

A brief outline of the geologic evolution of the Southern Appalachians, USA, and some of its associated metals mineralization

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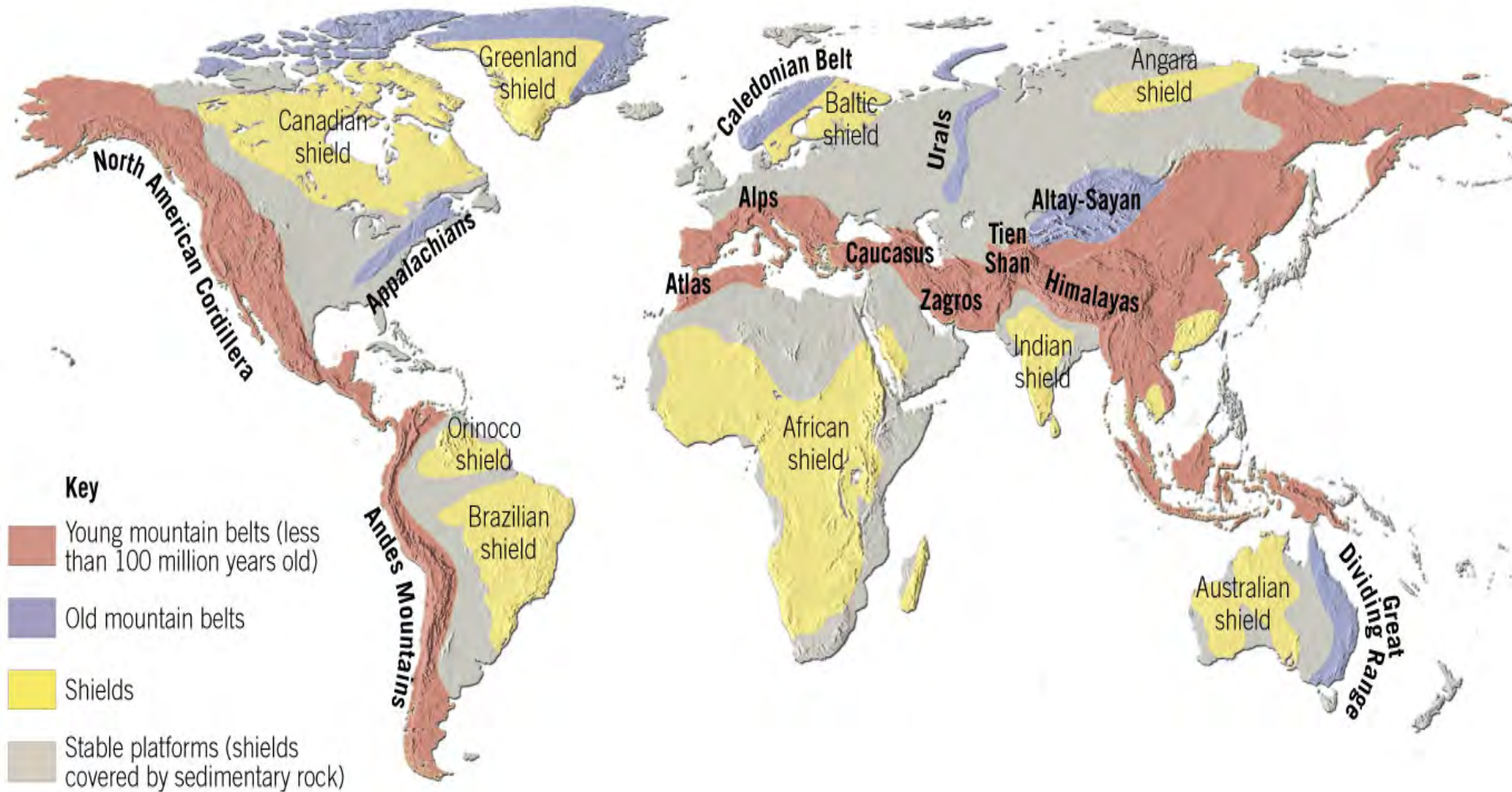
Outline of talk

- Location of the Southern Appalachians
- How and when were they formed
- Mafic/ultramafic rocks in the Southern Appalachians, and their origin
- Granitic plutons in the Southern Appalachians, and their origin
- Metals mineralization in the Southern Appalachians

NORTH AMERICA



Earth's major mountain belts



Notice the E-W trend of major mountain belts in Eurasia in contrast to the N-S trend of the North & South American Cordilleras.

Matching mountain ranges across the North Atlantic



A.



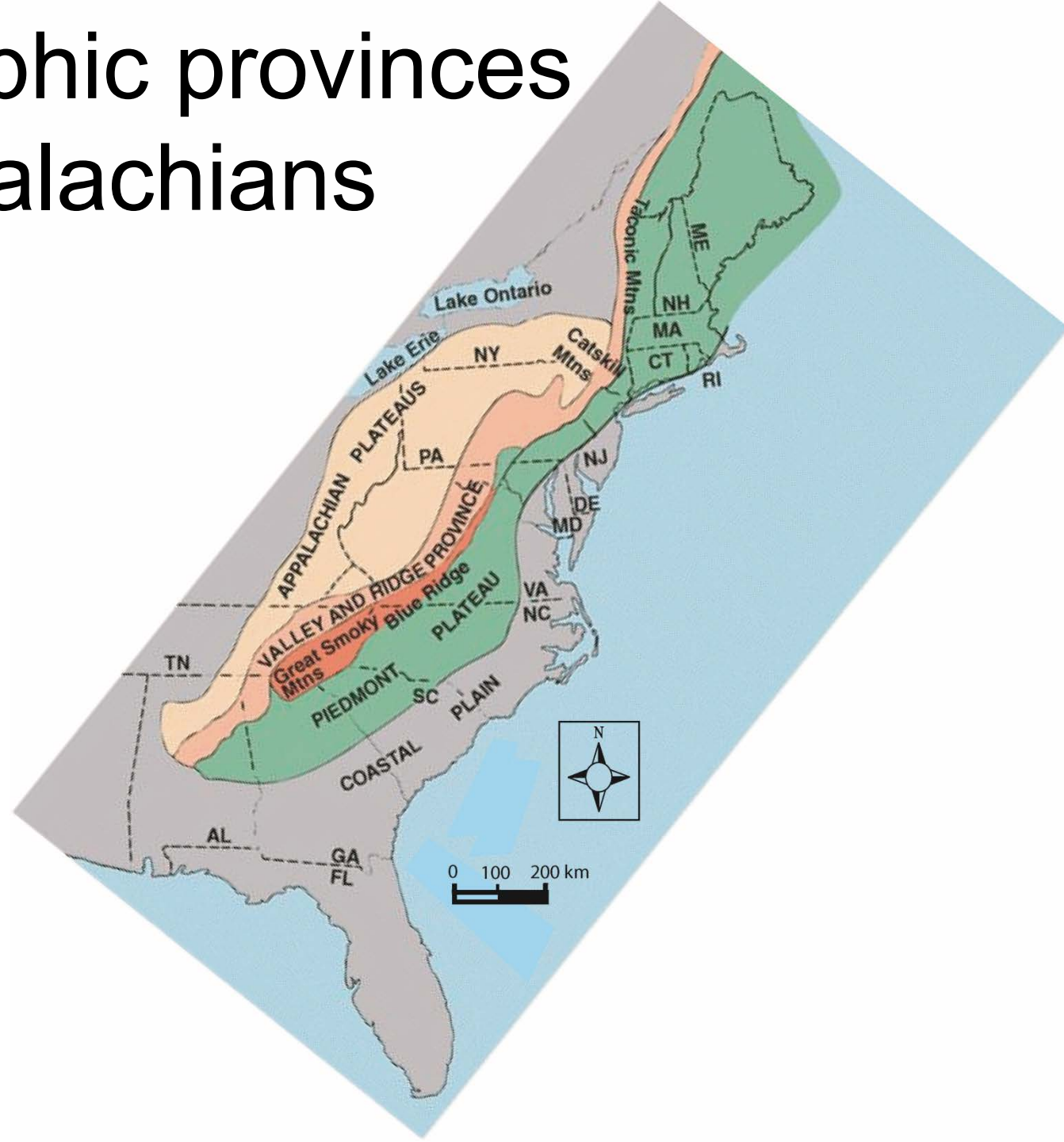
B.



Physical Geography of the United States

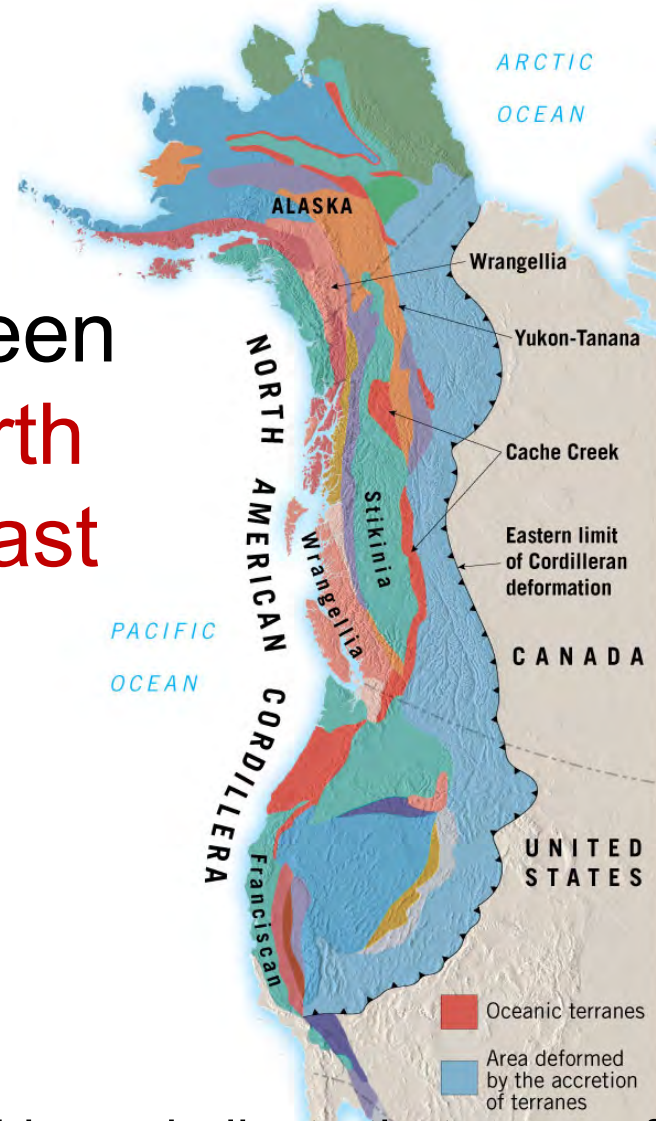


Physiographic provinces of the Appalachians

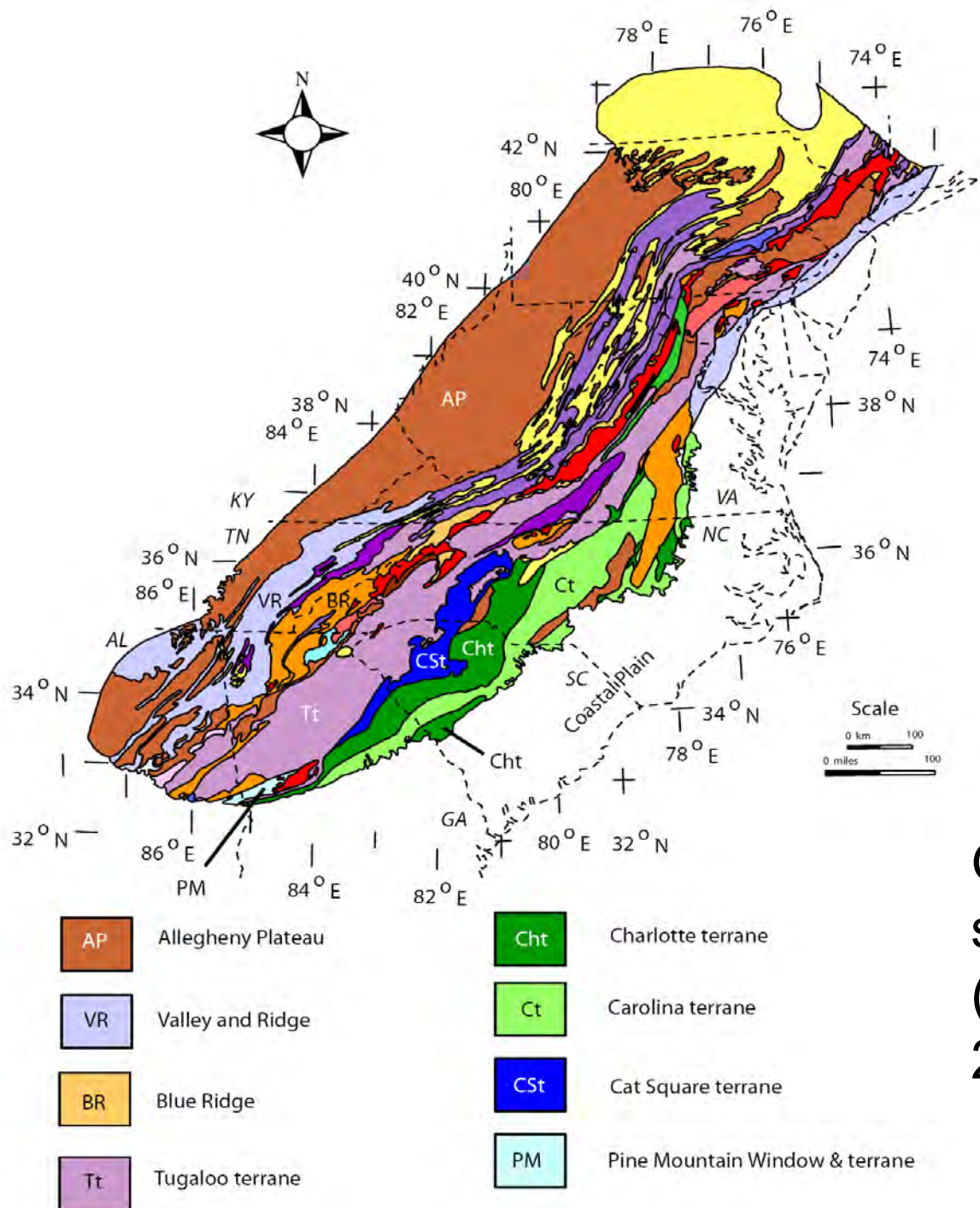


North American Cordillera

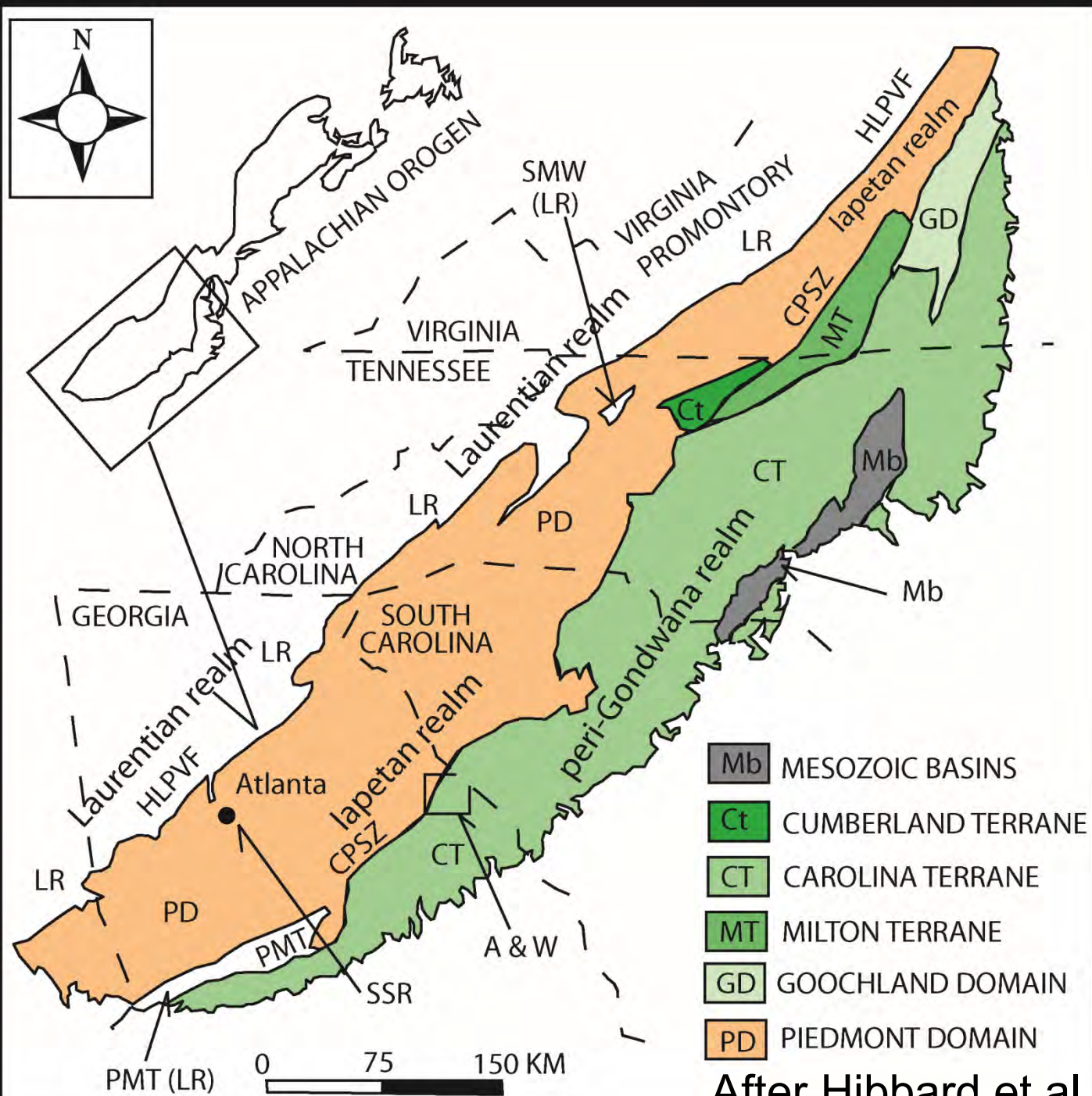
Terranes that have been added to **western North America** during the past 200 Ma



Paleomagnetic studies & fossil evidence indicate that some of these terranes originated thousands of km to the south of their present locations.



Geological map of southern Appalachians (after Hatcher *et al.*, 2007)



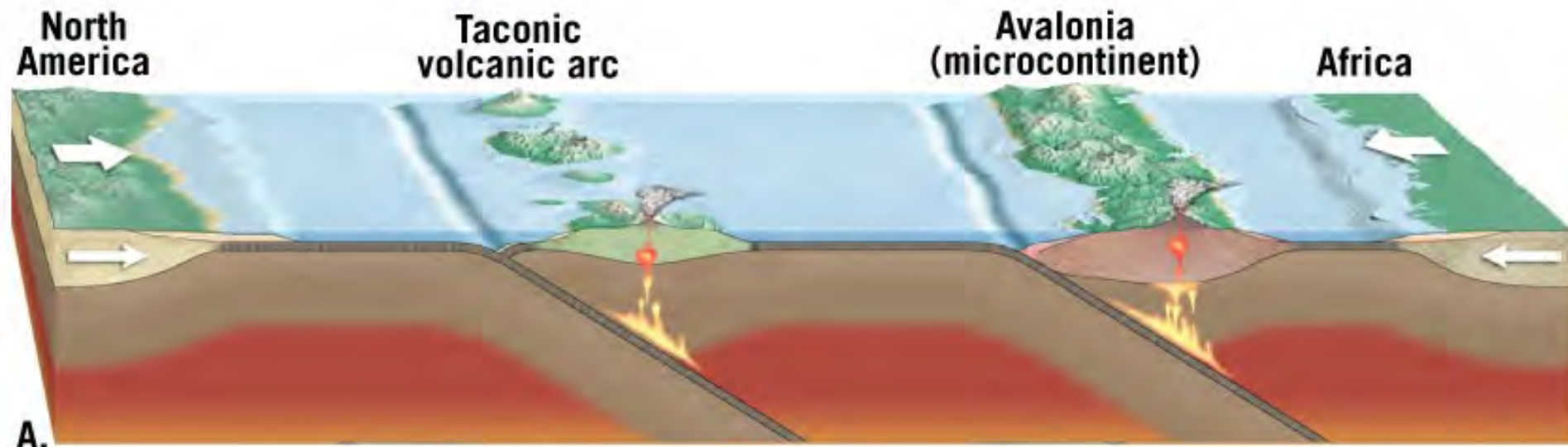
After Hibbard et al. (2006)

Orogenies

In the **Appalachian region**, there were **three** diachronous Paleozoic mountain-building events (or **orogenies**):

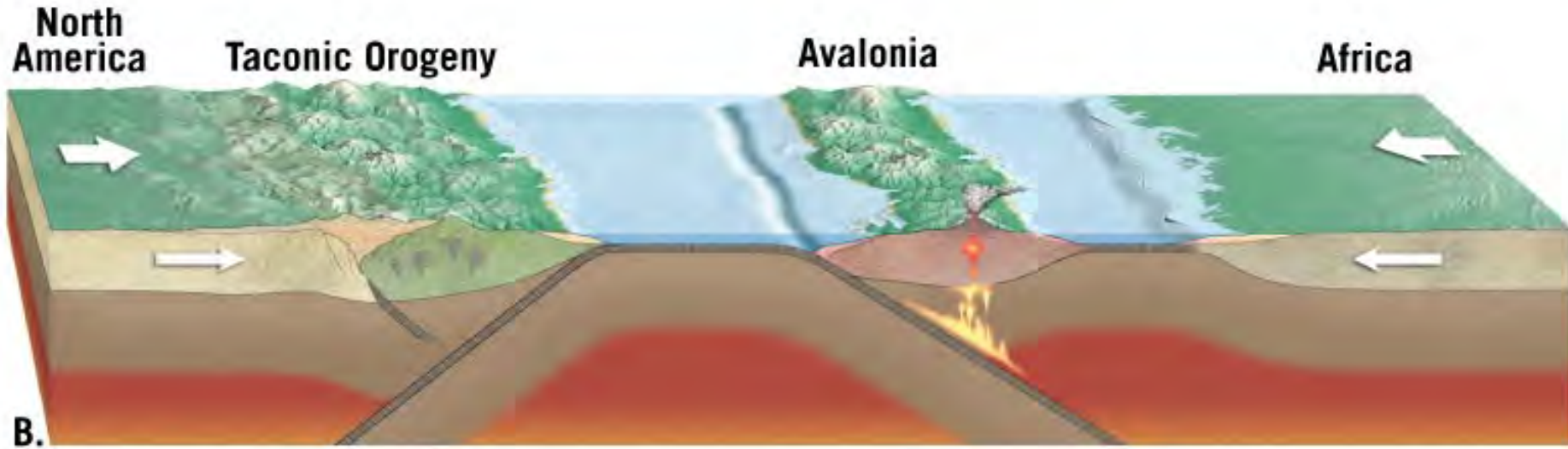
1. **Taconic orogeny** (Ordovician-Silurian – 480-440 Ma)
2. **Acadian orogeny** (Devonian – 375-325 Ma)
3. **Alleghanian orogeny** (Pennsylvanian-Permian – 325-260 Ma)

Closing of an ocean basin



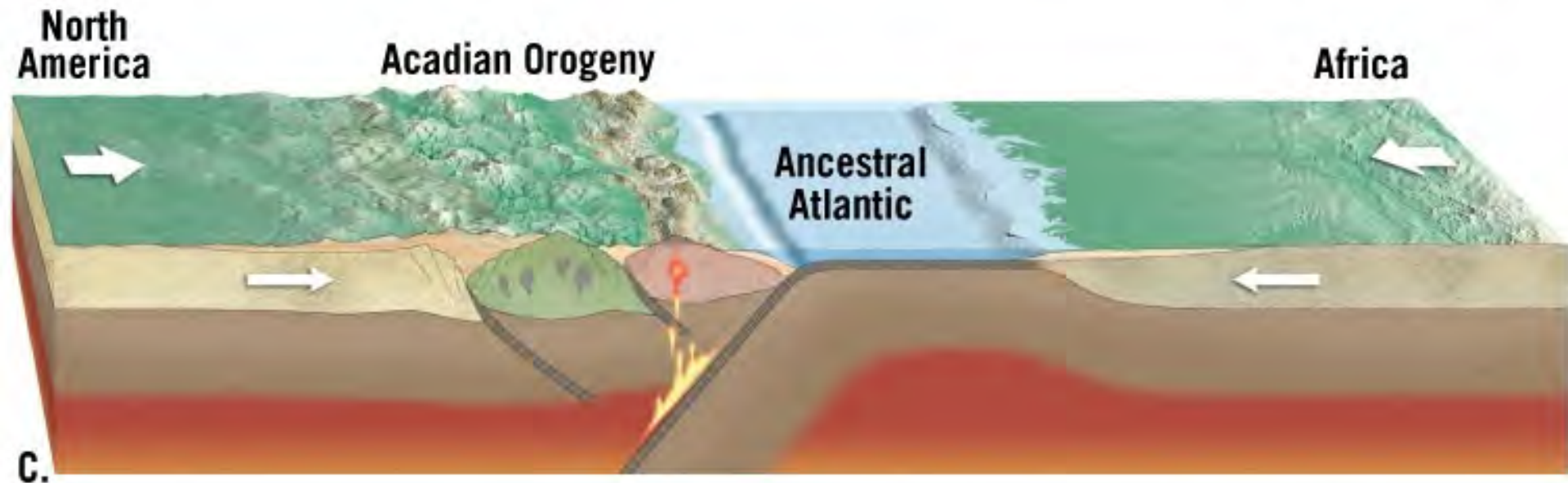
~600Ma, precursor to the North Atlantic began to close. Located within this ocean was an active volcanic arc off the coast of North America and a micro-continent situated closer to Africa

1. Taconic orogeny



~450Ma, the marginal sea between the volcanic island arc and North America closed. The collision, called the Taconic orogeny, thrust the island arc over the eastern margin of North America

2. Acadian orogeny



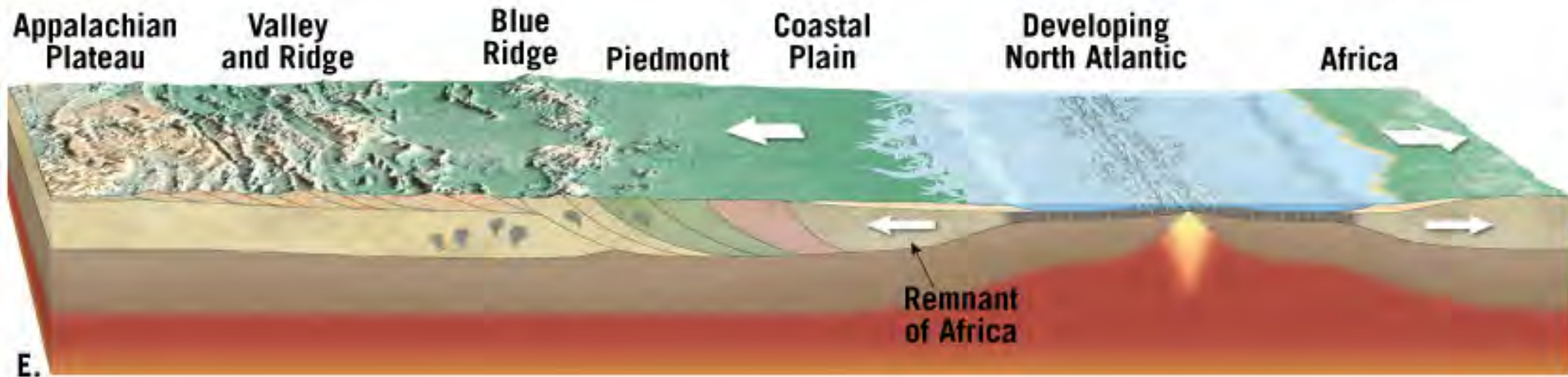
~350Ma, a second episode of mountain building, the Acadian orogeny, occurred. It involved the collision of a micro-continent with North America.

3. Alleghanian orogeny



~300-250Ma, Africa collided with North America forming the Alleghanian orogeny, the final event. This resulted in the formation of the Appalachian Mountains. The Appalachians lay in the interior of the newly assembled supercontinent of Pangea

Rifting of Pangea

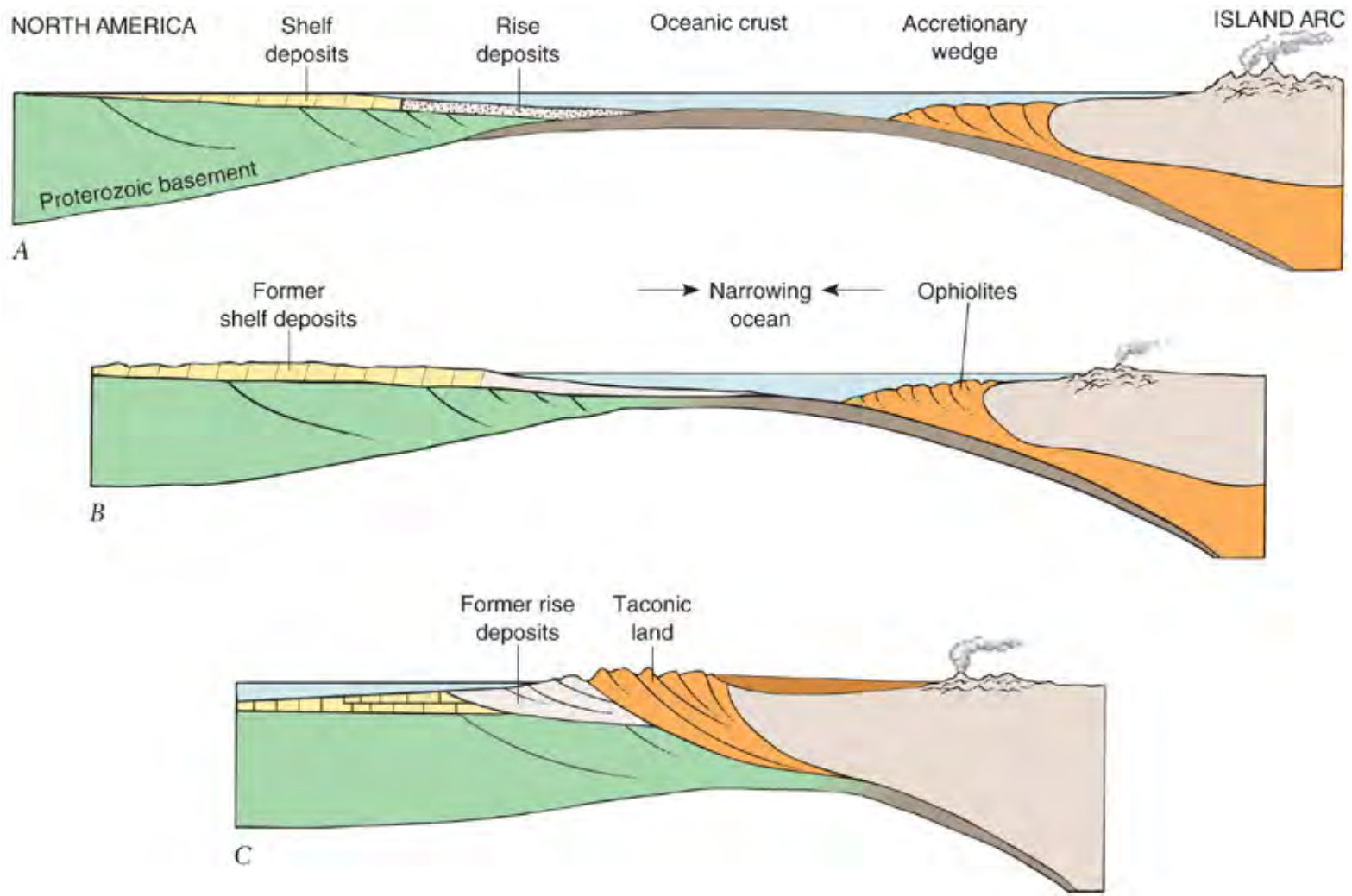


~180Ma, Pangea began to break into smaller fragments, ultimately forming the Atlantic Ocean. The zone of rifting occurred east of the suture, remnants of African crust remain 'welded' to the North American plate

A - Eastern North America in the Cambrian and early Ordovician, following the breakup of Rodinia.

B - Large volcanic island arc nears eastern North America.

C - Volcanic island arc collides with eastern North America causing Taconic orogeny.

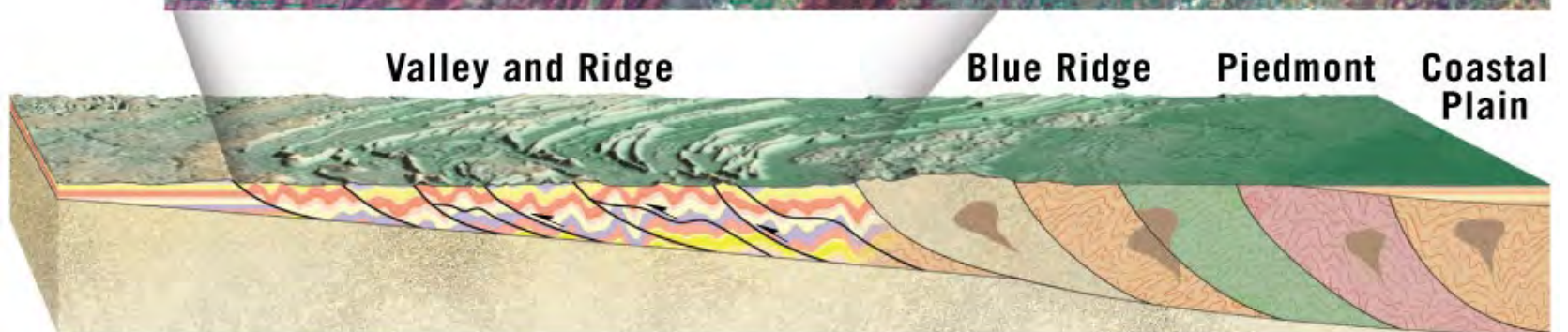
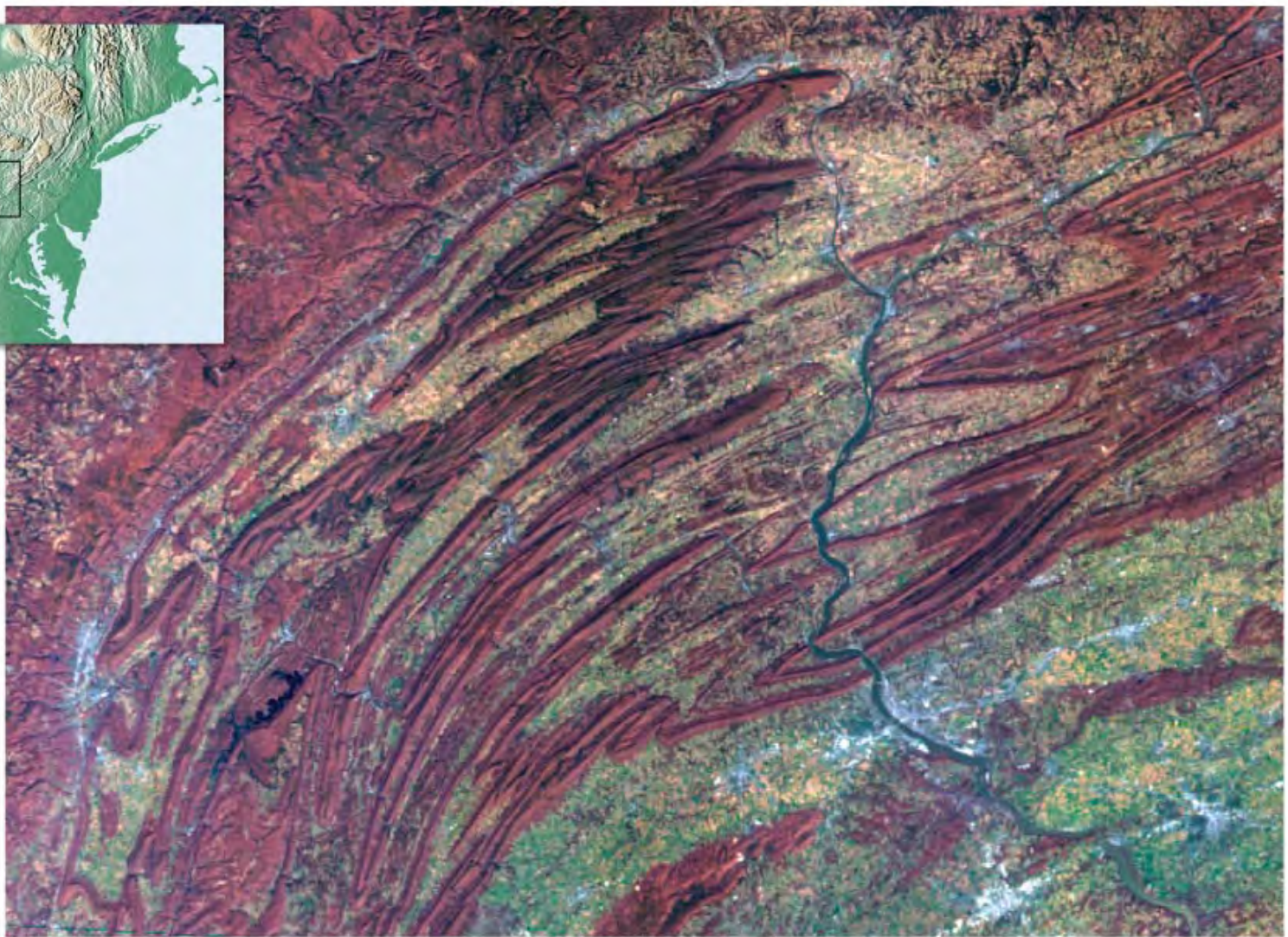


The Alleghanian orogeny

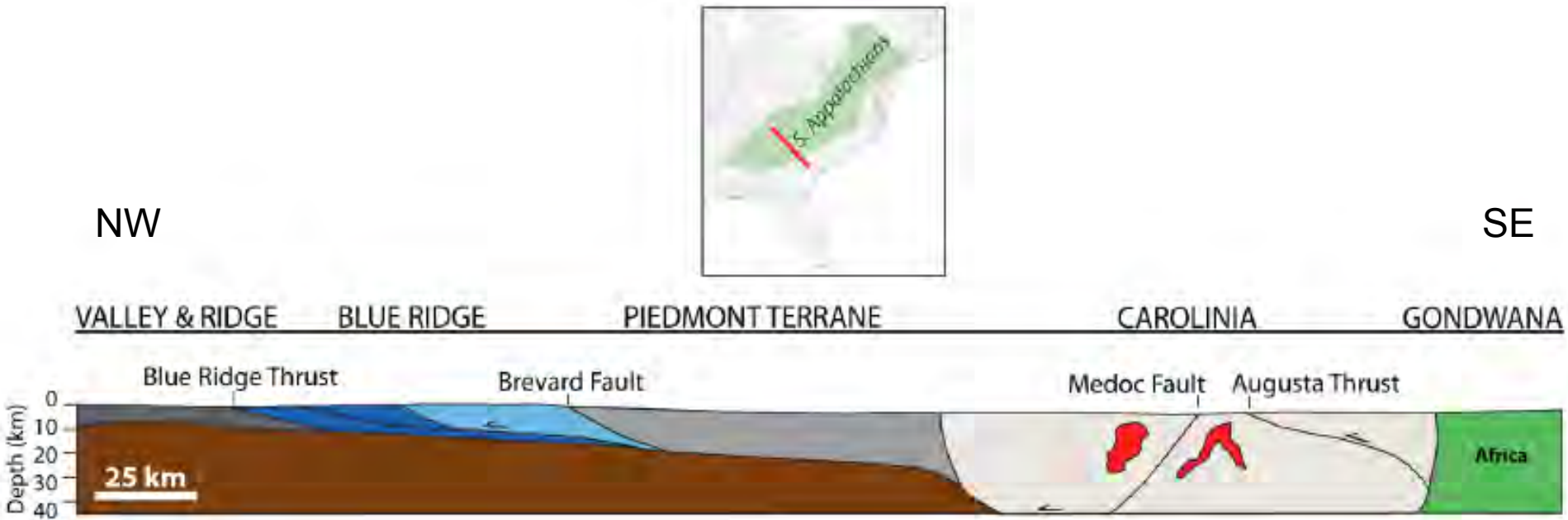
The Alleghanian orogeny produced **folds** in the **Valley and Ridge Province**, and large **thrust faults** in the southern Appalachians.

Many folds are asymmetrically overturned to the northwest, and surfaces of thrust faults dip to the southeast.

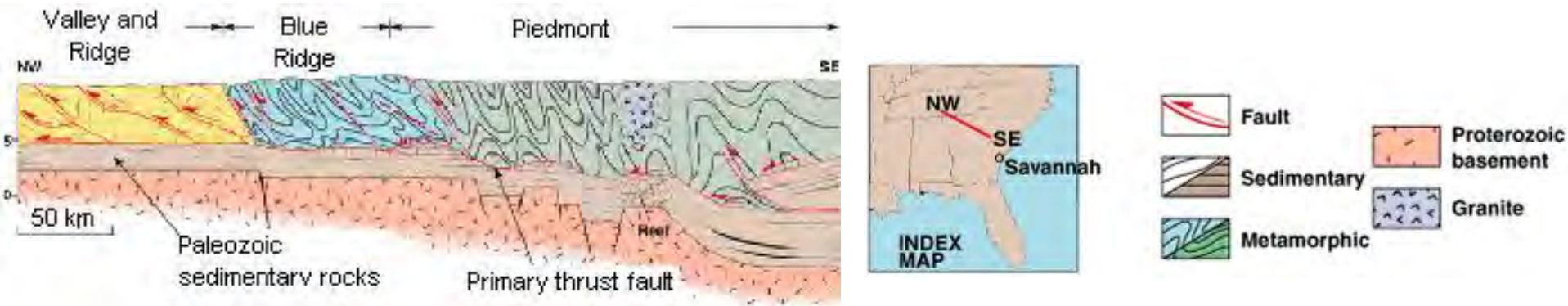




Cross-section of the Alleghanian orogeny

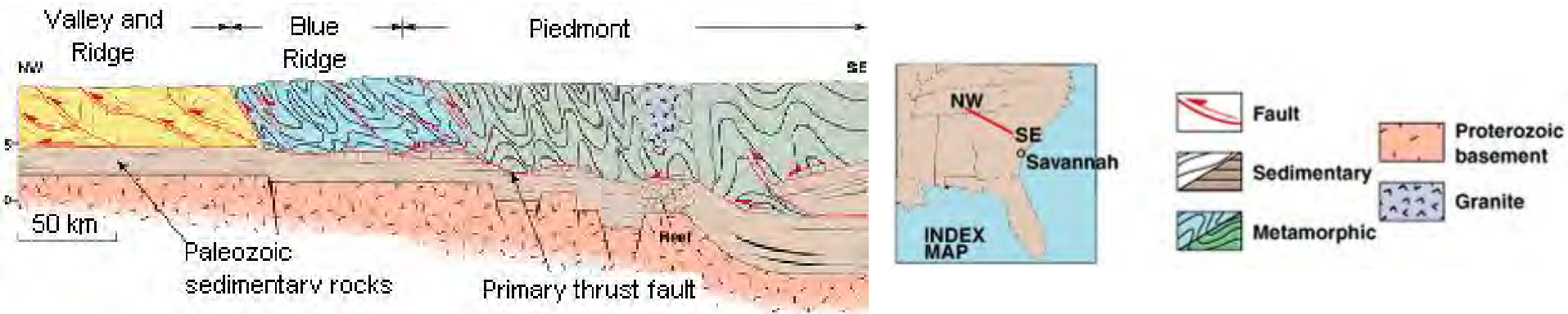


The Alleghanian orogeny



- Deep seismic reflection profiling indicates that crystalline rocks of the **Blue Ridge and Piedmont were thrust-faulted onto Laurentian** by the Alleghanian orogeny continental collision, **sliding at least 260 km to the west.**

The Alleghanian orogeny

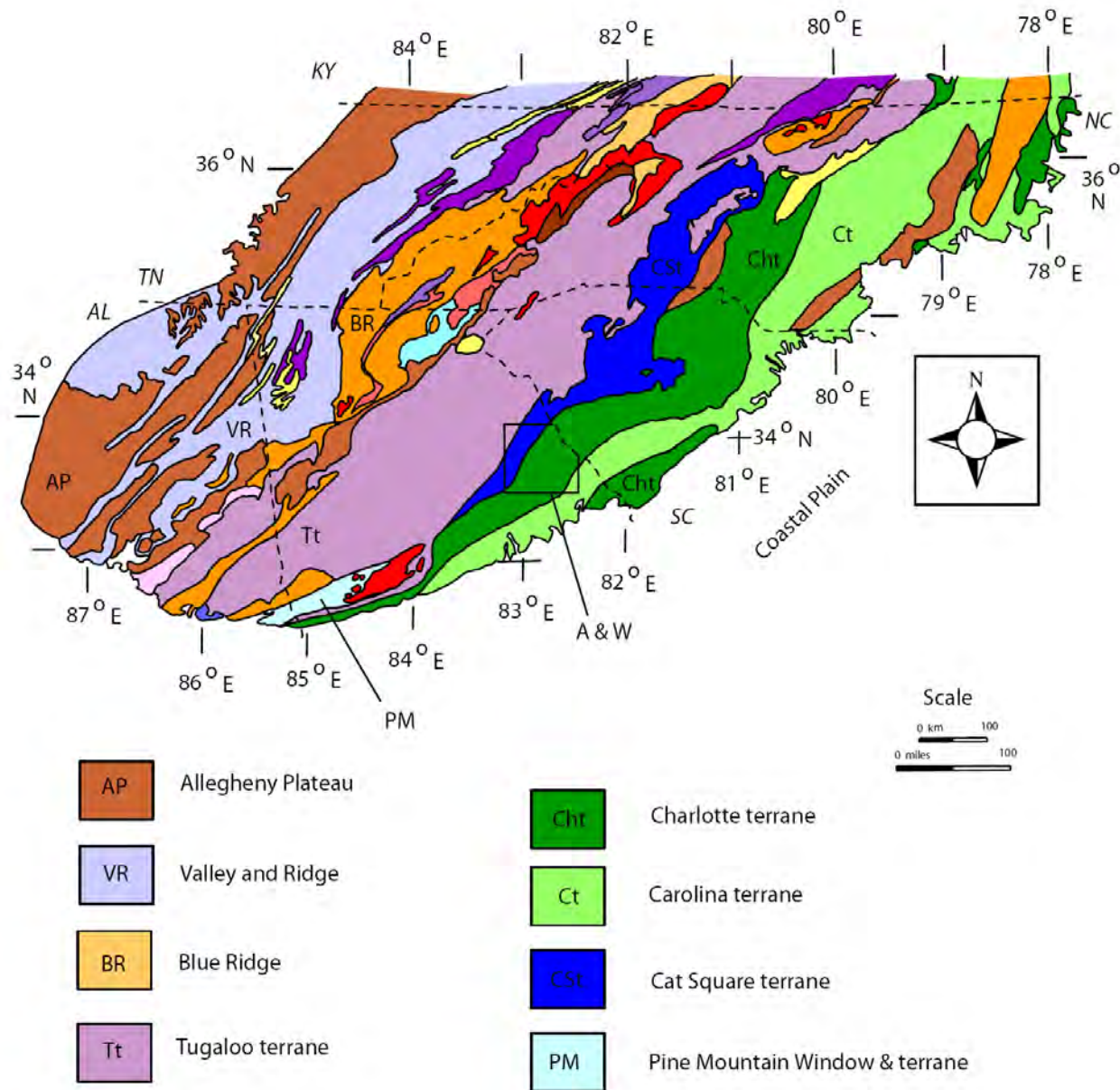


- Blue Ridge and Piedmont metamorphic and igneous rocks form a sheet ~6-15 km thick, overlying relatively flat-lying lower Paleozoic sedimentary rocks.
- This type of tectonic deformation is called "thin-skinned tectonics".

Plate tectonics model for continental collisions in the late Paleozoic

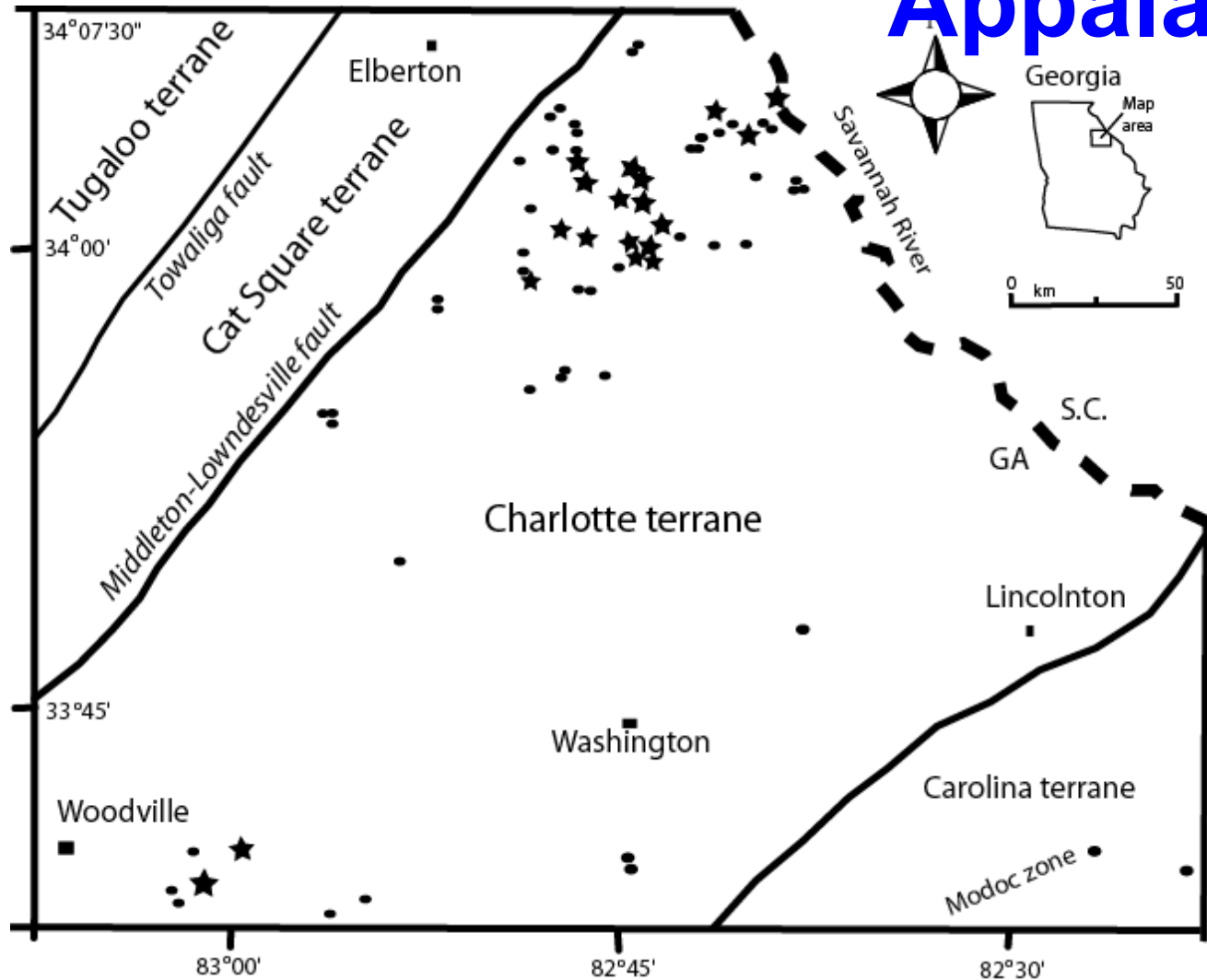


View show the relationships of North America, South America, & Africa during (A) Early Pennsylvanian, B Late Pennsylvanian, & (c) Permian. The Alleghenian orogeny began in the Mississippian & continued through the remainder of the Paleozoic. It was caused by the African & South American regions of Gondwana colliding with the underside of Laurentia



Map of the southern Appalachians investigated area marked as A & W

Case studies in the Southern Appalachians



Russell Lake Allochthon. Outcrops indicated in stars sampled for further investigation in this work

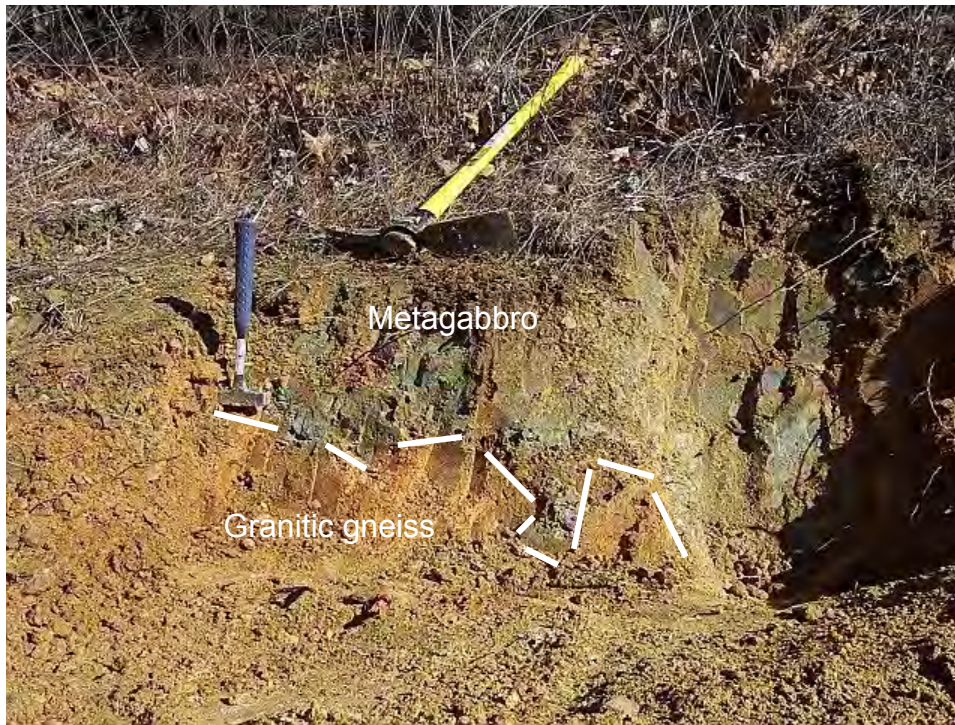


Hand specimen of **metawehrlite** showing chlorite and serpentine and amphibole. Lighter patches are inferred to be former cumulate olivine crystal in a matrix of former clinopyroxene.

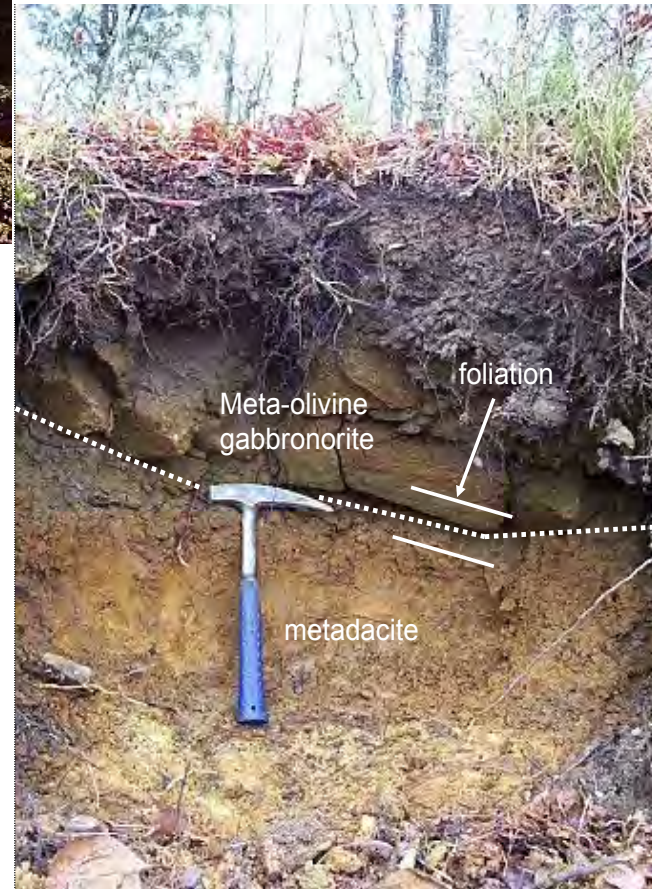
Spectacular outcrop of **meta-orthopyroxenite** showing cumulate megacrystic relict orthopyroxene crystals and interstitial material now almost all amphibole from the Soapstone Ridge complex.

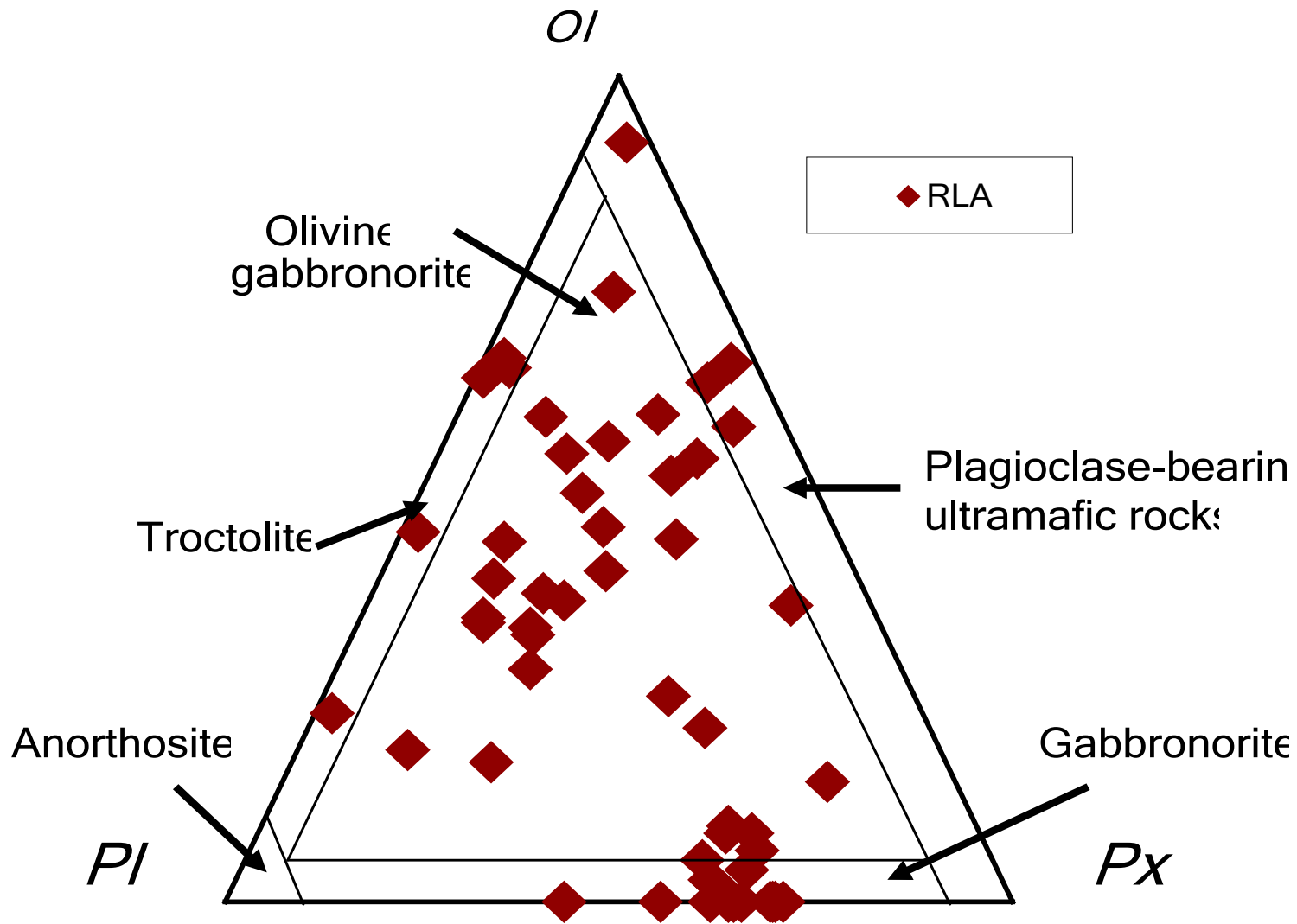


Durhamtown mafic complex overlying granitic gneisses, Randolph Church Road in Philomath Quadrangle, Georgia

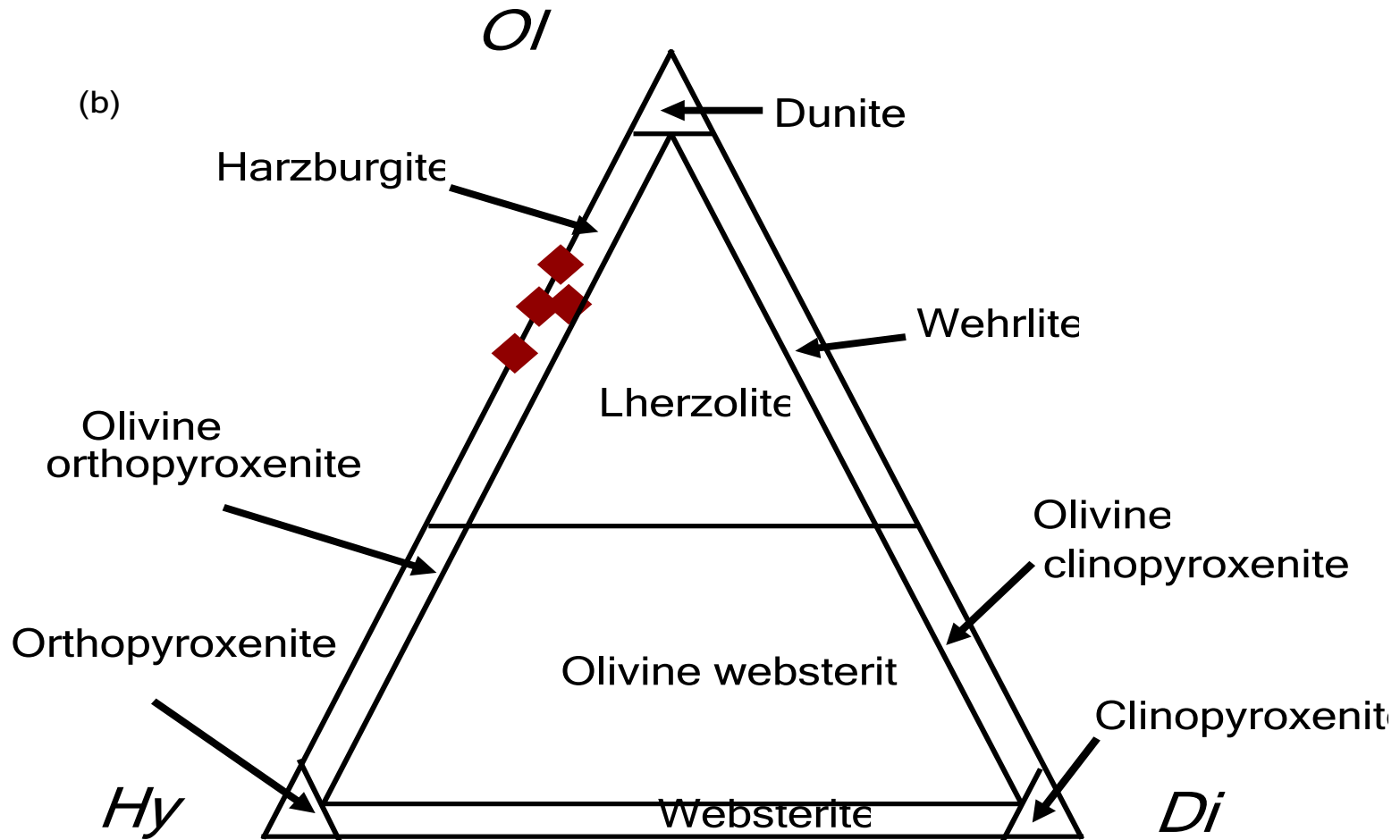


Horizontal foliation in mafic rocks
of the RLA overlying sheared
metadacitic country rocks.
Heardmont quadrangle, eastern
Georgia.



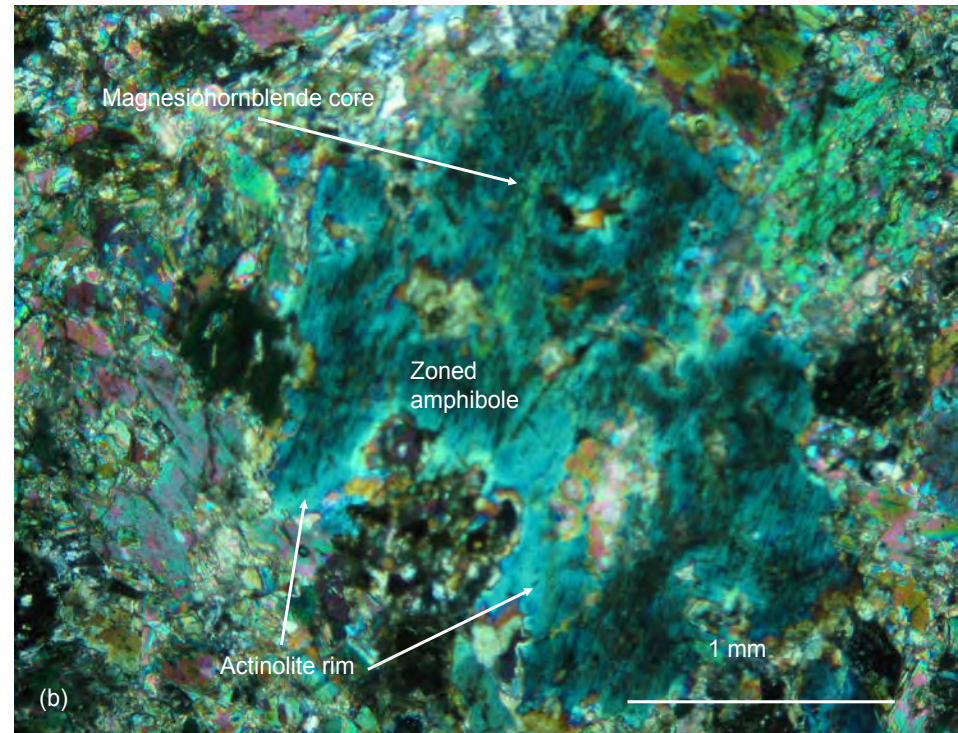
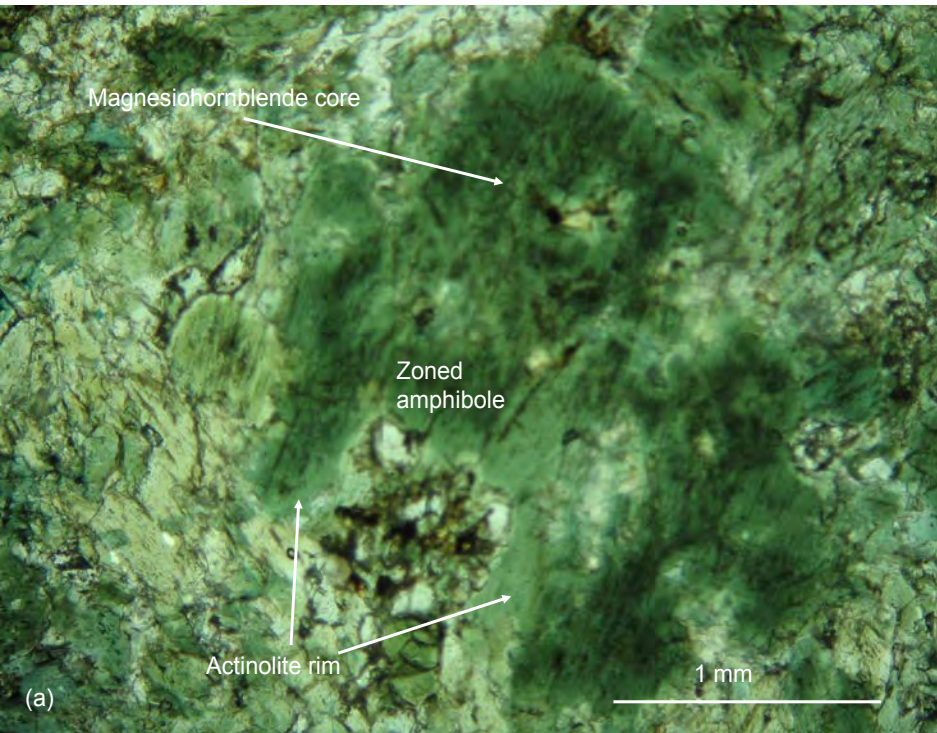


IUGS classification of rocks from the study area based on CIPW norms

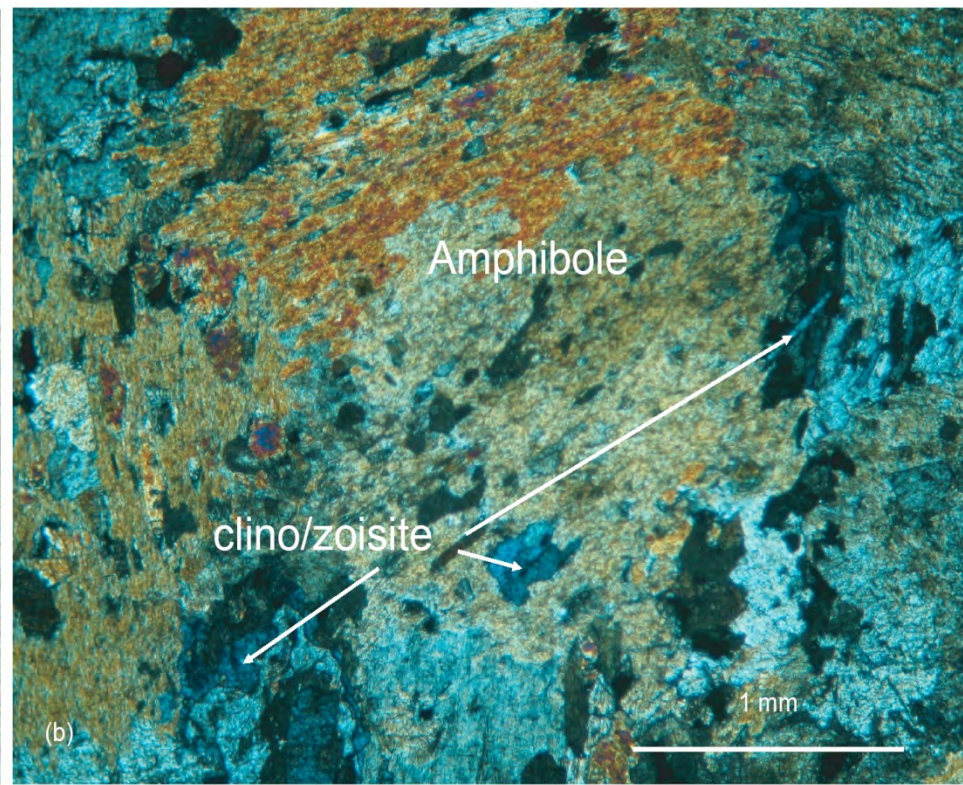
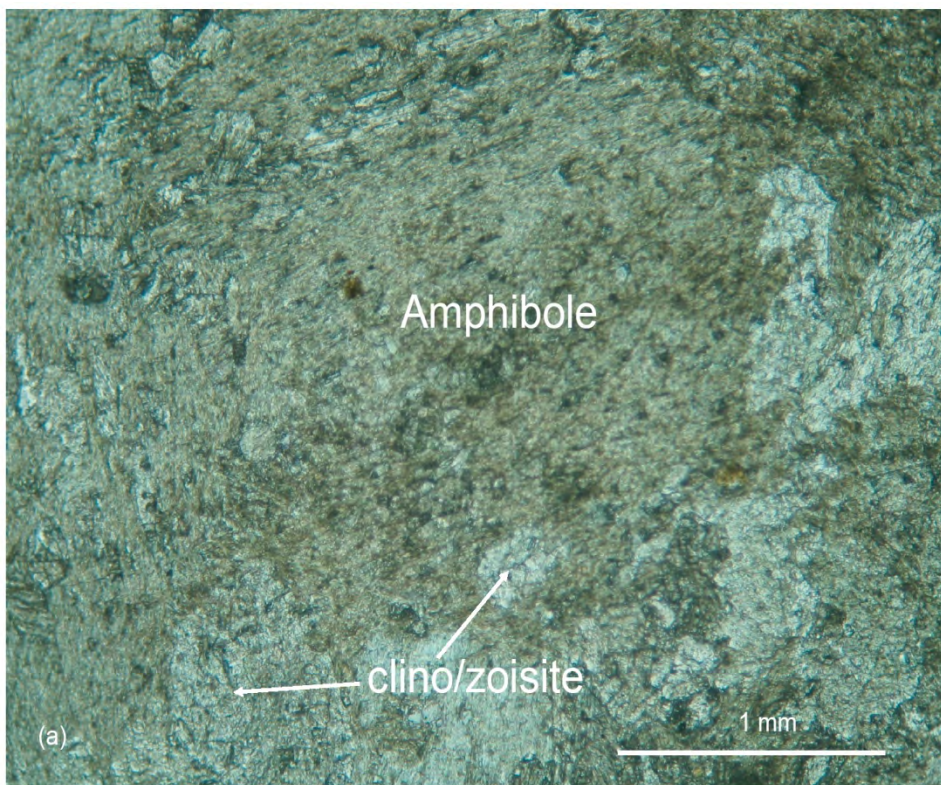


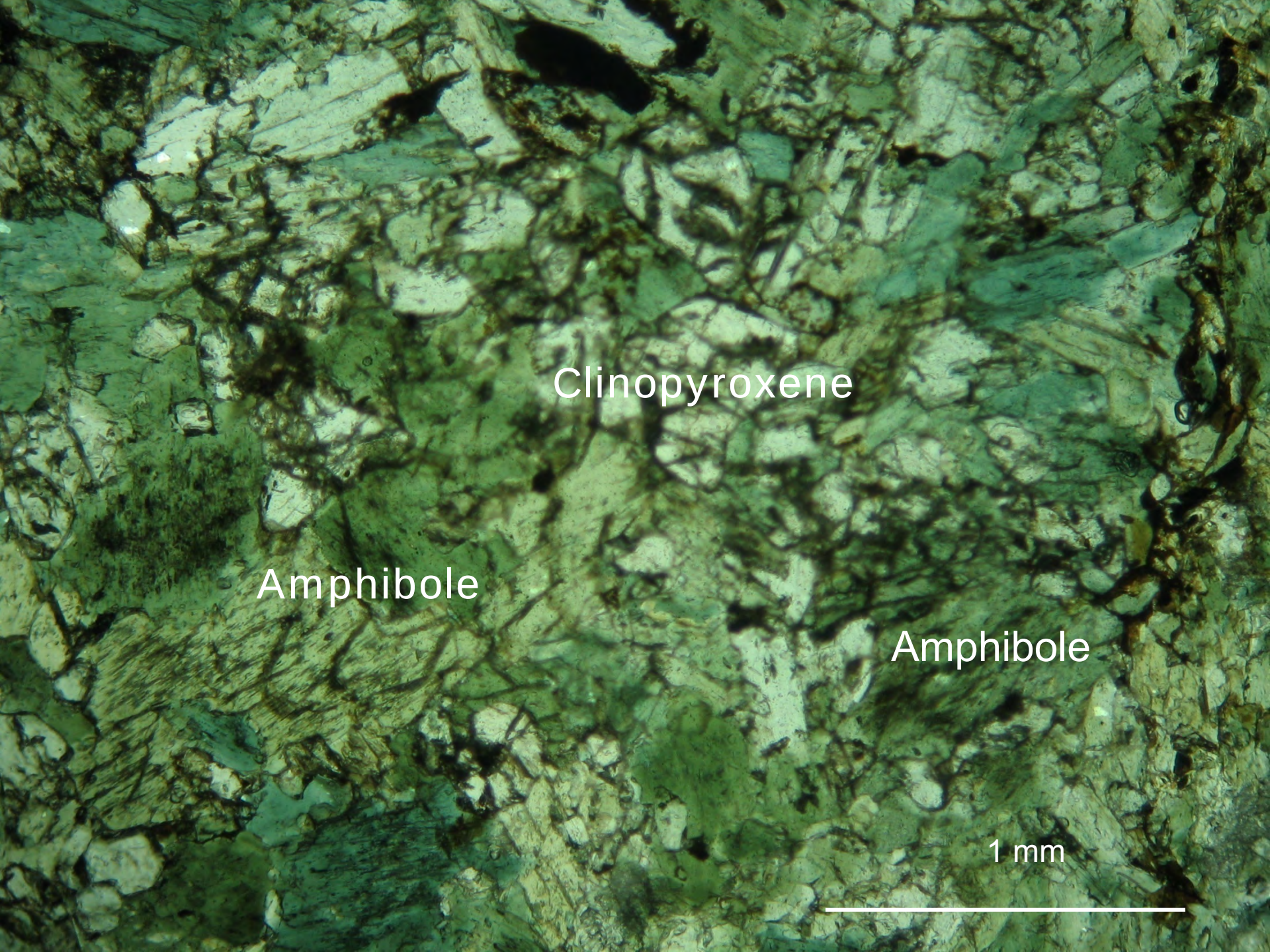
IUGS classification of meta-ultramafic rocks from the study area based on CIPW norms.

Metagabbro from Durhamtown metamafic complex consisting of plagioclase, zoned amphibole, and epidote/clinozoisite.



Meta-olivine gabbronorite from HGMS. Relict cumulate texture.



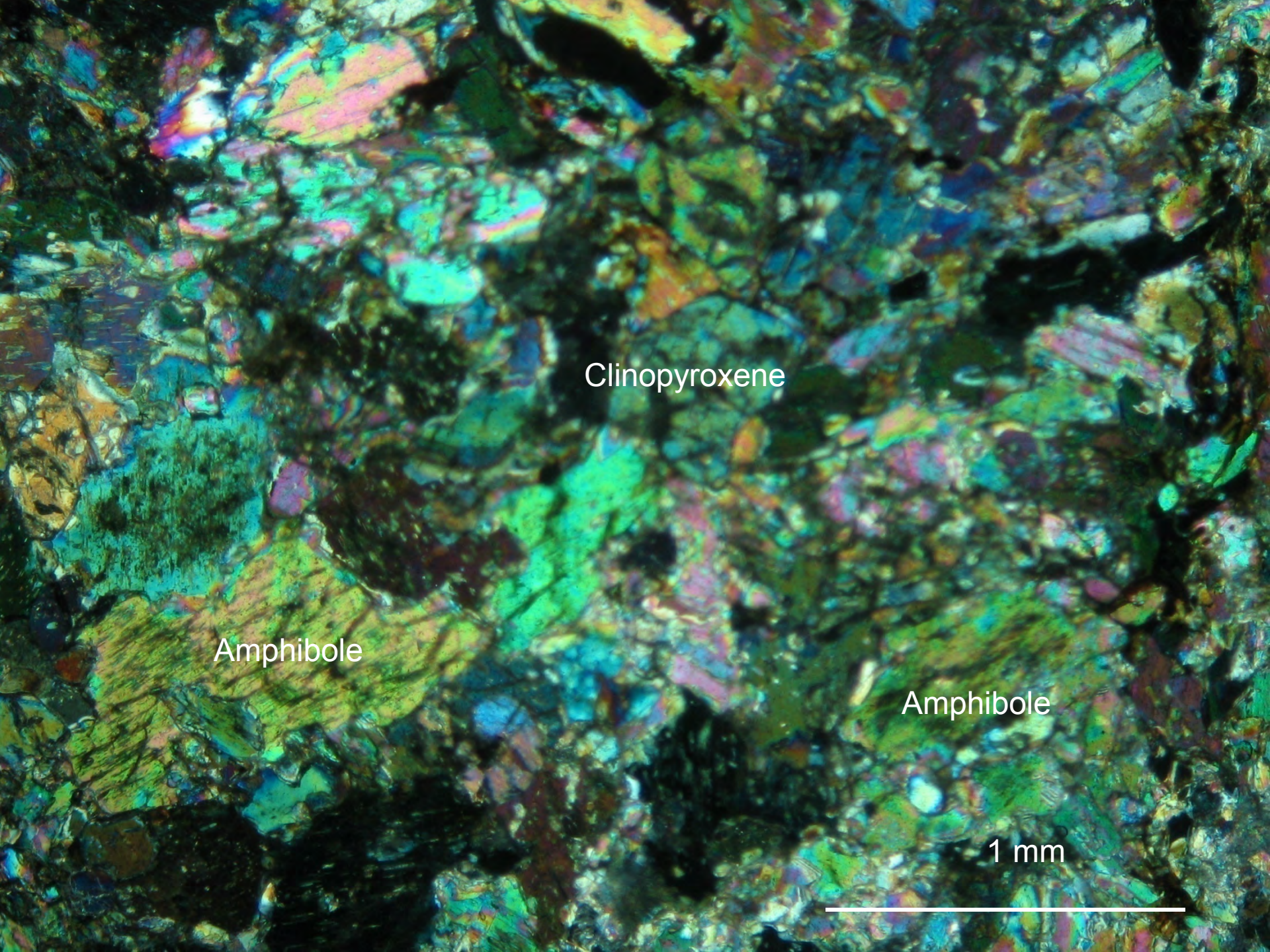


Clinopyroxene

Amphibole

Amphibole

1 mm



Clinopyroxene

Amphibole

Amphibole

1 mm

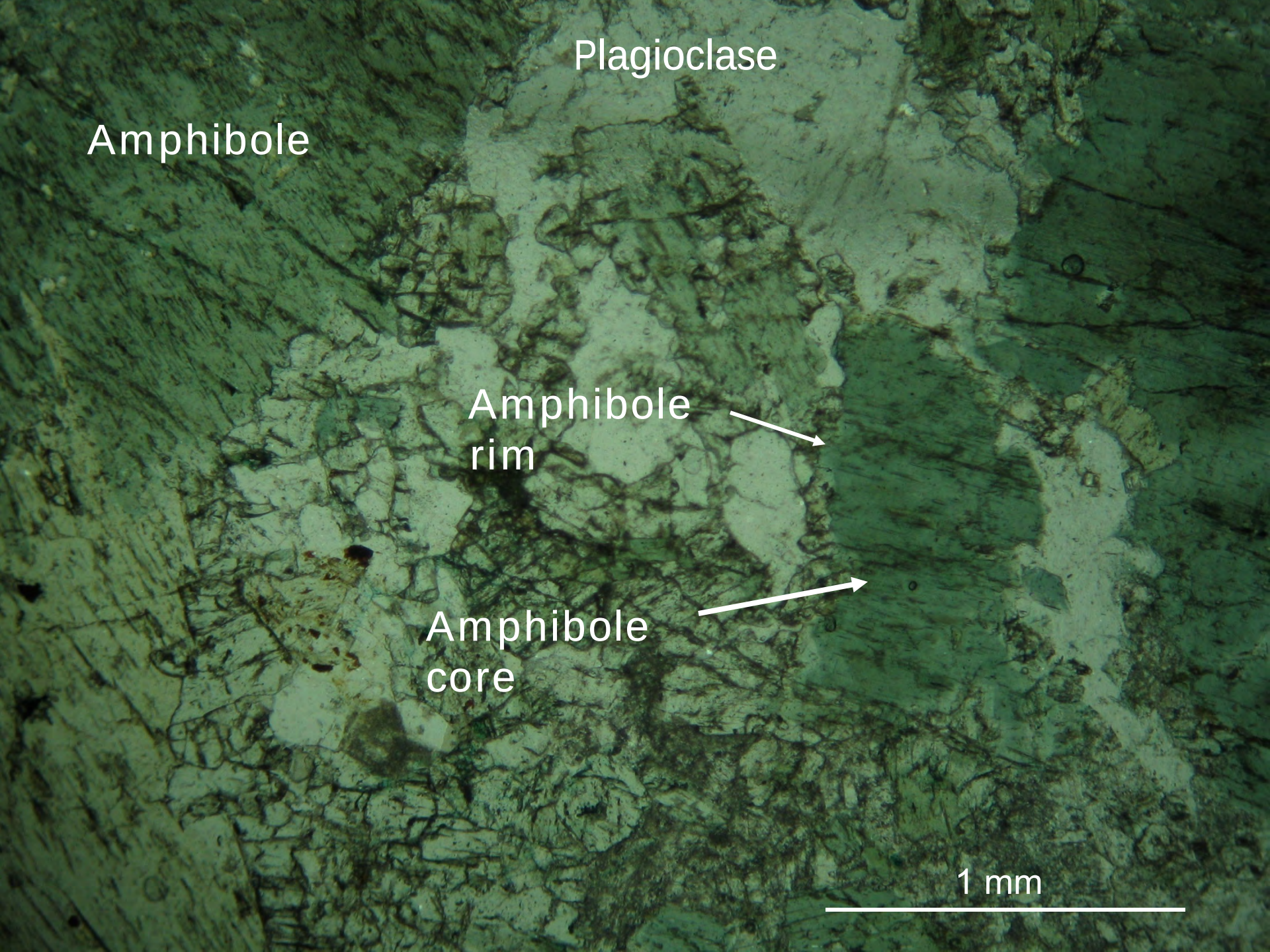
Plagioclase

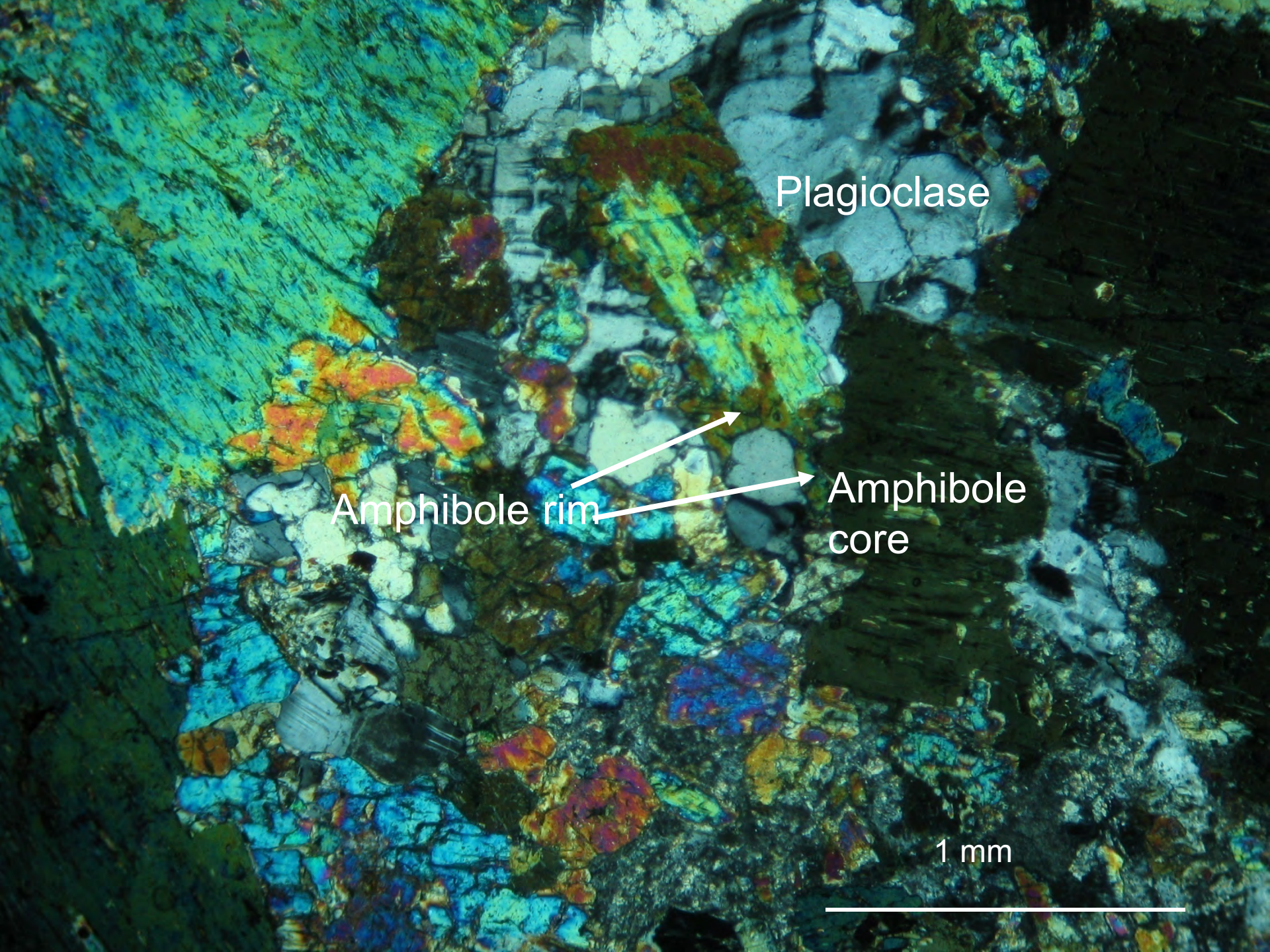
Amphibole

Amphibole
rim

Amphibole
core

1 mm





Plagioclase

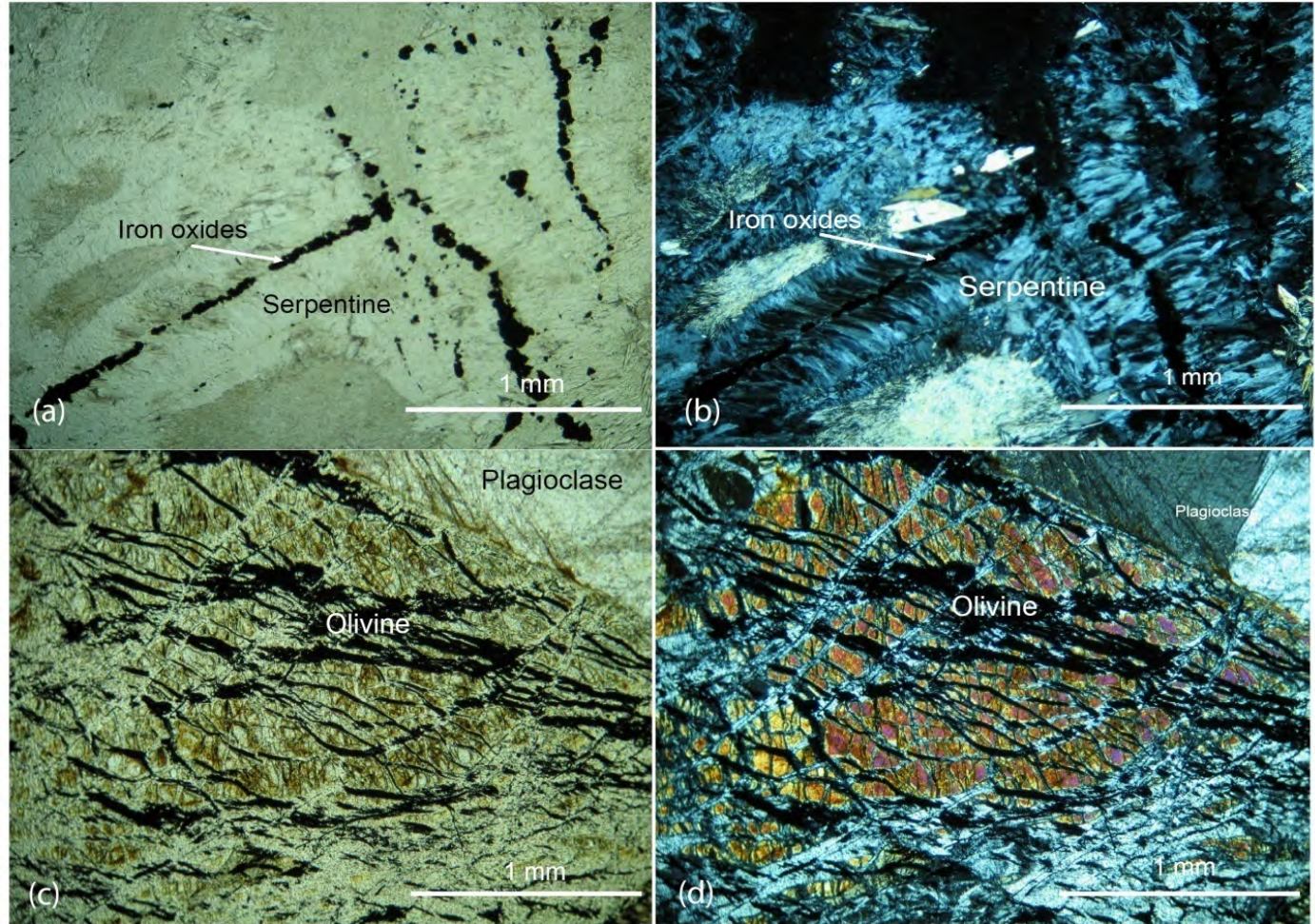
Amphibole rim

Amphibole
core

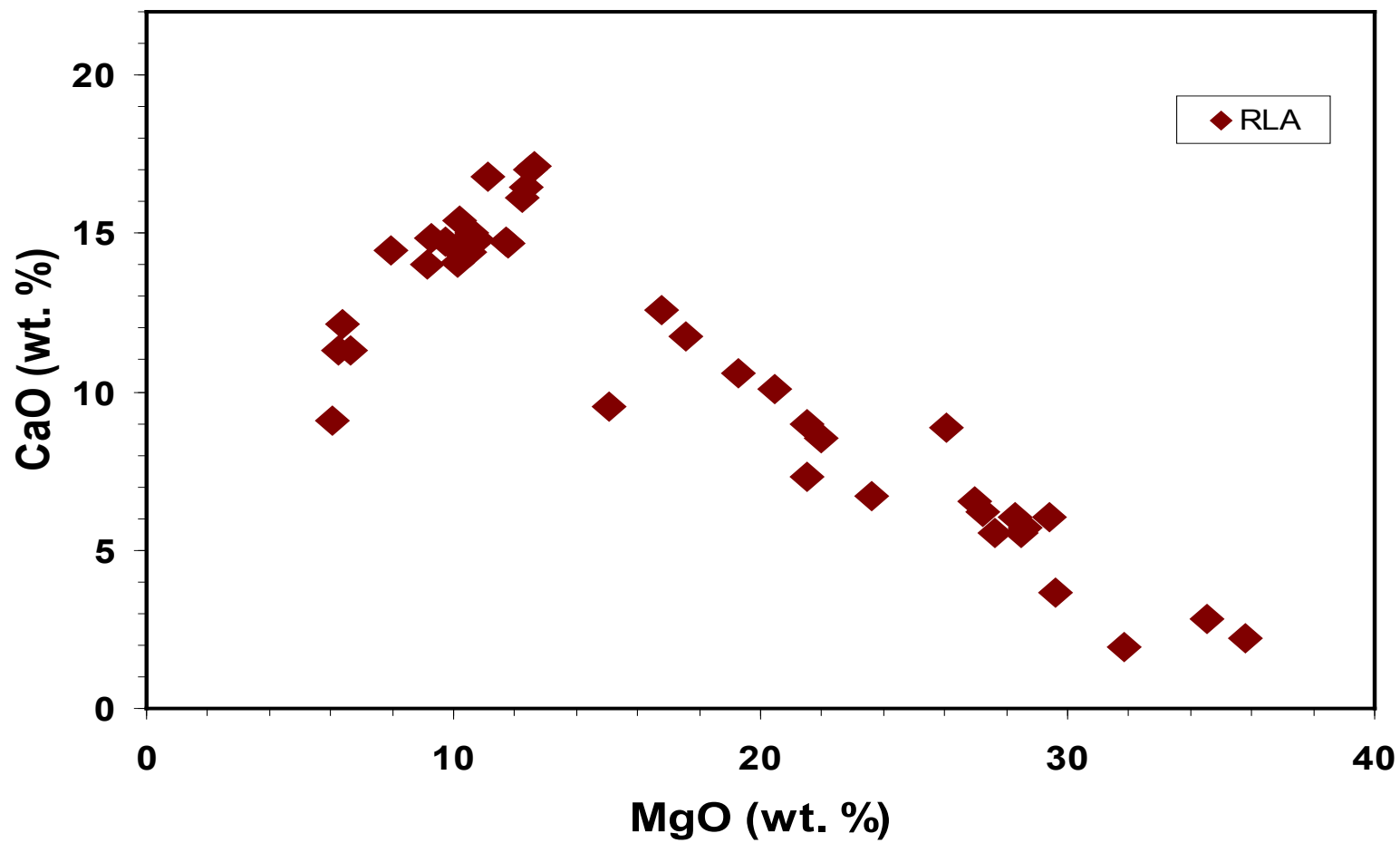
1 mm

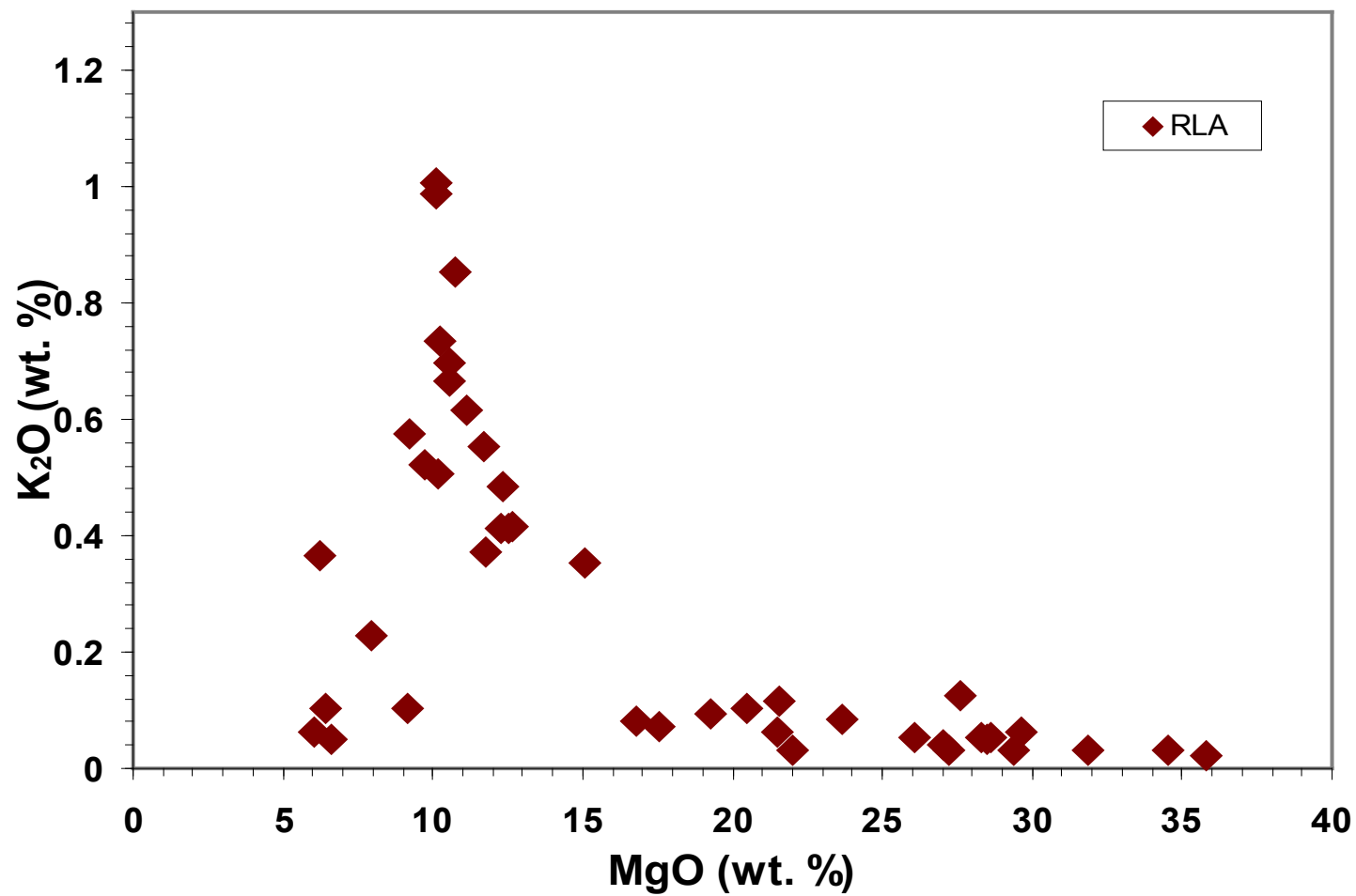
Relict cumulate texture in metatroctolites

Sample GW2: Elberton East Quadrangle

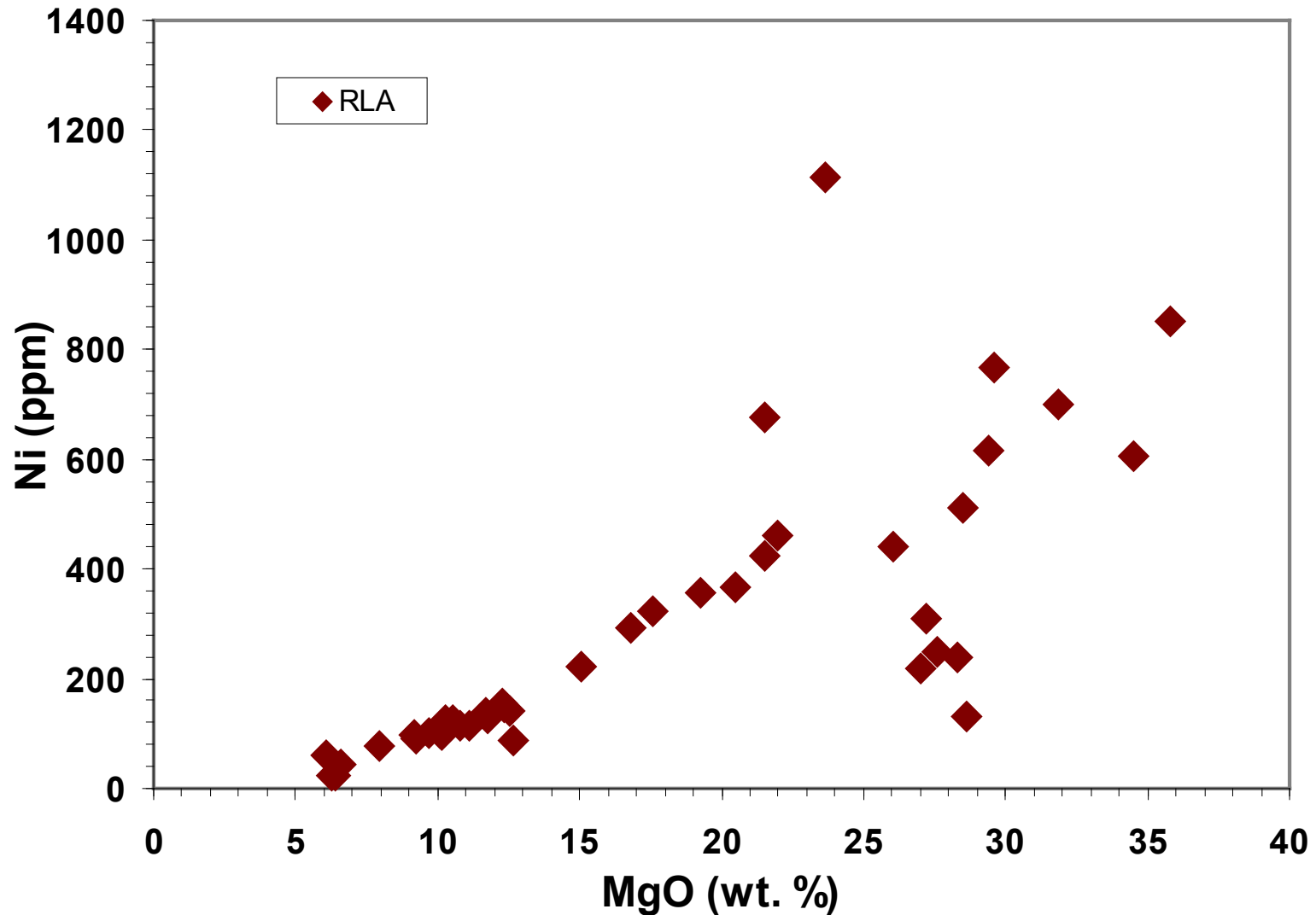


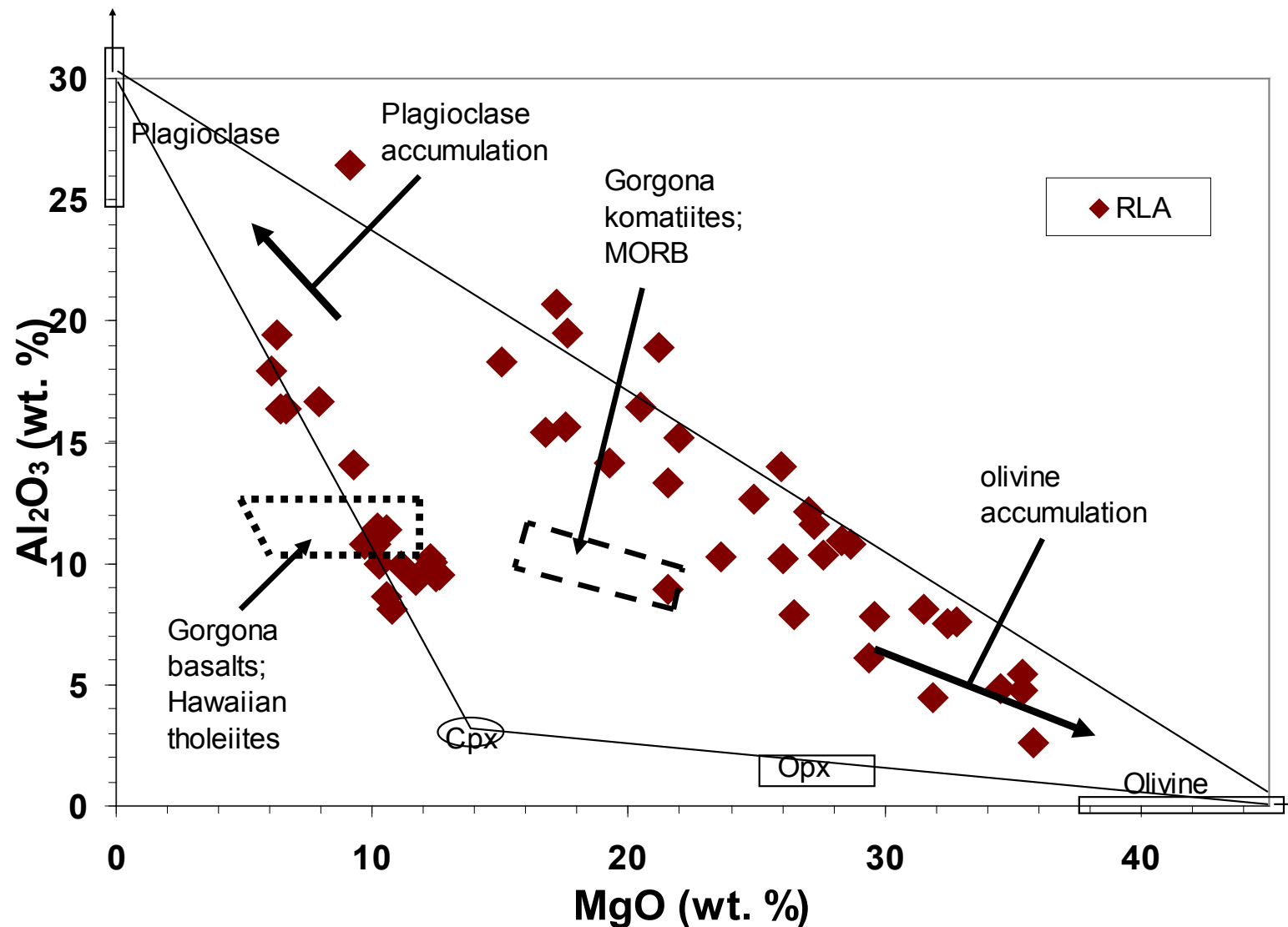
Sample RRN, Jackson Crossroads Quadrangle



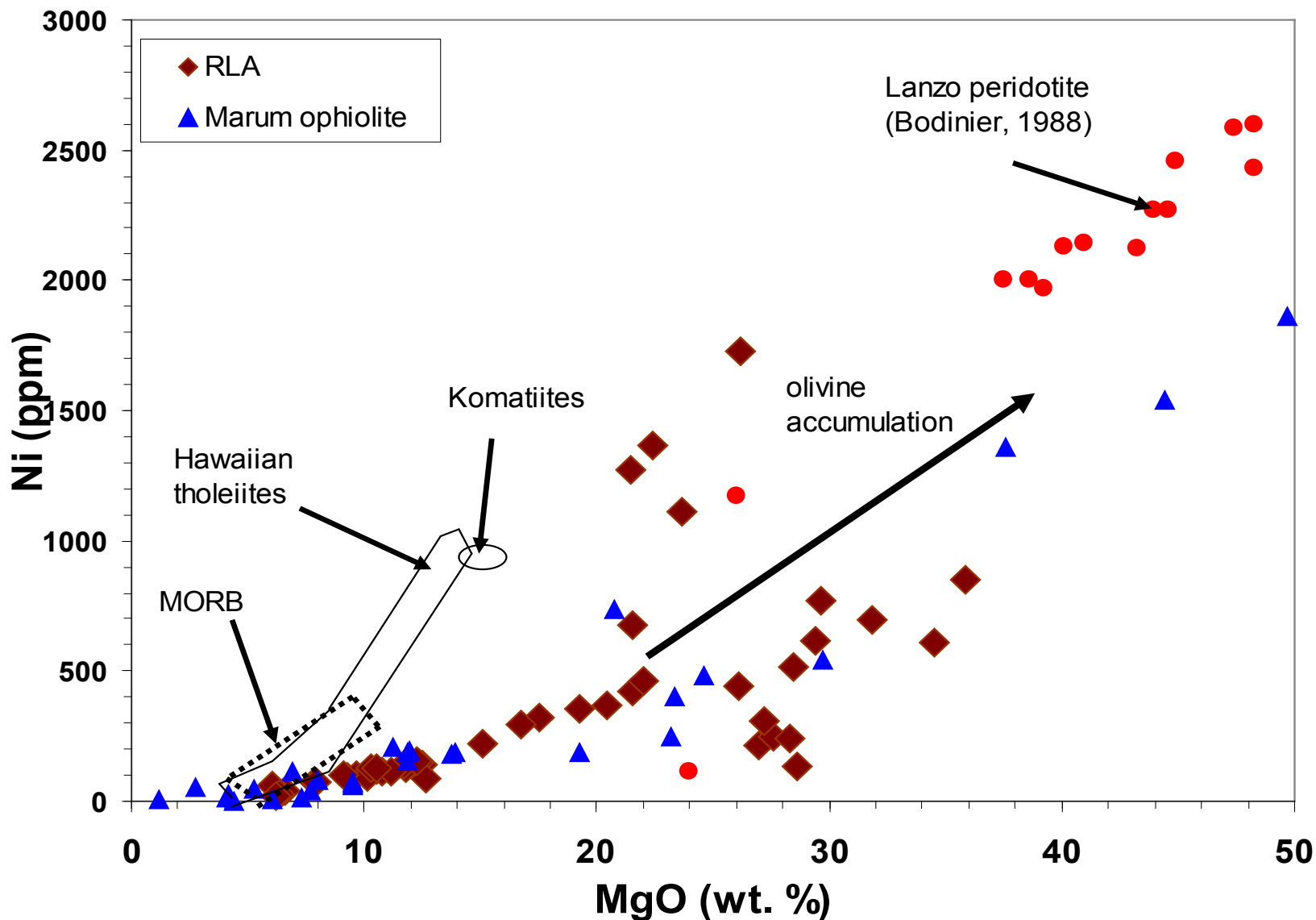


Bulk-rock trace element contents

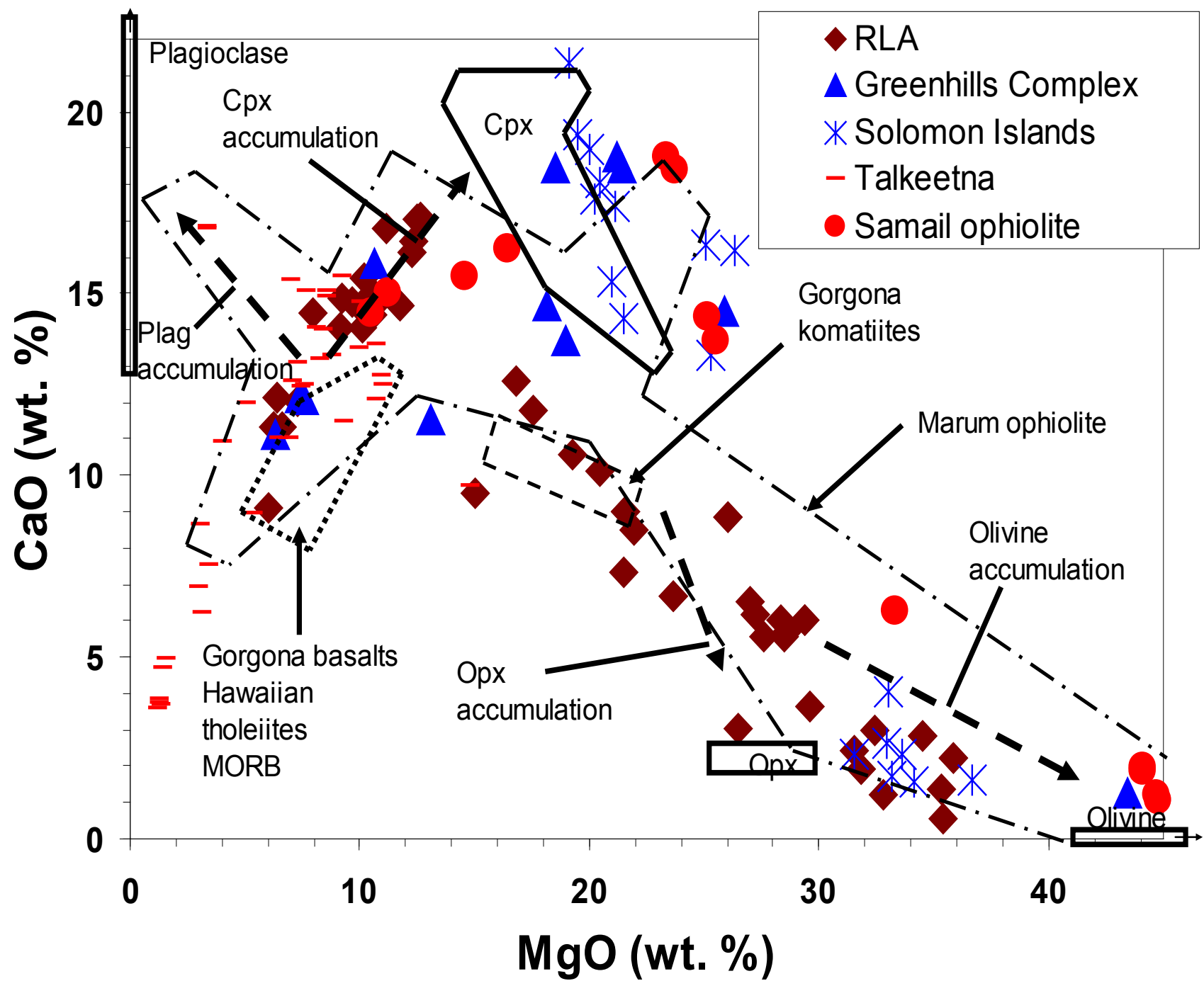




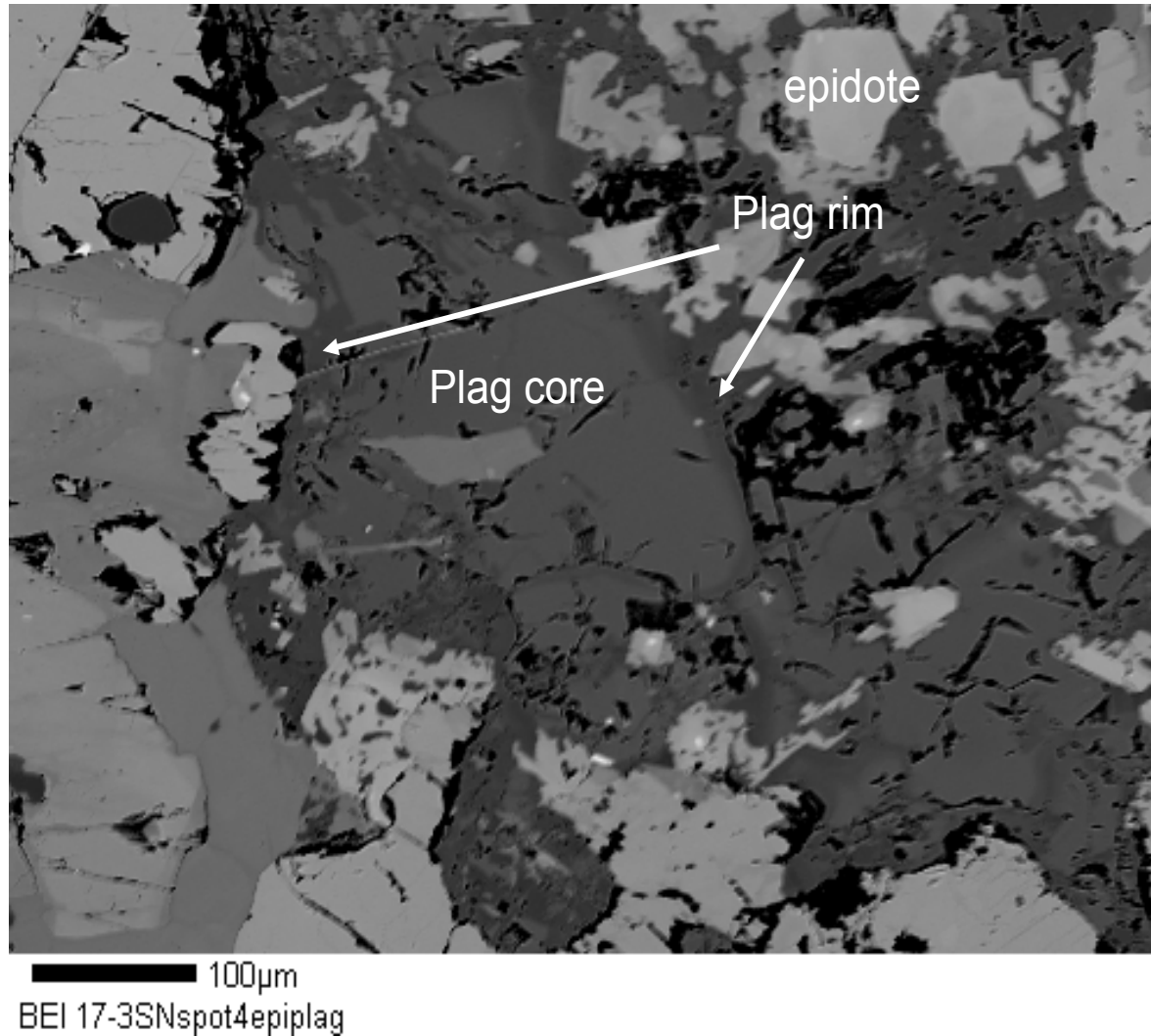
Plot of Al₂O₃ versus MgO for samples from the study area. The cumulates triangle apices (e.g., Peterson & Ryan, 2009) is defined by olivine, plagioclase, and cpx (clinopyroxene) compositions from the RLA.



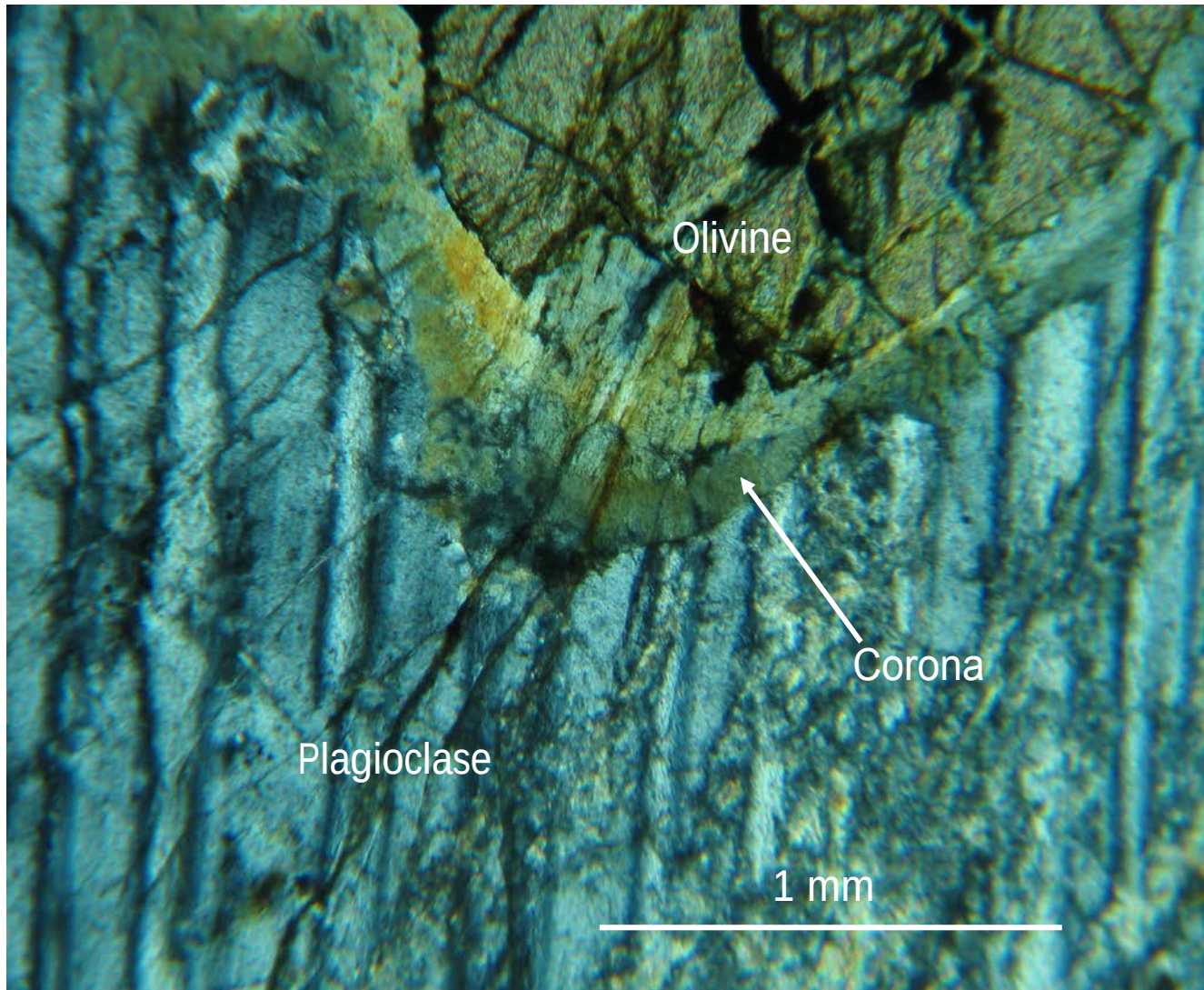
Plot of Ni *versus* MgO for samples from the RLA. Field for normal mid-ocean ridge basalts, Hawaiian tholeiites and Gorgona komatiites are also shown



Electron microprobe analyses

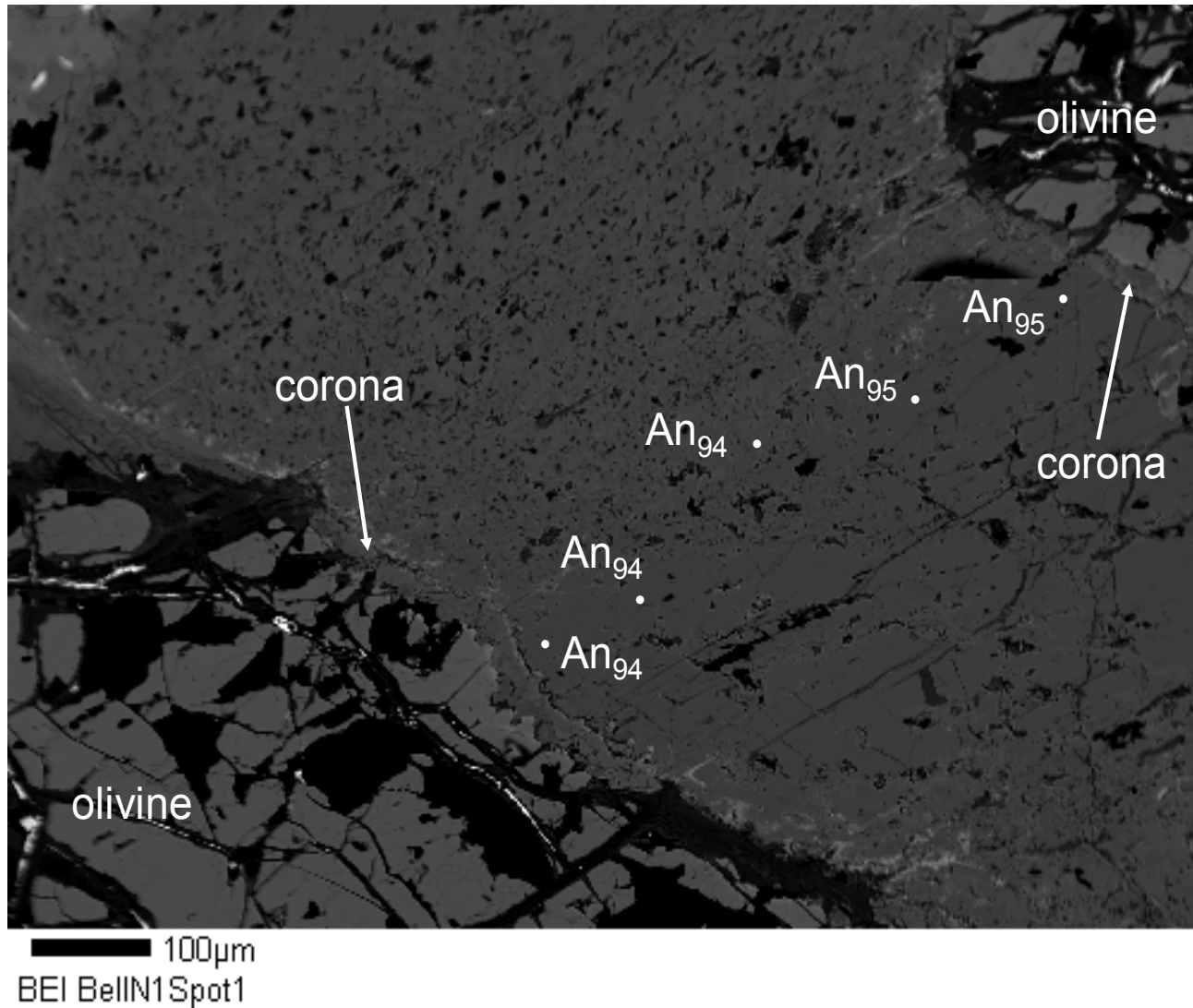


Plag from metagabbroic samples

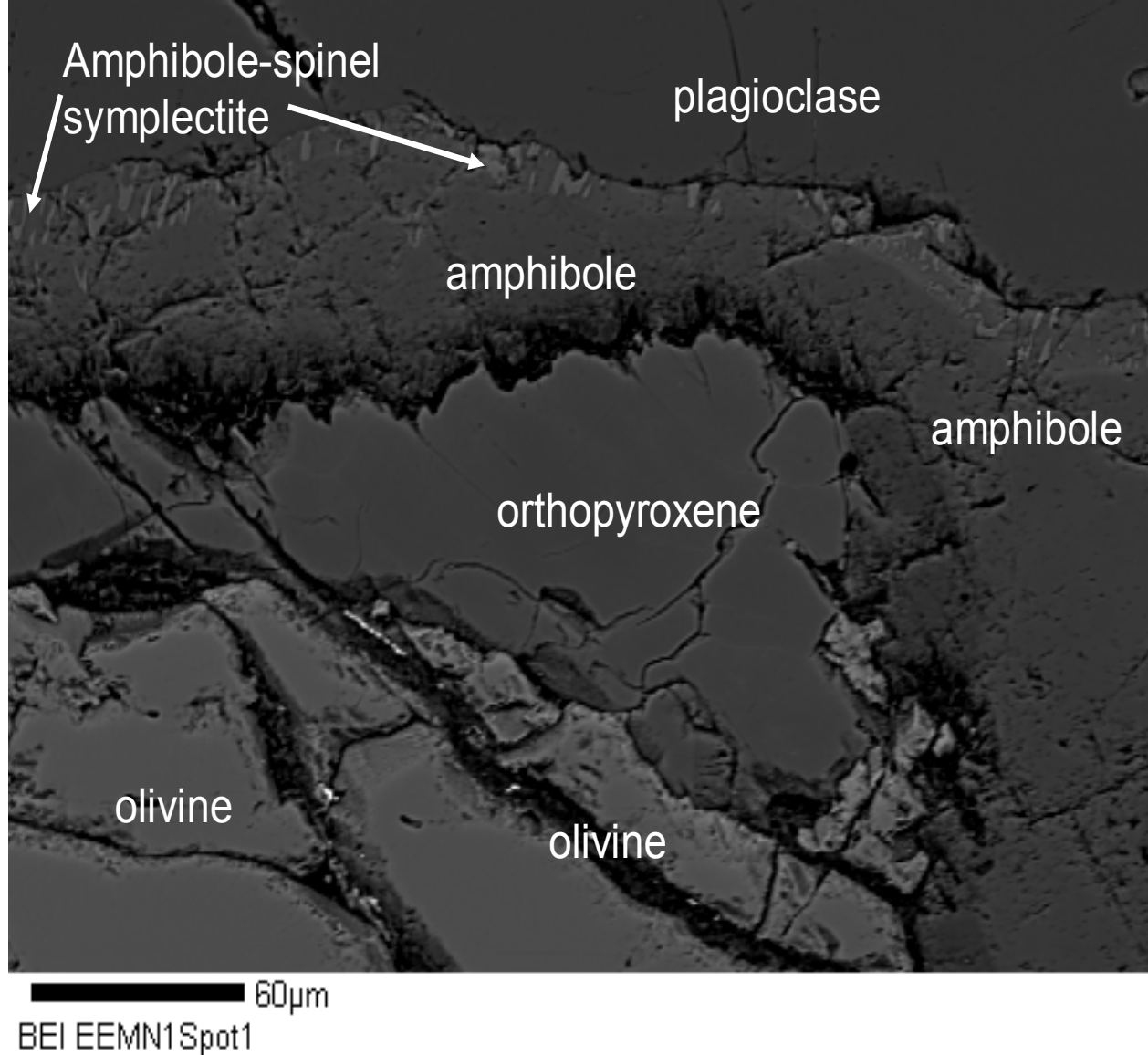


Metatroctolite from Bakers Ferry body showing corona texture between olivine and plagioclase. Sample 3-10a: Elberton East Quadrangle

Plag from olivine-bearing samples

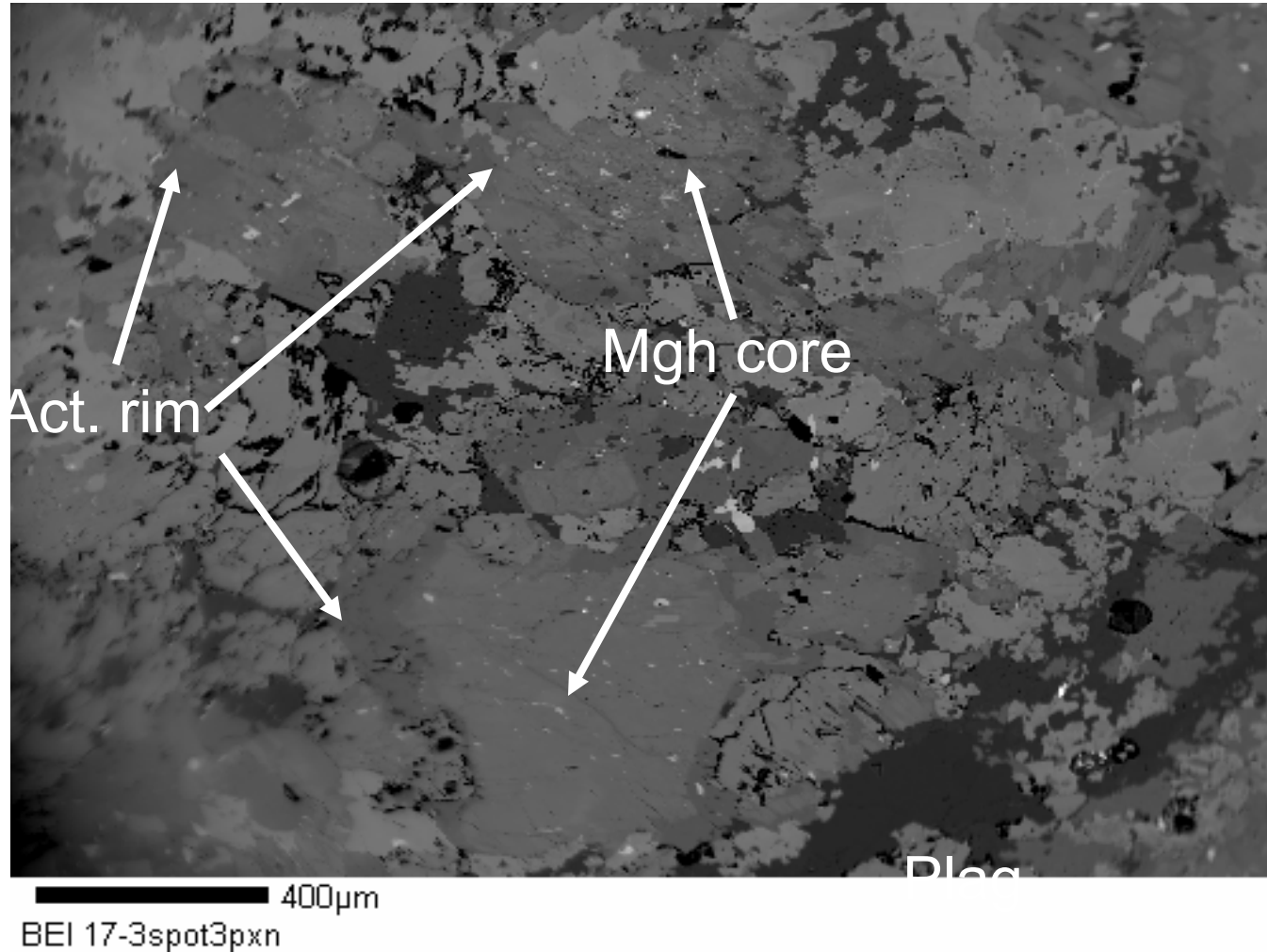


BEI showing highly calcic and unzoned plagioclase grain between two grains of olivine, sample BellN1, Nancy Hart complex, Jackson Crossroads Quadrangle



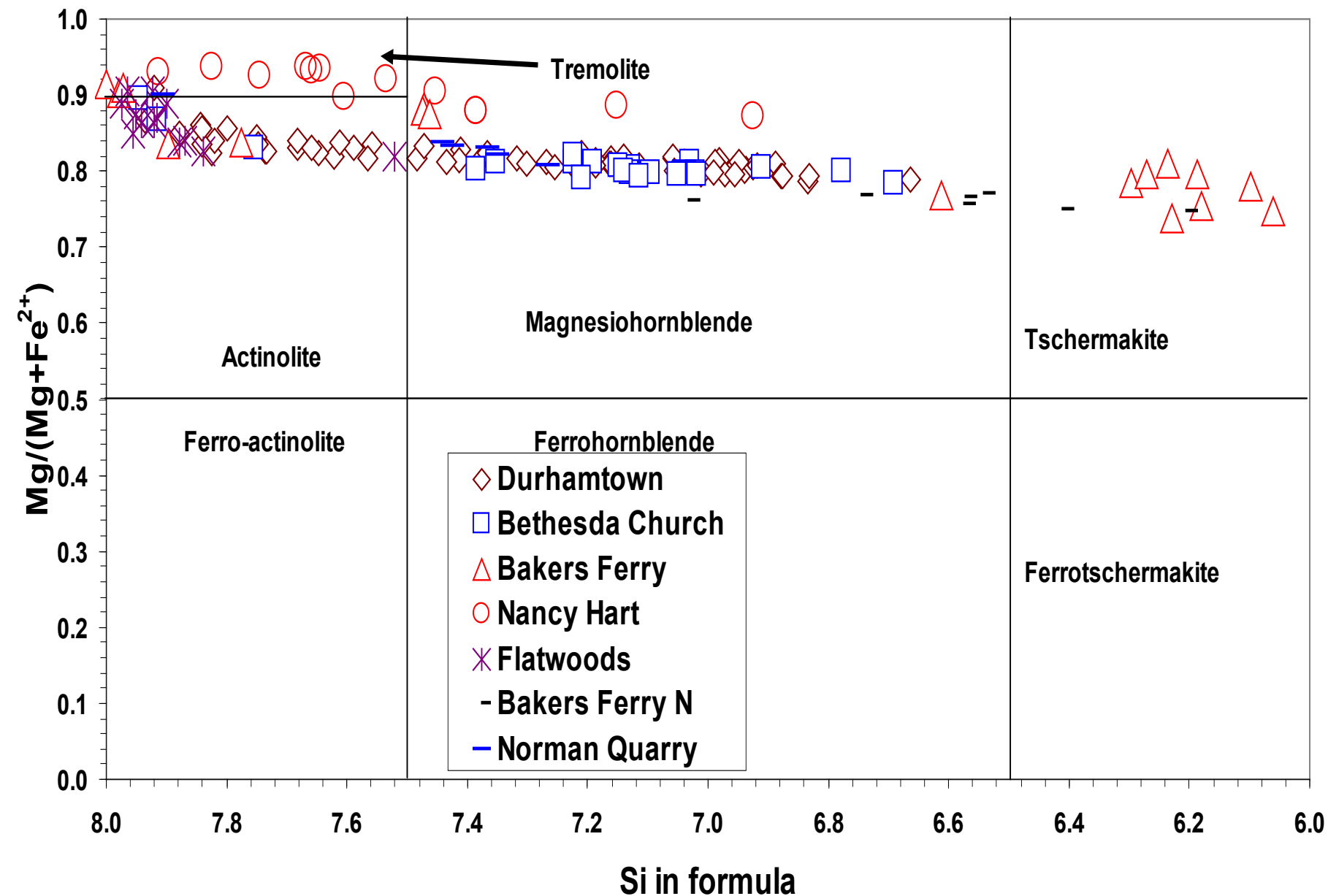
BSI image of typical corona textures from the RLA showing olivine rimmed by orthopyroxene which in turn is rimmed by amphibole. Near the amphibole-plagioclase interface, a zone of amphibole-spinel symplectite is developed

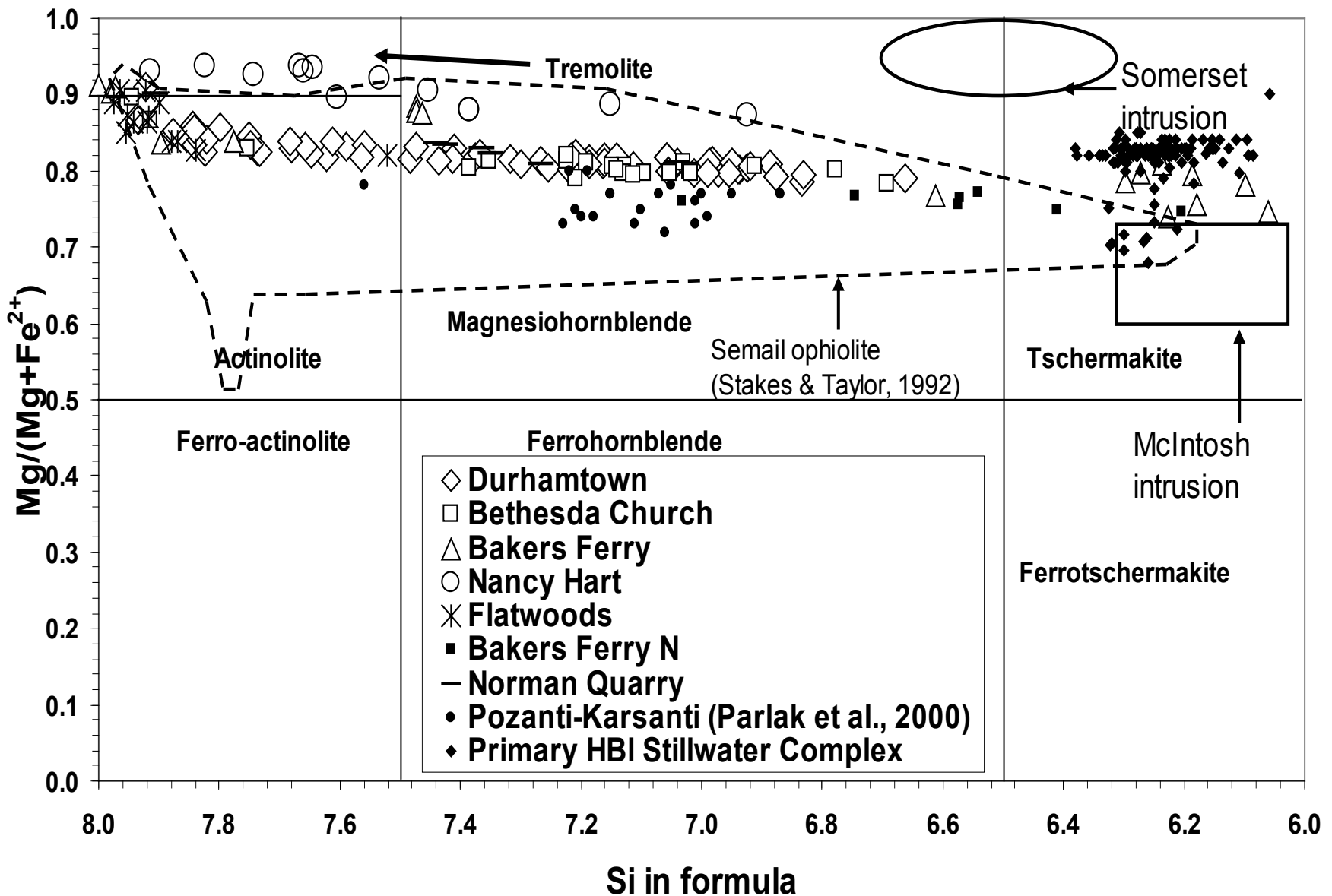
Zoned amphiboles



BEI showing magnesiohornblende (mgh) rimmed by actinolite (Act.), sample 17-3, Durhamtown body, Philomath Quadrangle

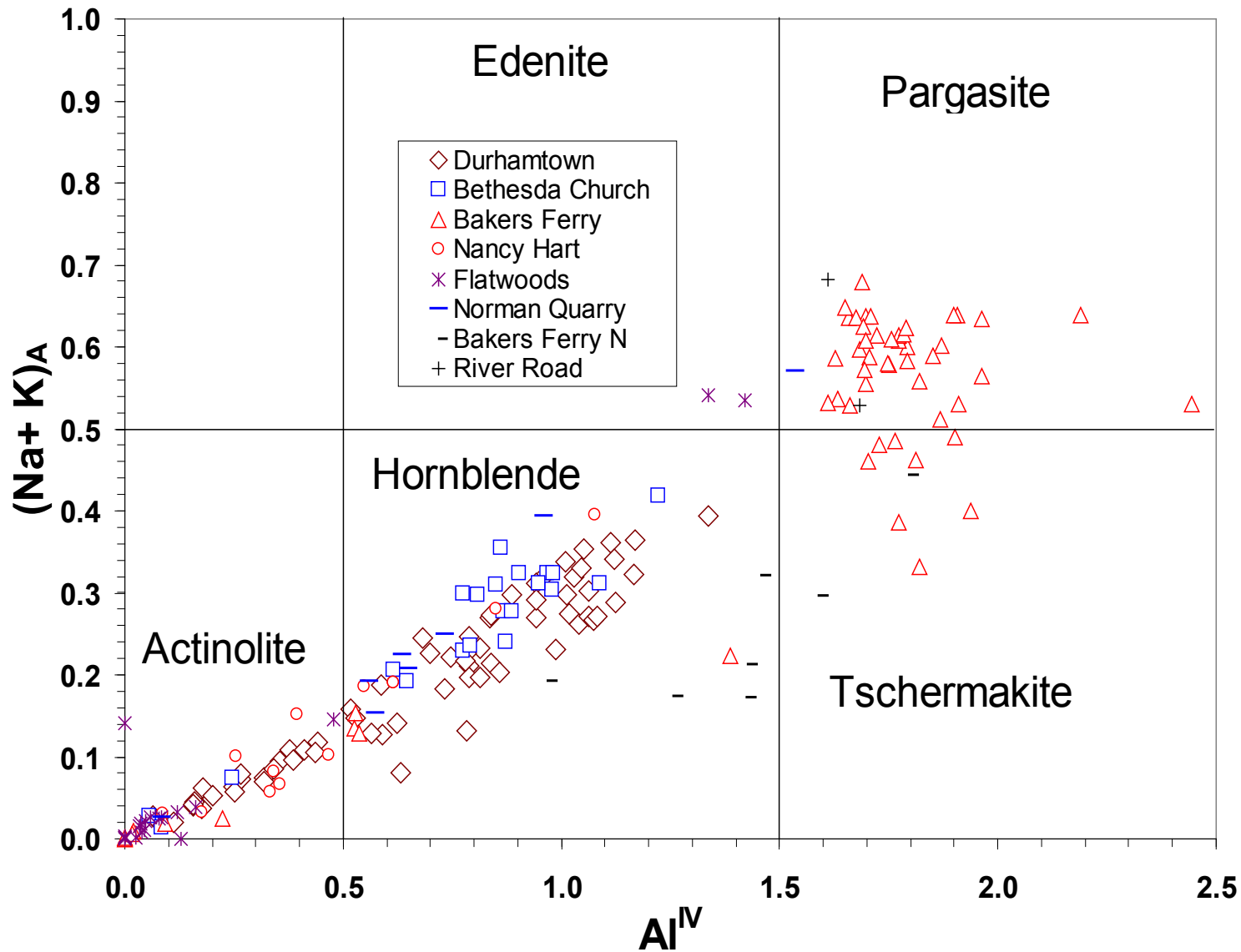
Amphibole compositions (Leake et al., 1997)



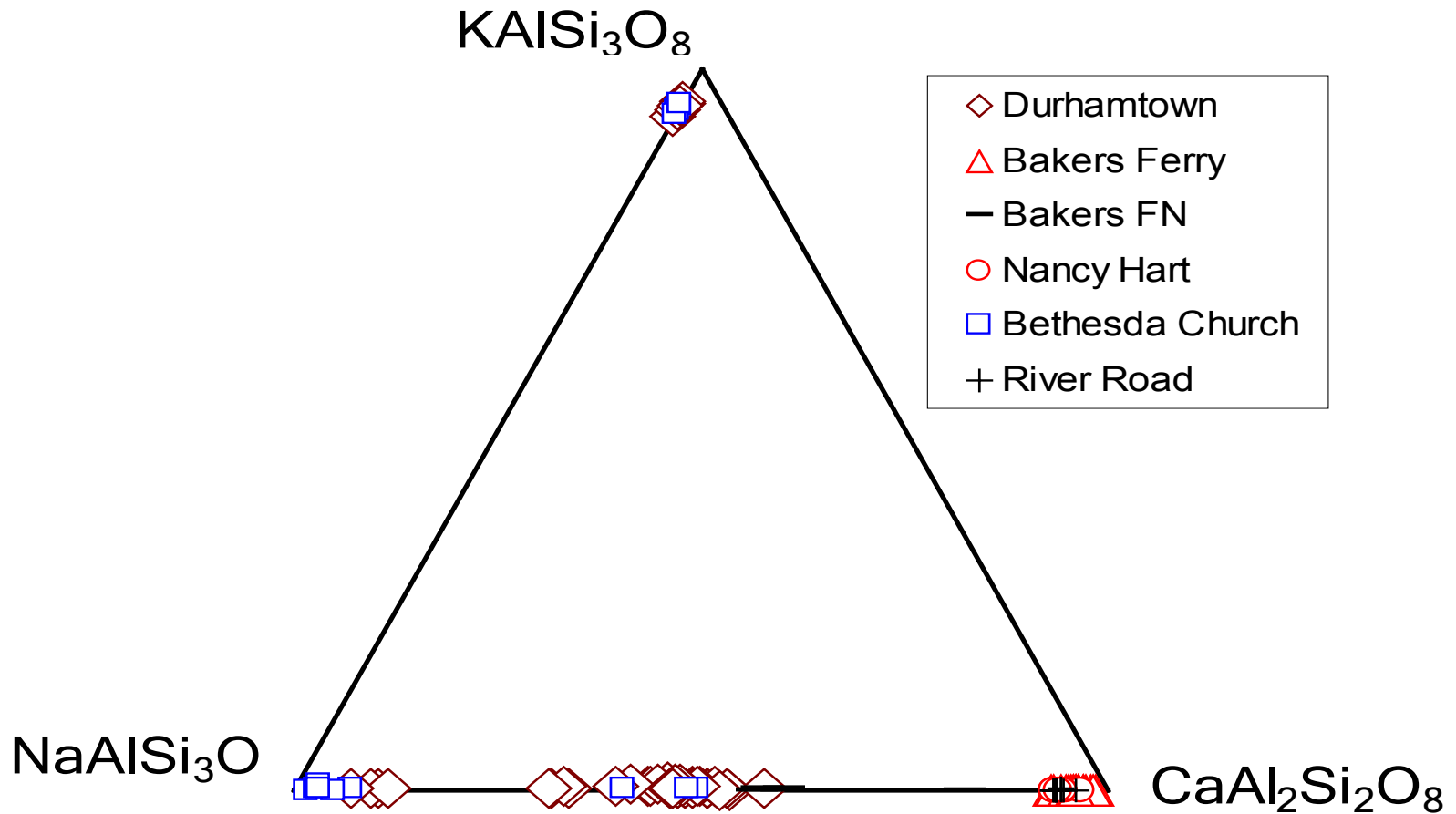


Plot of Mg# (assuming all Fe as Fe²⁺) *versus* Si in formula for amphiboles from the RLA with (Na+K)_A < 0.5, following the nomenclature of Leake *et al.* (1997)

Amphibole compositions (Deer et al., 1992)

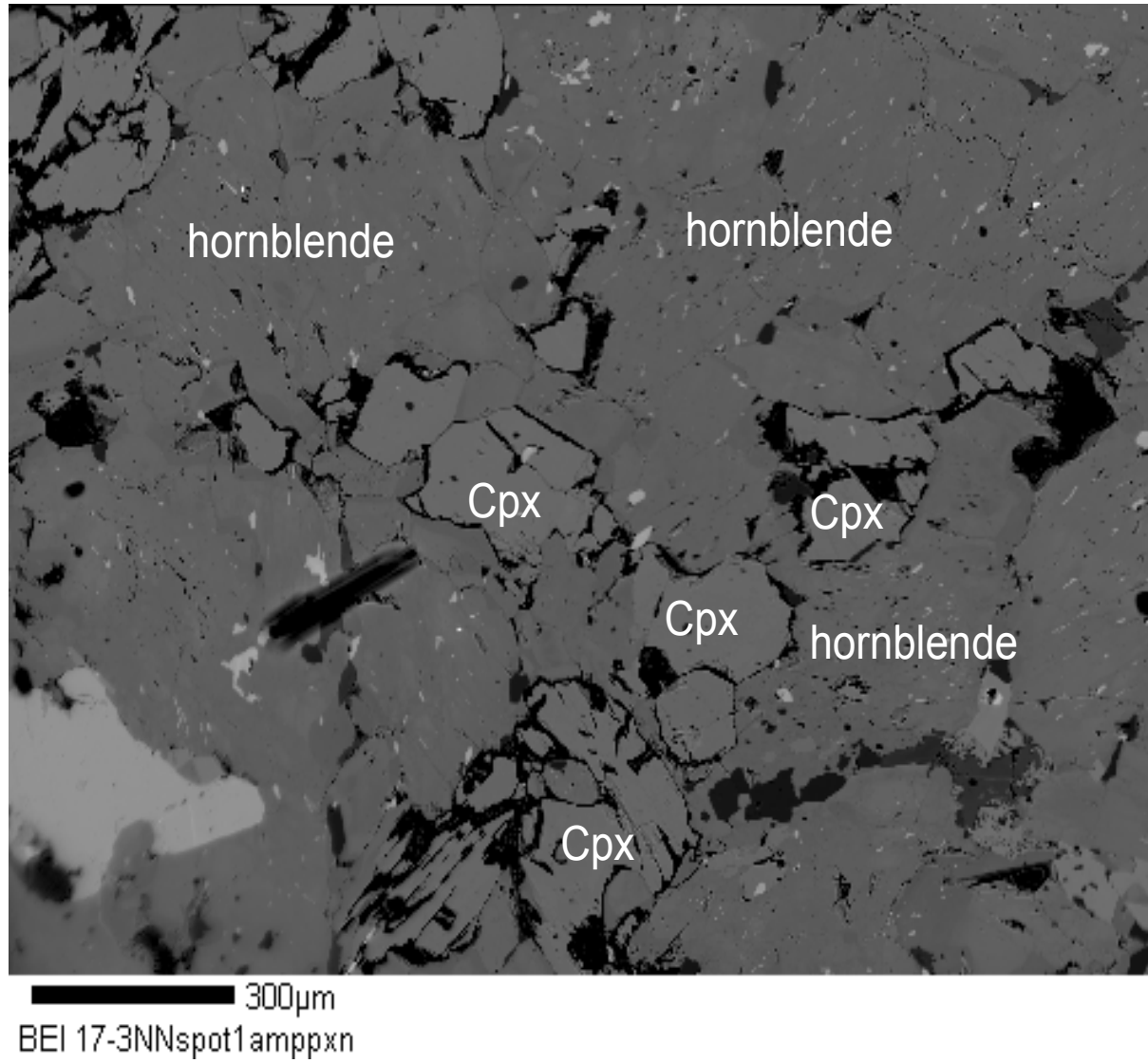


Feldspar compositions



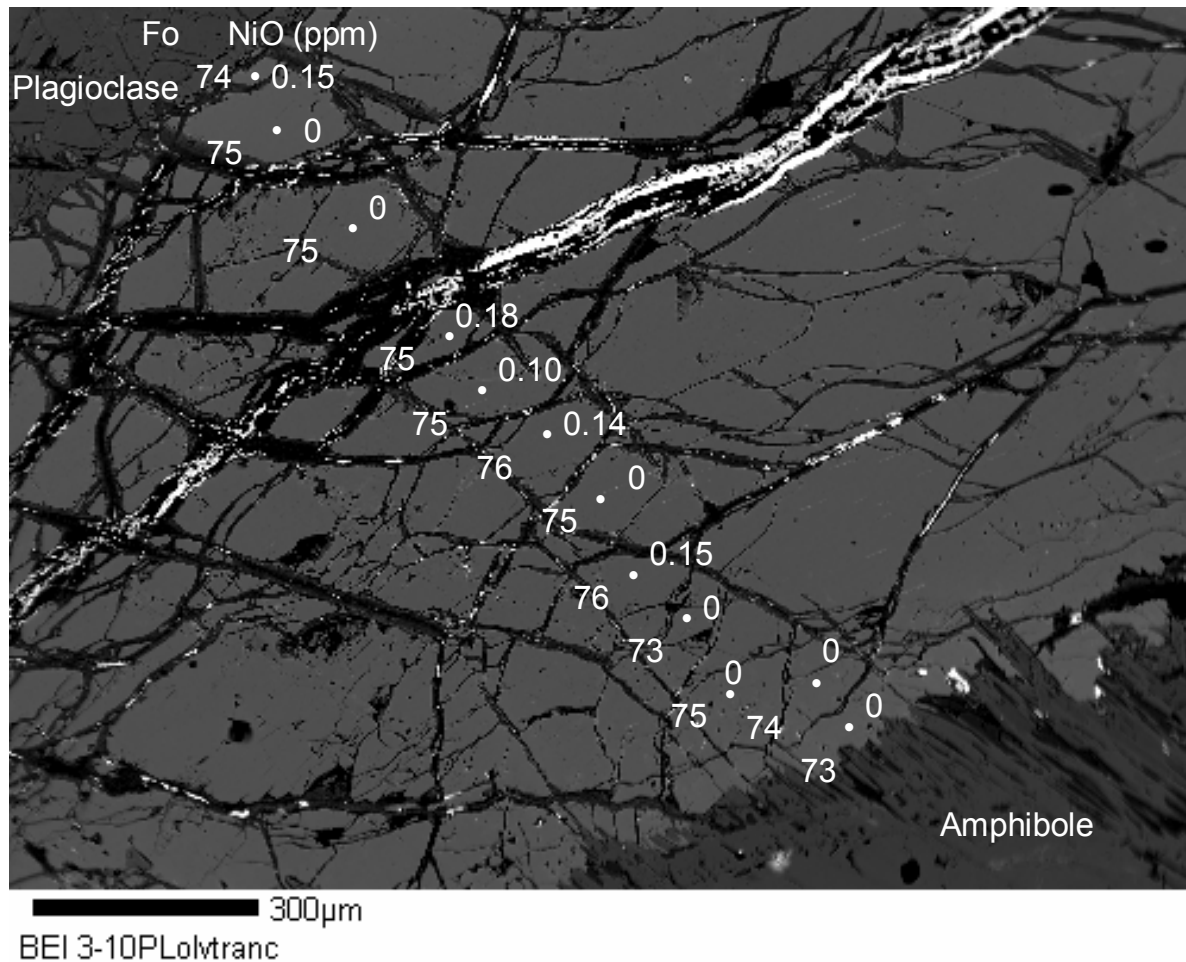
Ternary diagram showing plagioclase and alkali feldspar compositions from the RLA. Note the highly calcic nature of plagioclases from corona-bearing bodies such as Nancy Hart, Bakers Ferry and River Road

Cpx

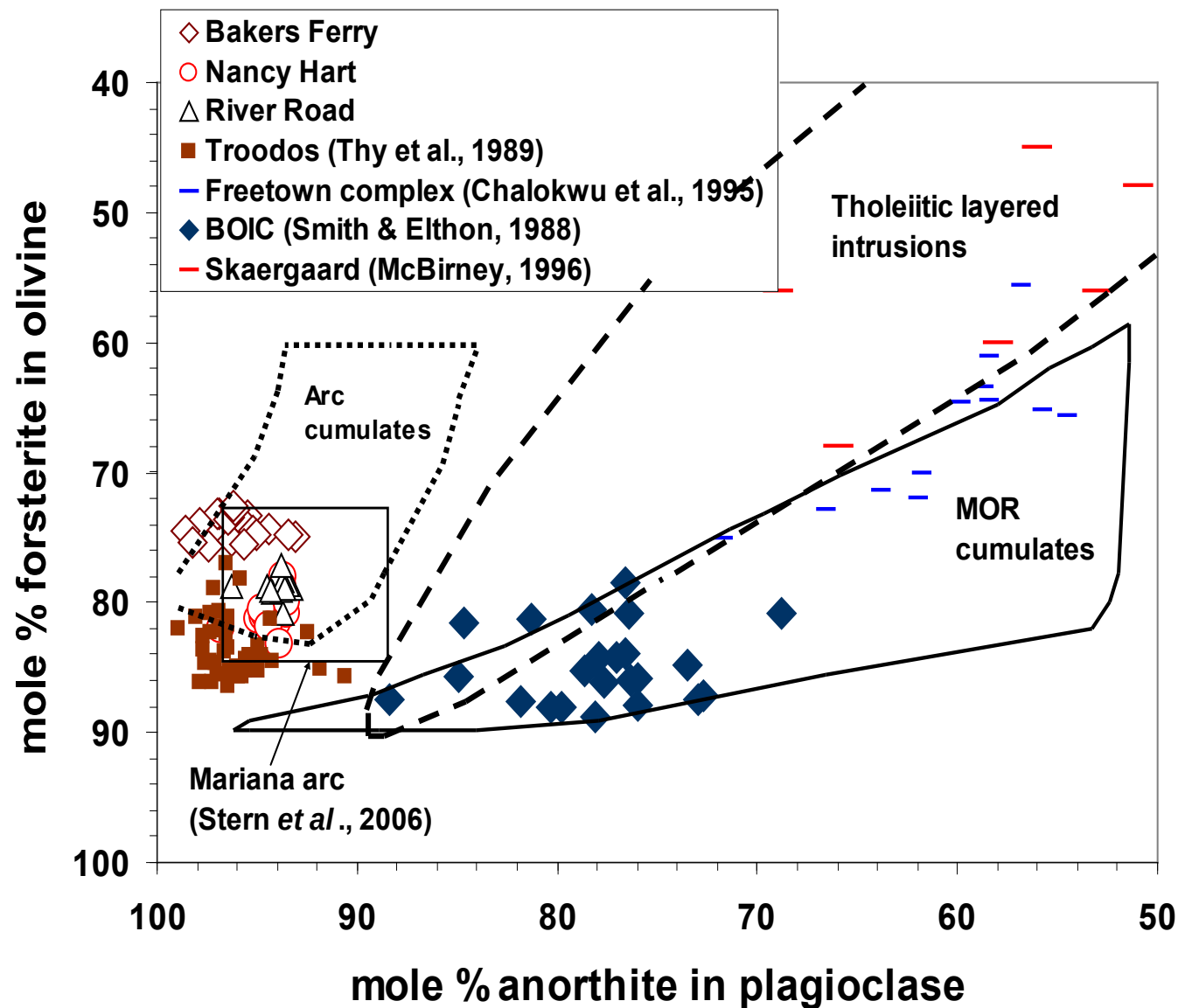


BEI showing clinopyroxene (Cpx) occurring together with hornblende.
Sample 17-3NN, Durhamtown body, Philomath Quadrangle

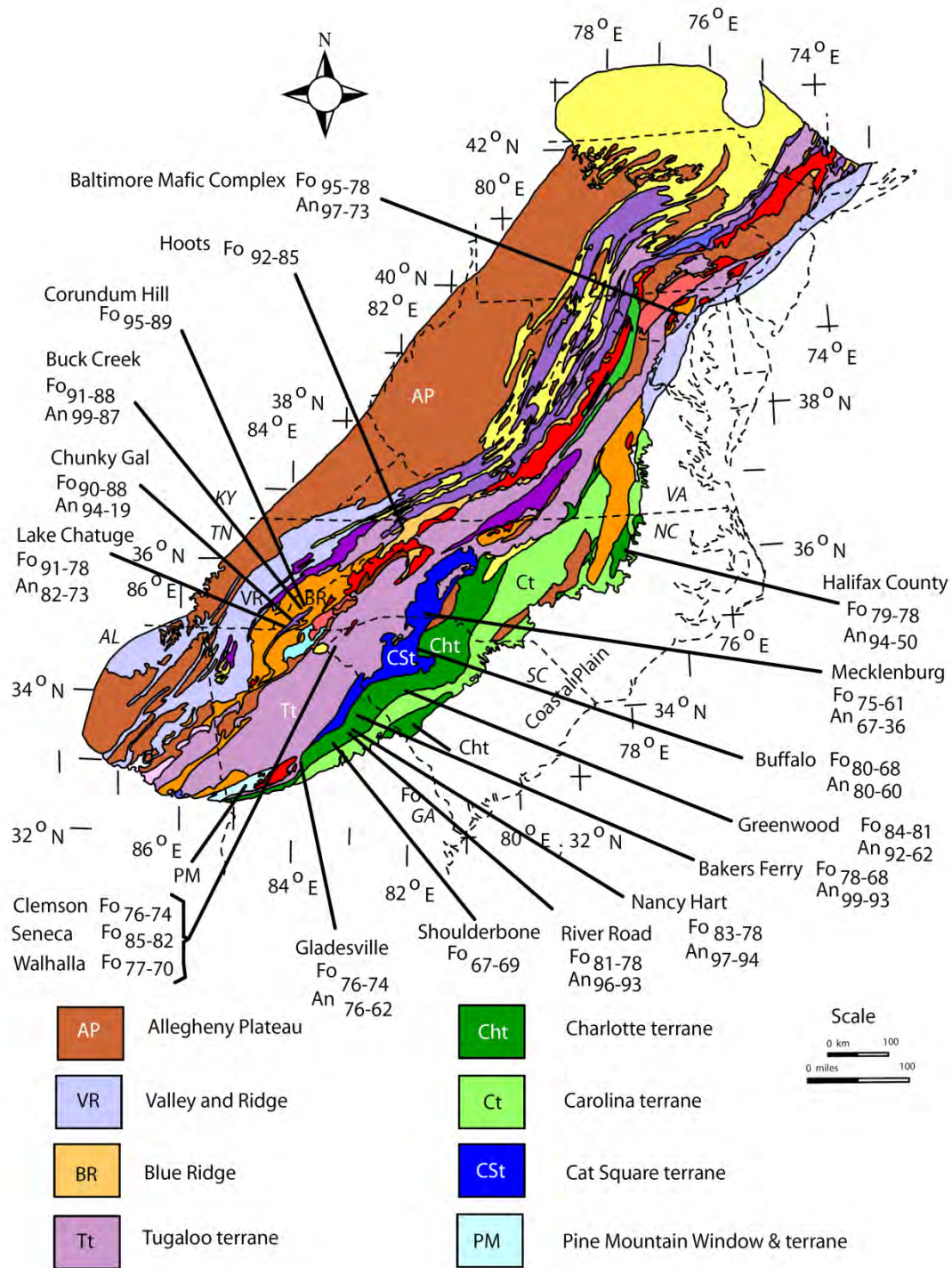
Olivine



Backscattered electron image (BEI) showing the variation of both NiO (ppm) and Fo contents across a single olivine grain in a metadunite, sample 3-10PL, Bakers Ferry body



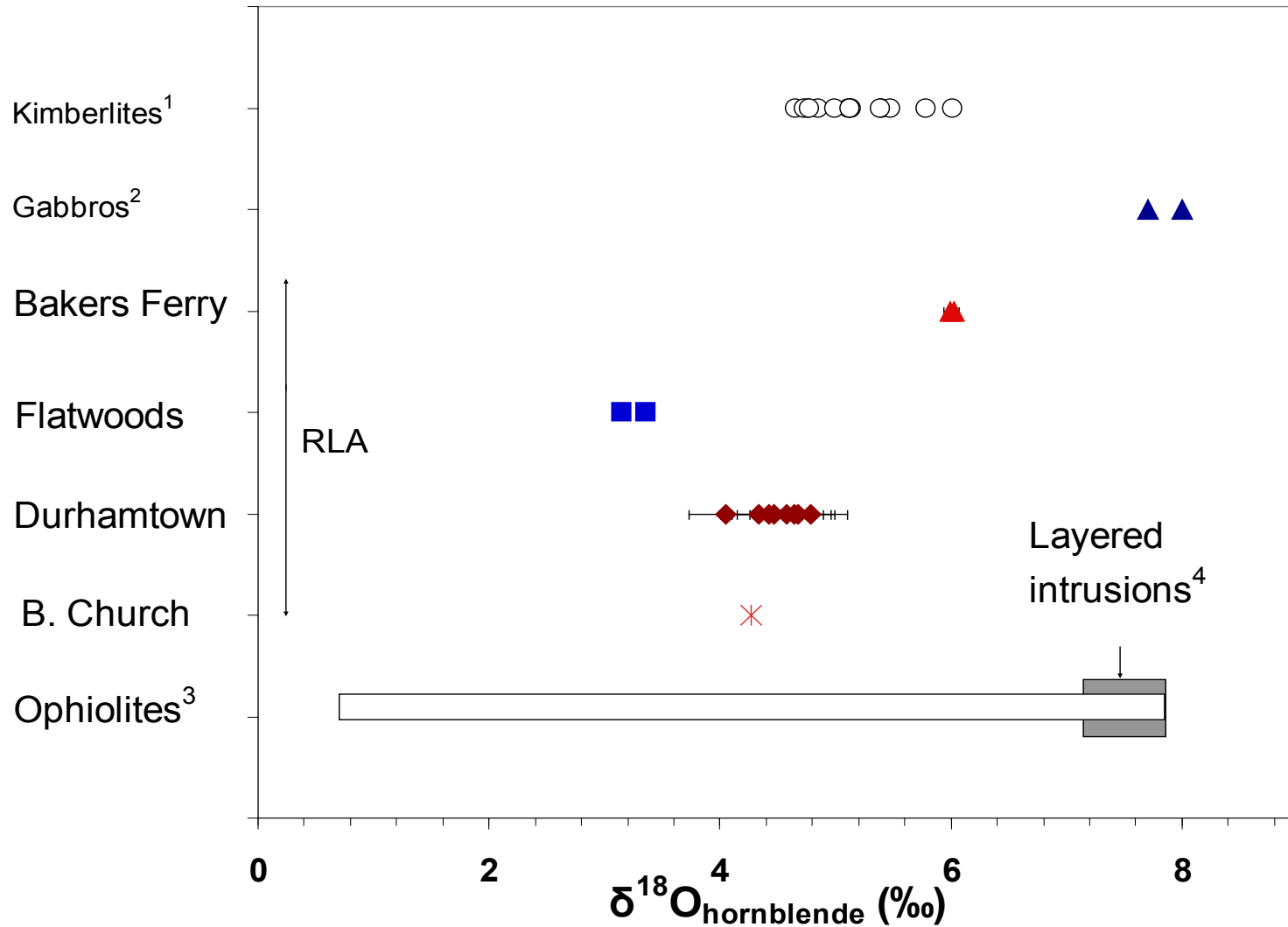
Plot of mole % forsterite in olivine *versus* mole % anorthite in plagioclase for samples from the study area. Note that all RLA bodies plot in arc cumulate field. Representative samples from the Troodos ophiolite (Thy et al., 1989)



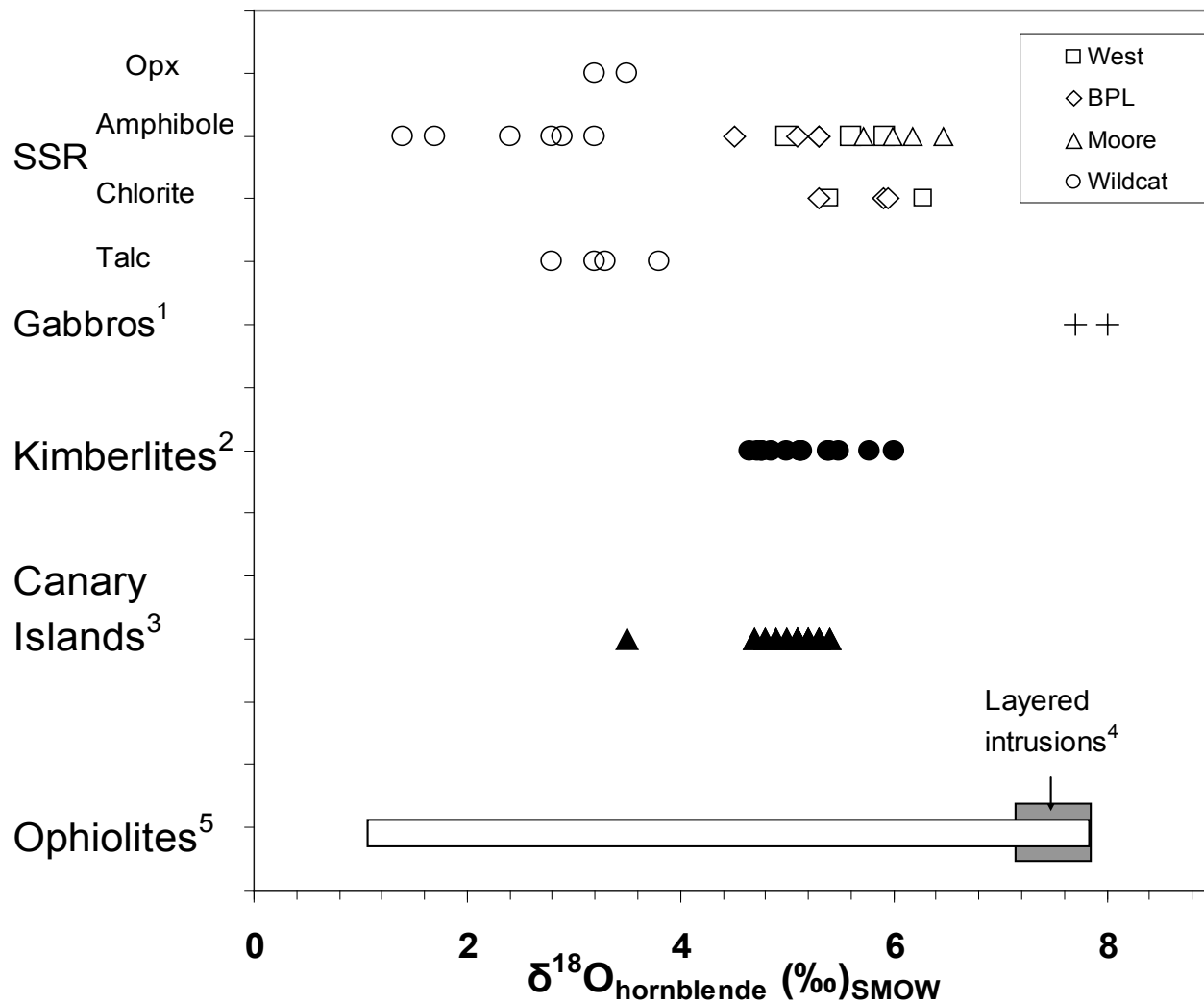
Stable isotopes – laser fluorination



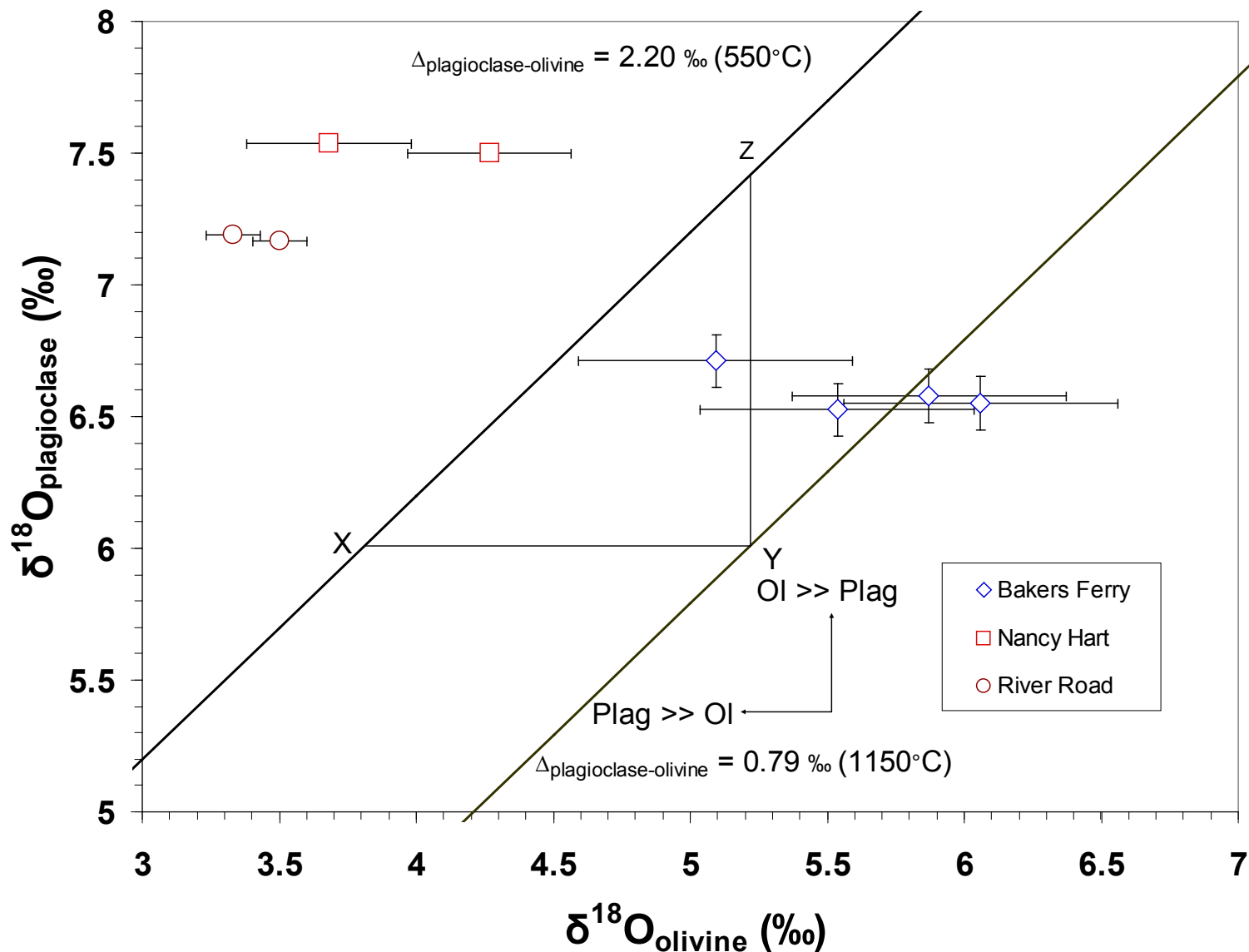




Plot of $\delta^{18}\text{O}_{\text{hornblende}} (\text{‰})$ value from the RLA compared with data from kimberlites, layered intrusions and ophiolite bodies



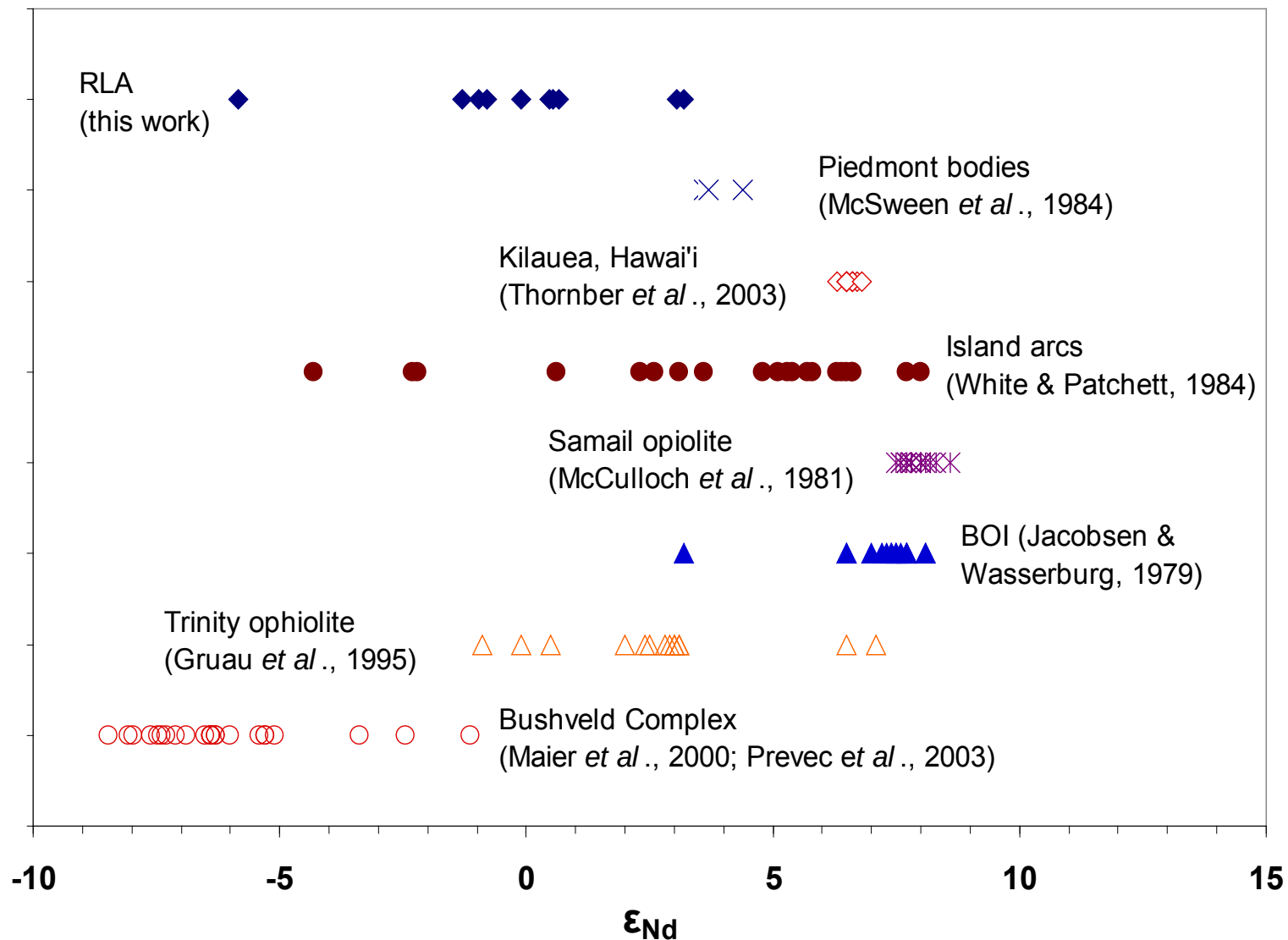
Plot of $\delta^{18}\text{O}_{\text{hornblende}} (\text{‰})$ value from the Soapstone Ridge Complex (Atlanta, Georgia) compared with data from kimberlites, layered intrusions and ophiolite bodies



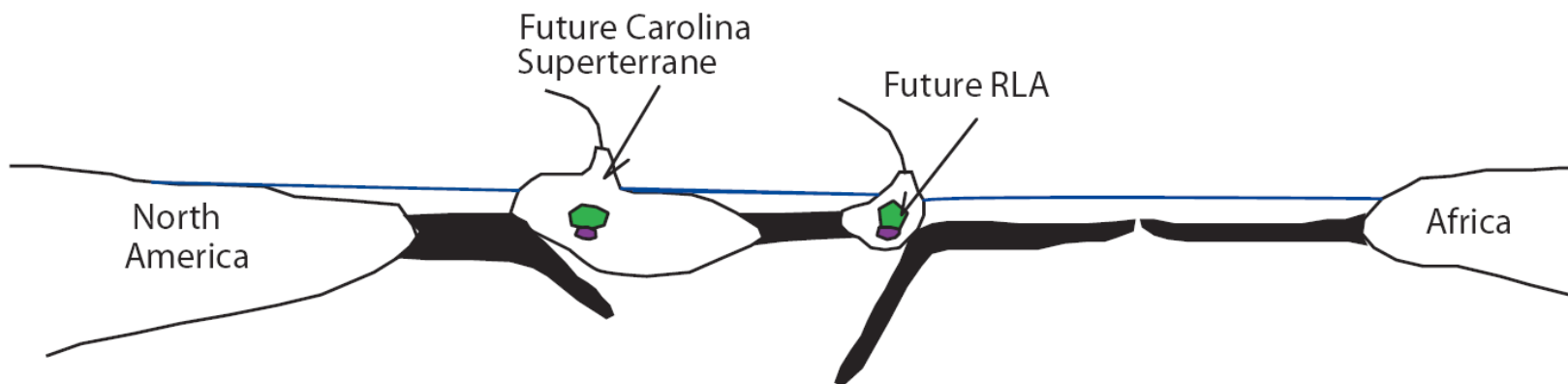
Plot of $\delta^{18}\text{O}_{\text{plagioclase}} (\text{‰})$ *versus* $\delta^{18}\text{O}_{\text{olivine}} (\text{‰})$ for coexisting minerals from the study area. Samples from the Bakers Ferry body plot between the 1150°C and 550°C isotherms. Samples from Nancy Hart and River Road bodies, however, plot above the 550°C isotherm

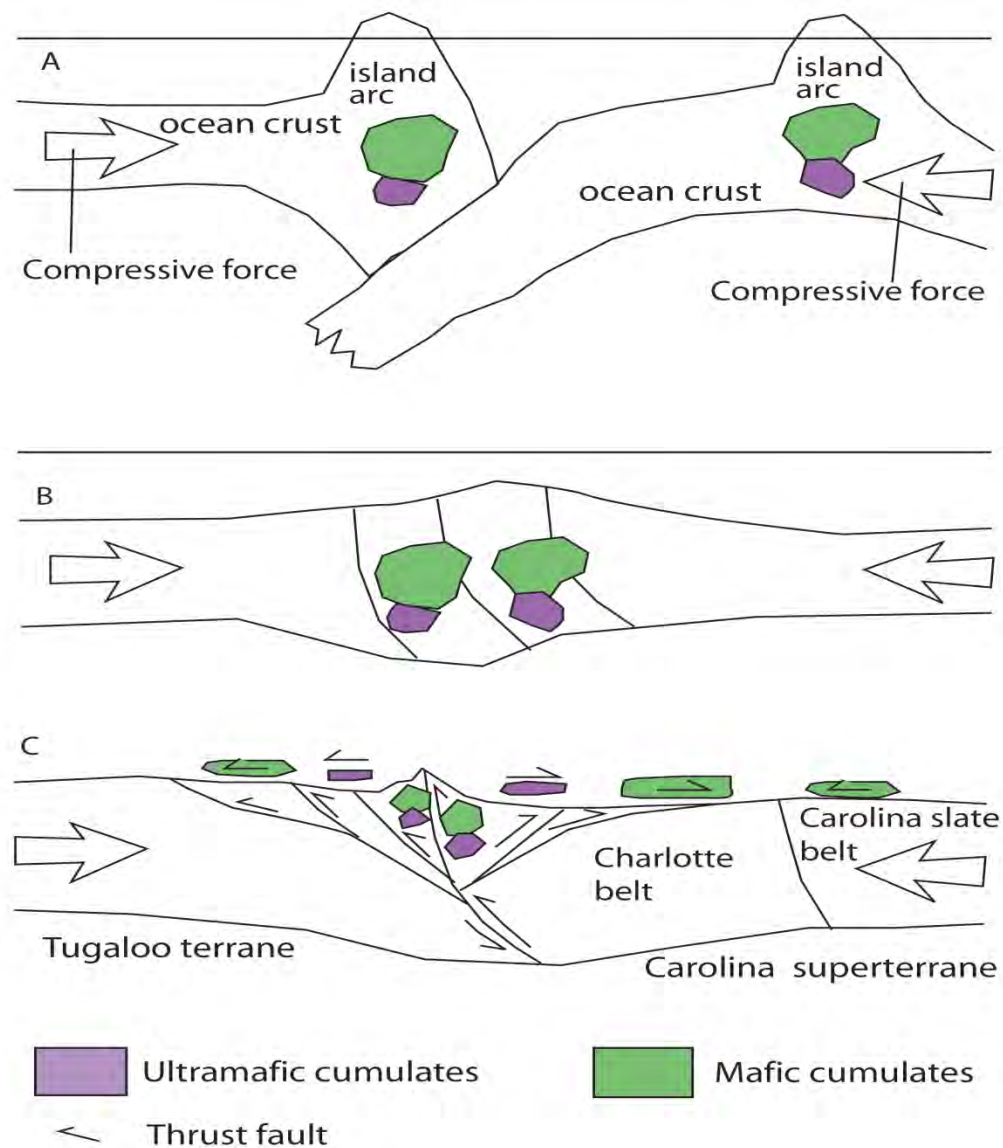
Radiogenic isotopes





Plot of ϵ_{Nd} values from the RLA (this work) together with ϵ_{Nd} values from gabbroic rocks from various tectonic settings the literature. Note the similarity of the RLA ϵ_{Nd} values to those from island arcs. BOI - Bay of Islands ophiolite





Sketch illustrating the envisaged events that led to development of the RLA. A. Arc-arc collision during initial stages of the assembly of Pangea, B. Development of corona textures due to high-pressure metamorphism resulting from arc-arc collision. C. Thrusting of the RLA onto present position due to collision of various arcs during final assembly of Pangea

Carolina Gold Rush

- The **first gold rush** in the US, followed discovery of **gold in North Carolina in 1799**.
- A few years later that word of the gold spread and men started coming to North Carolina from other states.
- The **US Mint** reported gold production from North Carolina in 1793.
- In 1799, young **Conrad Reed**, found a 17-pound shiny rock while playing at a creek on his family's farm in **Cabarrus County, NC**
- **Reed Gold Mine** - National Historic Landmark

Metallic Minerals

- **Gold** - The 1849 California gold rush was due to gold in gravels that is derived from gold-bearing quartz veins emplaced with the Sierra Nevada batholith.
- **Copper, silver and zinc** - These minerals are found in the Butte, Montana and Coeur d'Alene, Idaho mining districts and were emplaced as a result of **Cretaceous igneous activity**.
- A number of copper deposits in the western U.S. occur in porphyritic igneous rocks - porphyry copper deposits.

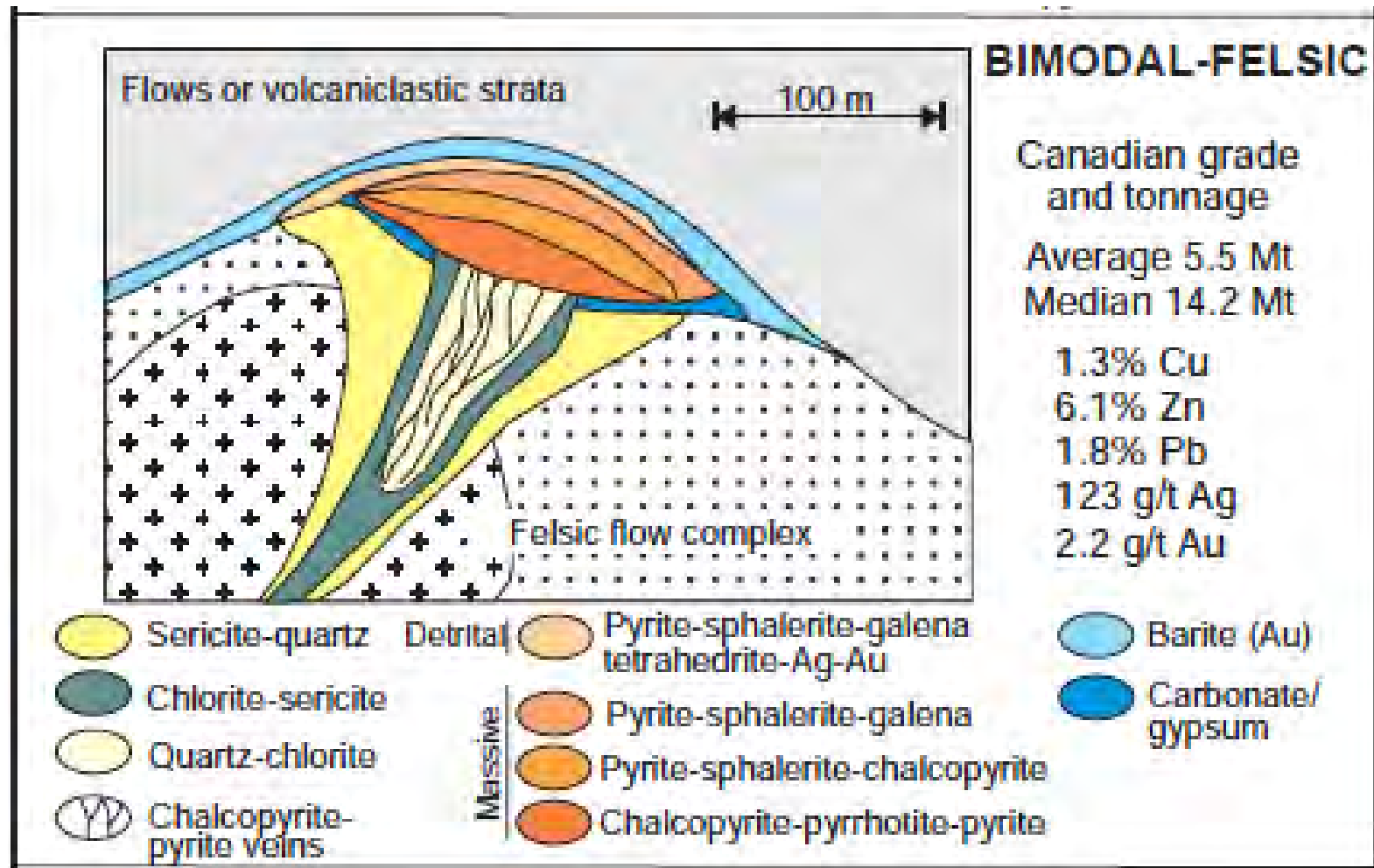
VMS Deposits

- **Volcanogenic massive sulfide** deposits occur in the Appalachian orogeny
- Numerous classifications for VMS
 - Metals - Zn-Cu, Cu-Zn, Zn-Pb-Cu, Au-rich
 - Type locality: Besshi, Cyprus, Kuroko
- **Six-fold classification of VMS** most useful as based on rock type and associations (e.g., Franklin et al., 2005; Galley et al., 2007):

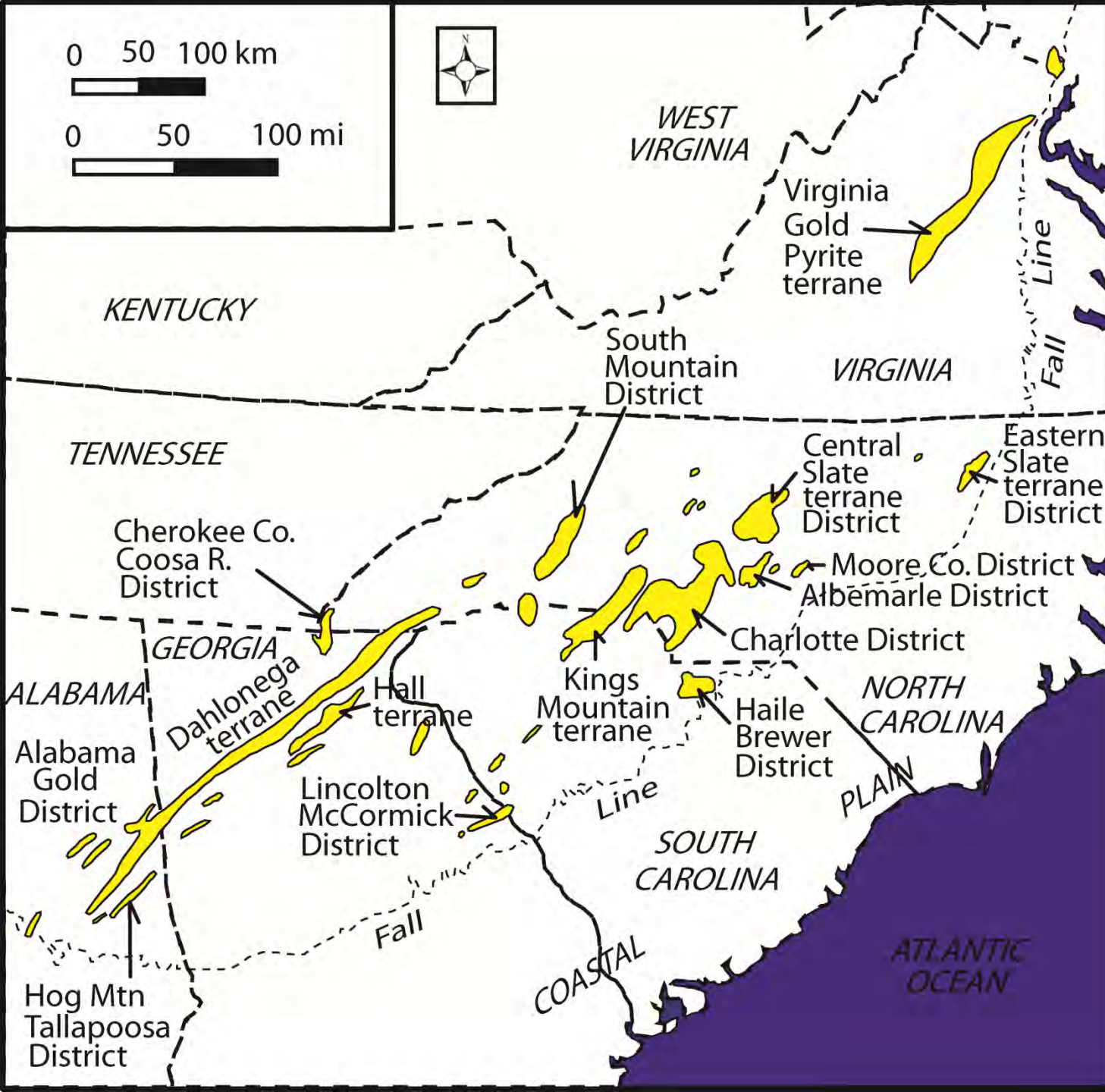
VMS Deposit Classification

1. Mafic (Cyprus-type)
2. Bimodal Mafic (Noranda-type)
3. Mafic Siliciclastic (Besshi-type) (aka Pelitic Mafic)
4. Bimodal Felsic (Kuroko-type)
5. Felsic Siliciclastic (Bathurst-type)
6. Hybrid Bimodal Felsic/Siliciclastic (Eskay Creek-type: a deposit in BC, Canada)

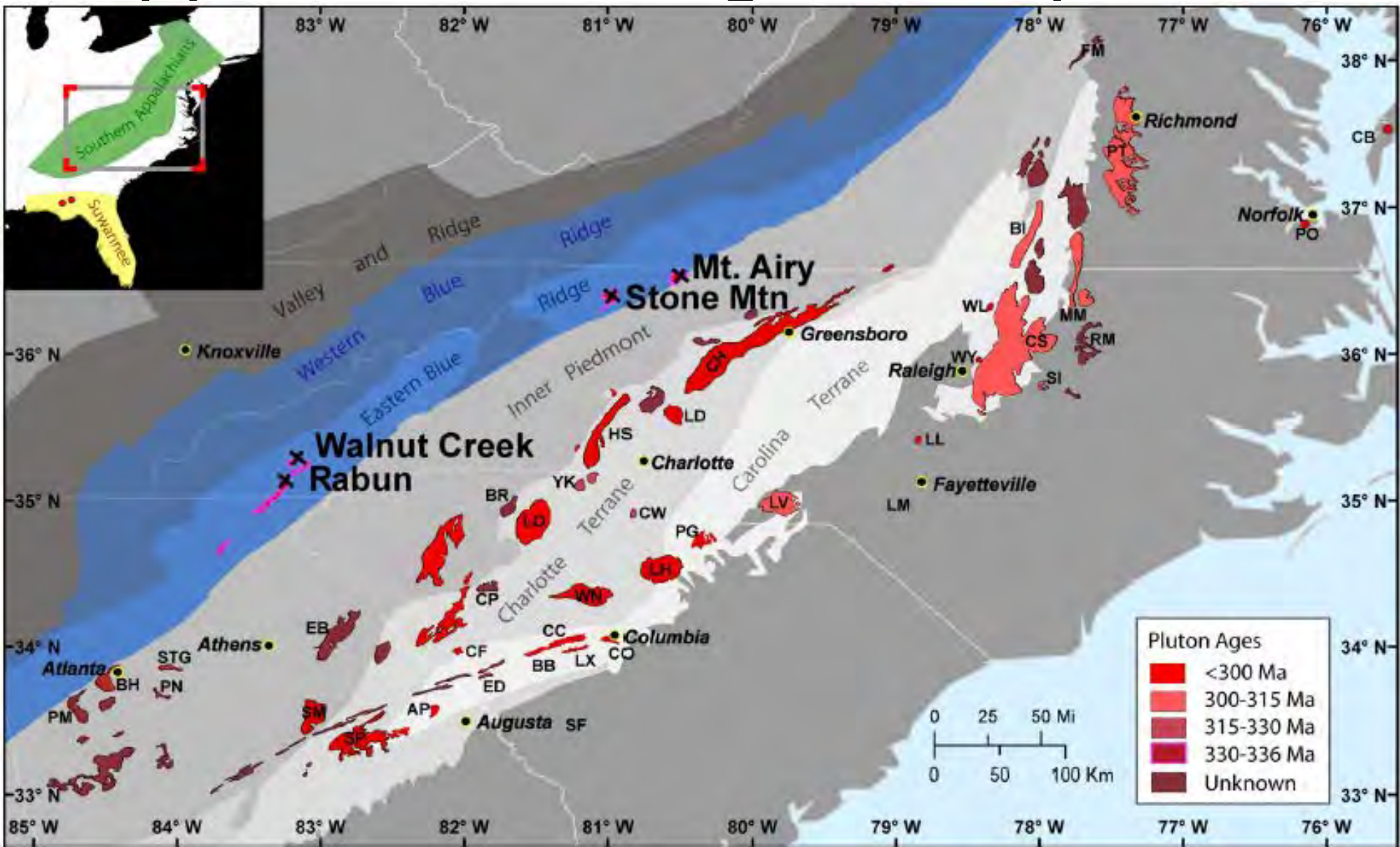
4. Bimodal Felsic (Kuroko-type)



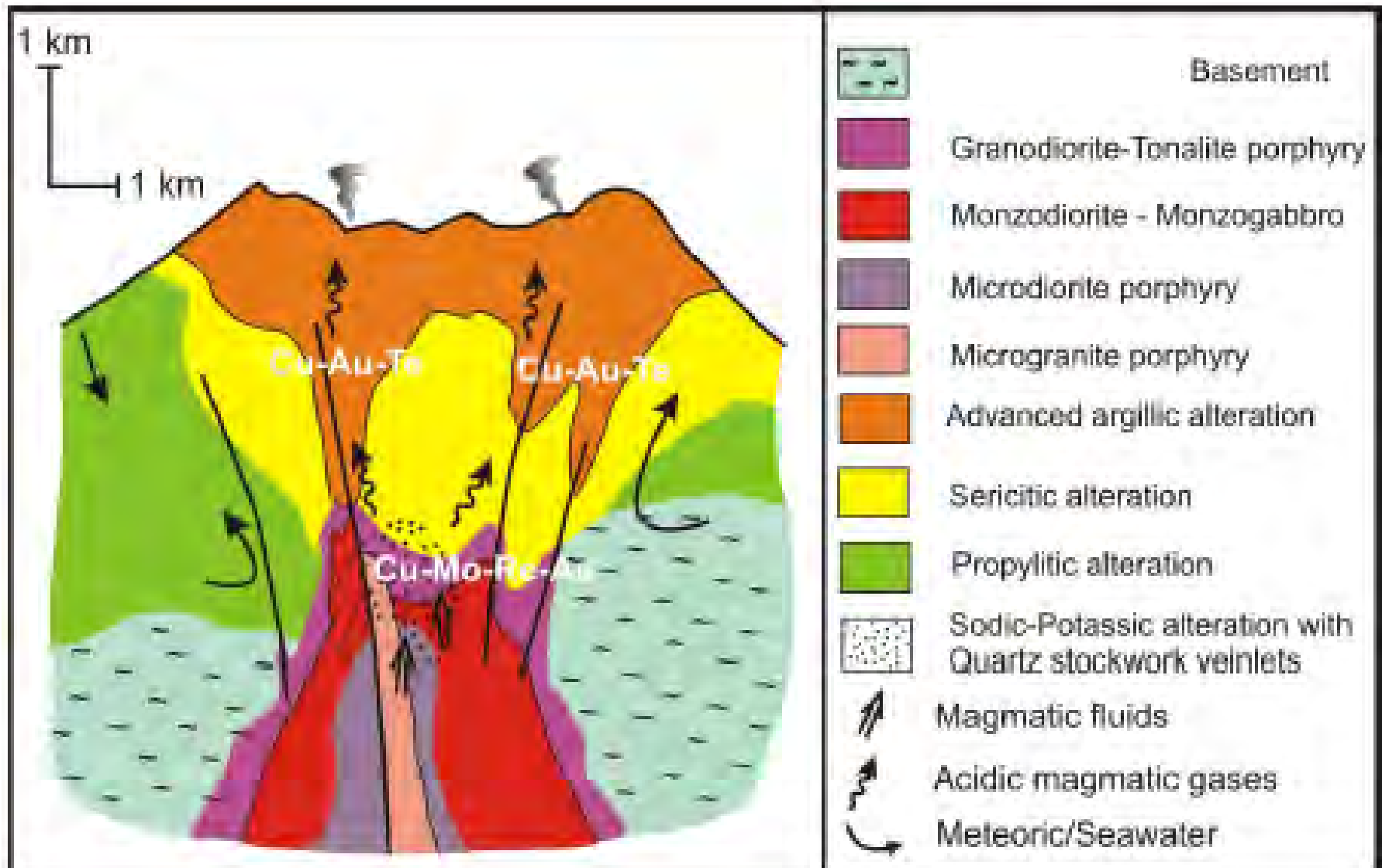
Gold districts



Location map of Southern Appalachian Alleghanian plutons



Schematic diagram integrating magma emplacement, degassing, and Cu-Mo porphyry - epithermal mineralizing processes



- Gold, Cu, Zn, & Pb associated with volcanic rocks (rhyolites to andesites)
- These minerals are inferred to have originated in island arc tectonic settings
- Mo and Cu associated with porphyritic intrusions

Summary

- Three collisional events involved in the formation of the Appalachian orogeny
- Amphiboles have cores consistent with amphibolite metamorphic conditions, rimmed by actinolite consistent with greenschist facies conditions
- Gold and other metals mineralization (low grade) occurs in the Appalachians
- RLA probably formed in island arc setting





Questions?