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The Geology and Geochemistry of the Agamenticus Complex, York, Maine

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INTRODUCTION

The Triassic Agamenticus Complex is the earliest phase of subalkalic to alkalic magmatism associated with the opening of the Atlantic Ocean during the Mesozoic Era. Recent geochemical analyses and field mapping have helped to clarify the petrologic relationships between syenite and granite phases present within this complex. Several features of this plutonic body make it an interesting focus of study: 1) the complex is the earliest pulse of rift-related magmatism in New England 2) the complex contains syenites and granites with no clear evidence of a basaltic parent, 3) gravity and magnetic anomalies indicate that such a parent is not present in the near surface, and 4) portions of the pluton have undergone significant deuteric metasomatism.

GENERAL

Topographic sheets: 15'- York and Kennebuck; 7.5'- York Harbor, York beach, Wells, and North Berwick.

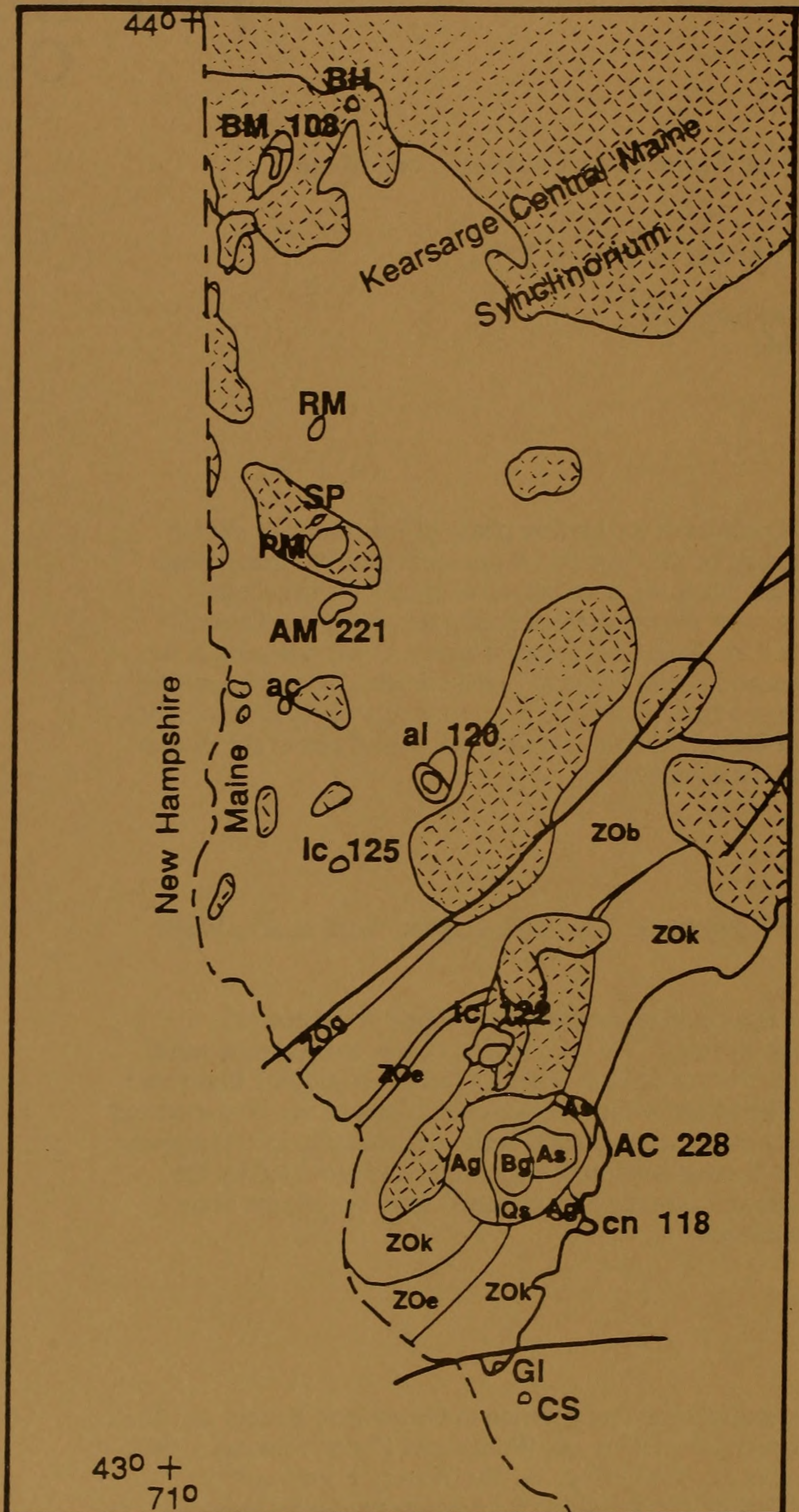
The Agamenticus Complex is located in southwestern Maine in the coastal townships of York, Wells and South Berwick. This is a region of low to moderate relief often covered with dense vegetation. Portions of the complex form topographic highs and provide good bedrock exposures. Elsewhere within the complex outcrops are best exposed along a limited number of secondary roads, small stream beds, and glacially oversteepened valley walls. A nearly continuous N-S cross section of the complex is provided by the outcrop exposures along I-95, but, permission must be obtained from the Maine State Turnpike Authority to visit these outcrops.

REGIONAL SETTINGS

Paleozoic Lithologies

The Agamenticus Complex intrudes the Precambrian to Ordovician Kittery and Eliot Formations of the Merrimack Group and the Devonian Webhannet Pluton (Hussey, 1962, 1985; Osberg et al., 1985; Gaudette et al., 1982) (Fig. 1). The Kittery Formation is comprised of thin- to thick-bedded feldspathic and calcareous quartzites, quartzites, siliceous phyllites, with subordinate interlayered marble beds. The Eliot Formation contains thin interbedded phyllite and quartzous phyllite. Rock types within the Webhannet Pluton range from quartz diorite to biotite granite.

The rocks of the Kittery and Eliot Formations experienced regional greenschist facies metamorphism prior to the emplacement of the Ordovician Exeter Diorite (Hussey, 1985; Gaudette et al.,1982). Contact metamorphism of these formations is apparent in close proximity to the Agamenticus Complex and in foundered blocks within the complex.



Legend

WMS-Felsic Series
- BH-Boston Hills Stock
- BM-Burnt Meadow Complex
- RM-Randall Mountain Stock
- SP-Symmes Pond Stock
- PM-Pickett Mountain Stock
- AM-Abbott Mountain Stock
- AC-Agamenticus Complex
  - Bg-Biotite-amphibole granite
  - Ag-Alkaline granite
  - As-Alkaline syenite
  - Qs-Quartz syenite
- GI-Gerrish Island explosion breccia
- CS-Chase Stock

WMS-Mafic Series
- ac-Acton Stock
- al-Alfred Complex
- lc-Lebanon Stock
- tc-Tatnic complex
- cn-Cape Neddick Complex

Merrimack Group
- ZOk-Kittery Fm.
- ZOe-Eliot Fm.
- ZOb-Berwick Fm.
- ZOg-Gonic Fm.

Other
- Faults
- Lithic contacts
- Undifferentiated Paleozoic igneous rocks

Fig. 1- Simplified geology of southwestern Maine. Adapted from Hussey 1985. Ages (Ma) indicated where known (Foland and Faul, 1977; Foland et al., 1977; Hoefs, 1967). Except for the Merrimack Group the metamorphic rocks are undifferentiated.

Xenoliths and foundered blocks of calcareous quartzite of the Kittery Formation contain abundant epidote and diopside indicating upper amphibolite facies metamorphism.

Mesozoic Plutons

The opening of the Atlantic Ocean was preceded and accompanied by the intrusion of the Mesozoic, subalkalic to alkalic White Mountain Plutonic Series (WMS) (Billings, 1956; Bedard, 1965; McHone and Butler, 1985).The Agamenticus Complex is at the southern end of a NNW-trending belt of small (1 to 50 km^2), felsic or mafic WMS bodies in southwestern Maine (Gilman, 1972,1979; Hussey, 1962, 1985; Osberg et al., 1985). Two of these bodies, the mafic Tatnic and Cape Neddick Complexes, are located in the vicinity of the Agamenticus Complex (Fig. 1). The gabbros to granodiorites of the Tatnic and Cape Neddick Complexes were intruded during the early Cretaceous period (122 to 119 Ma) (Foland and Faul, 1977) and are the last pulse of rift-related magmatism in this area. The felsic Agamenticus Complex, intruded during the late Triassic period (216-228 Ma) (Foland and Faul, 1977; Foland et al., 1971; Hoefs, 1967), is the earliest stage of rift-related magmatism .

AGAMENTICUS COMPLEX

Overview

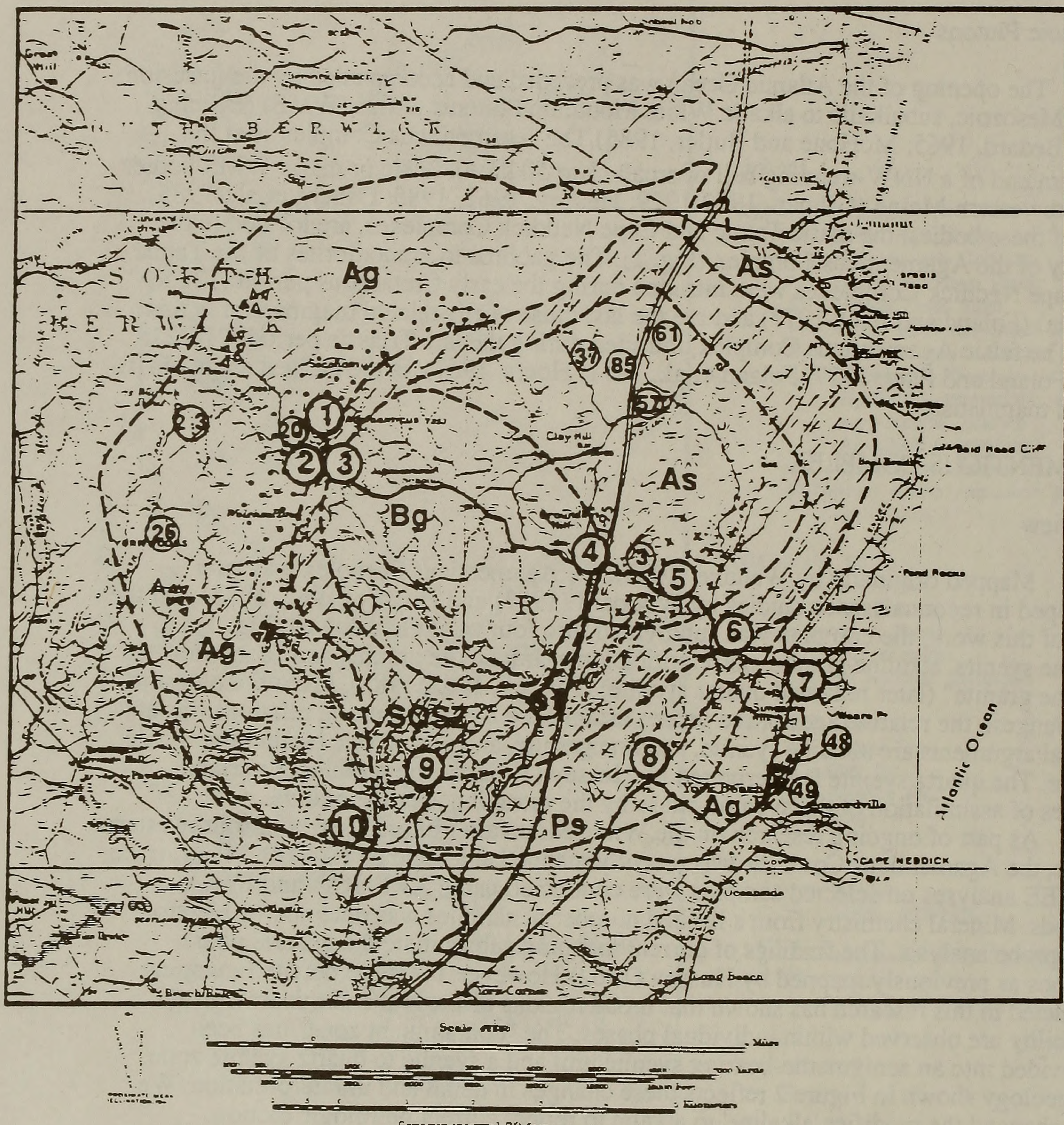
Mapped originally by Wandke (1922), the Agamenticus Complex was later remapped in reconnaissance studies by Woodard (1957) and Hussey (1962, 1985). On the basis of this work, the complex was subdivided into four major lithologies (Fig. 1); alkaline syenite, alkaline granite, porphyritic biotite-amphibole granite, and "contaminated alkaline granite" (later renamed quartz syenite) (Hussey, 1962, 1985). From the oldest to the youngest, the relative ages of the phases established by cross-cutting relationships and textural arguments are alkaline syenite, alkaline granite, and porphyritic biotite-amphibole granite. The quartz syenite is interpreted by Hussey (1962) as the product of variable degrees of assimilation of the syenitic phase by the intruding alkaline granite.

As part of ongoing research on the White Mountain Plutonic Series in southwestern Maine, the Agamenticus Complex was recently mapped at a scale of 1:24000. Major, trace and REE analyses on selected samples were conducted using XRF, ICP, and INAA methods. Mineral chemistry from a limited number of samples was obtained by electron microprobe analysis. The findings of current mapping substantiate the general phase relations as previously mapped by Hussey (1962) However, the more detailed mapping conducted in this research has shown that broad regions of textural and mineralogical variability are observed within individual phases. The "contaminant zone" has been subdivided into an aenigmatite-bearing syenite unit and a syenite to quartz syenite zone. The geology shown in Figure 2 reflects these changes in detail and in interpretation. We have changed the modifier 'alkaline' to alkalic to reflect current petrologic diction.

Alkalic granite to quartz syenite

Although the contacts of the western lobe of the alkalic granite remain unchanged, field work revealed a significant amount of leucocratic quartz syenite within the eastern portion of the body (Fig. 2; Table 1). Contacts between the alkalic granite and quartz syenite have not been observed and the two phases are considered to be transitional. Xenolith-rich areas occur within the alkalic granite (Fig. 2) and indicate that these regions were possibly close to the roof of the magma chamber. In xenolith zone A, amphiboles are subophitic to ophitic rather than interstitial as is typical of the alkalic granite elsewhere. This could reflect an increase in fluid pressure towards the top of the magma chamber during

Fig. 2 - Revised geology of the Agamenticus Complex. The starting point of the field trip is located just south of map coverage.



Legend

Agamenticus Complex

Bg- Biotite-amphibole granite

Ag- Alkalic granite

-quartz syenite portion of the alkalic granite

As- Amphibole-bearing alkalic syenite

-alkalic syenite

Ps- Porphyritic aenigmatite syenite

SQSZ- Syenite to quartz syenite zone

-Zone of pervasive intrusion by alkalic granites

-Xenolith rich zone

Other

Lithic contacts

Field trip route

(3) Stop numbers

(49) Sample location numbers other than stops

Table 1 - Mineral modes for representative rock types within the Agamenticus Complex.

Sample#	MAG 5	MAG 20	MAG 4	MAG 4	MAG 11b	MAG 139	MAG 3	MAG 91-1
Stop #	2		4	4	9	8		
Rock type	alk gran	alk gran	bio-amb gran	mafic xeno	porph sye	porph sye	sye	monzo-sye
Mineralogy								
ksp	70.58	61.72	27.96		70.10	69.51	85.88	70.46
plg	1.40	4.17	31.65	44.22	5.24	5.30	4.86	8.68
qtz	12.07	31.86	31.65	2.26	6.95	6.16	1.38	1.52
amb	15.37	2.00	2.99		16.29	6.34		5.74
aenig					1.24	5.49		
bio		0.08	5.52	50.25				
cpx						6.63	4.60	11.72
olv							3.09	1.41
other*	0.58	0.17	0.23	3.27	0.19	0.57	0.20	0.47
sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
*	Zr,Ap,Op,Al	Op,Fl	Zr,Ap,Op,Al		Op	Ap,+ Op	Op,Ap	Op,Ap

Abbrv.: ksp-alkali feldspar,plg-plagioclase,qtz-quartz,amb-amphibole,aenig-aenigmatite,bio-biotite, cpx-clinopyroxene,olv-olivine,Zr-zircon,Ap-apatite,Op-opaque,Fl-fluorite,Al-allanite crystallization, the greater impact of deuteric alteration, or the presence of a separate pulse of alkalic granite. The arfvedsonite amphibole compositions (Fig.3) observed at this location support the interpretation of enhanced deuteric alteration (Giret et al., 1980) but the subophitic to ophitic textures suggest that amphibole growth was synchronous with the growth of potassium feldspar.

The eastern lobe of alkalic granite (Fig. 1 and 2) is well exposed along the coastline adjacent to York Beach. At this locality the alkalic granite is medium- to coarse-grained and commonly contains miarolitic cavities, granitic autoliths, and xenoliths of Kittery Formation. An approximately 6 meter wide, northeast-trending dike or segregation of very coarse-grained to pegmatitic granite occurs within the central portion of the outcrop. Amphibole-rich trachytes intrude as 6 cm to 5 m wide dikes and contain abundant xenoliths of alkalic granite and Kittery Formation. These trachytic dikes are considered to be coeval with the late stage trachytic dikes that cut across all of the other phases within the complex.

Porphyritic biotite-amphibole granite

This rock is a gray to pink, fine- to medium-grained, porphyritic, subsolvus granite (Fig. 1 and 2; Table 1). The phenocryst assemblage is comprised of plagioclase and orthoclase and the matrix contains, quartz, biotite and subordinate amphibole. Textural variations of both matrix grain size and phenocryst abundance are observed within and between outcrops. These textural variations and the presence of Kittery-type xenoliths suggest that the current level of exposure was near the side or roof of the original magma chamber.

Alkalic Syenite

The alkalic syenite varies considerably in texture and in mineralogy (Fig. 2). The northern portions of the alkalic syenite are coarse to medium-grained and the southern portion is fine-grained. Perthite is the major phase in the alkalic syenite with interstitial hedenbergite, fayalite, and quartz occurring the the southern portions (Mag 3, Table 1) Other areas of the alkalic syenite contain the same mineralogy plus barrositic amphibole. The amphibole is interstitial and often rims the pyroxene. Amphibole compositions indicate either late magmatic crystallization, minor deuteric alteration (Giret et al., 1980), or both in this localized area. However, a contact observed between the medium-grained, amphibole-bearing syenite (Mag 61b, Fig. 2) and a fine-grained syenite mineralogically similar to the southern alkalic syenite suggests that the amphibole-bearing syenite instead may be a separate, more hydrous magma pulse.

"Contaminant Zone"

Field relationships within the "contaminant zone" are complex and are not yet fully understood. This complexity has resulted from the multiple intrusion in this zone of several syenite pulses with the subsequent intrusion by one or more granitic magmas. High volatile contents resulted in the growth of sodic and iron ($Fe3+$)-rich amphibole, turbid perthitic feldspars, interstitial microcline, the reaction of primary phenocrysts, and the development of greisen zones. Intrusion style within this zone was brittle to plastic-brittle as seen by the sharp angularity of many of the xenoliths. Some xenoliths have been rounded by mechanical disaggregation during transport and many have undergone variable degrees of assimilation. Ghost-like xenoliths of melanocratic to mesocratic syenites to quartz syenites are surrounded by alkalic granite. We suggest that the efficiency of assimilation in this zone is due to 1) the similarity in composition between the various syenites and the alkalic granite and 2) the likelihood that the syenites, although solid, were quite warm and that the difference in temperature between the syenites and the alkalic granite was relatively small.

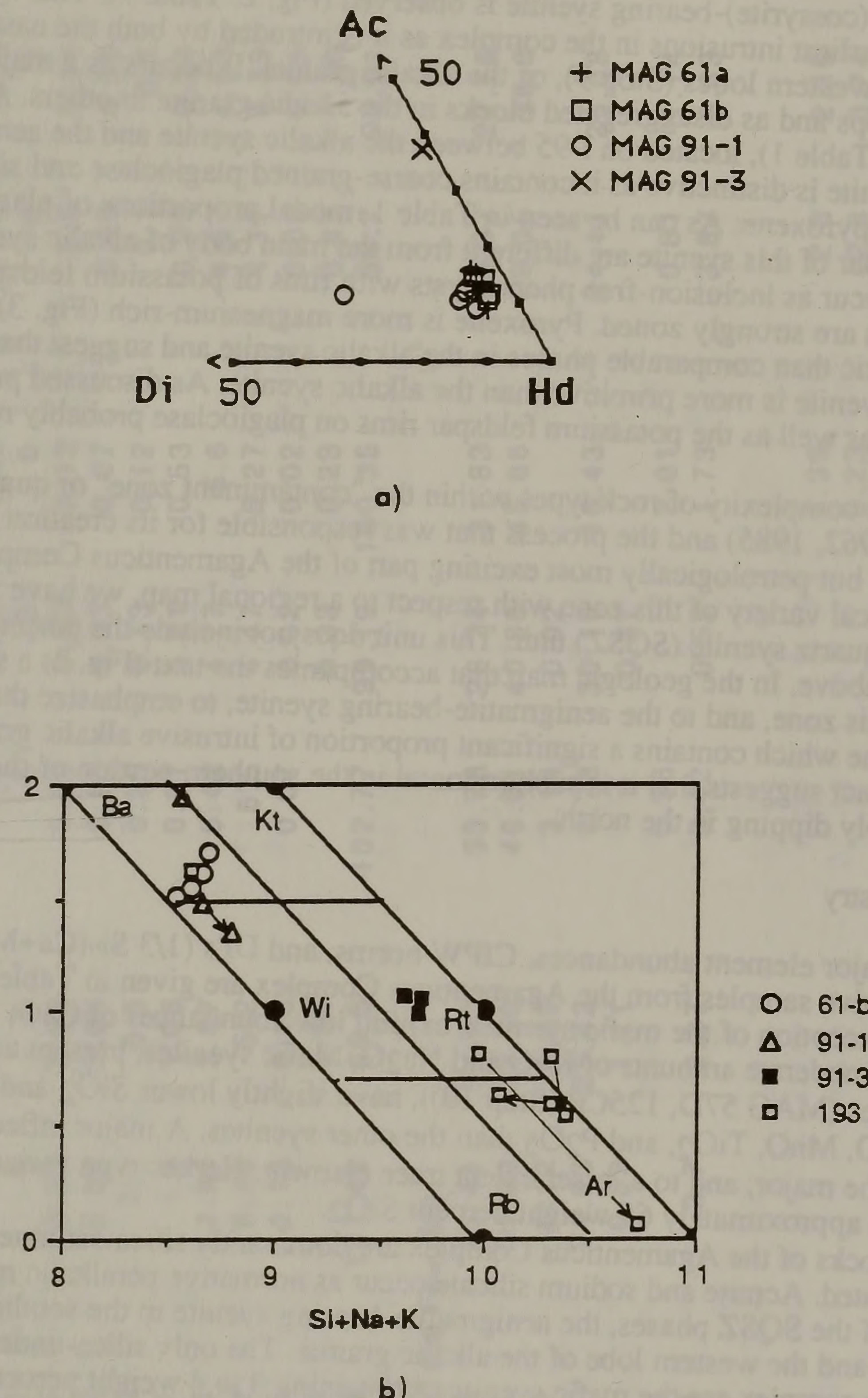


Fig. 3 - a) Clinopyroxene compositions plotted on an Acmite, Diopside, Hedenbergite (Ac-Di-Hd) ternary diagram (after Mitchell and Platt, 1977). b) Amphibole compositions for the Agamenticus Complex. Arrows connect core to rim compositions. Ba- Barrosite, Rt- Richterite, Wi- Winchite, Rb- Riebekite, Ar- Arfvedsonite (after Giret et al., 1980).

Within the southern and southeastern portion of the complex a porphyritic aenigmatite (cossyrite)-bearing syenite is observed (Fig. 2; Table 1). This syenite may be one of the earliest intrusions in the complex as it is intruded by both the eastern (Stops 6 and 8), and western lobes (Stop 9), of the alkalic granite. It occurs as a major phase in some outcrops and as disaggregated blocks in the alkalic granite in others. Another syenite (Mag 91-1, Table 1), located on I-95 between the alkalic syenite and the aenigmatite-bearing syenite is distinctive as it contains coarse-grained plagioclase and significant amounts of pyroxene. As can be seen in Table 1, modal proportions of plagioclase and alkali feldspar of this syenite are different from the main body of alkalic syenite. Both feldspars occur as inclusion-free phenocrysts with rims of potassium feldspar. Plagioclase phenocrysts are strongly zoned. Pyroxene is more magnesium-rich (Fig. 3) and plagioclase is more calcic than comparable phases in the alkalic syenite and suggest that this early pyroxene syenite is more primitive than the alkalic syenite. As discussed previously, amphibole as well as the potassium feldspar rims on plagioclase probably reflect deuteric alteration.

The complexity of rock types within the "contaminant zone" or quartz syenite (Hussey, 1962, 1985) and the process that was responsible for its creation make it the least understood but petrologically most exciting part of the Agamenticus Complex. To portray the geological variety of this zone with respect to a regional map, we have renamed it the syenite to quartz syenite (SQSZ) unit. This unit does not include the porphyritic syenite described above. In the geologic map that accompanies the text (Fig. 2) a slash pattern is added to this zone, and to the aenigmatite-bearing syenite, to emphasize that this region is a contact zone which contains a significant proportion of intrusive alkalic granite. The width of the contact suggests that it is subhorizontal in the southern portion of the complex and more steeply dipping in the north.

Geochemistry

Major element abundances, CIPW norms, and DI's (1/3 Si-(Ca+Mg+Mn)) for representative samples from the Agamenticus Complex are given in Table 2. All phases, with the exception of the mafic syenites, exhibit low abundances of CaO, MgO, MnO and TiO_2 and moderate amounts of K_2O and Na_2O. Mafic syenites, present at a limited number of localities (MAG 57D, 125CP (Stop 10)), have slightly lower SiO_2 and higher Al_2O_3, CaO, MgO, MnO, TiO_2, and P_2O_5 than the other syenites. A major inflection occurs on many of the major, and to a lesser extent trace element, Harker-type variation diagrams (Fig. 4) at approximately 65 weight percent SiO_2.

Rocks of the Agamenticus Complex are dominantly silica-saturated to silica-oversaturated. Acmite and sodium silicate occur as normative peralkalic minerals within a number of the SQSZ phases, the aenigmatite-bearing syenite in the southern portion of the complex, and the western lobe of the alkalic granite. The only silica-undersaturated rocks within the complex are the mafic syenites, containing 3 to 4 weight percent normative nepheline. The porphyritic biotite-amphibole granite is corundum normative (peraluminous). Plotted on a Qtz-Ab-Or ternary diagram (Fig. 5), the syenites and alkalic granites lie along the 1 to 3 kbar thermal trough for low An contents and moderate P_{H_2O}. The porphyritic biotite-amphibole granites are slightly more orthoclase-rich.

The rocks of the Agamenticus Complex are generally more agpaitic than other WMS rocks (Fig. 6). Many of the other WMS bodies, some of which contain mafic members, evolve from miaskitic through pulmaskitic to agpaitic compositions (Fig. 6) and from metaluminous to peraluminous and peralkalic compositions. On the agpaitic plot (Fig. 6) the mafic syenites plot within the pulmaskitic field and the other rocks plot within the agpaitic field and exhibit a rough correlation of increasing agpaitic index to decreasing (K+Na)/(Si/6). The porphyritic biotite-amphibole granite is distinct from this trend and

Table 2 - Major element analyses (Wt percent), CIPW normative assemblages, and Differentiation Indexes (DI) for selected samples.

	Sye	Amb sye	B+h granite		Alk Gran-West lobe			Alk gran-East lobe	
SAMPLE #	MAG-2	MAG 39	MAG-4	MAG-179	MAG-5	MAG-23	MAG-26	MAG-48	MAG-49
STOP #	5		4	3	2				
SiO2	65.7	61.7	72.24	71.5	69.34	75.64	70.95	73.8	70.9
TiO2	0.46	0.63	0.41	0.39	0.37	0.09	0.24	0.18	0.33
Al2O3	15.88	17.5	14	14.14	15.17	13.2	14.43	9.79	11.8
FeO	0	0	0	0	0	0	0	0	0
Fe2O3	6.52	5	3.23	2.62	5.59	0.63	3.12	5.6	5.08
MnO	0.2	0.12	0.07	0.05	0.15	0.03	0.07	0.08	0.09
MgO	0.27	0.5	0.7	0.5	0.25	0.13	0.12	0.1	0.1
CaO	1.56	1.87	1.4	1.08	0.91	0.21	0.53	0.26	0.34
Na2O	5.68	5.45	2.95	3.87	5.42	4.77	5.6	4.67	4.93
K2O	5.82	6.26	6.36	5.2	5.5	4.47	5.27	4.17	4.39
P2O5	0.05	0.15	0.13	0.15	0.07	0.02	0.02	0.05	0.05
LOI		0.6		0.56		0.33	0.23	0.43	1.16
SUM	102.14	99.18	101.49	99.5	102.77	99.19	100.35	98.7	98.01
CIPW Normative assemblages (FeO/Total Fe= .85)									
Or	35.26	38.18	31.41	31.48	33.78	26.74	31.83	26.37	27.76
Ab	49.29	47.61	31.99	33.56	46.61	40.86	45.88	29.05	38.8
An	0.33	4.95	6.12	4.49	3.14	0.92			
Q	3.74		24.93	25.42	9.78	30.18	16.43	34.41	25.08
C			0.59	1.11		0.37			
Di	5.48	2.89			0.96		2.01	0.81	1.14
Hy	3.11	1.48	2.7	2.27	3.42	0.57	1.73	3.87	3.33
Ol		2.17							
Ne									
Ac							1.39	2.3	2.36
Ns							0.23	2.4	0.74
AP	0.11	0.34	0.34	0.34	0.18	0.04	0.04	0.12	0.12
Il	0.9	1.24	0.93	0.76	0.91	0.17	0.47	0.37	0.67
Mt	1.46	1.13	0.69	0.58	1.22	0.14			
DI	25.14	24.67	28.47	27.8	26.73	30.09	28.53	28.65	28.09

Table 2 contd - Major element analyses (Wt percent), CIPW normative assemblages, and Differentiation Indexes (DI) for selected samples.

	Melano- to mesocratic SQSZ		Felsic SQSZ	Mafic syenites		Aenig sye
SAMPLE #	MAG-11a	MAG-91-1	MAG-11c	MAG-57D	MAG-125CP	MAG-139
	9		9		10	8
SiO2	63.9	60.18	67.9	57.93	59.22	62.11
TiO2	0.45	0.82	0.09	0.84	0.86	0.54
Al2O3	14.6	14.78	16.7	17.22	17.65	14.58
FeO	0	0	0	0	0	0
Fe2O3	7.69	9.59	2.12	6.65	6.73	8.76
MnO	0.2	0.24	0.02	0.14	0.14	0.22
MgO	0.1	0.43	0.1	1.95	1.97	0.13
CaO	1.54	2.89	0.13	3.27	3.28	1.46
Na2O	6.22	5.87	6.48	6.29	5.94	6.34
K2O	4.94	4.64	5.71	4.53	4.56	5.24
P2O5	0.06	0.22	0.05	0.23	0.25	0.09
LOI	0.2	0.15	0.39	0.27	0.46	0.3
SUM	99.7	99.66	99.3	99.05	100.6	99.47
CIPW Normative assemblages (FeO/Total Fe= .85)						
Or	30.42	28.35	35.15	27.14	27.22	33.45
Ab	53.29	51.37	56.14	44.97	44.06	49.52
An		0.29		7.4	6.72	
Q	0.21		4.48			
C						
Di	5.75	10.32	0.36	6.06	6.63	5.64
Hy	4.22	0.78	1.37			4.68
Ol		4.62		8.6	7.71	0.39
Ne				3.53	4.06	
Ac	3.64		0.88			4.11
Ns	1.38		1.34			0.89
AP	0.16	0.5	0.07	0.52	0.51	0.21
Il	0.93	1.61	0.2	0.32	1.64	1.11
Mt		2.16		1.46	1.45	
DI	24.01	20.03	29.05	17.24	17.33	23.9

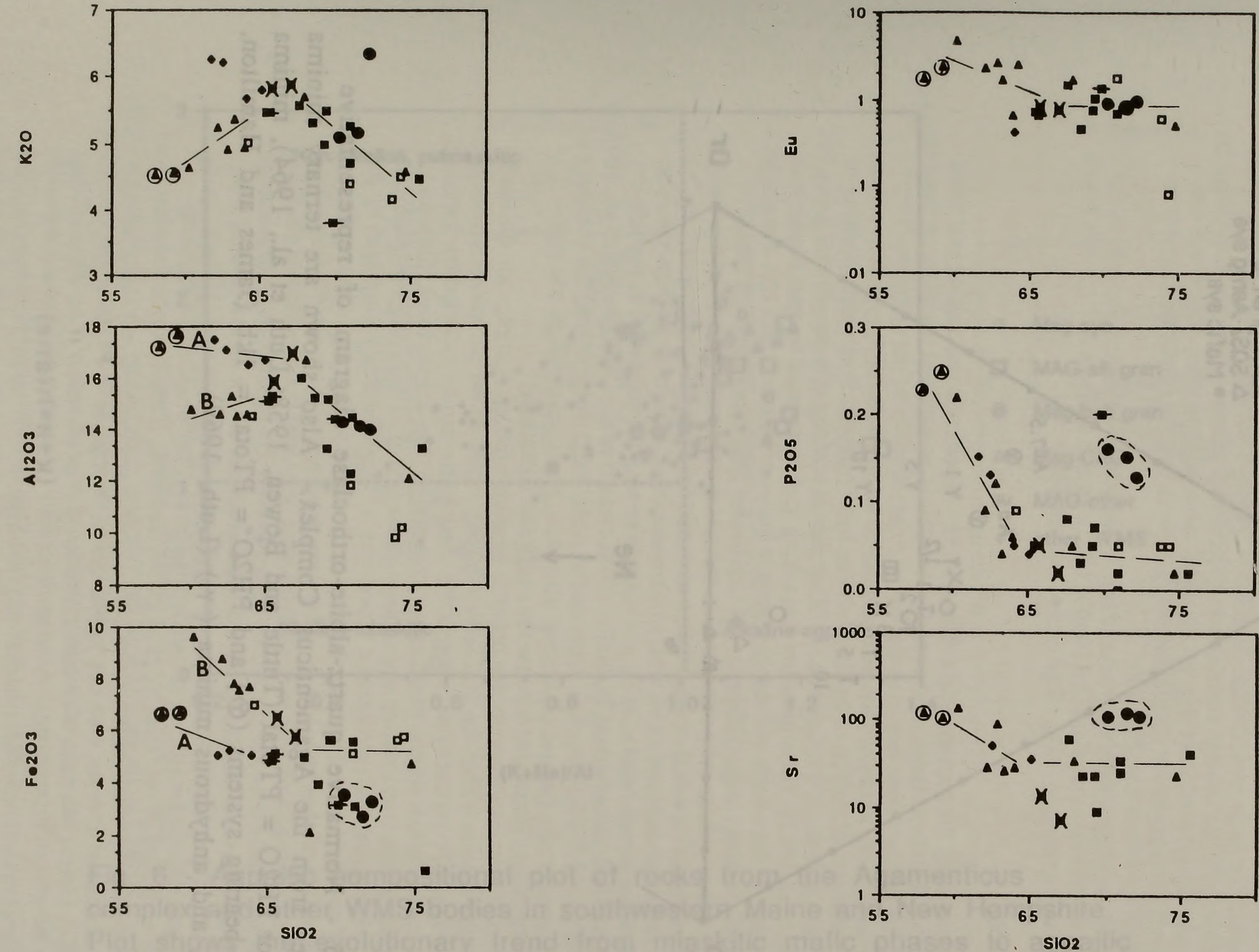


Fig. 4 - Harker diagrams of selected major and trace elements. A flexure commonly occurs at approximately 65% SiO2 on these diagrams. On the Al2O3 and Fe3O2 the rocks of the SQSZ plot along a separate trend (B) from the mafic and amphibole-bearing syenites (A). Biotite-amphibole granites often plot separately from the other phases. Symbols: ж-alkalic syenite, ◆ - amphibole-bearing alkalic syenites, Ⓐ - mafic syenites, ■ - alkalic granites-west lobe, □- alkalic granites-east lobe, ● - biotite-amphibole granites, -■- - misc. dikes, ▲ - SQSZ,

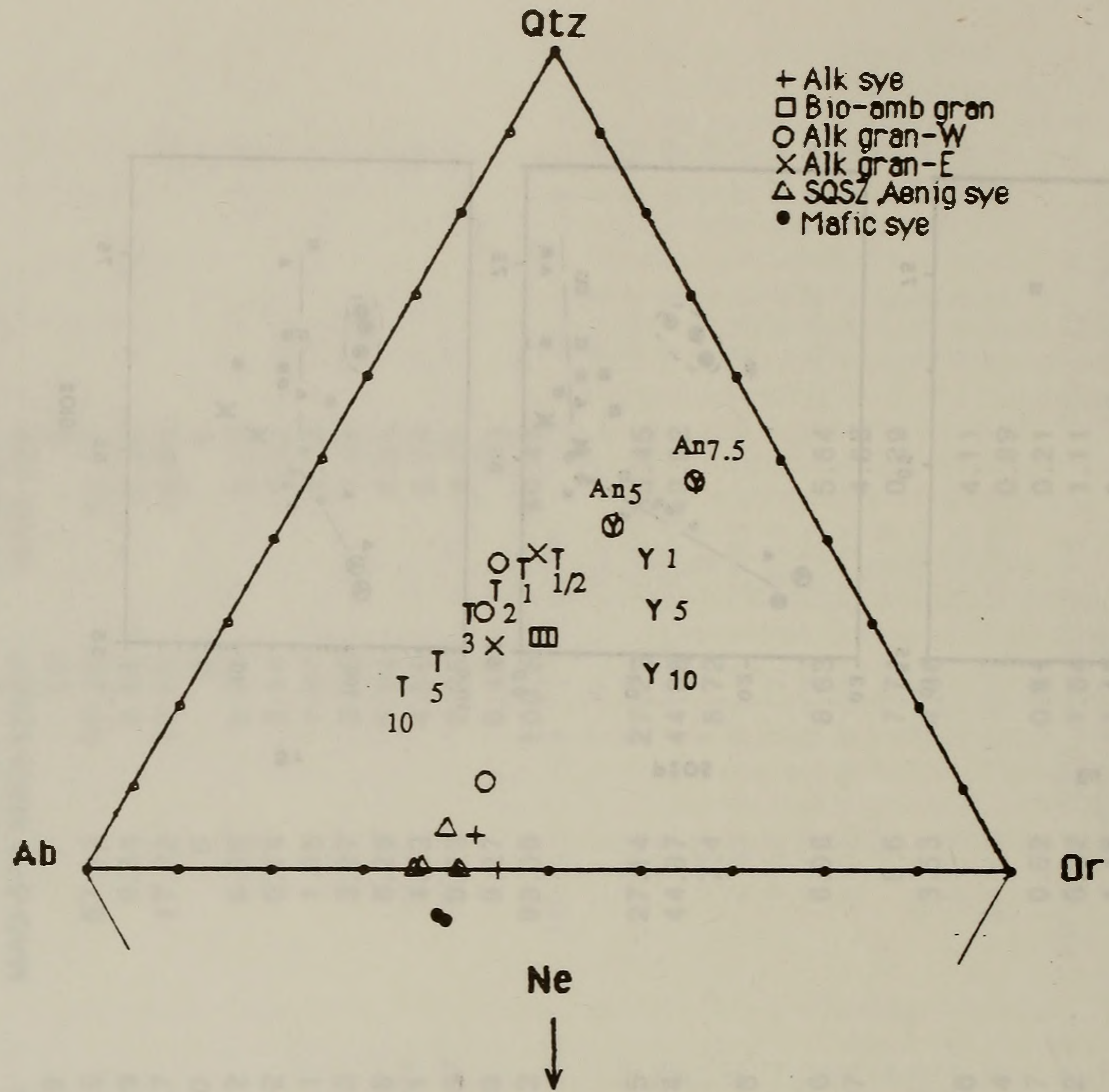


Fig. 5 - Normative quartz-albite-orthoclase diagram of representative samples from the Agamenticus Complex. Also shown are ternary minima (T) for PH2O = PTotal (Tuttle and Bowen, 1958; Luth et al., 1964), minima in An-bearing systems (Ⓨ) and PH2O = PTotal = 1kb (James and Hamilton, 1969), and anhydrous minima (Y) (Luth, 1969).

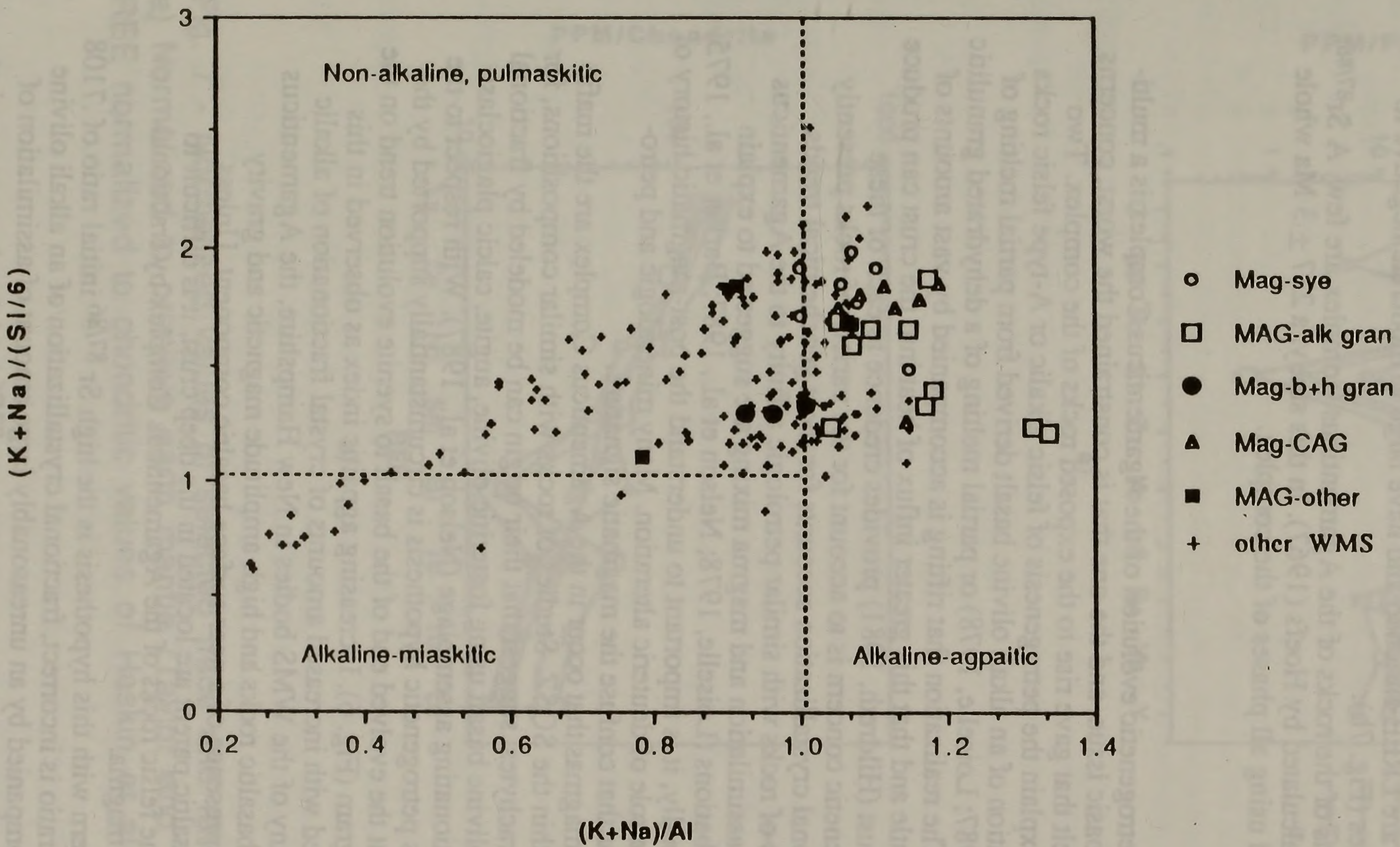


Fig. 6 - Agpaitic compositional plot of rocks from the Agamenticus complex and other WMS bodies in southwestern Maine and New Hampshire. Plot shows the evolutionary trend from miaskitic mafic phases to agpaitic felsic phases. The porphyritic biotite-amphibole granite plots within a discrete field from the main evolutionary trend.

plots within a well-defined field of pulmaskitic/agpaitic WMS rocks. This discrete field lies slightly below the main evolutionary trend exhibited by mafic to felsic WMS rocks.

Trace and rare earth element abundances for representative samples are presented in Figure 7. With the exception of Sr and Ba, the different phases all have similar trace element patterns. The large ionic lithophile (LIL) (except Sr) and high field strength (HFS) elements exhibit moderate to large enrichments relative to primitive earth mantle abundances (Fig. 7a). Sr and Ba have variable degrees of enrichment ranging from .3 to 9 and 4 to 400, respectively. The rocks are LREE enriched and have large to moderate negative to slightly positive Eu anomalies (Fig. 7b).

Isotopic compositions of the rocks of the Agamenticus Complex are few. A $Sr^{87/86}$ initial ratio of 0.7108 was calculated by Hoefs (1967). In this study, a 227 $\pm$ 3 Ma whole rock isochron was generated using all phases of the complex.

DISCUSSION

Understanding the petrogenetic evolution of the Agamenticus Complex is a multi-faceted problem. The most basic issue, and the one that is constrained the worst, concerns the nature of the primary melt that gave rise to the exposed rocks of the complex. Two models commonly used to explain the petrogenesis of felsic alkalic or A-type felsic rocks involve fractional crystallization of an alkali olivine basalt derived from partial melting of the mantle (Nelson et al., 1987; Loiselle, 1978) or partial melting of a dehydrated granulitic crust (Collins et al.,1982). The realization that rifting is accompanied by vast amounts of basalt production in the mantle and that this greater influx of heat into the crust can produce partial melts of the lower crust (Hildreth, 1981) provides credence to each of these hypothesis. Another petrogenetic concern is to account for the variety of rocks presently seen in the complex. Fractional crystallization accounts for most geochemical trends observed within other suites of rocks with similar petrologic affinity to the Agamenticus Complex, however, crustal assimilation and magma mixing are suggested to explain various geochemical perturbations (Loiselle, 1978; Nelson et al., 1987; Barker et al., 1975; Czamanski et al., 1977). Finally, it is important to understand the post-magmatic history of the complex, specifically the role of deuteric alteration. Many mineralogic and petro-chemical changes may occur that confuse the magmatic signature.

The most primitive magmas that occur in the Agamenticus Complex are the mafic syenites and the syenite within the SQSZ. Studies of rocks with similar compositions, for example, the Trans-Pecos trachytes, suggest that their origin can be modeled by fractional crystallization of an alkali olivine basalt using fosteritic olivine, augite, calcic plagioclase and Fe-Ti oxide as the fractionating assemblage (Nelson et al., 1987). With respect to the Agamenticus Complex, this petrogenetic hypothesis is circumstantially supported by the occurrence of the syenites at the evolved end of the basalt to syenite evolution trend on the agpaitic compositional diagram (Fig. 6). Increasing agpaitic index as observed in this diagram is usually associated with increased amounts of crystal fractionation of alkalic rocks. However, unlike many of the WMS bodies in New Hampshire, the Agamenticus Complex lacks observable basaltic rocks and high amplitude magnetic and gravity anomalies that indicate the presence of a near surface basaltic component. Unless significant amounts of a basaltic parent are located in the deep crust, it is difficult to envisage the evolution of the felsic rocks of the Agamenticus Complex by fractional crystallization of a basaltic magma.

An additional concern with this hypothesis is the high $Sr^{87/86}$ initial ratio of .7108 (Hoefs, 1967). Unless this ratio is incorrect, fractional crystallization of an alkali olivine basalt must have been accompanied by an unreasonably large amount of assimilation of quite radiogenic crustal material. Alternatively, the high $Sr^{87/86}$ initial ratio suggests that partial melting of old radiogenic crust is a viable process. A process involving multi-stage

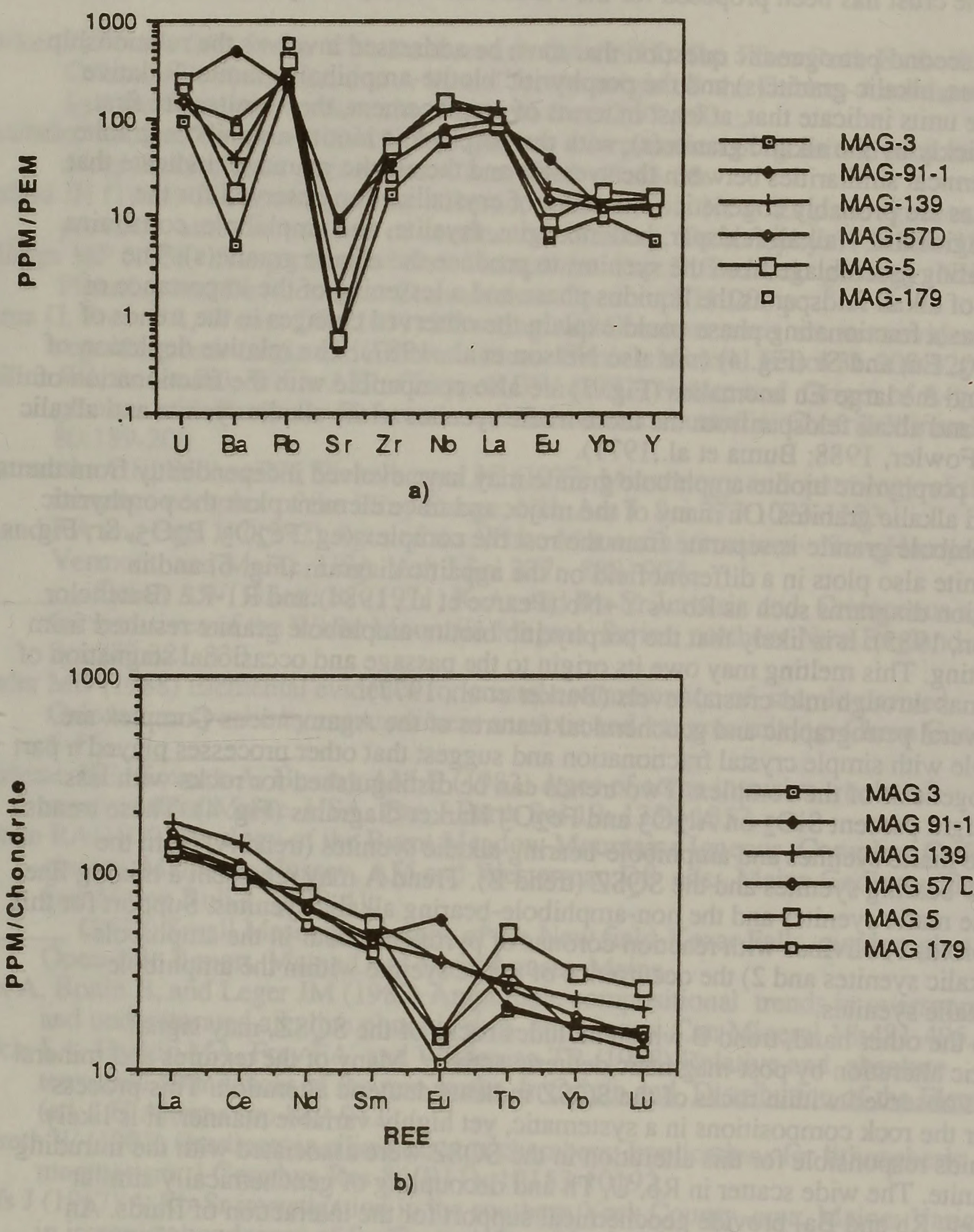


Fig. 7 - Normalized values of selected trace and rare earth abundances. a) Normalized to primitive earth mantle (Taylor and McLennan, 1981) b) REE normalized to chondritic values of Haskin et al. (1968).

melting of the crust has been proposed for the Pikes Peak Complex by Barker and others (1977).

The second petrogenetic question that must be addressed involves the relationship of the syenites, alkalic granite(s) and the porphyritic biotite-amphibole granite. Relative ages of these units indicate that, at least in terms of emplacement, the syenites are first, followed quickly by the alkalic granite(s), with the porphyritic biotite-amphibole granite last. Geochemical similarities between the syenites and the alkalic granite(s) indicate that these magmas are probably cogenetic. The order of crystallization observed for the syenites, plagioclase + alkali feldspar, hedenburgite, fayalite, and amphibole, constrains the fractionating assemblage from the syenites to produce the alkalic granite(s). The appearance of alkali feldspar as the liquidus phase and a lessening of the importance of plagioclase as a fractionating phase could explain the observed changes in the trends of K_2O, Al_2O_3, Eu, and Sr (Fig. 4) (see also Nelson et al., 1987). The relative depletion of Sr and Ba and the large Eu anomalies (Fig. 7) are also compatible with the fractionation of plagioclase and alkali feldspar from the more mafic syenites to the alkalic syenite and alkalic granite(s) (Fowler, 1988; Buma et al.,1971).

The porphyritic biotite-amphibole granite may have evolved independently from the syenites and alkalic granites. On many of the major and trace element plots the porphyritic biotite-amphibole granite is separate from the rest the complex (eg. Fe_2O_3, P_2O_5, Sr; Fig. 4). The granite also plots in a different field on the agpaitic diagram (Fig. 6) and in discrimination diagrams such as Rb vs Y+Nb (Pearce et al., 1984) and R1-R2 (Batchelor and Bowden, 1985). It is likely that the porphyritic biotite-amphibole granite resulted from crustal melting. This melting may owe its origin to the passage and occasional stagnation of other magmas through mid-crustal levels (Barker et al., 1977).

Several petrographic and geochemical features of the Agamenticus Complex are incompatible with simple crystal fractionation and suggest that other processes played a part in the petrogenesis of the complex. Two trends can be distinguished for rocks with less than 65 weight percent SiO_2 on Al_2O_3 and Fe_2O_3 Harker diagrams (Fig. 4). These trends separate the mafic syenites and amphibole-bearing alkalic syenites (trend A) from the aenigmatite-bearing syenites and the SQSZ (trend B). Trend A may represent a mixing line between the mafic syenites and the non-amphibole-bearing alkalic syenites. Support for this idea is twofold; 1) olivines with reaction coronas of pyroxene occur in the amphibole-bearing alkalic syenites and 2) the occurrence of mafic syenite within the amphibole-bearing alkalic syenites.

On the other hand, trend B which includes rocks of the SQSZ, may signal metasomatic alteration by post-magmatic deuteric activity. Many of the textures and mineral chemistries observed within rocks of the SQSZ indicate deuteric alteration. This process would alter the rock compositions in a systematic, yet highly variable manner. It is likely that the fluids responsible for this alteration in the SQSZ were associated with the intruding alkalic granite. The wide scatter in Rb, U, Th and decoupling of geochemically similar elements (eg. Rb and Ba) provide geochemical support for the interaction of fluids. An alternative explanation of these trends involves the mixing of magmas with different compositions. In their study of the Kaerven Complex, Greenland, Holm and Praegel (1988) suggest that similar geochemical variations, as well as a strong Sr-Ba correlation (also seen in the Agamenticus Complex) may indicate magma mixing of syenite and alkalic granite.

Many unanswered questions remain concerning the petrogenesis of the Agamenticus Complex. Continued field mapping, additional phase and rock chemistry, and isotopic studies are underway to help unravel some of the mysteries.

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ITINERARY

ASSEMBLY POINT: Meet in the rest area/ official information on the north bound side of I-95 3.1 miles north of Piscataqua River Bridge. Park in the rear behind the information building.

Mileage Total	Elapsed	Comments
0		Rest Area
3.3	3.3	Return to I-95N to Exit 1, "To Rts. 1 and 91, York,Ogunquit"
3.75	0.45	Left at end of exit ramp. Cross I-95.
4	0.25	Right on Chases Pond Road. straight at first Y intersection.
6.45	2.45	Intersection with Scituate Road; go straight
7.7	1.25	Continue straight onto Mountain Road. (Mt Agamenticus Road on topographic sheets).
10.5	2.8	Right onto tarred road; go to top of Mt Agamenticus.
11.1	0.6	Top of Mt Agamenticus. Park at end of parking area to right of fire tower.

Stop 1: Pavement outcrops of hypersolvus, quartz syenite to alkaline granite are in this locality. Alkaline granite is best exposed on the right hand edge of parking area. Outcrops of quartz syenite to alkaline granite with harrasitic layering of amphibole and xenoliths of Kittery Fm. and mafic hornfels can be found at the top of old ski trail head beyond the parking lot. Alkaline granite to the west of Mt. Agamenticus contains abundant metasedimentary xenoliths possibly indicating a close proximity to the roof of the magma chamber. The alkaline granite is dominated by medium-grained, euhedral to subhedral, patch and string perthite and subhedral quartz. Prior to exsolution of nearly pure albite and orthoclase lamellae, the alkali feldspar composition was Or_{50-55}. Interstitial microcline, albite, quartz and amphibole are present. Granular plagioclase rims most perthite grains.

Total	Elapsed	Comments
		Return to the bottom of mountain access road.
11.85	0.75	Right onto Mountain Road.
12	0.15	Top of hill pull off to left side of road. Outcrops on either side of the road.

Stop 2: Quartz syenite to alkaline granite (Mag 5, Table 1 and 2) similar to that observed at Stop 1 crops out on either side of the road. Farther west,the alkaline granite is more quartz rich (Mag 23+26, Table 2). Amphibole is included in the rims of and is interstitial to the perthite. Amphibole (MAG 193, Fig. 3) ranges from barrosite to arfvedsonite (Following Giret et al., 1980). Arfvedsonite is interpreted as the product of late deuteric growth. The turbid appearance and complete unmixing of the perthite, the presence of interstitial microcline, and the replacement textures of the amphiboles observed in thin sections provide evidence for a late deuteric event.

		Turn around and continue on Mountain Road. The contact between the alkaline granite and the biotite-amphibole granite is located in the small valley past the Mt. Agamenticus access road (Hussey,1962).
12.6	0.6	Park on either side of the road.

Stop 3: Outcrops of subsolvus, porphyritic, biotite-amphibole granite are exposed on either side of Mountain Road. At the western end of the outcrop on the north side of road two phases of the biotite-amphibole granite can be observed.

The majority of this outcrop is comprised of a medium gray porphyritic granite (MAG 179, Table 2) with a medium-grained matrix of biotite, plagioclase, orthoclase, quartz ± amphibole and phenocrysts of plagioclase and orthoclase. The second phase, seen here as a large autolith, is darker gray, has a finer grained matrix, and contains a smaller modal proportion of phenocrysts. Along the shores of Chases Pond, the variation between the two phases occurs over a much larger scale than observed here.

Late cross cutting rhyolitic veins can be observed near the mesocratic autolith and are interpreted to be a late residual phase intruded along cooling joints. Rhyolitic dikes with euhedral to subrounded orthoclase, plagioclase, and quartz phenocrysts also cross cut the syenitic phase on I-95 near the contact between the biotite-amphibole granite and the syenite. They are considered to be comagmatic with the biotite-amphibole granite and support the younger relative age assigned to this unit by Hussey (1962).

		Continue east along Mt. Road.
14.95	2.35	Left onto Mt. Road.
15.1	0.15	Park on right side of road.

Stop 4: This outcrop of biotite-amphibole granite (MAG 4, Table 1 and 2) is similar to the coarse-grained variety seen at Stop 3. This outcrop is near the contact of the biotite-amphibole granite and the syenite. The syenite can be observed in outcrops located directly across I-95.

The biotite-amphibole granite contains plagioclase phenocrysts that are discontinuously zoned with core compositions of An_{20-40} and rims of An_{8-17}. Orthoclase phenocrysts are unzoned with compositions of Or_{94-98}.

Enclosed in the granite at this location are numerous xenoliths and autoliths(?). Two dominant populations occur here; calcareous to non-calcareous quartzites and biotite-rich clots. The biotite-rich clots could either be xenoliths of an earlier mafic phase of the Agamenticus Complex or of the nearby Webhannet Pluton, restitic material, or autoliths of the biotite-amphibole granite.

		Continue eastward on Mountain Road.
15.8-15.9		No stop: outcrops on either side of road of coarse to medium- grained syenite with hedenbergite,fayalite ± amphibole.
16.15	1.05	Outcrops for the next stop are along the power line but park along the shoulder of the road somewhere before the power line.

Stop 5: This stop examines a series of outcrops that range from coarse-grained alkaline syenite to fine-grained alkaline syenite and quartz syenite. This variation is tentatively interpreted as a contact zone which has been truncated by the alkaline granite and/or the mesocratic syenite to be seen at Stop 9.

All of the outcrops are located along the power line which crosses Mountain Road. Stop 5a is to the north of the road on the other side of a low lying wet area. The rock at this outcrop is a dark green, coarse-grained alkaline syenite, typical of the southern portions of the alkaline syenite (Fig. 2). It consists dominantly of euhedral to subhedral perthite with interstitial fayalite and hedenbergite (MAG 3, Table 1). In the rest of the syenite body barrositic amphibole forms a reaction rim around the hedenbergite (MAG 61b, Fig. 3). Small alkaline granite dikes are located on the eastern portion of this outcrop and are interpreted to be stringers from the eastern lobe of the alkaline granite.

Stop 5b is located on the southern side of Mountain Road (MAG 2, Table 1 and 2). This medium-grained syenite contains the same mineralogy as Stop 5a. Clots of alkali feldspar can be seen on the weathered surface. These clots are interpreted to be cumulate and indicate that alkali feldspar fractionation has played an important role in the petrogenesis of the complex.

As you proceed over the hill to the south of the road, the syenite locally becomes finer grained and more quartz rich. Fresh samples can be observed at the base of the power line poles. At pole #64 several of the blocks brought up by blasting have a mottled appearance that is typical of portions of the mesocratic syenite to the west.The medium to fine-grained syenite to quartz syenite is continuous to the south up to pole #69 (We'll stop at pole #61 or 62 today). At this locality quartz,feldspar, amphibole stringers occur within the outcrop. These are similar to the amphibole concentrations that occur at the contact of the alkaline granite elsewhere. This contact relationship will be seen at many of the following stops. Within several tens of meters to the south of pole #96 alkaline granite becomes the dominant lithology. These relationships indicate that alkaline granite may underlie the syenite at Pole #69 along a subhorizontal contact.

		Return to the car along power line and then continue eastward on Mountain Road.
16.5	0.35	Right on Rt. 1
16.8	0.3	Left onto River Road. in Town of Cape Neddick. Those who did not bring a lunch should stop at one of the stores at this intersection.
17	0.2	Left into Cape Neddick Baptist Church parking lot.

Stop 6: Outcrop on left of parking lot is typical of the southeastern portion of the "contaminant zone"" or quartz syenite zone as mapped by Hussey (1962). This outcrop contains porphyritic, medium to dark gray syenite intruded by an alkaline granite to quartz syenite. Amphibole concentrations are common within restricted portions of intrusive fingers and suggest an increase in the volatile content in these regions.

		Continue east on River Road.
17.45	0.45	Right at end of road.
17.8	0.35	Take right at stop sign onto Shore Road. And park along side of road between here and Cape Neddick Campground which is located on other side of small bridge.
18.1	0.3	Cape Neddick Campground

Stop 7: Lunch Stop. Permission must be obtained from the owners of the campground to visit this stop. This stop demonstrates the intrusive relationships of the eastern lobe of the alkaline granite (MAG 48 and 49, Table 2) with the Kittery Formation. As seen at Stop 6, amphiboles are often concentrated within the more restricted small dikes or fingers of alkaline granite. Also present is a late cross-cutting basalt dike which are common within both the Agamenticus Complex and the country rock within the coastal region (Hussey,1962; Swansen,1982). The relationship of these dikes (if any) to the Agamenticus Complex is unknown.

		Continue south on Shore Road.
18.4	0.3	At stop sign go straight onto Rt. 1a S.
19	0.6	Bear right at Goldenrod Kisses in York Beach. No stop today, but a sharp left will lead along a rocky shore where the eastern lobe of the alkaline granite is well exposed. Access is limited so park in town and enter from beach.
19.15	0.15	Sharp right just as leaving town onto Bridge Road.
19.6	0.45	Right onto Rogers Road. Follow to intersection with Rt 1.
20.5	0.9	Intersection with Rt. 1. Take right and then almost immediate left. Rt. 1 is a busy highway so make sure both northbound lanes are empty before turning.
20.55	0.05	Left into parking lot of United Methodist Church. Park next to Rt. 1 across from brass bell. Outcrops on Rt 1. Narrow shoulder so be careful of traffic!

Stop 8: This stop provides a better view of the intrusive relationships observed at Stop 6. Alkaline granite to quartz syenite brittlely intrudes a dark gray, porphyritic, aenigmatite-bearing syenite (MAG 139, Table 1 and 2). The power line that crosses Rt. 1 just to the north of this outcrop is the same one that we walked along at Stop 5. Approximately 1 km. north on this power line, the contact between the porphyritic syenite and the alkaline granite can be observed at pole #75. The porphyritic syenite is not observed to the north of this contact along the powerline.

		Continue south on Rt 1.
20.85-21.05		No stop. Outcrops of dominantly alkaline granite with xenoliths of porphyritic syenite
21.4		Contact of alkaline granite and Kittery in valley before Faircrest Motel.
21.55		Kittery Fm in small quarry on west side of road.
22.85	2.3	Take right at lights onto connector road for I-95.
23.35	0.5	Right onto Chases Pond Road
24.0	0.65	Left onto Scituate Road.
24.5	0.5	Scituate Road bears sharply to right.
25.25	0.7	Outcrop located on right side of road. Go past and turn around in driveway on left and park on same side of road or along driveway.

Stop 9: At this stop the three dominant phases within the "contaminant zone" can be examined. The rock at northern end of the outcrop is a medium-grained, brown to gray weathering, quartz-bearing, mesocratic syenite (MAG 11a, Table 2). This rock has a mottled appearance, in which the early amphiboles appear to be rimmed by potassium feldspar. This petrographic feature is typical of the "contaminant zone" from here to I-95. An aenigmatite-bearing, porphyritic syenite (MAG 11b, Table 1) is located in the central

and southern portions of the outcrop. On the southern end of the outcrop and continuing to the the back of the outcrop a xenolith-rich zone of alkaline granite to quartz syenite can be observed (MAG 11c,Table 2). A large variety of compositions and textures can be seen in the angular and rounded xenoliths. In the central portion of the outcrop the xenolith-rich phase intrudes the porphyritic syenite and the mesocratic syenite. Amphibole concentrations occur at the contact of the alkaline granite with the mesocratic syenite. This can be observed both on the pavement and vertical surfaces and is marked by a change in outcrop appearance from a blocky one of the alkaline granite to a rubblely one of the mesocratic syenite.

		Continue south on Scituate Road.
26.1	0.85	Go straight
26.4	0.3	Right onto Fall Mill Road
26.8	0.4	Cross over river. Eliot Fm. occurs in river bed where it is cross cut by late mafic dikes.
26.95	0.15	At stop sign take right onto "Dead End" road.
27.1	0.2	At top of hill Eliot Fm exposed on right
27.25	0.15	Road to next stop is on right. Turn around and park on side of road. A mafic dike is exposed on east side of road. No stop now but a well exposed outcrop of alkaline granite is located farther on dead end road on east side.

Walk down dirt road. Go straight at the fork to bottom of hill. Turn left at bottom of hill. On the left between this corner and next fork, the contact between alkaline granite and Eliot Fm is located within small depression. No stop.

Take a sharp right at next fork. Go approximately 60 paces to the top of the hill. Outcrop is located in small riverbed slightly off the road to the left.

Stop 10: Several intrusive relationships are seen at this outcrop; 1) the contact of the western lobe of the alkaline granite with the Eliot Fm., 2) a basalt dike along the river bed, 3) remnants of a trachytic dike as a scab along the vertical walls of the riverbed, and 4) the informally named leopard rock.

The contact between the alkaline granite and the Kittery Fm is exposed twice as one walks downstream from the road. The orientation of this contact is N45W with a northward 40 to 60 dip. The orientation of the contact does not appear to be controlled by the orientation of the Eliot Fm. bedding (N2E 42S). The orientation of the contact measured here is similar to a contact measurement obtained on the western end of Boulter Pond. The geometry of the contact with the country rock has not been observed elsewhere along the perimeter of the complex.

Along both contacts of the alkaline granite and Eliot Fm. there is an approximately 1 meter wide zone in which the 'leopard rock' occurs. This rock is comprised of subrounded to rounded dark gray, clinopyroxene-rich mafic clasts or blobs (MAG 125CP, Table 2) contained within the alkaline granite. Two possible explanations for the origin of this rock are: 1) Time separated, multiple intrusion along zones of weakness, 2) Intrusion of two coexisting magmas along the same zone resulting in magma mixing. The composition of the mafic clasts is similar to that of a clinopyroxene-bearing dike that intrudes the syenitic phase located on I-95. Based on cross cutting relationships, that dike is older than the alkaline granite but younger than or coeval with the syenite. The interpretation of the mafic clasts as an earlier phase (hypothesis 1) at this locality is supported by their hornfelsic texture and absence of quench textures expected when mafic and felsic magmas intermingle. This texture is atypical of that expected from quenching and suggests that the mafic phase had cooled prior to the intrusion of the alkaline granite. Please use your discretion when sampling this rock!

This was last stop. Those who are in their own vehicles, and do not need to return to the rest area, retrace route to I-95 and go north to continue to Farmington. Those needing to return to rest area retrace route and cross over I-95 to Rt 1. Go south on Rt 1 for 6.2 miles. Take right onto access road for rest area. Will need to get to adjoining parking lot by going through small gate (with "Do Not Enter" sign) and turning left. Return to I-95 north to proceed to Farmington. Gas stations are available on Rt 1 south just past first set of lights.

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