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INTRODUCTION

The Blackstone Series of Northern Rhode Island is a rare example of a well-exposed Avalonian terrane consisting of rock assemblages commonly associated with active plate margins. The series contains pillowed and massive basalt flows which are associated with mafic volcaniclastics, thin interbedded quartz-rich layers, gabbros ,and possible serpentine bodies. Other units in the series include conglomerates, limestones, and medium to coarse-grained, poorly sorted quartz arenites which have slumped into fine grained, pelagic(?) clastics. The series is bordered in part by granitic bodies which show intrusive contact and have been dated as Late Precambrian/Early Cambrian in age (see Hermes, Gromet and Zartman, this volume).

Type localities for the rock units are located near the Blackstone River in the Pawtucket Quadrangle which was originally mapped by Quinn et. al. (1949). Quinn divided the Blackstone into four members, with the normal stratigraphic succession being, from oldest to youngest, Mussey Brook Schist, Westboro Quartzite, (later changed to the Quinnville quartzite, Quinn, 1971), Sneech Pond Schist and the Huntinghill Greenstone. The latter included extrusive and intrusive igneous rocks as well as clastic sediments. Reconnaissance work done by Mosher and Wood (1976) and Robare and Wood (1978) suggests that much of the Blackstone Series is a tectonically induced sedimentary melange. This article presents preliminary work from part of the first author's Ph.D. dissertation.

LITHOLOGIC UNITS

Each member of the Blackstone Series contains a wide variety of lithologies which are often similar to those in other members. This apparent similarity of portions of individual members is caused, in part, by syn-depositional mixing of the "members" and post-depositional interformational folding. The present study has each different type of lithology mapped separately rather than grouped into members. For the purpose of disscussion, the lithologies have been divided into three general catagories: greenstones, clastics, and carbonates.

Greenstones

The Huntinghill Greenstone contains mafic volcanic flows and volcaniclastic sediments. The flows are often pillowed with carbonate filling the interstices. Many massive flows show relict pillow structures. The flows are associated with rare occurances of gabrro and serpentine; the latter contains relict cores of olivine and pyroxene (Quinn et. al., 1949).

The volcaniclastics are mafic, fine grained thinly laminated sediments which are difficult to distinguish from flows in the field. Locally epidote-rich pods (up to a meter in diameter) and stringers parallel the prominant schistosity. Few, thin, pure quartz layers are interbedded with the volcaniclastics and possibly represent relict chert beds; however quartz recrystallization has obscured any initial sedimentary texture. Felsic volcanics are only present at one locality in a fault sliver which separates mafic flows from volcaniclastics.

Clastics

Quinn (1949) originally divided the clastic sediments into three separate units: Mussey Brook Schist, Quinnville Quartzite, and Sneech Pond Schist. New exposures along Highway 295 and in quarries bordering the Blackstone River suggest that only two units should be distinguished.

One unit is dominated by quartz-poor, mica-rich schists and interlayered, pure quartzites. The schists show no graded or cross bedding; laminations are rare. The quartzites are composed of poorly sorted, subrounded grains; layers range in width from meters to 10's of meters. Rarely quartzites occur as small pods or lenses. The quartzites show many characteristics of soft sediment slump blocks in a muddy matrix. These characteristics include: elongate "teardrop"-shaped lenses with mud armoring of the rounded ends and mixing of sand and mud within the sand body margin; "pull-a-part" structures; mud armoring of small semi-spherical quartzite pods; local, irregular thinning and thickening of layers; and "jiggle" structures where sand blocks have been slightly pulled apart into small pods and the fractures infilled with wispy mud

The other unit is a dark, quartz-rich schist containing conglomerates which increase in abundance and clast size to the south. Quartzite slump blocks are sometimes present. Mafic flows intrude these units and are found as clasts within the conglomerates.

Carbonates

Marble layers are located throughout the area but the largest are situated in the southwest. The marbles are in depositional contact with the quartz-rich, medium grained, dark sediments, and are intruded by mafic and granitic dikes and granodiorites. Two possible origins for the marbles are suggested: 1) shallow marine deposits which have subsequently been slumped, or 2) deep water limestones which are overlain by clastics containing slumps of shallow water sediments.

STRUCTURE

Post-deposition deformation includes at least two episodes of folding and a low angle thrusting. The first recognizable deformation resulted in isoclinal folding and the prominant schistosity (S1). The schistosity is subparallel to bedding (So) which is defined by layers of quartzite and fine laminations in the volcaniclastics. Few F1 folds have been observed in outcrop, however the map pattern is suggestive of large scale interformational folding. Mineral lineations oriented N14E and plunging 40 NE may parallel F1 fold axes as they are contained in S1 and are folded by the second folds. Shear zones are subparallel to S1.

The second event folds the prominant schistosity and bedding into large recumbent folds. Generally this folding is only observable on a regional scale, however in a quarry in the NW portion of the area excellent exposures show several of the different lithologies folded together by recumbent folds on all scales. (Access to the quarry is not permitted by owners.) An axial planar crenulation cleavage (S2) is locally developed. Crenulation axes and a second mineral lineation (on S1) parallels the F2 fold axes. Another crenulation of S1 is shallower and appears to be younger than S2.

METAMORPHISM AND INTRUSION

The Blackstone Series has been metamorphosed to upper greenschist facies. Mineral assembleges in the mafic units include epidote, green amphibole, chlorite, quartz, biotite, and albite; garnets are found in the epidote-rich pods. The quartzites contain minor amounts of chlorite, muscovite, and biotite. The schists are dominately composed of muscovite and biotite; the cement in the quartzites contain chlorite, biotite, and muscovite. Generally, chlorite and biotite are elongate parallel to F1, however, the biotite also is observed in a random orientation as is the muscovite. A metamorphism is therefore believed to have begun during D1 but culminated post D1.

Granitic plutons have intruded the Blackstone either pre- or syn-tectonically. Near contacts, the granitic rocks contain two foliations, a mineral lineation subparallel to F2 fold axes, and small scale folds. The grain size of Blackstone units increases with proximity to the intrusion, and marbles show mineralogical evidence (fosterite and diopside) of contact metamorphism (Quinn and Young, 1937; Quinn, 1971).

AVALONIAN TECTONICS

The Blackstone series has been tentatively correlated with other terrains bordering the North Atlantic (Wood, 1974; Rast et. al., 1976). In North America, these terrains have been termed Avalonian, after the Avalon Penninsula in Newfoundland which contains extensive late Precambrian exposures (Kennedy,1976; Rast et. al., 1976; Strong, 1979; Rast, 1980). Other late Precambrian terrains are found along the Virginia-North Carolina border (Glover and Sinha, 1973; Snoke et. al., 1980), in Rhode Island rimming the Narragansett Basin to the east and south (Skehan and others, 1978; Skehan and Rast, this volume), and in eastern Massachusetts, Maine and Nova Scotia (Schenk,1971, 1980), Angelsey (Wales) (Wood, 1974), and in the English Midlands (Rast et.al., 1976; Rast, 1980).

In general these terrains are characterized by thick volcanic and volcaniclastic sequences locally interbedded with other sediments. Some deformation is pre-Caledonian and late Precambrian granitic intrusives are common. Locally these provinces are underlain by either gneissic or sedimentary basements. Avalonian rocks are generally considered to be of island arc affinity, but have been variously interpreted as originating in back arc or fore arc regions.

The Blackstone series was deposited in a marine environment as indicated by the pillow basalts, fine grained clastics, probable cherts, and carbonates. The lack of felsic volcanics, the mafic composition of the volcaniclastics, and the intrusive contact of the basalts and volcaniclastics suggests that volcanism may be due to rifting of oceanic crust. The quartzites and conglomerates are of continental origin. The presence of sedimentary slumping of the quartzites and the complex intermixing of all units within the Blackstone suggest that much of the series comprises tectonically induced sedimentary melange.

Presence of oceanic rifting, continentally derived sediments, and active syndepositional tectonism and lack of felsic volcanism support an active back arc basin model for the origin of the Blackstone series. This is a tentative interpretation and other possible models cannot be ruled out at this time. Further mapping and geochemical work is in progress to help further define the tectonic setting of the Blackstone in an attempt to determine its relationship to the other Avalonian terrains. The relationship of deformation and metamorphism in the Blackstone Series to other Appalachian events has not yet been determined.

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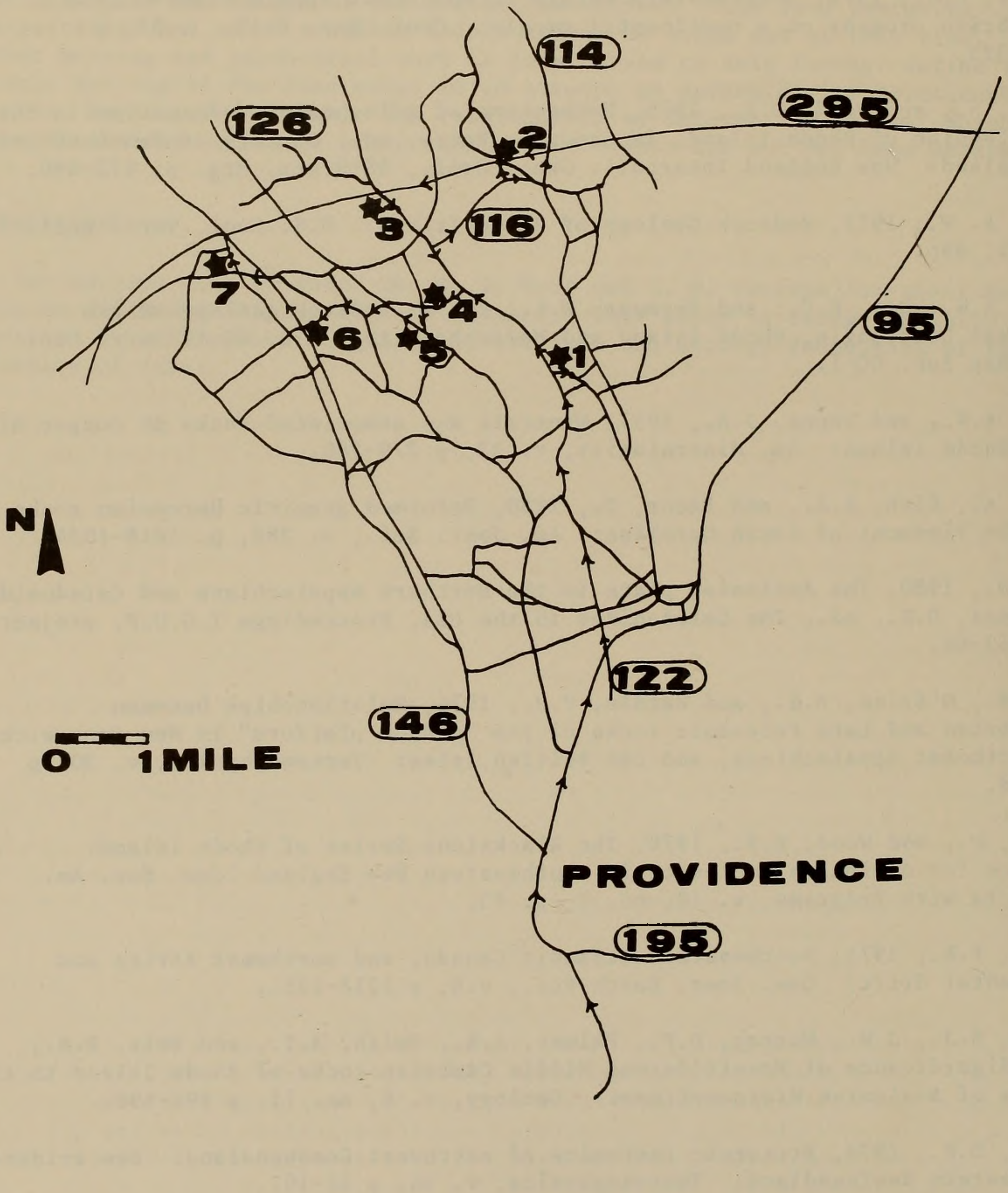

Fig. 1. Road map showing the route; stops are indicated with stars.

STOPS

Mileage

From Kingston take Rt 138 east to Rt 1. Turn left and follow Rt 1 and signs for Providence. You will take Rt 4 north to Interstate 95. Take Interstate 95 through Providence.

0.00 Take Exit 26 (Lonsdale Ave, Main Street, Rt 122) off Interstate 95. Follow signs for Rt 122, you will pass one stop sign, then two traffic lights, and cross over the freeway.

0.75 Turn left onto Connant St.

0.80 Turn left at next traffic light onto Mineral Springs St.; pass a cemetary on the right; then cross over a railroad bridge.

1.10 Turn right at next traffic light onto Lonsdale Ave. Go north on Lonsdale Ave. Pass 3 traffic lights, a large pond on the left, another traffic light.

4.10 Turn right on Broad St. just past Almacs.

4.25 STOP 1. Dandurand Florist Shop. The prominant roadside ledge directly east of the flower shop provides the best exposure of relatively undeformed pillow basalts in the area. The pillows are ellipsoidal with average long dimension of approximately 45 cm. Vesicles in the pillows are elongate subparallel to S1 with long dimensions ranging from .5 to 2 mm. Vesicles and interstices between pillows are commonly filled with calcite. Bedding as defined by the pillows is right side up. Low angle shear zones are found in the lower eastern part of the outcrop, and the pillow shapes are no longer discernable. These shear zones are cut by high angle faults showing small displacements. A small outcrop of gabbro is found in a back yard to the north of this outcrop.

4.35 Return to Rt 122 and turn right at the traffic light. Behind the American Legion are outcrops of volcaniclastics in contact with the pillow basalts.

5.90 Roadcuts are of quartzites and schists.

6.55 Turn right onto Rt 116 North (Angel Rd.) passing outcrops of quartzite and schist.

7.45 Front yard to left has gabbro outcrop. 0.1 miles further are basalt outcrops.

7.7 Turn left at sign for Lippitt Estates.

8.05 Cross under Interstate overpass and park.

STOP 2. Roadcut along Interstate 295. Excellent exposures of the Huntinghill Greenstone. Across the road from where the cars are parked and at the eastern end of the outcrop on Hwy 295, the greenstone has been intruded by granodiorite. Continuing to the west is approximately 10 m of massive, deep blue-gray metabasalt flows. In thin section these very fine grained rocks are chlorite- and amphibole-rich with rare relict plagioclase phenocrysts.

Most of the rest of the roadcut is dominated by very fine grained, blue-black mafic volcaniclastics which locally show layering. Included in the volcaniclastics are epidote-rich thin stringers and lensoid pods which parallel the prominant schistosity and increase in abundance to the west. The larger pods are rich in garnet, clinopyxonene, calcite, and minor amphibole; some pods have calcite- and/or quartz-rich centers.

Intruding the volcaniclastics are at least two dikes with a distinct layered texture. The dikes are folded and their attitude varies from sub-horizontal to subvertical (one rims a prominant west facing ledge). In the central portion of the road cut (to the west of major joint faces in a narrow overgrown break in the outcrop), a narrow high angle fault zone, containing brecciated felsic volcanic material, separates volcaniclastics with epidote-rich stringers to the east from a massive non-layered flow to the west.

Approximately 25m from the west end of the outcrop are two diabase dikes which intrude the greenstone. The dikes are altered but undeformed. Sediments between and to the east of the dikes are isoclinally folded. Locally, thin quartzite layers (possibly chert) are interbedded and infolded with fine-grained volcaniclastics.

8.30 Turn around and return to Rt 116 and turn left.
8.50 Turn left onto Rt 114 North; follow signs for Interstate 295 South.
8.80 Take 295 South. Immediately on the left is a granite outcrop. Next you will pass the outcrops from Stop 2.
10.35 Take Exit for Rt 122. (You pass through Stop 3 outcrops in the interchange.) Turn left on Rt 122 South, and make a left into the Burger Chef parking lot (0.3 miles).

Stop 3. Road cuts on exit ramp show good three dimensional exposures of the first clastic unit (quartz-poor, mica-rich schists interlayered with quartzite lenses). This unit displays soft sediment slumping features (see text for description) as well as later tectonic deformation. In the schists the prominant S1 schistosity is crenulated by a shallow crenulation and rarely a steep one. Some of the boudinage of the quartzite layers appears to be tectonic. Geometric analysis shows that this area is on the overturned limb of a regional scale F2 fold. (The other limb is exposed to the west across the Blackstone River on Hwy 295.)

LUNCH STOP. Across the highway from the Burger Chef are some small (1m) outcrops of schists which contain isoclinal folds, two crenulations, and the southern end of one of the largest quartzite slump blocks.

11.30 Turn left onto Rt 122 leaving the parking lot. Pass one traffic light.
12.35 Turn right at next traffic light.
12.60 Before railroad tracks, turn right into paved parking lot. Walk back up hill to fenced parking lot. Turn right and follow fence line to outcrop on far side of lot, next to quarry.

Stop 4. This stop contains the same units as stop 3. Here the soft sediment deformation features are well exposed on a glacially scoured surface.

12.65 Turn right out of parking lot and cross railroad tracks and bridge.
12.95 Curve right to stop sign. Take sharp left at stop sign and go up

hill.

13.00 At Y intersection bear to left.

13.25 At stop sign turn left and then immediately right into blasted area. Park.

Stop 5. Dexter Road. The complex intermixing of the different lithologies are exposed in the three northwest trending hills. Parts of these hills have been blasted so that some outcrops are not completely in place, however movement has not been sufficient to disrupt the stratigraphy. The northern outcrop contains a matrix-supported conglomerate with rounded quartzite clasts which are locally brecciated. The conglomerate is in gradational contact with a mafic flow, which is pillowed on the northwest side. Calcite as veins and interstitial material between pillows is common.

A small outcrop to the east of the central hill is composed of fine-grained, quartz-rich sediments which contain a mafic-flow clast. The northwestern portion of the central outcrop consists primarily of conglomerate. Here clasts appear sheared, and are in a matrix of volcaniclastic material similar to that of Stop 2. Southwest of the conglomerate at the edge of the outcrop, a thick calcite vein or a limestone clast is surrounded by a mafic flow. Here mafic flows (or volcaniclastics?) interfinger with fine-grained, layered clastic sediments. No conglomerates are found.

The southeastern portion of the southern outcrop consists of fine-grained, quartz-rich sediments which contain rare purple chert clasts and are cut by thin tightly folded quartz veins. In the northwestern portion of the outcrop, the sediments interfinger with mafic material.

13.40 Return to road and turn left; bear left onto Old River Rd.

14.10 Turn left on Simon Sayles Rd before tall silo.

14.40 Turn right at stop sign.

14.90 Bear left onto Wilbur Rd and turn into Conklin's Quarry (0.3 miles).

15.2 Stop 6. Limerock. The largest marble exposures are in three N50W trending quarries. We will look at the southern quarry, first on the northeastern side and then at the bottom on the southwestern side.

The southeastern side of the quarry shows a depositional contact between marble and dark, quartz-rich, laminated sediments. Locally there is a thin band of pure quartzite at the contact. The sediments immediately overlying the contact contain small quartzite clasts which are possibly slump blocks. The sediments are in intrusive contact with a granodiorite (at the far eastern exposure) which shows little deformational fabric. At the northwestern exposure of the marble/sediment contact, the marble appears frothy, iron-rich and is slightly brecciated. This is probably due to hydrothermal activity. On the west facing slope behind the contact, the sediments are cut by vertical strike slip faults. Further to the north a mafic flow is in fault contact with a sheared granodiorite.

Go to the southwestern margin for an excellent view looking across the quarry at the depositional contact. Note the mafic and granitic dikes which occur parallel to the vertical faults previously mentioned and the lack of offset of the contact by the faults. Walk along the road at the southern part of the quarry; Granodiorite is intrusive into quartziorite, and both units contain two foliations planes. On the southern side of the road the quartz diorite is sheared. Between the igneous units and the marble is an iron-rich chert breccia and more frothy marble. Contacts are not exposed.

Going northwest into the quarry, the road is lined on the east by hydrothermally altered marble. Further north on east facing slopes (close to where the road is being blasted) is a brecciated intrusive contact between granodiorite and marble. Float from this blasted region shows granodiorite intrusive into both marble and volcanics. On the top of the dump pile, the contact is again sheared. It is probable that the southwestern border of the quarry represents a shear zone. The similarity of units on both sides of the quarry suggests that the marble is in the nose of a tight fold.

15.20 Turn back onto Wilbur Rd and cross the first bridge ove~looking a marble quarry. Immediately turn right and go down a steep entrance ramp onto Rt 146.

16.10 Take Exit for Rt 116 South, the Lincoln Mall exit. (Also for North Central State Airport.)

16.80 Follow Rt 116. Turn right into Lincoln Mall at traffic light. Park next to McDonalds.

17.00 Stop 7. Lincoln Mall. The exposures are to the west of the mall along the road next to McDonalds. Mafic material, quartz-rich sediment, and fine-grained granodiorite (similar to that at stop 6) are interlayered and tightly folded (axes trend NS and plunge 26N). Behind the mall along the northern end of the parking lot, quartz diorite outcrops. The eastern exposures are intensely sheared and contain many dark, medium-grained xenoliths. The grainsize of the quartz diorite increases to the west where it been deformed by low angle (NW, 24NE) shear zones. The contact between the quartz diorite and Blackstone Series has undoubtably been reactivated as a shear zone.

---END OF TRIP---