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THE ASSOCIATION HYPERSOLVUS GRANITE — SUBSOLVUS GRANITE — "SOLVSBERGITE" AT ANDREW'S POINT, CAPE ANN, MASSACHUSETTS: A CASE OF LOCALIZED FENITIZATION

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ABSTRACT. The cogenetic dike rocks that cut the late Ordovician Cape Ann non-orogenic plutonic complex provide valuable insight into the final stages of emplacement of this rift-related suite of igneous rocks. At Andrew's Point, one such tabular body, called a sölvsbergite by H. S. Washington, is a fault-controlled zone of fenitization that cuts across hypersolvus and younger subsolvus granites. Metasomatism of crushed granite by peralkaline fluids is manifested by efficient desilication, alkali exchange, and precipitation of aegirine, riebeckite, and unusually well-ordered microcline + albite. These peralkaline fluids, which may have interacted with all rock units exposed, appear to have been released upon crystallization of subjacent batches of wet peralkaline melts, possibly of the type that gave rise to subsolvus granites, aplites, and pegmatites in the area.

INTRODUCTION

A long list of impressive petrographical, mineralogical, and geochemical investigations have made the late Ordovician Cape Ann plutonic series (Bell and Dennen, 1972) of northeastern Massachusetts one of the most studied igneous complexes in North America. Understandably, these studies have focused on major intrusive units and their interrelationships, at the expense of the more restricted suite of dike rocks. The main purpose of this note is to draw attention to the association of felsic plutonic rocks found at Andrew's Point, on the northeastern tip of Cape Ann, and to comment on the emplacement of one prominent dike there. This mesocratic dike, numbered 184a by Shaler (1889), is here reinterpreted as a product of replacement of granite along a fracture. The mineral assemblages found in the dike are those commonly developed in metasomatic aureoles surrounding alkaline complexes and carbonatites. That they are developed locally in the Cape Ann pluton should perhaps not be too surprising in view of the mildly alkaline character of this complex.

THE HOST ROCKS

The Cape Ann plutonic series, of late Ordovician age (Zartman and Marvin, 1971), consists of nearly contemporaneous gabbro, syenite, and granite that define a bimodal distribution of rock types, characteristic of non-orogenic suites (Martin and Piwinskii, 1972). The rocks are mildly alkaline, as recognized by Washington (1898a): alkali gabbros, type-locality essexites, and diorites which also contain titaniferous clinopyroxenes. The predominant felsic members of the association typically contain mafic minerals rich in alkalis, divalent iron, or both; lime content is low, and magnesium very low, as in quartz-bearing members of non-orogenic suites elsewhere (Martin and Piwinskii, 1972; Bowden, 1974, p. 115). Pirsson and Washington (1906, p. 514) grouped the Cape Ann plutonic series with the alkaline suites of the White Mountains, New Hampshire under the heading "Novanglian petrographic province". Though indeed very similar, these two series are now known to reflect two distinct periods of rift-related magmatism in the northern Appalachians.

The superb coastal exposures have led to detailed descriptions of textural variants and their mutual intrusive relationships. They have also afforded valuable insight into the intricate chain of events attending the cooling of a typical non-orogenic plutonic suite. At Andrew's Point, the predominant Cape Ann greenish-gray hypersolvus granite (compare, Tuttle and Bowen, 1958) contains large rafts of "nordmarkitic" granite (Warren and McKinstry, 1924, pl. II), that locally had been cut by basic dikes. The medium- to coarse-grained Cape Ann granite and its compound inclusions are cut by fine-grained subsolvus granites and associated pegmatites and aplites. Warren and McKinstry (1924, p. 320) proposed that this late fine-grained granite in turn grades into a syenitic facies that is itself cut by basic dikes, now dismembered by movement of the partially solidified host rock. Bonin and Martin (1974) suggested that the basic dikes may have induced fusion and remobilization of the earlier nordmarkitic granite. Both fine-grained host and broken-up portions of the basic dike are cut by a 1.5 m wide dike of coarse hypersolvus granite of Cape Ann type.

"SÖLVSBERGITE" DIKE 184a

One of the dikes on Andrew's Point, number 184a of Shaler (1889), particularly attracted H. D. Washington's attention. As a result of his methodical description of texture, mineralogy, and bulk composition, Washington (1898b) identified the dike rock as sölvsbergite, quite similar to the type-area sölvsbergite he had sampled in 1897 near Christiania, in the Permian rift-related epizonal suites of the Oslo graben. He concluded: "There can be absolutely no doubt that it is a true dike of igneous origin" (Washington, 1898b, p. 176). Shaler (1889, p. 610) also favored an igneous origin, on the basis of "crystals that look like porphyritic feldspars". Reexamination of the dike suggests that the issue is not so clear.

Dike 184a, averaging 1.2 m in width, cuts across the Cape Ann granite and its nordmarkitic inclusions. Shaler (1889) also mapped a narrower extension of this dike southeastward, where it cuts across the late fine-grained granite (Warren and McKinstry, 1924, pl. II). The emplacement of the dike thus may have been the latest event recorded at Andrew's Point.

The near-vertical walls of the dike constitute a sharp, essentially planar interface between a bluish-gray, fine-grained, compact dike rock devoid of phenocrysts and the yellowish Cape Ann hypersolvus granite. Washington (1898b) refers to a slight coarsening in grain size toward the center, but this is barely noticeable in the field. There are no signs of a chilled margin in the dike nor of contact effects in the host granite. However, at the margins, the dike rock does exhibit a schistosity parallel to its walls (Shaler, 1889, p. 610; Washington, 1898b, p. 176). The rock there is best described as streaky, with alternating light and dark layers parallel to the contact. The streaks even follow the contact in and out of the rare reentrants (pl. 1). The reentrant tapers off as a 6 cm long wedge of coarse-grained, strained, gray quartz. Parallel quartz lenses also occur isolated in the host rock near the reentrant.

In areas of slightly coarser grain size, the light-colored streaks are seen to contain the same minerals as the medium-grained host rock but as distinctly attenuated grains. Plate 1 also shows what Shaler took to be feldspar phenocrysts. These are yellowish perthite grains apparently detached from the host rock. All gradations can be found between such single-crystal inclusions and long, narrow, schistose inclusions 3 cm across (pl. 2). In addition, an 8 cm wide septum of unfoliated granite parallels one wall. The smaller schistose inclusions define an imbricate structure (pl. 2), with the streaks wrapping around the inclusions in a manner suggestive of a flowing medium.

Sampling was designed to test a working hypothesis that evolved during field work, that the mesocratic dike rock had caused partial melting and had been contaminated by assimilation of the Cape Ann granite near the dike walls. This hypothesis rested on (1) the presence of isolated feldspar crystals similar to those of the host rock, (2) aligned inclusions of deformed hypersolvus granite, and (3) light and dark streaks, rich in the light and dark minerals of the host rock.

PETROGRAPHY AND COMPOSITION OF DIKE 184a, HOST ROCK, AND INCLUSIONS

Two km away from Andrew's Point, in the Pigeon Hill quarry, the Cape Ann granite is purplish to greenish gray, medium-grained, and massive-looking. In thin section, however, the rock shows clear signs of post-crystallization deformation, as recognized by Shaler (1889, p. 605) and Washington (1898a, p. 790) for this unit as a whole. Quartz grains are strained, and their boundaries sutured. The equant mesoperthite grains consist of a relatively fresh, grid-twinned microcline host and exsolved albite lamellae. These perthite grains are generally rimmed by a late, probably post-magmatic albite; there is no evidence of migration of the exsolved albite to this intergranular position, such that the rock clearly is of hypersolvus type (Tuttle and Bowen, 1958). The accessory minerals ferrohastingsite, fluorite, magnetite, and zircon are typically clustered and partially mantled by undeformed annite. Both annite and fluorite also occur within perthite grains, postdating the appearance of exsolution lamellae. At Andrew's Point, the rock is texturally and mineralogically very similar to the Pigeon Hill example, except that it has a light tan color due to the occurrence of brown films that decorate tiny fractures and feldspar cleavages throughout the rock. These films are presumably iron oxide coatings linked to the deuteric release of iron

PLATE 1

Detail of reentrant along an otherwise planar contact between fine-grained dike rock and Cape Ann hypersolvus granite. Note the streaks that follow the contact and a wedge of strained quartz that forms the prolongation of the reentrant. Lower edge of ruler has major divisions in centimeters.

PLATE 2

Detail of contact between fine-grained dike rock and Cape Ann hypersolvus granite, showing imbricate nature of gneissose inclusions in dike rock. Note that streaks wrap around the inclusions in a way suggestive of a flowing medium.

during subsolidus oxidation of the ferrous-iron-rich mafic assemblage (Mackin, 1968).

Two analyses are presented of the Cape Ann hypersolvus granite (table 1, IE1 and BMS-91). Though there are minor differences between the two analyses, both conform to the characteristics of felsic members of silica-oversaturated non-orogenic suites. In particular, both rocks contain magnesium as a trace constituent and have relatively high values of (Na_2O + K_2O)/CaO and (Na_2O + K_2O)/Al_2O_3. The appearance of a small amount of normative corundum in rock IE1 may not be a characteristic of the melt from which this rock crystallized.

The fine-grained granites and associated fayalite- and annite-bearing pegmatite bodies that intrude the Cape Ann hypersolvus granite at Andrew's Point are commonly of subsolvus type (Tuttle and Bowen, 1958), in that essentially non-perthitic, untwinned microcline and albite coexist as separate grains. Some of these rocks also show evidence of a "trans-solvus" mineralogy (Bonin and Martin, 1974), that is, the presence of coarse mesoperthite grains in a matrix that has subsolvus character. Interestingly, the mesoperthites and coarse quartz grains in trans-solvus

TABLE 1

Composition of dike rock, inclusions, and host granites

Specimen*	IE 1	BMS-91	3567	IE 8	IE 4	IE 9	IE 10	IE 11	HWS
SiO_2	72.97	74.04	73.13	71.72	69.81	63.38	63.18	63.39	64.28
TiO_2	0.10	0.17	0.06	0.18	0.27	0.15	0.15	0.15	0.50
Al_2O_3	14.22	13.17	14.38	14.62	14.64	17.31	17.74	17.33	15.97
Fe_2O_3	0.28	0.72	1.09	1.24	0.92	2.43	2.19	2.73	2.91
FeO	1.29	2.14	0.44	1.46	1.72	3.08	3.16	2.90	3.18
MnO	0.032	0.06	0.021	0.044	0.063	0.120	0.128	0.132	tr
MgO	0.11	0.03	0.00	0.00	0.15	0.00	0.00	0.00	0.03
CaO	0.36	0.58	0.27	0.57	0.57	0.62	0.78	0.66	0.85
Na_2O	4.70	4.14	4.27	3.78	5.81	7.87	7.84	7.29	7.28
K_2O	4.96	4.95	5.36	5.90	5.42	4.46	4.18	4.53	5.07
BaO	—	0.02	—	—	—	—	—	—	0.00
P_2O_5	0.00	—	0.01	0.00	0.00	0.00	0.04	0.02	0.08
H_2O^+	0.51	—	0.45	0.22	0.25	0.22	0.29	0.40	0.20
H_2O^-	0.25	—	0.35	0.11	0.20	0.32	0.32	0.21	—
CO_2	0.007	—	0.003	0.000	0.002	0.000	0.006	0.004	—
F	0.424	—	0.319	0.340	0.421	0.276	0.225	0.684	—
$O\equiv F$	0.178		0.134	0.143	0.177	0.116	0.095	0.287	
Total	100.04	100.02	100.02	100.04	100.07	100.12	100.13	100.14	100.35

*IE 1 Cape Ann hypersolvus granite, Pigeon Hill quarry, Cape Ann, Mass. All IE samples analyzed by a combination of XRF and classical techniques by S. Horsky, McGill Univ.

BMS-91 Cape Ann hypersolvus granite, Andrew's Point, analyzed by XRF and emission spectrographic techniques by B. M. Survant and H. A. Norton, Jr., University of Kentucky.

3567 average of four subsolvus and trans-solvus granites, (IE 3, 5, 6, 7), Andrew's Point.

IE 4 inclusion of deformed, mildly fenitized Cape Ann hypersolvus granite in dike 184a.

IE 8 inclusion of deformed Cape Ann hypersolvus granite in dike 184a, Andrew's Point.

IE 9, 11 "streaky" fenite, dike 184a, Andrew's Point.

IE 10 homogeneous fenite, dike 184a, Andrew's Point.

HSW Dike rock 184a, labeled sölvsbergite by the analyst, H. S. Washington (1898b, p. 178).

rocks are strained, whereas the finer-grained "matrix" minerals appear unstrained.

An average of four analyses of subsolvus and trans-solvus granites is included in table 1. Compositionally, these rocks resemble the hypersolvus granites in all respects. Possibly significant are the higher Fe^{3+}/Fe^{2+} ratio, higher aluminum and potassium contents, and even lower magnesium and calcium contents.

One of the inclusions in the dike rock, IE8, resembles the host rock in general appearance. However, it is strongly deformed and gneissose; the primary quartz and perthite grains are strained and recrystallized along discrete planes that give the inclusion its gneissose appearance. The grid-twinned K-feldspar grains seem to contain few of the albite exsolution lamellae seen in the less deformed host granite; only a few wispy films of albite remain. The planar zones of recrystallization contain unstrained fine-grained quartz, with grain boundaries commonly defining 120° triple junctions; also present in these zones are fine-grained albite, K-feldspar, aegirine, riebeckite, fluorite, and zircon. This recrystallization has not been isochemical; an analysis of IE8 (table 1) shows that the deformed granite has been somewhat depleted in SiO_2 and Na_2O and has been oxidized slightly, with respect to the starting material. The enrichment in K_2O and Al_2O_3 reflects the appearance of newly-formed K-feldspar, presumably at the expense of quartz.

Another inclusion, IE4, is also a deformed piece of yellowish hypersolvus granite but shows clearer signs of cataclasis than IE8: the original quartz grains are granulated at their margins, and K-feldspar grains are bent and cracked, with tension gashes cutting across perthitic exsolution lamellae; each gash is filled with quartz, originally a single crystal but commonly also strained. The albite lamellae appear to have expanded and to have coalesced locally, leaving areas of grid-twinned K-feldspar grains free of albite lamellae. Intergranular fine-grained, rarely twinned albite and K-feldspar replace preexisting perthite. These parallel fine-grained zones that give the rock its gneissose character also contain aggregates of riebeckite that poikilitically enclose fine-grained albite and K-feldspar; these aggregates are mantled by stubby prisms of aegirine in association with fluorite and zircon. Locally, some riebeckite seems to replace aegirine and is itself replaced by a wispy fibrous yellowish amphibole, ferro-anthophyllite.

The composition of IE4 (table 1) shows that Si has been depleted further, with reference to deformed inclusion IE8, and that both Na and K have been added to the Cape Ann granite. The resultant rock plots in an intermediate position between Cape Ann granite and the mesocratic dike rock in the triangular diagram Ab–Or–Q (fig. 1). The changes have clearly been subsolidus, postdating the development of the coarse perthitic lamellae in the granite.

The bluish, fine-grained material that makes up the dike rock predominates in the three other analyzed rocks (IE9, 10, 11, table 1). Even

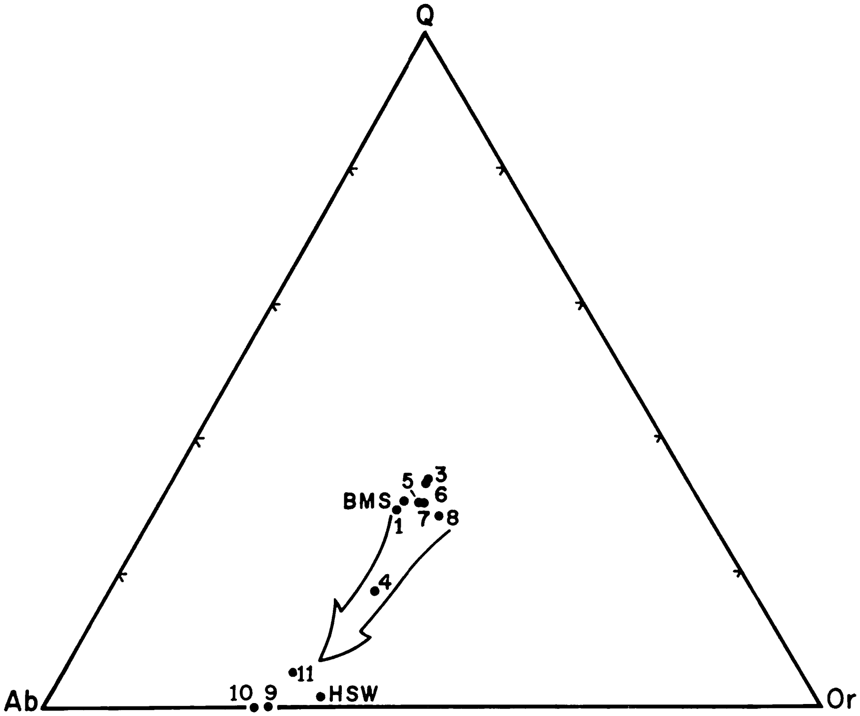

Fig. 1. Compositions of hypersolvus granites and associated trans-solvus and subsolvus granites (the host rocks) of deformed mildly fenitized inclusions and of the fine-grained fenite forming the bulk of the dike rock, as expressed by the three major normative components $NaAlSi_3O_8$(Ab), $KAlSi_3O_8$(Or), and SiO_2(Q). Sample numbers as defined in table 1. Arrow emphasizes the major trend of desilication and increase in total alkalis and in Na/K ratio.

in these, however, it is possible to see fine light-colored streaks made of relict host-rock minerals. The fine-grained assemblage consists of twinned albite, largely untwinned K-feldspar, aegirine, riebeckite, fluorite and rutile. Quartz is absent. A brown stain locally decorates cleavages and cracks in and around all grains. As the stain increases in intensity near the mafic minerals, its origin must be related to oxidation and leaching of these minerals, as in rock IE1. Both riebeckite and aegirine crystallize in clusters later than the feldspars, but interrelationships between the two mafic minerals are not consistent.

All three samples of dike material and the specimen analyzed by Washington (1898b; labelled HSW in table 1) have a syenitic bulk composition. Compared to the host granite, the dike is depleted in SiO_2 and MgO and enriched in total iron, ferric iron, manganese, sodium, and aluminum. Among minor elements, rubidium and lead have increased by a factor of 2, and zinc by a factor of 4. Strontium in the dike is only half what it is in the Cape Ann granite (13 ppm). In the triangular diagram Ab–Or–Q (fig. 1), these points reach the join Ab–Or.

TABLE 2

Cell parameters of alkali feldspars of dike rock, inclusions, and host granites, Andrew's Point

	a (Å)	b (Å)	c (Å)	α	β	γ	V (Å^3)	α^*	γ^*	st. error # of lines
IE 1	* 8.1387	12.7867	7.1600	94°17.0′	116°39.0′	87°42.6′	664.09	86°21.4′	90°24.9′	0.015
	14	20	16	2.0	1.1	1.1	.18	1.9	0.8	21
	8.5766	12.9638	7.2213	90°35.5′	115°55.3′	87°43.8′	721.53	90°26.7′	92°14.2′	0.024
	47	32	22	2.2	2.8	1.6	.39	2.2	1.5	23
IE 3	8.1403	12.7811	7.1592	94°15.3′	116°36.1′	87°41.4′	664.16	86°23.8′	90°27.3′	0.024
	18	35	22	2.0	1.3	1.2	.22	1.9	1.1	32
	8.5777	12.9598	7.2223	90°41.4′	115°57.3′	87°39.4′	721.27	90°22.3′	92°16.2′	0.017
	26	22	16	1.3	1.2	1.5	.22	1.4	1.5	28
IE 4	* 8.1360	12.7849	7.1593	94°17.1′	116°36.5′	87°40.3′	663.95	86°22.4′	90°27.7′	0.009
	6	11	6	0.6	0.4	0.4	.07	0.6	0.4	35
	8.5816	12.9627	7.2219	90°38.2′	115°59.1′	87°39.9′	721.54	90°25.8′	92°17.2′	0.008
	15	11	8	0.8	0.9	0.6	.13	0.8	0.6	22
IE 6	8.1387	12.7971	7.1600	94°17.9′	116°38.6′	87°41.2′	664.64	86°21.0′	90°26.1′	0.016
	14	27	15	1.5	1.1	1.1	.17	1.4	1.0	25
	8.5871	12.9662	7.2197	90°36.5′	115°57.9′	87°42.3′	722.11	90°26.4′	92°15.4′	0.018
	38	27	24	1.5	1.8	1.5	.31	1.4	1.3	23
IE 7	8.1389	12.7891	7.1603	94°20.5′	116°39.9′	87°42.1′	664.12	86°17.6′	90°23.6′	0.014
	13	29	13	1.4	1.0	1.0	.16	1.4	0.9	23
	8.5859	12.9659	7.2199	90°37.6′	115°55.5′	87°39.4′	722.23	90°26.6′	92°18.1′	0.015
	23	17	13	1.1	1.0	1.0	.18	1.0	0.9	32
IE 9	** 8.1370	12.7901	7.1633	94°20.9′	116°33.3′	87°36.5′	664.92	86°20.0′	90°30.3′	0.021
	16	36	19	2.3	1.2	1.2	.22	2.4	1.3	26
	8.5821	12.9661	7.2212	90°40.6′	115°52.0′	87°34.6′	722.38	90°25.4′	92°22.0′	0.016
	21	22	24	3.1	1.7	1.6	.29	2.9	1.3	15
IE 10	** 8.1367	12.7830	7.1583	94°18.4′	116°37.2′	87°42.1′	663.72	86°20.0′	90°24.9′	0.017
	15	26	16	1.6	1.2	1.2	.20	1.6	1.1	27
	8.5889	12.9622	7.2128	90°37.8′	115°49.9′	87°36.3′	722.11	90°27.6′	92°21.4′	0.027
	43	54	48	4.3	3.5	2.6	.55	4.5	2.9	15
IE 11	8.1360	12.7871	7.1600	94°18.0′	116°37.7′	87°38.3′	663.99	86°22.4′	90°29.3′	0.008
	7	14	8	0.8	0.5	0.5	.09	0.8	0.5	26
	8.5853	12.9638	7.2234	90°37.7′	115°57.8′	87°38.2′	722.17	90°27.1′	92°19.3′	0.016
	23	18	13	1.1	1.1	0.9	.18	1.0	0.8	32

* Albite > microcline, on basis of intensities of 201 reflections

** Albite >> microcline, on basis of intensities of 201 reflections

IE 11: Feldspars from an attenuated inclusion of deformed hypersolvus granite in the specimen IE 11 described in table 1. IE 1, 3, 4, 6, 7, 9, 10, 11 as defined in table 1.

The trend of progressive desilication manifested in figure 1, culminating in saturated compositions, the textural evidence for subsolidus replacement of relict host-rock feldspars, and the precipitation of a fine-grained assemblage rich in alkalis and ferric iron, suggest strongly that the changes documented here are metasomatic, identical to those expected during fenitization of host rocks around alkaline or carbonatitic complexes.

FELDSPAR MINERALOGY OF DIKE 184a, HOST ROCK, AND INCLUSIONS

Washington's interpretation that the dike was truly igneous rested not only on textural grounds but also on a mineralogical indicator. Anorthoclase was identified by Washington (1898b, p. 177) on the basis of a "moiré" or cross-hatched appearance but apparently without a thorough check of optical properties. Confirmation of the occurrence of anorthoclase in the dike and characterization of alkali feldspars in the host rock and schistose inclusions were attempted in a study of unit cell parameters. These cell constants were obtained by least-squares refinement of indexed 2θ reflections (Appleman and Evans, 1973). Hand-picked crystals, or, in the case of the fine-grained dike, pulverized whole rock were mixed with a synthetic spinel standard ($a = 8.0388$ Å at room temperature), and photographed with a Guinier-Hägg camera using Cu $K\alpha_1$ radiation ($\lambda = 1.54050$ Å). Cell constants are presented in table 2, and calculated indices of composition and degree of order are presented in table 3.

The cell dimensions show that all K-feldspars in the collection, including those of the dike rock, are very well-ordered, essentially pure microclines (table 3). In fact, the indicators of proportion of Al in the

TABLE 3

Composition and degree of order of alkali feldspars from dike rock, inclusions, and host granites, Andrew's Point

	Na-Feldspar				K-feldspar			
	N_{Or}*	t_1O	t_1m	$t_2O + t_2m$	N_{Or}	t_1O	t_1m	$t_2O + t_2m$
IE 1	0.014	0.985	0.004	0.011	0.959	0.987	0.010	0.003
(hypersolvus)	—0.019				0.959			
IE 3	—0.002	0.993	0.002	0.005	0.922	1.012	—0.001	—0.011
(subsolvus)	—0.018				0.951			
IE 4	0.008	0.994	—0.006	0.012	0.971	1.005	—0.003	—0.002
(inclusion)	—0.021				0.959			
IE 6	—0.005	0.980	—0.012	0.032	0.941	0.985	—0.005	0.020
(subsolvus)	—0.013				0.976			
IE 7	—0.005	0.985	0.001	0.014	0.938	0.998	—0.016	0.018
(subsolvus)	—0.019				0.979			
IE 9	—0.008	1.015	—0.014	—0.001	0.931	1.022	—0.032	0.010
(dike rock)	—0.009				0.984			
IE 10	—0.009	0.986	0.000	0.014	0.944	0.991	—0.048	0.057
(dike rock)	—0.024				0.976			
IE 11	0.008	1.000	—0.012	0.012	0.980	1.016	—0.006	—0.010
(inclusion)	—0.021				0.978			

* The first value of N_{Or} is calculated using an expression involving a and $t_1O + t_1m$ ($= \Delta$ (bc)), from Martin (1974, p. 348). The second estimate of N_{Or} is based on unit cell volume (Stewart and Wright, 1974, p. 364).

T_1O + T_1m sites, and of Al in the T_1O site, as calculated by the formulation of W. C. Luth (*in* Stewart and Wright, 1974, p. 361) exceed their theoretical limits in certain cases. Fully ordered microcline should have $T_1O = 1.00$, $T_1m = T_2O = T_2m = O$, and, according to Stewart and Wright (1974), the following cell parameters: a = 8.597 Å, b = 12.964 Å, c = 7.222 Å, α^* = 90°25.14′, γ^* = 92°16.02′. Microcline in the host rock IE1 is unique among the microclines described in table 2 in having α^* less than the proposed value. Four of the microclines in which γ suggests more perfect long-range order than in IE1 even give t_1O occupancies greater than 1.00 and correspondingly negative values of t_1m, t_2O, and t_2m. Only one albite, from the dike rock, has a calculated t_1O value exceeding 1.00 (table 3), but a number of them have γ^* in excess of 90°26.94′, suggested as typical of fully-ordered albite by Stewart and Wright (1974). It is unlikely that these aberrations from the norm are due to incorporation of a foreign cation in both sodic and potassic feldspars. Rather, the alkali feldspars appear unusually well-ordered because of the catalytic role of peralkaline fluids in the ordering process (Martin, 1973). Occurrences of similar albites and microclines seem restricted to fenites (Siemiatkowska and Martin, 1975), where the importance of peralkaline fluids is undeniable. The revised coordinates proposed for ordered albite and microcline by Stewart and Wright (1974) might have to be revised again to take into account these examples of the most-ordered alkali feldspars known.

Compositional estimates presented in table 3 suggest that all eight rocks considered contain pure albite and nearly pure microcline. Negative values of N_{Or} obtained for the albites again suggest that existing expressions used to derive N_{Or} from a or V are based on series that may contain albites that are less pure.

SÖLVSBERGITE OR FENITIZED GRANITE?

The occurrence of well-ordered, non-perthitic, rarely twinned microcline in the "sölvsbergite" dike suggests that its precipitation may in fact have occurred below the monoclinic-triclinic inversion. Coexistence with high-purity, very well-ordered albite and with a sodic mafic mineral assemblage further confirms the low temperature of equilibrium. The overall concordance of structural states and compositions of feldspars in host rock, associated subsolvus granites, pegmatites, dike rock, and its suite of gneissose inclusions, taken in conjunction with reports of microcline elsewhere in the pluton (Warren and McKinstry, 1924; Toulmin, 1960; Zartman and Marvin, 1971; Norton, ms) suggests that the whole area equilibrated with the same alkaline fluids. Both composition and structural state of coexisting feldspars in the dike rock are totally inconsistent with the occurrence of anorthoclase reported by Washington.

What appears convincingly in the field as a dike rock, apparently contaminated by granite near its margins, contains a mineral assemblage that developed at the expense of preexisting deformed Cape Ann granite. The cross-cutting tabular body must represent a fault zone; metasomatism, caused by a peralkaline fluid phase, transformed the cataclastic crushed zone into a dark, massive, fine-grained rock of overall syenitic composition. The process involved efficient removal of Si, and to lesser extents, K, Ca, Ti and Al; iron and sodium have clearly been added, as reflected by the appearance of aegirine, riebeckite, and the preponderance of albite over microcline (fig. 1). Metasomatic transformations of this type, referred to as *fenitization*, generally occur in an aureole surrounding carbonatitic or alkaline complexes. The paucity of CO_2 in the dike rocks (table 1) and the removal of calcium by the fluids suggest that the fluid phase in this area was not derived from a carbonatite but from the cooling Cape Ann plutonic complex.

Minor deformation followed the emplacement of the cooling plutonic complex, as evidenced by (1) widespread signs of minor grain-margin granulation apparent in thin section and (2) development of cataclastic zones. Advanced fenitization was localized in the zone of cataclasis, presumably because of greater permeability, greater surface area, and greater strain in the original minerals there. The same peralkaline fluids probably also affected rocks beyond the fault zones, adding fluorine (table 1), causing extensive ion-exchange and ordering in feldspars, and leading to incipient desilication and deposition of sodic pyroxene or amphibole. As a rule, replacement minerals are aligned but not deformed, so that fenitization reactions seem to have occurred mainly after the episode of adjustments due to emplacement. Minor movement did occur after fenitization, however; the dike seems to have been bent slightly about a near-vertical axis, explaining the reentrant in the dike wall (pl. 1) and its prolongation into a quartz wedge. This wedge and other en-échelon quartz stringers are interpreted in terms of open-space filling of late tension gashes formed during bending. Other examples are known in which the trend of desilication dominant during fenitization is reversed by a later and presumably even lower-temperature episode of rock-fluid interaction (for example, Van Zijl, 1962; Deans and others, 1972; Siemiatkowska and Martin, 1975).

The low-temperature of interaction of Cape Ann plutonic series rocks with an alkaline fluid phase derived largely from the cooling epizonal complex, as deduced from the direct coprecipitation of microcline and albite, is consistent with (1) the agreement of Rb–Sr whole rock age (435 ± 6 m.y.) and the zircon age (452 ± 10 m.y.) derived by lead isotopes, (2) the lack of any significant scatter in the isochron, and (3) an initial $^{87}Sr/^{86}Sr$ of 0.703 (Zartman and Marvin, 1971). These features contrast with possibly higher-temperature rock-fluid interaction in the nearby contemporary Quincy and Peabody granites, which have disturbed Rb–Sr systems and higher initial ratios. On the other hand, Zartman and Marvin (1971) document disturbances in the K–Ar system involving amphiboles and annite in the Cape Ann pluton, as reflected by a spread of K–Ar ages from 352 to 410 m.y. Although a mild reheating event caused by younger intrusive activity is considered by Zartman and Marvin

(1971, p. 950), an alternative proposal would attribute open-system behavior in the K–Ar system to the same peralkaline fluids that caused widespread excellent ordering of alkali feldspars and localized fenitization in fault zones. Micas and amphiboles in these non-orogenic suites may have lower-than-usual threshold temperatures due to their very ferriferous nature.

According to the accepted definition, *sölvsbergite* is a fine-grained, rarely porphyritic hypabyssal rock composed chiefly of sodic feldspar and a smaller amount of potassium feldspar, sodic pyroxene or amphibole, and little or no quartz. By definition, a fenite contains mostly alkali feldspar, with some aegirine, subordinate alkali-amphibole, and accessory sphene and apatite (Gary, McAfee, and Wolf, 1972). Despite mineralogical similarities, one rock is igneous, and the other metasomatic. The Andrew's Point "sölvsbergite", forcefully cited as an example of "a true dike of igneous origin" by Washington (1898b, p. 176), is here reinterpreted as a fault-controlled, dike-like body of fenitized Cape Ann granite. Future studies of the Cape Ann plutonic series will have to consider the true nature of sölvsbergite dikes elsewhere in the complex, for example where they cut syenite and diorite in the Salem quadrangle southwest of Cape Ann. Toulmin (1960; 1964, p. A50) has considered these "trachytic syenites" as truly igneous and has interpreted feldspar bulk compositions in terms of crystal-liquid equilibrium relationships. The major aim of these studies should be to evaluate the extent of major- and minor-element additions and subtractions and mineralogical adjustments that result from post-crystallization igneous rock-peralkaline fluid interactions. Well-integrated studies of these post-crystallization changes, for example of the behavior of potassium, strontium, lead, and oxygen isotopic systems, and of the distribution patterns of rare earths and other trace elements in these fenitized rocks, can be expected to outline the complete evolutionary history of this non-orogenic suite and to pinpoint the ultimate source of the fenitizing fluids. The most attractive hypothesis at present would have these fluids expelled during crystallization of subjacent batches of water-enriched granitic melts similar to those that gave rise to the suite of subsolvus granites, aplites, and pegmatites exposed at Andrew's Point.

Fenitization normally occurs in an aureole surrounding alkaline silicate complexes or carbonatitic intrusions. Some (compare, Gary, McAfee, and Wolf, 1972) would even consider that occurrences of fenitization imply nearby carbonatites, a restriction that has been criticized by Cooper, Gittins, and Tuttle (1975) and by Siemiatkowska and Martin (1975). This occurrence of fenitization further shows that such metasomatic transformations can also be expected in association with mildly alkaline silica-oversaturated suites. In these cases, fenitization is likely to be localized as at Andrew's Point, presumably because the supply of suitably peralkaline hydrothermal fluids was relatively short-lived. Furthermore, in these cases of localized fenitization, the resultant metasomatic rocks might more easily be mistaken for "a true dike of igneous origin" than where large-scale fenitization has provided rocks of gradational character.

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