GEO 407/607 FIELD TRIP

MESOZOIC MAGMATISM IN THE NEWARK BASIN

Saturday, March 11, 1995

THEMES OF THE TRIP:

Extrusive **BASALT VOLCANISM**

Intrusive gabbro plutonism - the **PALISADE SILL**

GRAIN-SIZE VARIATION and its causes

TEXTURES and their interpretation

MINERALOGY and its variation

FORM OF THE INTRUSION and the evidence for it

1A

Map of Newark Basin, and trip route

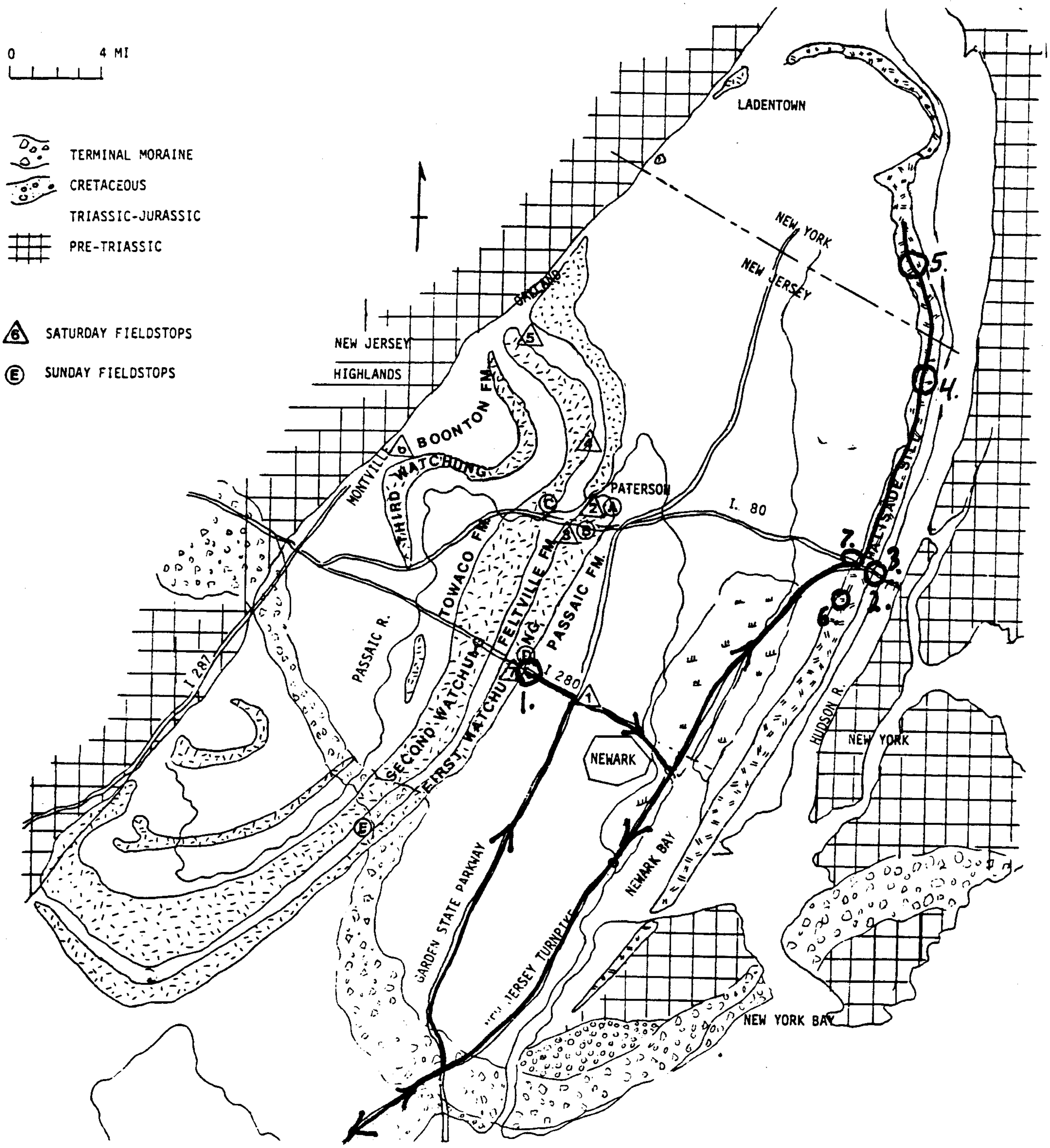


Fig. 2 Location map, showing generalized geology and field stops.

Manspeizer, 1980

GEO 407 FIELD TRIP

MESOZOIC MAGMATISM IN THE NEWARK BASIN

Saturday, March 11, 1995

Leave Penny Hall 0630; leave Mister Donut 0700.

Follow New Jersey Turnpike to exit 11, follow Garden State Parkway north to I-280. Exit onto I-280 westbound.

At the intersection and on 280 westbound, look for red sandstones and shales of the **Brunswick Formation,** of the late Triassic to early Jurassic **Newark Group**. These sediments formed the land surface onto which the Orange Mountain basalt flowed.

Which way to the sedimentary rocks dip?

As we drive west, are we going toward older or younger rocks?

What color are the rocks? Why are they that color? What kind of depositional environment do you think these rocks accumulated in? What's your evidence?

Begin to climb Orange Mountain. Pull over and stop at beginning of large roadcut on right.

STOP 1. ORANGE MOUNTAIN

1/2 - 1 hour; be **very careful of traffic**, and do not cross road. Take hammers, hand lenses and camera.

This magnificent road cut exposes the **Orange Mountain Basalt**, a 42-m-thick pile of Early Jurassic basalt flows. The Orange Mountain Basalt is the earliest of three periods of outpouring of basaltic lava onto the alluvial plain of the Newark rift basin. Each concentration of basalts holds up a major ridge, locally called the First, Second and Third WATCHUNG MOUNTAINS. Orange Mountain is another name for First Watchung Mountain. These large volumes of extrusive magma are almost certainly the extrusive representatives of the same magma system that created the nearly coeval, intrusive, Palisade sill.

The Orange Mountain Basalt consists of several major **lava flows**, some in direct contact with each other and others separated by sediment. See if you can identify flow boundaries in the cut. They probably resulted from **subaerial** (literally, "under the air", as opposed to subaqueous = underwater) eruption, above fluvial redbeds of the Brunswick Formation, which may be visible at base of the cut and eastward along 280.

Stop 1

Orange Mountain Basalt

65.2 **STOP 7 and D.** Orange Mountain Basalt; lower flow unit.

Objective: To examine a Tomkeieff sequence of colonnades and entablatures near the classical site of O'Rourke's Quarry. (See photograph facing the title page of this article.)

Background: This structure is described in the text under 'Columnar Jointing'.

When built in 1969, this road cut was the deepest federally-financed highway cut east of the Mississippi River. About 33 m deep, the cut exposes a complete section of the lower flow unit of the Orange Mountain Basalt, and a broad array of joint patterns that formed as the basalt cooled. The large "basin" structure on the southeast wall was first described about 100 years ago by J.P. Iddings (1886) of the U.S. Geological Survey in John O'Rourke's Quarry, about 300 m souh of the roadcut. While such complete structures have not been observed elsewhere in the Watchungs, similar joint structures, e.g. chevrons, oblique and reverse fans and rosettes (terminology of Spry, 1962) may be studied in this roadcut and in almost every quarry along strike for a distance of 80 to 100 km.

This structure (about 33 m thick) conformably overlies a fluvial red bed sequence of shales and sandstones and, when first exposed, displayed a complete Tomkeieff sequence of: (1) a lower colonnade (10-15 m); (2) entablatures (20-30 m); and (3) an upper colonnade (1-2 m) (Fig. 17). While the lower colonnade is composed of massive 4-5 or 6-sided polygonal and subvertical prisms, the entablature is composed of long (25-30 m) slender narrow joint prisms that radiate from an apparent focus. Several juxtaposed bundles or sheafs of radiating prisms may be observed in the roadcut, comprising fan and chevron-like features. Cross joints, intersecting radiating prisms at high angles, are prominent and appear to be concentrically arranged about the apex of radiation. An incomplete section pseudo-columns overlie the entablature.

Figure 18, depicting mineral and textural variations within the structure, shows an increase in grain size, an increase in the abundance and size of the interstitial glass, and an increase in the olivine content in the entablature (Fig. 19). This suggests that although cooling may have proceeded very slowly from the sediment-volcanic interface, once a groundmass capable of transmitting stress was established the remaining melt cooled almost instantly. The obscure joint pattern in the upper colonnade may form from convective heat loss near the upper part of the flow.

The early cooling history of the magma is manifested by well-developed horizontal striations observed on the joint surfaces of the lower colonnade. While Iddings (1886) may have been the first to report horizontal striations on joint surfaces (from O'Rourke's quarry), James (1920) speculated that these striations represent successive stages or pulses in which the rock broke and the columns formed. Recent studies by Ryan and Sammis (1978), and Justus and others (1978) at this site show that the striations are records of discrete thermal events, characterized by sudden periods of crack advance in the cooling basalt. Features such as chisel marks, pinch and swell and kink structures on the curvi-columnar joints may also represent an episodal cooling history. Each of these features may be observed on the walls of the highway cut.

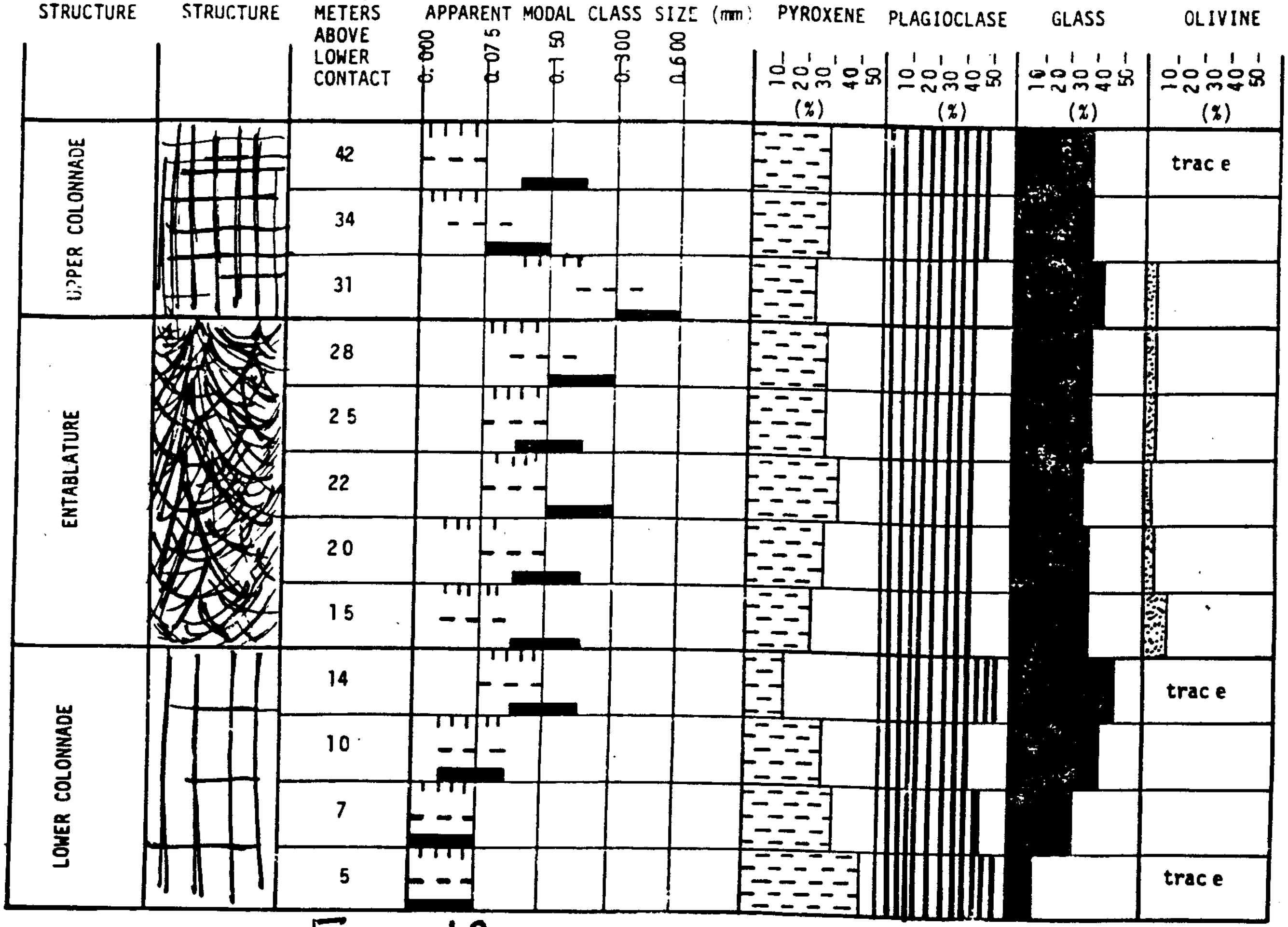
The striations reported by Iddings (1886) show up on joint surfaces of the lower colonnade as cyclical bands of smooth and rough zones, about every 5-7 cm. Ryan and Sammis (1978) report that as the crack growth procedes, the first-formed zone is smooth and associated with a thermal shock event; the second zone is rough, has positive relief, and is associated with the halting of each crack advance.

Joints of the entablature are also cut by concave-upward "dish-like" joints that are cut by strike-slip faults. While the origin of this structure is debatable, it trends N 50° E and evidently formed after the basalt cooled and before faulting occurred.

Dike intrusion into fluvial channel sands.

from Manspeizer, 1980

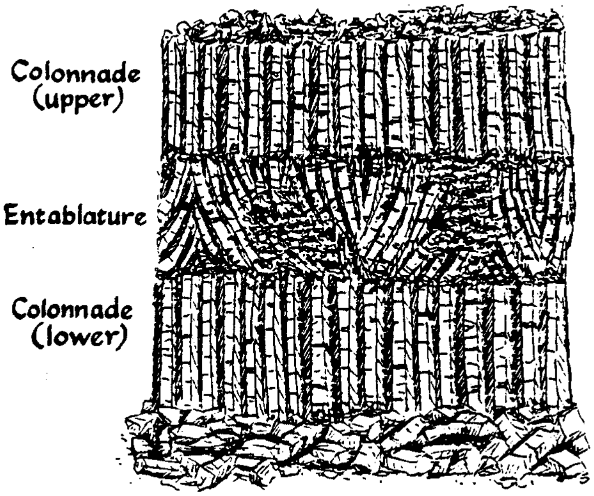
Orange Mountain Flow 1C



Manzspeizer, 1980

Fig. 18

Jointing in Flows



Williams + McBirney, 1979

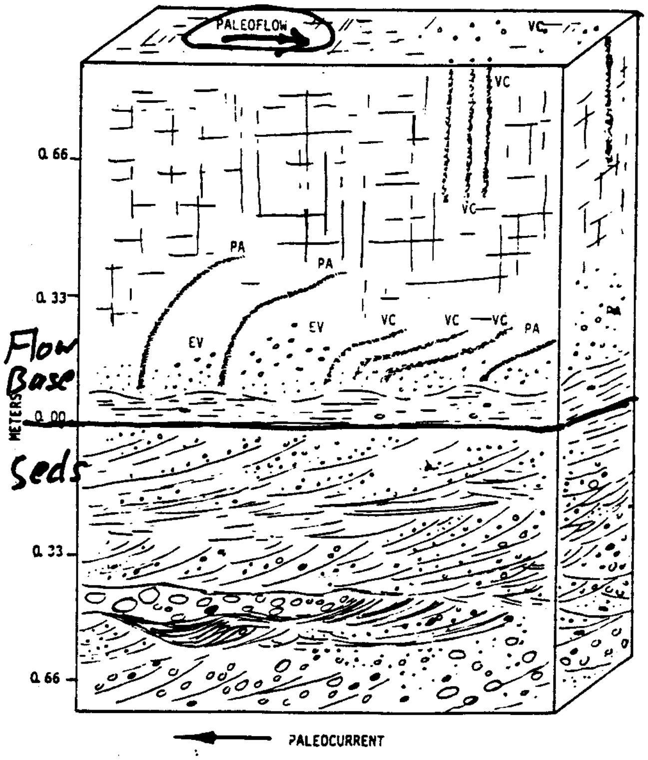


Fig. 6 Field sketch showing contact of the Orange Mountain Basalt with oriented pipe amygdaloids (pa), pipe vesicles (pv) and vesicle cylinders (vc), and underlying cross-bedded pebbly sandstone of the Passaic Formation, McBride Ave., Paterson. Structures indicate that the lava flowed towards the northeast, although the sedimentary paleoslope was inclined to the southwest.

1D

Columnar Joints at Orange Mountain

Columnar Jointing (Field trip stops 7 and D)

A spectacular columnar joint system, marked by a lower and upper colonnade with a central entablature, is the single most consistent and prominent feature of the lower flow unit of the First Watchung basalts (Fig. 17). It is remarkable that this three-fold joint pattern may be observed for a distance of almost 80 km along strike. It marks a uniform flow condition and cooling history over a vast area, suggesting that the lava was ponded. It is unlikely that these ponded lavas could have reached far beyond the northern limits of the current basin. First described almost 100 years ago by Iddings in 1886, these structures are equal in prominence to those described by Bailey (1924) of the Mull Province, Tomkeieff (1940) of the Devil's Causeway, and Waters (1960) of the Columbia River basalts.

This joint system is most completely exposed along Interstate Route 280 in West Orange, near the site of the O'Rourke Quarry described by Iddings in 1886 (Manspeizer, 1969). The structure, overlying a fluvial red bed sequence of shales and sandstones, consists of: (1) a lower colonnade; (2) an entablature; and (3) an upper colonnade. The lower colonnade, about 15 m thick, is composed of massive 4-5 or 6-sided polygonal subvertical joint prisms up to 13 m high and 0.5 - 1.2 m wide. The entablature consists of long (20 to 30 m), slender, slightly undulating curved polygonal columns that pinch and swell, and radiate from the apices of wide-angle cones that form upright, inverted and oblique fans and chevron structures (see Spry, 1961, p. 195.) Sheafs of curved downward radiating fans and chevrons are significantly more abundant than upward radiating structures by a factor of perhaps 10:1. Cross joints, intersecting the radiating columns at high angle, appear concentrically distributed about the apex of radiation. The density of joints, as manifested by the long slender prismatic columns, is the key factor differentiating the entablature from the colonnades. While the entablature of the First Watchung is curvi-columnar, in the Second Watchung it is characteristically composed of very long (about 25 m) and fairly continuous, slender (about 10 cm in diameter), non-radiating, parallel columns that are perpendicular to the flow surface. Poorly developed blocky columns and massive basalt of the upper colonnade overlie the entablature in most areas.

Petrographic studies of these structures in the First Watchung show some correlation between texture and mineralogy and the joint type (Fig. 18). The grain size is aphanitic throughout the flow but tends to increase from the lower contact to the base of entablature, remaining constant through the entablature, and reaching a maximum in the lower part of the upper colonnade. Microphenocrysts of plagioclase and augite occur in all three units.

The mineralogy includes pigeonite, augite, labradorite, and olivine (serpentinized) with few accessory minerals. Glass with magnetite is present in the interstices of almost all the samples. Six to ten percent olivine is present in the entablature and in the lower few feet of the upper colonnade, but only traces occur more than a few feet above or below the entablature. Pigeonite is absent from the entablature. The relative proportions of glass, total pyroxene and labradorite vary little in the upper two units. Glass and total pyroxene content in the lower colonnade show an inverse relationship. The amount of glass increases from 10% at the lower contact to 38% below the entablature. The pyroxene content decreases from 43% at the lower contact to 12% below the entablature. Glass and pyroxene content in the entablature and the upper colonnade are respectively 27 to 32% and 25 to 35% of the rock. Neither the anorthite content nor the total percentage of the labradorite shows any relationship to the joint structures of the flow.

Petrographically the curvi-columnar joint pattern of the entablature is characterized by an increase in grain size, an increase in the abundance and size of the interstitial glass, and the virtual restriction of olivine to this zone. These relationships suggest that although the rate of cooling of the hot flow interior may have proceeded slowly, once a ground mass capable of transmitting stress was established the remaining silicate melt cooled almost instantaneously. The greater rate of cooling near the center of the flow would produce more fractures per unit volume and a greater release of the total energy in the system (Spry, 1961). The clarity of joint reflection from the lower colonnade into the entablature indicates that joint propagation proceeded along master joints, as suggested by Spry (1961). The obscure joint pattern observed almost everywhere in the upper colonnade may be the result of convective heat loss near the upper part of the flow.

Other explanations offered for the origin of the curvi-columnar jointing in the entablature of the First Watchung basalts include: (1) an undulatory upper surface (Iddings, 1886; Manspeizer, 1969); (2) varying rates of cooling at the upper contact (Iddings, 1886); (3) the occurrence of feeder dikes (Bucher and Kerr, 1948); (4) the effects of master joints upon stress in the entablature (Spry, 1971), and a fracture-controlled quenching process whereby temperature and stress distribution are altered by water introduced through joints (Justus and others, 1978).This issue, and the observations by Ryan and Sammis (1978) are further discussed in the Road Log.

Manspeizer, 1980

We will examine outcrops in the lower part of the exposure, and will concentrate on looking at the east-facing cliff across the roadway.

THE ROCK ITSELF:

TEXTURES: In the outcrops, look for:

- **aphanitic grain size.** Typical of subaerial basalt.

- **Phenocrysts?** phyric or aphyric? Who are phenos?

- **Vesicles? Scoria? Amygdaloid?** any evidence for **vesiculation**? separation of a gas phase?

- Any internal structures in the basalt? is structure layered? or is it massive and homogeneous?

- Flow toes? tops? Pressure ridges?

- Look for vesicles. Had gas separated from this magma while it was being erupted? Why or why not? What is your evidence?

MINERALOGY: Look in the rocks with your hand lens. Try to see very small but visible grains of olivine, plagioclase, and probably pyroxene also.

THE COLUMNAR JOINTS:

Examine the columnar joints, and the columns, here on the east side.

What is the average width, or "diameter", of a column?

What is the average number of sides of a column?

Draw a cross-sectional view of the ends of some columns.

Draw a schematic view of the fanning behavior of columnar joints in the outcrop near where we are parked.

As you examine the cliff across the roadway, which if we played our cards right is basking in the bright sunlight, look at the <u>columnar jointing</u> that is spectacularly displayed. Consult the diagrams of jointed flow units on the next page, and try to find these features in the cliff:

- **a Tomkieff sequence**, which consists of

  upper and lower **<u>colonnades</u>**, of straight columnar joints. The lower colonnade is spectacular.

  Sketch one:

middle **entablature**, of curving, radiating columnar joints: sketch a bundle:

Contrast the columns of the colonnade and the entablature with respect to size, length, straightness, and **consistency of orientation**:

Columnar joints are commonly thought to develop with their long axes normal to the nearest cooling surface, and normal to the least principal stress axis σ_3. They are thought to be essentially tension joints, caused by contraction of the rock. The long dimension of the columns is normal to the plane in which o_3 lies. Why are the joints of the colonnade straight and parallel, while those of the entablature are curved and radiating?

THE PALISADE SILL

THEMES TO DEVELOP:

- the GRAIN SIZE story
- the MINERALOGY story
- the IRON-ENRICHMENT story
- the PEGMATITE-MICROPEGMATITE story

STOP 2. *PALISADE DRIVE BENEATH GEORGE WASHINGTON BRIDGE*

2.5 hours; take your gear with you. Take hammers and hand lenses, and rain gear if appropriate.

Start at south end of Palisade Drive, walk north beyond George Washington Bridge, examining rocks as we go.

First station: around the bend, first outcrop

examine and determine grain size, mineralogy, phenocrysts. Compare texture and mineralogy to those of Orange Mountain basalt.

What similarities?

What differences?

The large, flat vertical surfaces are columnar joints. Examine mineralogy on the weathered joint surfaces.

Describe the texture: equigranular? porphyritic? phaneritic? etc.

Take a sample for comparison later.

AT EACH SUCCEEDING STATION:

compare **grain size**, **mineralogy,** and **phenocrysts** with those of first station. Look for **trends of change** along the outcrop.

Take small samples at each station, for comparison, label them.

As you walk, pay attention to the changes in elevation of the road surface. It may be significant in your interpretations.

At about the 3rd or 4th station:

From what you have seen so far, can you tell what the **shape of the intrusion is?** or **what orientation it has?** What evidence can you use to reason this out? How do you know that your hunches are correct, based only of what you have seen so far?

What is the logic of locating your position in an igneous intrusion, in the absence of layering for reference? **Which way you are walking in the intrusion?** Parallel to a contact? toward a contact? away from a contact? What evidence do you have for which direction you are walking? **What would you expect to find when walking toward/away from a contact?**

What textural changes have you noticed in the rocks so far?

At about the 6th station:

You will encounter some changes. Figure out what they are.

What are the light and dark, layered rocks? what is your evidence? Sketch some evidences of the original nature of these rocks.

What happens to the homogeneity of the rock in this zone?

Compare and contrast the textures of grains in the dark rocks.

Sketch some evidences of **sill-like relations**, and some evidences of **dike-like relations.** What is the definition of each term dike and sill?

Eventually you will encounter some rocks that look different from what we've been seeing. Determine if these rocks are igneous, sedimentary, or metamorphic. What is your evidence? What kind of rocks were the parents of these present rocks? What convincing features of the rocks' origin can you find?

Sketch the relations of the rock masses at the north end of the layered rocks.

Are these layered rocks the **floor of the sill**? or are they a **xenolith**? What criteria did you use to make your decision?

Name some **primary sedimentary structures** you see in the layered rocks.

Look for small, light-colored **rheomorphic** (= remobilized) **dikes**, and figure out the intrusion sequence. What is mineralogy? Which rock is intruding which? Which is earlier and which is later? Sketch the relations:

Stand under the bridge, and look across into Manhattan. The east bridge towers are footed in Precambrian Fordham Gneiss, that was deformed during the Paleozoic Taconian and Acadian orogenies. The west towers are footed in late Triassic to early Jurassic sedimentary rocks of the Newark Basin. The unconformity separating Triassic from underlying Precambrian lies beneath the river.

Consider the **engineering geology** of the bridge. What factors would be important in locating the bridge at this particular spot? What effect on construction decisions would the **petrology** of the Palisade sill have?

Walk north of the Bridge, and **examine the basal contact of the Palisade sill in detail.** Observe and examine outstanding examples of:

- **concordant**, sill-like contact:
- **discordant,** dike-like contact;
- sharp (razor-sharp) and diffuse contacts;
- nearly vertical **normal faults**, with offsets of less than 2 m;
- **rheomorphic** relations in light-colored meta-sandstones;
- outstanding **primary sedimentary structures** in the now-metamorphic rocks; and
- dark "spots" in the light meta-sandstones; these are **porphyroblasts** of biotite, that were produced by nucleation and growth of new crystals during the contact metamorphism of sedimentary rocks by the sill's heat.

TURN AROUND AND WALK BACK TO THE VANS.

On the way back, study the cliff face on your right. Note a rather persistent "bench" - a slight change in slope, where there is more grass and more trees than on the steep rock portions above and below. Why is that bench there? Is it just coincidence, and meaningless, or is there a cause? and if there is a cause, is it man-made or natural?

STOP 3: SOUTH END, PALISADE DRIVE

Look at **weathered surfaces**, with hand lens. Look for mineralogy, closely. What minerals can you identify?

Why is the rock **so crumbly**? This is certainly anomalous, compared to the rocks we have just walked through. Look closely at it with hand lens. What is average grain size? How does grain size compare to our starting station?

Look at the weathered soil, the **rubble**, with your hand lens. Look for **poikilitic texture**, that is, grains of one mineral inside another mineral.

What is the **mineralogy** of these rocks?

Why is the rock so **red-stained?**

Where is this location **relative to the base of the sill?**

Where is this location **relative to the bench** you have been following?

Why is the rock so **apparently layered?** What do you think controls and produces that apparent layering?

What is the **best explanation** for these rocks?

STOP 4: *FORT LEE PARK.* Lunch and pits

Short stop to examine **texture, grain size and mineralogy** of sill 30-40 m above last station along Palisade Drive.

What is the **average grain size** (in mm) here?

Describe the overall **texture** of the rocks here.

Look with hand lens at low outcrops. Concentrate on the **pyroxenes** here.

You can see relatively large, 2-3 mm **bronzite** microphenocrysts. Tan to light brown, sometimes bronze-looking. Good crystals sometimes. They may be **ophitic** around plagioclase, if you look hard. Bronzite is an orthopyroxene, part of the enstatite series, and has a composition of $Mg_{90}Fe_{10}$ to $Mg_{70}Fe_{30}$. It is more magnesian than hypersthene.

Look hard for elongate, bladed black crystals. I haven't found any here as of yet. What does their absence signify?

What are **early-crystallizing minerals? Late-crystallizing minerals?**

Look at the **textures** in the rock. This is textbook-typical **diabasic texture**.

Look for **cumulate plagioclase** laths, arranged like logs and surrounded by pyroxene.

Look for **interstitial orthopyroxene** (or pigeonite). A beer (a six-pack) to anyone who finds inverted pigeonite with their hand lens.

These outcrops show glacial grooves and scour on the smooth rock surfaces; the ice got at least this far south.

STOP 5: TALLMAN MOUNTAIN STATE PARK, NY

Consider the major **themes of the trip** at this stop: **grain-size** variation, **textural** variation, and **mineralogical** variation. Compare these features here with their counterparts at the previous stop.

What are the **major minerals** in the rock here? What is the cm- to 2-cm-long **black bladed mineral?**

Any **preferred orientation** of the crystals?

How do **texture** and **grain size** compare with Fort Lee Park?

Look with hand lens at rock texture. Can you see **quartz? micropegmatite?** Look hard.

Look on the outcrop face for areas and patches of **pegmatite**, regions of rock that are significantly coarser-grained than the adjacent rock. The pegmatite masses have irregular, blob-like shapes and may have diffuse or gradational borders. Sketch a pegmatite mass.

What do you know in general about the cooling history of pegmatite masses? What was the cooling history of the pegmatite compared to that of the surrounding rock? What was different about the pegmatite cooling history?

How and why did the masses of pegmatite form? What do they signify about the magma from which they crystallized?

Why is the outcrop surface so smooth?

Note the big boulder sitting above the exposure. What kind of rock? Did it come from this outcrop? Why or why not?

STOP 6: US 9W, AT CLOSTER DOCK ROAD

20 minutes. Be careful of traffic here, especially when crossing the road.

The purpose of stopping here is to examine texture and mineralogy to see if you can **determine stratigraphic position** within the sill.

EXAMINE THE TEXTURES:

What is **average grain size?**

What is the dominant **texture?** any **phenocrysts**?

How do texture and grain size compare to those at Fort Lee Park?

to those at Tallman Mountain?

EXAMINE THE MINERALOGY:

What were the **major minerals crystallizing from the magma** here?

What kinds of **pyroxenes** are present? Anything new here?

How about the black, bladed mineral? Is it present here? If so, how does it compare to black mineral at Tallman Mountain?

Look carefully with hand lens for small, irregular patches of **micropegmatite**, which is interstitial between the large pyroxenes and plagioclases.

Where do you think you are in the sill? Higher or lower than Fort Lee Park? Higher or lower than Tallman Mountain? What's your evidence?

In arriving at your opinion, what model for the overall development of the sill did you use?

STOP 7: I-80 WESTBOUND, NORTH WALL

Take hard hats, hammers, boots. Do not leave vans unattended, or they will be towed.

STAY BEHIND THE GUARDRAIL AT ALL TIMES. WATCH YOUR FOOTING, AND WATCH OUT FOR FALLING ROCKS FROM ABOVE.

The road cut exposes the uppermost 340 feet (98 m) of the sill. The upper third. Keep these stories doing: the **textural variation** story, the **mineralogy change** story, and the **pegmatite-micropegmatite** story. All three stories come together here.

Start at the east end of the outcrop just beyond the on-ramp, and walk west to the end of the outcrop. You are walking obliquely up-section, and are getting higher in the sill.

As you examine the section, use the high bridge as a dividing point. **Compare and contrast the rocks EAST OF and WEST OF the high bridge.**

EAST OF THE HIGH BRIDGE:

What are the **major minerals** in the rock?

Look for free **quartz**, and **K-feldspar**.

What mineral constitutes the largest grains in the rock?

Watch the grain size change as you go west. How does it change?

Is the texture **equigranular?** or **inequigranular?** Watch the texture change toward the west.

Look for clearly visible patches of **micropegmatite** (grain scale) in between the feldspar and pyroxene grains of the diabase.

Watch for the appearance of **pegmatite**. What **minerals** are found in the pegmatites?

How are the pegmatites **distributed** in the rock? What are the **shapes and sizes** of the pegmatite masses? What are the contacts with surrounding rock like (sharp or gradational)?

What are the **grain sizes** of the various minerals in the pegmatites?

Watch how the grain size in the pegmatites varies as you go west.

Is there any correlation between [grain size] and sharpness of the contacts] with the [size of the mass] of pegmatite bodies as you go west? Work on this particularly just west of the high bridge.

STRUCTURAL GEOLOGY:

The rock is strongly jointed here, but these are secondary, tectonic joints rather than cooling joints. Zones of closely-spaced joints represent fracture and fault zones, and slickensides are common on the fractures surfaces and mineral coatings.

Identify **conjugate shear fracture** pairs, by the acute inter-fracture angle.

Look at the **hydrothermal alteration** adjacent to some of the fractures. These are filled with **calcite** and **zeolite** and **prehnite** mineralization along the fracture surfaces. Some good calcite collecting. I once found an impressive crystal of **galena** here.

WEST OF THE HIGH BRIDGE:

What happens to the **overall grain size** as you go west from the bridge?

Is the texture **equigranular?** or **inequigranular?** Does it change? or stay the same?

What happens to the **micropegmatite** as you go west?

What happens to the **pegmatite** masses? to the **maximum grain size** in the pegmatites? to the **sharpness of their borders?**

What are the **major minerals** in the rocks west of the bridge? What is the largest mineral you can identify?

Where else today have you seen rocks that look like these rocks west of the bridge?

Where does it all end? Will it ever end?

How do you tell when you are in **metamorphic rocks?** What are the criteria for metamorphic (= non-igneous) origin of these rocks?

Find and **xenolith** in the sill rocks, and sketch the relations.

Are the contact relations **sill-like** or **dike-like**? What is your evidence?

Where else today have you seen **metamorphic rocks** like these?

CENTRAL QUESTIONS TO PONDER: SUMMARY OF THE TRIP

- Where in the sill was the **maximum grain size**? Why was it there (in that place)? What petrologic processes might have been involved in locating it there?

- Did the position of maximum grain size correspond to the position of maximum pegmatite abundance? If so, why should that be? What does the correspondence mean in petrologic terms?

- What petrologic processes does the **grain-size variation** represent?

- What processes do the **pegmatites** represent? What causes the irregular, localized concentrations of such very coarse grains?

- What do the **contact relations** indicate about the mechanism of intrusion of the magma?

- What evidence did you see that supports a model of **fractional crystallization** of magma?

- What evidence did you see that supports a model of **gravity settling** as a mechanism of **differentiation** of the sill?