Geology and Geochemistry of the Jonestown Volcanics, Pennsylvania

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Abstract

The Jonestown Volcanic Complex is a 30 km^2 area of igneous rocks located in the Ordovician Hamburg Klippe, a Taconic allochthon. Detailed field mapping of these igneous rocks shows that hypabyssal rocks (diabase) comprise about eighty percent of the areal extent, while basaltic volcanic rocks, including pillows and pillow breccia, comprise only twenty percent, and are restricted to one of the four structural belts of igneous rocks. Field observations show that it is doubtful that there are intact sedimentary or igneous contacts between the igneous rocks and the flysch of the Hamburg Klippe, adjacent to them. The volcanic rocks, however, are locally in original association with massive limestone, the closest regional lithologic analogues of which are Laurentian platform carbonates. The volcanics and associated limestone may be a structural equivalent of the Lebanon Valley sequence to the south, and the limestone resembles the Annville Formation of that sequence. We suggest that the quartzose sandstone capping the Bunker Hills is an outlier of the Silurian Bloomsburg/Tuscarora Formation. Whole rock analysis of trace and rare earth elements shows that the Jonestown igneous rocks are basaltic, and that they are mildly enriched relative to MORB and have sub-alkaline tendencies. Trace element patterns of the hypabyssal rocks can be interpreted to contain hints of continental contamination. Uncertainties in the age of these rocks allow for alternative interpretations of the igneous activity, including a seamount in the Taconic ocean before collision, or on the Laurentian foreland either well before, or during, the arrival of the Taconic subduction system. All possibilities require the igneous rocks to be transported significant distances relative to the flysch. The chemical evidence for crustal involvement and the association of volcanic rocks exclusively with carbonate rocks lacking clastic input suggest a Laurentian foreland interpretation is more likely. The preferred hypothesis, which requires subsequent out of sequence thrusting, is that the igneous activity occurred on the Laurentian foreland just before Taconic collision.

Contacts

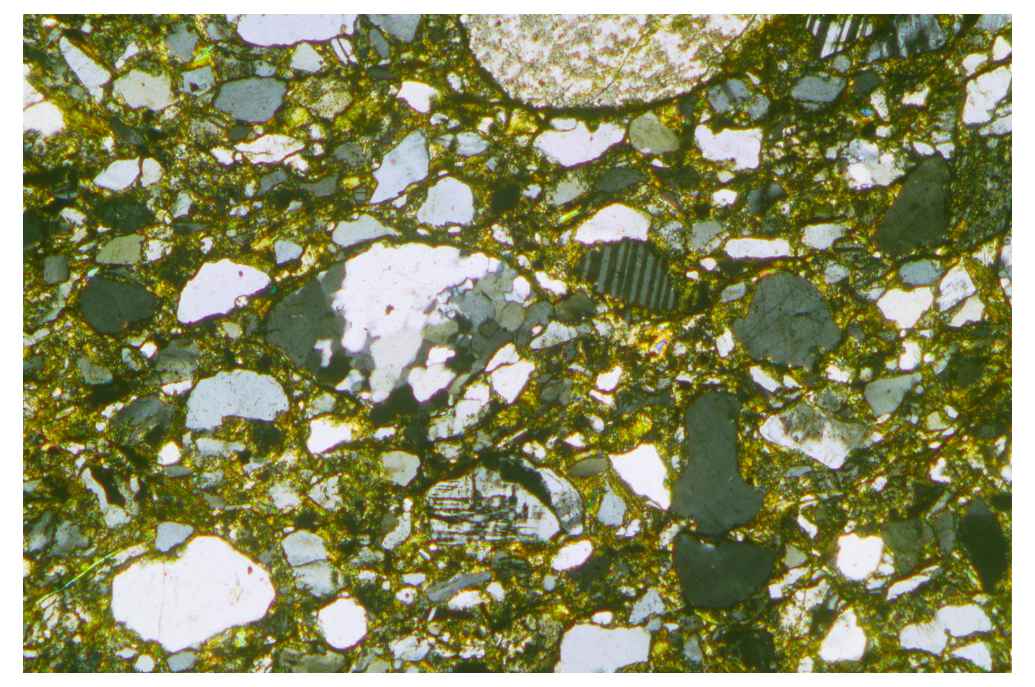
Limestone in pillow basalt just south of the abandoned Reading Railroad bridge over Swatara Creek. Arrows point to limestone pieces. Small sledge for scale. The limestone in this outcrop is visually indistinguishable from the massive limestone outcrop beneath Swatara Creek bridge. That massive limestone was not likely deposited in a trench, so the basalt could not have been erupted in one.

The recessed contact zone between flysch of the Hamburg Klippe on the right (north) and diabase of the Jonestown Volcanics on the left (south), in the west side of the abandoned railroad grade in Bunker Hill, Pa. Rocks on both sides of the contact are fractured and exhibit slickenlines. The contact also truncates bedding in the sedimentary rocks. Hammer for scale.

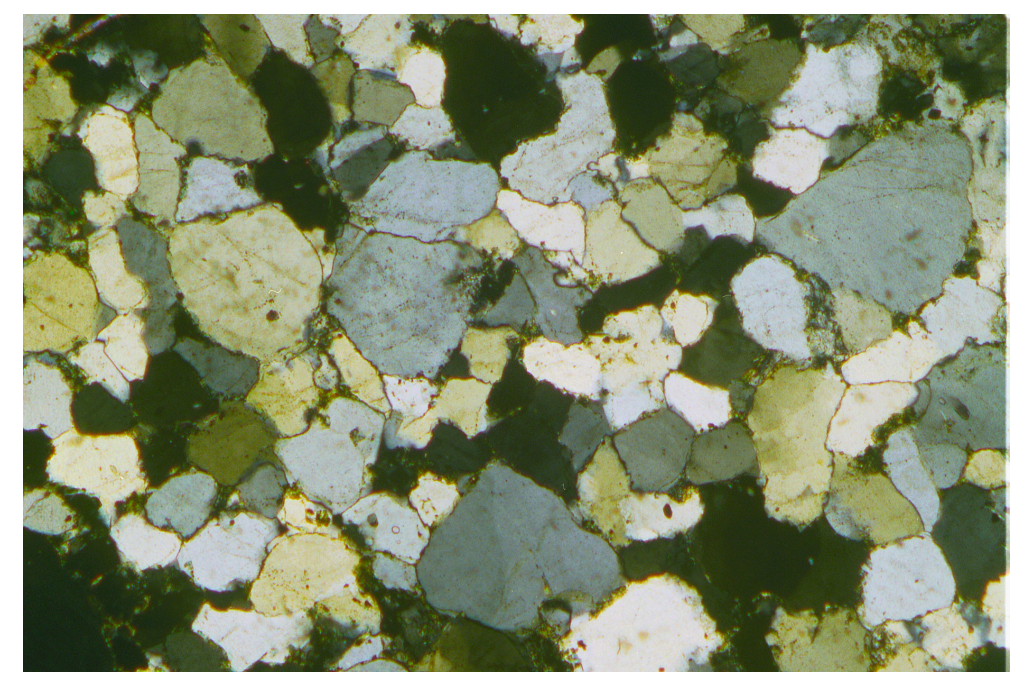
Massive limestone beneath the southern end of abandoned railroad bridge over Swatara Creek. The limestone matches field descriptions of the Annville limestone, part of the Lebanon Valley sequence to the south. Its age is uncertain, so the two can not yet be directly corellated. Hammer for Scale.

The relationship between the pillow basalt and the massive limestone shows that that limestone was present when the basalt was erupted. This limestone is only present below the basalt, and is not conformable to the flysch of the Hamburg Klippe. Two possible places this Ordovician limestone could have formed are a seamount or the Laurentian (Taconic) foreland.
Contacts between the diabase and the flysch show significant structural complication. They are routinely recessed or covered, and marked by increases in fractures and slickenlines on the fracture surfaces. There are neither chilled margins in the diabase or contact metamorphic zones in the sedimentary rocks. Discernable bedding in the sedimentary rocks is truncated by the contact with the igneous rocks. The evidence suggests that the contacts are not original (neither depositional nor intrusive), and the structural complications allow for significant motion to have occurred along those contacts.

Bunker Hill Sandstone Compared to Typical Klippe Flysch

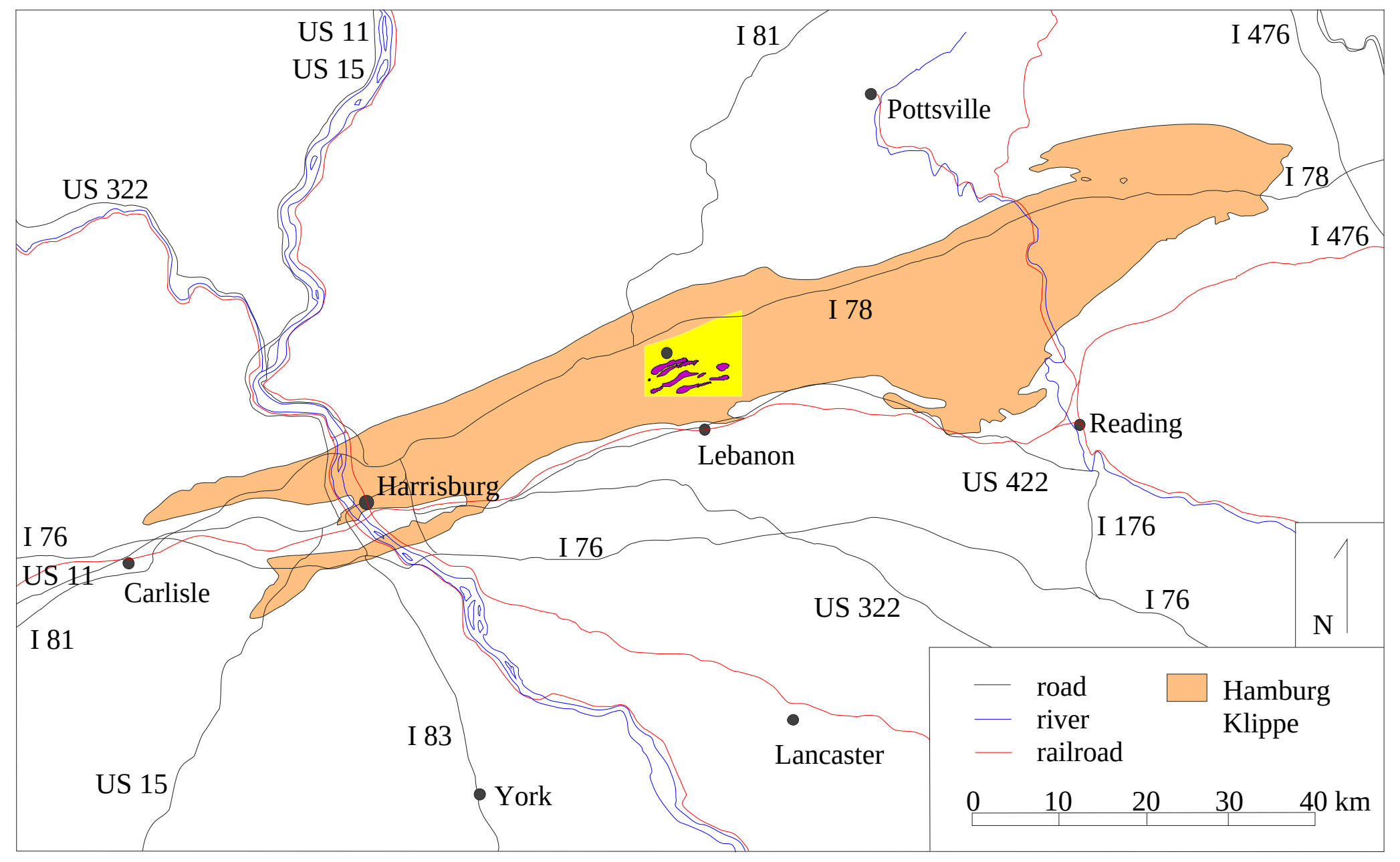


Thin section of HK-16, a representatve sample of Hamburg Klippe flysch, viewed under crossed polars. Note the grains of plagioclase, microcline, and polycrystalline quartz, the lithic fragment, and the significant mud matrix. Field of view is 2.12 mm by 1.38 mm.



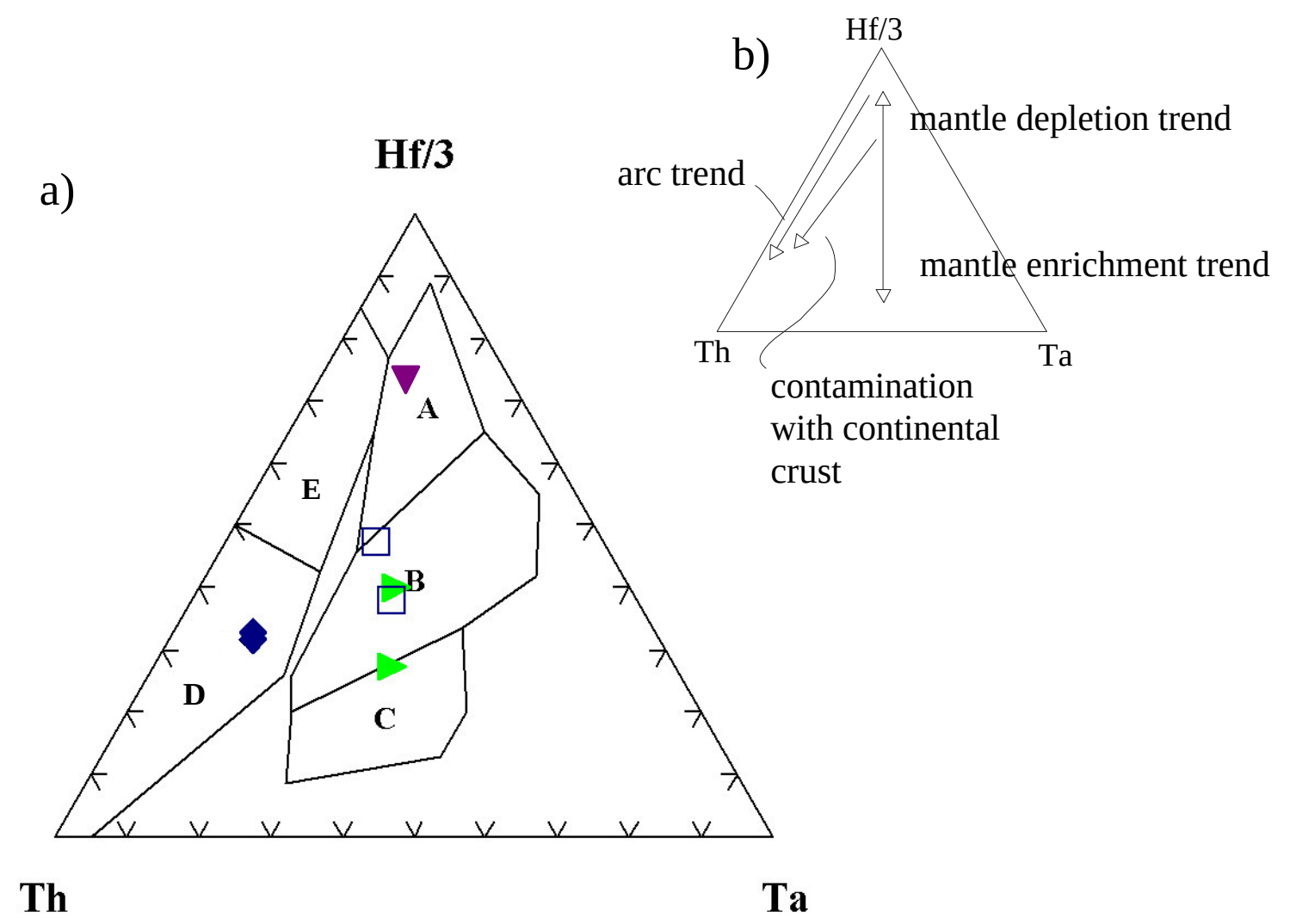
Thin section of HK-26, a sample of Bunker Hill sandstone, viewed under crossed polars. The sample consists almost entirely of monocrystalline quartz, with little matrix. Field of view is 2.12 mm by 1.38 mm.

The two sandstones are visibly different in outcrop as well. In outcrop and in thin section, the Bunker Hill sandstone most resembles the Silurian Tuscarora formation. It is likely an outlier of the Tuscarora/ Bloomsburg to the north, and its Silurian age helps constrain structure in the field area.



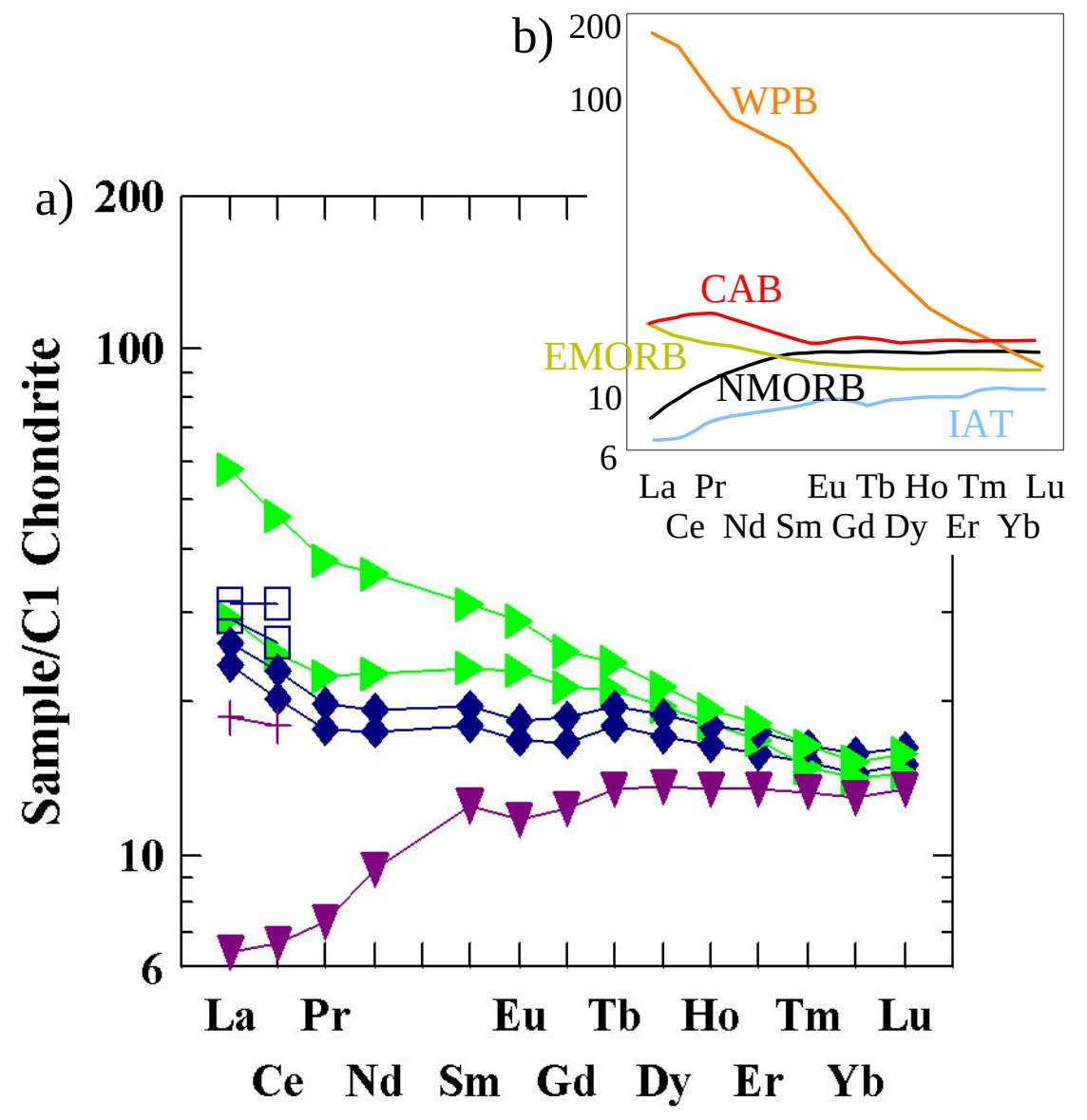
Location map of the Hamburg Klippe (undifferentiated) showing overall extent. The Jonestown volcanics are shown in purple. The field area mapped in this project is highlighted in yellow. After Berg, et al. (1980)

Trace and Rare Earth Elements: Taconic Foreland
(Jonestown Volcanics and Stark's Knob)



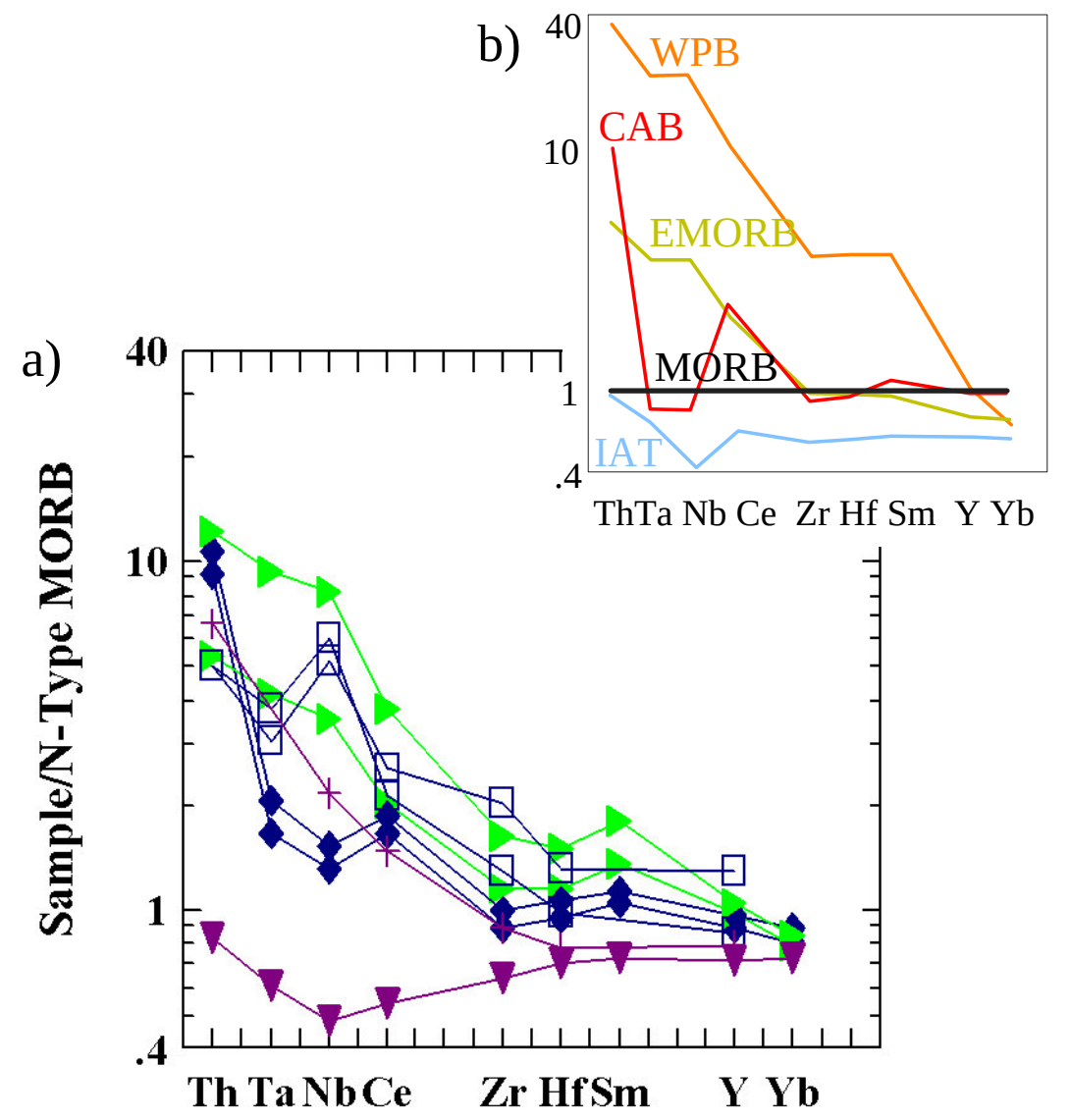
A Normal Mid-Ocean Ridge Basalt
B Enriched Mid Ocean Ridge Basalt and Tholeiitic Within Plate Basalt
C Within Plate Basalt
D Calc-Alkaline Basalt
E Island Arc Tholeiite

a). Hf-Th-Ta (Wood, 1980). b). Schematic showing important trends on the Hf-Th-Ta diagram, from Pearce (1996).



a). Rare earth elements normalized relative to C1 Chondrite (values from Sun and McDonough, 1989). b). Patterns of common basalt types shown for reference. Normalizing values for normal mid-ocean ridge basalt, enriched mid-ocean ridge basalt, and within-plate basalt are from Sun and McDonnough (1989). Normalizing values for calc-alkaline basalt and island arc tholeiite are from Pearce, et al. (1995).

Hand sample analysis, thin section petrography, and CIPW-norm calulations all show that the extrusive rocks are basalt, and that the hypabyssal rocks are diabase. The basalt and diabase, have simlar major element abundances, but show a few significant differences in trace element abundances.



a). Mid-ocean ridge basalt normalized spider diagram for the Jonestown igneous rocks, shown along with Stark's Knob. Element order is simplified from Pearce (1982). b). Patterns of common basalt types shown for reference. Normalizing values for normal mid-ocean ridge basalt, enriched mid-ocean ridge basalt, and within-plate basalt are from Sun and McDonnough (1989). Normalizing values for calc-alkaline basalt and island arc tholeiite are from Pearce, et al. (1995).

- ▶ Basalt Pillow. This Study
- ◆ Diabase. This Study.
- ☐ Basalt Pillow Breccia. Smith and Barnes (1994).
- \+ Diabase. Smith and Barnes (1994).
- ▼ Stark's Knob Basalt. This Study.

The diagrams here suggest the diabase and basalt cooled out of separate melts. The two rock types exhibit similar slopes on the REE diagram, allowing that both could have derived from a similar primary source. The Hf-Th-Ta diagram suggests two possible origins for the diabase, but because of a dearth of evidence of a volcanic arc in the field area, the diabase is probably not arc related. It more likely interacted with continental crust. The Ta and Nb anomaly on the MORB normalized spider diagram could also have been caused by significant interaction with continental crust (Legault et al., 1994). The basalt does not show this continental contamination, however.
Due to the coincidence that the basalt and diabase are currently juxtaposed and share similar field relationships, it is unlikely they originated in a significantly dissimilar time and place. The difference between the two likely represents less than a few million years or not more than a few tens of kilometers. The continental contamination in the diabase should not be found on a seamount, and would place this volcanism on the Laurentian foreland.

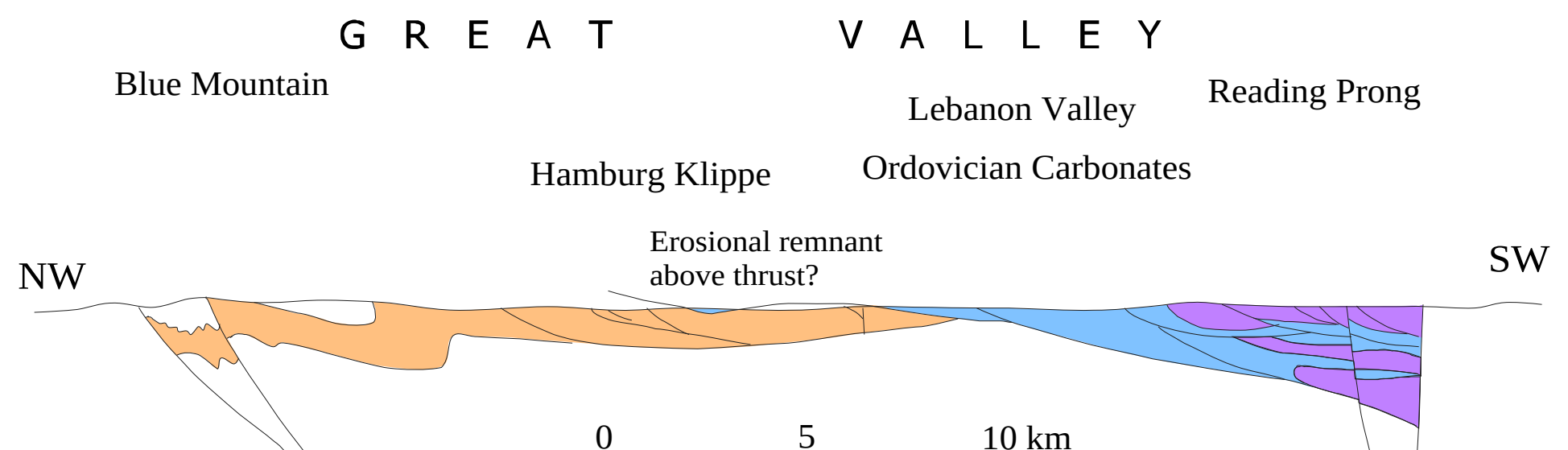
The Silurian Bunker Hill sandstone
1) Dips shallowly to the south and is not folded.
2) Is not repeated in the field ara.

The Bunker Hill sandstone rests on the Hamburg Klippe on either an unconformity or a low angle fault that is roughly parallel to the bedding of the Bunker Hill sandstone. Its truncation to the south suggests the presence of a high angle thrust fault.

The field area has at least two distinguishable structural styles, the low angle thrusting that is likely associated with emplacement of the Hamburg Klippe, and may have been reactivated in the Alleghanian, and the high angle faulting, which came later, and must be Alleghanian.

Bunker Hill quartzarenite, dipping south. Picture taken at outcrop near eastern limit of outcrop belt. Hammer for scale.

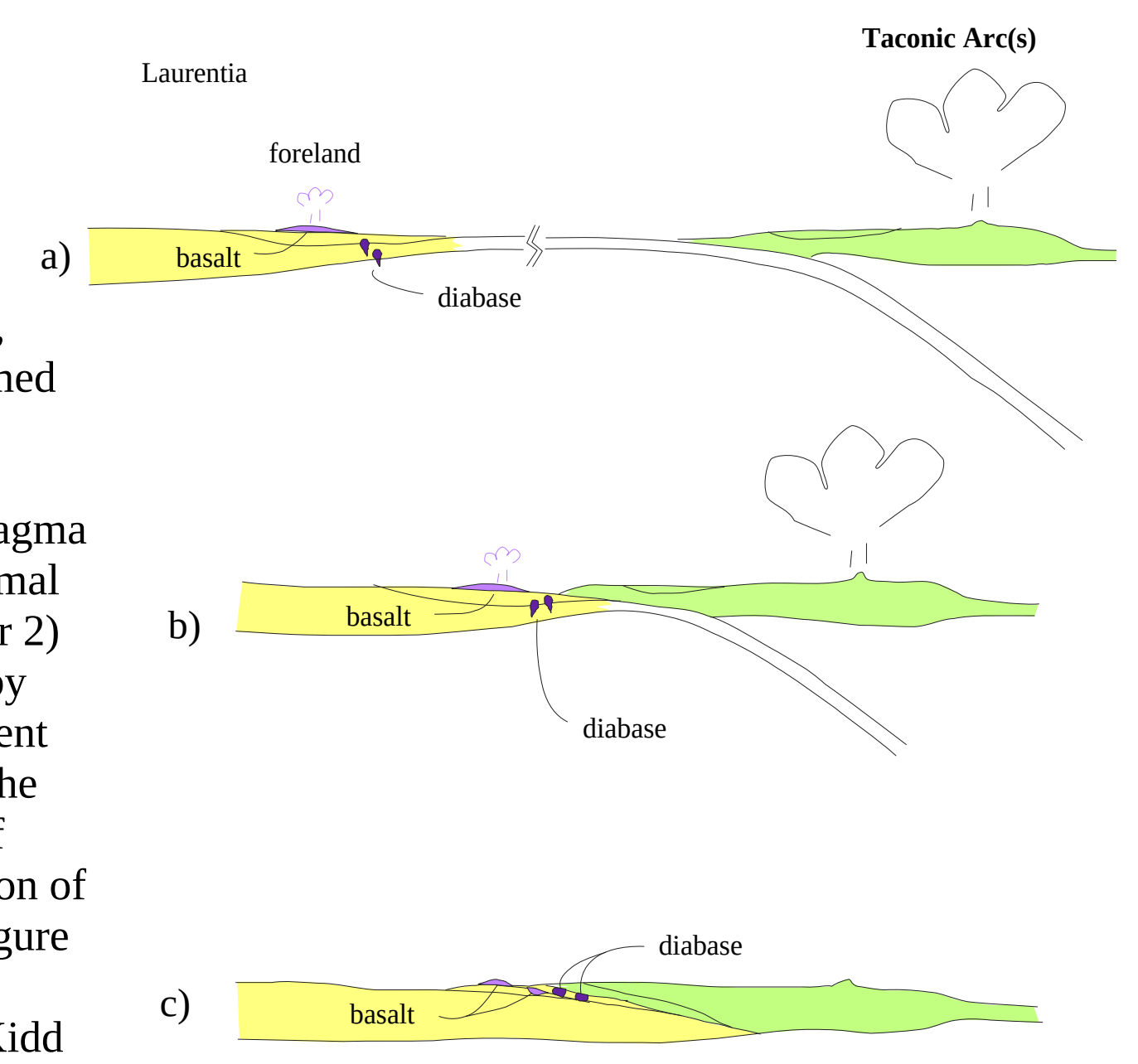
Structure



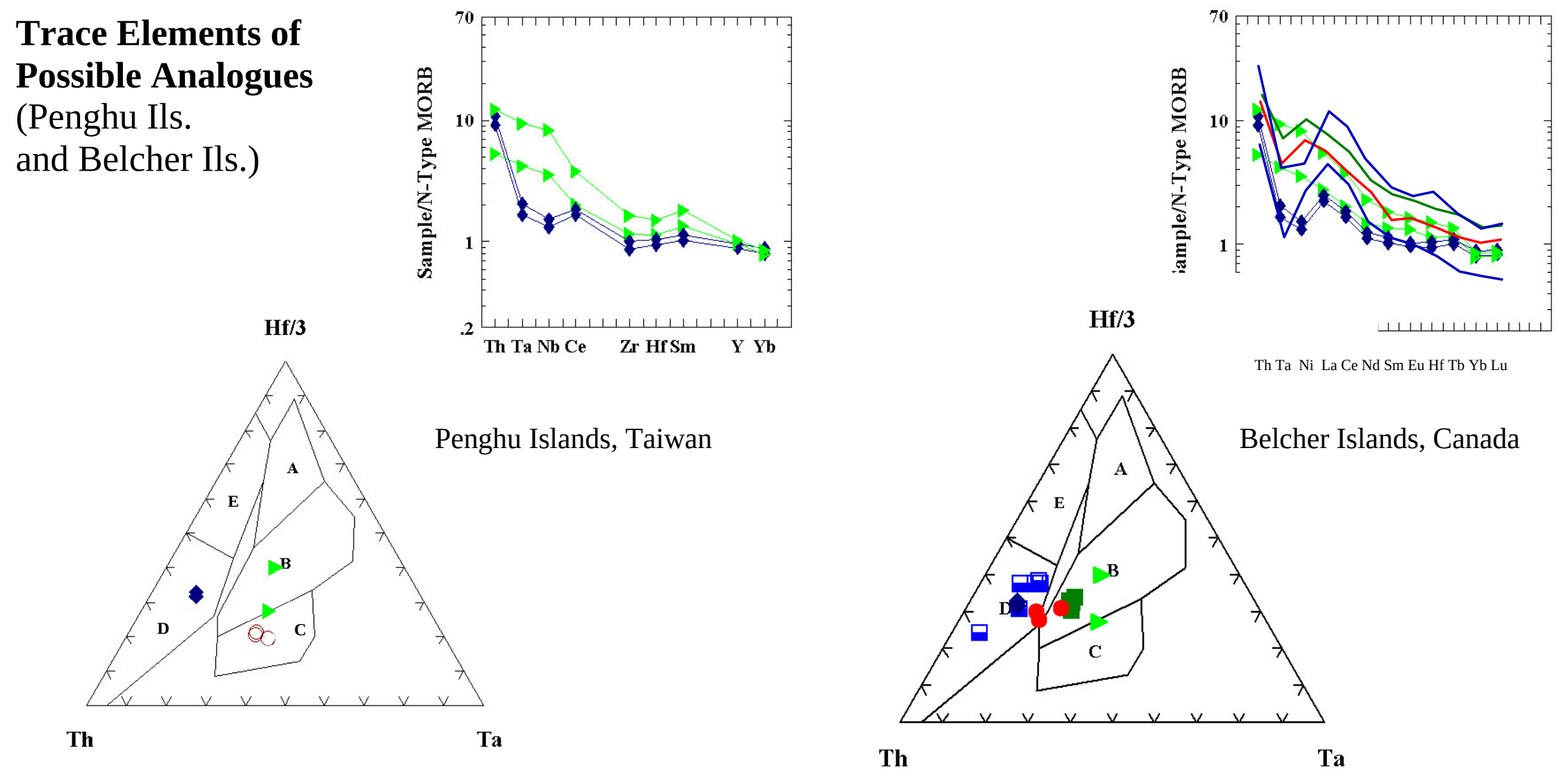
Generalized cross section (after Berg, et al., 1980) of the Great Valley- Hamburg Klippe (in orange), Ordovician carbonates (in blue) and Reading Prong crystalline basement (in purple). In this interpretation, later high angle thrusting offsets the earlier low angle thrusts. This section shows a scenario where the limestones (and associated volcanic rocks) are an erosional remnant of one of the thrust sheets of Ordovician carbonate in the Lebanon valley. These Laurentian margin carbonates have been thrust over the previously emplaced Hamburg Klippe on an out of sequence thrust. In this scenario, the limestones and volcanics rest in the only true klippe in the field area. The high angle faults offsetting the volcanics and truncating the Bunker Hill sandstone are not shown here, but they must exist. No vertical exaggeration.

Tectonic Model

Series of simple sketches suggesting a history of emplacement and subsequent juxtaposition of the Jonestown igneous rocks. Timing of the volcanism on the Laurentian foreland is not precisely constrained, and the igneous rocks may have formed either during the time represented in figure a or figure b. Possible mechanisms for the generation of magma could be 1) foreland flexure and normal faulting (Bradley and Kidd, 1991), or 2) orogen-normal fractures, described by Sengor et al. (1978), in an environment much like the one which generated the basalts of the Penghu Islands west of Taiwan. The subsequent juxtaposition of the basalt and diabase is shown in figure c. Overall geometry of the Taconic convergence based on Rowley and Kidd (1981). Not to scale.



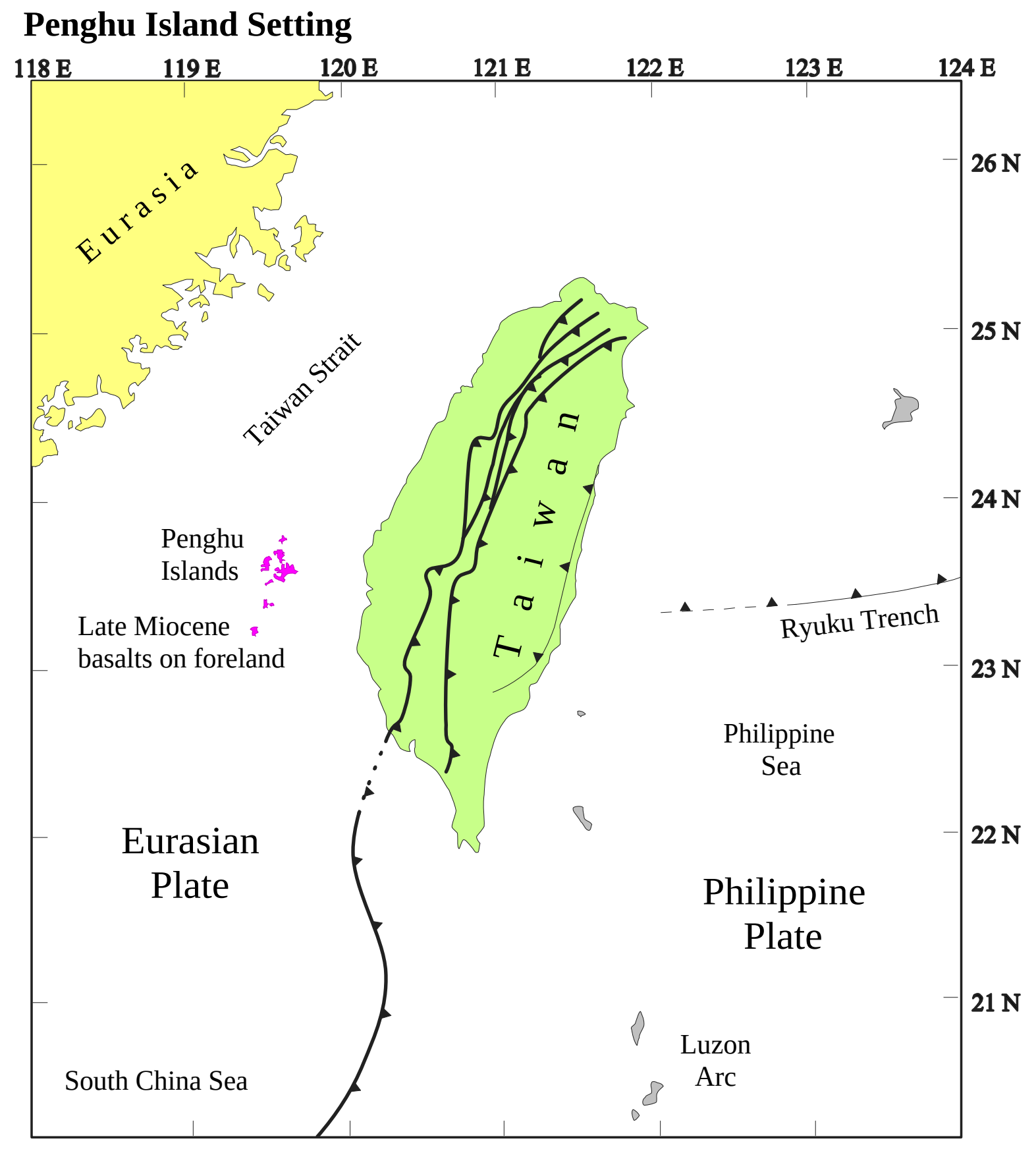
Trace Elements of Possible Analogues
(Penghu Ils.
and Belcher Ils.)



- ▶ Basalt. This Study
- ◆ Diabase. This Study.
- ○ — Average Penghu Island Alkali Basalt. Greenough, et. al (1999), Chen (1988).
- — Average Penghu Island Tholeiite. Chen (1988).

- ■ — Flaherty Formation, High Zr Rock. Legault, et al. (1994).
- ● — Flaherty Formation, Low Zr Rock. Legault, et al. (1994).
- ▣ — High and Low values of the Eskimo Formation. Legault, et al. (1994).

Penghu Island Setting



Map showing the location of the Penghu Islands and the present day tectonic setting of Taiwan. The Penghu Islands are in the Asian foreland, but are nearing the collisional zone in Taiwan. The basalts of the Penghu Islands were erupted between 11 and 8 million years ago (Juang and Chen, 1992), At that time, the regional tensional stress field was oriented NE to SW, roughly parallel to the subduction in Taiwan, and was likely related to the approach of the Philippine plate. Map based on Angelier et al. (1990), location of trenches and thrust faults is from Suppe (1980). With respect to trenches or thrust faults, teeth are on overiding plate.

Conclusions and Interpretations

Detailed analysis of the contacts between igneous and sedimentary rocks shows:
1) The pillow basalts, can be shown to be conformable to the massive limestone that occurs stratigraphically below them. However, this massive limestone is not conformable to the flysch of the Hamburg Klippe. The association between the massive limestone and the pillow basalts suggests the pillow basalts were extruded onto a carbonate bank.
2) The diabase can not be shown to be conformable to any other rocks in the field area, inclucing the massive limestone and the basalt. However, they likely originated in the same magmatic province.

A study of the whole rock geochemistry of the igneous rocks shows:
1) The rare earth element patterns of the basalt are similar to the patterns of basalts extruded in extensional environments in foreland settings of collisional belts. The rare earth element pattern of HK-43 is nearly identical to these foreland basalts.
2) Ralative abundance of the trace elements Ta and Nb suggests that the source magma for the diabase probably had some significant continental contamination.

The structural geology of the field area is complex, but there are at least two distinct structural events.
1) The initial low angle thrusting occurred during the Taconic Orogeny, during emplacement of Taconic flysch on the Laurentian margin.
2) High angle thrusting during the Alleghanian orogeny truncated the southern margin of the volcanic rocks and the Bunker Hill sandstone.

These conclusions suggest that the igneous rocks of the Jonestown volcanics originated on the Laurentian carbonate shelf. Their genesis was likely related to the evolution of the Laurentian margin from a passive margin (carbonate deposition) to a continental foreland basin (clastic deposition). Magma genesis could have been related to tensional stresses normal to the approaching Taconic allochthon. The timing of the igneous activity is intimately related to the uncertain age of the Limestone at Swatara Creek bridge (Lash, 1984). It is quite likely that the limestone is the upper Llanvirn to Llandeilo Annville Formation, and magmatism would have roughly been coeval with the Llandeilo to Caradoc deposition of the preserved flysch of the Hamburg Klippe. In this scenario, the limestone and volcanics are erosional remnants resting on a low angle thrust above the flysch sediments of the Hamburg Klippe.

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