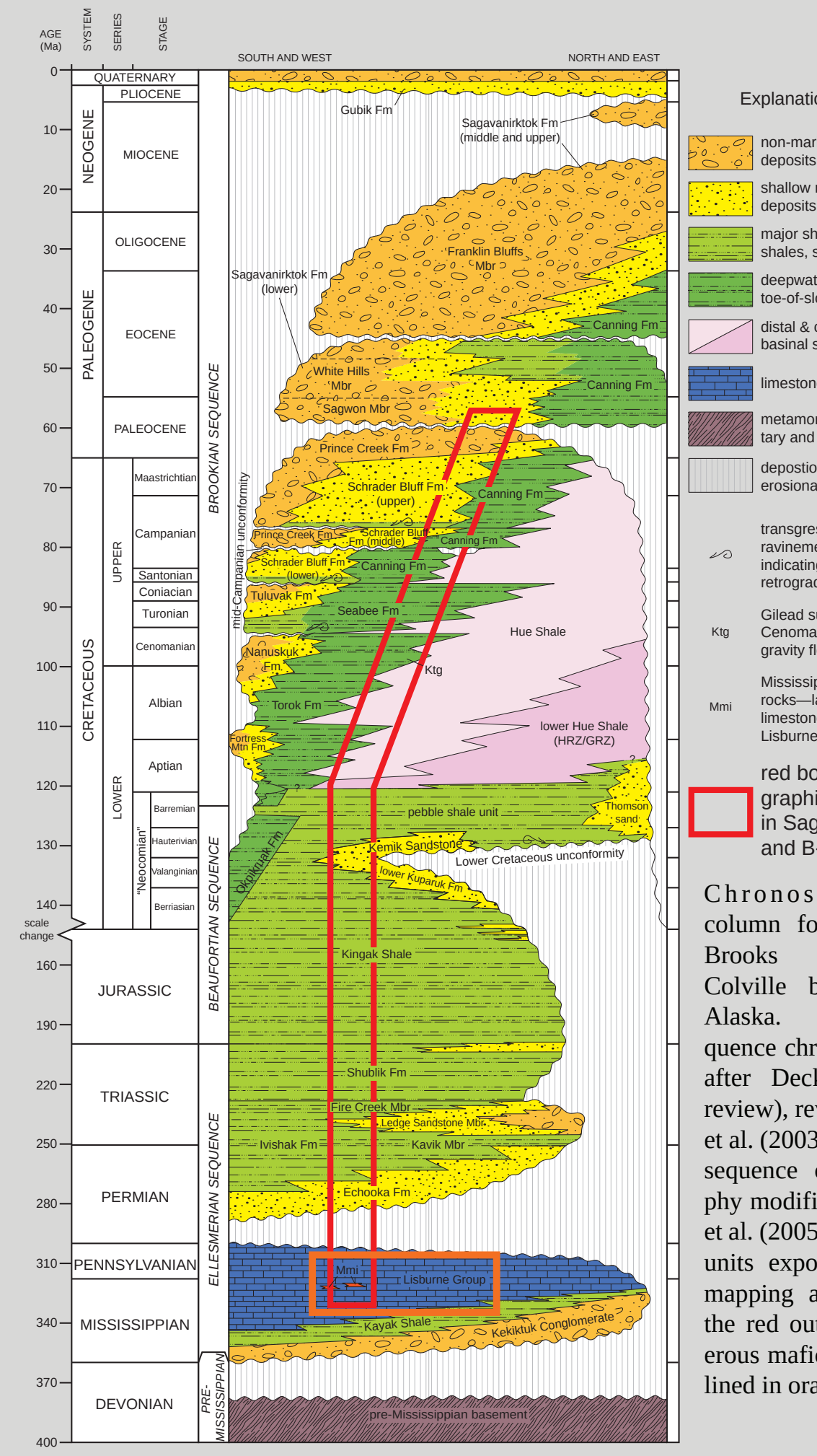
Overturned bedding

Slaty cleavage

Traceable bed

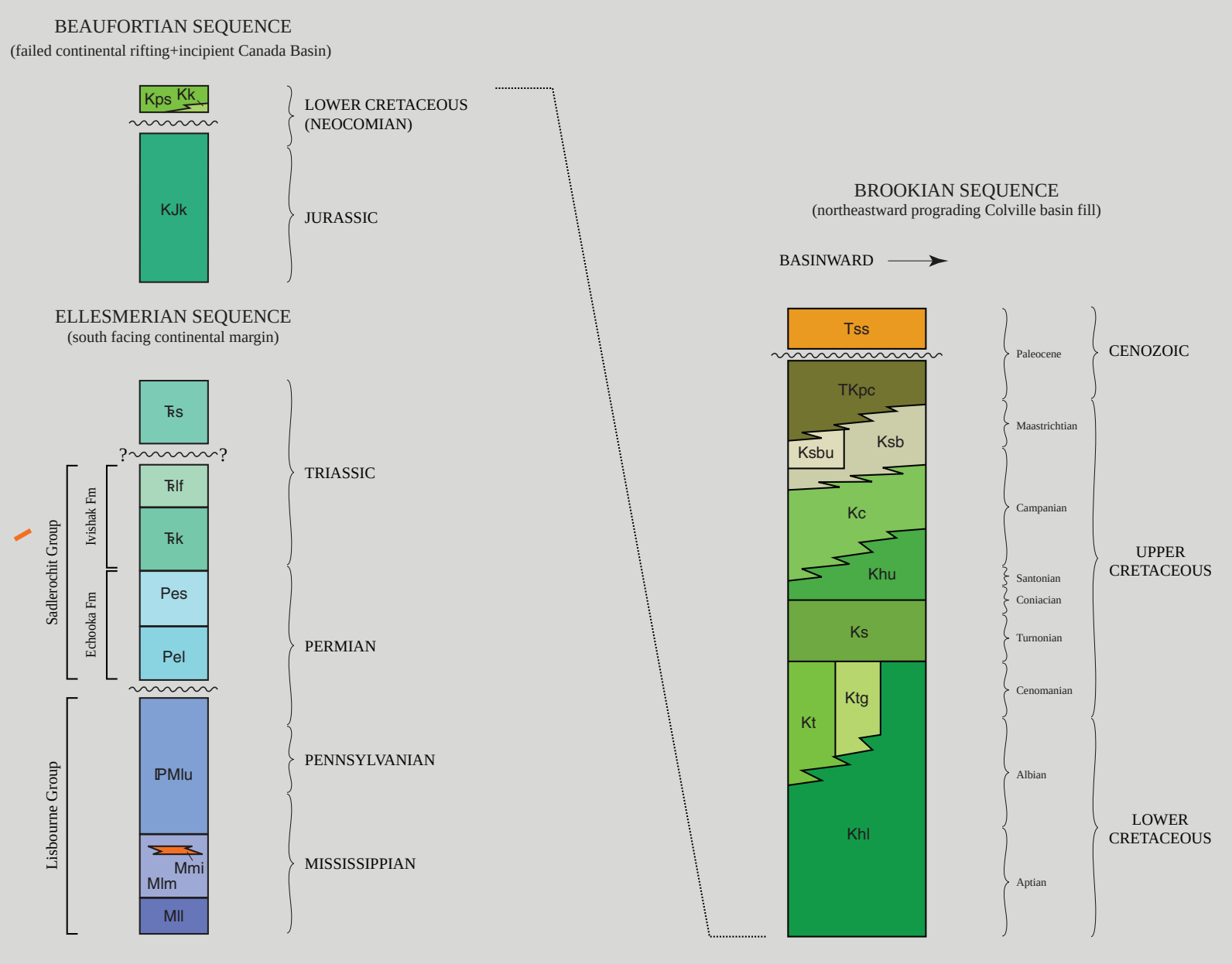
Ktg rubble-covered slope

CHRONOSTRATIGRAPHY


AGE (Ma)
SYSTEM
SERIES
STAGE
SOUTH AND WEST
NORTH AND EAST
QUATERNARY
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
NEOGENE
PALEOGENE
CRETACEOUS
UPPER
LOWER
JURASSIC
TRIASSIC
PERMIAN
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
BROOKIAN SEQUENCE
BEAUFORTIAN SEQUENCE
ELLESMERIAN SEQUENCE
PRE-MISSISSIPPIAN
Gubik Fm
Sagavanirktok Fm (middle and upper)
Sagavanirktok Fm (lower)
Franklin Bluffs Mbr
White Hills Mbr
Sagwon Mbr
Canning Fm
Prince Creek Fm
Schrader Bluff Fm (upper)
Schrader Bluff Fm (middle)
Schrader Bluff Fm (lower)
Tuluvak Fm
Seabee Fm
Nanushuk Fm
Torok Fm
Hue Shale
lower Hue Shale (HRZ/GRZ)
pebble shale unit
Thomson sand
Kemik Sandstone
lower Kuparuk Fm
Lower Cretaceous unconformity
Kingak Shale
Shublik Fm
Fire Creek Mbr
Ledge Sandstone Mbr
Ivishak Fm
Kavik Mbr
Echooka Fm
Mmi
Lisburne Group
Kayak Shale
Kekiktuk Conglomerate
pre-Mississippian basement
Ktg
Explanation
non-marine deposits
shallow marine deposits
major shelfal/platform shales, siltstones
deepwater slope & toe-of-slope deposits
distal & condensed basinal shales
limestone & dolomite
metamorphosed sedimentary and igneous rocks
depositional hiatus or erosional interval
transgressive flooding/ravinement surface, indicating direction of retrogradation
Gilead succession—Albian to Cenomanian age sediment gravity flow deposits
Mississippian mafic igneous rocks—lava flows, tuffaceous limestone, and sills within Lisburne Group, middle unit
red box outlines stratigraphic units exposed in Sagavanirktok A-2 and B-2 quadrangles

Chronostratigraphic column for the northern Brooks Range and Colville basin, northern Alaska. Brookian sequence chronostratigraphy after Decker et al. (in review), revised after Mull et al. (2003); pre-Brookian sequence chronostratigraphy modified after Garrity et al. (2005). Stratigraphic units exposed within the mapping area are within the red outline; Carboniferous mafic rocks are outlined in orange.

CORRELATION OF BEDROCK MAP UNITS


BEAUFORTIAN SEQUENCE
(failed continental rifting+incipient Canada Basin)
LOWER CRETACEOUS (NEOCOMIAN)
JURASSIC
ELLESMERIAN SEQUENCE
(south facing continental margin)
TRIASSIC
PERMIAN
PENNSYLVANIAN
MISSISSIPPIAN
Sadlerochit Group
Ivishak Fm
Echooka Fm
Lisbourne Group
BROOKIAN SEQUENCE
(northeastward prograding Colville basin fill)
BASINWARD
Paleocene
Maastrichtian
Campanian
Santonian
Coniacian
Turnonian
Cenomanian
Albian
Aptian
CENOZOIC
UPPER CRETACEOUS
LOWER CRETACEOUS
Kps
Kk
KJk
T̄Rs
T̄Rif
T̄Rk
Pes
Pel
IPMlu
Mmi
Mlm
Mll
Tss
TKpc
Ksbu
Ksb
Kc
Khu
Ks
Kt
Ktg
Khl

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ABSTRACT

Recent geologic mapping along the northeastern Brooks Range salient offers new documentation of Upper Mississippian mafic igneous rocks associated with deposition of the Ellesmerian Sequence. Evidence for this episode of magmatism is extremely rare within parautochthonous Ellesmerian strata and this study offers new constraints on the tectonic evolution of the late Paleozoic passive margin of northern Alaska.

The mafic rocks lie within carbonate-platform strata of the Carboniferous Lisburne Group that are exposed in the Ivishak River area near the Brooks Range mountain front. Three general localities were examined in this study. Columnar-jointed to pseudo-pillowed to massive basaltic lava and fine-grained tuffaceous limestone north of the Ivishak River (locality 1) comprise a locally ~100-m-thick package (Robinson et al., 1989) that crops out along a 5-km-long northwest trend. This succession lies within, and laterally grades into, our informal Lisburne middle unit (Mlm) that is in part equivalent to the Upper Mississippian Alapah Limestone. Lithologically similar volcanic and volcaniclastic rocks lie south of the Ivishak River (locality 2) along a 3-km-long east trend. This package is locally up to ~275 m thick and grossly occupies the same stratigraphic position as at locality 1. Volcanic intervals at localities 1 and 2 likely diminish to zero depositional thickness near each end of the reported ~strike-parallel exposures. Locality 3 lies ~1 km south of locality 2 and consists of a mafic sill that is up to ~125 m thick. This sill crops out along a minimum 0.5-km-long northeast trend and is observed to pinch-out to the northeast. Recrystallized/altered host rock lies at the sill's upper and lower contacts and the stratigraphic context suggests the intrusion is coeval with or post-dates the volcanic rocks farther north. Finally, mafic rocks cropping out in a prominent km-scale anticline several kilometers south of locality 3 were previously reported to comprise a 45-m-thick "diabase" sill. This occurrence may be genetically related to the locality 3 sill and, as suggested by Reiser et al. (1979), may represent an intrusive equivalent of the extruded rocks to the north—i.e., our localities 1 and 2.

Major and trace element geochemical data were collected via Wavelength-Dispersive X-Ray Fluorescence Spectrometry for four samples from three distinct lithologies: 1) medium-gray, medium- to thick-bedded, plane-parallel laminated and locally cross stratified, very fine- to medium-grained tuffaceous limestone (locality 1, one sample); 2) dark-gray to gray-green, very thick, aphanitic to porphyritic mafic lava (locality 1, two samples); and 3) medium- to light-gray, porphyritic mafic sill (locality 3, one sample). Despite probable shifts of major element compositions in some samples due to chemical alteration, high Cr, V, and Ti concentrations indicate basaltic parent rocks. Moreover, Nb/Y–Zr/TiO2 volcanic classification plots indicate the samples were originally alkali basalts or fragments thereof. Ti/100–Zr–3Y and 2Nb–Zr/4–Y trace element tectonic discrimination diagrams chiefly suggest within-plate basalt and within-plate alkalic basalt origins, respectively. These are the first geochemical results to demonstrate that magmatism in the parautochthon is related to extension.

Mafic igneous rocks have been documented elsewhere in the continental Arctic Alaska terrane, although they are everywhere uncommon except as abundant mafic sills in the structurally uppermost Ipnavik River allochthon (Mayfield et al., 1988). Allochthonous Devonian to Jurassic mafic and ultramafic rocks of the oceanic-affinity Angayucham terrane are, however, common in the southern and western Brooks Range, but are distinctly not part of the continental Arctic Alaska terrane. The structural context and terrane or allochthon assignments at some localities remains enigmatic—e.g., the uppermost klippe in the Mount Annette "allochthon" (Brosgé et al., 2001), the Kikiktat Mountain klippe (Solie and Mull, 1991), and the Maiyumerak basalts (Karl, 1992). Nevertheless, a preponderance of published observations and geochemical data from known occurrences of mafic rocks within the Arctic Alaska terrane either permit or strongly suggest that within-plate extensional magmatism occurred locally during Mississippian–Pennsylvanian(?) time (e.g., Werdon et al., 2004); regional extension during this period is further suggested by precipitation of world-class sedimentary exhalative massive sulfide deposits (e.g., Red Dog) and regional stratigraphic relationships among allochthons. Furthermore, detailed studies of Lisburne Group lithofacies in the central Brooks Range document marked lateral variation in paleobathymetry, potentially reflecting extension and graben development during Late Mississippian–Early Pennsylvanian time (Dumoulin et al., 2008). Finally, geochemical signatures of gabbro at Koiyaktot Mountain (Werdon et al., 2004) and a 223-m-thick volcanic interval penetrated in the Tunalik well (Sherwood et al., 2002) suggest extension-related magmatism either extended into or reoccurred during the Permian.

Additional geochemical, petrographic, and radioisotopic analyses of mafic rocks collected during this study will further increase our understanding of the tectonomagmatic evolution of the Ellesmerian passive margin in northern Alaska.

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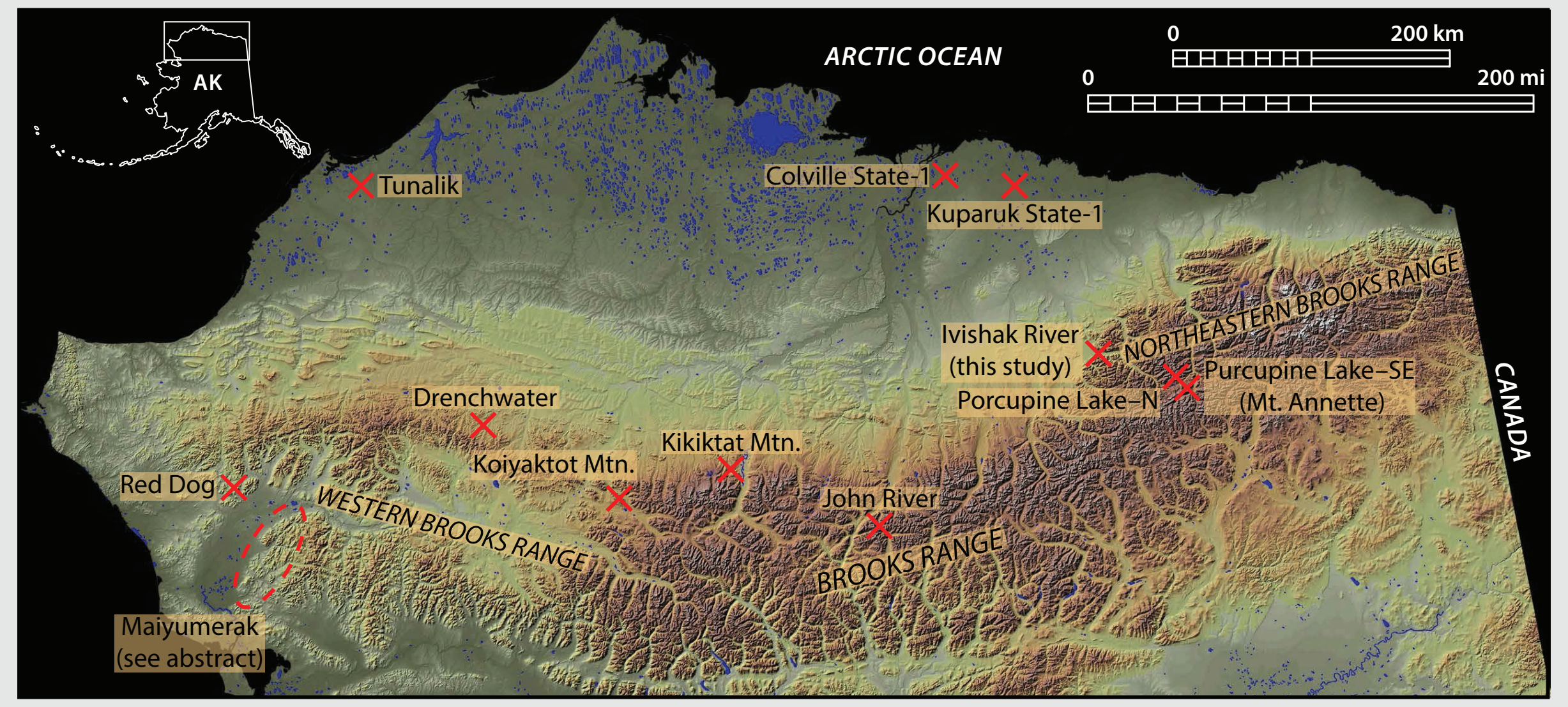
Werdon et al., 2004, 40Ar/39Ar dating of Zn-Pb-Ag mineralization in the northern Brooks Range, Alaska: Economic Geology, vol. 99, p. 1,323–1,343.

REGIONAL CONTEXT

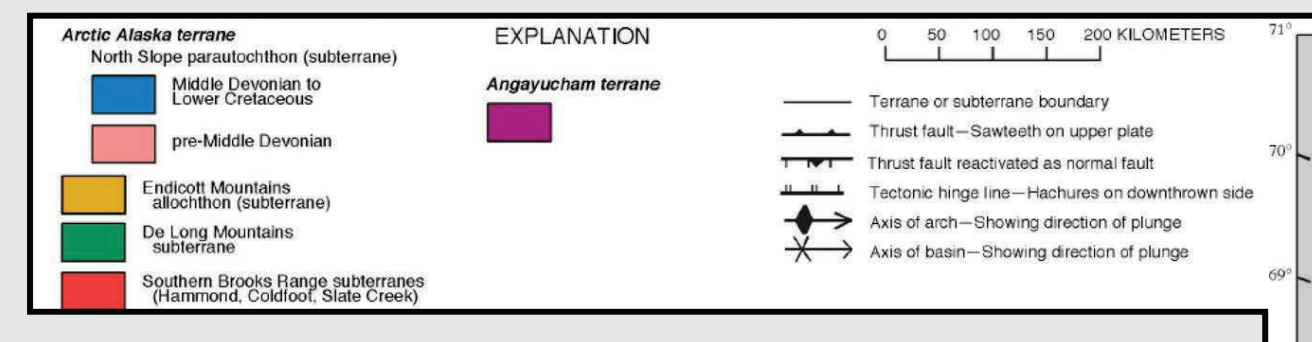

ARCTIC OCEAN
AK
0
200 km
0
200 mi
Tunalik
Colville State-1
Kuparuk State-1
Ivishak River (this study)
Porcupine Lake–N
Purcupine Lake–SE (Mt. Annette)
NORTHEASTERN BROOKS RANGE
CANADA
Drenchwater
Red Dog
Koiyaktot Mtn.
Kikiktat Mtn.
John River
WESTERN BROOKS RANGE
BROOKS RANGE
Maiyumerak (see abstract)

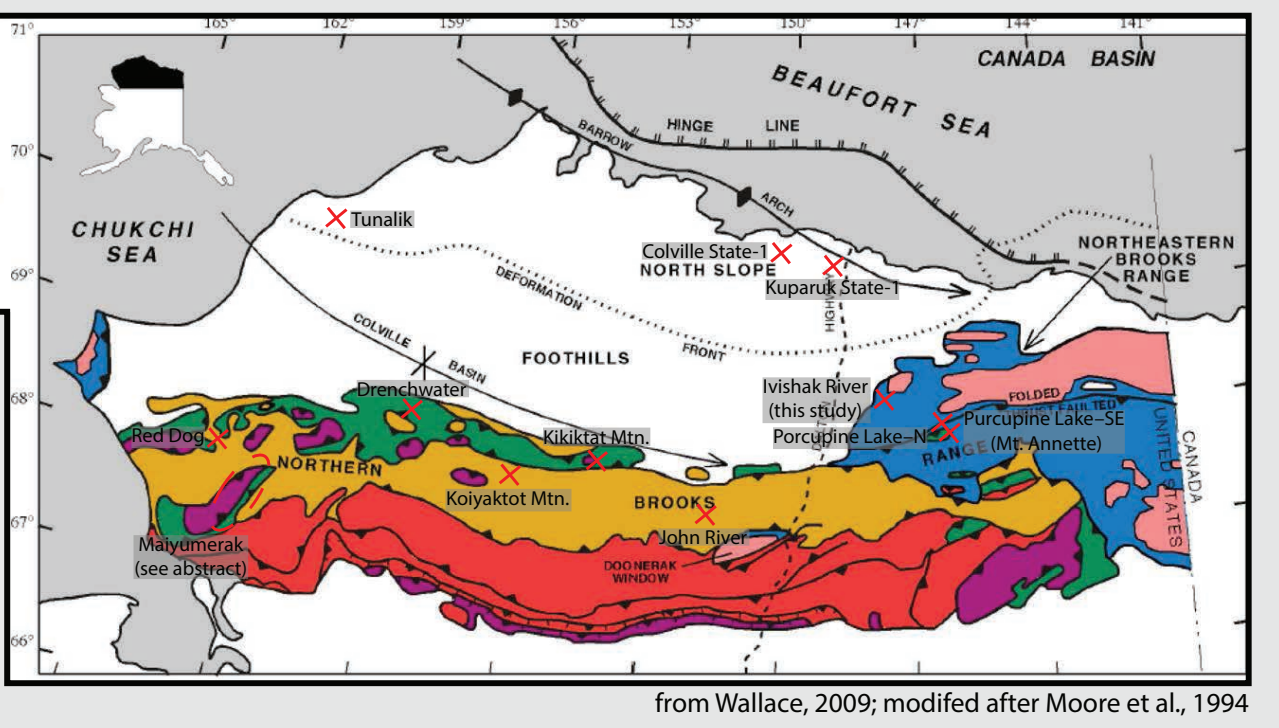
PRELIMINARY CATALOG OF KNOWN POST-DEVONIAN MAFIC ROCK OCCURRENCES—ARCTIC ALASKA TERRANE

Brooks Range Locality (W to E)	General Location	Structural Context	General Lithologic Description	Age	Host Rock	Sample ID	Geochemical Lithology	Geochemical Tectonic Affinity	References
Ipnavik River allochthon (geographically extensive)	western Brooks Range (not depicted above)	IRA	mafic sills and dikes	Max: Upper Miss. through lower(?) Permian	Lisburne and lower Etivluk groups	N/A	tholeiitic to mildly alkaline microgabbro	N-MORB–like, continental margin, or ocean island	Mayfield et al., 1988; Moore et al., 1994; Moore, 1987
Red Dog	western Brooks Range	EMA	gabbro sill (sample)	343.7 ± 2.7 Ma	Kuna Formation	MBWBIO	alkali basalt	within-plate felsic through mafic magmatism	Werdon et al., 2004; see also Werdon, 1996
Drenchwater		EMA	gabbro sill (sample)	336.6 ± 2.9 Ma		DW12	alkali gabbro		
		EMA	tuff (sample)	N/A		DW09	basanite		
Koiyaktot Mountain–south		EMA	gabbro sill (sample)	276.4 ± 14.8 Ma	Kanayut Conglomerate	91Pe49	sub-alkalic basalt	within-plate tholeiitic gabbro	
Kikiktat Mountain–upper basalt	central Brooks Range	NRA(?)	mafic flows	Upper Miss. to Lower Penn.(?)	overlies Nuka Fm	N/A	tholeiite basalt	N-MORB to within-plate basalt(?)	Solie and Mull (1991); Moore (1987);
Kikiktat Mountain–lower basalt		IRA	mafic flows	Mississippian or younger	Lisburne and Etivluk(?) groups	N/A	alkali to tholeiitic basalt		
John River–headwaters		EMA	tuff, tuffaceous limestone mafic flows	Lower Miss. (Kinderhookian(?	Kayak Shale	N/A	N/A	N/A	Reiser et al., 1979
Ivishak River area	northeastern Brooks Range	NSP	mafic tuffaceous limestone, volcaniclastic conglomerate, lava flows,	Upper Miss. (latest Visean or early Namurian)	Lisburne Group	see "Samples" below	alkali basalt	within-plate basalt	this study; Reiser et al., 1979; see also Keller et al., 1961
Porcupine Lake–southeast (Mt. Annette "allochthon"		DLMS(?)	volcaniclastic conglomerate, tuffaceous limestone and mafic flows	Permian(?) Lower Triassic(?)	unknown (klippe)	N/A	N/A	N/A	Reiser et al., 1979; Brosge et al., 2001
Porcupine Lake–north		NSP	volcaniclastic conglomerate, tuffaceous limestone, and mafic flows	Pennsylvanian or Permian	Lisburne Group	N/A	N/A	N/A	Reiser et al., 1979; Peace, 1979; Brosge et al., 2001
North Slope Subsurface (W to E)	**General Location**	**Structural Context**	**Lithology**	**Age**	**Host Rock**	**Sample Name**	**Geochemical Lithology**	**Geochemical Tectonic Affinity**	**References**
Tunalik well	western North Slope	NSS	mafic flows and volcaniclastic strata	Lower Permian	uppermost Lisburne Group (or	N/A	N/A	N/A	Sherwood et al., 2002
Colville State-1 well	east-central North slope, Colville high		diabasic dikes or sills	Max: Lower(?) to Middle(?) Miss.	Endicott Group	N/A	N/A	N/A	Moore et al., 1992
Kuparuk State-1 well						N/A	N/A	N/A	

Although late Paleozoic mafic magmatism is locally documented in the continental Arctic Alaska terrane, mafic rocks are typically uncommon except in the structurally uppermost Ipnavik River allochthon (IRA). However, limited geochemical results (summary table at left and this study), the Red Dog and associated sedimentary exhalative massive sulfide deposits of the western Brooks Range, and detailed stratigraphic observations strongly suggest extension occurred, at least locally, within the southward facing, carbonate platform-dominated passive margin of the Arctic Alaska terrane during Carboniferous time. DLMS–De Long Mtns. subterrane; EMA–Endicott Mtns. allochthon; IRA–Ipnavik River allochthon; NRA–Nuka Ridge allochthon; NSP–North Slope parautochthon; NSS–North Slope subterrane.

TECTONIC MAP OF NORTHERN ALASKA


Arctic Alaska terrane
North Slope parautochthon (subterrane)
Middle Devonian to Lower Cretaceous
pre-Middle Devonian
Endicott Mountains allochthon (subterrane)
De Long Mountains subterrane
Southern Brooks Range subterranes (Hammond, Coldfoot, Slate Creek)
EXPLANATION
Angayucham terrane
0 50 100 150 200 KILOMETERS
Terrane or subterrane boundary
Thrust fault—Sawteeth on upper plate
Thrust fault reactivated as normal fault
Tectonic hinge line—Hachures on downthrown side
Axis of arch—Showing direction of plunge
Axis of basin—Showing direction of plunge


BEAUFORT SEA
CANADA BASIN
CHUKCHI SEA
BARROW ARCH
HINGE LINE
DEFORMATION FRONT
COLVILLE BASIN
FOOTHILLS
NORTHEASTERN BROOKS RANGE
NORTHERN BROOKS RANGE
Tunalik
Colville State-1
Kuparuk State-1
NORTH SLOPE
Ivishak River (this study)
Porcupine Lake–N
Purcupine Lake–SE (Mt. Annette)
Drenchwater
Red Dog
Kikiktat Mtn.
Koiyaktot Mtn.
John River
Maiyumerak (see abstract)
DOONERAK WINDOW
CANADA
UNITED STATES

Because allochthonous Devonian to Jurassic mafic and ultramafic rocks of the oceanic-affinity Angayucham terrane are common in the southern and western Brooks Range—but are distinctly not part of the continental Arctic Alaska terrane—well established terrane associations are key to understanding the tectonomagmatic implications of these rocks. However, terrane affinities at some localities remains enigmatic—e.g., the uppermost klippe in the Mount Annette "allochthon" (DLMS(?)), the Kikiktat Mountain klippe (NRA(?)), and the Maiyumerak basalts (Angayucham terrane(?)).

from Wallace, 2009; modifed after Moore et al., 1994

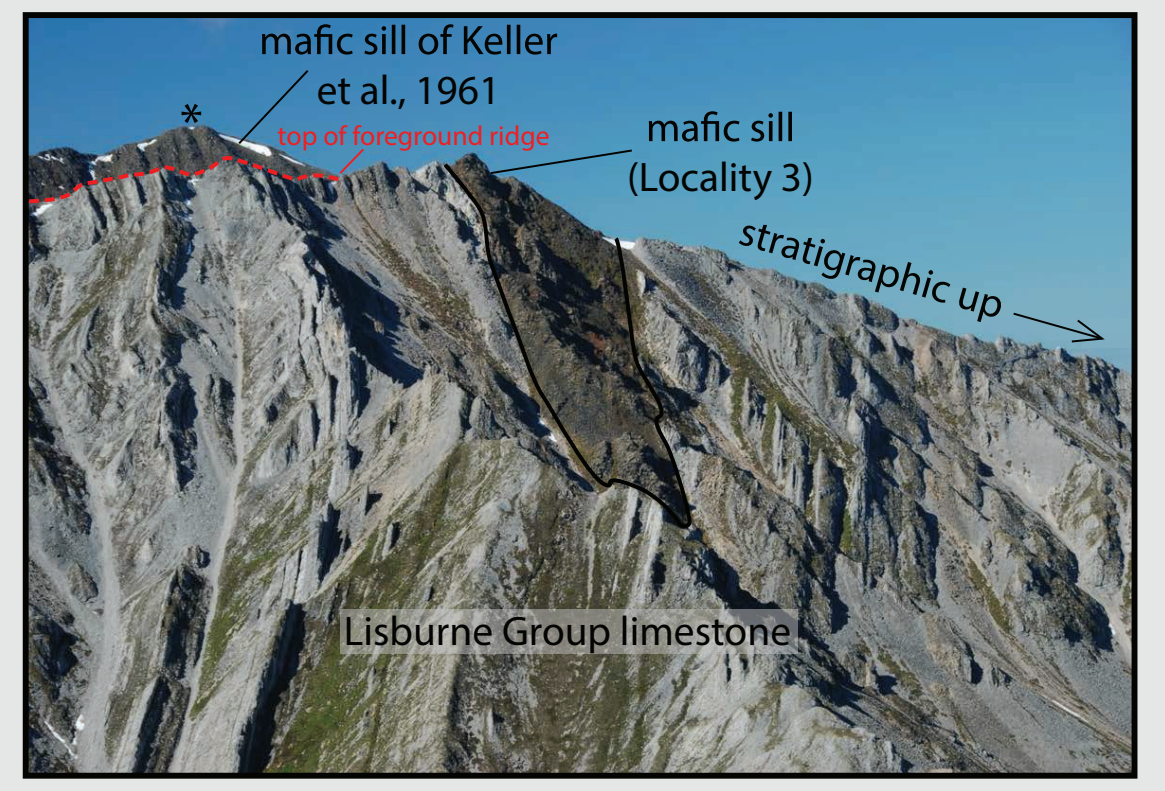
OBSERVATIONS, PHOTOGRAPHS, AND XRF GEOCHEMISTRY

FIELD PHOTOGRAPHS

Observed mafic lava flows are commonly dark-gray to gray-green (fresh surface groundmass), very thick, aphanitic to porphyritic, and apparently structureless to columnar jointed (left) to pseudo-pillowed (below). The lava flows pictured at left and below are lithologically similar to geochemistry samples 09BG112A and 09TMH022A.

Fine-grained tuffaceous limestone (above) lies at the base of the Locality 1 mafic rock sequence north of the Ivishak River and is flaggy weathering, medium- to thick-bedded, plane-parallel laminated and locally cross stratified; small scale structures with normal separation are locally observed (inset). Geochemistry sample 09BG111A was collected at the pictured outcrop.

Very thick (up to several meters) mafic lava flows are vesicular in part (left), with vesicles locally being calcite filled.


mafic sill of Keller et al., 1961
*
top of foreground ridge
mafic sill (Locality 3)
stratigraphic up
Lisburne Group limestone

A mafic sill lies at the southernmost extent of our current study area at Locality 3 (above left; view to southwest); this sill is up to ~125 meters thick, pinches out to the northeast, and crops out in a subvertically dipping, overturned anticlinal forelimb. Geochemistry sample 09TMH160-1 was collected at this outcrop. Farther south, a more prominent sill lies in a similar stratigraphic position as the one observed at Locality 3 and may be a lateral equivalent (above right; view to southwest). This latter sill was originally reported by Keller et al. (1961); Reiser et al. (1979) suggested this sill may represent an intrusive equivalent of the volcanic rocks to the north (i.e., those observed at Localities 1 and 2 of the current study). Asterisks denote same peak in above photographs.

SAMPLES

Sample ID	Location*	Sample Description
09BG111A	Locality 1	Orange-tan weathering, medium gray (fresh surface), medium- to thick-bedded, plane parallel laminated and locally trough cross stratified, very fine- to medium-grained tuffaceous limestone. Sampled near base of ~100-m-thick volcanic section north of the Ivishak River.
09BG112A	Locality 1	Dark gray to gray-brown and locally olive green weathering, dark gray (fresh surface groundmass), aphanitic, mafic lava flow; locally contains calcite-filled vesicles. Overlies tuffaceous limestone interval of sample 09BG111A and is stratigraphically associated with columnar jointed lava flows.
09TMH022A	Locality 1	Medium brown weathering, dark gray-green (fresh surface of groundmass; chlorite(?) alteration), porphyritic (abundant opaque, equant phenocrysts to 3 mm and plagioclase (calcite(?) altered) laths to 2 mm), mafic lava flow. Sampled flow is massive (i.e., structureless) at outcrop scale, but is stratigraphically associated with pseudo-pillowed and columnar-jointed flows. Sampled near top of ~100-m-thick volcanic section north of the Ivishak River.
09TMH160-1	Locality 3	Rusty orange to orange-brown weathering, medium to light gray (groundmass), porphyritic (abundant pyrite crystals to 0.25 mm) mafic sill that is up to ~125 m thick. Limestone at upper contact immediately above igneous rocks is coarsely crystalline with calcite crystals to 4mm (recrystallized?) and underlying limestone is chalky and foliated (talc(?) alteration) at contact. General outcrop observations, top and bottom contacts indicative of contact metamorphism, and association with documented diabase sill farther south (Keller et al., 1961) are suggestive of an intrusive origin for this sample.

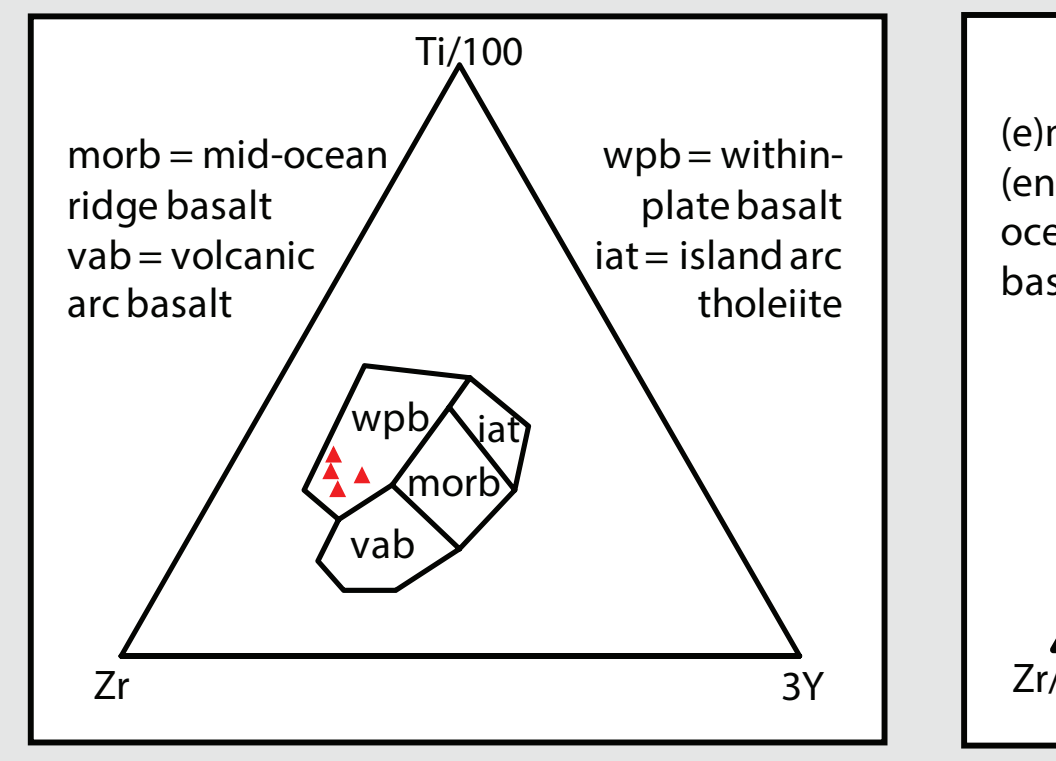
*See 1:24,000-scale map for sample collection sites and context.

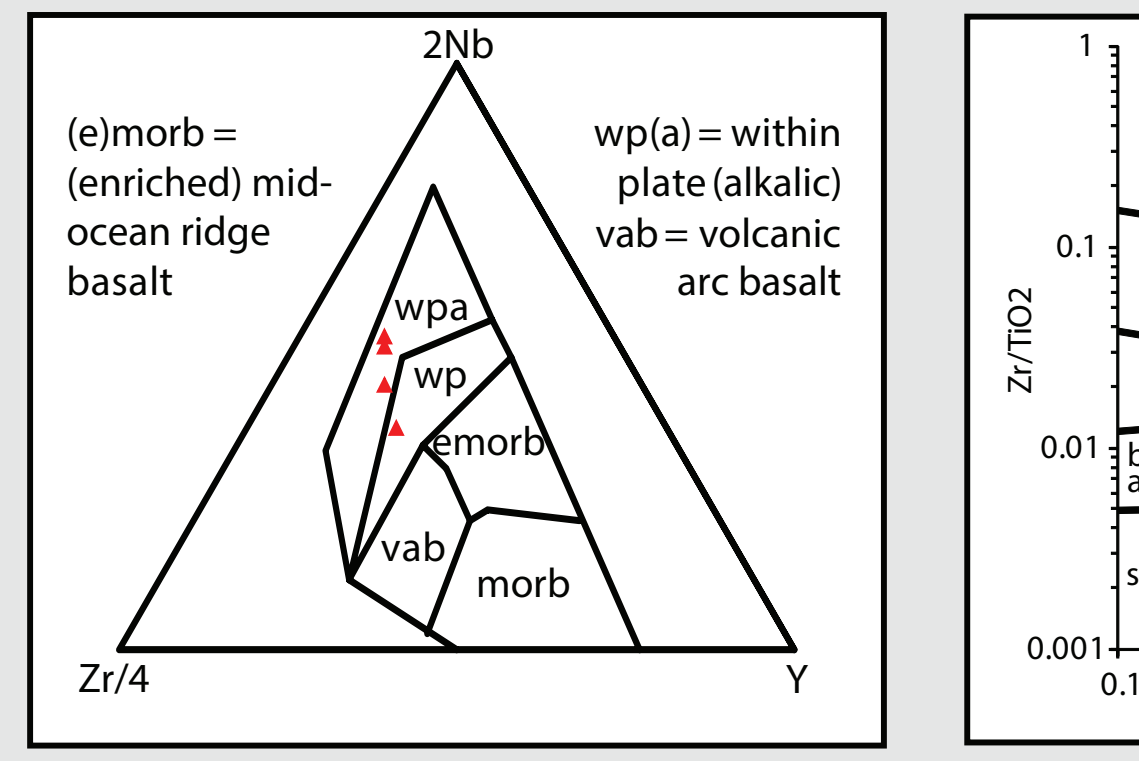
XRF RESULTS

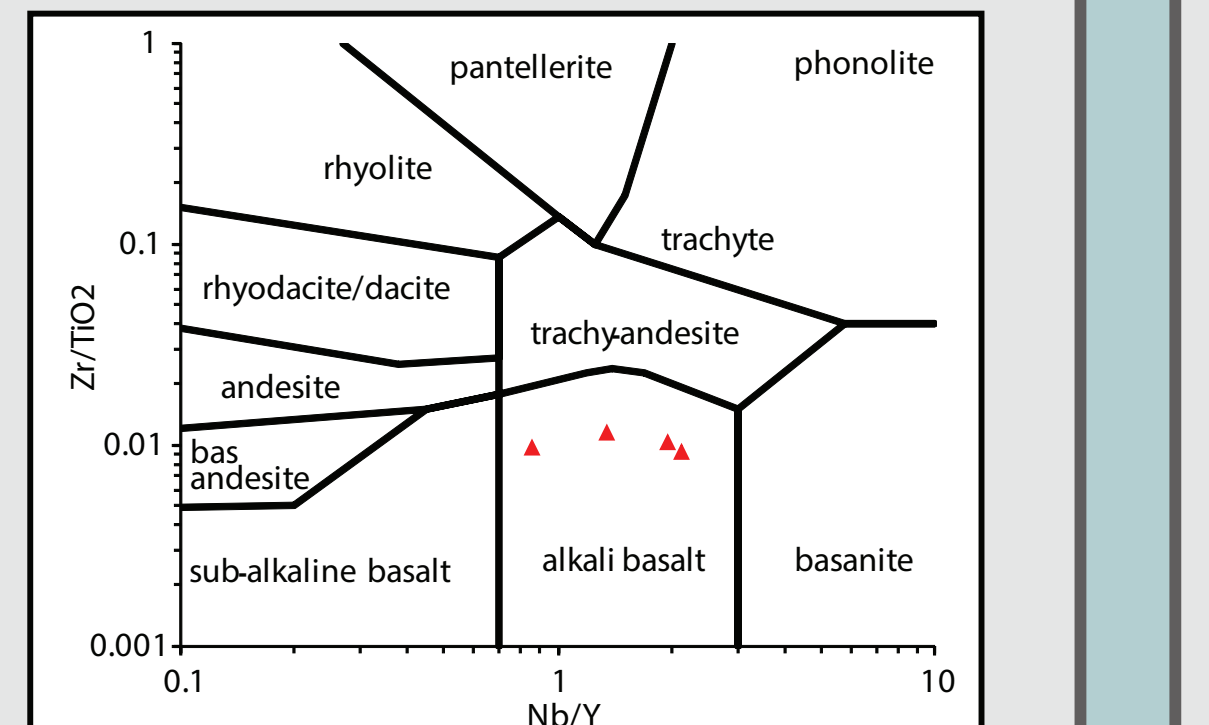
Sample ID	SiO2	Al2O3	CaCO3	CaO	FeO	FeS2	K2O	MgO	MnO	Na2O	P2O5	TiO2	BaO	Cl	Cr	Cu	F	Ga	Ni	Pb	Rb	S	Sr	V	Zn	Zr	Nb	Y	Nb/Y	Zr/TiO2
09BG111A	32.1	7.27	41.6		8.13		1.1	5.5	0.0437	0.0352	0.276	1.82		36.8	153	48.6	1990	26.6	157		20	1010	328.4	178	84	166.2	33	15.3	2.12	0.00913
09BG112A	51.2	15.3		8.1	9.52		1	4.9	0.119	5.37	0.439	2.58	0.0307	64.5	281	93.4		25.1	162	23	18	402	264	314	186	265.9	50	25.3	1.96	0.01031
09TMH022A	60.5	15.6		4.27	6.93		1.2	3.9	0.059	4.91	0.243	1.57	0.0424	89.6	146	28.2		27.3	97	41	27	342	616.6	208	107	152.2	18	20.9	0.85	0.00969
09TMH160-1	62.9	14.4		0.759	0.333	6.1	1.1	3.6	0.0523	5.56	0.58	2.68	0.02	131	51.9	146		24.9		38	40		197.1	286	99	309	46	34	1.34	0.01153

XRF geochemical analyses were conducted by Rainer J. Newberry at the UAF Advanced Instrumentation Laboratory.

TRACE ELEMENT DISCRIMINATION PLOTS







Despite probable shifts of major element compositions in some samples due to chemical alteration, high Cr, V, and Ti concentrations (see XRF Results) indicate basaltic parent rocks for all samples. Moreover, Nb/Y–Zr/TiO2 (above right; diagram after Winchester and Floyd, 1977) volcanic classification plots indicate the samples were originally alkali basalts or fragments thereof. Ti/100–Zr–3Y (above left; diagram after Pearce and Cann, 1973) and 2Nb–Zr/4–Y (above middle; diagram after Meschede, 1986) trace element tectonic discrimination diagrams chiefly suggest within-plate basalt and within-plate alkalic basalt origins, respectively. These are the first geochemical results to demonstrate that magmatism in the parautochthon is related to extension.