Petrology and U-Pb geochronology of buried Avalonian plutonic rocks on southeastern Cape Cod

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Plutonic rocks have been intersected by two separate drill holes on southeastern Cape Cod. Hole CC2 is located at Chatham Harbor about 7 km south of the Nauset anomaly, an east-northeast-trending magnetic lineament that was considered to separate the distinct plutonic zones of Avalon terrane. This drill hole intersected weakly foliated, fairly homogeneous biotite granite. Zircons from this granite give a U-Pb age of 584+9/-8 Ma. Hole CC1 is located near North Eastham, about 12 km north of the Nauset anomaly. The drill core intersected foliated, sheared, biotite granodiorite and biotite-hornblende-clinopyroxene-quartz gabbro, metamorphosed to greenschist facies. The deformed and altered state of these rocks, as well as their geochemistry, suggest that their origin and possibly their ages are distinct from the granite in hole CC2. No datable zircons were obtained from rocks in CC1.

The age of 584 Ma for the CC2 granite sample is within the range of published ages for plutonic rocks of the Avalon terrane and confirms the suggestion of Hutchinson *et al.* (1988) that the southern plutonic zone is a part of the Avalon terrane. The data also indicate that the Nauset anomaly is not the Avalon-Meguma terrane boundary in this area.

Des roches plutoniques ont été recoupées par deux forages distincts dans le sud-est de Cape Cod. Le forage CC2 est situé à Chatam Harbor à environ 7 km au sud de l'anomalie de Nauset, un linéament magnétique d'orientation est-nord-est qui était considéré comme séparant les zones plutoniques distinctes du terrain d'Avalon. Ce forage a recoupé un granite à biotite faiblement folié et très homogène. Des zircons de ce granite donnent un âge U-Pb de 584 + 9/-8 Ma. Le forage CC1 est situé près de North Eastham, à environ 12 km au nord de l'anomalie de Nauset. Le sondage a recoupé de la granodiorite à biotite et du gabbro à biotite-hornblende-clinopyroxène-quartz foliés et cisaillés, métamorphisés au faciès des schistes verts. La nature déformée et altérée de ces roches, ainsi que leur géochimie, suggère que leur origine et possiblement leur âge soient distinct du granite du forage CC2. Aucun zircon datable ne fut obtenu des roches dans le CC1.

L'âge de 584 Ma pour l'échantillon de granite CC2 tombe dans l'intervalle des âges publiés pour les roches plutoniques du terrain d'Avalon et confirme la suggestion de Hutchinson *et al.* (1988) que la zone plutonique méridionale est une partie du terrain d'Avalon. Les données indiquent aussi que l'anomalie de Nauset n'est pas la frontière des terrains d'Avalon et de Méguma dans cette région.

[Traduit par la rédaction]

INTRODUCTION

In the fall of 1987, the United States Geological Survey (USGS), in collaboration with the Massachusetts Department of Environmental Management, Division of Water Resources, drilled two wells through nonlithified Pleistocene sediments into bedrock at North Eastham and Chatham, Cape Cod (Figs. 1, 2) (Leo and Phillips, 1989; Leo *et al.*, 1991). The purpose of the drilling was four-fold: (1) to collect a complete lithostratigraphic record of Quaternary and possibly Coastal Plain sediments; (2) to delineate potential aquifer zones that might contribute to public supply wells; (3) to assess the rock types and geochemistry of the bedrock; and (4) to attempt to obtain U-Pb zircon ages on the cores. The present paper deals with the last two objectives. The following descriptions of the geology of central Cape Cod are based largely on Wones and Goldsmith (1991). We discuss the petrological characteristics of igneous rocks intersected by the two drill holes, and report a U-Pb zircon age for a sample of granite from hole CC2.

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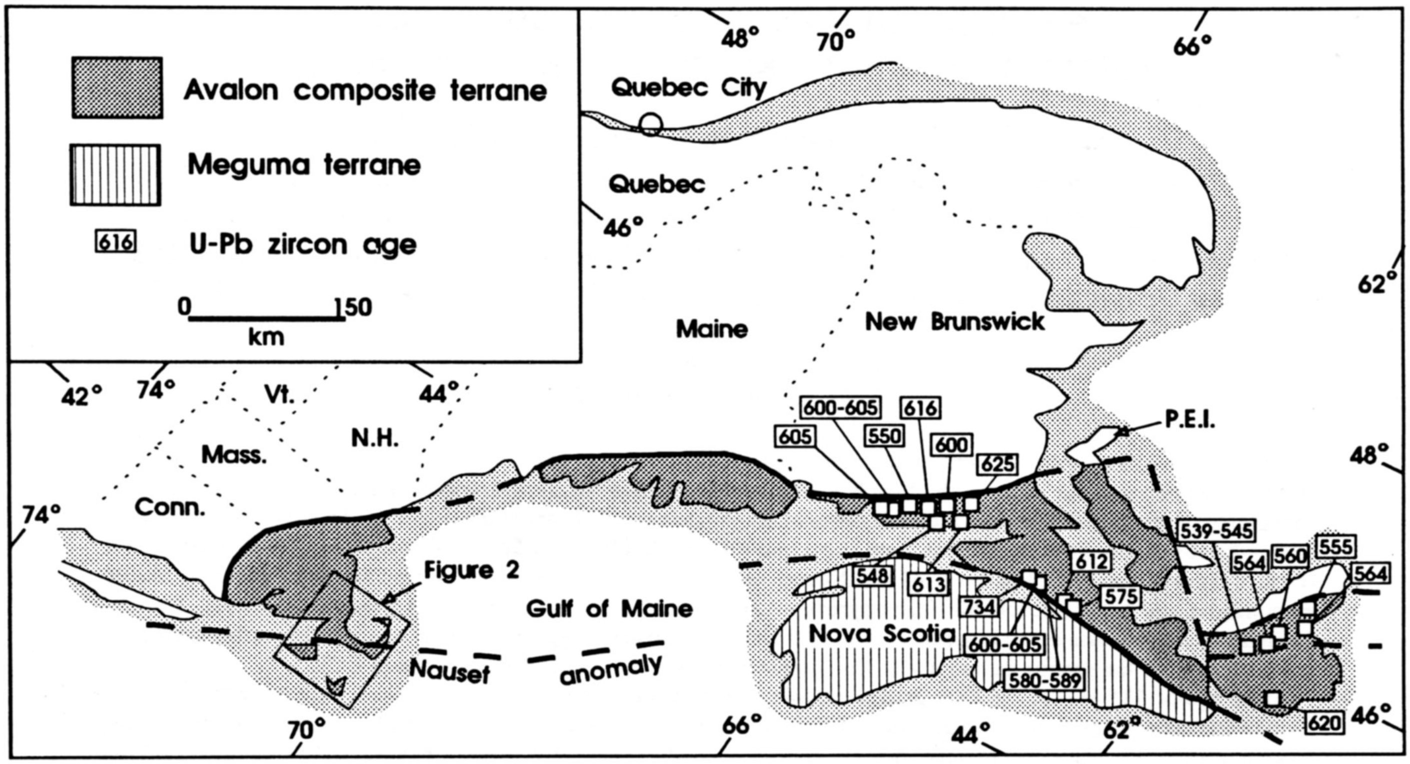


Fig. 1. Map of the northern Appalachians, showing known and inferred extent of the Avalon composite terrane (modified from Hutchinson *et al.*, 1988; Barr *et al.*, 1990; Keppie *et al.*, 1990). U-Pb zircon ages for Late Proterozoic and Cambrian volcanic and plutonic rocks in the Avalon terrane from Bevier and Barr (1989), Bevier *et al.* (1990), Barr *et al.* (1990), Dallmeyer *et al.* (1990), Sangster *et al.* (1990), and Doig *et al.* (1991).

Geology of Cape Cod

Cape Cod is covered entirely by Pleistocene glacial deposits, and the geology of underlying bedrock is known only from several deep drill holes. The westernmost outcrops near the Cape are exposed along a line running approximately from Rocky Point to Marion, Massachusetts (Fig. 2). The concealed crystalline bedrock of the Cape was designated as undivided granite, gneiss, and schist by Zen *et al.* (1983) and Wones and Goldsmith (1991, p. I27). K-Ar mineral ages have been reported (Zartman and Marvin, 1991) from granitoid rocks in several drill cores in the Harwick-Brewster area (Fig. 2). One such core, north of Brewster, gave K-Ar (biotite and hornblende) ages in the range of 566 to 348 Ma (Zartman and Marvin, 1991). These were considered to be minimum ages, and a Proterozoic Z (Avalonian) age was assumed for at least part of the basement under Cape Cod. Few petrologic or geochemical data are available for these scattered drill cores, and the significance of the isotopic ages obtained from them is uncertain.

New Drill Intersections of Crystalline Basement

Hole CC1 is located in a gravel pit on the northern outskirts of North Eastham, 300 m east of US Route 6, and north of Oak Leaf Road, about 20 km north from the center of Chatham village. Hole CC2 is located on Champlain Road at its intersection with State Harbor Road about 2 km south-southwest of the center of Chatham village (Fig. 2).

The northern hole (CC1) was drilled to a depth of 185 m and penetrated 35 m into crystalline basement. The southern hole (CC2) at Chatham Harbor was drilled to a depth of 123 m and penetrated 11 m into basement. Compositionally, the CC1 core ranges from gabbro to granodiorite or monzogranite (analyses 1-3, Tables 1, 2; Figs. 3, 4). The texture is mostly medium-grained and equigranular with a more or less well-preserved hypidiomorphic granular aspect, but locally it is blotchy and uneven with granite dikes and veins crosscutting gabbro (Fig. 3-1). The quartz gabbro (analysis 1, Table 1) contains plagioclase, hornblende, clinopyroxene, biotite, epidote, and about 6% magnetite. Plagioclase (30%) shows sharp albite twinning and moderate zoning. Compositions of representative grains determined by flat-stage optical methods yield An_{44}, $An_{25\text{-}40}$, and $An_{24\text{-}31}$. Metamorphic recrystallization is minimal to moderate, indicated by slight to extensive replacement by sericite and epidote. Large grains of green hornblende poikilitically enclose green-gray, non-pleochroic clinopyroxene. Olive-brown biotite and blebby, strongly strained quartz each constitute 2% of the quartz gabbro by volume. Titanite is an uncommon accessory. The quartz gabbro sample is mildly tectonized and locally intruded by

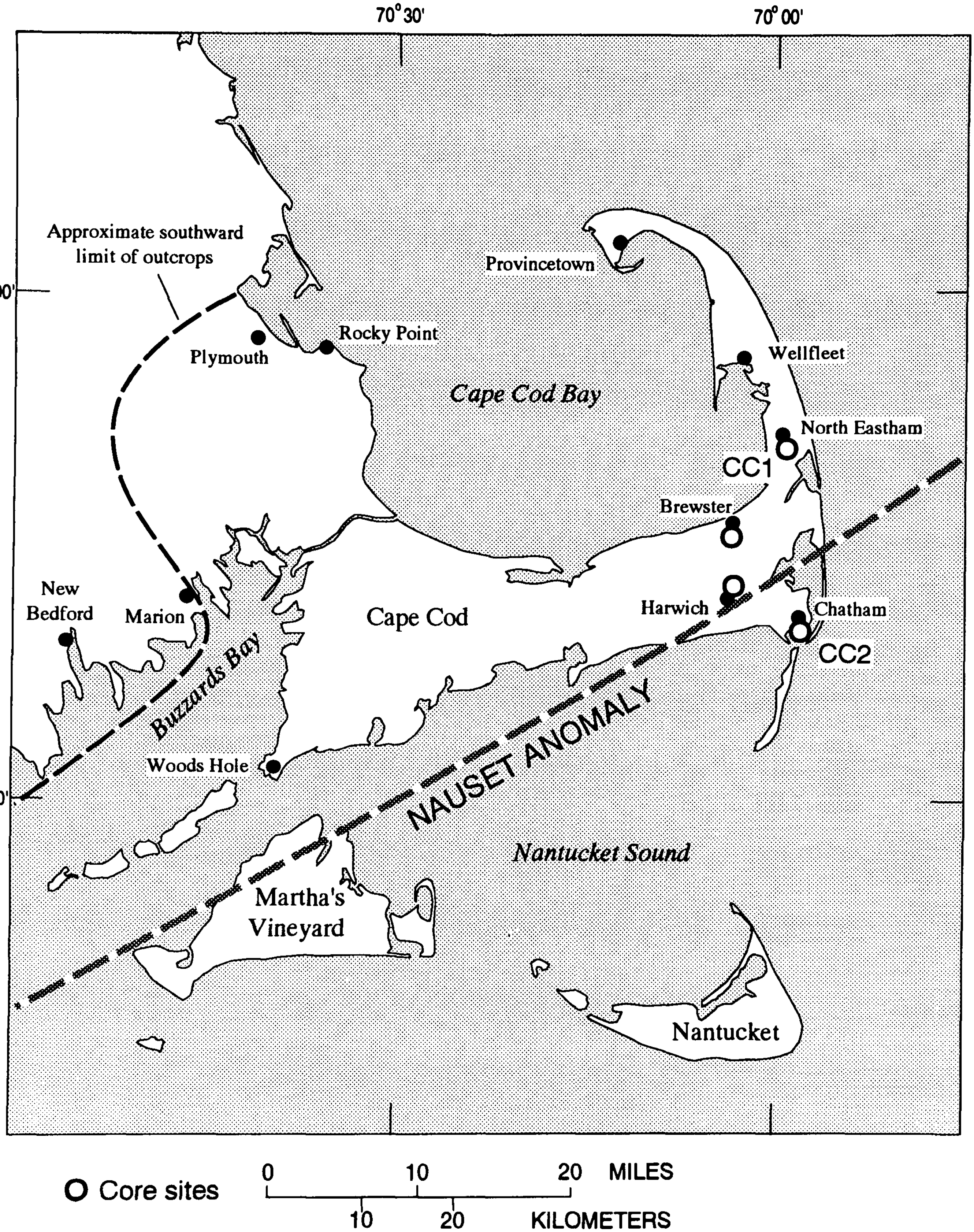


Fig. 2. Location map of Cape Cod (modified from Wones and Goldsmith, 1991, fig. 17), showing selected drill hole sites in crystalline basement rocks, some with K-Ar age determinations. Filled circles = towns; open circles = drill hole localities in the Harwich-Brewster area, as well as the North Eastham (CC1) and Chatham Harbor (CC2) localities.

Table 1. Modal analyses[1] of drill core samples, southeastern Cape Cod, Massachusetts.

	Core CC1, North Eastham, MA					Core CC2, Chatham Harbor, MA		
Sample No.	CC1-151	CC1-163	CC1-175	CC1-160	CC1-185	CC2-125	CC2-128	CC2-123
Analysis No.	1	2	3					4
Analysis Symbol	○	○	○					□
Quartz	10.2	19.4	21.7	25.9	9.0	30.9	40.7	25.9
Plagioclase	51.3	48.7	45.6	37.4	36.3	26.7	30.8	29.1
K-feldspar	–	8.2	18.7	29.2	–	37.4	25.4	42.0
Biotite	11.9	15.2	7.6	4.5	–	2.9	2.2	2.3
Hornblende	9.4	3.5	1.0	1.0	39.6	–	–	–
Clinopyroxene	6.7	tr	–	–	–	–	–	–
Magnetite	5.8	1.8	0.3	0.9	4.6	1.8	0.6	0.6
Apatite	1.2	0.6	tr	tr	0.2	tr	tr	tr
Titanite	tr	1.3	0.4	0.6	0.2	tr	0.2	0.3
Miscellaneous[2]	3.1*	1.1*	4.4**	0.3**	9.6**	–	tr***	0.1***
Total	99.6	99.8	99.7	99.8	99.5	99.7	99.9	100.3

[1]Modal values normalized to quartz+plagioclase+K-feldspar. Three-digit numbers in suffix of sample numbers indicate depths of core samples in meters. ○ and □ indicate chemically analysed samples of cores CC1 and CC2, respectively (see Table 2 and Figure 4).

[2]tr = trace; -- = absent; * = actinolite, epidote, chlorite, and saussurite, undivided; ** = mostly garnet; *** = garnet.

associated granitic rocks that may have differentiated from gabbro. Available data suggest a similarity with the Dedham Granite to the west (Wones and Goldsmith, 1991).

The monzogranite phase of the associated granitic rocks (analyses 2-3, Table 1) consists of plagioclase, quartz, potassium feldspar, green hornblende, olive-brown biotite, and 4 to 0.5% each of magnetite, titanite and apatite. These rocks reflect lower greenschist facies metamorphism.

The granite at Chatham Harbor (CC2) is fairly homogeneous, fine- to medium-grained pink granite with a weak foliation (Table 1). Microcline and stringy perthite are about equally abundant and together constitute about 25 to 40% (Fig. 3). The matrix consists of hypidiomorphic granular quartz and subordinate sodic plagioclase. Olive green biotite, magnetite, and titanite constitute 3 to 5%; rounded zircon grains are locally concentrated in biotite.

Textural and compositional comparison between the granite at Chatham Harbor and the granitic phase of the North Eastham cores suggest that the two granites are petrologically distinct.

GEOCHEMISTRY

Major- and trace-element analyses and CIPW normative mineralogy for four samples of core are shown in Table 2. The CC1 samples illustrate the compositional variations of this inhomogeneous rock, which ranges from gabbro to monzogranite. Inspection of the core suggests that bulk compositions in hole CC1 are variable from bottom to top, although the composition generally becomes more felsic at shallower depths. The single Chatham Harbor sample was considered large enough to characterize the relatively homogeneous rock, as well as the differences between it and the CC1 core.

A linear arrangement of analyzed CC1 samples (Fig. 4) could be interpreted as differentiation within the CC1 magma. No comparable trend is evident for CC2 samples. A clearer distinction between the quartz gabbro and monzogranite phases can be seen in trace element plots. Figure 5 shows Harker plots of relatively stable trace elements or ratios (e.g., Zr/Hf, Fig. 5-2) which typically yield linear relationships for a given group of related data points. Each plot shows a sublinear relationship through points CC1-151, CC1-163, and CC1-175. However, trace element abundances or ratios corresponding to CC2-123 (Chatham Harbor) have distinct values. In Figure 5-2, the three most felsic samples (CC1-163, CC1-175 and CC2-123) show comparable linear relationships, but the Zr/Hf value of CC1-151 is relatively high. Cr, Th and Ta (Fig. 5-3) have similar abundances for the three CC1 samples, but the Th content of the granite at Chatham Harbor is significantly higher than in the CC1 cores. The relative trace-element abundances are not distinctive in themselves, but they do suggest that the CC1 and CC2 samples represent separate magmas.

Rare-earth element (REE) patterns of the four samples (Fig. 6) all indicate moderate enrichment in light REE and moderate depletion in heavy REE with negligible to moderate Eu anomalies. Total REE abundances, contrary to expectations, are successively higher in the CC1 samples in inverse relation to SiO_2 content, whereas the granite at Chatham Harbor (CC2-123) has the highest total REE

Table 2. Chemical analyses[1] and CIPW normative mineralogy of samples from drill cores from southeastern Cape Cod, Massachusetts.

	Core CC1, North Eastham, MA			Core CC2, Chatham Harbor, MA
Sample No.	CC1-151	CC1-163	CC1-175	CC2-123
Analysis No.	1	2	3	4
Analysis Symbol	○	○	○	□
Oxides in percent				
SiO_2	50.40	63.50	69.70	73.40
TiO_2	1.84	0.68	0.37	0.29
Al_2O_3	16.20	16.00	14.20	13.40
Fe_2O_3	5.00	2.37	1.55	0.93
FeO	7.20	2.80	1.40	0.84
MnO	0.32	0.10	0.06	0.09
MgO	4.26	1.67	0.98	0.49
CaO	8.31	3.76	2.25	0.91
Na_2O	3.30	3.36	3.26	4.10
K_2O	1.25	4.09	4.18	4.36
P_2O_5	0.72	0.21	0.11	0.07
H_2O+	0.91	0.81	0.62	0.21
H_2O-	0.09	0.07	0.09	0.06
CO_2	0.23	0.08	0.11	0.11
Total	100.0	99.5	98.9	99.2
Ba	378	1790	1940	451
Th	5.02	5.85	5.78	20.40
U	1.74	1.56	1.28	2.60
Y	42.2	23.2	10.1	26.9
Zr	260	261	146	149
Hf	1.53	5.68	3.8	5.78
Ta	1.11	0.39	0.32	1.51
Co	25.10	9.09	5.51	1.39
Cr	6.30	6.10	5.80	2.30
Sc	37.8	12.8	7.0	5.1
La	27.0	22.0	22.4	36.9
Ce	60.7	40.8	37.9	68.9
Nd	32.0	20.2	13.9	27.6
Sm	7.58	4.25	2.51	6.07
Eu	1.77	1.44	0.83	0.78
Tb	1.04	0.57	0.36	1.03
Yb	3.10	1.61	1.04	3.37
Lu	0.47	0.27	0.16	0.49
CIPW Normative minerals				
%An	48	37	27	10
Q	4	17	28	30
or	7	24	25	26
an	26	16	10	35
c	0	0	0	0
di	9	1	0	0
hy	13	6	3	2
mt	7	3	2	1
il	3	1	1	1
ap	2	0	0	0

[1]Major elements were determined by XRF, with supplementary determinations of FeO, CO_2, and ± H_2O+. Analysts, J. Taggart, A. Bartel, and D. Siems. Rb, Sr, Ba, Y, Nb, and Zr were determined by energy-dispersive XRF; analyst, J.R. Evans. The remaining trace elements including REE were done by INAA, long count; analyst, J.S. Mee.

Fig. 3-1

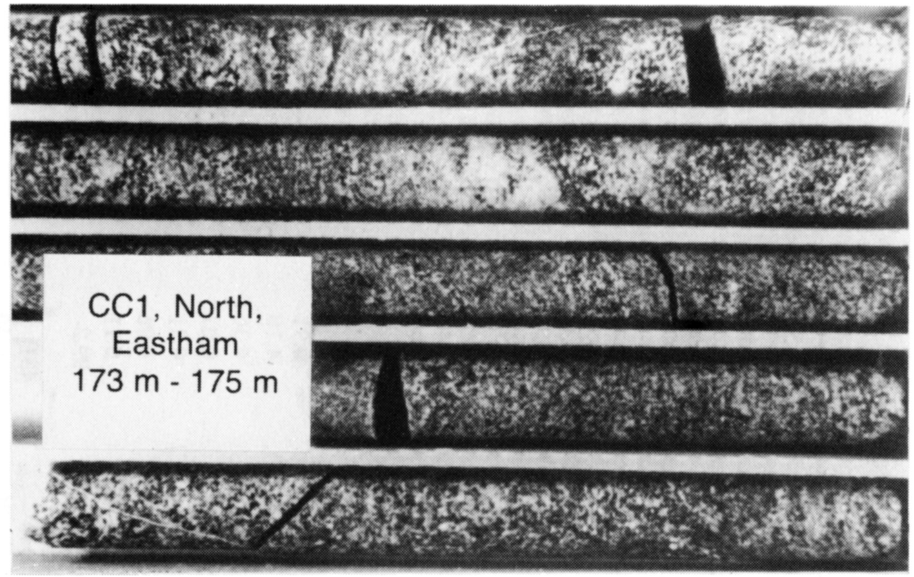


Fig. 3-3

Fig.3-2

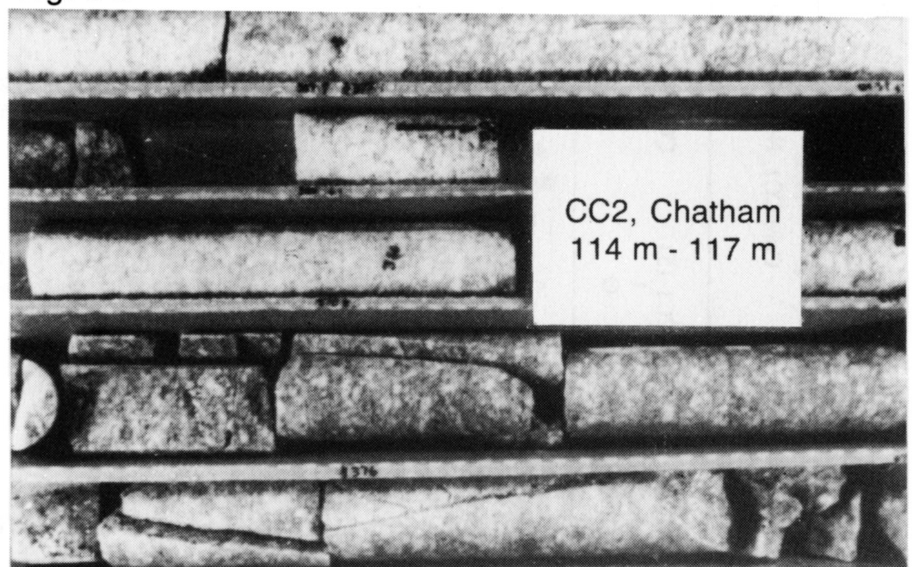


Fig. 3-4

Fig. 3. Selected drill cores from boreholes CC1 (North Eastham) and CC2 (Chatham Harbor). (3-1) Quartz gabbro approximates analysis 1, Table 2. Note felsic dike, and blotchy texture related to smaller cross-cutting granitoid veins and dikes. (3-2) Relatively homogeneous quartz diorite-granodiorite-monzogranite corresponding to analysis 2, Table 2. (3-3) Homogeneous, more felsic granitoid, approximately granodiorite (analysis 3, Table 1). (3-4) Granite at Chatham Harbor, homogeneous, porphyritic, slightly foliated granite (analysis 4, Table 2).

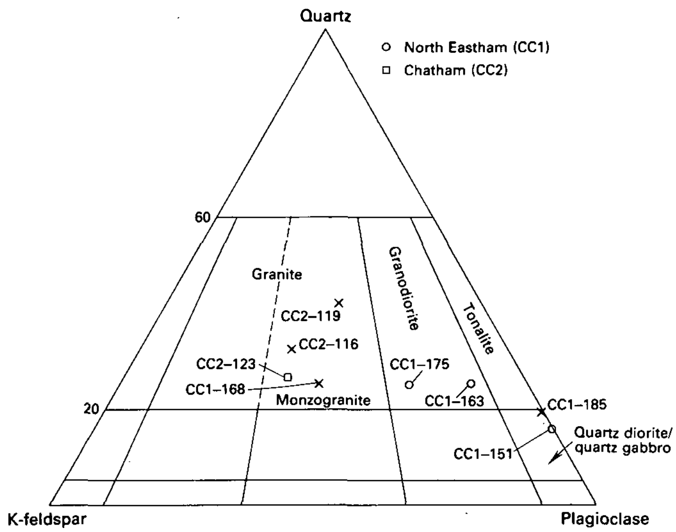


Fig. 4. Modal plot of quartz-K-feldspar-plagioclase from samples of cores CC1 and CC2 normalized to quartz+K-feldspar-plagioclase=100%. Chemically analyzed rocks (Table 2) are labelled o for CC1 and □ for CC2, respectively; modally analyzed samples are shown by x.

abundance and also shows a significant negative Eu anomaly. These patterns are comparable to many calc-alkaline granites (e.g., Cullers and Graf, 1984), but may include more mafic rocks with calc-alkaline affinities. Taken together, the geochemical data suggest a somewhat different petrogenesis for the CC1 samples as compared to that of CC2-123. The granite at Chatham Harbor is the most evolved of the four, consistent with other features described earlier.

Geophysical Expression of Bedrock

The two drill holes (CC1 and CC2; Fig. 2) straddle the Nauset anomaly, a linear, east-northeast trending feature marked by distinct gravity (Fig. 7-2) and magnetic anomalies (Fig. 7-1) that constitutes the boundary between the central and southern plutonic zones of Hutchinson *et al.* (1988). Aeromagnetic and gravity measurements of the drill sites were made to evaluate corresponding anomalies at depth (Leo and Phillips, 1989). The mineralogy of the crystalline cores generally reflects the observed patterns in regional magnetic susceptibility. The gabbroic phase of core CC1 contains about 5% magnetite, whereas the associated monzogranite phase contains 0.5 to 2% and the granite at Chatham Harbor about 0.5% (see Table 1). Hole CC1 coincides with a magnetic high subparallel to the Nauset anomaly, which is likely related to the relatively high magnetite content (~5%) of the gabbroic phase. The felsic phase of CC1, and also the granite of Chatham Harbor (CC2), are situated over magnetically featureless terrain which evidently defines the southern margin of the Nauset anomaly. The elongate gravity anomaly associated with the granite at Chatham Harbor (Fig. 7-1) and the negative anomaly trending eastward from Chatham suggests that the

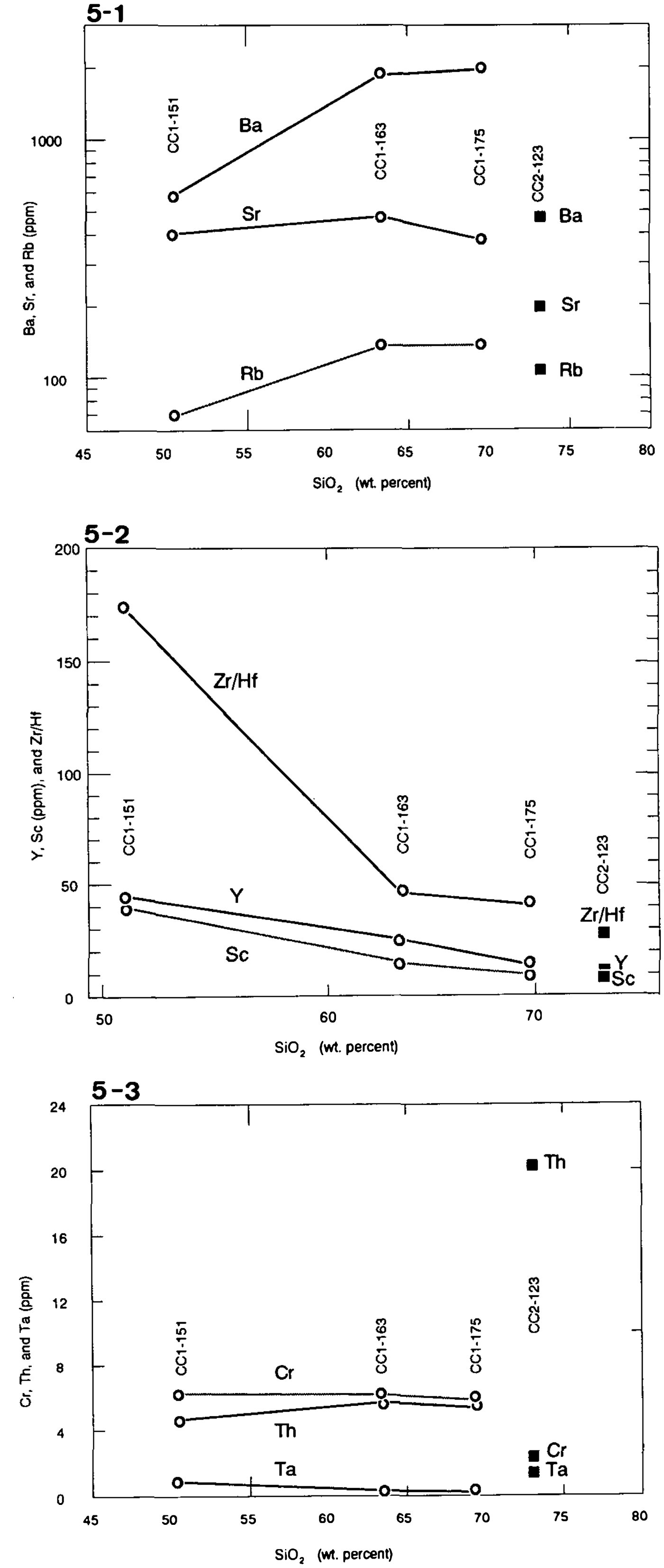


Fig. 5. Harker plot for Ba, Sr, and Rb abundances (Fig. 5-1), Y, Sc, and Zr/Hf (Fig. 5-2), and Cr, Th, and Ta (Fig. 5-3) in CC1 (North Eastham) and CC2 (Chatham Harbor) cores.

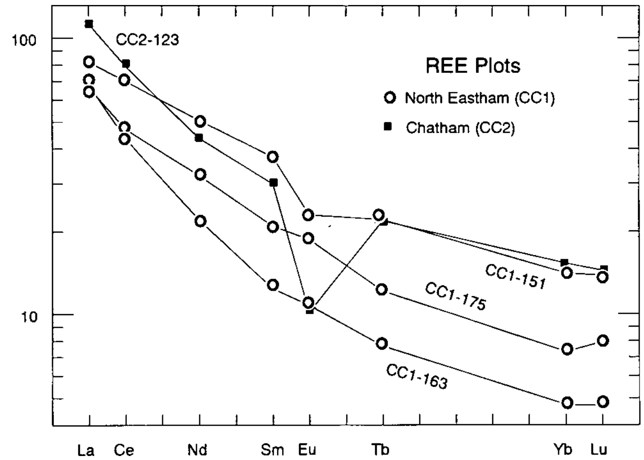


Fig. 6. REE plots for analyzed samples of North Eastham (CC1) and Chatham Harbor (CC2) granite.

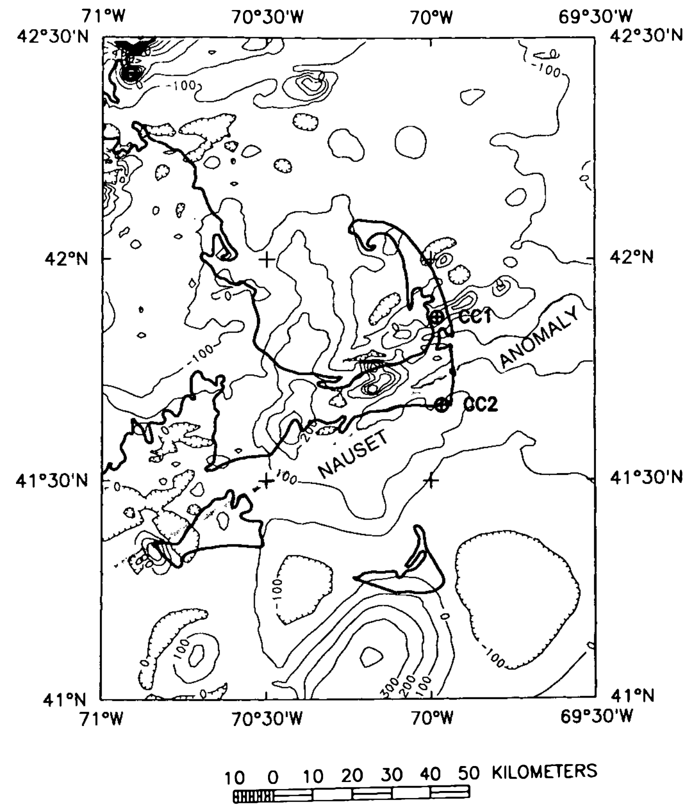
granite at Chatham Harbor may be the western end of a larger granite body.

Geochronology

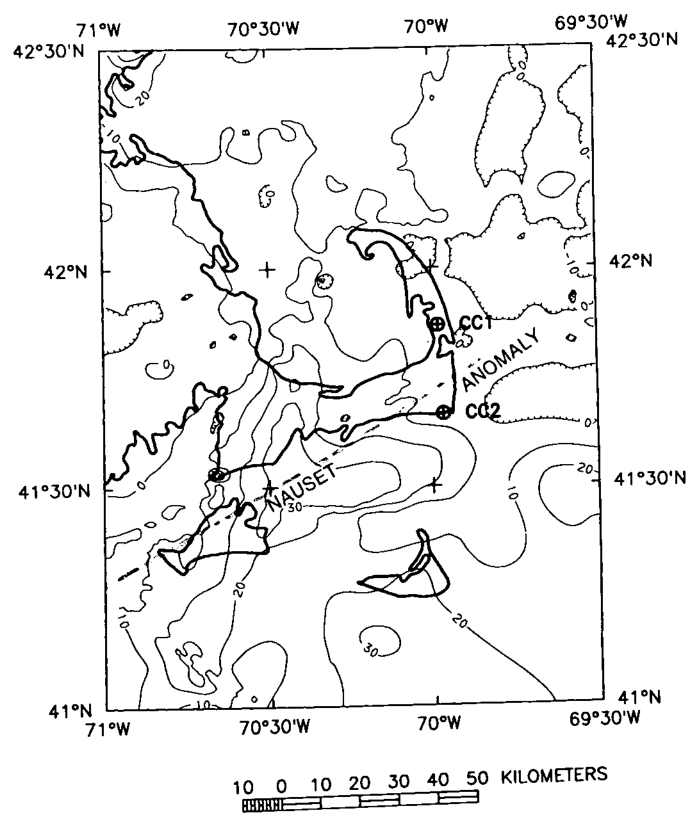
Zircon was recovered only from sample CC2-132. Mineral concentrates were prepared using standard Wilfley table, heavy liquid and magnetic separation techniques. Individual mineral fractions for U-Pb analysis were separated and purified based on grain size, morphology and magnetic susceptibility, and hand-picked to 100% purity. Four zircon fractions were analyzed at Dartmouth College, and three additional fractions were subsequently analyzed at the Geochronology Laboratory of the Geological Survey of Canada (GSC) in Ottawa.

U-Pb analytical techniques employed at Dartmouth College were modified slightly from those of Mattinsen (1987). Data reduction was done using the PBDAT program (v. 1.06) of Ludwig (1990). Errors were estimated based on reproducibility of standards. U and Pb procedural blanks averaged 0.030 and 0.120 ng, respectively. Analytical procedures used at the Geological Survey of Canada are described in detail by Parrish *et al.* (1987). Concentration data were obtained using a $^{233\text{-}235}U/^{205}Pb$ spike. Measured blank levels were 0.006 to 0.015 ng for Pb, and <0.001 ng for U. Isotopic measurements were made on a Finnegan MAT 261 solid source mass spectrometer operated in static mode. Errors were propagated numerically using the method described by Roddick (1987).

Both the Dartmouth and GSC analyses were corrected for initial common Pb using the Pb isotopic composition measured on coexisting potassium feldspar. Discordia line fitting and calculation of upper and lower concordia intercept ages and associated errors employed the regression model of Davis (1982). All errors are quoted at the 2δ level.



7-1 Aeromagnetic map (contour interval = 100 nT)



7-2 Gravity map (contour interval = 10 mGal)

Fig. 7. Aeromagnetic map (Fig. 7-1) and gravity map (Fig. 7-2) of Cape Cod region.

Table 3. U-Pb data for granite (CC2) at Chatham Harbor, southeastern Cape Cod.

Sample Description[1]	Wt (mg)	U (ppm)	Pb[2] (ppm)	$^{206}Pb/^{204}Pb$ (meas.)[3]	% ^{208}Pb[2]	$^{206}Pb/^{238}U$[4] (± % 1σ)	$^{207}Pb/^{235}U$[4] (± % 1σ)	$^{207}Pb/^{206}Pb$[4] (± % 1σ)	$^{207}Pb/^{206}Pb$ age (Ma; ± % 2σ)
A: N,+105,clr,bulk,DC	1.72	71	5.6	1007	21.7	0.06769(0.50)	0.5495(0.50)	0.05888(0.05)	562.6(2.5)
B: N,+105,brn,bulk,DC	2.12	431	37.8	1585	21.5	0.07461(0.50)	0.6089(0.50)	0.05919(0.05)	574.2(2.5)
C: N,+105,brn,bulk,DC	1.91	646	54.6	1536	22.6	0.07090(0.50)	0.5797(0.50)	0.05930(0.05)	578.1(2.5)
D: N,+105,brn,bulk,DC	4.44	550	47.2	1052	21.1	0.07345(0.50)	0.5999(0.50)	0.05924(0.05)	575.7(2.5)
E: N,+105,clr,3,a,GSC	0.043	153	17.5	1864	26.1	0.09286(0.09)	0.7676(0.13)	0.05995(0.08)	601.8(3.3)
F: N,+105,clr,1,a,GSC	0.018	237	25.6	2684	22.2	0.09189(0.09)	0.7577(0.14)	0.05980(0.09)	596.4(3.9)
G: N,+105,clr,1,a,GSC	0.014	143	15.7	1219	23.6	0.09160(0.13)	0.7505(0.18)	0.05942(0.05)	582.5(6.0)

[1]clr, clear; brn, brown; +105, >105μ diameter; DC, Dartmouth analyses; GSC, Geological Survey of Canada; a, abraded; 3,1, number of grains analysed
[2]radiogenic Pb; corrected for blank, spike, and initial common Pb (measured on coexisting feldspar) at $^{208}Pb/^{204}Pb$ = 38.65, $^{207}Pb/^{204}Pb$ = 15.65, $^{206}Pb/^{204}Pb$ = 18.91
[3]corrected for spike and fractionation
[4]corrected for blank Pb and U, and common Pb

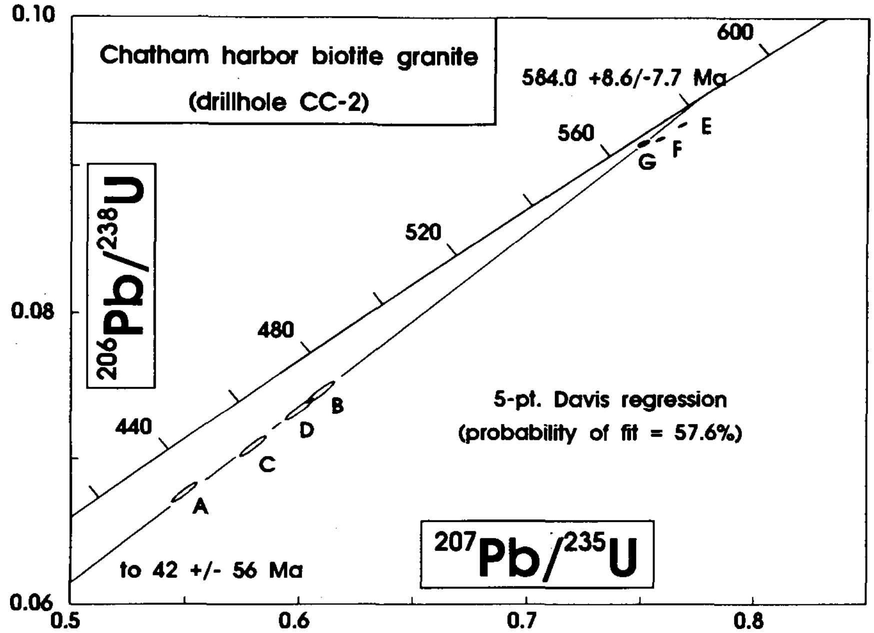


Fig. 8. Concordia plot for granite at Chatham Harbor (sample CC2).

Zircons recovered from the sample consist of pale to dark brown, strongly fractured, stubby, euhedral prisms with abundant clear, bubble- and rod-shaped inclusions. Vague- to well-developed igneous zoning is visible in most of the grains, but no inherited cores were observed.

Analytical data for the seven fractions (Table 3) are shown on a conventional U-Pb concordia plot in Figure 8. The original four analyses (open ellipses A-D; see Fig. 8) were of bulk unabraded zircon fractions. The analyses define a short linear array, but are all strongly discordant (24-31%). Two single grains and a fraction consisting of three grains were subsequently selected from the best quality zircons remaining, and strongly abraded. The three new analyses (solid ellipses E-G; see Fig. 8) plot much closer to concordia (3-5% discordant), but display considerable scatter that we interpret to reflect the presence of a minor inherited zircon component. Data for the three abraded fractions do not define a sufficiently long array to give meaningful upper and lower intercept ages. The $^{207}Pb/^{206}Pb$ age of the most concordant fraction (G; 582.5 ± 6.0 Ma) represents a maximum possible age for the sample. A regression line through this analysis and the four more discordant analyses (A-D) gives calculated upper and lower intercept ages of 584.0 + 8.6/-7.7 Ma and 42 ± 56 Ma, respectively, with a probability of fit of 57.6%. The lower intercept age indicates that the Pb-loss that affected this unit was mainly relatively recent. We consider the upper intercept age to be the best estimate for the crystallization age of the rock. The data preclude the calculation of an average age for the inherited zircon component.

DISCUSSION

Recent seismic reflection profiling in the Gulf of Maine by Hutchinson *et al.* (1988) has identified the major tectonic features in this region. The exact location of the Avalon-Meguma boundary in the Gulf of Maine is a matter of some debate. This boundary is well defined in northern Nova Scotia (see summary by Keen *et al.*, 1991), from where it turns southeastward into the Gulf of Maine (Fig. 1). Keen *et al.* (1991) argued that the Avalon-Meguma boundary is marked by the previously described Nauset anomaly (Figs. 1, 2), an east-northeast-trending, relatively low amplitude magnetic lineament. Hutchinson *et al.* (1988) concluded that much of the central and southern Gulf of Maine is underlain by plutonic rocks which they divided into two zones, based on minor differences in magnetic and seismic signatures. The Nauset anomaly coincides with the boundary between their central and southern plutonic zones. Both of these zones were considered by Hutchinson *et al.* (1988) to be part of the Avalon terrane, with the Avalon-Meguma boundary lying at least 30 km farther southeast of the Nauset anomaly. As discussed above, the two drillholes from which we obtained our samples for this study are located on opposite sides of the Nauset anomaly (Fig. 2). Petrographic data presented here support the existence of the anomaly. The 584 Ma U-Pb zircon age for the granite at Chatham Harbor on the southern side of the Nauset anomaly is in good agreement with U-Pb zircon ages reported for volcanic and plutonic units in the Avalon terrane farther north (Fig. 1). Although some plutons in the Meguma terrane in Nova Scotia contain inherited zircon cores in the range of 650 to 560 Ma (Krogh and Keppie, 1988), only Silurian and Devonian crystallization ages have been obtained thus far for plutons in this terrane. Thus our age data indicate that the part of Cape Cod southeast of the Nauset anomaly is part of the Avalon terrane, as suggested by Hutchinson *et al.* (1988).

Although the plutonic rocks intersected by the two drill holes show a generally calc-alkaline character, petrographic and geochemical studies suggest that the granite at Chatham Harbor (CC2) is distinct from the more heterogeneous plutonic unit(s) intersected by hole CC1, and apparently represents a distinct igneous suite. Available data do not permit determination of the relative age of the plutonic rocks intersected by the two drill holes.

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