PRE-CAMBRIAN AND PALEOZOIC GEOLOGY OF THE HUDSON HIGHLANDS

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Trip D

Introduction

The route of Trip D crosses the Hudson Highlands northwestward (perpendicular to the structural trend) affording opportunities of studying the petrology, structure and geomorphology of the Pre-Cambrian crystallines. It then turns northeastward to reach the northern gateway of the Hudson gorge at Cornwall-on-Hudson by following the belt of early Paleozoic sediments along the northwest border of the Highlands. These sediments and their structural relations to the Highlands crystallines are briefly examined in the field. The return leg of the trip again crosses the Highlands (this time oblique to the structure) along the west side of the Hudson gorge to Bear Mt., where it crosses the River to Peekskill.

The reader is referred to Lowe (1949, 1950) from which much of the following information has been extracted.

The Hudson Highlands

The Highlands are a chain of low, but rugged, mountain ranges extending about 140 miles from Reading, Pa. northeastward through northern New Jersey and southeastern New York into western Connecticut. They are mostly Pre-Cambrian crystallines, representing an ancient orogenic belt of Grenville (?) sediments which were folded, faulted, metamorphosed and invaded by several igneous phases (Plate 1).

The Hudson Highlands, a rather loose geographical term, refers to that portion of the mountain chain which lies athwart the Hudson River in New York State.

Geomorphology

Geomorphically the Highlands are known as the Reading Prong of the New England Upland.

In view of the long, continued exposure of the Highlands to subaerial erosion (perhaps since early Mesozoic times) present topographic features exhibit the effects of structural and lithologic control to a high degree. Hessian Lake, a glacially scoured depression along the contact of the resistant Storm King granite and the weaker metasediments (Stop D-2), and the prominent notch at Timp Pass where a major thrust fault crosses the ridge (seen from Stop D-3) are but two examples observed on this trip.

In some instances even minor internal rock structures (e.g. obscure platy flow structure in the Storm King granite) are emphasized by the development of subsequent erosional surfaces (Stop D-2 and Plate 12, west shore of Hessian Lake). Thus geomorphic expression is frequently used to interpret concealed or questionable subsurface structures.

The origin and development of the Hudson Rivergorge through the Highlands has been a source of controversy for many years. The reader is referred to the discussion of Trip C(and Stop C-1), written by a geomorphologist, for a brief resume of the salient features and arguments.

An unusual erosional feature in this Highlands terrane is the Natural Bridge at the southwest end of Popolopen Lake where a creek flowing into the lake has tunnelled through a thick bed of coarse (Paleozoic ?) marble.

Certain characteristic weathering phenomena also bear mentioning. The Storm King granite exhibits prominent sheeting or exfoliation parallel to existing topographic surfaces (Stops D-2 and D-3), which can best be explained by "unloading".

In localities where glaciation failed to remove the residual mantle this granite weathers to a characteristic "rubble". The elongate weathered fragments were produced by kaolinization of the feldspars and relative preservation of the parallel alignment (lineation) of the hornblende prisms (Stop D-3).

Huge talus boulders of Storm King granite (often parts of ancient landslides) are common along the steep flanks of Bear Mt. where they were derived by mechanical weathering of joint blocks produced by near-vertical longitudinal (SW-NE) and transverse (NW-SE) joints (Stop D-2; west shore of Hessian Lake).

Evidence of Wisconsin glaciation is abundant. Upland surfaces (Bear Mt., The Torne, etc.) show glacial polishing and chatter marks. Glacial striae, however, are relatively uncommon, because weathering and exfoliation on exposed granite ledges have effectively destroyed such markings. Glacial boulders are scattered over the entire region. Till and drift have accumulated to considerable depths in some of the valleys (e.g. Doodletown Brook valley, Popolopen Creek valley NE of lunch stop, etc.).

Regional Structures

The folded structure of the Highlands is clearly indicated by the topography of the Bear Mt. region (Plate 10). Ridges of resistant Storm King granite, which was intruded conformably with the structure of the country rocks, depart from their prominent northeasterly trend indicated by Cranberry Hill - Long Mt. - Holmans Hill. The trends of Turkey Hill - Summer Hill - West Mt. - The Timp - Dunderberg (the last two are not shown on Plate 10) describe a distinct arcuate pattern with Bear Mt. as the center. Field measurements proved the existence of a large, synclinal structure with a northeast plunge of 40° at Bear Mt., steepening rapidly to 50° and 60° at Fort Montgomery.

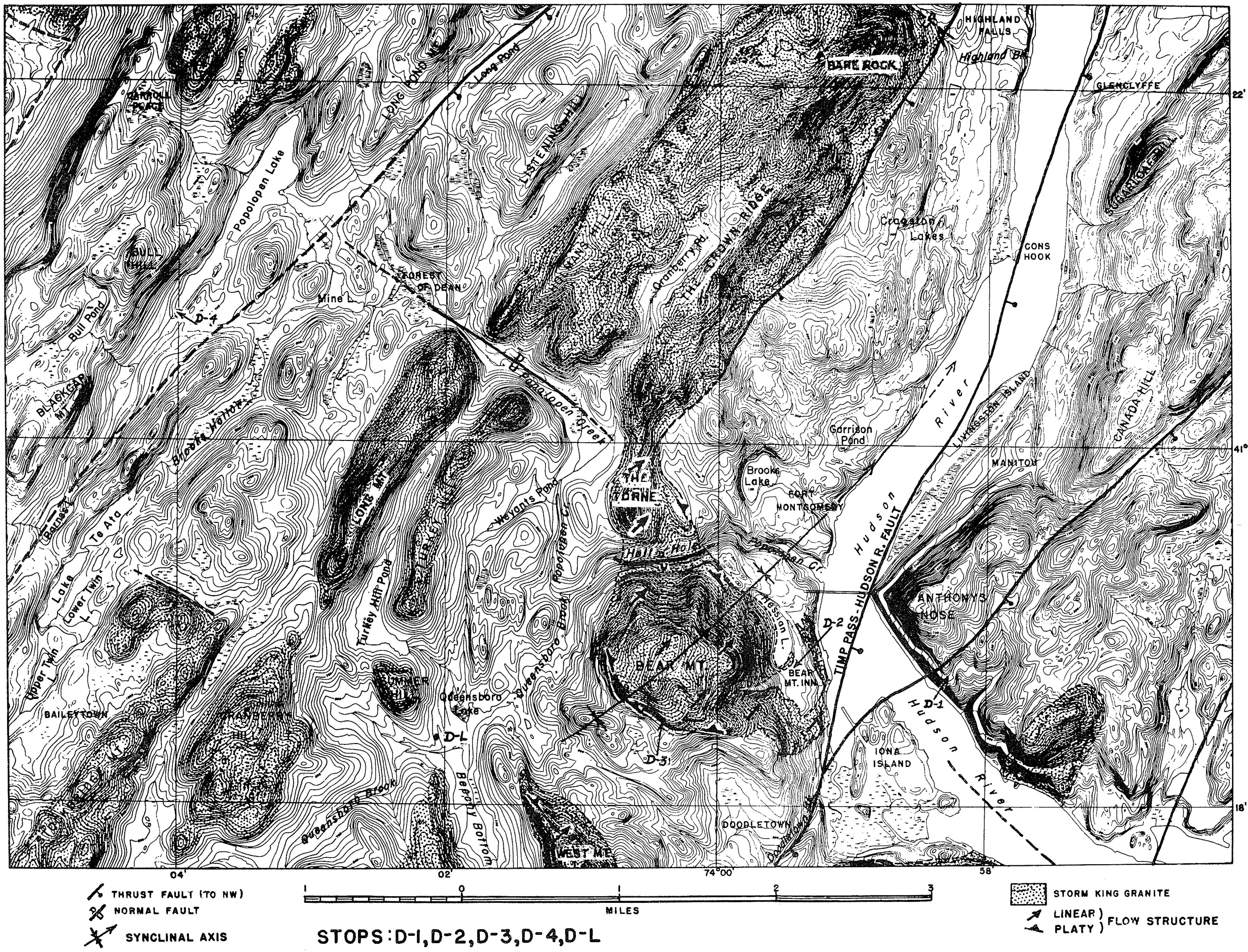
The major, probably Pre-Cambrian, faults strike northeast (parallel to the tectonic trend) and indicate overthrusting to the northwest. The more northerly strike of the Timp Pass- Hudson River fault (north of Doodletown Brook) suggests possibly Paleozoic (Taconic) origin. Overthrusting along this fault is believed to account for the absence of the eastern limb of the Bear Mt. syncline and for intense crumpling, shearing and overturning of minor folds in the Doodletown Brook valley (thrust sole).

Cross faults at Highland Brook, Popolopen Creek and Hell Hole are interpreted as high-angle tear faults with large vertical components of displacement (Plate 13).

The northwest and southeast borders of the Hudson Highlands are in fault contact with the younger sediments. Along the southern margin of the Highlands the Triassic sediments west of the Hudson have been down-dropped along a series of prominent normal faults (Ramapo fault between Suffern, N.Y. and Stony Point, N.Y. - Trip C, Stops 6, 7 and 9). A continuation of this fault east of the Hudson is partially responsible for the preservation of the Paleozoic Peekskill inlier (Trip 1). Along the northern border of the Highlands, the Pre-Cambrian crystallines have been thrust over the early Paleozoic sediments of the Great Valley along steeply southeast dipping fault planes. In some localities (as at Stop C-6) thrust slices have produced crystalline outliers.

HUDSON HIGHLANDS IN THE VICINITY OF BEAR MT., N.Y.

PLATE 10



STOPS: D-1, D-2, D-3, D-4, D-L

Petrology

Highlands Complex

This term includes the entire sequence of Pre-Cambrian crystalline rocks older than the Storm King granite, which is the youngest of the Highlands granites and the only one which can be readily identified in the field.

The oldest components of the Complex appear to be meta-sediments of Grenville (?) age (according to Berkey and Rice, 1919) comprising quartzitic, micaceous and calcareous rocks which are characteristically layered and were intensely metamorphosed during several intervals of regional deformation and igneous invasions. A great variety of rock types resulted. At Bear Mt. where the Grenville (?) series constitutes the major part of the Complex, biotite, hornblende, epidote, and graphite schists and garnetiferous biotite gneisses are common. Some of these will be seen at Stops D-2 and D-3.

In many localities (e.g. Doodletown Brook valley opposite Iona Island) intercalated lenticular beds of graphitic marble, showing intense plastic flow deformation are exposed. The calcareous and foliate facies of the Grenville series behaved as incompetent layers compared with the rocks more clearly associated with igneous activity (mainly granites, granite gneisses and pegmatites). Hence these beds appear most frequently distorted, crumped and drag-folded. They are also most readily affected by chemical weathering and are therefore differentially eroded to produce most of the topographic lows of the region (Hessian Lake, Stop D-2).

The oldest igneous representative distinguishable in the Hudson Highlands is of dioritic composition (Pochuck diorite) and almost always intimately associated with the Grenville metamorphics (Berkey and Rice, 1919). Exposures of the uncontaminated diorite parent rock are rare, but have been observed by the writer on the west shore of Lake Tiorati (7 miles SW of Bear Mt.) and by Colony (1921) in some of the old magnetite mines in this region. The writer, therefore, prefers to use the term Pochuck diorite phase.

In place of the Canada Hill, Reservoir and Mahopac granites described by Berkey and Rice (1919), the term Canada Hill granite phase includes all rocks representative of granitic igneous activity in the Hudson Highlands after the Pochuck diorite phase and earlier than the Storm King granite intrusion. Perhaps the most typical representative of the Canada Hill phase is a medium-grained, medium-gray biotite granite. The white and gray feldspars are principally albite-oligoclase and perthite with orthoclase and microcline sometimes present in appreciable amounts. Gray quartz is an essential constituent, and violet-red to dull-red garnet is an abundant accessory. Biotite flakes are characteristically oriented in layers which give the rock a faint to excellent foliation structure depending on the quantity of biotite present. The writer believes that metasomatism (granitization) is responsible for the formation of the granitic rocks of the Canada Hill phase.

An excellent example of selective replacement by fluids of the Canada Hill phase can be observed at Stop D-3. Below the Storm King granite contact, layers of granitic composition alternate with biotite schists and biotite-hornblende gneisses. The layers of different composition are sharply defined, have uniform thickness, and can be traced for more than 600 feet at this locality. The granitic layers are remarkably uniform, medium-grained quartz-feldspar rocks containing discontinuous stringers of coarser pegmatitic material invariably oriented parallel to the rock structure. There are no dikes or off-shoots from these granitic rocks into adjacent, thin, continuous layers of well-foliated and fissile biotite schist and hornblende gneiss. Under the microscope, intergrown aggregates of feldspar (microperthite, acid plagioclase and microcline) seem to have replaced the larger quartz grains, producing deeply embayed outlines and veinlike structures along visible fractures. The quartz is clear and has uniform extinction. Also most of the larger feldspar grains are not confined to a particular variety and contain a profusion of unoriented inclusions of all other types of feldspar.

All these features strongly suggest replacement and recrystallization of a pre-existing rock (possibly a rather pure arkosic sandstone) by hydrothermal solutions, rich in alkalies, from a magmatic source of perhaps granitic composition. The writer has suggested the term "pseudo-alaskite" to describe these igneous-looking rocks which are comparable in texture and composition to intrusive alaskites. It is interesting to note that where biotite appears in visible quantities, the rock becomes indistinguishable from an intrustive biotite granite such as the Canada Hill granite of Berkey and Rice (1919).

The Highlands Complex is cut by a variety of pegmatites which have not been studied in detail and are difficult to relate to a particular magmatic phase in the long and involved geologic history of the region. Frequent dikes of a coarse,pinkish quartz-microcline-hornblende pegmatite, however, can be recognized as off-shoots from Storm King granite intrusions (often not exposed in the vicinity).

Storm King Granite

The Storm King granite represents the last major invasion of magmatic origin in the Hudson Highlands. In contrast to the great variety of rock types in the Highlands Complex and their involved field relations, this granite occurs in large masses of rather uniform character. Hence, it is the most distinct lithologic unit encountered in the crystallines of the Hudson Highlands.

The typical Storm King granite (Berkey and Rice, 1919) is a medium-to coarse-grained rock which is dull gray on fresh exposures, sometimes with a greenish to pinkish-buff tinge and a somewhat greasy luster. Its characteristic streaky appearance, the result of linear alignment of the dark minerals, constitutes one of the most constant structural criteria for the recognition of this granite in the field.

More than 60% of the rock (by volume) is gray and reddish feldspar. Microcline, microcline-microperthite and perthite predominate. Orthoclase and albite-oligoclase occur in relatively minor amounts. The abundance of potash feldspars is perhaps the most characteristic petrographic feature. The quarts content ranges from practically none to about 30% by volume. Subhedral to euhedral hornblende is the important mafic mineral, but augite and biotite may be present. Common accessory minerals are zircon, apatite and magnetite. Allanite is present occasionally.

Certain distinct mineralogical changes occur in the granite near contacts with the Highlands Complex. Composition of this contact facies seems to be related to the lithology of the adjacent country rocks. Increasing quantities of biotite, plagioclase feldspars, garnet and graphite are usually present near contacts with basic Grenville gneisses and schists. Lack of dark constituents, increase of potash-soda feldspars (perthite) and abundance of quartz characterize contacts with rocks of the Canada Hill phase. Another rather unusual type of contact facies may be observed at Stop D-3 where intense chloritization along quartz fractures and feldspar cleavages imparts a dark-green color to the rock.

Brownish-green quartz has a decidedly greasy luster. Biotite partly altered to chlorite is the dark mineral.

Most of these contact features are undoubtedly the result of reaction between the Storm King magma and its wall rocks. Cross assimilation (reactive solution and precipitation) involving an exchange of certain components (Shand, 1943, p. 95) would account for the field evidence. The writer believes that local contact zones rich in chlorite and quartz can be explained more satisfactorily by the action of volatile end-stage products, escaping from the Storm King magma, upon the chilled borders of the intrusion.

Linear parallelism of prismatic hornblende crystals and crystal aggregates is characteristic and gives the rock a streaky, gneissoid appearance on most exposures. This linear structure has a constant orientation of N 40° E, 40°, or nearly parallel to the tectonic axis of the Bear Mt. syncline (Plate 11, Fig. B). In the marginal portions of the granite mass at Bear Mt., the linear hornblende elements commonly acquire an additional plane-parallel alignment. Such platy structure has invariably the same attitude as the nearest granite contact surface (Plate 11, Fig. B).

Petrofabric studies reveal that quartz grains in the interior of the Storm King granite mass have no clearly preferred space-lattice orientation. There is certainly no evidence of a tectonic pattern of orientation of the quartz c-axes.

At Bear Mt., this granite occupies the core of the syncline (maximum thickness: 3000 ft.) and extends in sheet-like fashion along its western limb, forming the continuous ridge crests of the Torne, Crown Ridge and Bare Rock (Plate 10). Contact exposures aggregating some 5000 ft. prove that the granite mass is entirely concordant with the structure of the Highlands Complex. Contacts are sharp and show no gradational transition. Xenoliths of the country rocks are found only in the near-contact portions of the granite. They generally maintain the same structural attitude as the adjacent parent rocks and exhibit sharp, angular borders without any evidence of fusion (Stop D-3).

Emplacement of the Storm King granite

The evidence cited appears to be in favor of magmatic intrusion of the Storm King granite in the form of a synclinal pluton following the pre-existing structure of the Highlands Complex. Linear and platy mineral structures are interpreted as the result of magmatic (laminar) flow of a viscous melt.

Postkinematic nature of the intrusion is indicated by complete absence of secondary foliation and lack of preferred (tectonic) orientation of quartz space-lattices. Since this sizable granite pluton was evidently the result of quiet intrusion at depth and under no great deformational stress, it is unlikely that it made room for itself by lifting the overlying country rocks. It is suggested, therefore, that gradual sagging of the synclinal structure under plastic conditions into the emptying magmatic chamber below created space in the more solid rocks above, which in turn was occupied by the rising magma. This concept of "exchange of space" was first proposed by Loewinson-Lessing (1933) to explain emplacement of large, gently dipping trap sheets in Siberia.

In the Hudson Highlands, field evidence proves that the Storm King granite is unquestionably younger than the Canada Hill granite phase. Recent potassium-argon age determinations on feldspars and mica from both granites by the Lamont Geological Observatory of Columbia University indicate that the Canada Hill phase is from 800 to 900 million years old while the age of the Storm King granite is between 600 and 700 million years.

About 12 miles southwest of Bear Mt. (Plate 13) the Storm King granite disappears as a recognizable intrusive unit and mixed granite gneisses take its place, suggesting formation by granitization rather than by magmatic intrusion. In the Highlands of New Jersey and Pennsylvania, the Byram and Losee gneisses which were correlated by Berkey and Rice (1919) with the Storm King and Canada Hill granites respectively, appear to be of nearly the same age, because they have been found cross-cutting each other.

This age discrepancy and somewhat different mode of formation of the principal granite phases in the continuous Highlands chain of mountains may be simply a function of the regional structure. The tectonic structure of the Highlands has a consistent northeast plunge. Thus the Hudson Highlands represent a younger stratigraphic horizon than those of New Jersey and Pennsylvania. Both granites probably originated from a single magmatic source, in view of their very similar chemical composition, which differs to any extent only in the potash-soda ratio.

In the southwestern Highlands, granites were formed at greatest depth, i.e. under greatest pressure and temperature. In such environment the magmatic fluid was probably very liquid, mobile and chemically active, because it still contained all its volatiles, and therefore was peculiarly well suited to act as "granitizing agent". The most volatile and reactive components (soda-rich in this case) then penetrated the upper rock horizons, causing formation of the Canada Hill granite phase by metasomatism. At the same time, the viscosity and chemical stability of the residual liquid gradually increased, with loss of volatiles, until a true magmatic melt had formed. With increasing viscosity, this (potash-rich) magma intruded ever more slowly into the higher levels of the crust to form the Storm King granite.

In conclusion, it might be suggested that the opposing camps of "granite makers" are not nearly as far apart as they would have us believe. It is quite plausible that granitization and magmatic intrusion are merely phases of one and the same process and depend largely upon the crustal horizon at which the formation of a granite takes place.

Dike Rocks

Basalt dikes cutting all the crystalline rocks are the only evidence of post-Storm King (Paleozoic or Mesozoic) magmatic activity in the Hudson Highlands. They appear in large numbers throughout the Highlands terrane and vary in composition from dioritic to camptonitic. Some acid varieties were described by Kemp (1888). The dike materials evidently chilled rapidly and were clearly guided by open fractures in the crystallines. Contacts are always sharp and evidence of contact effects is lacking, both in the dike and wall rocks.

PLATE II

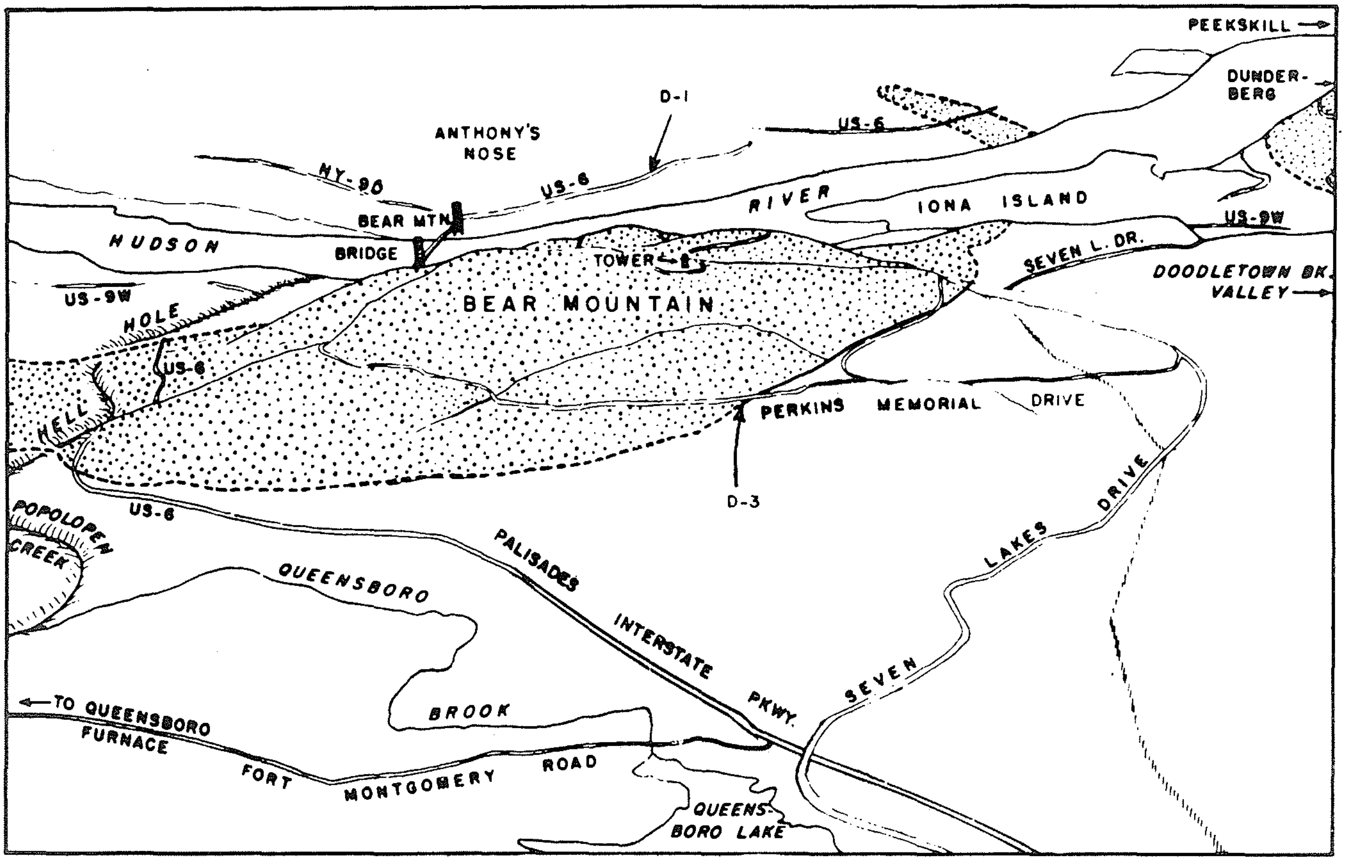
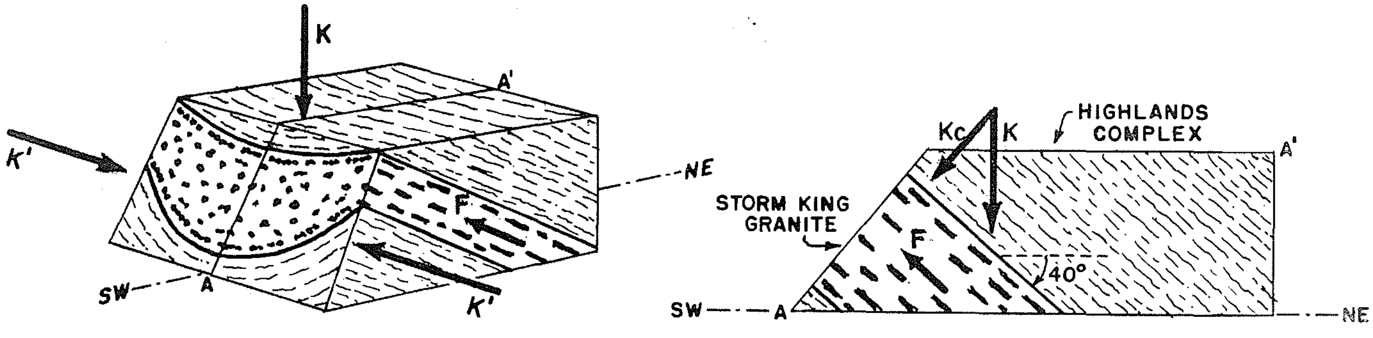


FIG. A

VIEW OF BEAR MT., N.Y.

LOOKING EAST FROM 5000 FT.
STORM KING GRANITE STIPPLED



Perspective View

Section AA'

F- DIRECTION OF FLOW DURING INTRUSION

K- UNIFORM LOAD STRESS

Kc-LOAD STRESS COMPONENT PERPENDICULAR TO FLOW DIRECTION

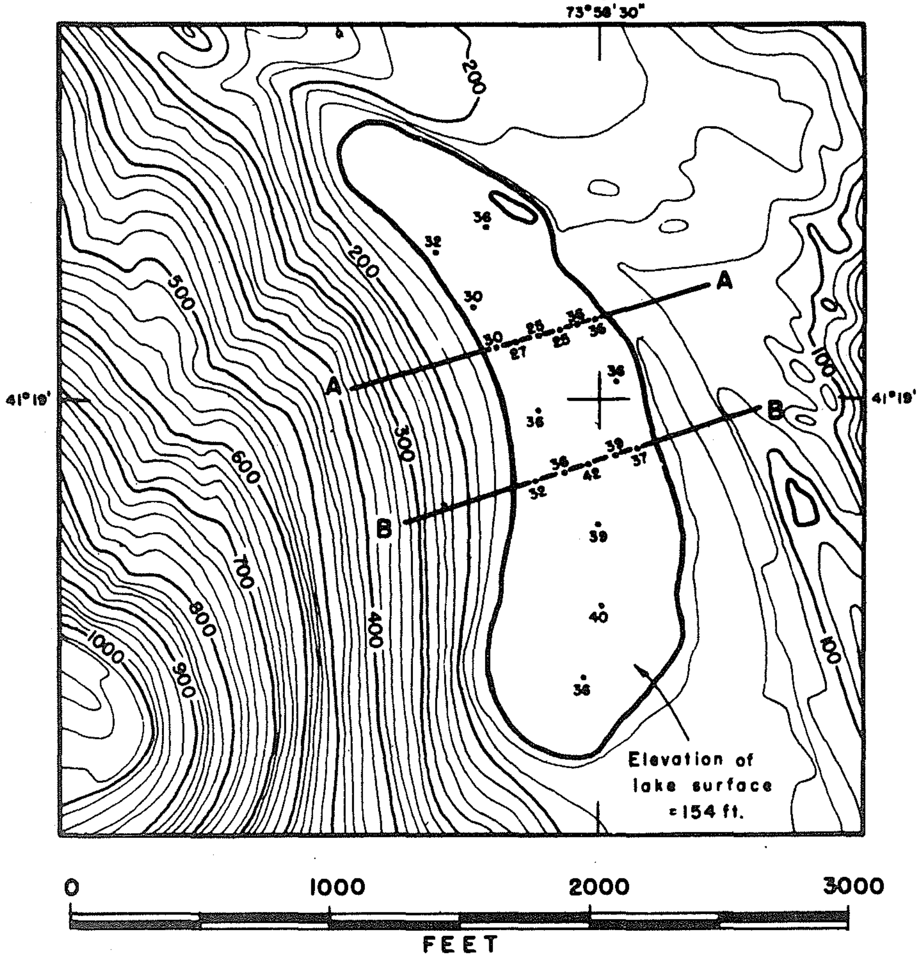
K'-DIFFERENTIAL OROGENIC STRESS PERPENDICULAR TO FLOW DIRECTION

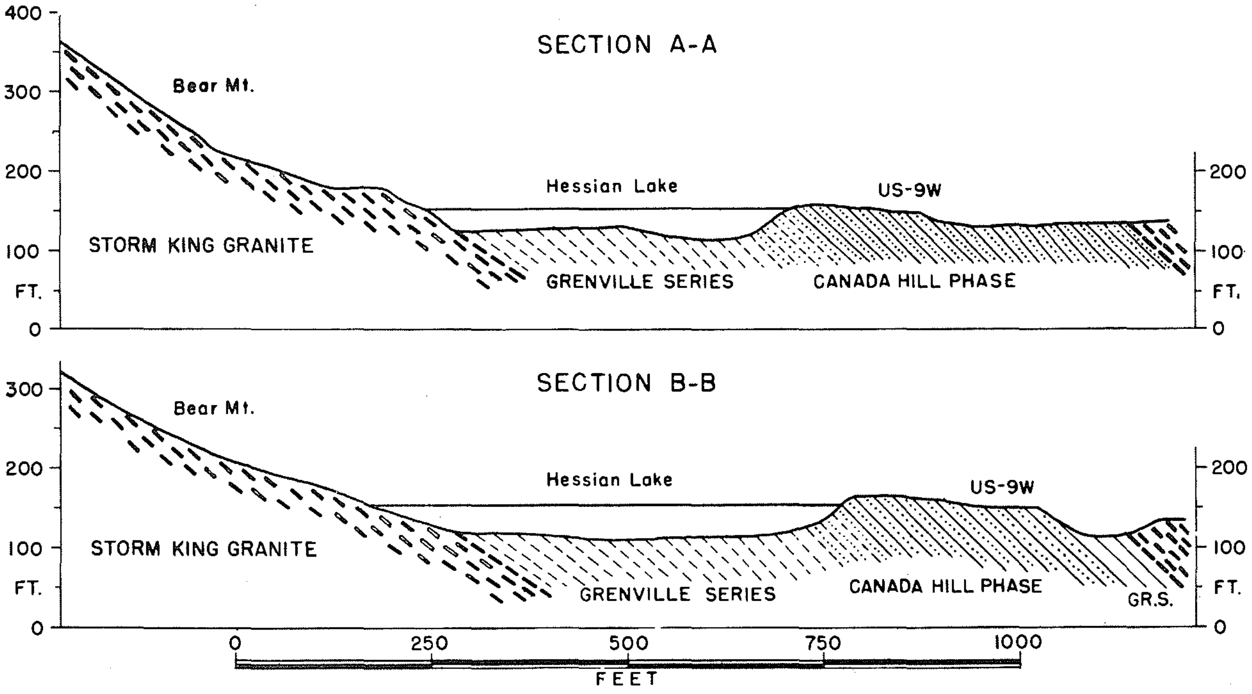
FIG. B

STRUCTURE OF THE BEAR MT. PLUTON

PLATE 12

HESSIAN LAKE, N.Y.





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For references on the geomorphology of the Hudson gorge see Trip C.

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Trip D

Route Description

Mileage	
	Note: The first part of the trip (9.3 mi. to Bear Mt.) including Stop No. D-1 is the same as that of Trip C.
0	Shustin's Locust Manor (headquarters) - left (N) on Locust Ave.
.9	left (SW) on Oregon Road
2.0	pass under Bear Mt. Parkway
2.3	right (W) on Pemart Avenue
2.5	right (N) on Highlands Ave. passing again under Bear Mt. Parkway
3.0	road cut through Gallows Hill; Annsville phyllite (Cambro-Ordovician Hudson River pelite group; see Trip 1, Stop 1-2)
3.3	pass under US-9 and turn sharp left (W) on approach road to US-9
3.4	straight (W) on US-9 following north shore of Peekskill Hollow Creek; note remnants of glacial deltas along both valley walls
4.3	right (N) on US-6-202
4.6	road starts climbing Highlands escarpment (fault line scarp); continuous exposures of Highlands crystallines (Pre-Cambrian gneisses, schists and granites) from here to Bear Mt. Bridge
7.4	cross to left (W) side of road and lookout point

STOP No. D-1: Anthony's Nose Lookout (See Plates 10 and 11, Fig. B)

Lithology: Canada Hill phase of Highlands Complex (Canada Hill granite of Berkey, 1919) - biotite oligoclase granite with epidote pods; gneissoid structure not pronounced; interpreted as granitized meta-sediments

Hudson Gorge: Southeastern gateway of Hudson gorge; superposition versus progressive headward stream erosion of the Hudson River; Iona Island and abandoned River channel; significance of bedrock terrace at Bear Mt. Inn

Faulting: Timp Pass - Hudson River thrust fault; channel fault (?) at Dunderberg Mt.; Hell Hole tear fault (Popolopen Creek)

Regional Structure and Intrusive Plutons: Synclinal plutons of Storm King granite: Dunderberg and West Mts. (lower pluton)
Bear Mt. - The Torne and Crown Ridge (upper pluton)

7.4	continue (N) on US-6-202
8.2	left (W) across Bear Mt. Bridge Excellent views crossing bridge:

Left (S): Iona Island and Southeastern gateway - prominent notch at Timp Pass, where fault crosses West Mt. - Dunderberg ridge

Ahead (W): South of bridge: Bear Mt. terrace
North of bridge: Mouth of Popolopen Creek (drowned); Hell Hole fault notch between Bear Mt. (left) and The Torne right (N)

Right (N): Hudson gorge (southern portion); Sugarloaf Hill on E-shore (3 mi. NE) (Canada Hill granite phase); abandoned river channels at Livingston Island (1 mi. on E shore) and Cons Hook (2 mi. on W shore); bedrock terraces, particularly on W-side of river

Mileage	
8.6	toll booths - W-end of bridge
8.8	traffic circle; $^3/_4$ around circle and left (S) on US-9W-202
9.3	passing under foot bridge and right (SW) on approach road to Bear Mt. Inn
9.35	straight on Seven Lakes Drive (do not turn right into circular drive leading to Inn and parking field)
9.6	Administration Building (rear) and entrance to SW parking field

STOP No. D-2: (on foot - 1 mi.) Bear Mt. Inn Terrace

Walk N along W-edge of playing field
glaciated and striated outcrops of pegmatitic Canada Hill granite phase (S of roller skating rink); outcrop of sillimanite-garnet-biotite gneiss and schist (metasediments of Highlands Complex) at SE corner of rink

Hessian Lake: Shallow, glacially scoured contact line depression in Grenville (?) metasediments (including marble bands); intrusive contact with Storm King granite pluton along S and W shores of lake; Canada Hill granite phase along NE shore (Plate 12).

Ancient landslides of large Storm King granite blocks (SW shore) from near vertical cliffs (obscured by trees) developed along major NE trending longitudinal joints in granite; prominent exfoliation of Storm King granite along W-shore; steep W-shore profile developed parallel to linear and platy structure of hornblende crystals in Storm King granite

Mileage	
9.9	exit of parking field - right (W) on Seven Lakes Drive
10.1	Bear Mt. traffic circle - continue on Seven Lakes Drive (right)
10.5	massive Storm King granite at right (N)
11.9	entrance to Perkins Memorial Drive (right) - park buses

STOP No. D-3: Storm King Granite Contact

This stop on SW flank of Bear Mt. will be reached on foot (.6 mi. from entrance), because buses are not permitted on the Perkins Drive. It is regrettable that the planned visit to the top of Bear Mt. had to be eliminated for the same reason.
Keep to the left side of the Drive facing traffic and watch for cars on this winding 2-lane, 2-way road.

Layered sequence of Highlands Complex rocks: Biotite and hornblende gneisses and schists with intercalated bands of pseudo-alaskite (Canada Hill granite phase); interpreted as the result of selective granitization of metasediments (micro-pegmatite bands parallel to structure; replacement of quartz by plagioclase feldspars and perthite in thin-section); biotite in places makes rock indistinguishable from Canada Hill granite of Berkey.

Lower contact of Storm King granite pluton (at nose of syncline) with metasediments; xenoliths near contact; dark-green, chloritized, quartz-rich contact phase of Storm King granite 500 ft. NW along road; prominent exfoliation of massive granite; typical "rubbly" weathering along linear hornblende structure; if time permits: visit to eclogite locality 100 feet below on abandoned road; metamorphic pyroxene (diallage) - garnet - graphite - quartz layer in Highlands Complex; source rock questionable.

return to Perkins Drive entrance

Mileage	
11.9	continue on Seven Lakes Drive (W)
12.9	straight ahead on overpass over Palisades Parkway following road curving left (SW)
13.4	prominently banded metasediments (biotitic and graphitic gneisses and schists) at left along Palisades Parkway
13.7	traffic circle - keep right (W) on US-6 toward Central Valley
13.9	right into Brooks picnic grounds

LUNCH STOP: 1 Hour

14.0	continue uphill (W) on US-6
15.5	nearing top of Long Mt. ridge; view of Bear Mt. at right (E) (Plate 11, Fig. A)
16.5	old (drained) beaver swamp along right (N) side of road
17.2	passing between Lake TeAta (left -S) and Lake Massawippa (right -N); construction of dam (at N end of Lake Massawippa) across the Brooks Hollow Creek temporarily uncovered a striking coarse-grained marble (contact-metamorphosed by intrusive Storm King granite) consisting of pink calcite, pale-green diopside and brownish phlogopite (named the Brooks Hollow marble)
17.7	sharp right (NE) on NY-293 leaving the Palisades Interstate Park
19.7	left into parking field of Camp Natural Bridge (West Point Military Reservation

STOP No. D-4: Popolopen Natural Bridge

Walk $^1/_4$ mile to SW end of Popolopen Lake
Natural Bridge across creek flowing into Popolopen Lake, developed through coarse, white, chondrodite-bearing marble; spinel dike on down-stream (lake-side) of bridge; curious dense, dark gray rock paralleling marble and creek on upstream side; thin-section study suggests a metamorphosed graywacke; both rock types along creek are completely different from known Pre-Cambrian metasediments in the Hudson Highlands; preliminary reconnaissance also indicates strong deformation of Highlands rocks along both sides of Popolopen Lake valley; rocks at this locality are, therefore, interpreted as infolded (and possibly infaulted) Paleozoic sediments(inlier)

return to buses at Camp Natural Bridge

20.0	right (SW) on NY-293
22.0	intersection with US-6; straight (SW) on US-6
23.2	top of NE-trending fault-line escarpment of crystalline Hudson Highlands; view of Central Valley (belt of early Paleozoic limestones)
23.3 to 23.4	brecciated zones in Highlands gneisses at right (only evidence of steeply SE dipping border thrust at base of escarpment)
23.6	last outcrop of Highlands crystallines (Pre-Cambrian)
24.4	passing over N.Y. Thruway; view (straight ahead) of Schunemunk Mt. (Devonian orthoquartzite and conglomerate)
30.0	Central Valley - right (N) on NY-32 (Albany Turnpike)
31.2	Highland Mills - right (E) on Park Ave.
31.5	Highland Mills Railroad Station

STOP No. D-5: Devonian Sediments

Cross railroad tracks to prominent outcrops along E-side of right of way Devonian shaly sandstones (Oriskany-Esopus-Schoharie horizons)

Fossils: Lower strata:
poorly preserved sponges of type Titusvillia (?)
Leptocoelia flabellites, Leptaena rhomboidalis and other brachiopods

Middle strata:
Spirophyton caudagalli (worm burrows or algal swish marks??)

Upper strata:
Cypricardinia (pelecypod)
Brachiopods (several genera)
Phacops and Dalmanites (trilobites) (confined to a single layer, hard to find)

Time will not permit to traverse across hill to E; in valley E of hill can be found (in descending stratigraphic order) Lower Devonian and Upper Silurian limestone (with corals), Silurian red shales (Longwood) followed by Lower Silurian conglomerate (Shawangunk) in Pine Hill beyond. Between Pine Hill and the Highlands escarpment to the E are beds of Wappinger limestone (Cambro-Ordovician). The exact structural relations between these stratigraphic sequences are not known with certainty. Westward across the valley of Woodbury Creek the shaly sandstones of the Highland Mills station appear to include the Hamilton group and are finally overlain by (Uppper ?) Devonian orthoquartzites and conglomerates of Schunemunk Mt. (a shallow syncline).

Approximately 1 mile to the north, along the E-side of the railroad, rocks of Oriskany lithology have been correlated with the Kanouse horizon (Onondaga) on good fossil evidence. (Eidman and Kindle, 1955)

31.6 return (W) on Park Ave.
31.9 right (N) on NY-32 (Albany Turnpike)
34.2 pass under N.Y. Thruway
34.5 Glacial delta deposits on both sides of narrow valley
39.2 right on NY 307
39.7 pass under US-9W

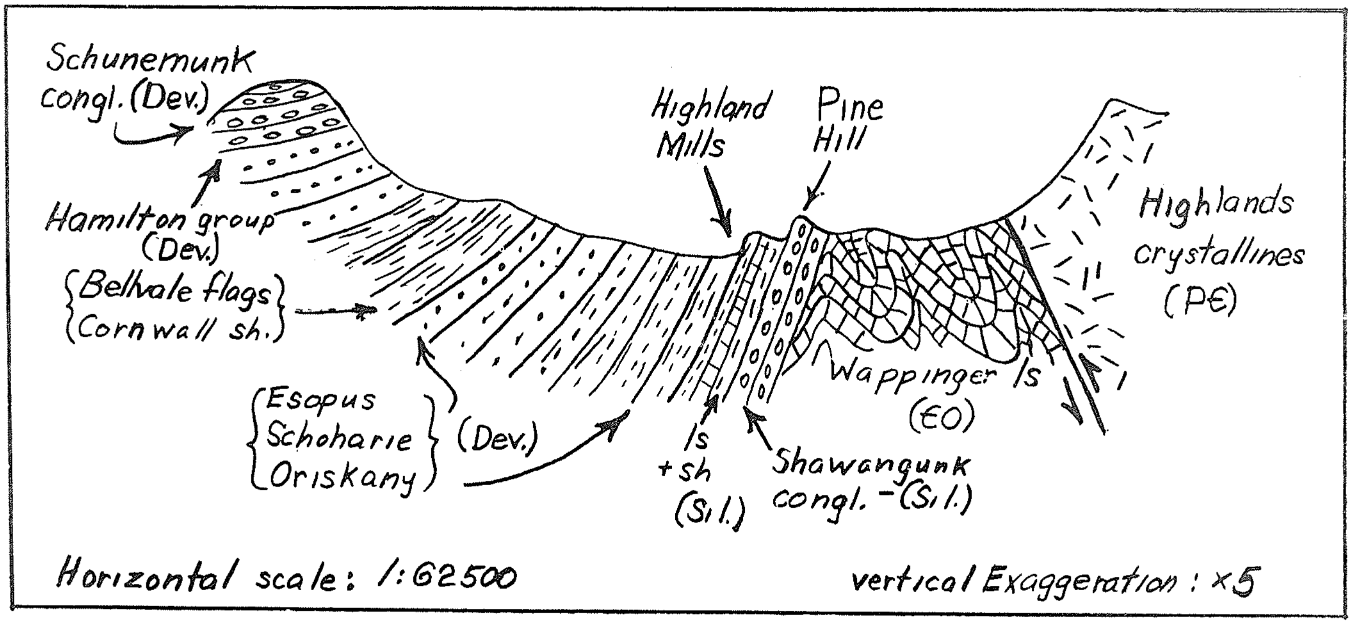


Fig. 3 Cross-Section at Highland Mills (generalized)

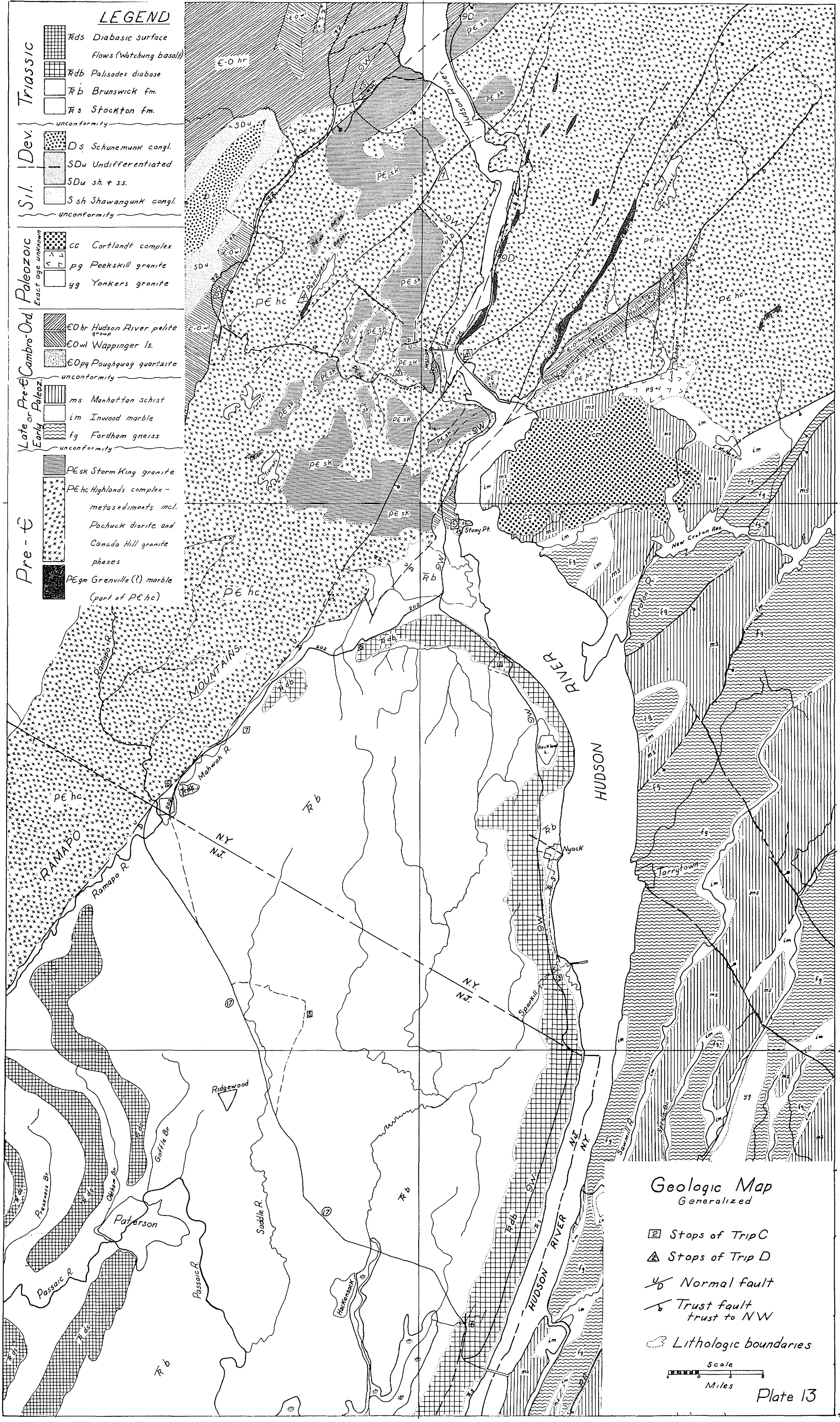
Mileage	
40.1	Cornwall - bear left (NE) on Main St.
40.6	take right fork (E) at monument on NY-307
41.1	straight ahead at blinker light
41.4	right (SE) on Hudson St. (NY-218)
41.7	sharp right (S) on Lafayette St.
41.9	swing left (E) and park buses at intersection with Mountain Rd.

STOP No. D-6: Overthrust in Highlands Outlier
Walk S on Mountain road, crossing bridge to outcrop in hill at left (E) side of road (appr. 300 yds.)
Overthrust of Storm King granite (Pre-Cambrian) on intensely crumpled slaty shales of the Hudson River pelite group (Cambro-Ordovician). Thrust plane dips rather gently toward the southeast. Small hill appears to be an outlier, because Lower Paleozoic sediments have been found between it and the Highlands escarpment a short distance to the SE. Attitude of thrust plane here is atypical of Highlands border thrust which generally dips at high angles (70° in Delaware Aqueduct Tunnel E of Hudson River) to the SE.
Return to buses

41.9	left (N) on Mountain Road
42.0	left (W) on Hudson St. (NY-128); follow Hudson St. bearing left
43.2	left on Main St. (traffic light)
43.8	bear right to stay on NY-307
44.4	pass under US-9W and turn left (SE) on US-9W-south approach road; continue SE on US-9W
48.7	cross highway to left (through break in center mall) to Crow's Nest Lookout - dangerous crossing

STOP No. D-7: Crow's Nest Lookout
View of middle Hudson gorge; West Point Military Academy on rock terrace below; Constitution Island with abandoned river channel; similar to Iona Island (Stop No. D-1), but on E-side of valley; Schooley Upland level E of the Hudson

48.7	cross highway again heading south
49.3 to 49.9	large xenoliths of hornblende gneiss in pegmatite phase of Storm King granite at right (W)
55.7	Bear Mt. Bridge traffic circle; left (E) on US-6-202 to Bear Mt. Bridge
56.4	right (S) at E end of bridge
60.3	left (NE) on US-9 (do not cross bridge over Peekskill Hollow Creek)
61.1	right turn off US-9
61.3	right (SE) on Highlands Ave. (through Annsville road cut)
62.0	left (E) on Pemart Ave. (after passing under Bear Mt. Parkway)
62.2	left (NE) on Oregon Rd.
63.6	right (SE) on Locust Ave.
64.5	right at headquarters

74°15'
74°00'
73°45'
41°15'
41°00'
40°50'
LEGEND
Triassic
₸ds Diabasic surface Flows (Watchung basalt)
₸db Palisades diabase
₸b Brunswick fm.
₸s Stockton fm.
unconformity
Sil. Dev.
Ds Schunemunk congl.
SDu Undifferentiated
SDu sh. + ss.
S sh Shawangunk congl.
unconformity
Paleozoic Exact age unknown
cc Cortlandt complex
pg Peekskill granite
yg Yonkers granite
Cambro-Ord.
€O hr Hudson River pelite group
€O wl Wappinger ls.
€O pq Poughquag quartzite
unconformity
Late Pre-€ or Early Paleoz.
ms Manhattan schist
im Inwood marble
fg Fordham gneiss
unconformity
Pre-€
P€ sk Storm King granite
P€ hc Highlands complex - metasediments incl. Pochuck diorite and Canada Hill granite phases
P€ gm Grenville (?) marble (part of P€ hc)
Hudson River
RAMAPO MOUNTAINS
Ramapo R.
Mahwah R.
N.Y.
N.J.
Stony Pt.
Nyack
Sparkill
Torrytown
New Croton Res.
Croton R.
Rockland L.
Ridgewood
Paterson
Passaic R.
Saddle R.
Hackensack
Goffle Br.
Peckman Br.
Oldham Br.
Sprain Br.
Sawmill R.
HUDSON RIVER
202
9W
17
Geologic Map
Generalized
Stops of Trip C
Stops of Trip D
U/D Normal fault
Trust fault trust to NW
Lithologic boundaries
Scale
Miles
Plate 13