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IGNEOUS ROCKS OF THE NASHOBA BLOCK, EASTERN MASSACHUSETTS

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INTRODUCTION

Eastern Massachusetts is underlain by a distinctive sequence of igneous, metamorphic and sedimentary rocks quite different from those found in most of the rest of New England. The region can be subdivided into three northeast-trending belts (Fig. 1), separated by major fault zones (Zartman & Naylor, 1984). The easternmost block, underlain by Late Precambrian to lower Paleozoic rocks of the Boston Platform, has been identified as belonging to the fragmented Avalon microcontinent (Skehan & Rast, 1976; Rast et al., 1976; Rast, 1980). To the northwest, across the Bloody Bluff Fault zone, lies the Nashoba Block, a suspect terrane (Zen, 1983a) of generally high metamorphic grade with distinctly different geologic features. Farther west, across the Clinton-Newbury Fault zone lies the Merrimack Trough, a region with a geological and intrusive history that contrasts with both the Boston Platform and the Nashoba Block.

The stratified rocks of the Nashoba Block are largely high-grade metasediments and amphibolites in the mid-to-upper amphibolite facies. The rocks in the western portion of the area include the Tadmuck Brook Schist and schists and gneisses of the Nashoba Formation and the Fish Brook Gneiss (Bell & Alvord, 1976). Further east lies the Marlboro Formation, a thick sequence dominated by amphibolites. The absolute ages of all these formations, except the Fish Brook, are still in question and range from Ordovician to Precambrian (Zen, 1983a,b). Olszewski (1980) obtained a 730 m.y. U-Pb age from volcanic zircons in the Fishbrook, and our Nd isotope studies of the Marlboro Fm. metabasalts suggests they formed 450-550 m.y. ago (see discussion in DiNitto et al., this volume).

The igneous rocks of the Nashoba Block contrast strongly with those of the Boston Platform. Neither the large, Late Precambrian intrusions (Dedham Granodiorite, Milford Granite) nor the Ordovician to Devonian alkaline intrusions (Quincy, Peabody, Cape Ann Granites) which characterize the Boston Platform are present in the Nashoba Block. In contrast, the Nashoba Block contains abundant metabasaltic flows in the stratified sequence (Marlboro Fm. and Boxford member of the Nashoba Fm.) and was intruded by Ordovician to Silurian calc-alkaline plutons (Sharpners Pond Diorite, Straw Hollow Diorite, Assabet Quartz Diorite, older dioritic phase of the Indian Head Hill pluton) and deep-seated peraluminous granites (different phases of the Andover Granite, perhaps extending over a 40 m.y. period - see below).

Roughly half of the exposed Nashoba Block is underlain by igneous or meta-igneous rocks (Fig. 2); deciphering the evolution of this terrane requires that we understand why the magmas formed and the nature of their source materials. The units to be visited on this trip are briefly outlined below; the stops are shown in circles on Fig. 2.

MARLBORO FORMATION

The Marlboro Fm. is dominated by amphibolite with subordinate pelitic schist

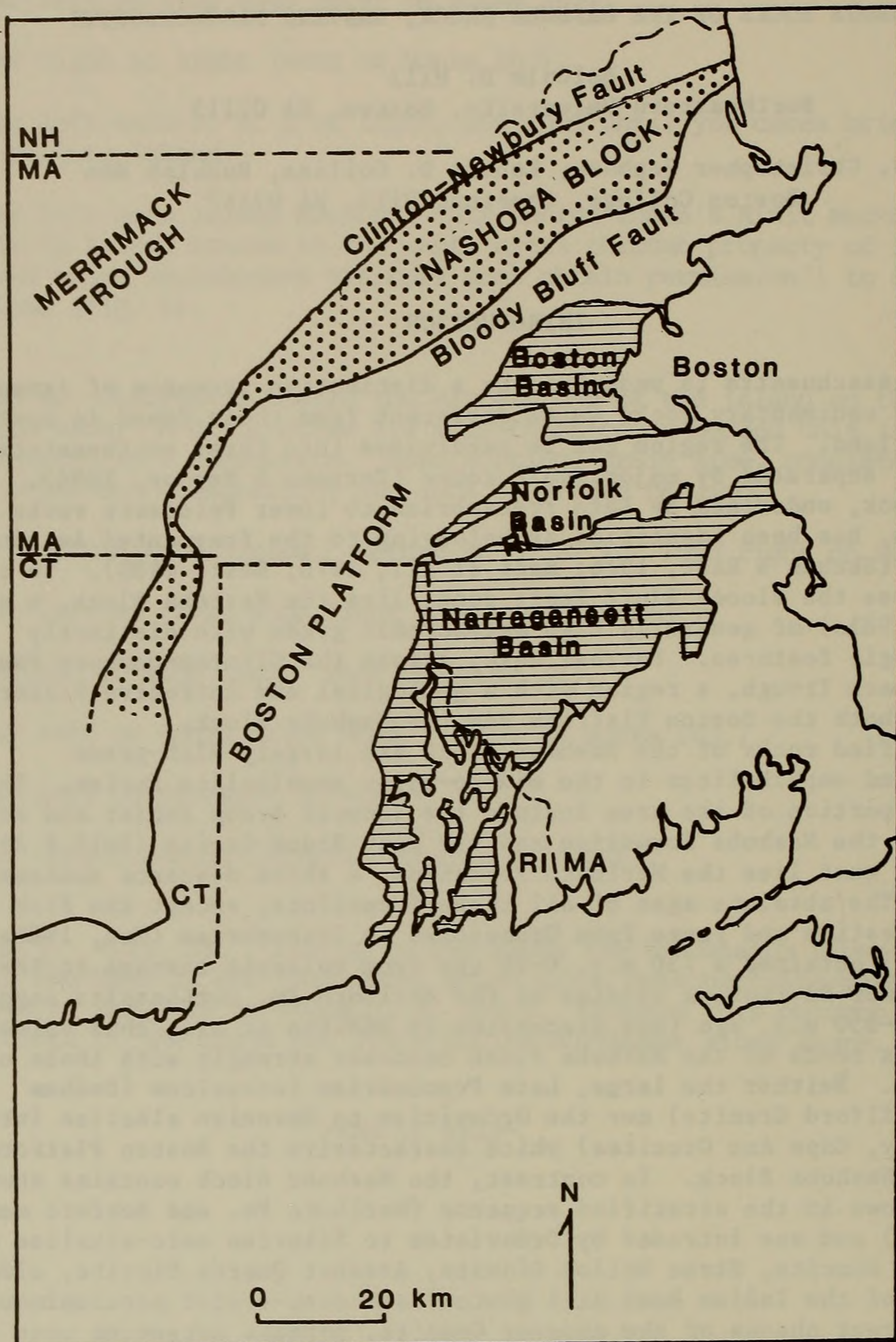

Figure 1. Location of the Nashoba Block, eastern Massachusetts. Sedimentary basins of the Boston Platform shown by lined pattern: Boston Basin, Late Proterozoic-Early Paleozoic; Narragansett and Norfolk Basins, Carboniferous. Outlined square shows area of Figure 2.

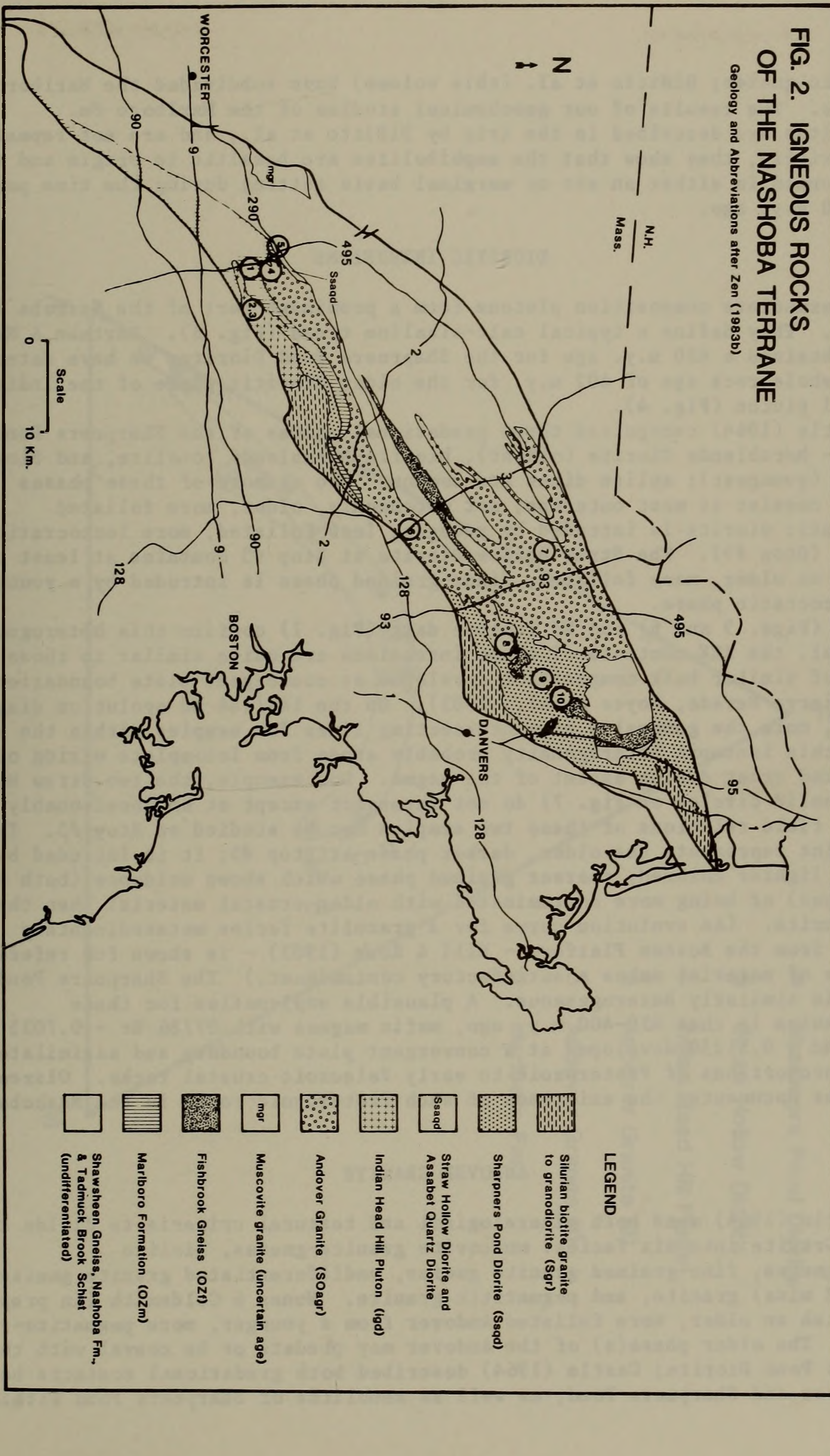

FIG. 2. IGNEOUS ROCKS OF THE NASHOBA TERRANE

Geology and Abbreviations after Zen (1983b) and felsic gneiss; DiNitto et al. (this volume) have subdivided the Marlboro into 5 members. The results of our geochemical studies of the Marlboro Fm. amphibolites are described in the trip by DiNitto et al., and are not repeated here. Briefly, they show that the amphibolites are basaltic in origin and most likely formed in either an arc or marginal basin setting during the time period 450 - 550 m.y. ago.

DIORITIC INTRUSIONS

Intermediate composition plutons form a prominent part of the Nashoba Block (Fig. 2). They define a typical calc-alkaline trend (Fig. 3). Zartman & Naylor (1984) obtained a 430 m.y. age for the Shaprners Pond Diorite; we have determined a Rb-Sr whole rock age of 402 m.y. for the older dioritic phase of the Indian Head Hill pluton (Fig. 4).

Castle (1964) recognized three gradational phases of the Sharpners Pond Diorite - hornblende diorite (oldest), biotite-hornblende tonalite, and biotite tonalite (youngest); aplite dikes are common. Two or more of these phases commonly coexist at most outcrops; not uncommonly, older, more foliated melanocratic diorite is intruded by younger, less foliated, more leucocratic tonalite (Stop #9). The Straw Hollow Diorite at Stop #5 contains at least two phases - an older, more foliated, finer-grained phase is intruded by a younger, more leucocratic phase.

REE (Figs. 5 and 6) and Nd isotope data (Fig. 7) confirm this heterogeneity. In general, the REE contents of these intrusions are quite similar to those in plutons of similar bulk composition developed at convergent plate boundaries (e.g., Sierra Nevada, Noyes et al., 1983). On the 143/144 Nd evolution diagram (Fig. 7), note the generally non-intersecting lines for samples within the same pluton; this isotopic heterogeneity probably arose from incomplete mixing of assimilated crust during ascent of the magma. For example, the two Straw Hollow curves (solid circles on Fig. 7) do not intersect except at an unreasonably old age; the field relations of these two samples can be studied at Stop #5. The upper point represents the older, darker phase at Stop #5; it is intruded by a slightly lighter colored, coarser grained phase which shows evidence (both Sr and Nd isotopes) of being more contaminated with older crustal material than the older diorite. (An evolution curve for a granulite facies metasedimentary xenolith from the Boston Platform - Hill & Ross (1983) - is shown for reference. This type of material makes a satisfactory contaminant.) The Sharpners Pond Diorite is similarly heterogeneous. A plausible explanation for these relationships is that 430-400 m.y. ago, mafic magmas with 87/86 Sr = 0.7035 and 143/144 Nd = 0.51250 developed at a convergent plate boundary and assimilated varying proportions of Proterozoic to early Paleozoic crustal rocks. Olszewski (1980) has documented the existence of such Proterozoic rocks in the Nashoba Block.

ANDOVER GRANITE

Castle (1964) used both mineralogical and textural criteria to divide the Andover Granite into six facies: muscovite granite-gneiss, biotite granite-gneiss, fine-grained granite gneiss, undifferentiated granite gneiss, binary (2 mica) granite, and pegmatitic granite. Wones & Goldsmith (in prep.) distinguish an older, more foliated Andover from a younger, more pegmatite-rich Andover. The older phase(s) of the Andover may predate or be coeval with the Sharpners Pond Diorite; Castle (1964) described both gradational contacts between the Andover and Sharpners Pond, as well as xenoliths of Sharpners Pond within the

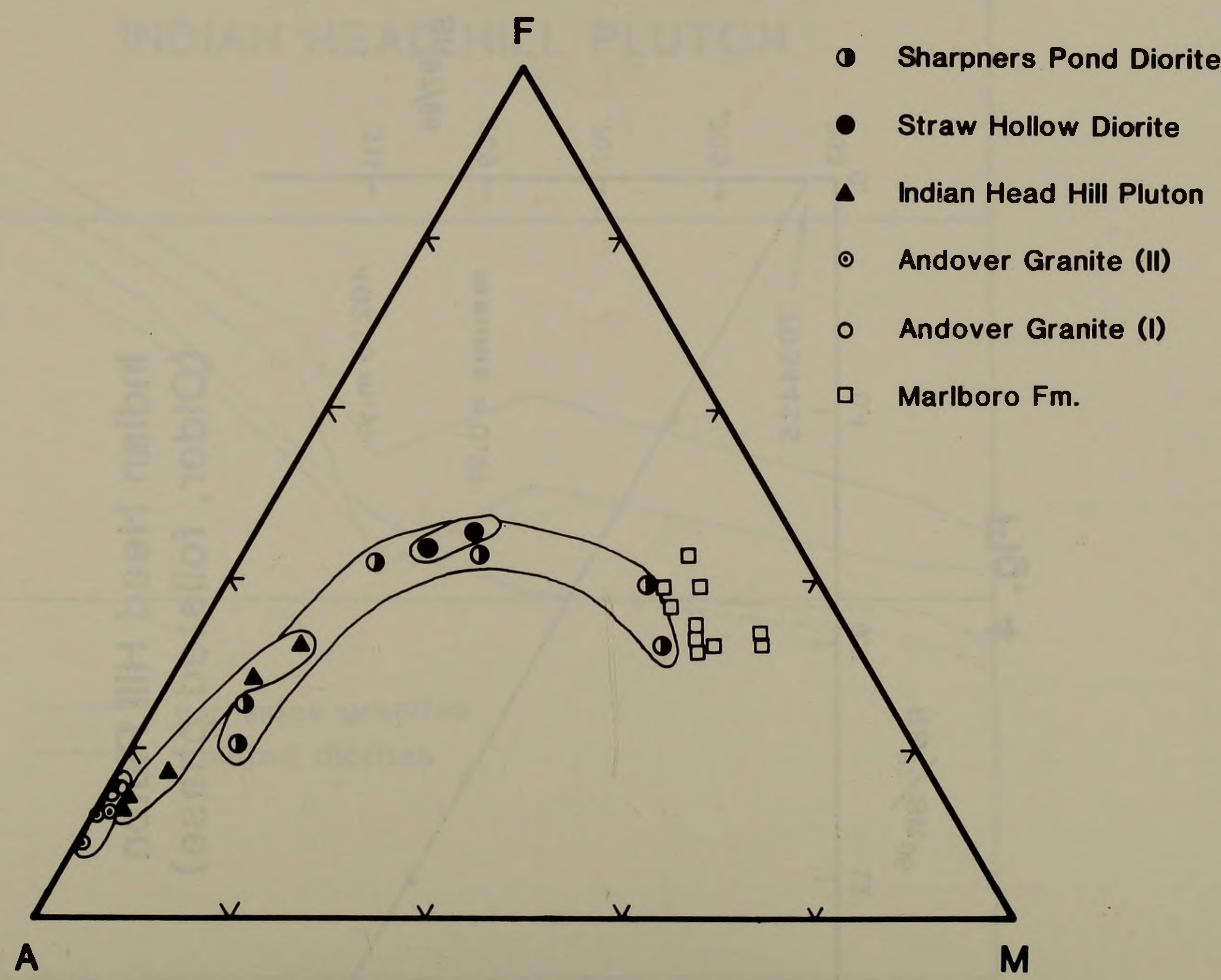

Fig. 3 AFM Diagram, Nashoba Block

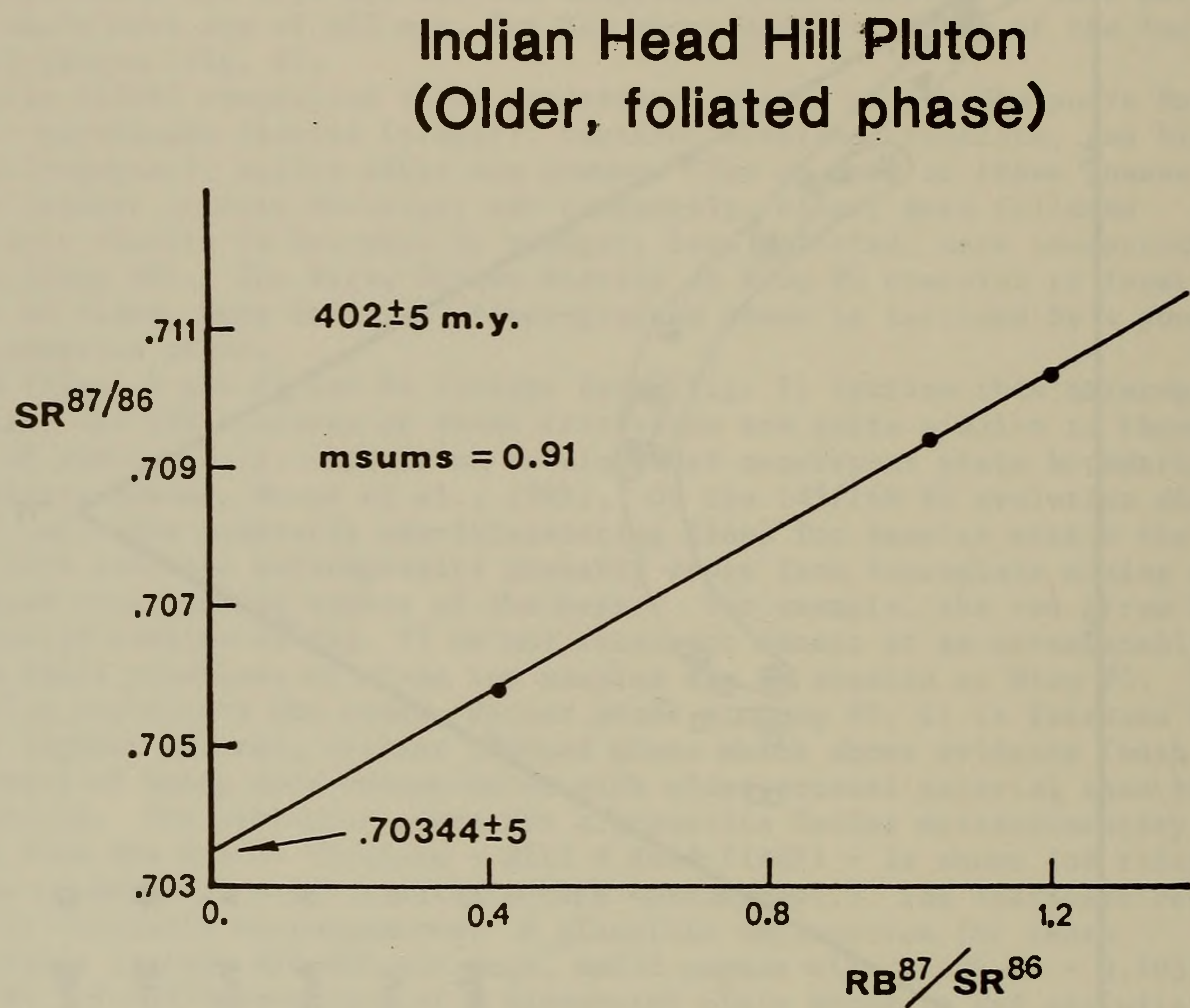
Indian Head Hill Pluton
(Older, foliated phase)
402±5 m.y.
msums = 0.91
SR87/86
.711
.709
.707
.705
.703
.70344±5
0.
0.4
0.8
1.2
RB87/SR86

Fig. 4

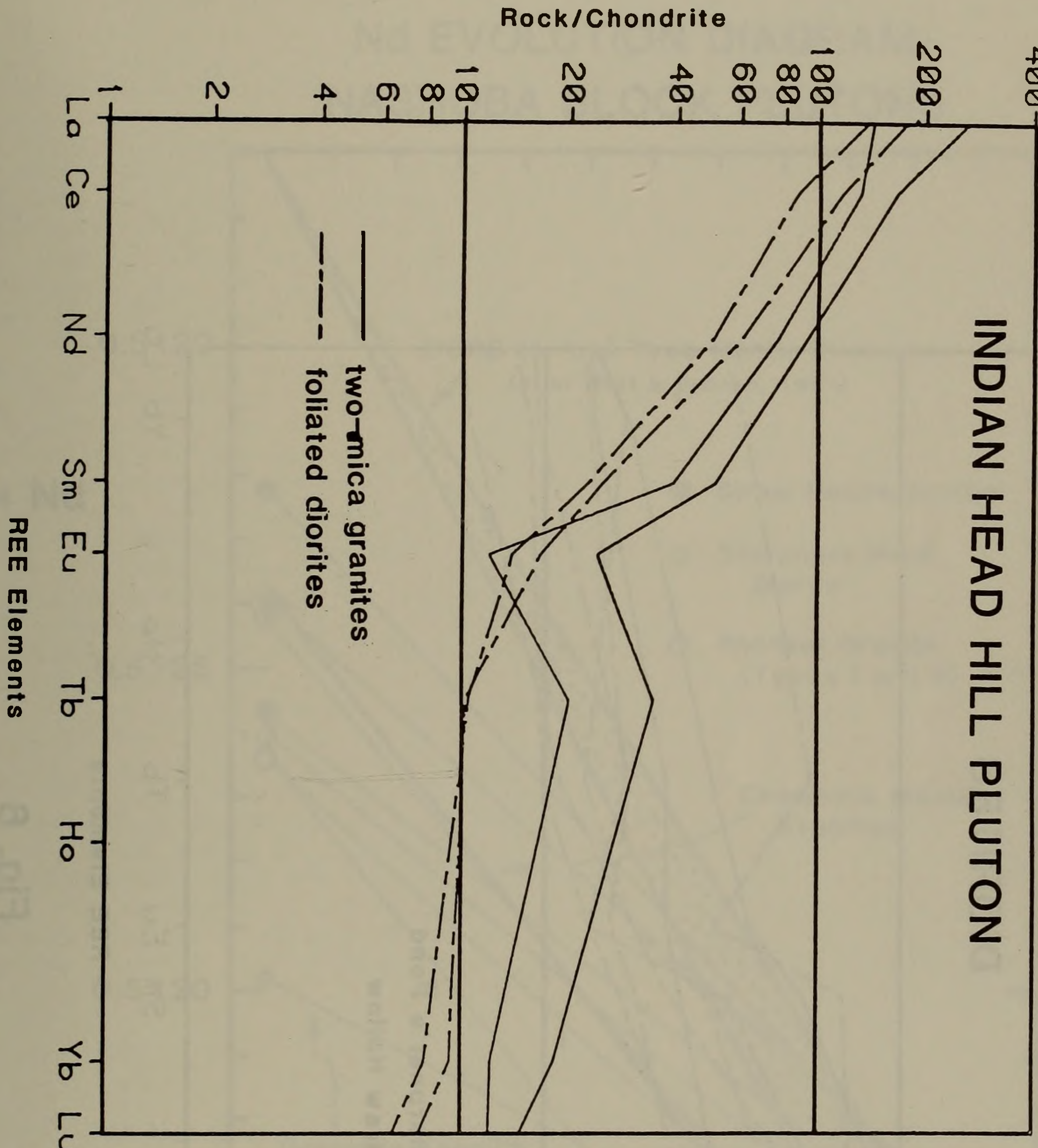
INDIAN HEAD HILL PLUTON
Rock/Chondrite
400
200
100
80
60
40
20
10
8
6
4
2
1
La Ce Nd Sm Eu Tb Ho Yb Lu
two-mica granites
foliated diorites
REE Elements

Fig. 5

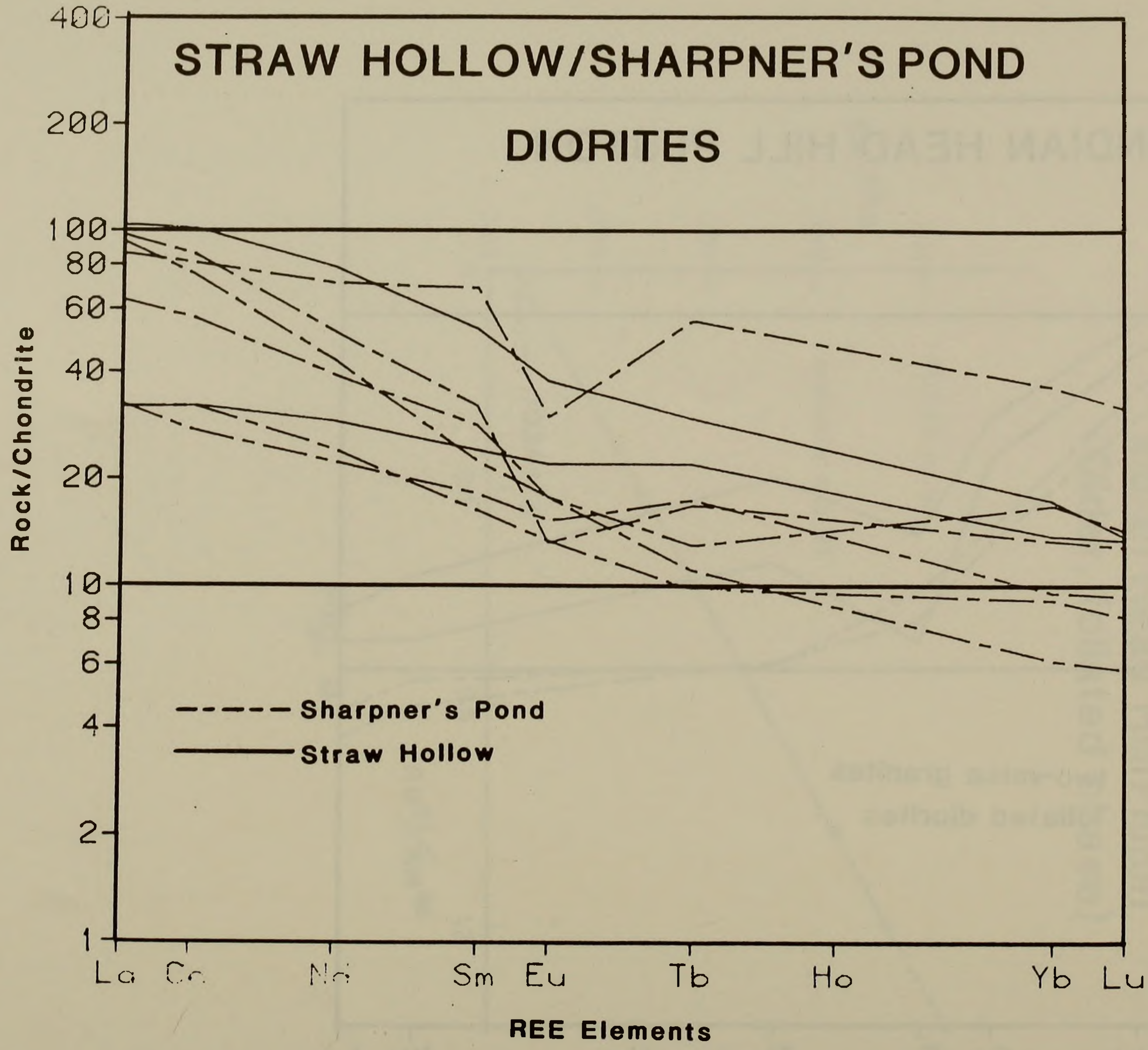
STRAW HOLLOW/SHARPNER'S POND
DIORITES
400
200
100
80
60
40
20
10
8
6
4
2
1
Rock/Chondrite
Sharpner's Pond
Straw Hollow
La
Sm
Eu
Tb
Ho
Yb
Lu
REE Elements

Fig. 6

Nd EVOLUTION DIAGRAM
NASHOBA BLOCK PLUTONS

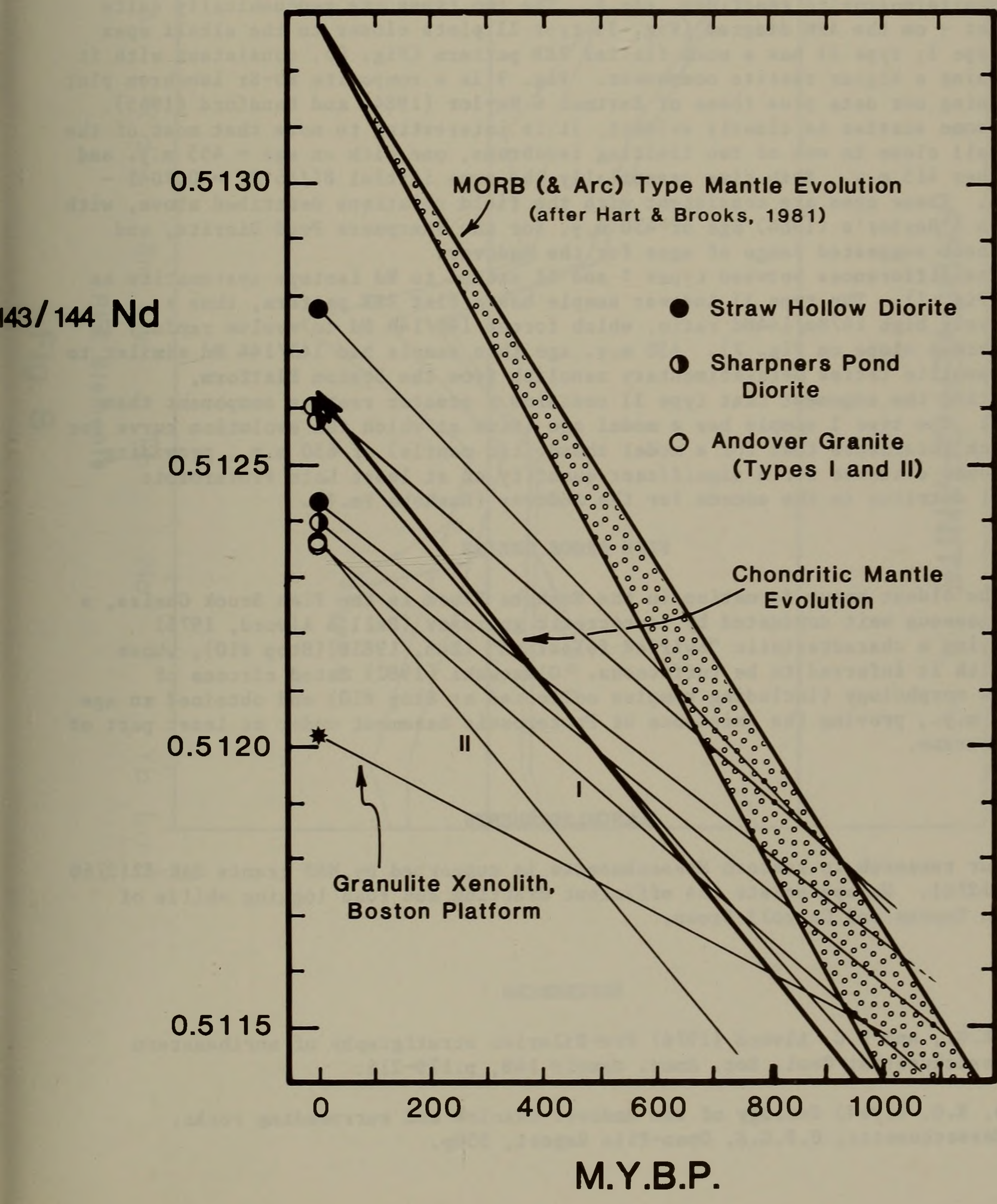

Fig. 7

less foliated phase of the Andover (see Stop #8).

Our data suggest that there are (at least) two fundamental units within the Andover - herein designated Andover I and Andover II. Type I Andover is a mildly peraluminous biotite-muscovite-garnet granite while type II is a strongly peraluminous muscovite-garnet granite. Petrographic evidence suggests that type II contains a greater restite component than type I (abundant sillimanite/muscovite reactions, etc.). The two types are geochemically quite distinct - on the AFM diagram (Fig. 3) type II plots closer to the alkali apex than type I; type II has a much flatter REE pattern (Fig. 8), consistent with it containing a higher restite component. Fig. 9 is a composite Rb-Sr isochron plot containing our data plus those of Zartman & Naylor (1984) and Handford (1965). While some scatter is clearly evident, it is interesting to note that most of the data fall close to one of two limiting isochrons, one with an age = 455 m.y. and the other 415 m.y. Both give essentially the same initial 87/86 Sr = 0.7043 - 0.7044. These ages are consistent with the field relations described above, with Zartman & Naylor's (1984) age of 430 m.y. for the Sharpners Pond Diorite, and with their suggested range of ages for the Andover.

The differences between types I and II extend to Nd isotope systematics as well (Fig. 7). The type II Andover sample has a flat REE pattern, thus a relatively high 147Sm/144Nd ratio, which forces 143/144 Nd to evolve rapidly in time (steep slope on Fig. 7). 450 m.y. ago this sample had 143/144 Nd similar to the granulite facies metasedimentary xenolith from the Boston Platform, supporting the argument that type II contains a greater restite component than type I. The type I sample has a model age (time at which the evolution curve for the rock intersects that for a model chondritic mantle) of 650 m.y., providing additional evidence for a significant quantity of at least Late Proterozoic crustal detritus in the source for the Andover (Nashoba Fm.?).

FISH BROOK GNEISS

The oldest known formation in the Nashoba Block is the Fish Brook Gneiss, a heterogeneous unit dominated by leucocratic gneisses (Bell & Alvord, 1976) displaying a characteristic "swirled foliation" (Zen, 1983b)(Stop #10), whose protolith is inferred to be tuffaceous. Olszewski (1980) dated zircons of igneous morphology (including samples collected at Stop #10) and obtained an age of 730 m.y., proving the existance of Proterozoic basement under at least part of this terrane.

ACKNOWLEDGEMENTS

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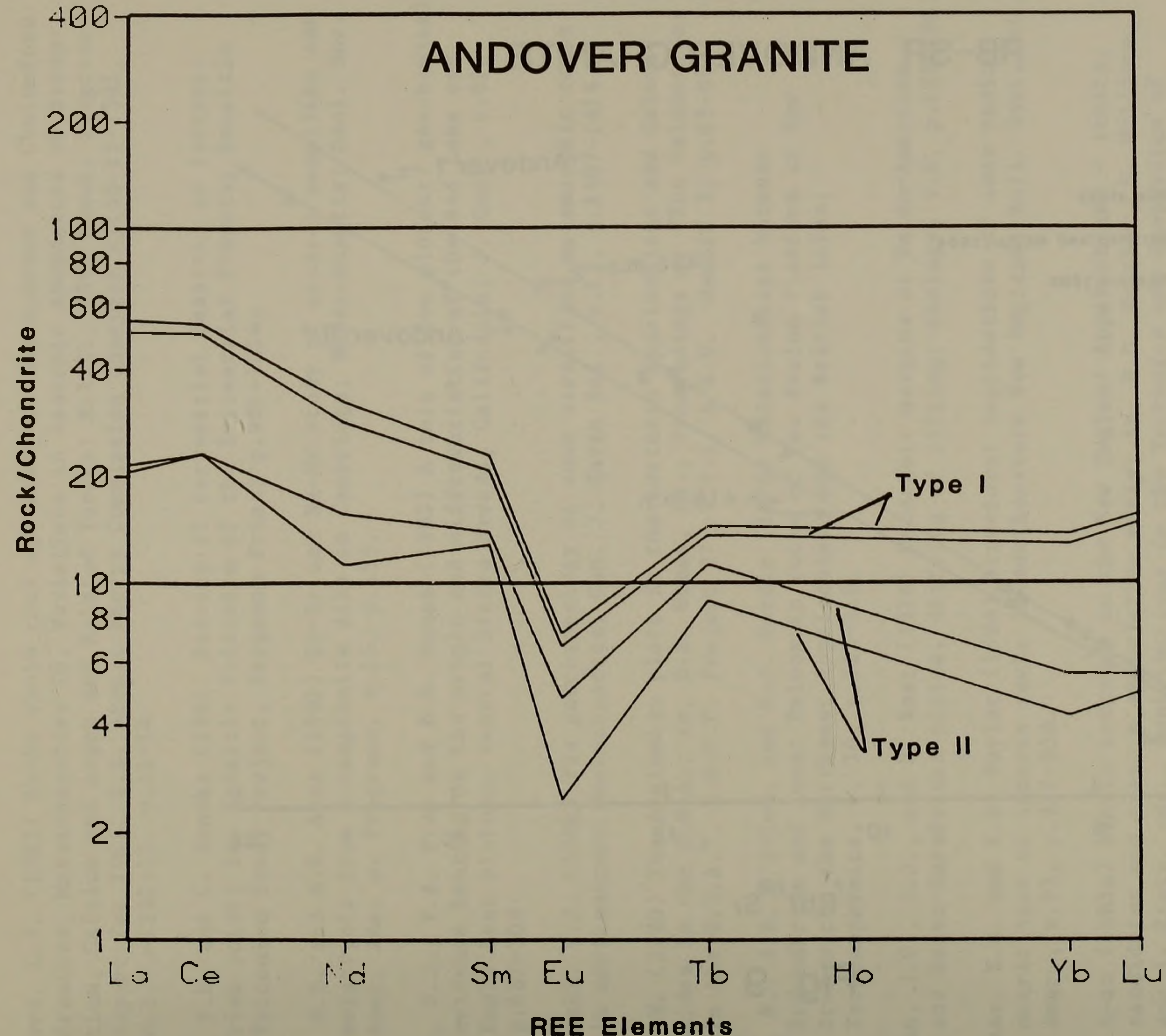
ANDOVER GRANITE
Rock/Chondrite
400
200
100
80
60
40
20
10
8
6
4
2
1
La Ce Nd Sm Eu Tb Ho Yb Lu
REE Elements
Type I
Type II

Fig. 8

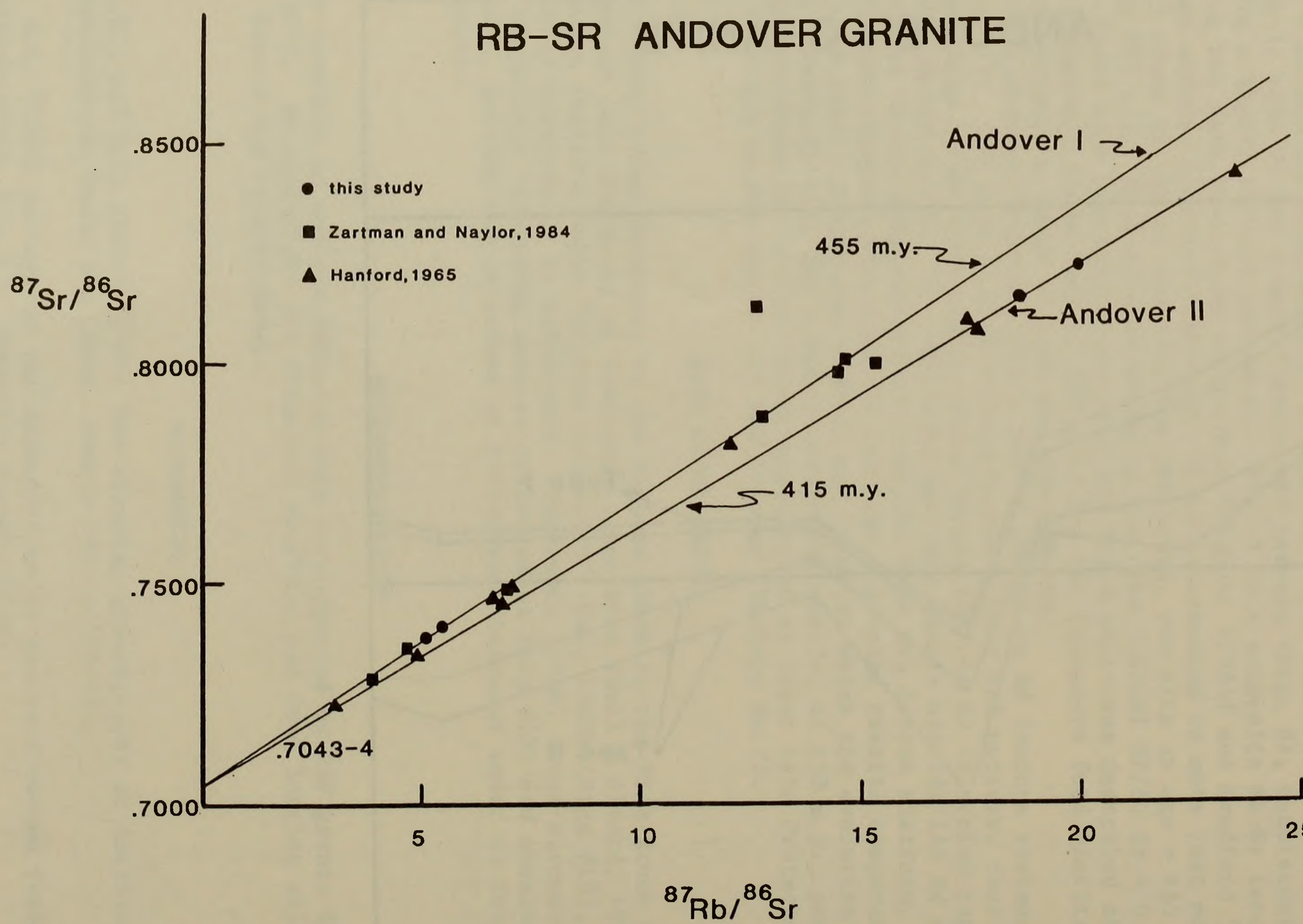
RB-SR ANDOVER GRANITE
this study
Zartman and Naylor, 1984
Hanford, 1965
Andover I
Andover II
455 m.y.
415 m.y.
.7043-4
$^{87}Sr/^{86}Sr$
.8500
.8000
.7500
.7000
5
10
15
20
25
$^{87}Rb/^{86}Sr$

Fig. 9

Handford, L.S. (1965) Rb-Sr whole rock age study of the Andover and Chelmsford Granites, Massachusetts; in, Variations in Isotopic Abundances of Strontium, Calcium and Argon and Related Topics: M.I.T., 13th Annual Progress Report for 1965, U.S. Atomic Energy Commission Contract AT(30-1)-1381, M.I.T.-1381-13, p.11-14

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ROAD LOG

MEETING SPOT and STOP #1. Parking lot of Holiday Inn at junction of Rte. 20 and I-495 in Marlborough, MA. Examine outcrops of Marlboro Fm. amphibolite (Sandy Pond Member) along the east side of the parking lot. Poison ivy abounds. The amphibolite is tightly folded; micaceous horizons are crenulated.

Look for coticules: siliceous layers composed of spessartine, quartz, albite and magnetite; the protolith for these may have been Mn-cherts. This sequence has been cut by garnet-tourmaline-muscovite-bearing pegmatites, provisionally related to the Andover Granite; note that the pegmatites have been sheared.

Mileage in the left-hand column will be cumulative from this location (cum.); and the right-hand column will record mileage from site to site (s/s) noted in the text of the log.

cum.	s/s	
0.0		Exit Holiday Inn parking lot, turn left (east) on Rte. 20.
		Proceed through the town of Marlborough, straight on Rte. 20.
1.5	1.5	Type locality of the Marlboro Fm. on left (north) side of Main Street (Emerson, 1917). See DiNitto et al. (this volume) for additional details of this locality.
1.6	0.1	Junction with Rte. 85; continue straight on Rte. 20.
1.7	0.1	Left turn, follow Rte. 20.
1.8	0.1	Marlboro Fm. amphibolite on left side of road.
2.1	0.3	Right turn, follow Rte. 20.
3.9	1.8	Traffic lights; continue straight on Rte. 20.
4.3	0.4	Turn right at entrance to shopping mall (Zayre's); go to outcrops at right side of parking lot, behind the Shawmut bank. <u>STOP #2.</u> This location is at the north end of Indian Head Hill, the type locality of the <u>INDIAN HEAD HILL PLUTON</u>. Originally, Emerson (1917) mapped this as part of the Dedham Granodiorite, but it is quite different from the Dedham; Hepburn & DiNitto (1978) designated it as a separate unit. The pluton is composite and contains an older, foliated dioritic phase intruded by a non-foliated biotite granite. The latter phase is exposed here, cut by pegmatites. Observe the pegmatites, and contrast them with those clearly associated with the Andover, to be seen later in the day. Despite the proximity to the Bloody Bluff fault, this granite is undeformed.
4.5	0.2	Return to entrance to parking lot, turn left (west) on Rte. 20.
4.9	0.4	Traffic lights (at Mobil Station); turn left on Farm Rd. Pass small airport on left.
5.3	0.4	Turn left on Broad Meadow Road. Continue straight to a fork in the road.
5.9	0.6	At the fork, bear left towards the entrance to Gulbankian Mobile Home Village.

6.0	0.1	Turn left into the main entrance (not the office) of the trailer park. Continue straight, to a cross roads.
6.2	0.2	Left at cross street.
6.3	0.1	T-intersection, outcrop on left beside mailboxes. PARK ON THE BLACKTOP. <u>STOP #3.</u> <u>NO HAMMERS PLEASE.</u> The owners have always granted permission to study these outcrops, but be sure to ask first. These rocks constitute part of the older, dioritic phase of the Indian Head Hill pluton; a 3 point Rb-Sr isochron yields an age of 408 m.y. (Fig. 3). The older diorites have been cut by aplites, and later by the fine grained, granite seen at the last stop. Return to main road.
6.4	0.1	Right turn on main road.
6.5	0.1	Right turn onto Broad Meadow Road.
6.6	0.1	Right turn takes you to Office of Gulbankian Mobile Home Village If time permits, we will examine outcrops beside the gray house. Do not block buildings. <u>STOP 3A.</u> Good pavement exposures of the fine-grained granite intruding foliated diorite, as at Stop 3. Return to Broad Meadow Rd.
6.8	0.2	Right turn on Broad Meadow Rd.
6.9	0.1	Junction with Perimeter Rd.; continue straight on Broad Meadow Rd.
7.4	0.5	Turn left (west) on Farm Road.
7.8	0.4	Turn right on Phelps St.; go to Rte. 20.
8.4	0.6	Turn left on Rte. 20 (west). Continue through the town of Marlborough, heading for I-495.
9.3	0.9	Left turn, follow Rte. 20.
9.6	0.3	Right turn; follow Rte. 20.
10.1	0.5	Bear left; follow Rte. 20.
11.4	1.3	Junction with I-495; take I-495 North towards Lowell-Lawrence. Prepare to pull over just past the first bridge.
11.9	0.5	<u>STOP #4.</u> <u>ANDOVER GRANITE</u>, containing garnet, muscovite and sillimanite, cut by pegmatites. This location is near the southernmost exposure of the Andover Granite. Contrast the mineralogy and structure of this outcrop with that of the youngest granite in the Indian Head Hill pluton seen in the previous two stops.
		Continue north on I-495.

12.9	1.0	Exit I-495 north at Exit-25A, "Hudson, To 85". Prepare to pull off on right side at end of exit ramp.
13.3	0.4	Park on the right just past the electrical box. STOP #5. STRAW HOLLOW DIORITE. We will spend roughly one hour at this stop; we could easily spend a day. This area is cut by a splay of the Assabet River fault zone; look for evidence of both deep (blastomylonite) and late shallow (breccia) faulting. Does the Straw Hollow intrude the blastomylonite, or is the mylonite developed from the Straw Hollow? The Straw Hollow contains at least two phases, a finer grained, more foliated phase intruded by a coarser grained, lighter colored, less foliated phase. These units are geochemically distinct (see discussion in text). Both have been cut by granitic pegmatites and aplites (presumed to be related to the Andover Granite), which have themselves been extensively deformed. In addition, the Straw Hollow contains gabbroic pegmatite segregations genetically related to the diorite. (The curbstones along the highway are the ubiquitous Chelmsford Granite, from the Merrimack Trough - the next tectonic block to the west.) Continue east towards Rte. 85.
14.3	1.0	Traffic light, intersection with Fitchburg St.; continue straight. (Fitchburg St. to the right leads to the Assabet Valley Regional Vocational School, which has a large outcrop of foliated Andover Granite next to the main entrance.)
14.7	0.4	Turn right on Rte. 85 South.
16.0	1.3	Marlborough High School on left.
16.5	0.5	Traffic lights; straight through.
16.8	0.3	Traffic lights; turn left on Lincoln St. (east).
17.1	0.3	Traffic lights; straight through, now on Rte. 20 (east). Continue on Rte. 20 to Weston.
18.9	1.8	Traffic lights, Mobil station on right; straight through.
20.2	1.3	Traffic lights; straight through.
20.3	0.1	Sudbury town line.
24.8	4.5	Bear left, stay on Rte. 20. Wayland town line.
27.1	2.3	Continue east on Rte. 20.
28.7	1.6	Weston town line, sign on right.
29.6	0.9	Left turn on Boston Post Rd., toward Weston Center.
30.2	0.6	Left turn, past Gulf station, on Concord Rd.

30.6	0.4	Road crosses railroad tracks (bridge).
31.0	0.4	Bear left, stay on Concord Rd.; sign "To Campion Center".
31.7	0.7	Campion Center on right.
31.8	0.1	Bear right.
31.9	0.1	Right turn into Weston Observatory of the Dept. of Geology and Geophysics, Boston College, then left to Observatory parking lot. LUNCH STOP.
32.1	0.2	Exit Weston Observatory, left turn.
32.2	0.1	Left turn on Concord Rd.
33.0	0.8	Bear right, stay on Concord Rd.
33.9	0.9	Bear left, through Weston Center.
34.6	0.7	Left turn on Rte. 20 (east).
35.8	1.2	Left turn to Rte. 128 (north). Continue north on Rte. 128 to Rte. 3 (north).
44.3	8.5	Take exit 43N to "Lowell - To Rte. 3N". Continue on Rte. 3 (north).
46.8	2.5	Take exit 26 - "Rte. 62 - Bedford - Burlington".
47.0	0.2	Turn left (west) on Rte. 62. Prepare to stop.
47.3	0.3	Outcrop of Andover Granite.
47.4	0.1	Park either on south side of Rte. 62 across from Earl Rd.,or else along Earl Rd. STOP #6. ANDOVER GRANITE. Foliated Andover 2-mica granite, with massive dioritic inclusions, cut by garnet-apatite bearing pegmatites. Continue east on Rte. 62.
47.8	0.4	Take Rte. 3 (north) toward Lowell.
51.8	4.0	Rest area.
55.9	4.1	Take Exit 30N to the Lowell Connector. (Note - due to construction-imposed detours at the time this road log is being compiled, the mileage at this point will be different from that on the trip. The log should regain reliability at Exit 38 from I-495, to Rte. 38 south.)
56.8	0.9	Detour for I-495 south.

58.7	1.9	Rejoin I-495 <u>north</u>.
61.2	2.5	Take Exit 38 from I-495, to "Lowell - Tewksbury - Rte. 38".
61.4	0.2	Left turn (south) to Tewksbury.
63.5	2.1	Traffic lights; straight.
63.7	0.2	Left turn on North Street.
63.8	0.1	Straight through intersection, continue on North Street.
64.0	0.2	North Street School on right.
64.3	0.3	Railroad tracks; parking for next stop if many cars on trip.
64.4	0.1	Outcrops of <u>ANDOVER GRANITE</u> under power lines. <u>STOP #7.</u> Foliated, massive garnet-bearing Andover Granite; contrast with previous stop. Cut by pegmatites and finer grained granite. Continue south on North Street towards Rte. 38.
65.3	0.7	Stop sign; continue straight.
65.4	0.1	Turn left (south) on Rte. 38.
65.8	0.4	Traffic lights; continue south on Rte. 38.
67.6	1.8	Traffic light; straight through, continue on Rte. 38.
68.3	0.7	Left turn on Salem Rd. (east).
68.4	0.1	Cross South Street; continue on Salem Rd.
69.7	1.3	Cross railroad tracks.
69.9	0.2	Cross railroad tracks.
70.3	0.4	Turn right on Middlesex Ave. (south).
70.6	0.3	Turn left on Rte. 62 (east).
71.0	0.4	Cross over I-93.
71.3	0.3	Intersection; continue straight on Rte. 62.
71.9	0.6	Gravel pit on left.
72.8	0.9	Turn left on North Street.
72.9	0.1	M. Murphy School on left.

73.2	0.3	Traffic lights; straight through on North Street - cross Main St.
73.7	0.5	Hillview Country Club on left.
73.9	0.2	Flashing light - straight through on North Street.
74.1	0.2	Bear right, stay on North Street.
75.0	0.9	T-intersection; turn right on Haverhill Street.
75.3	0.3	Turn left (west) on Aspen Rd.
75.5	0.2	Take the first left onto Colonial Hill Rd.
75.6	0.1	Outcrop on left - <u>STOP #8</u>. Small quarry in housing development shows 2-mica granite (Andover) intruding diorite (Sharpners Pond). Loose blocks near road show best relations. Reverse direction in cul-de-sac.
75.8	0.2	Turn right on Aspen Rd.
76.0	0.2	Turn left on Haverhill St. (will soon become Jenkins St.). Proceed north on Haverhill St.
76.1	0.1	Intersection with Marblehead Rd., flashing yellow light. Straight through; stay on Jenkins St.
78.1	2.0	Intersection - straight through.
79.7	1.6	Turn right (south) on Salem Turnpike - a fast, two-lane road. In 2 miles you will make a left turn off this road.
81.9	2.2	Turn left (east) on Sharpners Pond Road (yes, there is a Sharpners Pond).
82.5	0.6	Outcrop of <u>SHARPNERS POND DIORITE</u> on both sides of road. <u>STOP #9.</u> This is a typical example of the Sharpners Pond, aplites and felsic diorite cut foliated, more mafic diorite.
		Continue east on Sharpners Pond Rd.
83.7	1.2	Park at guardrails blocking straight continuation of road. Walk 1/4 mile along dirt trail to excavations which expose <u>FISH BROOK GNEISS</u> - <u>STOP #10</u>. These exposures typify the "swirled foliation" characteristic of the Fish Brook. Although Bell & Alvord (1976) included the Fish Brook in the stratigraphic sequence of the Marlboro/Nashoba, Olszewski (1980) obtained zircons from this and other Fish Brook localities which yielded Proterozoic (730 m.y.) ages. If the protolith to the predominant swirled gneiss is waterlain tuff (Bell & Alvord, 1976) and the zircons are igneous (Olszewski, 1980), then the Fish Brook Gneiss represents the oldest (meta)igneous unit so far documented in the Nashoba Block. Return to cars.

		Proceed left on paved road past parking area.
84.7	1.0	Turn right on Lacy St.
86.4	1.7	Turn right on Lawrence St. (east).
86.8	0.4	Turn right on Main St.
87.7	0.9	Turn left on Middleton Rd. towards East Boxford.
88.1	0.4	Turn right towards Topsfield.
88.2	0.1	Turn left towards Boxford Village.
89.4	1.2	Turn right onto I-95 (south).
91.0	1.6	Outcrop on right of Sharpners Pond Diorite with multiple injection dikes, just before exit to Endicott Rd.
95.4	4.4	Take Centre St. Exit to Danvers.
95.7	0.3	Outcrop of Salem Gabbro-Diorite - a major component of the Boston Platform, but not found anywhere in the Nashoba Block. This outcrop is easily accessible from the parking lot of NEIGC headquarters, and may be contemplated in comfort from the lounge.
95.8	0.1	Turn right to Dayton St., then left on Dayton to motel entrance.
96.0	0.2	Lobby of the Inn at Danvers (Best Western) - NEIGC '85 headquarters.