Geology and Geochronology of the Southern Adirondacks

James McLelland
Department of Geology
Colgate University
Hamilton, NY 13346

PROLOGUE

Geologic investigations of the Adirondack Region began in the nineteenth century with the early surveys of Ebenezer Emmons and later with important contributions from Kemp, Smyth, and Cushing (see Buddington 1939, for complete bibliographic references of these and other early workers). in the first three decades of the twentieth century a large number of significant publications were forthcoming from Miller, Newland, Alling, and Balk, as well as those cited previously, including Buddington. The essence of these contributions is summarized in Buddington's classic Geological Society of America Memoir (1939) entitled "Adirondack Igneous Rocks and their Metamorphism". The central, dominant theme of this work is that the Adirondacks consist of a vast collection of intrusive igneous complexes ranging in composition from anorthosite to granite. This consensus view was strongly supported by a wealth of field and chemical data and may be regarded as comprising Phase I in the history of Adirondack geology. The culmination of Phase I corresponds with the publication of U.S. Geological Survey Professional Papers 376 and 377 by Buddington and Leonard (1962) and Leonard and Buddington (1964), respectively. These works were the result of government sponsored mineral exploration efforts during World War II. Both reports manifest the classical view of the Adirondacks as an igneous-plutonic domain.

Phase II begins with Engel and Engel (1958, 1964) in the lowlands and Walton and deWaard (1963) and deWaard (1964, 1965) in the highlands. Conceptually, this phase is characterized by paradigms of stratigraphy and stratigraphic correlation. Its modus operandi was the recognition and definition of rock sequences, interpreted as stratigraphic, and correlated over great distances. Depending upon the particular investigators, this stratigraphic framework was cross-bred with varying degrees of granitization and metasomatic transformations.

A late stage of Phase II is represented by the investigations of McLelland in the highlands (McLelland and Isachsen, 1986) and Carl, Foose, deLorraine, and others in the lowlands (see Carl et al. 1990 for references). In this stage, metavolcanics played a burgeoning role in the interpretation of Adirondack layered sequences (Whitney and Olmsted 1989). In addition, structural investigations documented the existence of large fold-nappe structures within most of the Adirondacks (deWaard 1964, McLelland 1984). A characteristic of this stage of Phase

II was to downgrade the importance of widespread igneous intrusion and to substitute for it metamorphic processes involving recrystallization of stratified volcanics and sediments into layered gneisses modified by local anatectic effects (Carl et al. 1990; Whitney and Olmsted 1989).

Phase III of Adirondack geology began in the mid-1970's when Eric Essene, together with his students John Valley and Steve Bohlen (see Bohlen et al. 1985 and Valley et al. 1990) established a quantitative framework for Adirondack pressure, temperature, and fluid conditions during metamorphism. This approach has been significantly augmented by the oxygen isotope studies of John Valley and Jean Morrison (see Morrison and Valley 1988 for complete reference) and the U-Pb studies of Klaus Mezger (1990), all of which have provided critical data that constrain models of Adirondack evolution. Simultaneously, McLelland and Chiarenzelli (McLelland et al. 1988, 1991a,b; McLelland and Chiarenzelli 1990, 1991) have conducted a U-Pb zircon study of the Adirondacks in order to follow up on Silver's (1969) pioneering, landmark investigations. The quantitative results of these research programs have provided unequivocal boundary conditions with which any interpretations of Adirondack geology must be consistent. These results and associated boundary conditions are presented in the text that follows. Significantly, and interestingly, the numbers demonstrate that Phase I interpretations were much closer to the truth than the elaborate stratigraphic models of Phase II. It has become increasingly clear that, in the Adirondacks, intrusive igneous rocks greatly dominate over metavolcanics, or even possible candidates for metavolcanics. Accordingly, it has become evident that layering in orthogneisses is not of primary origin but represents examples of tectonic layering of the sort described by Davidson (1984) in tectonites referred to as straight gneisses. Highly strained rocks of this sort have been described for the Piseco anticline by McLelland (1984) and are common throughout the region.

In conclusion, modern quantitative petrologic and isotopic data strongly indicates that the early, and classic, interpretations of the Adirondacks were, in the main, very nearly correct and herein lies a lesson worth pondering. These results offer additional support for the well documented thesis that granites are plutonic, intrusive rocks and that attempts to form them by circuitous, non-intrusive mechanisms are both outdated and destined to failure. This assessment applies equally well to long discredited examples of granitization and to more modern attempts to account for granites by metamorphosing acidic volcanics. Among the critical observations related to these conclusions are quantitative results from geothermometry, geobarometry, geochronology, and petrochemistry. Combined with a modern understanding of tectonic layering, these considerations can greatly constrain the interpretation of complex geologic terranes, as described below for the southern Adirondack region.

INTRODUCTION AND GEOCHRONOLOGY

The Adirondacks form a southwestern extension of the Grenville Province (fig. 1) and are physiographically divided into the Adirondack highlands (granulite facies) and lowlands (amphibolite facies) by a broad zone of high strain referred to as the Carthage-Colton Mylonite Zone (figs. 2,3) which is continuous with the Chibougamau-Gatineau line (AB on fig. 1). Together these two zones separate the Grenville Province into two major blocks with the Central Granulite Terrane (CGT) lying east of AB and the Central metasedimentary Belt (CMB) and Central Gneiss Belt (CGB) lying to the west. Within the southwestern portion of the Grenville Province further subdivisions exist and are shown in figure 3.

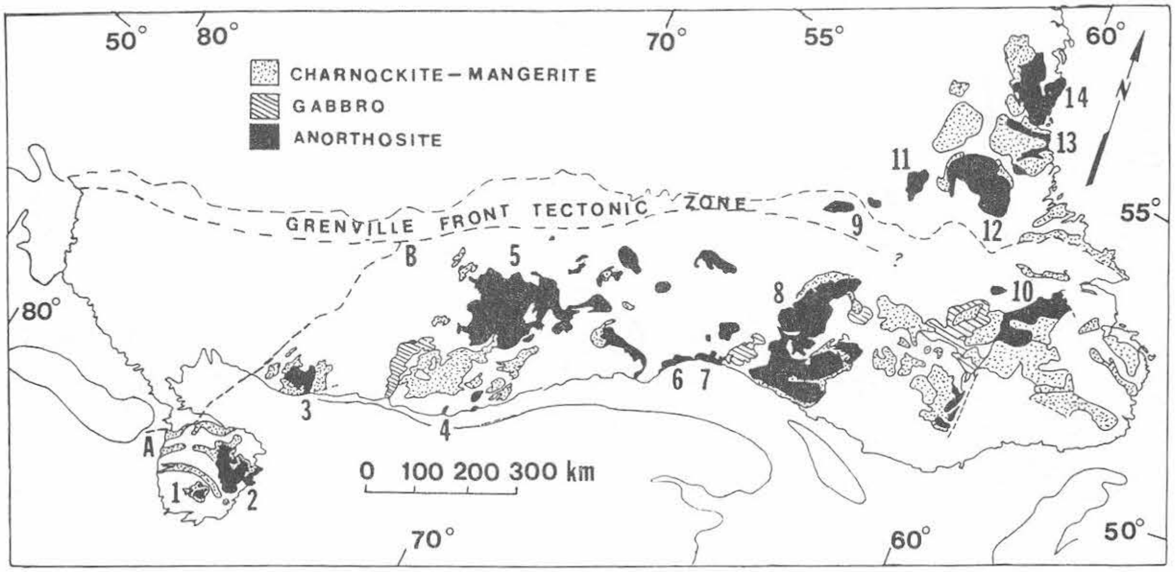


Fig. 1. Generalized map of anorthositic massifs within the Grenville Province and adjacent Labrador. The dashed line, AB, separates terranes with anorthosite massifs on the east from ones lacking them on the west and corresponds to the Carthage-Colton-Gatineau-Chibougamau Line. 1-Snowy Mt. and Oregon domes (ca. 1130 Ma); 2-Marcy massif (ca. 1135 Ma); 3-Morin anorthosite and Lac Croche complex (1160±7 Ma); 4-St. Urbain anorthosite (ca. 1070 Ma); 5-Lac St. Jean complex (1148±4 Ma); 6-Sept Isles (1646±2 Ma); 7-8–Harvre St. Pierre complex (1126±7 Ma) including the Pentecote (1365±7 Ma) anorthosite; 9-Shabagamo intrusives; 10-Mealy Mts. anorthosite (1646±2 Ma); 11-12-Harp Lake anorthosite (ca. 1450 Ma); 13-Flowers River complex (ca. 1260 Ma); 14-Nain complex (1295 Ma) including Kiglapait intrusive (1305±5 Ma). From McLelland (1989).

As demonstrated by recent U-Pb zircon and Sm-Nd geochronology summarized (table 1) by Daly and McLelland (1991), McLelland and Chiarenzelli (1991) and Marcantonio et al. (1990), the Adirondack-CMB sector of the Grenville Province contains large volumes of metaigneous rocks that represent recent (i.e., ca. 1400-1200 Ma) additions of juvenile continental crust. These results (fig. 4) indicate that the Adirondack-CMB region experienced wide-spread calcalkaline magmatism from ca. 1400-1230 Ma. Associated high grade (sillimanite-K-feldspar-garnet) metamorphism has been fixed at 1226±10 Ma by Aleinikoff (pers. comm.) who dated dust air abraded from metamorphic rims on 1300 Ma zircons. Identical rocks, with identical ages, have been described from the Green Mts. of Vermont by Ratcliffe and Aleinikoff (1990), in northern Ireland by Menuge and Daly (1991), and in the Texas-Mexico belt of Grenville rocks (Patchett and Ruiz 1990). It appears, therefore, that a major collisional-magmatic belt was operative along the present southern flank of the Grenville Province during the interval 1400-1220 Ma and may have been related to the assembly of a supercontinent at this time. More locally, this magmatism along with associated metamorphism, represents the Elzevir Orogeny of the Grenville Orogenic Cycle. as defined by Moore and Thompson (1980). Within the Adirondacks Elzevirian rocks are

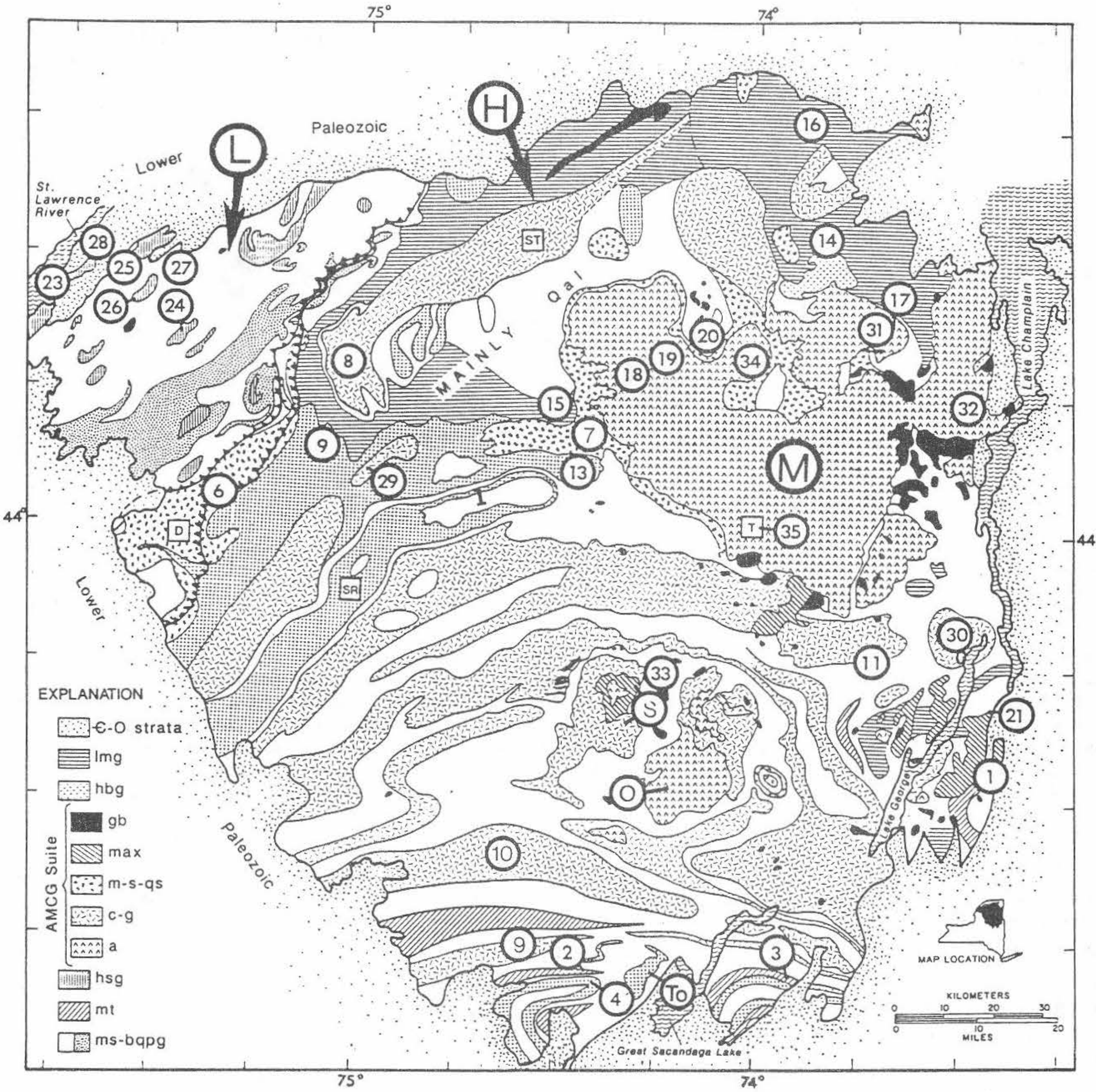


Fig. 2. Generalized geologic map of the Adirondack Highlands (H) and Lowlands (L). The Carthage-Colton Mylonite Zone (CCMZ) is shown with sawteeth indicating directions of dip. Numbers refer to samples listed in Tables 1 and 2. Map symbols: lmg=Lyon Mt. Gneiss, hbg=hornblende-biotite granitic gneiss, gb=olivine metagabbro, max=mangerite with andesine xenocrysts a=metanorthosite, m-s-qs=mangeritic-syenitic-quartz-syenitic gneiss, ms=metasediments, bqpg=biotite-quartz-plagioclase gneiss, hsg=Hyde School Gneiss, mt=metatonalitic gneiss. Locality symbols: A=Arab Mt. anticline, C=Carthage anorthosite, D=Diana complex, O=Oregon dome, S=Snowy Mt. dome, ST=Stark complex, SR=Stillwater Reservoir, T=Tahawus, To=Tomantown pluton. From McLelland and Chiarenzelli (1990) and Daly and McLelland (1991).

TABLE I
U-PB ZIRCON AGES FOR META-IGNEOUS ROCKS OF THE ADIRONDACK MOUNTAINS

No.	Age (Ma)	Location	Sample No.
HIGHLANDS			
Tonalitic gneiss and older charnockite			
1	1329 ±37	South Bay	AM-87-12
2	1301[*]	Canada Lake	AM-86-12
3	1336[*]	Lake Desolation	LDT
4	1233[*]	Canada Lake	AM-87-13
Mangeritic and charnockitic gneiss			
5	1155 ±4	Diana complex	
6	1147 ±10	Stark complex	AM-86-15
7	1134 ±4	Tupper Lake	AC-85-6
8	1125 ±10	Schroon Lake	9-23-85-7
Older hornblende granitic gneiss			
9	1156 ±8	Rooster Hill	AM-86-17
10	1150 ±5	Piseco dome	AM-86-9
11	1146 ±5	Oswegatchie	AC-85-2
Younger hornblende granitic gneiss			
12	1100 ±12	Carry Falls	AM-86-3
13	1098 ±4	Tupper Lake	AM-86-6
14	1093 ±11	Hawkeye	AM-86-13
Alaskitic gneiss			
15	1075 ±17	Tupper Lake	AM-86-4
16	1073 ±6	Dannemora	AM-86-10
17	1057 ±10	Ausable Forks	AM-86-14
Anorthosite and metagabbro			
18	1054 ±20	Saranac Lake	AC-85-8[§]
19	1050 ±20	Saranac Lake	AC-85-7[‡]
20	996 ±6	Saranac Lake	AC-85-9
Xenolith-bearing olivine metagabbro			
21	1144 ±7	Dresden Station	AM-87-11
22	1057	North Hudson	CGAB[**]
LOWLANDS			
Leucogranitic gneiss			
23	1415 ±5	Wellesley Island	AM-86-16
Alaskitic gneiss			
24	1284 ±7	Gouverneur dome	AC-85-4
25	1236 ±6	Fish Creek	AM-87-4
26	1230 ±33	Hyde School	AC-85-5
Granitic and syenitic gneiss			
27	1160 ±4	Edwardsville	AM-87-5
28	1155 ±15	North Hammond	AM-87-3
HIGHLAND SAMPLES OF SILVER (1969)[§§]			
29	1113 ±10	Fayalite granite, Wanakena	
30	1109 ±11	Charnockite, Ticonderoga	
31	1084 ±15	Undeformed syenite dike, Jay	
32	1074 ±10	Anorthosite pegmatite, Elizabethtown	
33	1064 ±10	Metanorite, Snowy Mountain dome	
34	1054 ±20	Sheared anorthosite pegmatite, Jay	
35	1009 ±10	Magnetite-ilmenite ore, Tahawus[‡‡]	

Note: Errors at two sigma.
[*] Minimum Pb/Pb age.
Data from Grant et al (1986).
[§] Contains zircon cores,>1113 Ma, air abraded.
[‡] Baddeleyite age of >1086 ±5 Ma from this sample.
[**] Contains baddeleyite >1109 Ma.
Monazite age of 1137 ±1 Ma.
[§§] Decay constants of Steiger and Jager (1977).
[‡‡] Location same as Sanford Lake (SL) in Figure 1.

Table 2.: Sm-Nd data (sample numbers in Table 1)

sample	L	Zircon age[1]	t_{DM}[2]
ADIRONDACK HIGHLANDS			
Tonalites			
1 :AM87-12	t	1329 ± 36	1403
2 :AM86-12	t	1307 ± 2	1366
3 :LDT	t	>1366	1380
AMCG granitoids			
5 :DIA	s	1155 ± 4	1430
6 :AM86-15	r	1147 ± 10	1495
7 :AC85-6	m	1134 ± 4	1345
9 :AM86-17	e	1156 ± 8	1436
10 :AM86-9	g	1150 ± 5	1346
Younger granitoids			
13 :AM86-6	gd	1098 ± 4	1314
15 :AM86-4	a	1075 ± 17	1576
(repeat)			
:SK2A	tr	c.1060	1330
(repeat)			1373
Metasediment			
:JMCL-1	p	>c.1330	2075
Gabbro			
21 :Ali-1	g	1144 ± 7	1331
ADIRONDACK LOWLANDS			
Wellesely Island			
23 :AM86-16	l	1415 ± 6	1440
Fish Creek			
25 :AM87-4	a	1236 ± 6	1210
:5/90-5	t		
Hyde School			
26 :AC85-5	a	1230 ± 33	1351
:HS3	t	1230 ± 33	1397
:HS4	t	1230 ± 33	1350
Governeur			
24 :AC85-5	a	1284 ± 7	1525
ELZEVIR TERRANE			
Northbrook			
9/88-9	t	1250	1245
Elzevir			
9/88-10	t	1275	1397

1: U-Pb zircon ages in Ma from McLelland and Chiarenzelli (1990a,b) and Grant et al. (1986); 2: Sm-Nd model ages in Ma (DePaolo 1981) from Daly and McLelland (1991) for the Highlands and McLelland, Daly and Perham (1991) for the Lowlands; L: lithologies, a=alaskite, e=enderbite, g=granite, gd=granodiorite, m=mangerite, p=pelite, s=syenite, t=tonalite, tr=trondhjemite, l=leucogranite, initial digits of sample numbers refer to localities in Fig. 2.

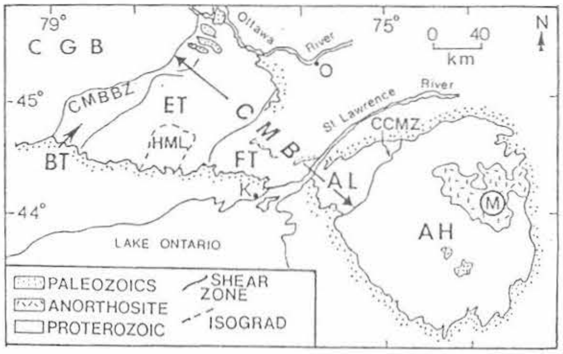


Fig. 3. Southwestern Grenville Province. CMB=Central Metasedimentary Belt, CGB=Central Gneiss Belt, BT=Bancroft Terrane, ET=Elzevir Terrane, FT=Frontenac Terrane, AL=Adirondack Lowlands, HL=Adirondack Highlands, HML=Hastings metamorphic low, K=Kingston, O=Ottawa, CCMZ=Carthage-Colton Mylonite Zone, M=Marcy massif.

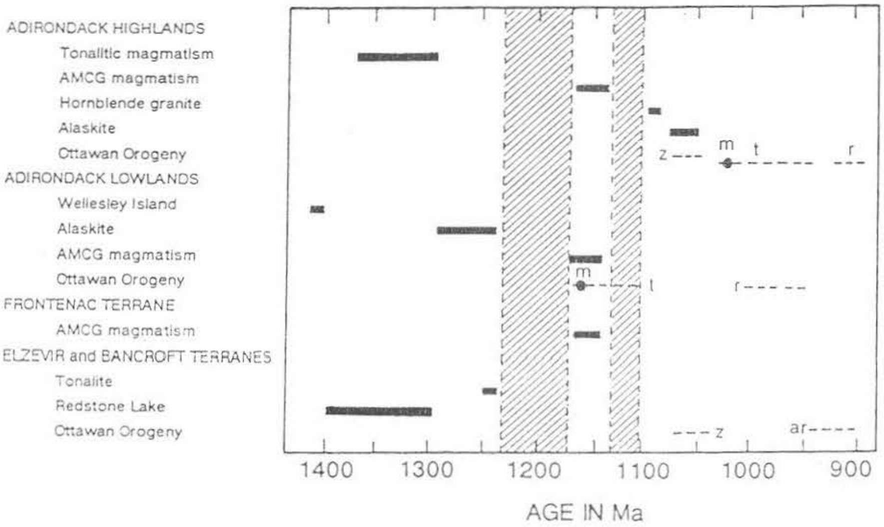


Fig. 4. Chronology of major geological events in the southwestern Grenville Province. z=zircon, t=titanite, m=monazite, r=rutile, ar=Ar/Ar. Diagonal ruling=quiescence. From McLelland and Chiarenzelli (1991).

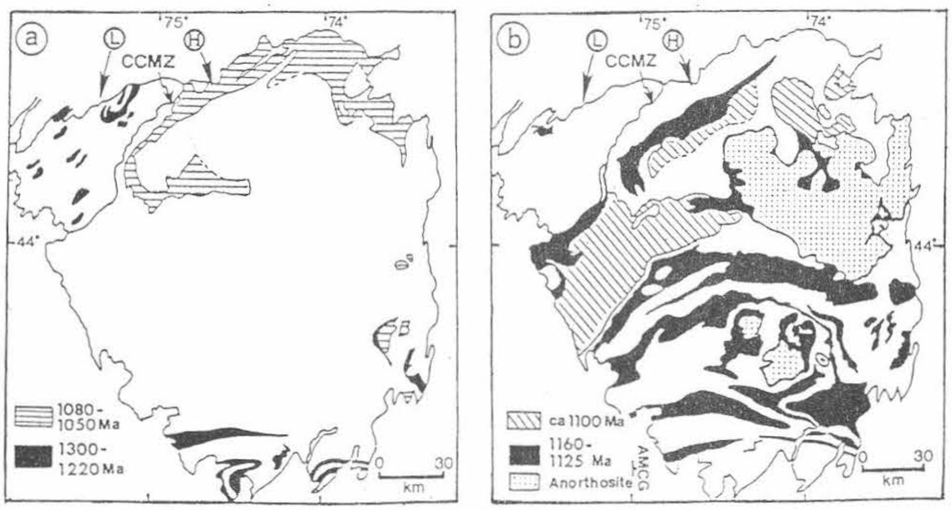


Fig. 5. Chronological designation of Adirondack units. L=Adirondack Lowlands, H=Adirondack Highlands, CCMZ=Carthage Colton Mylonite Zone. From Chiarenzelli and McLelland (1991).

represented by 1300-1220 Ma tonalites and alaskites whose distribution is shown in figure 5. The apparent absence of this suite from the central Highlands is believed to be the combined result of later magmatic intrusion and recent doming long a NNE axis.

Shown in figure 6 are paleoisotherms determined by Bohlen et al. (1985) and zircon ages divided according to origin and degree of disturbance. Note that the locus of disturbed ages corresponds with peak paleotemperatures. This result is discussed again in the metamorphic section. Within the Frontenac-Adirondack region, the Elzevir Orogeny was followed by 40-50 Ma of quiescence terminated at 1170-1130 Ma by voluminous anorogenic (fig. 4) magmatism referred to as the anorthosite-mangerite-charnockite-granite (AMCG) suite. The older ages are characteristic of AMCG magmatism in the Frontenac Terrane (including the Lowlands) while the Highlands commonly exhibit ages of 1150-1130 Ma (fig. 5). The large Marcy anorthosite massif (fig. 2) and its associated granitoid envelope have been shown to have an emplacement age of ca. 1135 Ma (McLelland and Chiarenzelli 1990). These ages are similar to those determined (Emslie and Hunt 1990) for the Morin, Lac St. Jean, and several other large massifs farther northeast in the Grenville Province (fig. 1). Rocks of similar age and chemistry (i.e., Storm King Granite) have been described within the Hudson Highlands (Grauch and Aleinikoff 1985). The extremely large dimensions of the AMCG magmatic terrane emphasize its global-scale nature corresponding, perhaps, to supercontinent rifting with the rifting axis located farther to the east. Valley (1985), McLelland and Husain (1986), and McLelland et. al. (1991a,b) have provided evidence that contact, and perhaps also regional, metamorphism accompanied emplacement of hot (~1100°C, Bohlen and Essene 1978), hypersolvus AMCG magmas. Wollastonite and monticellite occurrences related to thermal pulses from AMCG intrusions occur in proximity to AMCG intrusions (Valley and Essene 1980). In the Lowlands and the Canadian sector of the Frontenac Terrane monazite (table 1., no. 28), titanite (Rawnsley et al. 1987), and garnet ages (Mezger 1990) all indicate high temperatures (~600-800°C) at ca. 1150 Ma. Rutile ages and Rb/Sr whole rock isochron ages document temperatures not exceeding ~500 °C at ca. 1050-1000 Ma.

Following approximately 30 Ma of quiescence (Fig. 4), the Adirondacks, along with the entire Grenville Province, began to experience the onset of the Ottawan Orogeny of the Grenville Orogenic cycle (Moore and Thompson 1980). Initially the Ottawan Orogeny appears represented by 1090-1100 Ma hornblende granites in the northwest Highlands. These rather sparse granites were followed by deformation, high grade metamorphism, and the emplacement of trondhjemitic to alaskitic magnetite-rich rocks (Lyon Mt. Gneiss of Whitney and Olmstead 1988) in the northern and eastern Adirondacks. The zircon ages of these rocks fall into an interval of 1050-1080 Ma (table 1) which corresponds to the peak of granulite facies metamorphism when crust currently at the surface was at ~25 km. Accordingly, the alaskitic to trondhjemitic rocks are interpreted as synorogenic to late-orogenic intrusives. They were followed by the emplacement of single bodies of fayalite granite (ca. 1050 Ma) at Wanakena and Ausable Forks (fig. 2).

Sm-Nd analysis (Daly and McLelland 1991) demonstrates that the emplacement ages of the ca. 1300 Ma tonalitic rocks of the Highlands correspond closely to their neodymium model ages (table 1 and fig. 7a) indicating that these represent juvenile crustal additions. As seen in figure 7a, ϵ_{Nd} evolution curves for AMCG and younger granite suites pass within error of the tonalitic rocks and suggest that the tonalites, together with their own precursors (amphibolites?), served as source rocks for succeeding magmatic pulses. Remarkably, none of these igneous suites gives evidence for any pre-1600 Ma crust in the Adirondack region and the entire terrain appears to have come into existence in the Middle to Late Proterozoic. Significantly, Sm-Nd analysis for the ca. 1230-1300 Ma tonalitic to alaskitic Hyde School Gneiss (table 1, fig. 7b) demonstrates that it has model neodymium ages and ϵ_{Nd} values closely similar to Highland tonalites. The results are interpreted to reflect the contiguity of the Highlands and Lowlands at ca. 1300 Ma. Given this, the Carthage-Colton Mylonite Zone is interpreted as a west-dipping extensional normal fault that

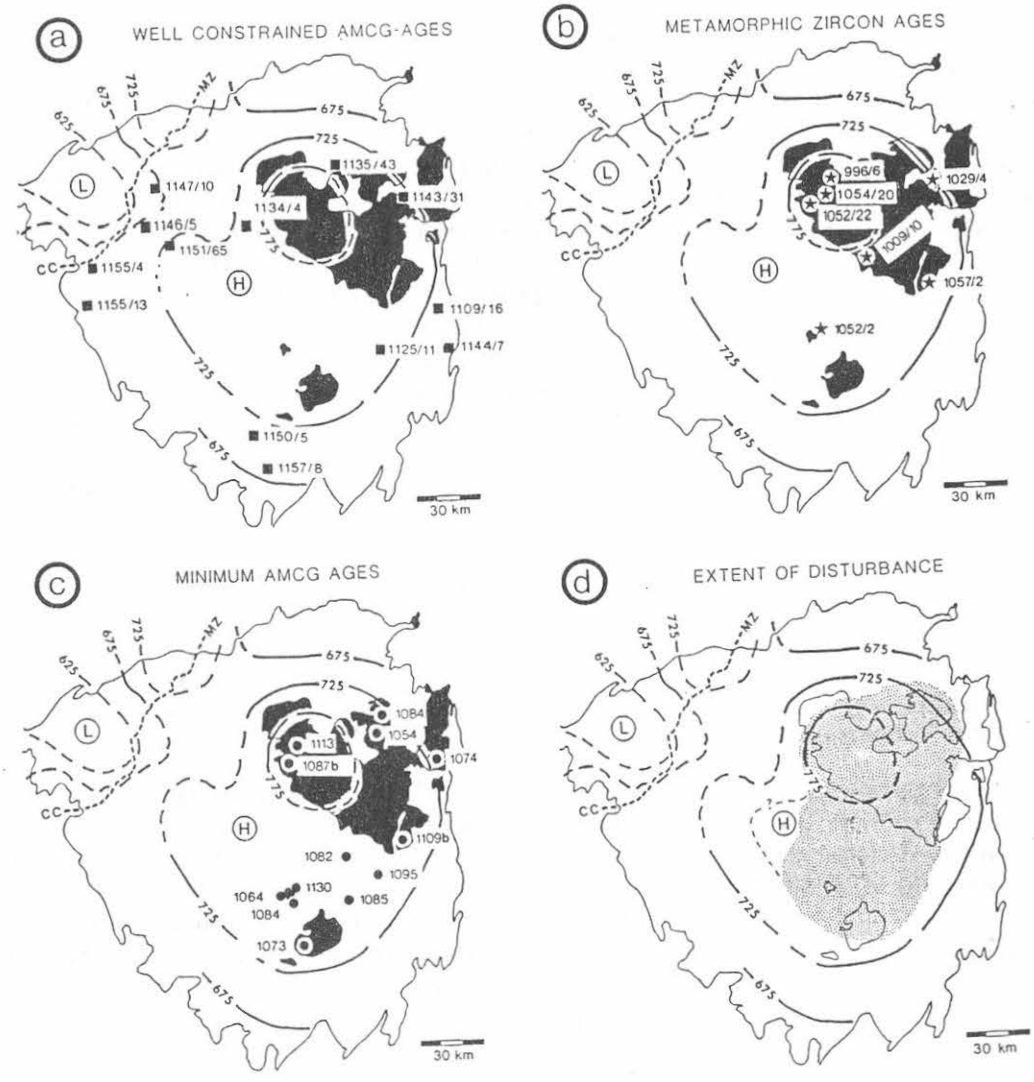


Fig. 6. Relationship between various U/Pb zircon ages and Adirondack paleoisotherms. Shaded area in (d) shows the extent of zircons whose U/Pb systematics have been disturbed. H=Highlands, L=Lowlands, CC=Carthage Colton Mylonite Zone. From Chiarenzelli and McLelland (1991).

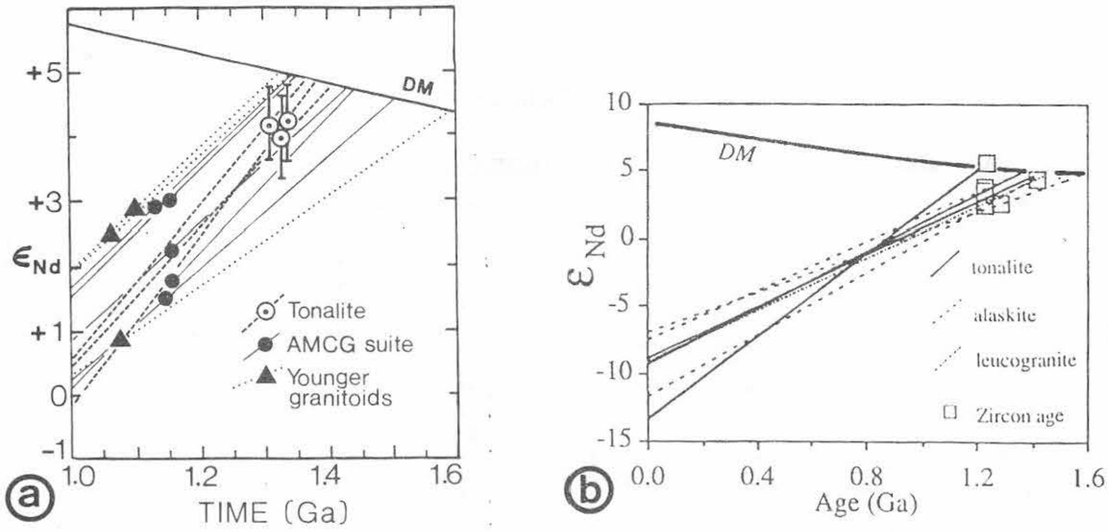


Fig. 7. ϵ_{Nd} evolution diagrams for (a) Adirondack highlands (Daly and McLelland 1991), (b) Adirondack lowlands (Hyde School Gneiss). U-Pb zircon ages are indicated by circles, triangles and squares (from table 1). DM=depleted mantle evolution curve (DePaolo 1981).

formed during the Ottawan Orogeny in response to crustal thickening by thrust stacking (Burchfiel and Royden 1985). East dipping extensional faults of this sort and age have been described by van der Pluijm and Carlson (1989) in the Central Metasedimentary Belt. Motion of this sort along the Carthage-Colton Mylonite Zone would help to explain the juxtaposition of amphibolite and granulite facies assemblages across the zone. A downward displacement of 3-4 km would satisfactorily explain the somewhat lower grade of the Lowlands terrane.

PETROLOGY CHARACTERISTICS OF THE PRINCIPAL ROCK TYPES IN THE SOUTHERN ADIRONDACKS

The following discussion is divided into igneous and metasedimentary sections. Only rock-types occurring within the southern Adirondacks are discussed.

Igneous Rocks

A) Tonalites and related granitoids. Typical whole rock chemistries for these rocks are given in table 3. Figure 8 shows the normative anorthite (An)-albite (Ab)-orthoclase (Or) data for these rocks and compares them to similar rocks in the Lowlands. AFM plots are given in figure 9 and calc-alkali index versus silica plots in figure 10; both figures illustrate the strongly calcalkaline nature of the Highland tonalite to granitoid suite.

The tonalitic rocks, which will be visited at Stop 4, outcrop in several E-W belts within the southern Adirondacks. in the field they can be distinguished from, otherwise similar, charnockitic rocks by the white alteration of their weathered surfaces and the bluish grey on fresh surfaces. A distinctive characteristic is the almost ubiquitous presence of discontinuous mafic sheets. These have been interpreted as disrupted mafic dikes coeval with emplacement of the tonalites.

Associated with the tonalitic rocks are granodioritic to granitic rocks containing variable concentrations of orthopyroxene. These are best represented by the Canada Lake Charnockite (Stop 3) and by the large Tomantown pluton (fig. 2) whose minimum emplacement age is 1184 Ma (table 1).

TABLE 3

	EARLY CALCALKALINE ROCKS			OLDER ANOROGENIC PLUTONIC ROCKS					
	AM-87-13	TOE	CL-6	AM-86-17	AM-86-1	AC-85-1	AM-86-9	AM-86-15	AC-85-2
SiO_2	65.00	65.68	74.63	68.90	71.88	73.72	69.14	67.47	75.17
TiO_2	0.75	1.16	0.37	0.59	0.36	0.04	0.89	0.72	0.20
Al_2O_3	15.10	14.97	14.22	14.50	14.82	13.54	13.78	15.12	12.63
FeO	Nd	Nd	Nd	2.16	1.27	0.87	2.83	3.34	1.11
Fe_2O_3	6.03	6.79	1.53	1.1	0.96	0.11	1.82	1.59	1.07
MnO	0.10	0.08	0.04	0.02	0.03	0.01	0.04	0.10	0.02
MgO	0.46	1.15	0.55	0.84	0.43	0.20	0.45	0.51	0.19
CaO	2.71	2.56	1.66	2.3	1.87	0.85	2.26	2.57	0.88
Na_2O	4.10	2.80	3.56	3.06	3.93	5.71	3.07	3.41	2.99
K_2O	5.13	4.52	4.26	4.18	3.99	4.42	4.91	5.18	5.49
P_2O_5	0.10	0.51	0.10	0.24	0.09	0.01	0.23	0.19	0.04
LOI	0.39	0.74		0.40	0.27	0.17	0.19	0.39	0.17
Σ	99.87	100.96	99.42	99.63	99.65	99.61	100.59	99.96	
Ba(ppm)	1230	710	510	680	660	1100	736	810	442
Rb (ppm)	100	97	170	160	200	406	81	128	230
Sr (ppm)	260	230	260	200	130	26	211	215	99
Y (ppm)	70	70	37	40	110	321	60	71	77
Nb (ppm)	20	19	17	30	30	15	19	21	15
Zr (ppm)	790	345	160	270	670	118	538	546	284

	YOUNGER ANOROGENIC PLUTONIC ROCKS							
	AC-85-6	AC-85-10	AM-86-7	WPG	SLC	AM-87-9	AM-86-8	AM-87-10
SiO_2	62.15	54.94	58.50	69.20	60.64	61.05	60.94	62.14
TiO_2	0.88	1.55	0.68	0.51	1.14	0.78	1.39	0.36
Al_2O_3	16.40	14.87	20.32	13.90	15.27	15.98	15.91	12.35
FeO	3.96	10.25	2.81	3.1	9.28	4.60	6.51	10.32
Fe_2O_3	1.49	2.80	0.43	1.34	1.77	2.10	1.02	1.7
MnO	0.09	0.24	0.01	0.05	0.19	0.05	0.14	0.01
MgO	1.06	0.96	1.47	0.52	0.74	1.64	1.70	0.83
CaO	3.27	5.52	6.16	2.03	3.97	3.63	4.53	3.65
Na_2O	4.81	3.45	5.02	3.02	3.34	3.41	3.55	6.05
K_2O	5.13	3.83	3.35	5.48	3.70	4.76	3.86	1.26
P_2O_5	0.30	0.65	0.32	0.11	0.31	0.42	0.46	0.09
LOI	0.41	0.37	0.43	0.39	0.01	0.91	0.37	0.67
Σ	99.95	99.43	99.50	99.65	100.46	99.63	100.38	99.24
Ba(ppm)	850	625	Nd	1279	823	Nd	1100	Nd
Rb (ppm)	106	47	Nd	124	87	Nd	83	29
Sr (ppm)	335	367	Nd	184	215	Nd	410	180
Y (ppm)	60	55	Nd	48	121	Nd	110	63
Nb (ppm)	21	14	Nd	14	38	Nd	25	79
Zr (ppm)	464	431	Nd	382	647	Nd	1200	309

	YOUNGER GRANITIC ROCKS						LATE LEUCOGRANITIC ROCKS				
	AM-86-3	AM-86-6	NO-Fo1	AM-86-13	AM-87-6	GHA	AM-86-11	AM-87-7	AM-86-4	AM-86-10	AM-86-14
SiO_2	68.62	68.05	71.75	76.30	69.00	73.2	69.98	67.80	70.01	69.05	72.39
TiO_2	0.48	0.55	0.41	0.18	1.43	0.35	0.46	0.42	0.69	0.57	0.38
Al_2O_3	14.37	14.67	13.49	11.64	12.12	13.1	12.37	15.76	12.43	13.06	12.63
FeO	3.01	3.51	2.39	1.13	4.94	0.84	5.13	1.2	4.23	3.50	1.6
Fe_2O_3	0.93	1.18	1.12	0.61	1.16	2.1	1.11	2.8	1.5	1.42	4.13
MnO	0.06	0.07	0.05	0.01	0.02	0.02	0.14	0.03	0.03	0.01	0.03
MgO	0.49	0.45	0.11	0.01	0.67	0.33	0.08	0.56	0.01	0.17	0.29
CaO	1.99	1.81	1.43	0.45	0.75	1.55	1.25	2.35	0.94	0.35	1.07
Na_2O	3.71	3.81	2.99	3.32	2.79	4.16	3.99	3.71	1.92	1.08	6.63
K_2O	5.67	5.61	5.79	5.22	6.50	4.01	4.91	4.91	8.34	9.64	0.52
P_2O_5	0.13	0.12	0.07	0.03	0.17	0.07	0.04	0.13	0.17	0.12	0.70
LOI	0.40	0.58	0.5	0.30	0.25	0.39	0.21	0.31	0.23	0.41	0.10
Σ	99.86	100.41	100.00	99.20	99.80	100.3	99.67	99.98	100.50	99.38	100.47
Ba(ppm)	861	715	692	Nd	1014	1249	160	Nd	840	290	98
Rb (ppm)	161	148	182	188	214	178	190	Nd	315	330	16
Sr (ppm)	209	240	115	132	303	211	20	Nd	73	60	42
Y (ppm)	65	62	72	157	35	86	120	Nd	66	75	117
Nb (ppm)	20	20	25	29	17	19	30	Nd	18	23	27
Zr (ppm)	394	542	595	392	507	338	1230	Nd	414	600	786

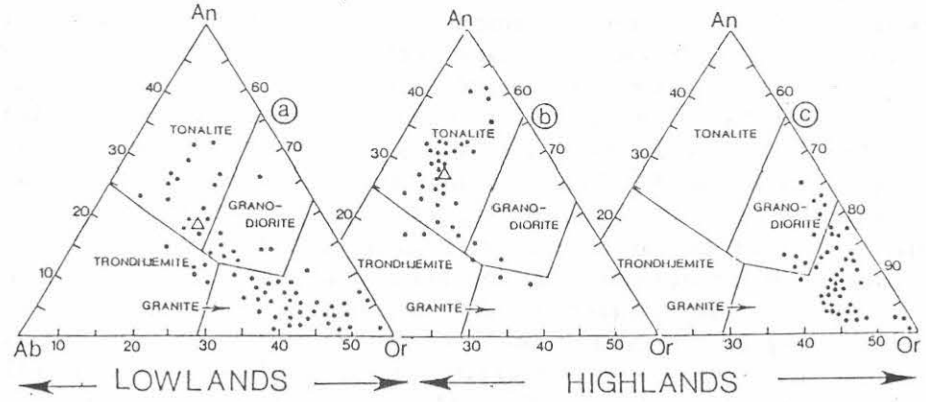


Fig. 8. Plots of normative albite (Ab)-anorthite(An)-orthoclase (Or) for (a) Hyde School Gneiss, (b) Highlands tonalites, and (c) Tomantown pluton. Open triangles give average values for tonalitic samples. Definition of fields due to Barker (1979).

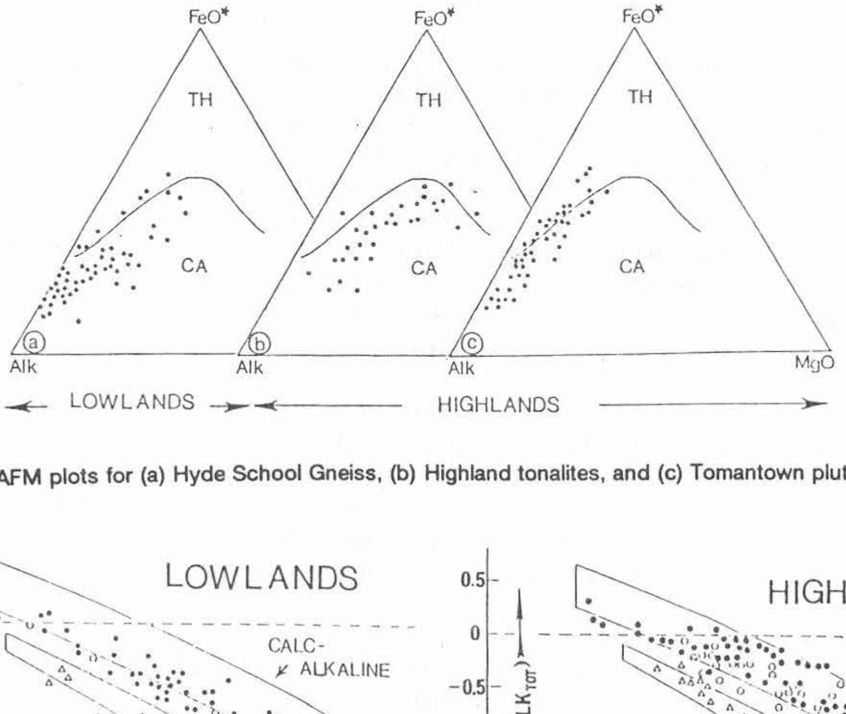


Fig. 9. AFM plots for (a) Hyde School Gneiss, (b) Highland tonalites, and (c) Tomantown pluton.

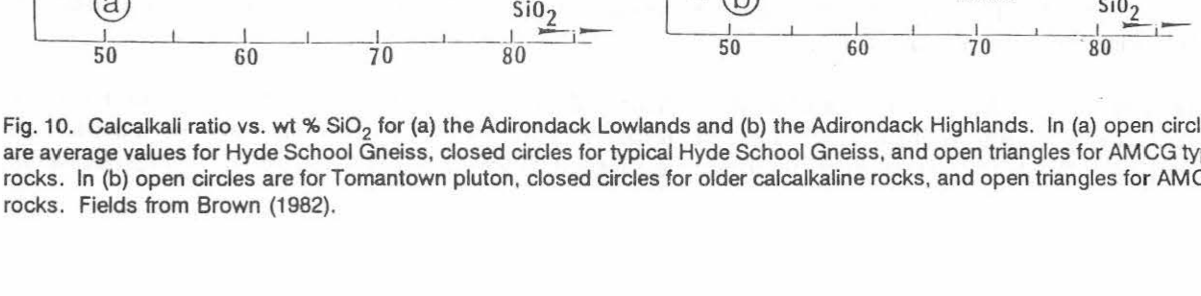


Fig. 10. Calcalkali ratio vs. wt % SiO_2 for (a) the Adirondack Lowlands and (b) the Adirondack Highlands. In (a) open circles are average values for Hyde School Gneiss, closed circles for typical Hyde School Gneiss, and open triangles for AMCG type rocks. In (b) open circles are for Tomantown pluton, closed circles for older calcalkaline rocks, and open triangles for AMCG rocks. Fields from Brown (1982).

McLelland et al. (1991b) have interpreted the early calcalkaline rocks of the Highlands as correlative with the Hyde School Gneiss of the Adirondack Lowlands (fig. 2). This interpretation is consistent with the Sm-Nd results (table 1b) discussed previously and shown in figure 7.

B) AMCG Suite. Within the southern Adirondacks AMCG rocks are widely developed and abundantly represented in the Piseco anticline (Stop 6) as well as the Oregon (Stop 8) and Snowy Mt. Domes. The chemistry of granitoid (mangeritic to charnockitic varieties of these rocks is given in table 3, especially for the older anorogenic plutonic rocks to which southern Adirondack suites belong. As shown in figure 10, the AMCG rocks have calcalkali-silica trends that are distinctly different than those shown by the tonalitic suites. McLelland (1991) and McLelland and Whitney (1991) have shown that the AMCG rocks exhibit anorogenic geochemical characteristics (figs. 11, 12, 13) and also constitute bimodal magmatic complexes in which anorthositic to gabbroic cores are coeval with, but not related via fractional crystallization to the mangeritic-charnockitic envelopes of the AMCG massifs (i.e., Marcy massif, fig. 2). Bimodality is best demonstrated by noting the divergent differentiation trends of the granitoid members on the one hand and the anorthositic-gabbroic rocks on the other (Buddington 1972). This divergence is nicely exhibited by the variation of the FeO-MgO ratio with wt.% SiO_2 (fig. 12) Ga-Al_2O_3 trends (fig. 13), and by Harker variation diagrams for AMCG rocks of the Marcy massif (fig. 14) (McLelland 1989). The extreme low-SiO_2, high-iron end members (fig. 14) of the anorthosite-gabbro family will be seen at Stop 8 and are believed to represent late liquids developed under conditions of low oxygen fugacites (i.e., dry, Fenner-type trends).

C) Metasedimentary Rocks. Within the southern Adirondacks the metasedimentary sequence is dominated by quartzites and metapelites with marbles being virtually absent. The quartzites are exceptionally thick and pure and comprise an ~1000 m-thick unit referred to as the Irving Pond Quartzite (Stop 2). Of even greater extent, as well as thickness, is the Peck Lake Formation which consists of garnet-biotite-quartz-oligoclase ± sillimanite gneiss (referred to as kinzigite) together with sheets, pods, and stingers of white, minimum melt granite that commonly contains garnets (Stop 1). McLelland and Husain (1986) interpreted the kinzigites and their leucosomes as restite-anatectite pairs and attributed partial melting to heating accompanying AMCG magmatism. It is now believed that an additional period of anatexis probably preceded the 1130-1150 Ma AMCG magmatism during the 1300-1220 Elzevir Orogeny.

The occurrence of anatexis within the kinzigites is corroborated by the presence of sparse hercynitic spinel within either garnets or sillimanite-rich wisps in leucosomes. McLelland et al. (1991a) have shown that extraction of anatectic material from the least altered kinzigites can satisfactorily account for the composition of more aluminous, lower-silica kinzigites. The ultimate evolution of this process would be to produce assemblages of aluminous sillimanite-garnet-biotite gneiss together with granitic material of the sort that characterizes the Sacandaga Formation (Stop 9).

Based on the bulk chemistry of kinzigites in the southern Adirondacks, McLelland and Husain (1986) interpreted their protoliths as Proterozoic greywackes and shales. More recently, McLelland et al. (1991b) have provided evidence to support the conclusion that the Peck Lake Fm. kinzigites of the southern Adirondacks can be correlated with the markedly similar Major Paragneiss of the Adirondack Lowlands (bqpg on fig. 2). McLelland and Isachsen (1986) have also argued that the Peck Lake Fm., and associated rocks, continues eastward into the eastern Adirondacks in the vicinity of Lake George.

In contrast to the southern and eastern Adirondacks, the central Adirondacks contain only sparse kinzigite, and metasediments are principally represented by synclinal keels of marble and calcsilicate (Stop 7). It is possible that the change from carbonate to pelitic metasediments

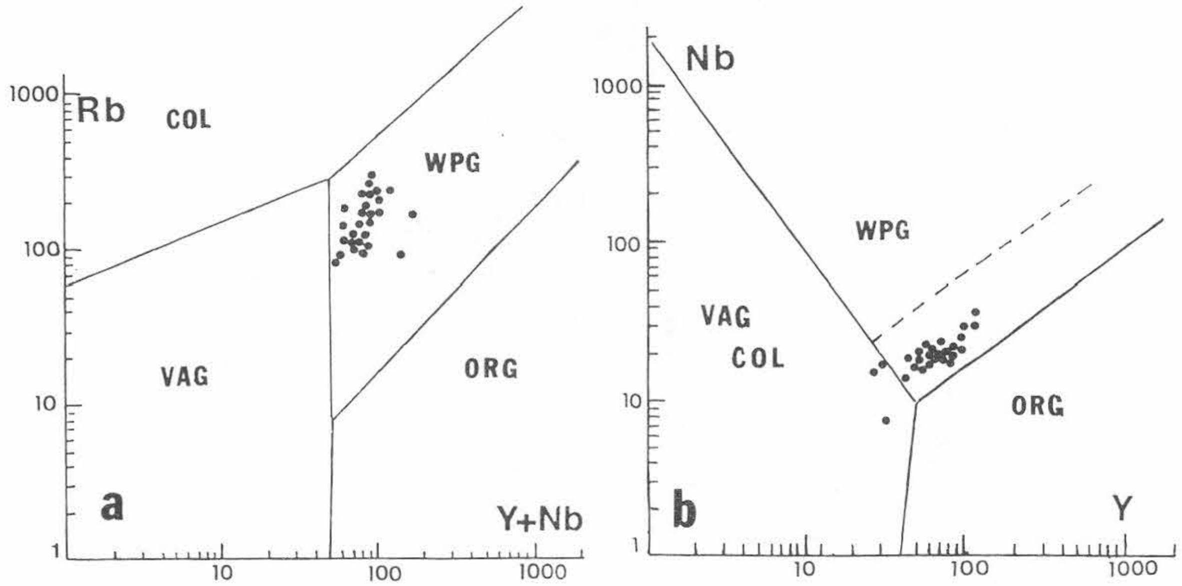
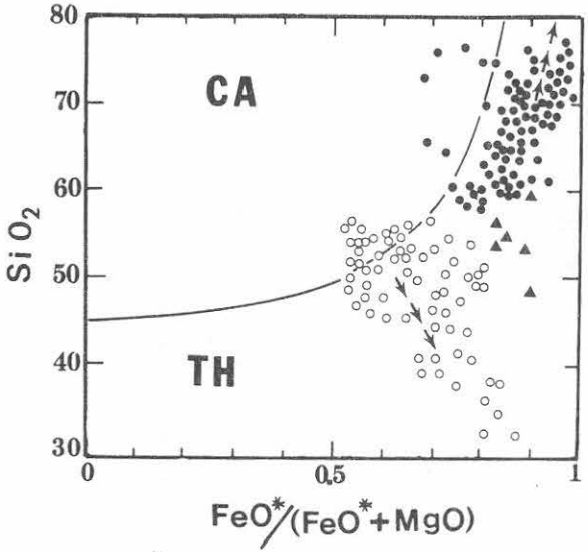


Fig. 11. Tectonic discrimination diagrams (Pearce et al. 1984) for AMCG granitoids from the Marcy massif. COL=collisional, WPG=within plate granites, ORG=-ocean ridge granites, VAG=volcanic arc granites.



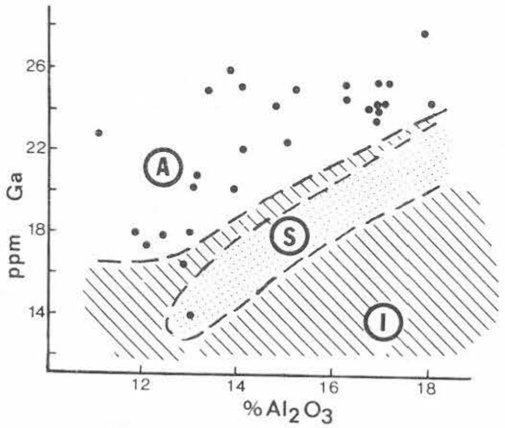


Fig. 12. FeO^*-MgO vs. wt.% SiO_2 variation for anorthositic suite (open circles) and mangeritic-charnockite suite (filled circles). Triangles designate mixed rocks at contacts. Arrows indicate differentiation trends of the two suites, CA=calcalkaline, TH=tholeiitic. (after Anderson 1983)

Fig. 13. Ga vs. Wt.% Al_2O_3 for AMCG suite granitoids of the Marcy massif. Fields of A-,S-, and I-type granites and shown (after White and Chappell 1983).

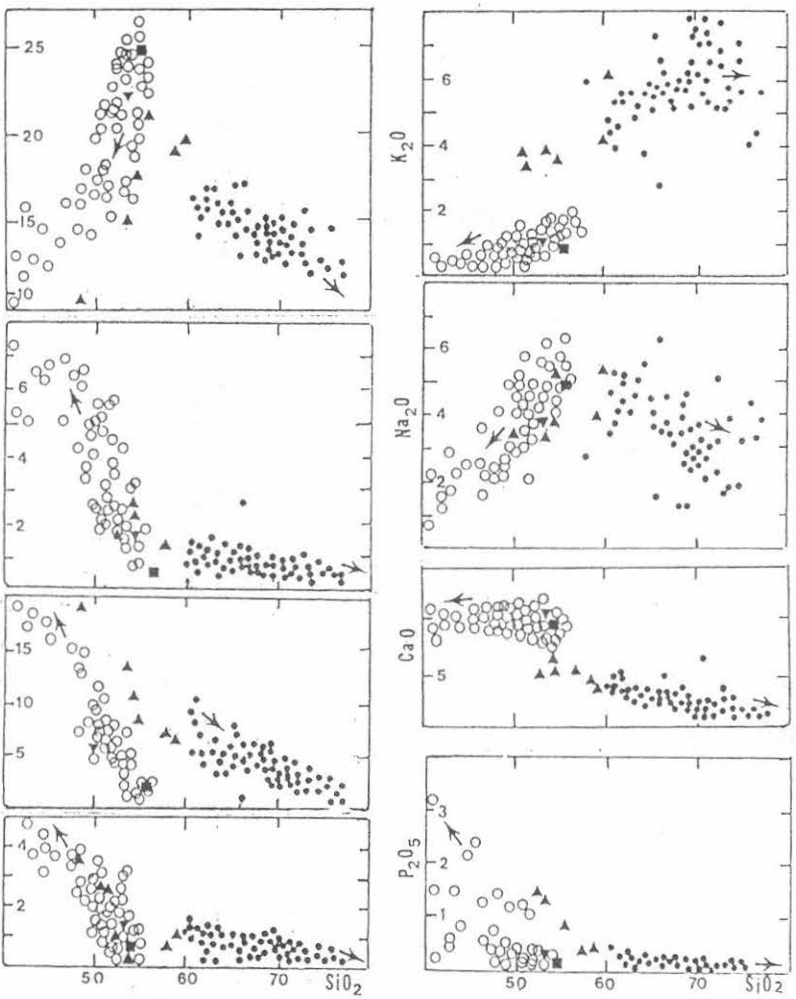


Fig. 14. Harker variation diagrams or AMCG-rocks of the Marcy massif. Open circles=anorthositic suite, filled circles=granitoid suite, upright triangles=mixed rocks, inverted triangles=Whiteface facies, square=Marcy facies. Arrows indicate differentiation trends.

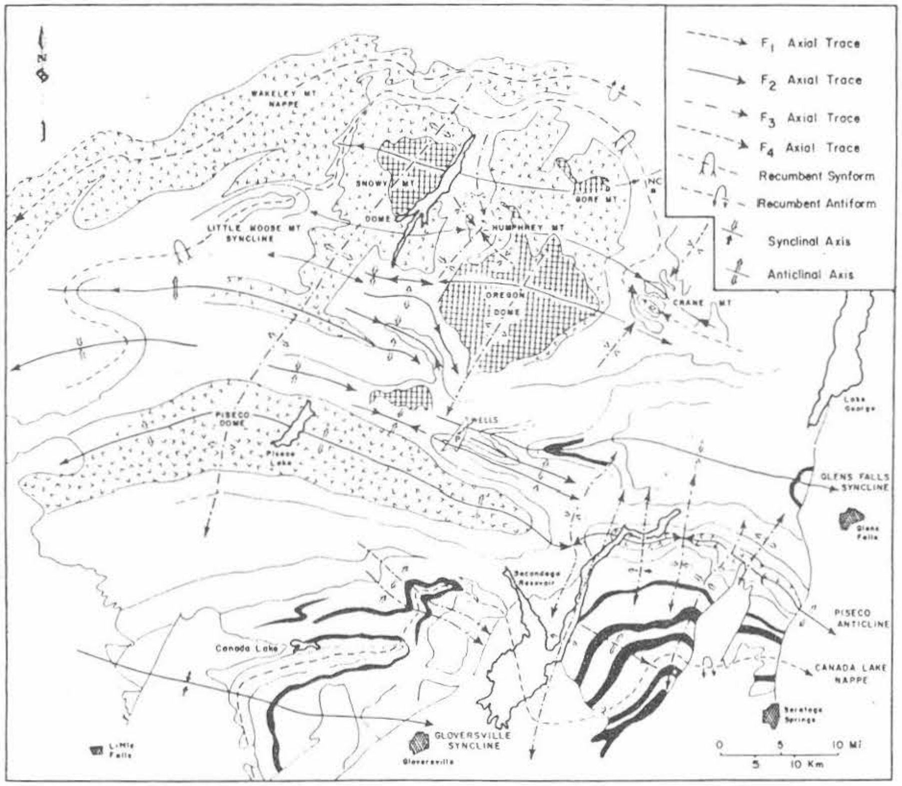


Fig. 15. Fold axes within the southern and central Adirondacks. Designation of folds as synclines and anticlines is provisional, since facing directions are not yet known.

corresponds to an original shelf to deep water transition, now largely removed by later intrusion, doming, and erosion. The Irving Pond quartzite may represent a siliceous clastic cap closing out the earlier deep water basin.

A single specimen of metapelite (no. 21, table 2) has yielded a T_{DM} of 2075 Ma. This model age approximates the time at which source rocks for the metasediment separated from the mantle. Although the age may be the result of mixing rocks >2075 Ma with younger components, the older material clearly predates any possible Adirondack sources.

STRUCTURAL GEOLOGY

The southern Adirondacks is an area of intense ductile strain, essentially all of which must postdate the ca. 1150 Ma AMCG rocks which are involved in each of the major phases of deformation, i.e., the regional strain is associated with the Ottawan Orogeny.

As shown in figures 2 and 15, the southern Adirondacks are underlain by very large folds. Four major phases of folding can be identified and their intersections produce the characteristic fold interference outcrop patterns of the region (fig. 16).

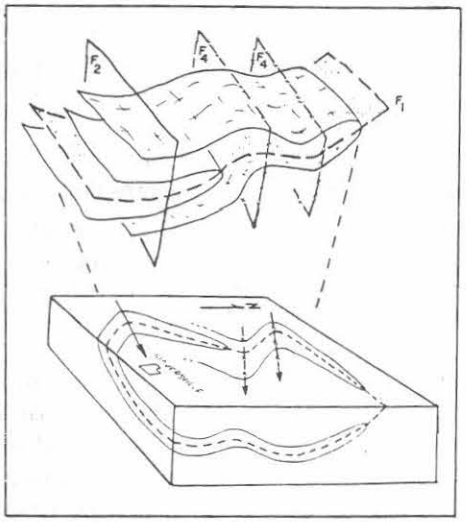


Fig. 16. Block diagram showing how interference between F_1, F_2, and F_4 fold sets produce the outcrop pattern of the F_1 Canada Lake isocline. The axial plane of the F_1 fold is stippled and its fold axis plunges 10-15° to the southeast. The city of Gloversville is shown.

The earliest recognizable map-scale folds (F_1) are exceptionally large isoclinal recumbent structures characterized by the Canada Lake, Little Moose Mt., and Wakely Mt. isoclines, whose axes trend E-W and plunge 10-15° about the horizontal. The Little Moose Mt. isocline is synformal (deWaard 1964) and the other two are antiformal, and suspected to be anticlinal, but the lack of stratigraphic facing directions precludes any certain age assignments although these are designated in figure 15 on a provisional basis. All of these structures fold an earlier tectonic foliation consisting of flattened mineral grains of unknown age and origin. An axial planar cleavage is well developed in the Canada Lake isocline, particularly in the metapelitic rocks.

F_2-folds of exceptionally large dimensions trend E-W across the region and have upright axial planes (fig. 15). They are coaxial with the F_1 folds suggesting that the earlier fold axes have been rotated into parallelism with F_2 and that the current configurations of both fold sets may be the result of a common set of forces. An intense ribbon lineation defined by quartz and feldspar rods parallels the F_2-axes along the Piseco anticline, Gloversville syncline, and Glens Falls syncline and documents the high temperatures, ductile deformation and mylonitization that accompanied the formation of these folds.

Large NNE trending upright folds (F_3) define the Snowy Mt. and Oregon domes (fig. 15). Where the F_3 folds intersect F_2 axes structural domes (i.e., Piseco dome) and intervening saddles result. A late NW-trending fold set results in a few F_4 folds between Canada Lake and Sacandaga Reservoir (fig. 15).

Kinematic indicators (mostly feldspar tails) in the area suggest that the dominant displacement involved motion in which the east side moved up and to the west (McLelland 1984). In most instances this implies thrusting motion, however, displacement in the opposite sense has also been documented. This suggests that relative displacement may have taken place in both senses during formation of the indicators. A movement picture consistent with this is still under investigation, although regional extension analogous to that in core complexes might resolve the situation.

METAMORPHISM

Figure 6 shows the well known pattern of paleoisotherms established by Bohlen and Essene (1977) and updated in Bohlen et al. (1985). Paleotemperatures have been established largely on the basis of two-feldspar geothermometry but (Fe, Ti)-oxide methods have also been used and, locally, temperature-restrictive mineral assemblages have been employed (Valley 1985). The bull's eye pattern of paleoisotherms, centering on the Marcy massif, is believed to the due to late doming centered on the massif. Paleopressures show a similar bull's eye configuration with pressures of 7-8 kbar decreasing outward to 6-7 kbar away from the massif and reaching 5-6 kbar in the Lowlands (Bohlen et al. 1985).

Bohlen et al. (1985) interpret the paleotemperature pattern of figure 6 as representative of peak metamorphic temperatures in the Adirondacks, and paleopressures are interpreted similarly. Chiarenzelli and McLelland (1991) show that disturbance of U-Pb systematics in zircons corresponds with Bohlen et al.'s (1985) paleoisotherms (fig. 6), and this correlation strengthens the conclusion that the pattern is one of peak temperatures rather than a retrograde set frozen in from a terrane of uniform temperatures in the range ~750°-800°C.

The P,T conditions of the Adirondack are those of granulite facies metamorphism, and for the most part conditions correspond to the hornblende-clinopyroxene-almandine subfacies of the high-pressure portion of the granulite facies. These conditions must have been imposed during the Ottawan Orogeny in order to have affected rocks as young as 1050 Ma. The identification of ca. 1050-1060 Ma metamorphic zircons by McLelland and Chiarenzelli (1990) fixes the time of peak metamorphic conditions and corresponds well with titanite and garnet U-Pb ages of ca. 1030-1000 Ma in the Highlands (Mezger 1990). Rb-Sr whole rock isochron ages of ca. 1100-1000 Ma also reflect Ottawan temperatures and fluids. Despite the high-grade, regional character of the Ottawan Orogeny, the preservation of foliated garnet-sillimanite xenoliths in an 1147±4 Ma metagabbro (McLelland et al. 1987a), and the report of some 1150 Ma U-Pb garnet ages (Mezger 1990), reveals that earlier assemblages from the Elzevirian and AMCG metamorphic pulses managed to survive locally. The dehydrating effects of these high temperature events, as well as the anhydrous nature of the AMCG rocks themselves, are thought to be responsible for creating a water-poor terrane throughout the Adirondack Highlands prior to the Ottawan Orogeny.

The present day depth to the Moho beneath the Adirondack Highlands is ~35 km (Katz 1955). Since metamorphic pressures of 7-8 kbar correspond to ~20-25 km depth of burial, it follows that during metamorphism the Adirondack region consisted of a double thickness of continental crust. Present day examples of doubly thickened continental crust are found in continent-continent collisional margins such as the Himalayas or Andean margins such as along the coast of South America. The latter model is not readily applicable to the Ottawan-age Adirondacks, because of the absence of calcalkaline magmatism of that age. On the other hand, the Himalayan-Tibetan analogue provides a strikingly consistent model, including the rather limited amount of associated magmatism. Because no suggestion of a suture exists between the Green Mts. of Vermont and the Grenville Tectonic Front, and because of the dominance of tectonic vergence to the northwest throughout the region, the Ottawan plate margin has been placed east of the Grenville inliers of the Appalachians and assigned an eastward dip. Although highly speculative, this possibility, together with other plate tectonic reconstructions are shown in figure 17.

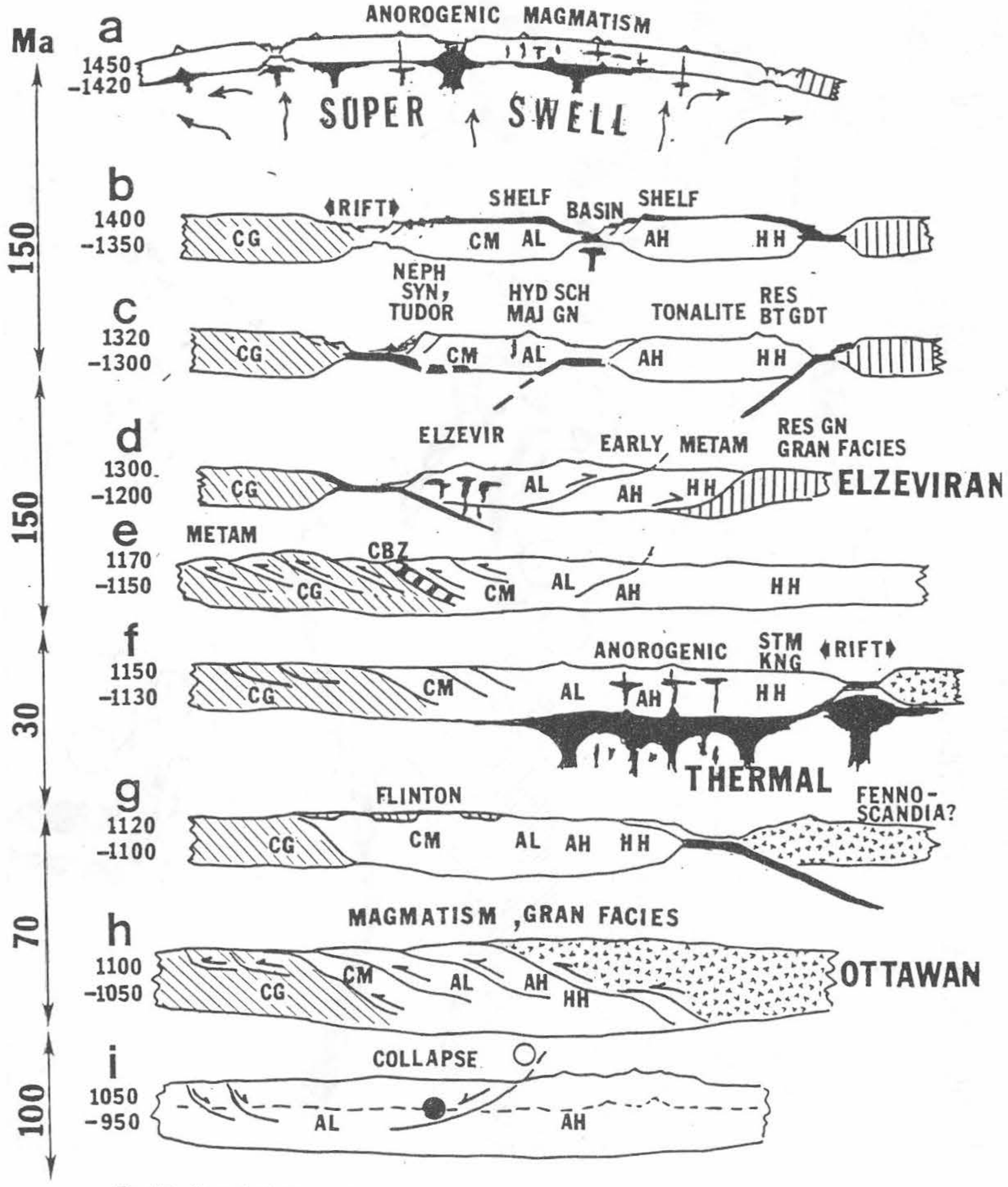


Fig. 17. Hypothetical plate tectonic scenarios for the southwestern Grenville Province.

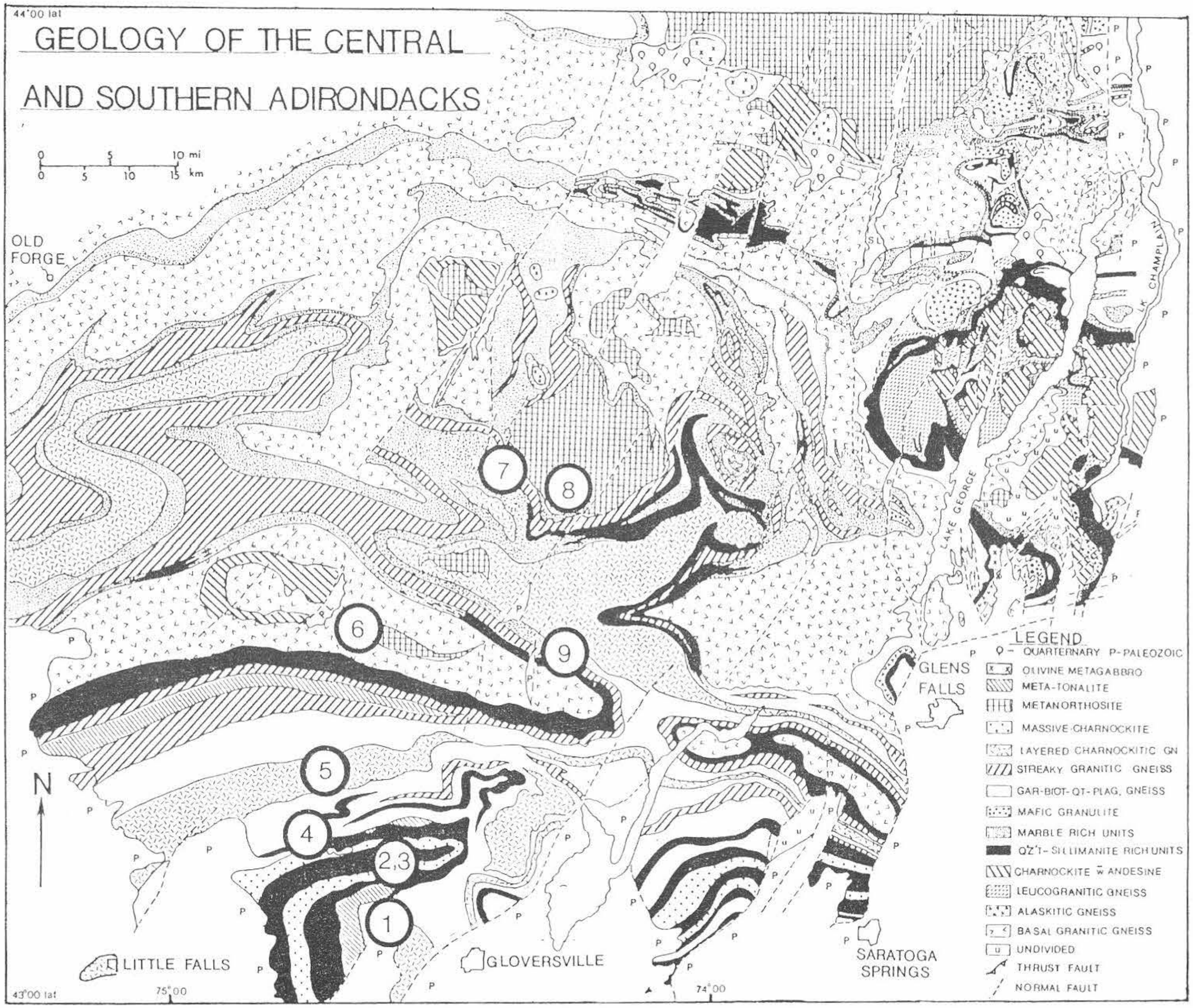


Fig. 18. Geologic map of the southern and central Adirondacks with field trip stops 1-9 indicated (McLelland and Isachsen 1986).

ROAD LOG

(See fig. 18 for stop locations)

CUMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
	0	Junction of Willie Road, Peck Hill Road, and NY Rt. 29A
1.3	1.3	Mud Lake to northeast of NY Rt. 29A
1.8	1.5	Peck Lake to Northeast of NY Rt. 29A
3.6	1.8	STOP 1. Peck Lake Fm.

STOP 1.

This exposure along Rt. 29A just north of Peck Lake is the type locality of the sillimanite-garnet-biotite-quartz-feldspar gneisses (kinzigites) of the Peck Lake Fm. in addition, there are exposed excellent minor folds of several generations. Note that the F_1 folds rotate an earlier foliation. The white quartzo-feldspathic layers in the kinzigites consist of quartz, two feldspars,and garnet and ar believed to be anatectic and have been folded by F_1 indicating pre-F_1 metamorphic events. Typical whole rock compositions are shown below. Spinel has been found enclosed in garnets at this outcrop. The similarity of the Peck Lake Fm. to the Major Paragneiss of the Lowlands suggests that the Adirondacks were contiguous at the time of deposition of the rocks.

Table 4.

COMPOSITIONS OF REPRESENTATIVE LEUCOSOME AND HOST ROCK — SELECTED CLASTICS

	Leucosome		Host Rock		Average Greywacke[a] (Σ = 23)	Average PC Slate[b] (Σ = 33)	Average Slate[c] (Σ = 36)
	LL1	9-17-2A	10-29-1B	9-11-4B			
SiO_2	75.61	74.60	68.04	64.24	64.70	56.30	60.64
Al_2O_3	13.75	13.49	13.93	16.16	14.80	17.24	17.32
TiO_2	.02	.19	.86	.90	.50	.77	.73
Fe_2O_3	.51	1.47	6.08	7.44	4.10	7.22	4.81
MgO	.11	.54	1.45	1.57	2.20	2.54	2.60
CaO	.36	1.64	1.65	3.41	3.10	1.00	1.20
Na_2O	2.19	3.25	2.84	3.20	3.10	1.23	1.20
K_2O	6.82	4.69	3.27	2.92	1.90	3.79	3.69
MnO	.02	.04	.06	.09	.10	.10	...
P_2O_5	.09	.08	.18	.17	.20	.14	...
LOI	.31	.25	.66	.66	2.40	3.70	4.10
TOTAL	99.78	100.24	99.80	99.76	101.00	98.70	98.00

CUMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
6.1	2.5	Junction NY Rt. 29A and NY Rt. 10
8.0	1.9	Nick Stoner's Inn on west side of NY Rt. 29A-10
8.6	.6	STOP 2. Irving Pond Fm., .5 mile north of Nick Stoner's Inn, Canada Lake. Very near hinge line of F_1 Canada Lake isocline.

STOP 2.

The outer portion of the Irving Pond Fm. is exposed in low cuts along the east side of Rt. 29A just prior to the crest in the road heading north.

At the southern end of the cut typical, massive quartzites of the Irving Pond are seen. Proceeding north the quartzites become "dirtier" until they develop sillimanite-garnet-biotite-feldspar (kinzigites) layers along with quartzite.

At the northern end of the cut, and approximately on the Irving Pond/Canada Lake Fm. contact there occurs an excellent set of F_1 minor folds. Polished slabs and thin sections demonstrate that these fold an earlier foliation defined by biotite flakes and flattened quartz grains.

At the southern end of the outcrop dark, fine grained metadiabase sheets crosscut the quartzite. Near the telephone pole erosional remnants of diabase appear to truncate approximately horizontal foliation in the quartzite suggesting that the diabase was emplaced after an early metamorphism. At the north end of the cut a diabase sheet of variable thickness is folded in the F_1 fold. The folding is interpreted as Ottawan, the diabase as AMCG in origin, and the early foliation as Elzevirian. This is consistent with the presence of quartzite xenoliths in the ca. 1300 Ma tonalites.

The Irving Pond Fm. is the uppermost unit in the lithotectonic sequence of the southern Adirondacks. Its present thickness is close to 1000 meters, and it is exposed across strike for approximately 4000 meters. Throughout this section massive quartzites dominate.

8.8	.2	STOP 3. Canada Lake Charnockite (>1233 Ma, table 1, sample AM-87-13. Now fixed at 1251±43)

STOP 3.

Large roadcuts expose the type section of the Canada Lake charnockite. Lithogically the charnockite consists of 20-30% quartz, 40-50% mesoperthite, 20-30% oligoclase, and 5-10% mafics. The occurrence of orthopyroxene is sporadic. These exposures exhibit the olive-drab coloration that is typical of charnockites. Note the strong foliation in the rock. Farther north along the highway there are exposed pink leucogranitic variants of this unit. The chemical composition of these is given in table 3 (ab-6). The whole rock chemistry of the charnockitic phase is similar to AM-86-17 in table 3. The lateral continuity of the Canada Lake is striking (fig. 2) but the presence of xenoliths reveals an intrusive origin.

10	1.2	STOP 4. Royal Mt. Tonalite (>1301 Ma, table 1, sample AM-86-12, now fixed at 1307±2 Ma).

STOP 4.

Steep roadcuts, exposed across from the Canada Lake Store, expose typical examples of the early tonalitic rocks that occur within the southern and eastern Adirondacks and that manifest the presence, throughout the region, of collisional magmatic arcs of calcalkaline chemistry that existed along the eastern margin of Laurentia from ca. 1400-1200 Ma. Amalgamation of these arcs culminated in the Elzevirian Orogeny at ca. 1250-1220 Ma.

The whole rock chemistry of the tonalitic rocks is given in table 3 and important chemical trends are portrayed in figures 8, 9, and 10. Figure 7 shows the ϵ_{Nd} characteristics of these rocks and emphasizes their petrologically juvenile character, i.e., they are not derived from any crustal rocks with long-term crustal residence but are essentially mantle derived (including derivation from melting of basaltic rock derived from the mantle at ca. 1300-1400 Ma). The ϵ_{Nd} characteristics are compared with those from Lowland tonalites and granitoids of similar age, and the similarity suggests that they are essentially the same, strongly suggesting contiguity across the entire Adirondacks at that time (~1300 Ma).

A disrupted layer of amphibolitic material runs down the outcrop to road level at the east end of the outcrop. This, and other mafic sheets in the outcrop, are interpreted as dikes an sheets coeval with the tonalite. In the eastern Adirondacks it has been possible to document mutually crosscutting relationships between these rock types. Also documented there are xenoliths of kinzigitic rock in the tonalites. Within the southern Adirondacks xenoliths of quartzite similar to the Irving Pond Fm. have been found in the tonalite.

11.8	1.8	Pine Lake, Junction NY Rt. 29A and NY Rt. 10. Proceed north on NY Rt. 10.
17.5	5.7	STOP 5. Rooster Hill megacrystic gneiss at the north end of Stoner Lake (1156±8 Ma, table 1, sample AM-86-17).

STOP 5.

This distinctive unit belongs to the AMCG suite and is widespread in the southern Adirondacks. Here the unit consists of a monotonous series of unlayered to poorly layered gneisses characterized by large (1-4") megacrysts of perthite and microcline perthite. For the most part these megacrysts have been flattened in the plane of foliation, however, a few megacrysts are situated at high angles to the foliation and show tails. The groundmass consists of quartz, oligoclase, biotite, hornblende, garnet, and occasional orthopyroxene. An igneous rock analogue would be monzonite to quartz-monzonite (see table 3 for chemical composition) and the presence of orthopyroxene makes the rock mangeritic to charnockitic.

The contacts of the Rooster Hill megacrystic gneiss are everywhere conformable, but the presence of xenoliths of kinzigite indicate its intrusive nature. Rocks such as the Rooster Hill are interpreted as derived from melting of ca. 1300 Ma tonalitic and lower crustal granitoid rocks with heat derived from large AMCG gabbroic intrusions that would ultimately differentiate to anorthosite. This suggestion is consistent with the ϵ_{Nd} trends of AMCG and tonalitic rocks in figure 7a and with the REE distributions shown in figure 19, where it appears that melting of tonalite so as to leave a plagioclase-rich residue can give the AMCG REE-trends.

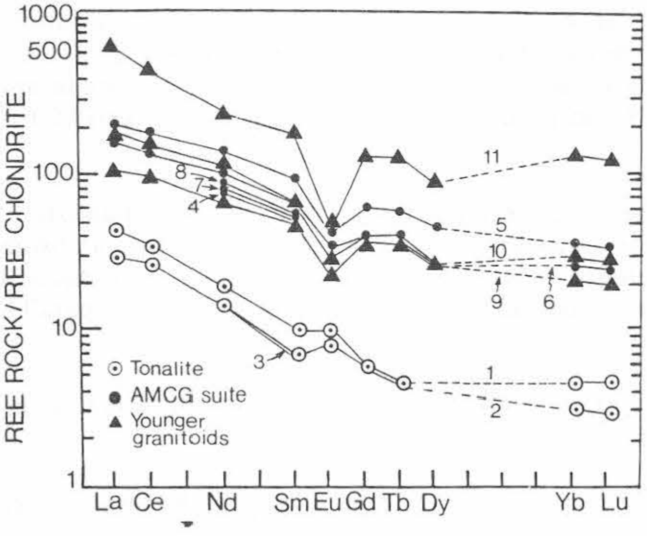


Fig. 19. Chondrite normalized REE concentrations for the Adirondack highlands. Numbers refer to samples in table 1 of Daly and McLelland (1991).

20.0	2.5	Low roadcut in kinzigites.
21.4	1.4	Avery's Hotel on west side of NY Rt. 10
22.5	1.1	Long roadcuts of pink quartzofeldspathic gneisses and metasediments of intruded metagabbro and anorthosite metagabbro. The igneous rocks are believed to belong to the AMCG suite.
23.6	1.1	Roadcut of anorthositic metagabbro and metanorite of AMCG suite.
23.9	.3	Roadcut on west side of highway shows excellent examples of anorthositic gabbros intrusive into layered pink and light green quartzofeldspathic gneisses.
24.0	.1	Pink granitic gneiss of AMCG suite intruded by anorthositic AMCG gabbros and gabbroic anorthosites. Large boudin of calcsilicate in granite.
24.3	.3	Roadcuts of quartzites and other metasediments of the Sacandaga Fm. Mezger (1990) obtained a U-Pb garnet age of ca. 1154 from these rocks.
31.0	5.7	Red-stained AMCG quartzofeldspathic gneisses that have been faulted along NNE fractures.
31.5	.5	Junction of NY Rt. 10 and NY. Rt. 8. End Rt. 10. Turn east on NY Rt. 8.
32.0	.5	STOP 6. Core rocks of the Piseco anticline (1150±5 Ma, table 1, sample AM-86-9).

STOP 6.

This stop lies along the hinge line of the F_2 Piseco anticline near its domical culmination at Piseco Lake. The rocks here are typical ofthe granitic facies of quartzofeldspathic gneisses such as occur in the Piseco anticline and in other large anticlinal structures, for example Snowy Mt. dome, Oregon dome.

The pink "granitic" gneisses of the Piseco anticline do not exhibit marked lithologic variation. Locally grain size is variable and in places megacrysts seem to have been largely grain size reduced and only a few small remnants of cores are seen. The open folds at this locality are minor folds of the F_2 event. Their axes trend N70W and plunge 10-15° SE parallel to the axis of the Piseco anticline.

The most striking aspect of the gneisses in the Piseco anticline is their well-developed lineation. This is expressed by rod, or pencil-like, structures which are clearly the result of ductile extension of quartz and feldspar grains in a granitic protolith. The high temperature, grain size reduction that has occurred results in a mylonite. Where recognizable, early F_1 isoclinal fold axes parallel the lineation.

These rocks are similar in age and chemistry to other AMCG granites and are considered to be part of that suite.

Smooth outcrops of Piseco Core rocks showing exceptionally strong mylonitic ribbon lineations.

43.5	11.5	Junction NY Rt. 8 and NY Rt. 30 in Speculator. Head southeast on NY Rt. 8-30.
47	3.5	STOP 7. Northern intersection of old Rt. NY 30 and new Rt. NY 30, 3.3 miles east of Speculator, New York.

STOP 7.

Typical Adirondack marble is exposed in roadcuts on both sides of the highway. These exposures show examples of the extreme ductility of the carbonate-rich units. The south wall of the roadcut is particularly striking, for here relatively brittle layers of garnetiferous amphibolite have been intensely boudinaged and broken. The marbles, on the other hand, have yielded plastically and flowed extensively during the deformation. As a result, the marble-amphibolite and marble-charnockite relationships are similar to those that would be expected between magma and country rock. Numerous rotated, angular blocks of amphibolite and charnockite are scattered throughout the marble in the fashion of xenoliths in igneous intrusions. At the eastern end of the outcrop tight isoclinal folds of amphibolite and metapelitic gneisses have been broken apart and rotated. The isolated fold noses that remain "floating" in the marble have been aptly termed "tectonic fish". The early, isoclinal folds rotate on earlier foliation. The garnetiferous amphibolites have typical igneous compositions and are interpreted as flows or sills.

Near the west end of the outcrop a boudin of charnockite is well exposed. McLelland and others (1987) have presented evidence that boudin represents a local example of charnockitization by carbonic metamorphism. However, granites of similar composition outside the marble do not develop orthopyroxene, demonstrating the local nature of the process and the limited permeation of the fluid phase.

Exposed at several places in the roadcut are crosscutting veins of tourmaline and quartz displaying a symplectic type of intergrowth. Other veins include hornblende- and sphene-bearing pegmatites.

Almost certainly these marbles are of inorganic origin. No calcium carbonate secreting organisms appear to have existed during the time in which these carbonates were deposited (>1200 Ma ago). Presumably the graphite represents remains of stromatolite-like binding algae that operated in shallow water, intertidal zones. This is consistent with the presence of evaporitic minerals, such as gypsum, in Lowland marbles.

At the eastern end of the outcrop coarse diopside and tremolite are developed in almost monomineralic layers. Valley et al. (1983) showed that the breakdown of almost Mg-pure tremolite to enstatie, diopside, and quartz in these rocks requires low water activity at the regional P,T conditions. Similarly, the local presence of wollastine requires lowering of CO_2 activity, presumably by H_2O. These contrasts demonstrate the highly variable composition of the fluid phase and are consistent with a channelized fluid phase within a largely fluid-absent region.

47.5	.5	Extensive roadcuts in lower part of marble. Quartzites, kinzigites, and leucogneisses dominate. Minor marble and calcsilicate rock is present.
47.9	2.5	Large roadcuts in well-layered, pink quartzofeldspathic gneisses with subordinate amphibolite and calcsilicate rock. The layering here is believed to be tectonic in origin, and the granitic layers represent an intensely deformed granite. The calcsilicate layers may be deformed xenoliths.

49.0	1.1	STOP 8. One half mile south of southern intersection of old Rt. 30 and with new Rt. 30. Anorthositic rocks on the SW margin of the Oregon Dome.

STOP 8.

On the west side of the highway a small roadcut exposes typical Adirondack anorthosite and related phases.

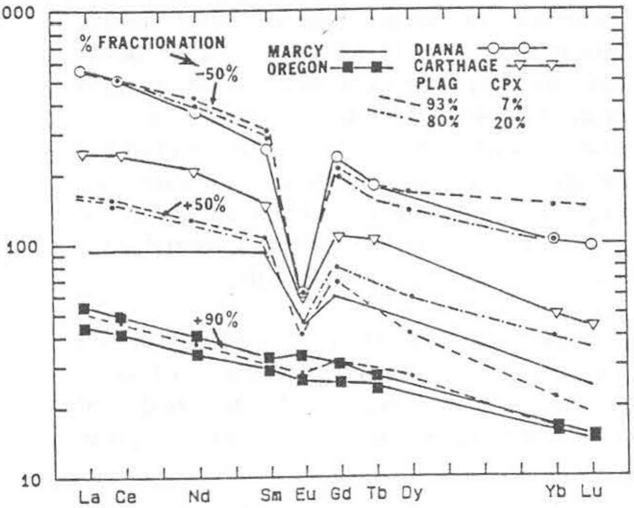


Fig. 20. Chondrite normalized REE concentrations for several Adirondack ferrogabbroic occurrences. Percentage fractionation of plagioclase and clinopyroxene are shown for a starting composition given by Carthage ferrogabbro (trianges). The Diana occurrence corresponds to sheets of breccia-bearing mafic material referred to by Buddington (1939) as shonkinite. The breccia consists of K-feldspar fragments from the host pyroxene syenite of the Diana complex.

The glacially smoothed upper surface of the roadcut reveals the presence of three major igneous phases: 1) a dark, pyroxene-rich dike that crosscuts the anorthosite, contains anorthosite xenoliths, and contains a large irregular, disrupted mass of sulfidic calcsilicate; 2) a coarse grained, Marcy-type anorthosite facies with andesine crystals 6-8" across; and 3) a fine grained anorthositic phase. Some of the coarse grained facies has been crushed and these portions bear some resemblance to the finer grained phase (note, for example, those places where fractures cross large andesine grains and produce finer grained material). However, close inspection of the finer grained material reveals the presence of ophitic texture with pyroxenes of approximately the same size as the plagioclase, and this texture and association are much better explained as igneous in origin. Therefore, the texture of the fine grained phase is interpreted as igneous in origin and may be due to chilling near the contact of the Oregon Dome massif. By contrast, large (3-4 cm) rafts of coarse grained, ophitic gabbroic anorthosite seem to be "flat" in the fine grained phase. Analyses of typical anorthositic rocks are shown in Table 5.

The pyroxene-rich ferrogabbro dike shows "soft" contacts with the anorthosite and is interpreted as essentially coeval. Zircons from it give a minimum age of 1087 Ma and, by comparison with other Adirondack anorthosites, its emplacement age is set at ca. 1135 Ma. The composition of the ferrogabbro is shown in table 5 where it is seen to be rich in TiO_2 and P_2O_5. Similar rocks occur together with other Adirondack anorthosites and are interpreted as late, Fe-enriched differentiates of a Fenner-type fractionation trend (see fig. 14). It is suggested that further differentiation within these rocks can result in liquid immiscibility and the production of magnetite-ilmenite liquids.

Table 5.

No. of Samples	Jotunite	Anorthositic Gabbro Green Mt.	Anorthosite Green Mt.	Anorthosite Owls Head	Mangerite Tupper Lake	Keene Gn. Hulls Falls	Marcy-type Anorthosite[a]	Whiteface Anorthosite[a]
	1	1	1	1	3	2	4	7
SiO_2	47.16	55.88	56.89	53.65	62.12	51.63	54.54	53.54
TiO_2	2.20	1.6	0.47	0.52	0.87	3.1	0.67	0.72
Al_2O_3	17.23	18.23	23.82	24.96	16.48	14.23	25.61	22.50
Fe_2O_3	2.75	2.4	1.21	0.41	1.49	2.1	1.00	1.26
FeO	9.24	6.57	1.3	0.70	3.96	13.5	1.26	4.14
MnO	0.15	0.09	0.02	0.02	0.09	0.16	0.02	0.07
MgO	2.71	2.08	0.65	1.45	1.06	2.63	1.03	2.21
CaO	9.04	4.87	8.19	12.21	3.27	6.5	9.92	10.12
Na_2O	6.61	4.26	5.38	3.92	4.81	2.67	4.53	3.70
K_2O	2.27	2.76	1.13	1.20	5.13	2.41	1.01	1.19
P_2O_5	0.59	0.48	0.09	0.09	0.30	0.57	0.09	0.13
H2O	0	0.09	0.42	0.04	0.32	0.07	0.55	0.12
Total	99.70	99.94	99.57	99.17	99.90	99.57	100.17	100.00

The upper, weathered surface of the outcrop affords the best vantage point for studying the textures and mineralogy of the anorthositic rocks. In several places there can be seen excellent examples of garnet coronas of the type that are common throughout Adirondack anorthosites. These coronas are characterized by garnet rims developed around iron-titanium oxides and pyroxenes. Recently McLelland and Whitney (1977) have succeeded in describing the development of these coronas according to the following generalized reaction:

Orthopyroxene + Plagioclase + Fe-bearing oxide + Quartz = Garnet + Clinopyroxene.

This reaction is similar to one proposed by de Waard (1965) but includes Fe-oxide and quartz as necessary reactant phases. The products are typomorphic of the garnet-clinopyroxene subfacies of the granulite facies (de Waard 1965). The application of various geothermometers to the phases present suggests that the P,T conditions of metamorphism were approximately 8 kb and 700±50°C respectively.

51.0	2.0	Minor marble, amphibolite, and calcsilicate rock. Predominantly very light colored sillimanite-garnet-quartz-feldspar leucogneisses interpreted as minimum-melt granitic due to anatexis of kinzigite near Oregon dome anorthosite. Enclaves of spinel- and sillimanite-bearing metapelite are present.
52.0	1.0	Junction to NY Rt. 8 and NY Rt. 30. Continue south on NY Rt. 30. To the west of the intersection are roadcuts in garnetiferous metasediment. A large NNE normal fault passes through here and fault breccias may be found in the roadcut and the woods beyond.
52.5	.5	Entering granitic-charnockitic gneiss on northern limb of the Glens Falls syncline. Note that dips of foliation are to the south.
54.8	2.3	Entering town of Wells which is situated on a downdropped block of lower Paleozoic sediments. The minimum displacement along the NNE border faults has been

		determined to be at least 1000 meters.
58.3	3.5	Silver bells ski area to the east. The slopes of the ski hill are underlain by coarse anorthositic gabbro that continues to the west and forms the large sheet just south of Speculator.
60.3	2.0	Entrance to Sacandaga public campsite. On the north side of NY Rt. 30 are quartzo-feldspathic gneisses and calcsilicates. An F_1 recumbent fold trends sub-parallel to the outcrop and along its hinge line dips become vertical.
60.8	.5	Gabbro and anorthositic gabbro.
62.0	1.2	STOP 9. Pumpkin Hollow.

STOP 9.

Large roadcuts on the east side of Rt. 30 expose excellent samples of the Sacandaga Fm. At the northern end of the outcrop typical two pyroxene-plagioclase granulites can be seen. The central part of the outcrop contains good light-colored garnet-microcline-quartz gneisses (leucogneisses). Although the weathered surfaces of these rocks are often dark due to staining, fresh samples display the typical white vs. grey color of the Sacandaga Fm. The characteristic and excellent layering of the Sacandaga Fm. is clearly developed. Note the strong flattening parallel to layering. Towards the southern end of the outcrop calc-silicates and marbles make their entrance into the section. At one fresh surface a thin layer of diopsidic marble is exposed.

At the far southern end of the roadcut there exists an exposure of the contact between the quartzo-feldspathic gneisses of the Piseco anticline and the overlying Sacandaga Fm. The hills to the south are composed of homogenous quartzo-feldspathic gneisses coring the Piseco anticline (note how ruggedly this massive unit weathers). The Sacandaga Fm. here has a northerly dip off the northern flank of the Piseco anticline and begins its descent into the southern limb of the Glens Falls syncline.

The pronounced flaggy layering in the Sacandaga Fm. is not of primary sedimentary or volcanic origin. Instead it is tectonic layering within a "straight" gneiss. Hand specimen and microscopic inspection of the light layers, particularly, reveals the existence of extreme grain size reduction and ductile flow. Long quartz rods consist of rectangular compartments of recovered quart and annealed feldspar grains occur throughout. The rock is clearly a mylonite with its mylonitic fabric parallel to compositional layering.

The chemistry of the light colored layers in the Sacandaga Fm. indicates that they are minimum melt granites. As one proceeds away from the core of the Piseco anticline, these granitic layers can be traced into less deformed sheets and veins of coarse granite and pegmatite. In the most illustrative cases the granitic material forms anastamozing sheets that get grain size reduced and drawn into parallelism as high strain zones are approached. The Sacandaga Fm. is interpreted as an end result of this process and represents a mylonitized migmatite envelope developed in metapelites where they were intruded by AMCG granites at ca. 1150 Ma and then intensely strained during the Ottawan Orogeny at ca. 1050 Ma. This interpretation is consistent with field relationships, the presence of spinel and sillimanite restites in the leucosomes, and with the fact that similar metapelitic rocks are crosscut by ca. 1300 Ma tonalites. The latter observation makes the Sacandaga Fm. protoliths older than the ca. 1150 Ma granitic rocks in the Piseco anticline and makes an intrusive relationship obligatory despite the conformable contact at the south end of the roadcut.

62.5-67.0	.5-4.5	All exposures are within the basal quartzo-feldspathic gneisses at the core of the Piseco anticline.
67.0	4.5	Re-enter the Sacandaga Fm. Dips are now southerly.
68.0	1.0	In long roadcuts of southerly dipping pink, quartzo-feldspathic gneisses with tectonic layering. The coarse grain size of the gneissic precursors can be seen in many layers.
70,4	2.4	Cross bridge over Sacandaga River.
74.4	4.0	Bridge crossing east corner of Sacandaga Reservoir into Northville, N.Y.

END LOG

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