DIVISION OF LAND RESOURCES
DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES

NORTH CAROLINA GEOLOGICAL SURVEY
GEOLOGIC MAP SERIES

BEDROCK GEOLOGIC MAP OF THE BENT CREEK RESEARCH AND DEMONSTRATION FOREST, SOUTHERN RESEARCH STATION, USDA FOREST SERVICE, INCLUDING THE NORTH CAROLINA ARBORETUM AND A PORTION OF THE BLUE RIDGE PARKWAY

BY
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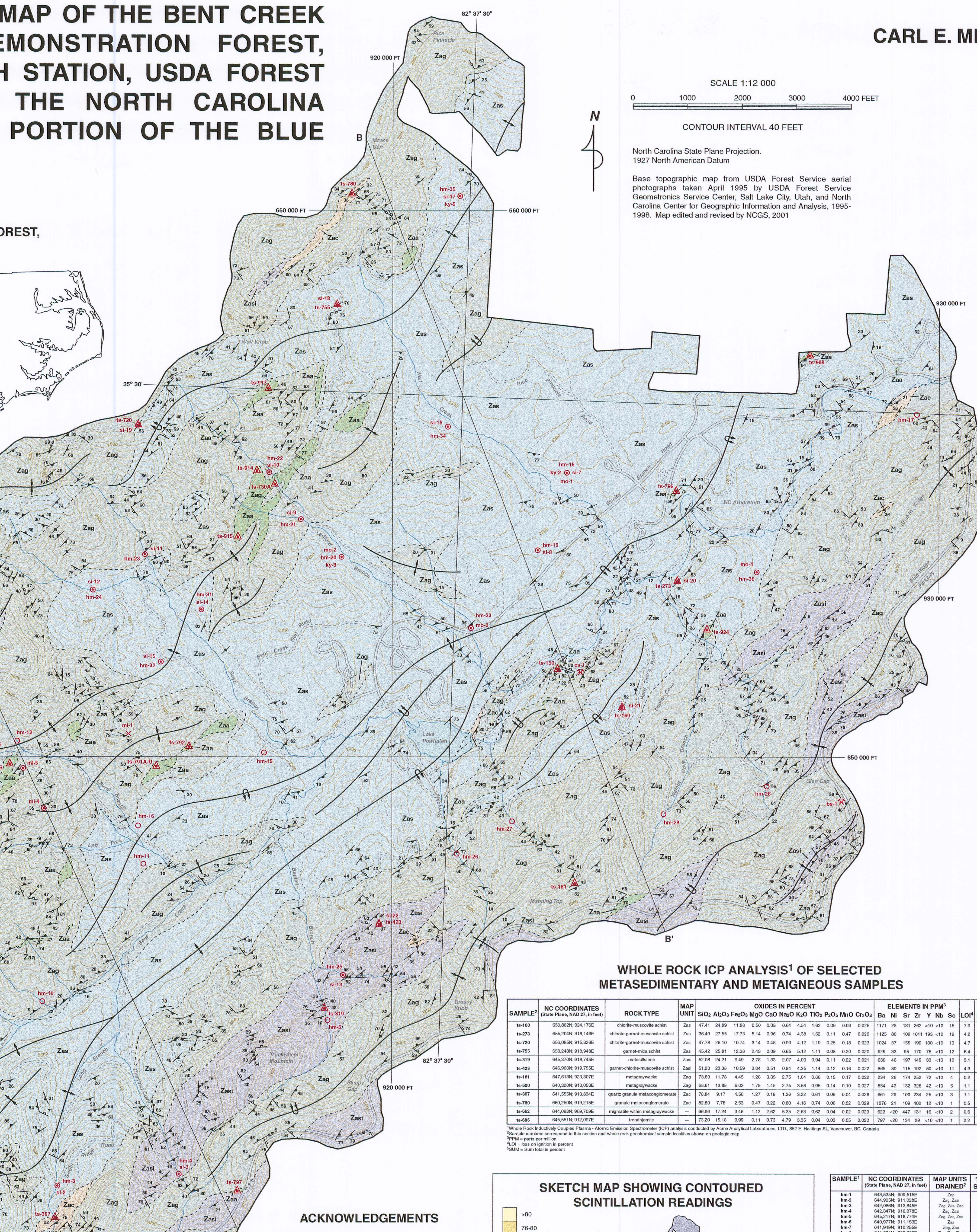
2002

SCALE 1:12 000

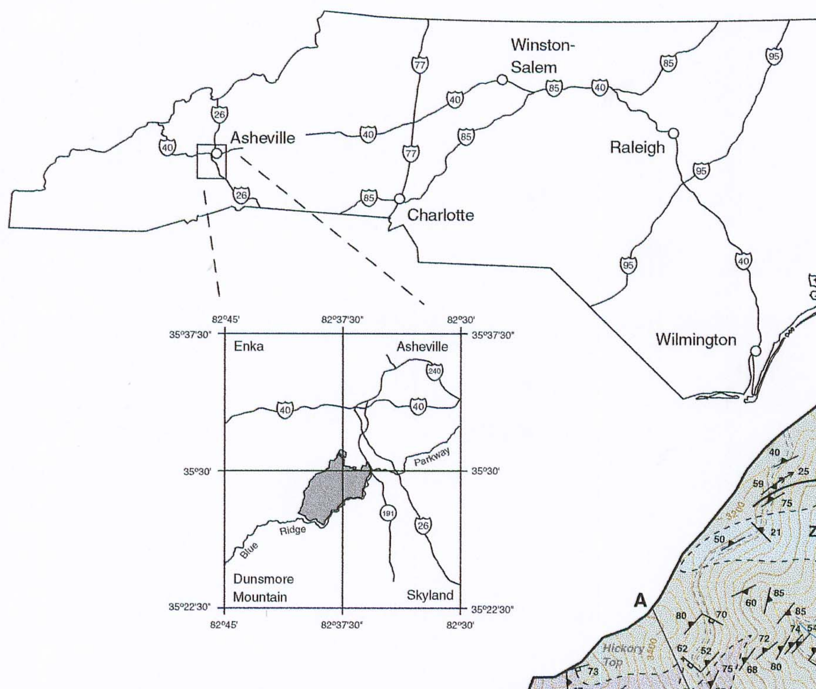
CONTOUR INTERVAL 40 FEET

North Carolina State Plane Projection.
1927 North American Datum

Base topographic map from USDA Forest Service aerial photographs taken April 1995 by USDA Forest Service Geometronics Service Center, Salt Lake City, Utah, and North Carolina Center for Geographic Information and Analysis, 1995-1998. Map edited and revised by NCGS, 2001



LOCATION OF THE BENT CREEK RESEARCH AND DEMONSTRATION FOREST, ASHEVILLE, NORTH CAROLINA



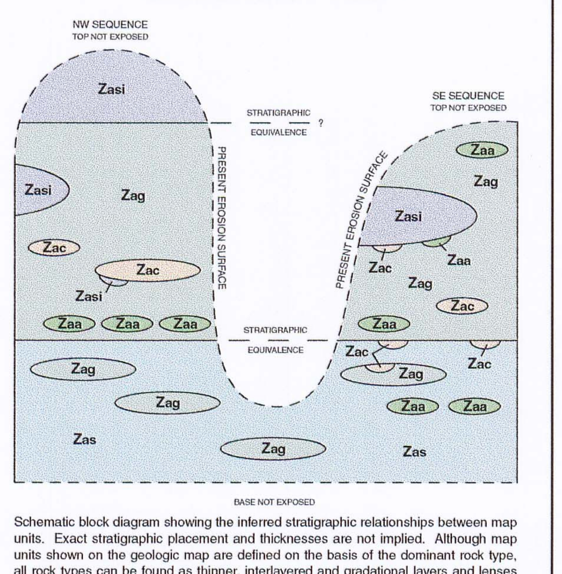
MAP UNITS

ASHE METAMORPHIC SUITE

LATE PROTEROZOIC

- Zasi — Sillimanite-Garnet-Chlorite-Mica Metasiltstone
- Zag — Metagraywacke
- Zac — Metaconglomerate
- Zaa — Amphibolite
- Zas — Sillimanite-Garnet-Chlorite-Mica Schist

BLOCK DIAGRAM SHOWING INFERRED STRATIGRAPHIC RELATIONSHIPS BETWEEN MAP UNITS



Schematic block diagram showing the inferred stratigraphic relationships between map units. Exact stratigraphic placement and thicknesses are not implied. Although map units shown on the geologic map are defined on the basis of the dominant rock type, all rock types can be found as thinner, interlayered and gradational layers and lenses within each map unit.

DESCRIPTION OF MAP UNITS[1]

Ashe Metamorphic Suite: In the Bent Creek Research and Demonstration Forest, the Ashe Metamorphic Suite is a heterogeneous unit consisting of repetitive layers and lenses of sedimentary and mafic volcanic rocks metamorphosed to sillimanite grade. It is subdivided and mapped based on dominant rock type into five lithologic units:

Sillimanite-Garnet-Chlorite-Mica-Metasiltstone (Zasi): Medium-gray to dark-gray; strongly foliated; fine- to medium-grained; equigranular to inequigranular; lepidoblastic to weakly granoblastic to porphyroblastic; locally migmatitic; consists of 3.6-21.4% quartz, 0.4-17.2% plagioclase, 37.6-71.0% muscovite, 10.6-15.8% chlorite, 5.6-10.0% garnet, 3.0-3.6% ilmenite and other black opaque minerals, 0.0-0.2% epidote group minerals, and a trace of sillimanite; thickness of layering ranges from several millimeters to several centimeters; commonly interlayered with metagraywacke and sillimanite-garnet-chlorite-mica schist.

Metagraywacke (Zag): Medium-light-gray to medium-dark-gray; non-foliated to weakly foliated; medium- to coarse-grained; equigranular to inequigranular; granoblastic to lepidoblastic; locally migmatitic; consists of 26.4-37.2% quartz, 31.8-42.2% plagioclase, 0.0-28.4% k-feldspar, 3.8-8.0% muscovite, 6.0-11.4% biotite, 0.6-2.0% garnet, 0.0-1.0% hornblende, trace-10.8% epidote group minerals, trace-0.6% ilmenite and other black opaque minerals, trace-0.4% apatite, and a trace of zircon; thickness of layering ranges from several decimeters to several meters.

Metaconglomerate (Zac): Medium-light-gray to medium-dark-gray; non-foliated to weakly foliated; coarse-grained (most commonly granule size); inequigranular; granoblastic; consists of 62.6-66.2% quartz, 6.4-16.8% plagioclase, 0.0-4.4% k-feldpar, 6.8-16.6% biotite, 5.4-13.0% muscovite, 0.2-0.8% ilmenite and other black opaque minerals, 0.0-0.4% epidote group minerals, 0.0-0.2% garnet, 0.0-0.2% apatite, and a trace of zircon; thickness of layering ranges from decimeters to meters; granule composition is dominantly quartz; commonly interlayered with metagraywacke, but also occurs locally as very thin interlayers in sillimanite-garnet-chlorite-mica-metasiltstone. Many metaconglomerate layers are difficult to recognize because of migmatization and metamorphic recrystallization.

Amphibolite (Zaa): Two textural varieties of amphibolite occur in the Bent Creek Research and Demonstration Forest, but can not be mapped separately into distinct map units. One is dark-green to black, equigranular, fine- to medium-grained, strongly foliated, and nematoblastic. The other is dark-gray to dark-greenish-gray, equigranular to inequigranular, medium- to coarse-grained, non-foliated, and granoblastic to porphyroblastic. Thickness of layering in both varieties ranges from centimeters to meters. Collectively, both consist of 32.2-76.2% hornblende, trace-38.1% plagioclase, 0.0-7.6% quartz, 0.0-3.0% garnet, 0.0-6.6% chlorite, 0.0-11.2% ilmenite and other black opaque minerals, 0.0-1.2% apatite, 0.0-8.2% biotite, 0.0-27.4% epidote group minerals, 0.0-10.0% actinolite and tremolite, 0.0-6.8% diopside and other clinopyroxenes, 0.0%-trace myrmekite, 0.0-7.4% sphene, 0.0%-trace tourmaline, 0.0-2.0% rutile, 0.0-1.4% sericite, 0.0-0.4% zircon, and 0.0-0.6% k-feldspar. One sample of chlorite-actinolite/tremolite schist (map number ts-791U) consists of 56.4% actinolite and tremolite, 38.6% chlorite, 3.2% quartz, 1.2% rutile, 0.6% sphene, and traces of diopside and other clinopyroxenes, epidote group minerals, and biotite. Thinner layers and lenses of amphibolite, too small and discontinuous to be shown at this scale, are interlayered with other rock types in all map units.

Sillimanite-Garnet-Chlorite-Mica Schist (Zas): Very light-gray to greenish-gray to medium-gray; strongly foliated; fine-grained; equigranular to inequigranular; lepidoblastic to porphyroblastic; consists of 0.6-13.6% quartz, 0.0-0.6% plagioclase, 31.6-74.4% muscovite, 0.0-18.0% sericite, 6.2-15.2% chlorite, 0.2-25.6% garnet, 3.0-7.8% opaques, and a trace of sillimanite; thickness of layering ranges from millimeters to centimeters; commonly interlayered with sillimanite-garnet-chlorite-mica metasiltstone.

DESCRIPTION OF OTHER ROCK TYPES

WHOLE ROCK ICP ANALYSIS[1] OF SELECTED METASEDIMENTARY AND METAIGNEOUS SAMPLES

SAMPLE / columns to left	Sc	LOI[4]	SUM[5]
[illegible]	15	7.9	99.76
[illegible]	19	4.2	99.72
[illegible]	13	4.7	100.11
[illegible]	12	6.4	99.91
[illegible]	10	3.1	100.51
[illegible]	11	4.3	99.83
[illegible]	4	0.2	100.44
[illegible]	5	1.1	100.56
[illegible]	3	1.1	100.54
[illegible]	1	0.5	100.10
[illegible]	2	0.6	100.82
[illegible]	1	2.2	100.80

STREAM SEDIMENT HEAVY MINERAL ANALYSIS

Stream sediment heavy mineral analysis was conducted June-July 1998 to aid geologic mapping, better define conditions of metamorphism, and inventory minerals of potential economic significance. Procedure: In the field, approximately 13.6 kg of stream sediment material is panned to approximately 300 g of heavy mineral concentrate at each sample locality (scintillation data are also collected at the sample site). In the laboratory, concentrate is washed and passed through heavy liquid separation using tetrabromoethane, and scanned with short- and long-wave ultraviolet illumination using an Ultra-voilet Products Inc. Model UVGL-48 Mineralight Lamp. Magnetite is removed with an alnico hand magnet. A sample split is grain mounted on a standard 27x46 mm glass slide and approximately 200 grains are identified and counted with the aid of a petrographic microscope and 1.67 index of refraction oil. Results of stream sediment heavy mineral analysis are tabulated below.

Mineral abbreviations used in table: Mag-magnetite; Gt-garnet; Hbl-hornblende; Z-zircon; Ep-epidote group minerals; Ilm-ilmenite and other black opaques; Hem-hematite and other red opaques; Sil-sillimanite; Rt-rutile; Ky-kyanite; Mon-monazite; Spn-sphene; St-staurolite

MAP UNITS DRAINED[2]	%HM IN SAMPLE[3]	Mag	Gt	Hbl	Z	Ep	Ilm	Hem	Sil	Rt	Ky	Mon	Spn	St
Zag	0.84	0.85	32.22	16.36	7.93	8.92	21.81	9.42	0.99	0.50	0.99	-	-	-
Zag, Zasi	0.91	1.13	47.46	4.94	7.91	7.91	26.20	3.96	tr	0.49	-	-	-	-
[illegible]g, Zas, Zac	0.99	0.94	49.53	12.88	2.48	6.44	20.80	5.94	0.99	-	-	tr	tr	-
Zag, Zasi	0.71	0.09	50.45	5.50	3.50	7.49	26.97	5.00	1.00	-	-	-	-	-
[illegible]g, Zas, Zaa	1.10	0.42	67.21	3.98	2.50	4.48	15.43	5.98	-	-	-	-	-	-
Zas	1.49	0.41	29.88	19.92	11.95	4.48	27.89	4.48	-	1.00	-	-	-	-
Zag, Zaa	0.54	0.33	32.39	19.93	5.98	13.95	17.44	8.97	1.00	-	-	-	-	-
[illegible]g, Zac, Zasi	0.30	0.82	36.20	13.39	8.93	2.98	29.75	7.44	0.50	-	-	tr	-	-
[illegible]g, Zasi, Zaa	0.51	0.11	17.48	11.49	15.48	2.00	50.45	3.00	-	tr	tr	tr	-	-
Zag, Zaa	0.29	0.91	29.23	18.83	14.86	1.98	29.23	4.96	-	-	-	tr	-	-
[illegible]s, Zag, Zaa	0.25	1.07	29.19	9.89	18.30	3.46	33.14	4.95	tr	-	-	-	-	-
Zag, Zasi	0.74	0.58	19.88	5.47	9.45	4.97	50.71	7.95	tr	0.50	-	tr	-	-
[illegible]g, Zasi, Zas	0.79	1.65	15.24	10.33	14.26	2.95	53.60	1.97	tr	-	tr	tr	-	-
[illegible]g, Zasi, Zas	0.37	1.55	34.46	13.29	4.92	12.80	27.08	4.92	0.98	-	-	tr	-	-
[illegible]s, Zag, Zaa	0.57	0.89	63.93	3.47	1.98	6.94	22.30	-	-	-	-	-	-	-
[illegible]g, Zas, Zaa	0.22	0.56	9.94	20.39	20.88	3.48	38.29	6.46	-	-	-	-	-	-
Zag	0.47	0.41	55.28	2.99	7.47	9.46	23.41	1.00	-	-	tr	tr	-	-
Zas	0.19	4.33	2.87	tr	21.05	0.96	42.57	3.35	8.61	1.44	9.57	5.26	-	tr
Zas, Zag	1.09	0.18	14.47	5.99	19.96	7.49	49.91	0.50	1.50	tr	tr	tr	tr	-
Zas, Zag	1.28	0.06	26.48	6.00	11.49	6.00	43.47	2.00	-	tr	2.50	2.00	tr	-
[illegible]g, Zaa, Zas	1.67	0.95	20.31	1.98	12.38	5.94	55.47	1.49	1.49	-	-	tr	-	-

ACKNOWLEDGEMENTS

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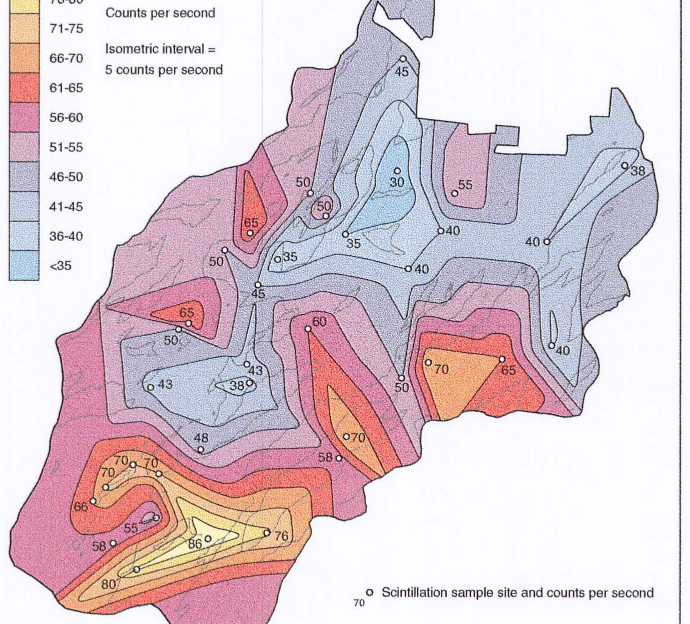
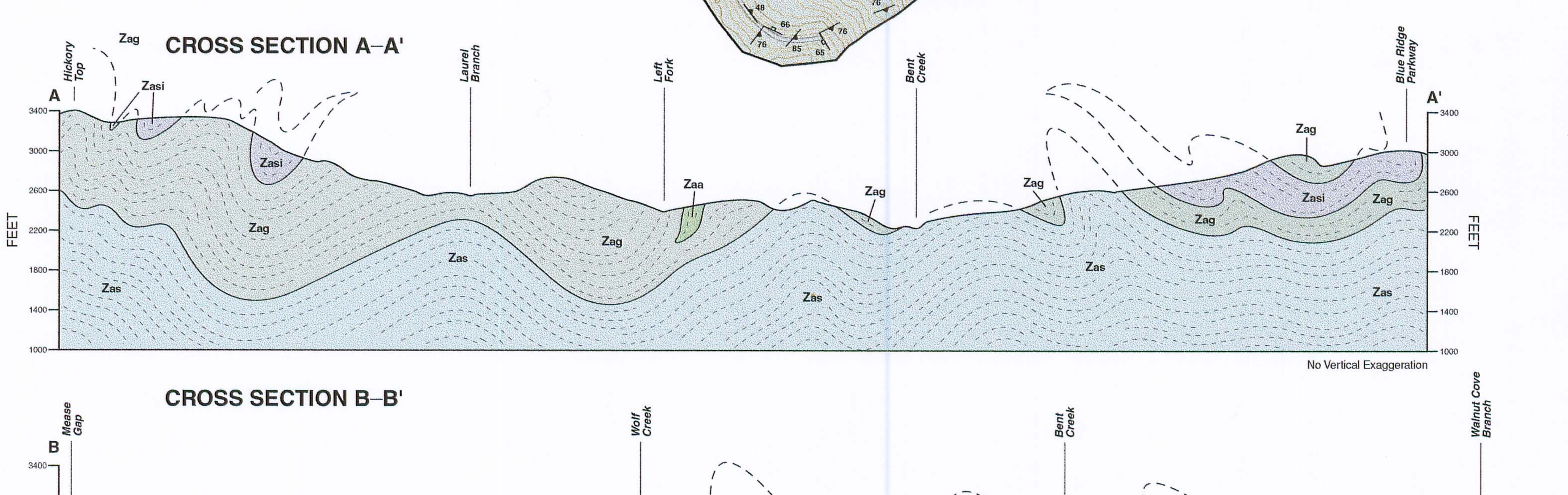
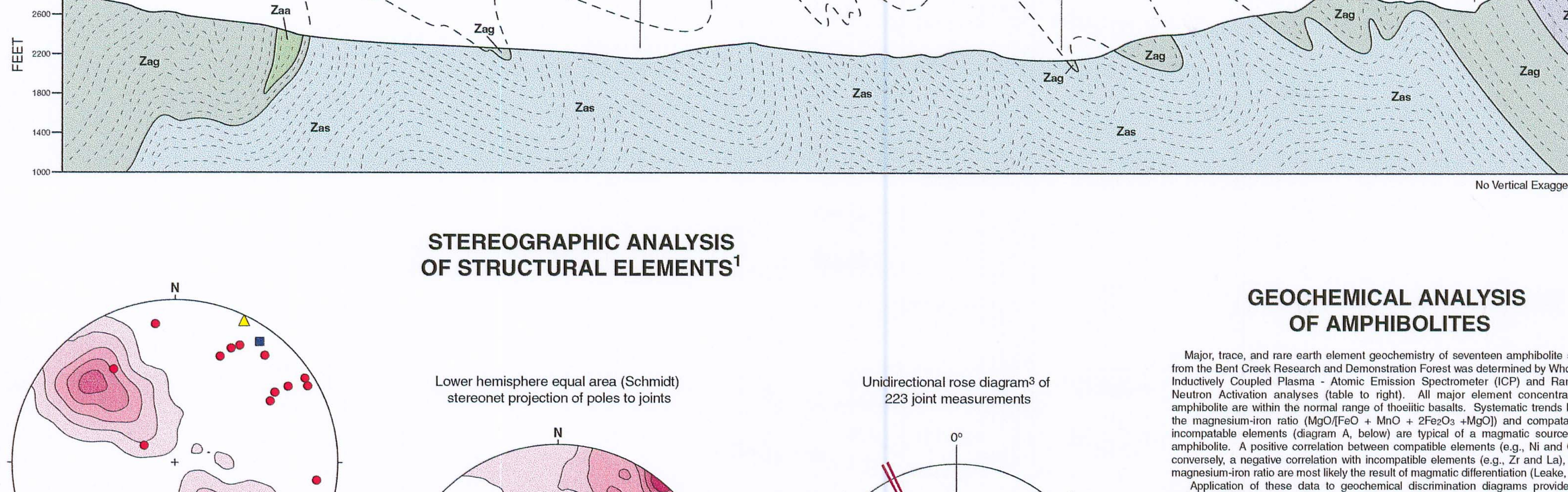
SKETCH MAP SHOWING CONTOURED SCINTILLATION READINGS



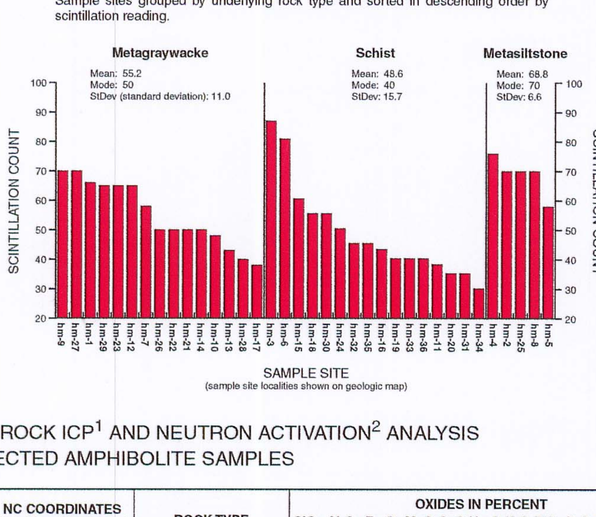
CROSS SECTION A–A'



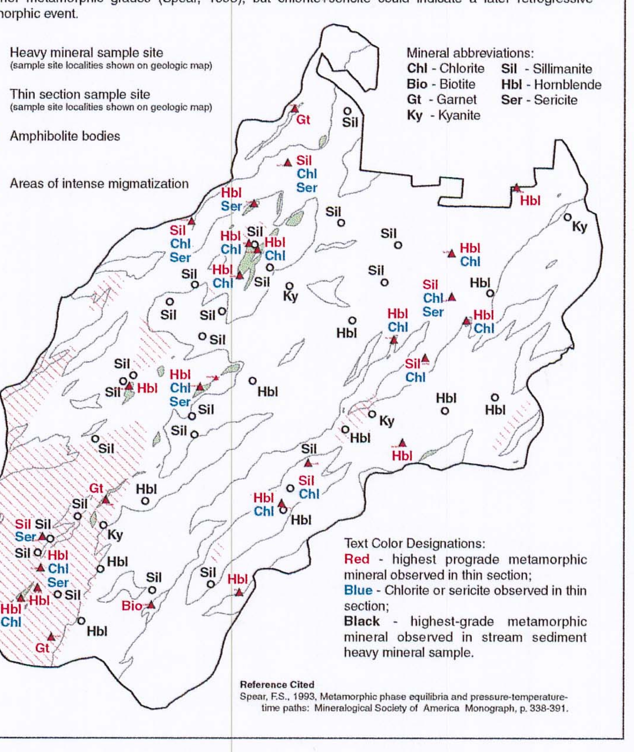
CROSS SECTION B–B'



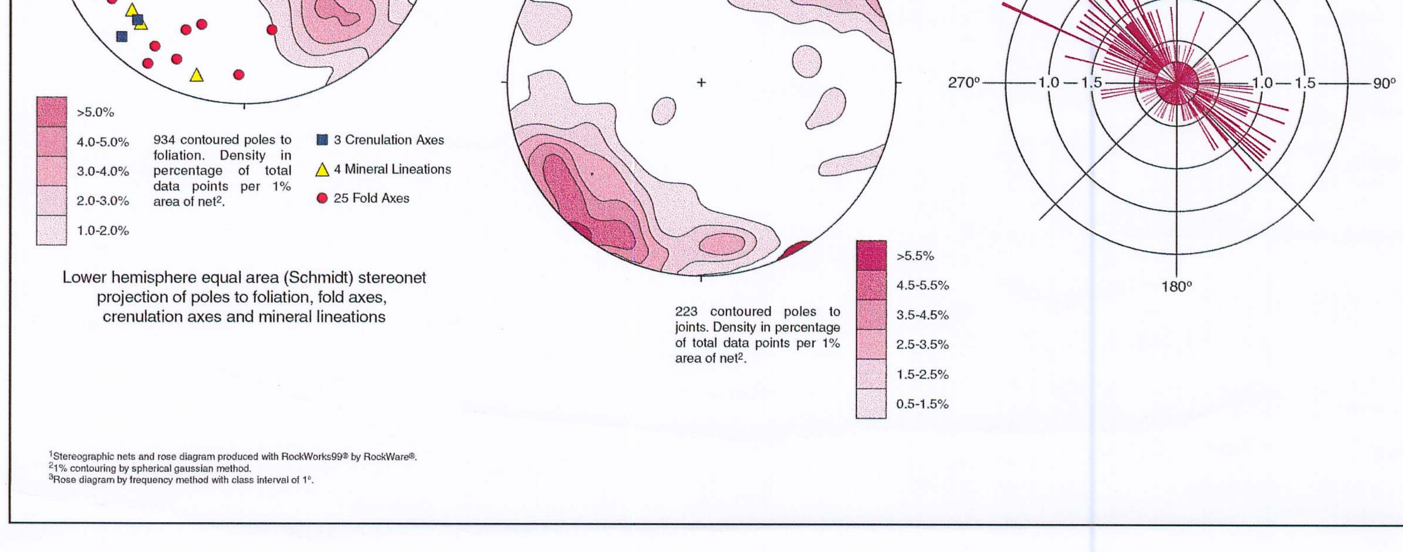
HISTOGRAM SHOWING SCINTILLATION READINGS BY SAMPLE SITE



SKETCH MAP SHOWING ELEMENTS OF METAMORPHIC CONDITIONS



STEREOGRAPHIC ANALYSIS OF STRUCTURAL ELEMENTS[1]



GEOCHEMICAL ANALYSIS OF AMPHIBOLITES

Major, trace, and rare earth element geochemistry of seventeen amphibolite samples from the Bent Creek Research and Demonstration Forest was determined by Whole Rock Inductively Coupled Plasma - Atomic Emission Spectrometer (ICP) and Rare Earth Neutron Activation analyses (table to right). All major element concentrations of amphibolite are within the normal range of thoeiitic basalts. Systematic trends between the magnesium-iron ratio ($MgO/[FeO + MnO + 2Fe_2O_3 + MgO]$) and compatable and incompatable elements (diagram A, below) are typical of a magmatic source for the amphibolite. A positive correlation between compatible elements (e.g., Ni and Cr), and conversely, a negative correlation with incompatible elements (e.g., Zr and La), and the magnesium-iron ratio are most likely the result of magmatic differentiation (Leake, 1964).

Application of these data to geochemical discrimination diagrams provides some preliminary conclusions about the tectono-magmatic setting of amphibolite. Most of the samples plot consistently into Mid Ocean Ridge Basalt (MORB) -type tectonic settings on several discrimination diagrams (diagrams B and C, below). Three samples (150, 795, and 909), however, consistently plot outside of the MORB field. This may indicate metamorphic alteration after igneous emplacement, or different tectonic settings for these three samples.

Results of all such geochemical discrimination analyses are seldom unequivocal, especially from limited data sets, and particularly in progressively older metamorphic terranes (Rollinson, 1993).

Explanation of geochemical and discrimination diagrams (explanation of symbology at far right):

A: Variation diagram comparing compatable (Ni, Cr) and incompatable (Zr, La) trace and rare earth elements with the magnesium-iron ratio for a suite of amphibolite samples from the Bent Creek Research and Demonstration Forest. Sample 791U plots out of the range for Cr and La.

B: Tectono-magmatic discrimination diagram (after Mullen, 1983) classifying amphibolite samples from the Bent Creek Research and Demonstration Forest. All samples are in the range 45-54% SiO2.

C: Tectono-magmatic discrimination diagram (after Pearce, 1982) classifying amphibolite samples from the Bent Creek Research and Demonstration Forest.

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Leake, B.E., 1964, The chemical distinction between ortho- and para-amphibolites: Journal of Petrology, v. 5., part 2, p. 238-254.

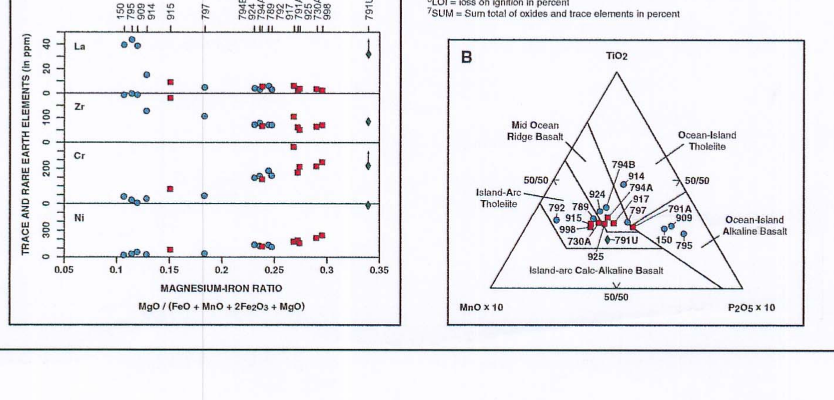
Mullen E. D., 1983, MnO/TiO2/P2O5: A minor element discriminant for basaltic rocks of oceanic environments and its implications for petrogenesis: Earth and Planetary Science Letters, v. 62, pg. 53-62.

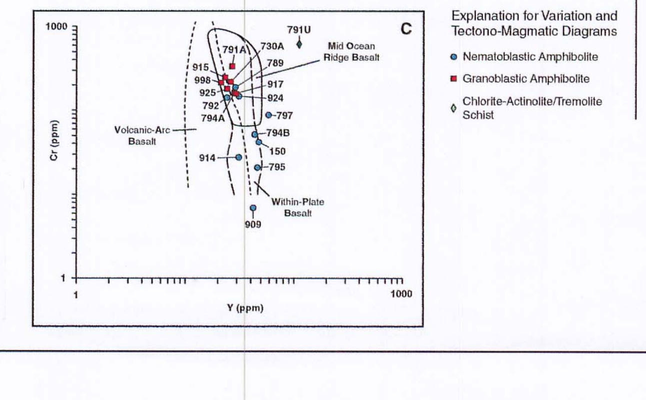
Pearce, J.A., and Norry, M.J., 1979, Petrogenetic implications of Ti, Zr, Y, and Nb variations in volcanic rocks: Contributions to Minerology and Petrology, v. 69, pg. 33-47.

Pearce, J.A., 1982, Trace element characteristics of lavas from destructive plate boundaries, *in* Thorpe, R.S. ed., Andesites: Orogenic Andesites and Related Rocks: John Wiley & Sons, London, p. 525-548.

Rollinson, H.R., 1993, Using geochemical data: Evaluation, presentation, interpretation: Longman Scientific and Technical, Essex and Wiley and Sons, New York, p. 171-214.

WHOLE ROCK ICP[1] AND NEUTRON ACTIVATION[2] ANALYSIS OF SELECTED AMPHIBOLITE SAMPLES





STRUCTURAL FEATURES

MINERAL RESOURCES

COMMODITY DESCRIPTIONS

Mica Occurences

Map Number	NC Coordinates	Map Number	NC Coordinates
[illegible]	[illegible]	[illegible]	[illegible]
mi-3	645,438N; 910,990E	mi-5	649.772N; 913,230E
mi-4	649,043N; 913,596E		

Garnet: Garnet occurs as an accessory mineral all of the rocks in the Bent Creek Research and Demonstration Forest. Point counts of thin sections indicate that garnet constitutes up to 25 percent of the finer-grained rock types. Garnet also occurred in varying abundance in all stream sediment heavy mineral samples. It does not occur in significant enough concentrations, however, to be potentially economic.

Sillimanite: Point counts of several thin sections and stream sediment heavy mineral analysis revealed that sillimanite occurs throughout the the Bent Creek Research and Demonstration Forest (localities listed in table below). Generally, sillimanite is more abundant in the finer-grained rock types. It does not occur in significant enough concentrations, however, to be potentially economic.

Sillimanite Occurences

Map Number	NC Coordinates	Map Number	NC Coordinates
si-1	643,535N; 909,515E	si-12	653,032N; 914,507E
si-2	642,086N; 913,845E	si-13	645,970N; 919,109E
si-3	642,347N; 916,078E	si-14	652,666N; 916,493E
si-4	641,949N; 910,255E	si-15	651,727N; 915,782E
si-5	644,074N; 909,965E	si-16	656,049N; 921,001E
si-6	650,036N; 912,742E	si-17	660,248N; 921,198E
si-7	655,190N; 923,172E	si-18	658,248N; 918,948E
si-8	653,771N; 922,641E	si-19	656,085N; 915,326E
si-9	654,335N; 918,291E	si-20	655,204N; 918,146E
si-10	655,171N; 917,740E	si-21	650,882N; 924,176E
si-11	653,668N; 915,473E	si-22	646,960N; 919,755E

Kyanite: Kyanite in the Bent Creek Research and Demonstration Forest is sparse, probably because at high metamorphic grade, it is replaced by sillimanite as the dominant aluminum silicate mineral. Kyanite was identified in several stream sediment heavy mineral samples, however (localities listed in table below). It does not occur in significant enough concentrations, however, to be potentially economic.

Kyanite Occurences

Map Number	NC Coordinates	Map Number	NC Coordinates
ky-1	643,535N; 909,515E	ky-4	656,049N; 921,001E
ky-2	655,190N; 923,172E	ky-5	660,248N; 921,198E
ky-3	653,633N; 919,041E		

Monazite: Monazite, an ore of thorium, was identified in four stream sediment heavy mineral samples (localities listed in table below). All sample sites drain sillimanite-garnet-chlorite-mica schist in the northeast end of the Bent Creek Research and Demonstration Forest.

Monazite Occurences

Map Number	NC Coordinates	Map Number	NC Coordinates
mo-1	655,190N; 923,172E	mo-3	652,306N; 921,425E
mo-2	653,633N; 919,041E	mo-4	653,362N; 926,631E