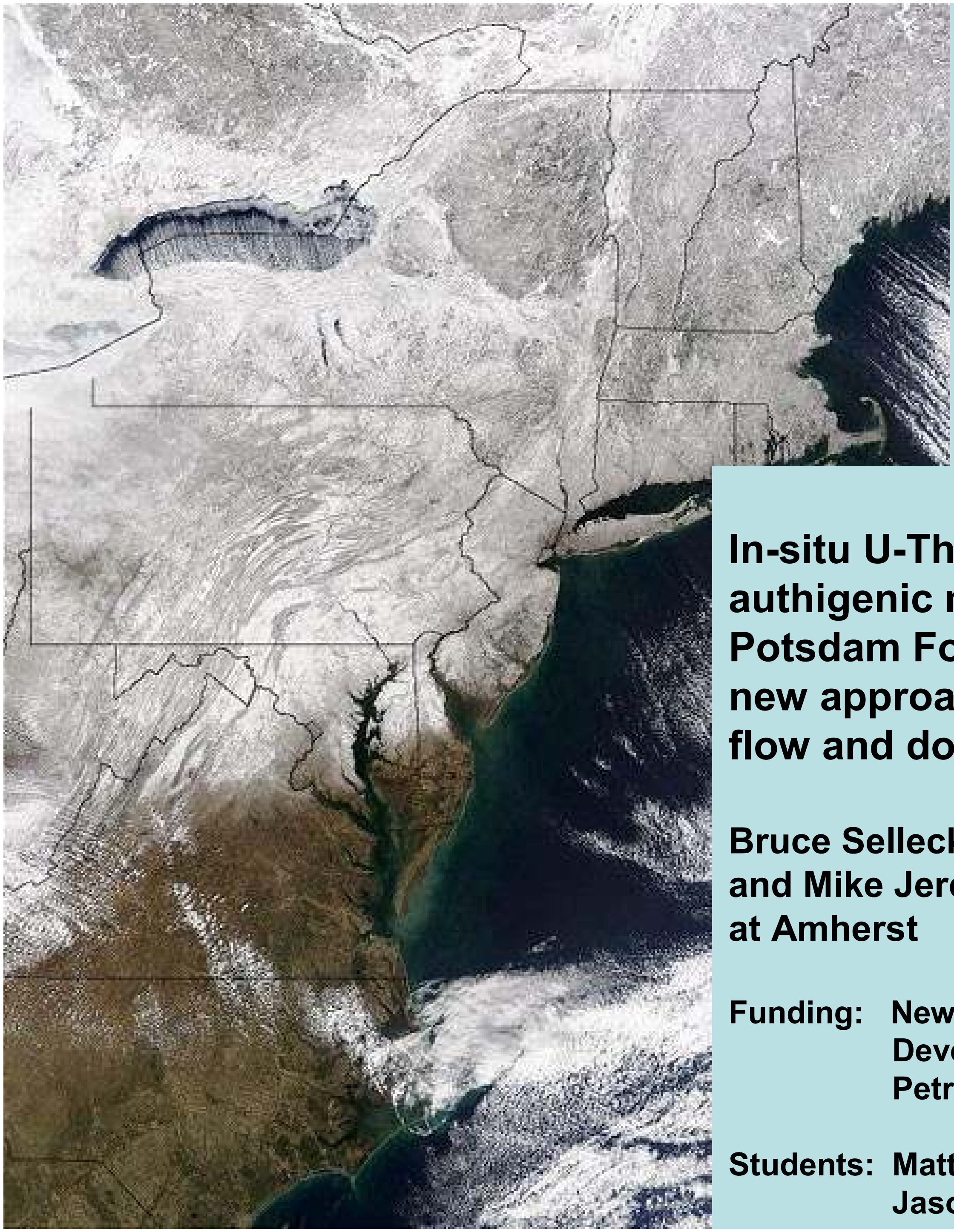
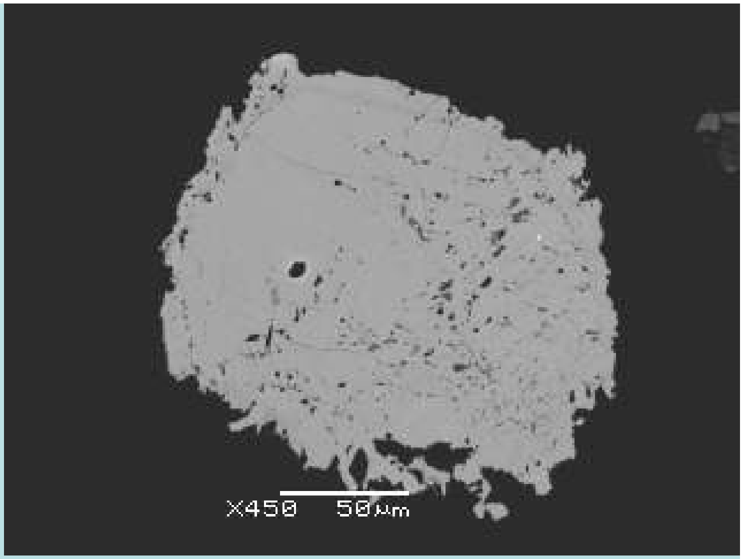




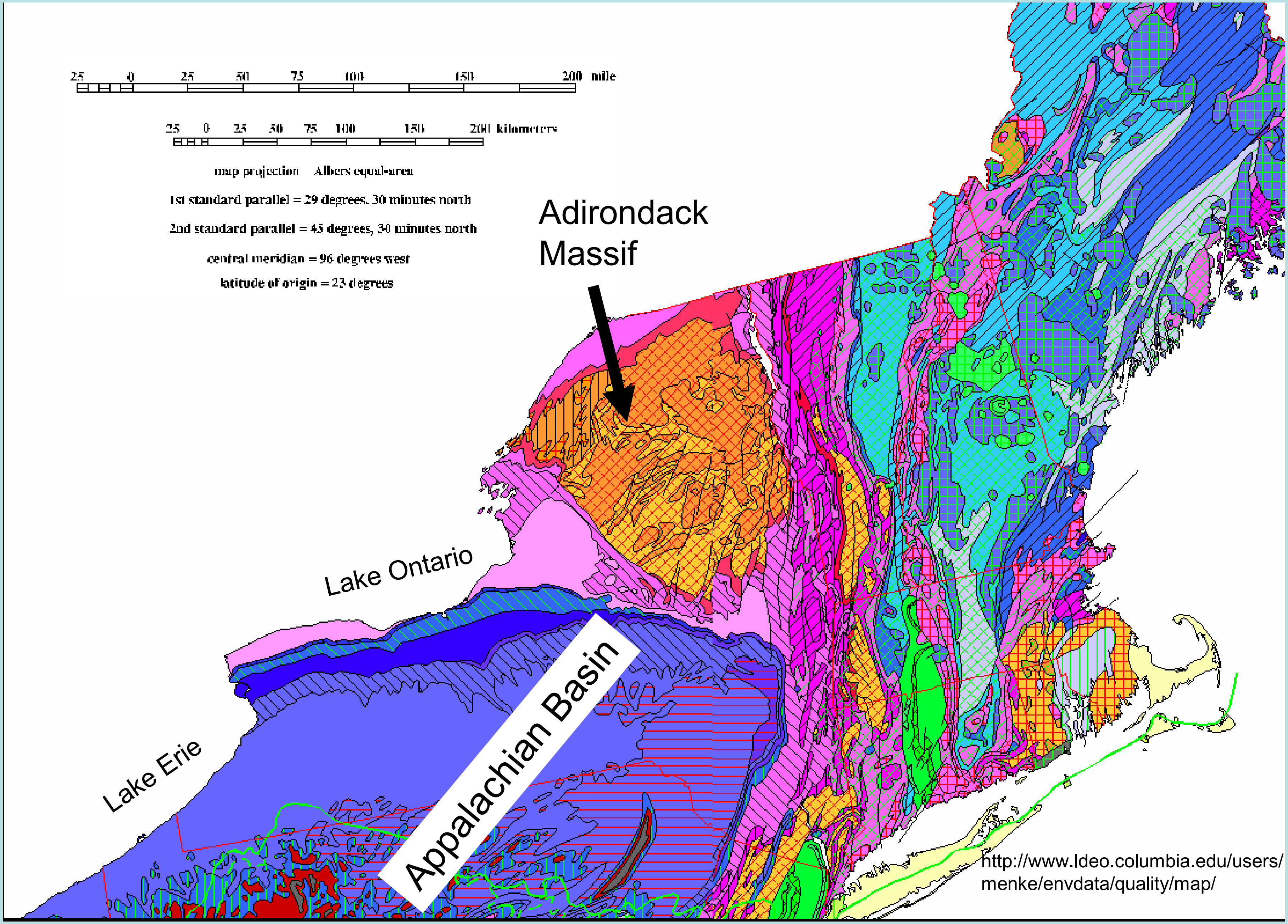
In-situ U-Th-Pb microprobe dating of authigenic monazite and xenotime in the Potsdam Formation, eastern New York: A new approach to dating hydrothermal fluid flow and dolomitization

Bruce Selleck, Colgate University; Mike Williams and Mike Jercinovic, University of Massachusetts at Amherst

Funding: New York State Energy Research and
Development Authority
Petroleum Research Foundation

Students: Matt Loewenstein
Jason Fredricks

Colgate UNIVERSITY



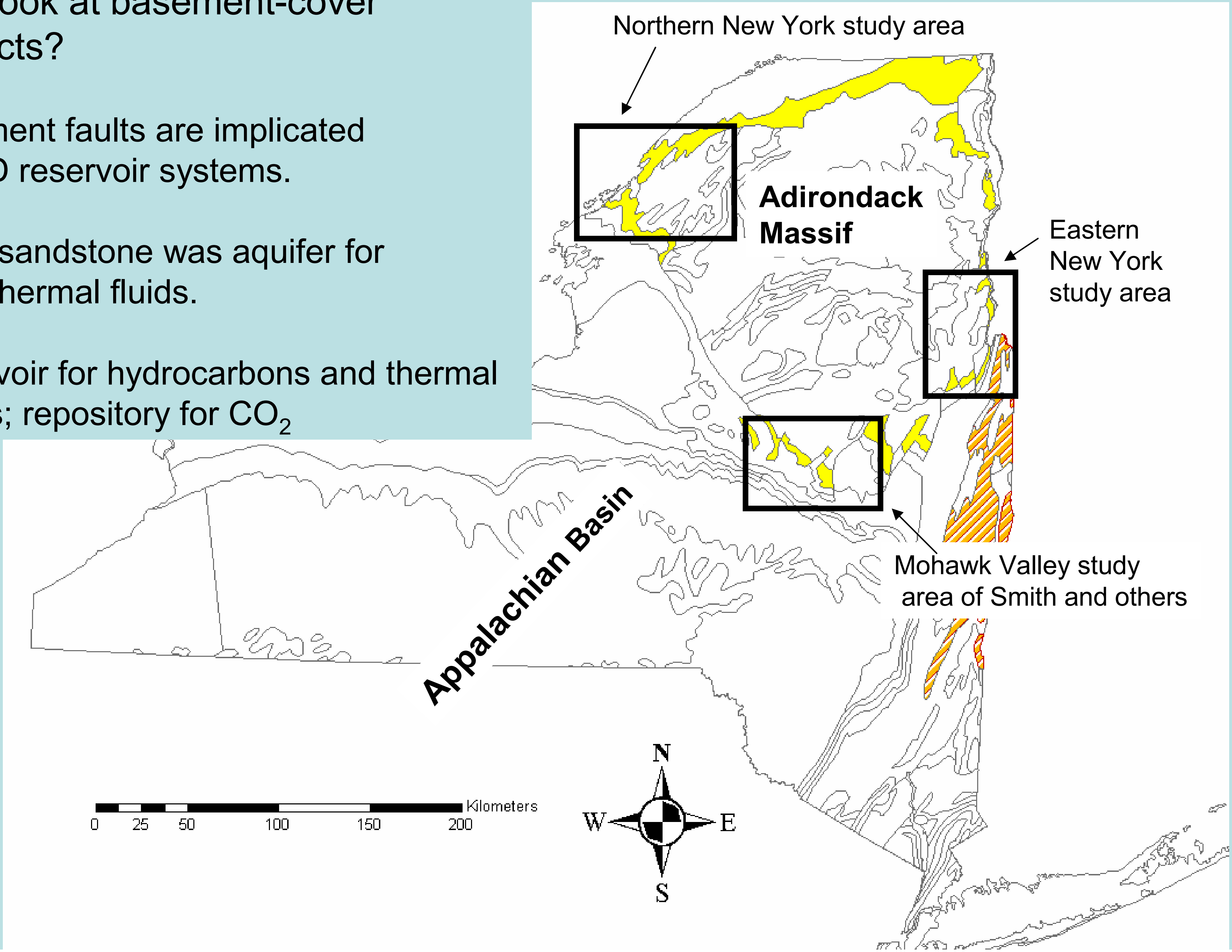
http://www.ldeo.columbia.edu/users/menke/envdata/quality/map/

Why look at basement-cover contacts?

Basement faults are implicated in HTD reservoir systems.

Basal sandstone was aquifer for hydrothermal fluids.

Reservoir for hydrocarbons and thermal waters; repository for CO_2



Hydrothermal alteration of Proterozoic and basal Paleozoic rocks in New York State

Dolomitization of basement marble; vuggy porosity; calcite and dolomite veins and vug fill

Sand ‘dikes’ in fault/veins; hydrothermal karst in marble basement; sandstone fill in pipe and tunnel networks; sandstone+marble breccia;

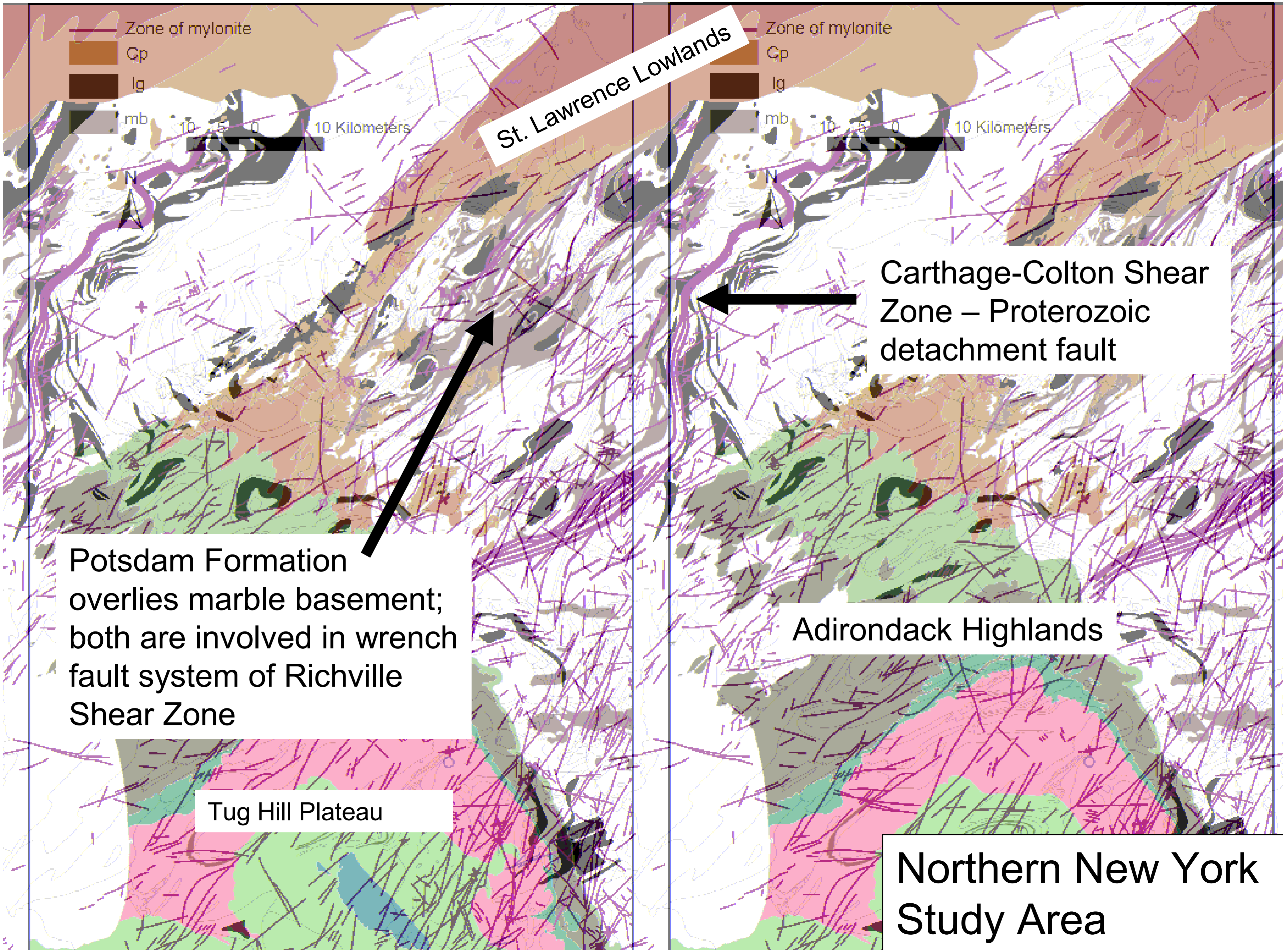
Widespread alteration of silicate minerals in marble and associated gneisses; Fe-chlorite and illite replace Al-silicate minerals

Hematite and siderite common; hematite ‘staining’ of marble on margins of dolomitized areas; deposits of hematite ore spatially associated with dolomitized marbles in Adirondack Lowlands

Other minor (but often spectacular) hydrothermal minerals: quartz, barite, fluorite, Fe-chlorite, celestine, strontianite, apatite, xenotime, monazite, millerite, magnetite, tourmaline

Minor development of MVT mineralogy – sphalerite, galena, pyrite

Northern New York Study Area



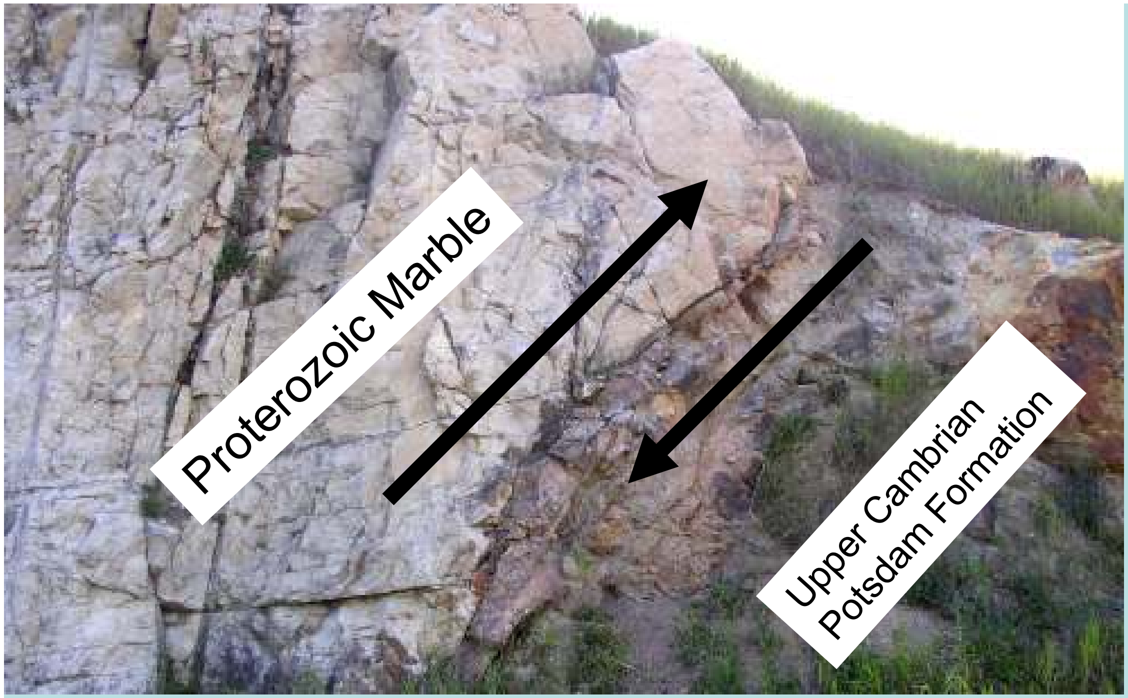
St. Lawrence Lowlands

Potsdam Formation overlies marble basement; both are involved in wrench fault system of Richville Shear Zone

Tug Hill Plateau

Carthage-Colton Shear Zone – Proterozoic detachment fault

Adirondack Highlands



Above: Reverse fault places marble over Upper Cambrian Potsdam Formation in Richville Shear Zone wrench fault system.

Right: Hematite-stained fault gouge in sandstone; note sheared quartzite clast.

Right: Upper Cambrian Potsdam Formation sandstone fills hydrothermal karst depression in marble.

Left: Sandstone partially fills large hydrothermal karst void in marble. Note crystalline calcite and dolomite on top of sandstone surface.

Void is hydrothermal solution channel in marble.

Left: Grey sandstone fills vertical fracture in "Popple Hill" basement Gneiss.

Sandstone contains fragments of phosphatic lingulid brachiopods, indicating derivation from overlying lower Paleozoic units.

Right: Sandstone-filled open fracture in gneiss. Sandstone is cemented by dolomite.

Natural fractures propped open by sand introduced by rapid fluid flow. A good model for hydrofrac systems?

Left: Dolomitized zone in Proterozoic marble with central sand-filled fracture.

Sand consists of rounded quartz grains.

Right: Near-vertical sand-filled fracture in dolomitized marble

Left: Dolomitization front extending from fracture. Note compositional banding in undolomitized marble.

Right: Dolomite, calcite and quartz in voids in dolomitized marble. Fabric suggests collapse brecciation related to solution and dolomitization.

Left: 85% of dolo-fractures measured in the northern New York study area are near vertical ($90^{o}\pm10^{o}$). However a number of horizontal fractures with dolomitized margins have been documented.

Some fracturing occurred at relatively shallow depths.

Right: Many dolomitized fractures show evidence of multiple events of cracking and fluid migration.

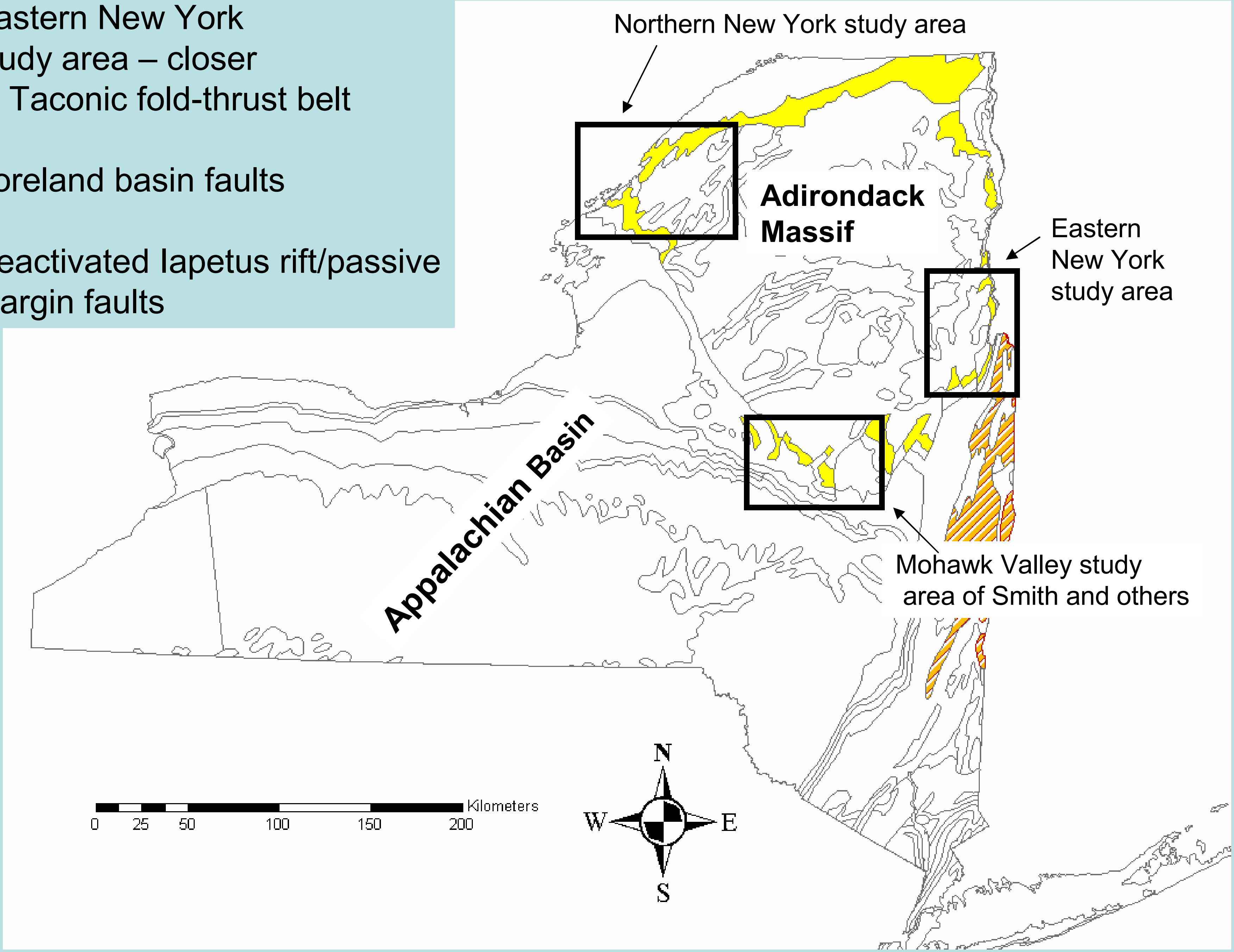
Large voids have multi-layer, repetitive, void-fill sequences.

Repetitive seismic-pumping events.

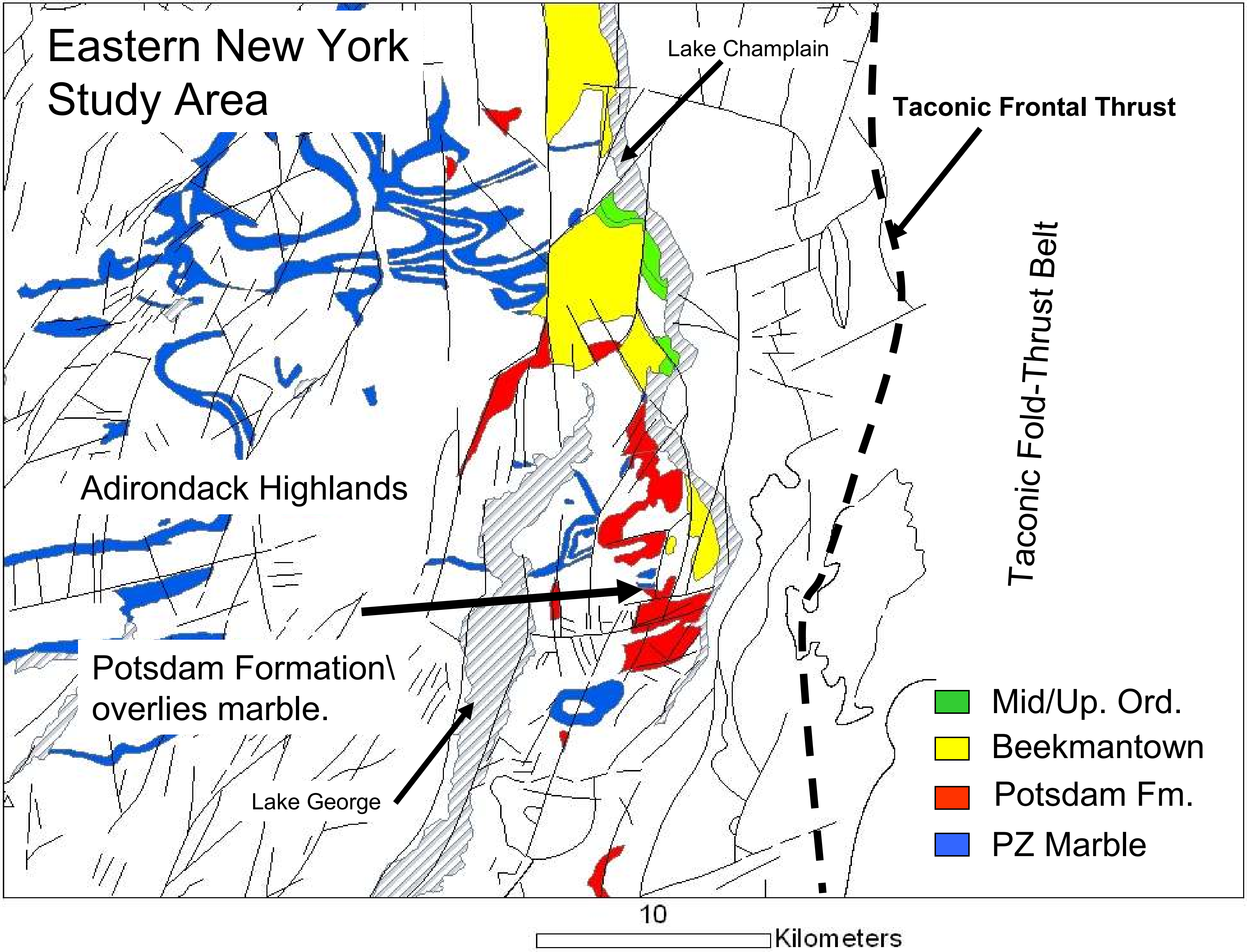
Eastern New York study area – closer to Taconic fold-thrust belt

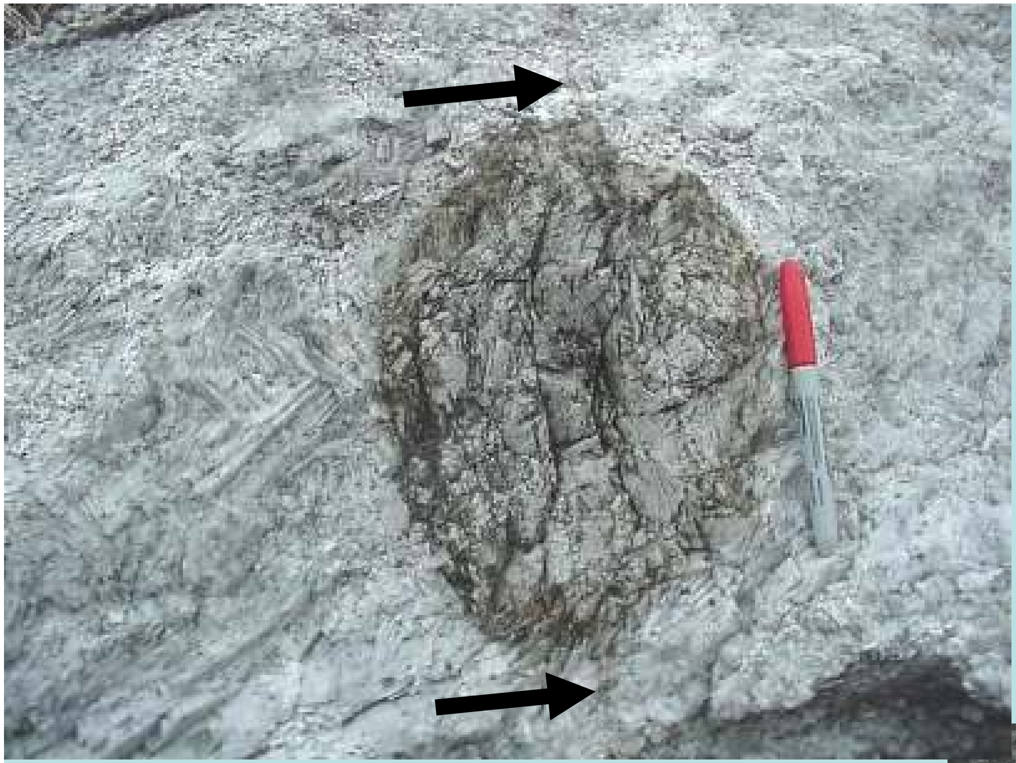
Foreland basin faults

Reactivated Iapetus rift/passive margin faults



Eastern New York Study Area



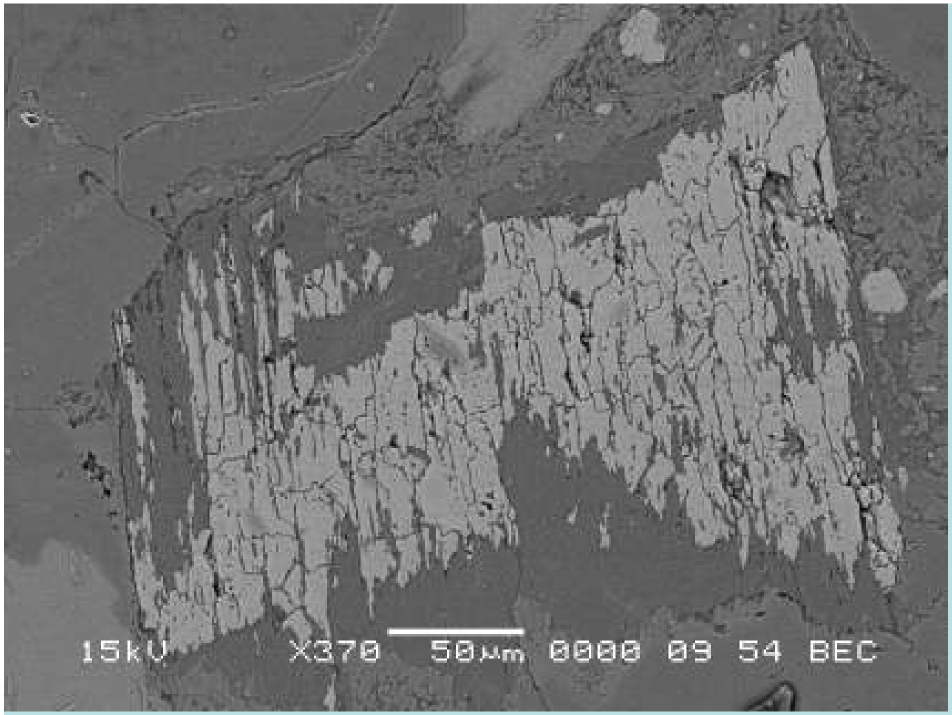


Left: Dolomite in marble. Note fracture (arrows) extending from top and bottom of dolomite mass; excellent pseudomorphing of coarsely crystalline calcite crystals by dolomite; porosity in dolomite.

Right: Dolomite surrounds remnant area of marble. Note Fe-rich dolomite at margin of marble; porosity in dolomite. mm-scale saddle dolomite and doubly-terminated quartz crystals in vugs in dolomite.

Left: Contact of dolomitized and undolomitized marble. Graphite crystals in dolomitized marble are unaltered; diopside and phlogopite are altered to chlorite/chert

Right: Dolomite bed in upper Potsdam Formation. Vugs contain saddle dolomite, quartz, and sulfides.

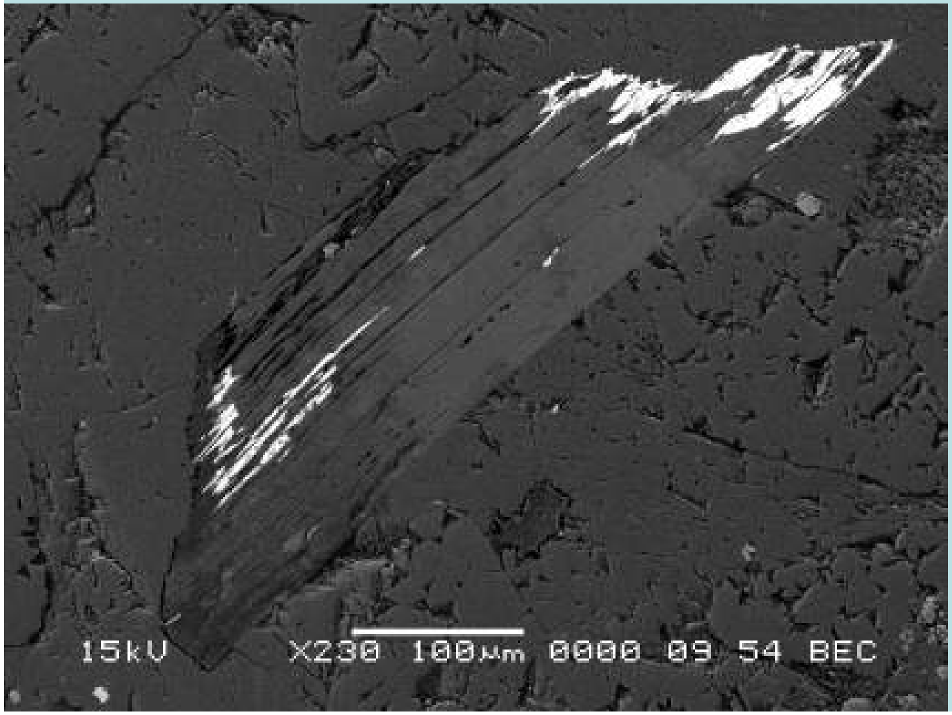


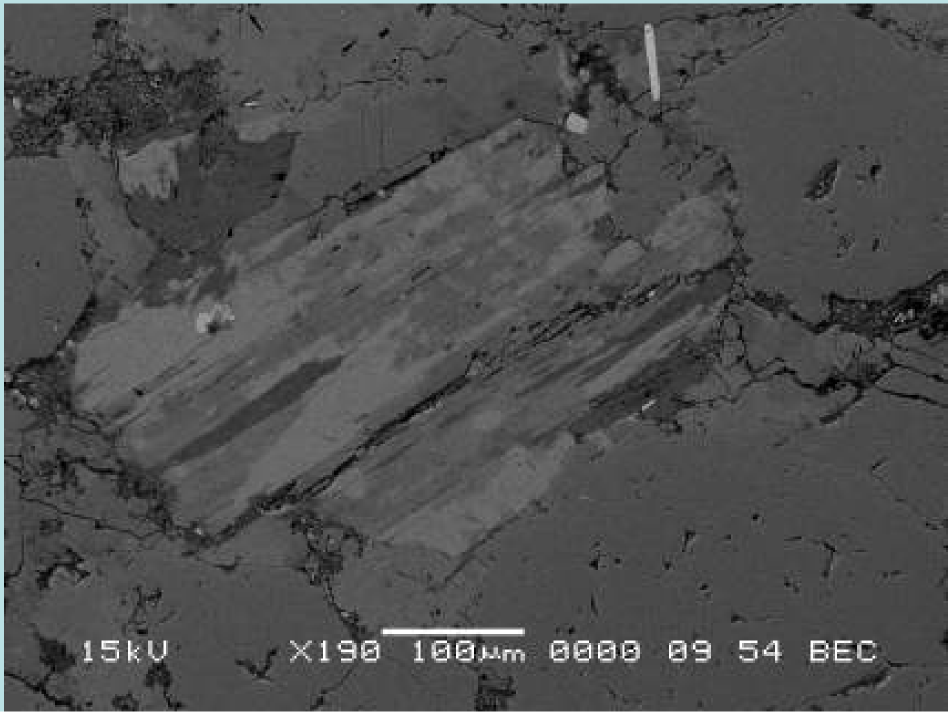
Phlogopite in dolomitized marble.

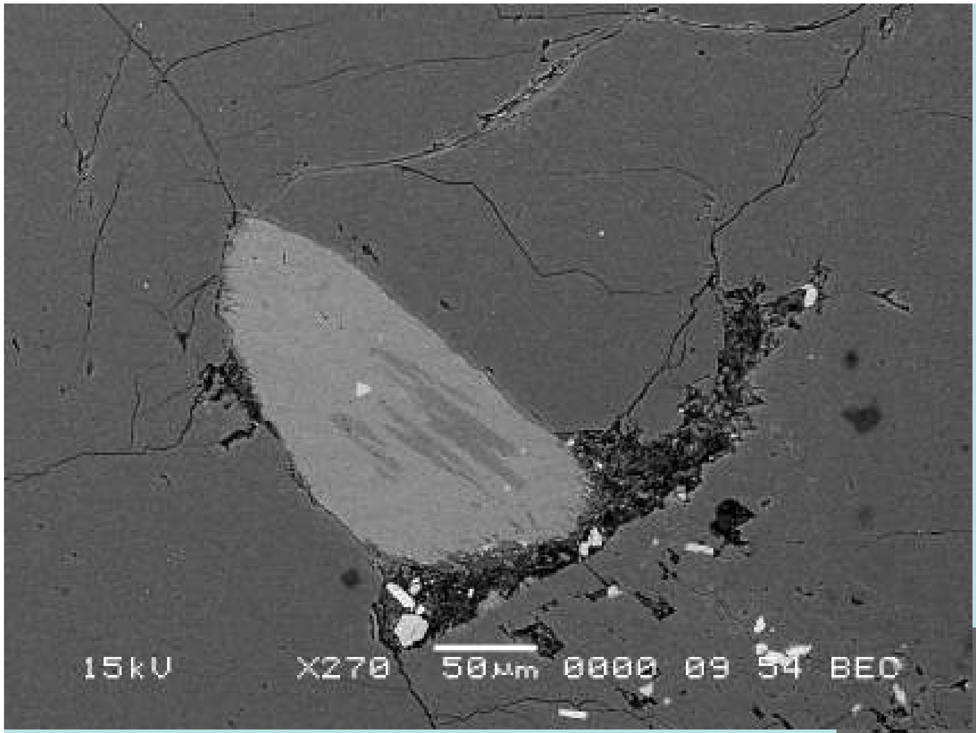
Left – replaced by fluorite (bright) and calcite.

Below left – partial replacement by barite and illite.

Below – replaced by illite and Fe-chlorite

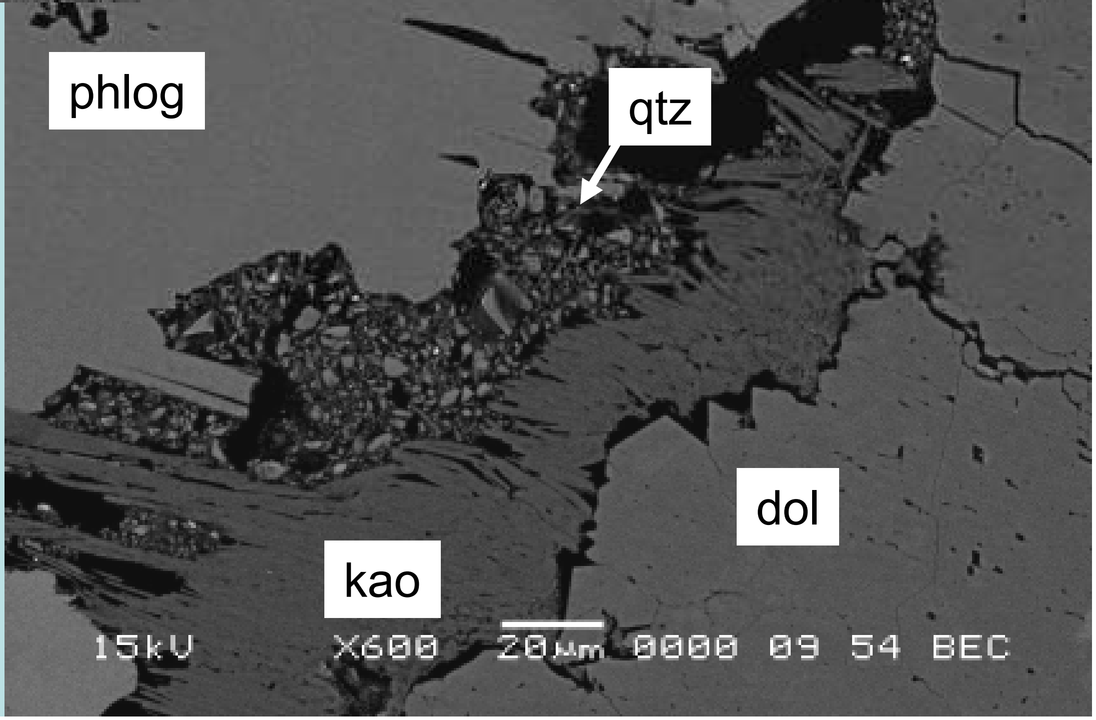




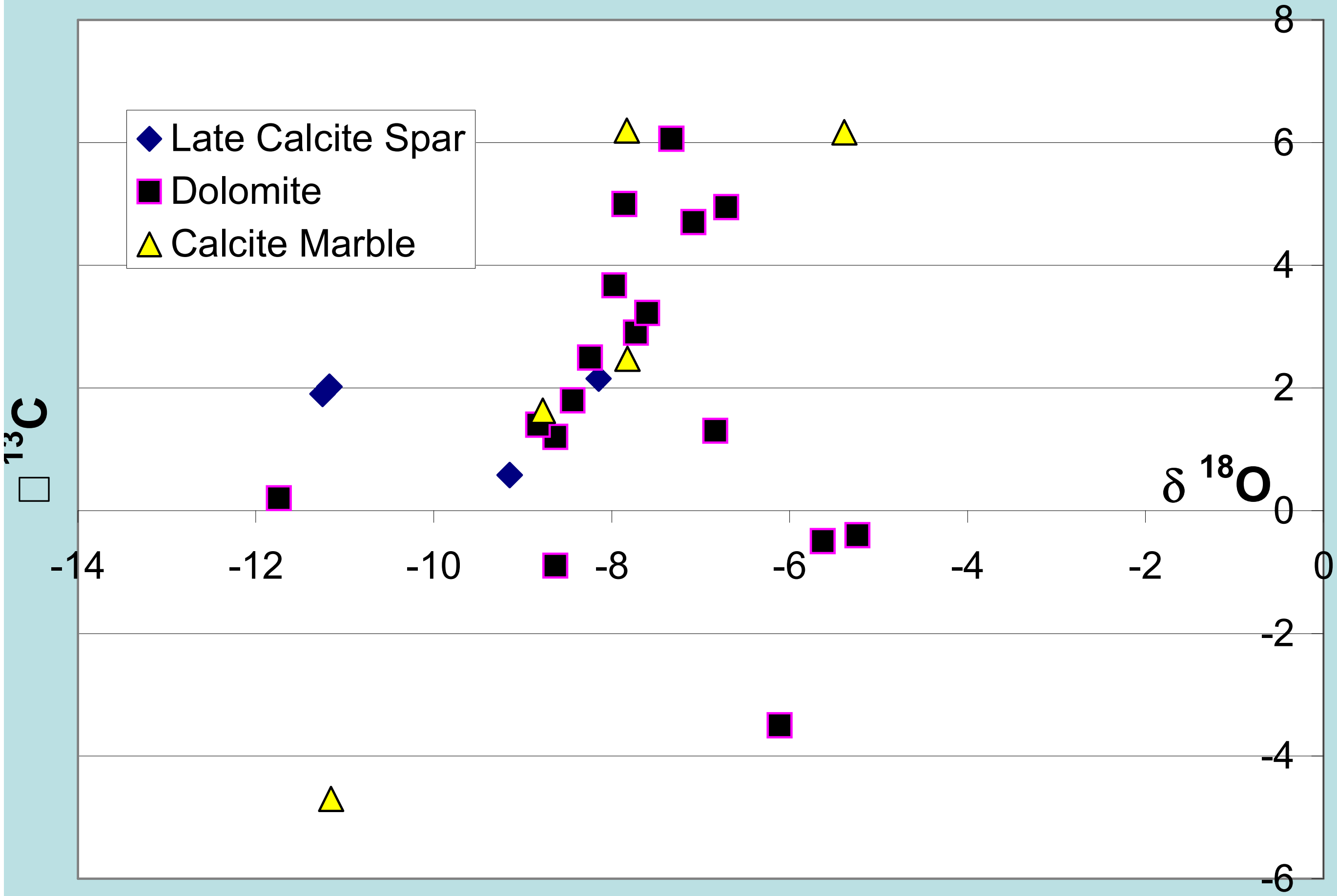


Alteration of phlogopite (and diopside, tremolite, garnet, actinolite) in dolomitized marble –

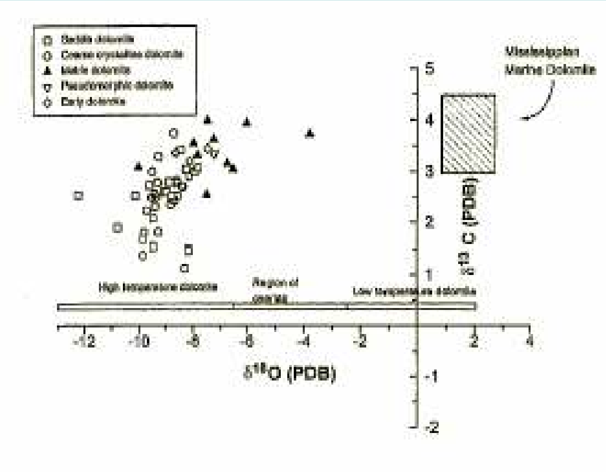
a source of Mg2+ for dolomitization



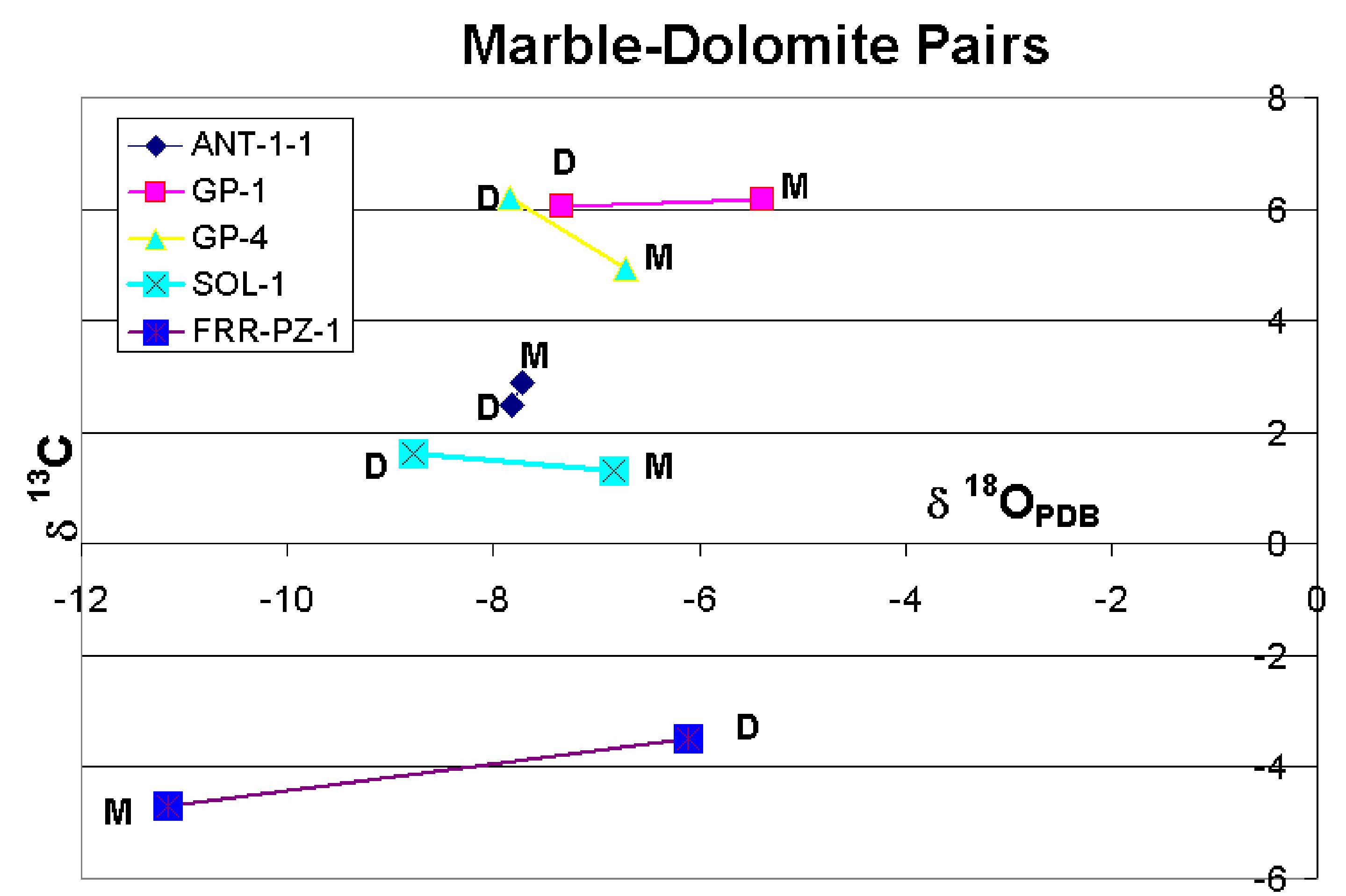
phlog >> qtz + kaolinite + Ca^{2+} + **Mg^{2+}**



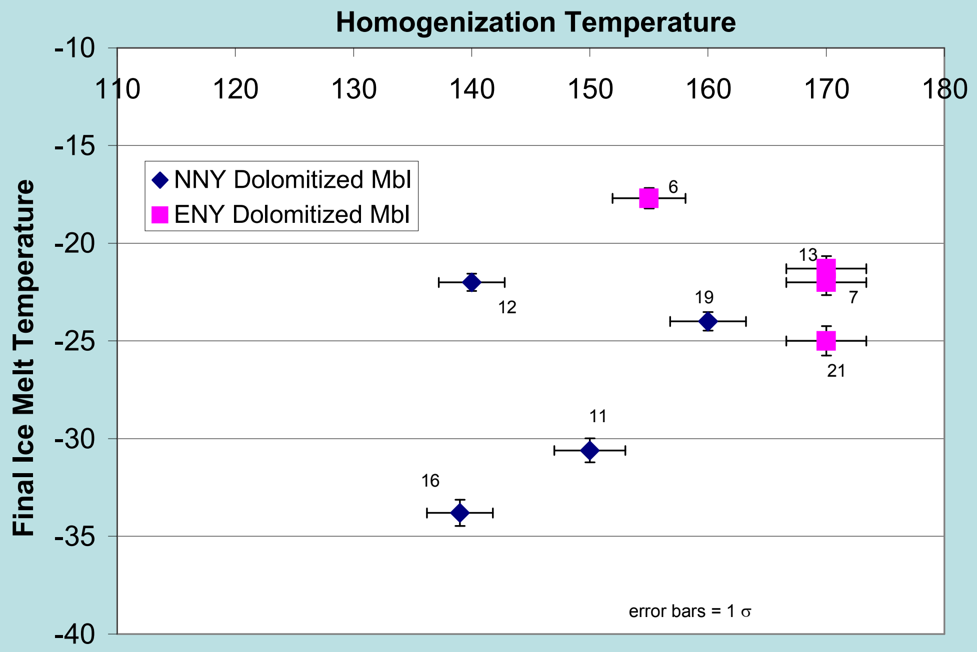
Stable isotopes of dolomitized marble, sparry dolomite and late calcite spar resemble the isotopic signature of other HTD systems.



Upper Debolt Formation, BC
White and Al-Asam, 1997



In general, there are relatively small differences in stable isotope signatures of dolomite vs. host marble. This suggests that the system was rock-buffered, thus stable isotope signatures are controlled by host rock, not fluid.

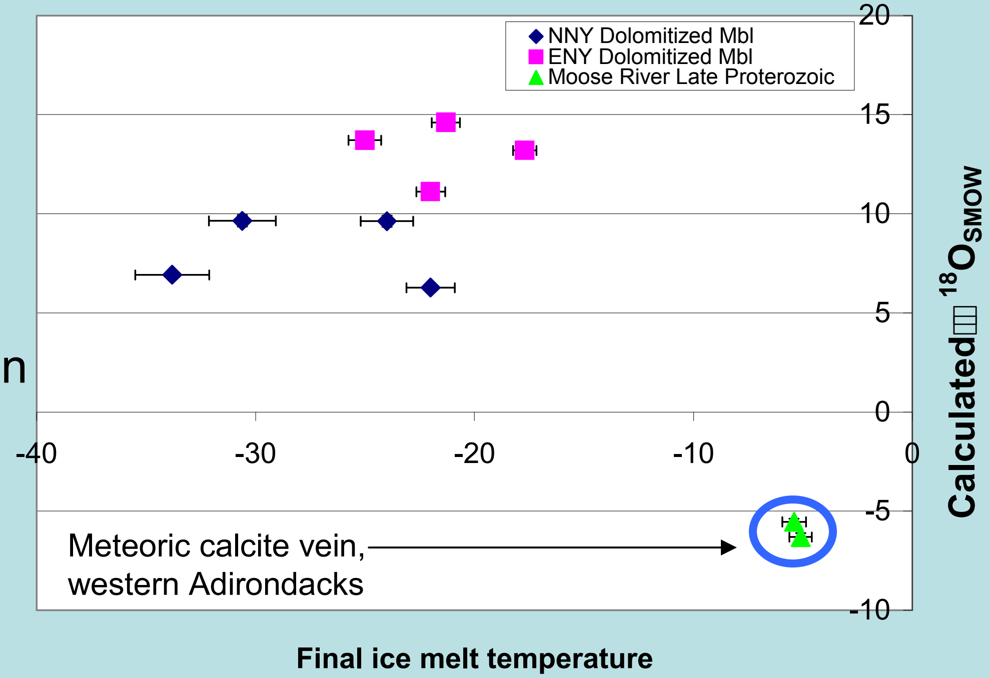


2-phase aqueous inclusions;
methane inclusions occur
in associated quartz

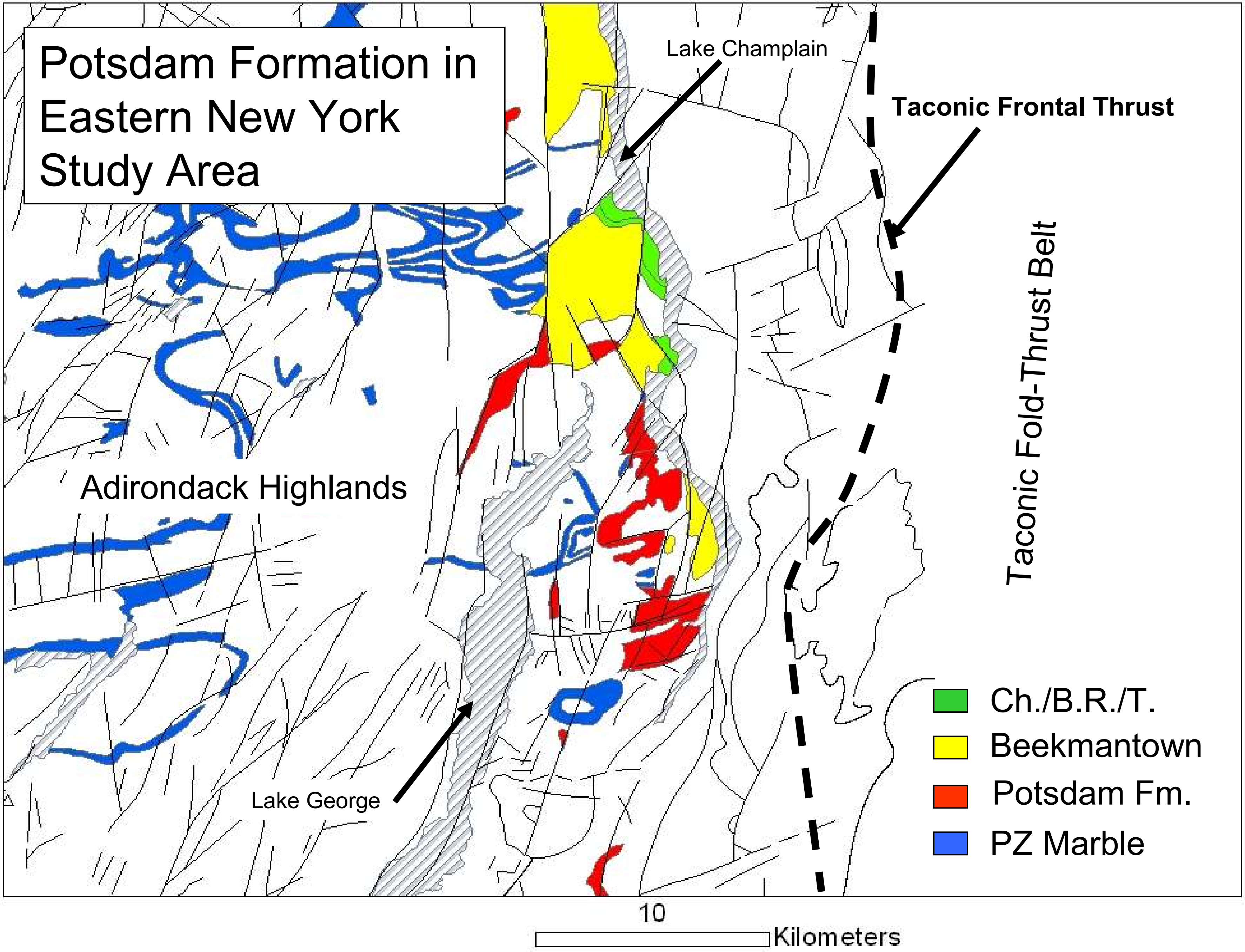
Calculated $\delta^{18}O$ dolomitizing fluid

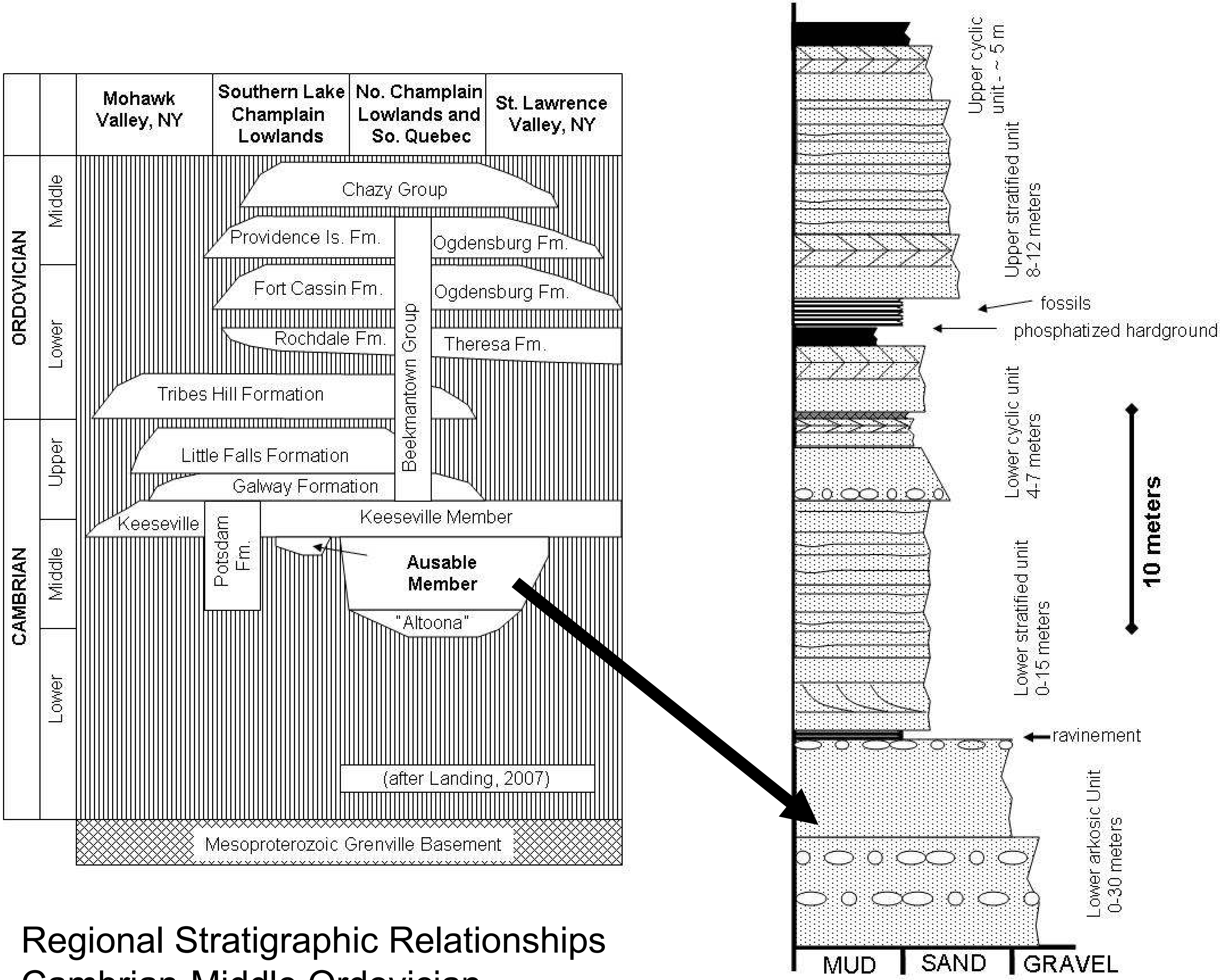
Fluid inclusions indicate minimum temperatures of dolomitization of ~140-170^{o}C. Fluids were Na-Ca-Cl brines with salinity ~20% NaCl equivalent.

Fluids were isotopically ‘evolved” suggesting extensive water-rock interaction (low water-rock ratio). No evidence that meteoric or ‘mixed’ fluids were involved in dolomitization.

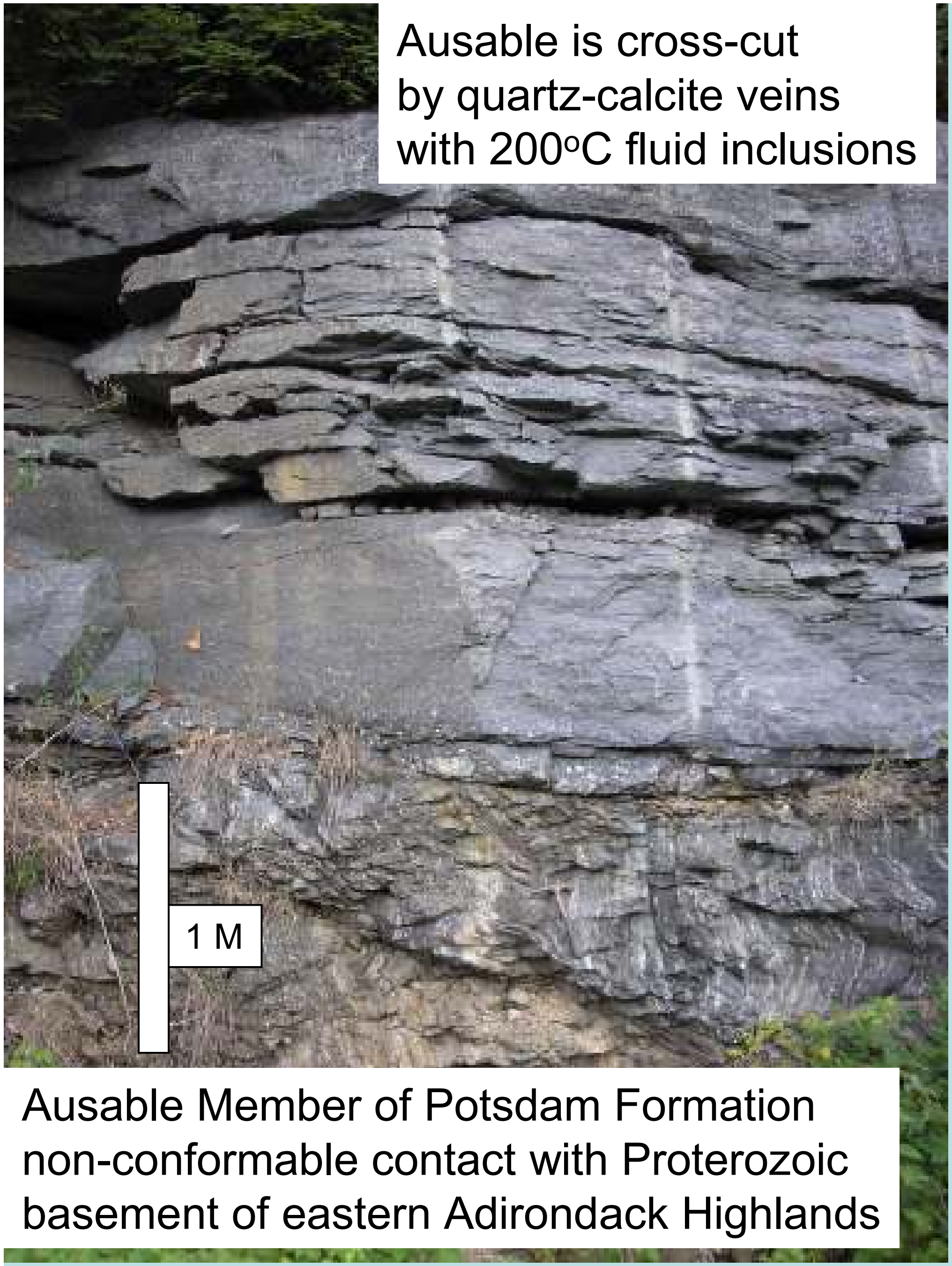


Potsdam Formation in Eastern New York Study Area



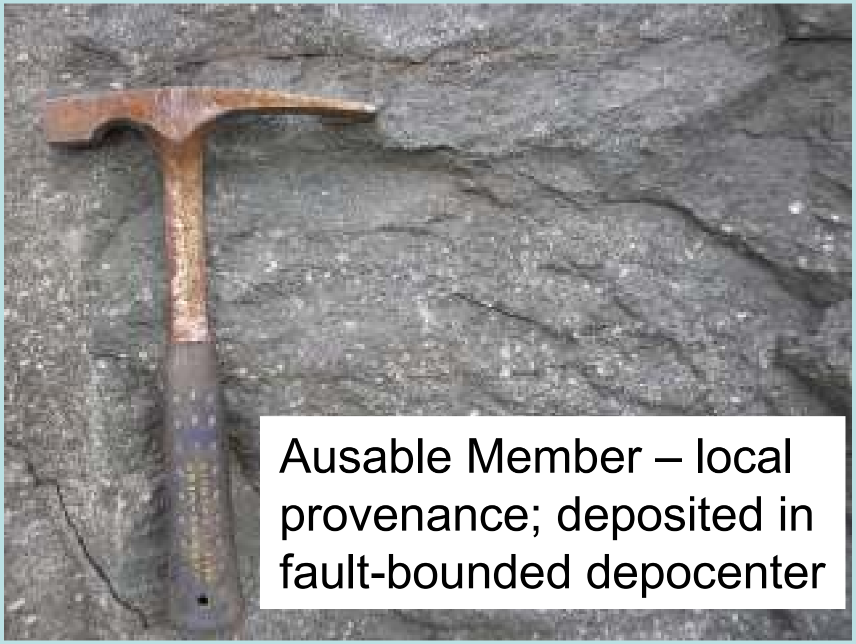


Regional Stratigraphic Relationships Cambrian-Middle Ordovician



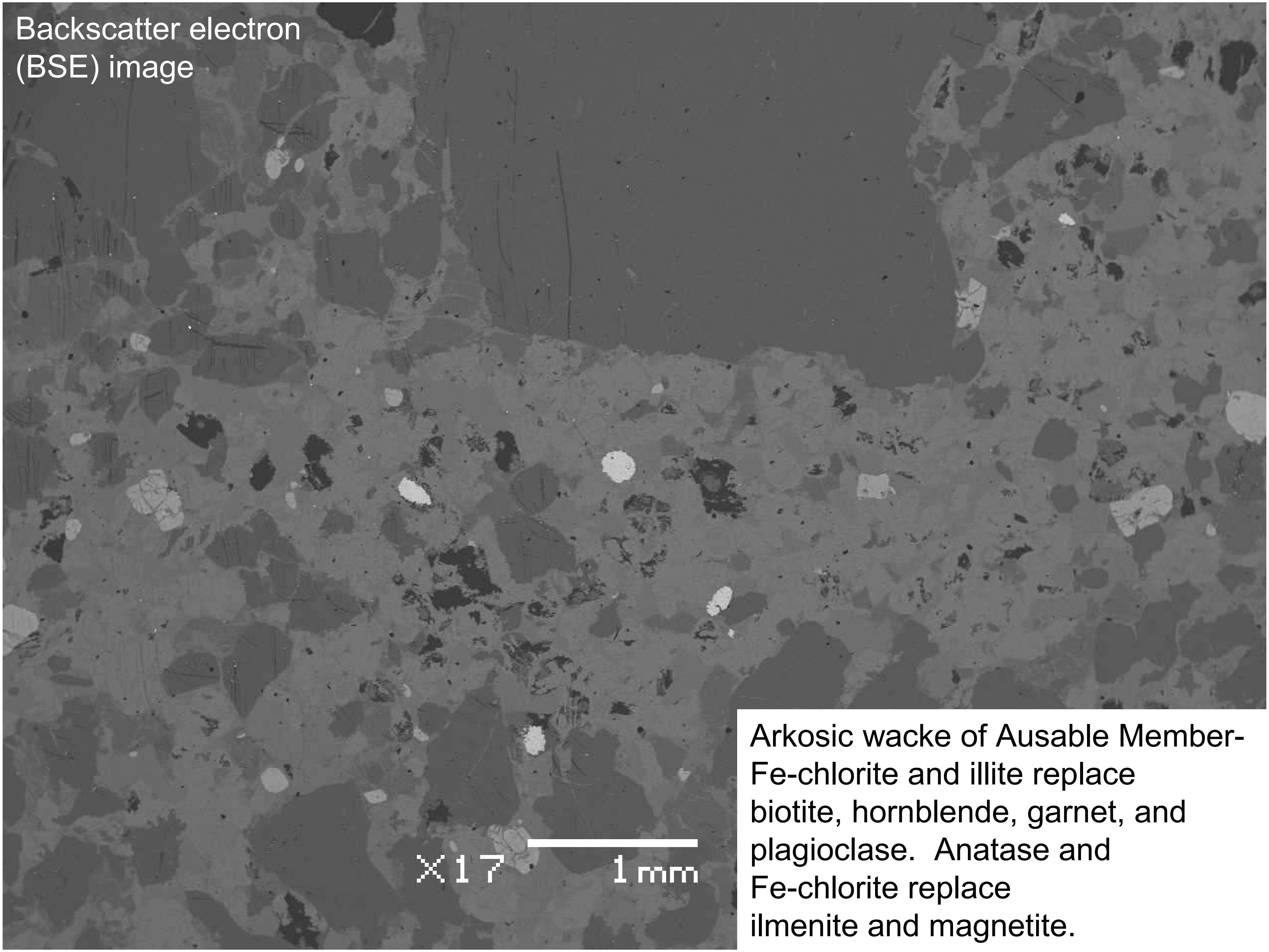
Ausable is cross-cut by quartz-calcite veins with 200^{o}C fluid inclusions

Ausable Member of Potsdam Formation non-conformable contact with Proterozoic basement of eastern Adirondack Highlands



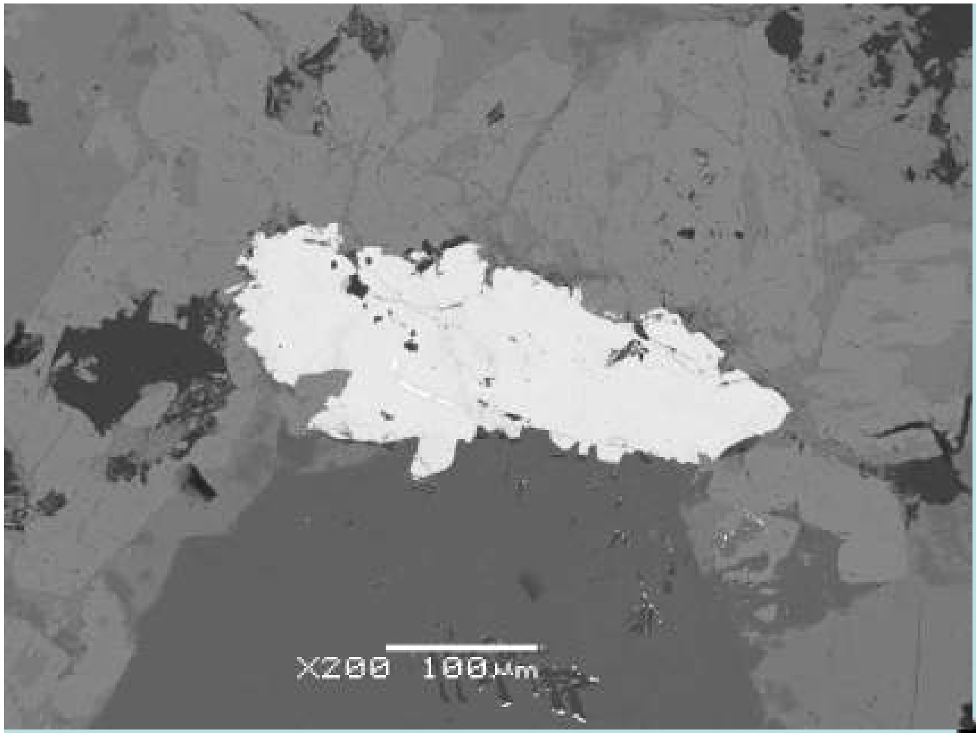
Ausable Member – local provenance; deposited in fault-bounded depocenter

Heavy mineral lamina contain abundant zircon and monazite; very hot gamma source



Arkosic wacke of Ausable Member-
Fe-chlorite and illite replace
biotite, hornblende, garnet, and
plagioclase. Anatase and
Fe-chlorite replace
ilmenite and magnetite.

REE phosphate minerals as authigenic mineral phases in Potsdam Formation

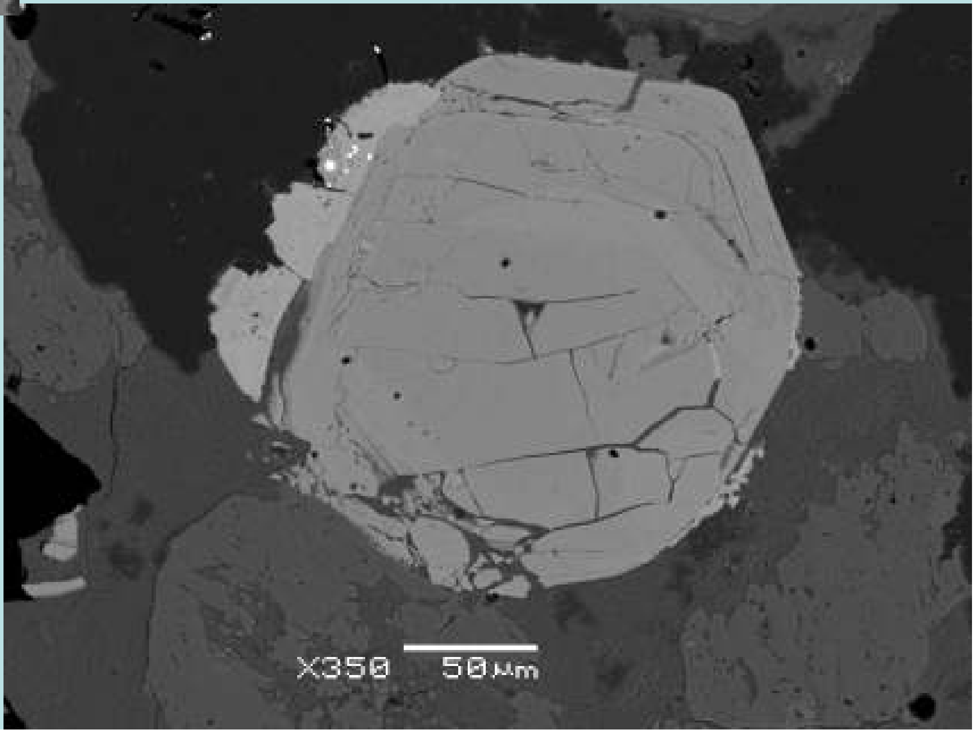


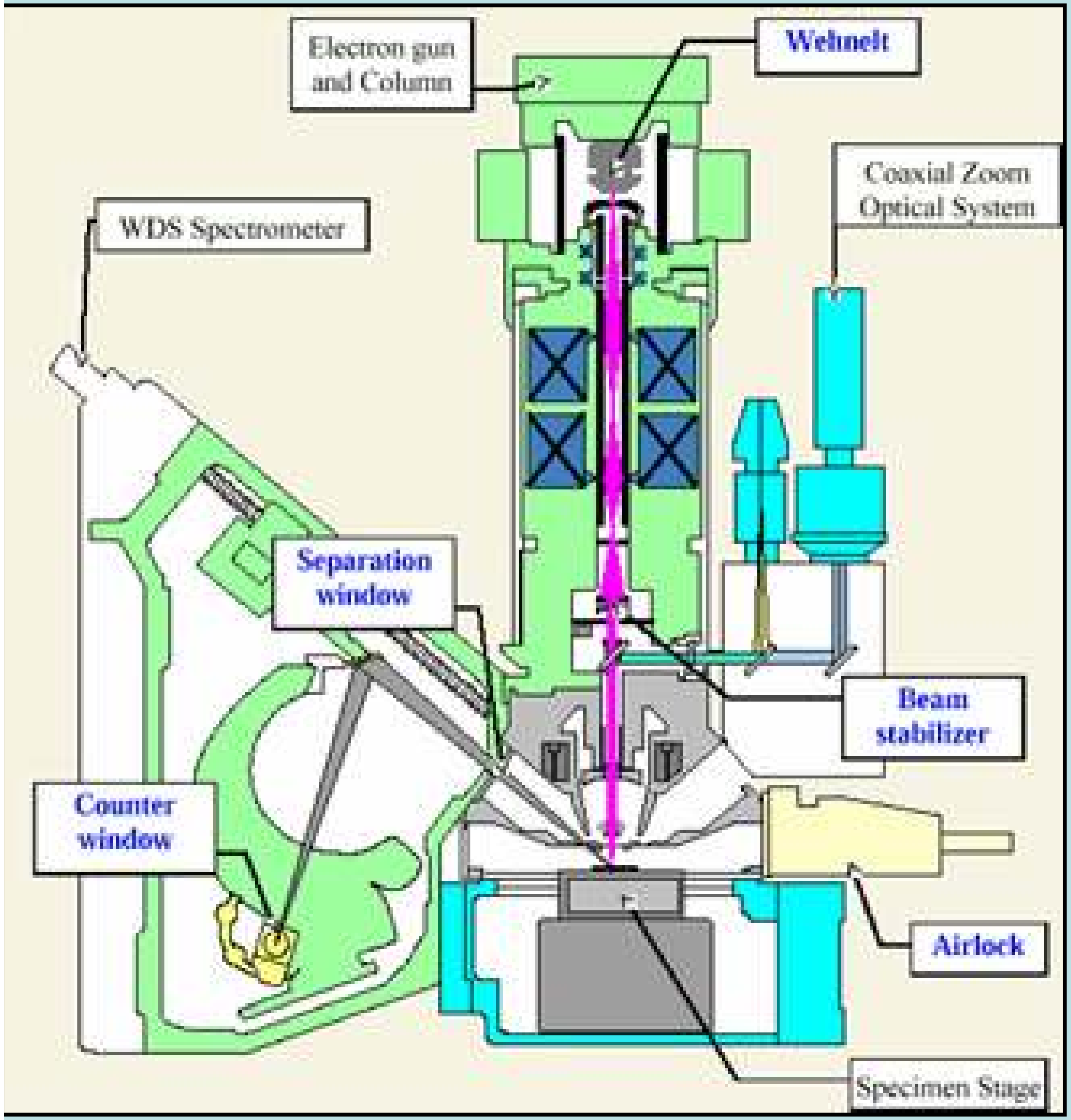
Above: Detrital monazite with authigenic overgrowth

REE from alteration of garnet, ilmenite, allanite, apatite during burial.

Can we use authigenic REE minerals to date hydrothermal fluid alteration events?

Below: Authigenic xenotime on detrital zircon





Chemical age dating of monazite and xenotime uses a specially-designed electron microprobe (Cameca “Ultrachron’) to analyze U, Pb, Th, REE and other trace elements with very high precision and accuracy.

Low U concentrations require special analytical approaches to maximize Th counts.

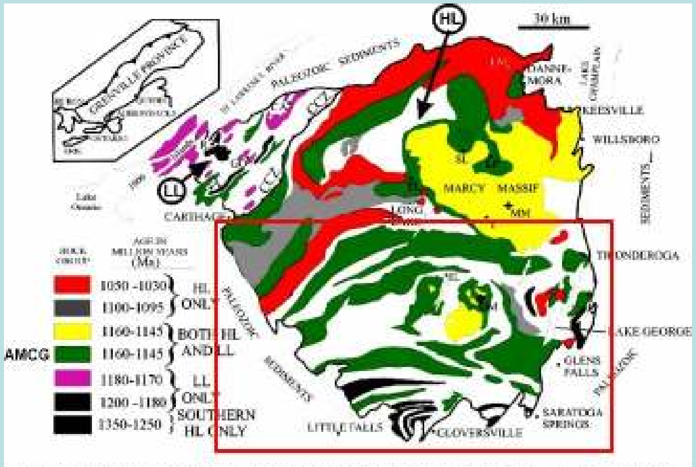
Elemental maps of polished grains provide spatial framework for definition of chemical domains; relationships among domains define relative ages of mineral growth phases.

A new Microprobe and new methods for Trace-elements

“Rosetta Stone” approach

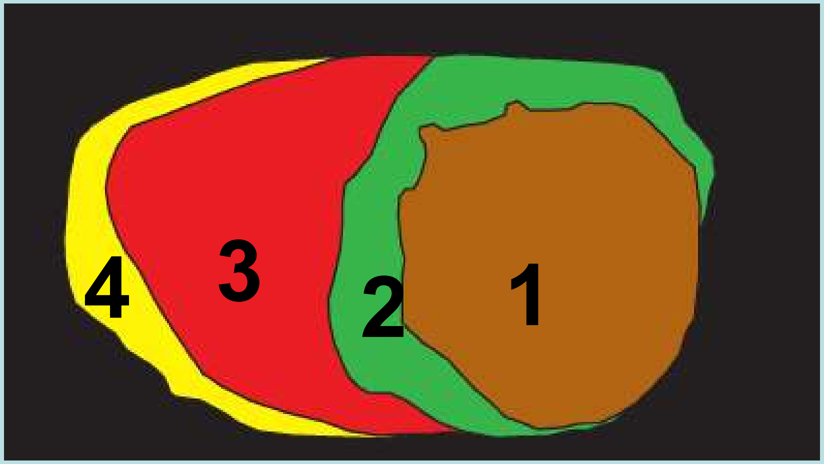
1. Determine the general spectrum of compositions (and dates).

2. Find “Rosetta” grains that link monazite generations to reactions or deformation.

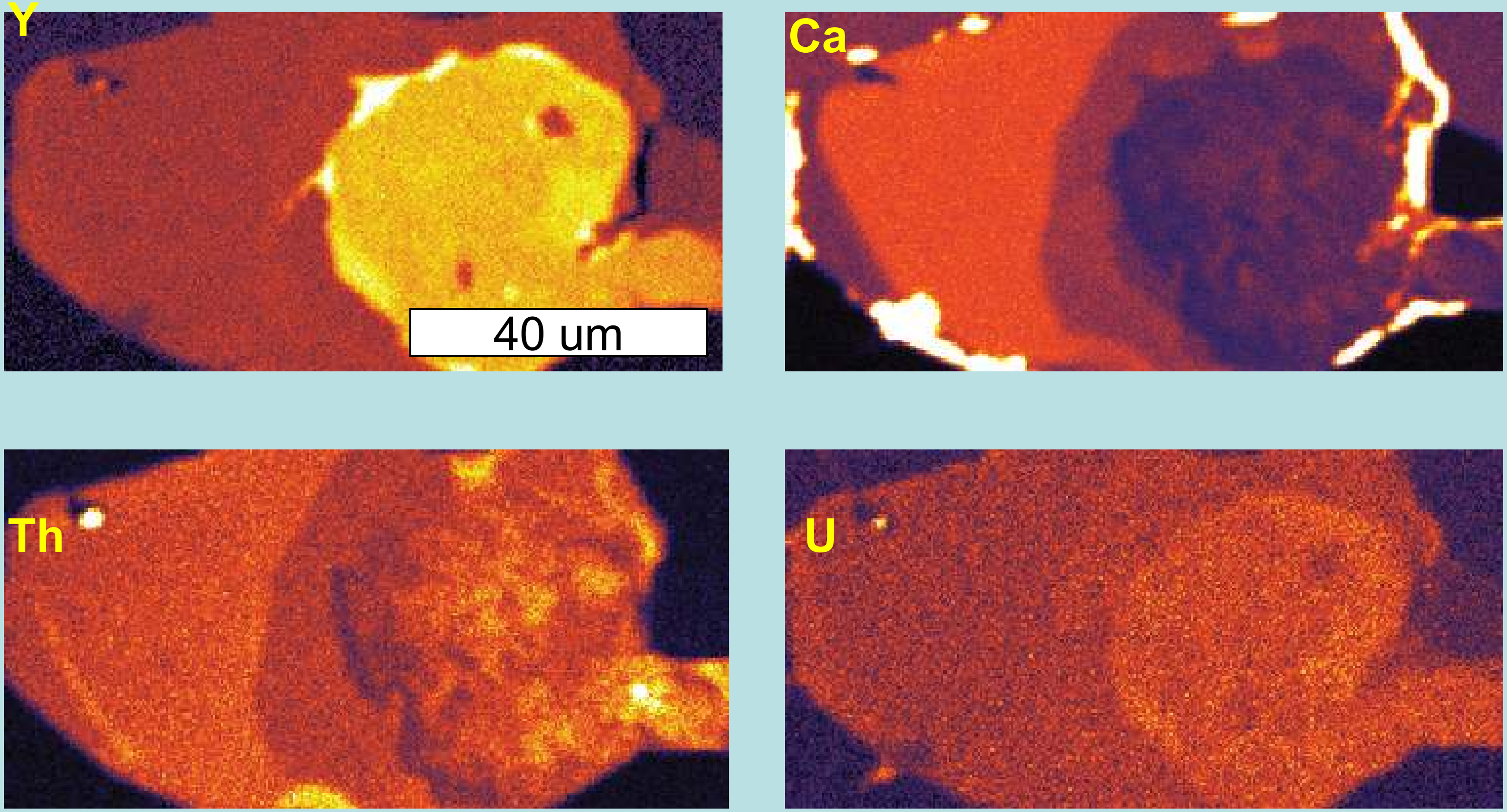


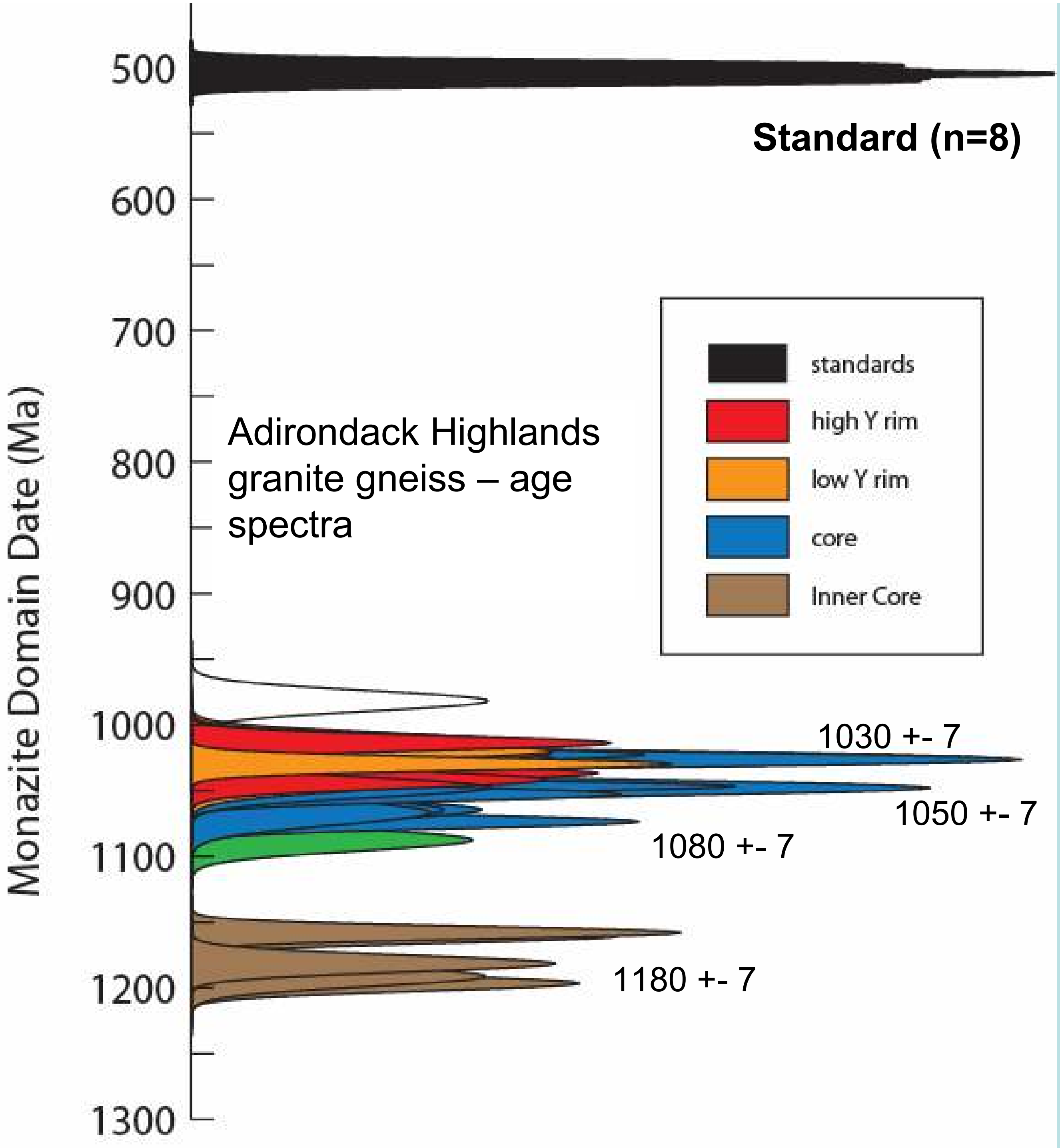
SCHEMATIC GEOLOGICAL- GEOCHRONOLOGICAL MAP O

II: OUTLINE-SOUTHERN & CENTRAL ADIRON



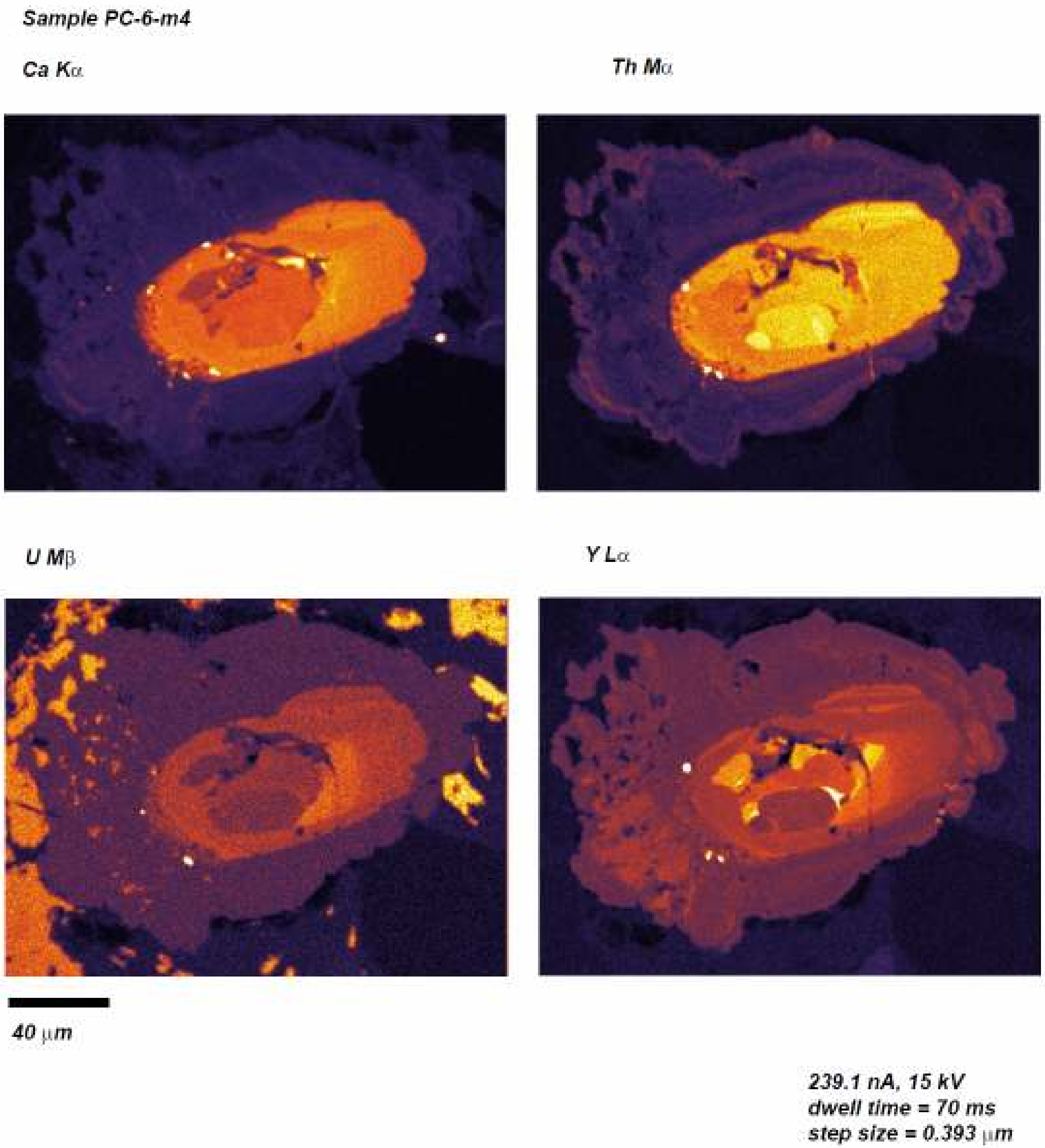
Monazite from granitic gneiss - “Grenville” Basement



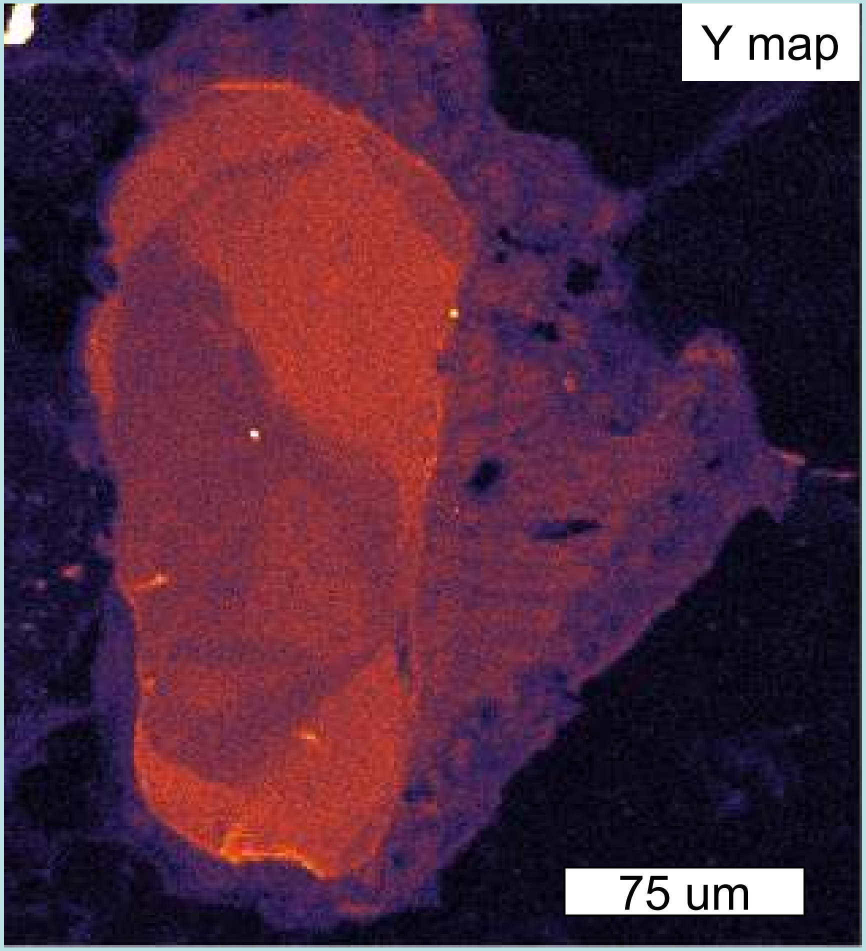


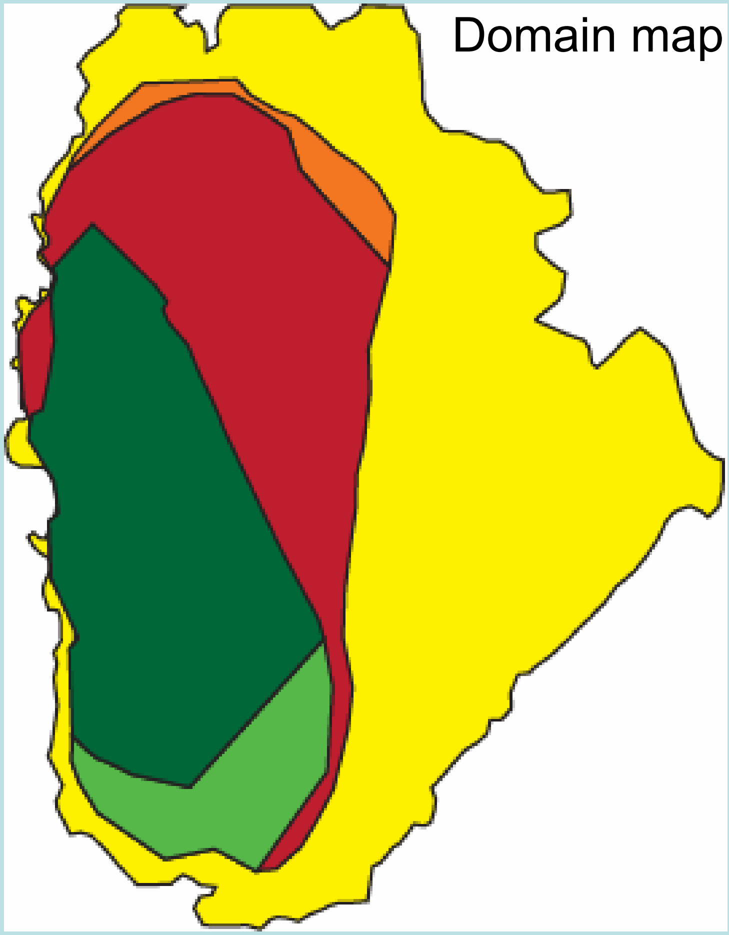
Adirondack Highlands granite gneiss – age spectra

Ca, Th, U and Y elemental maps of detrital monazite with authigenic overgrowth – Ausable Member of Potsdam Formation.

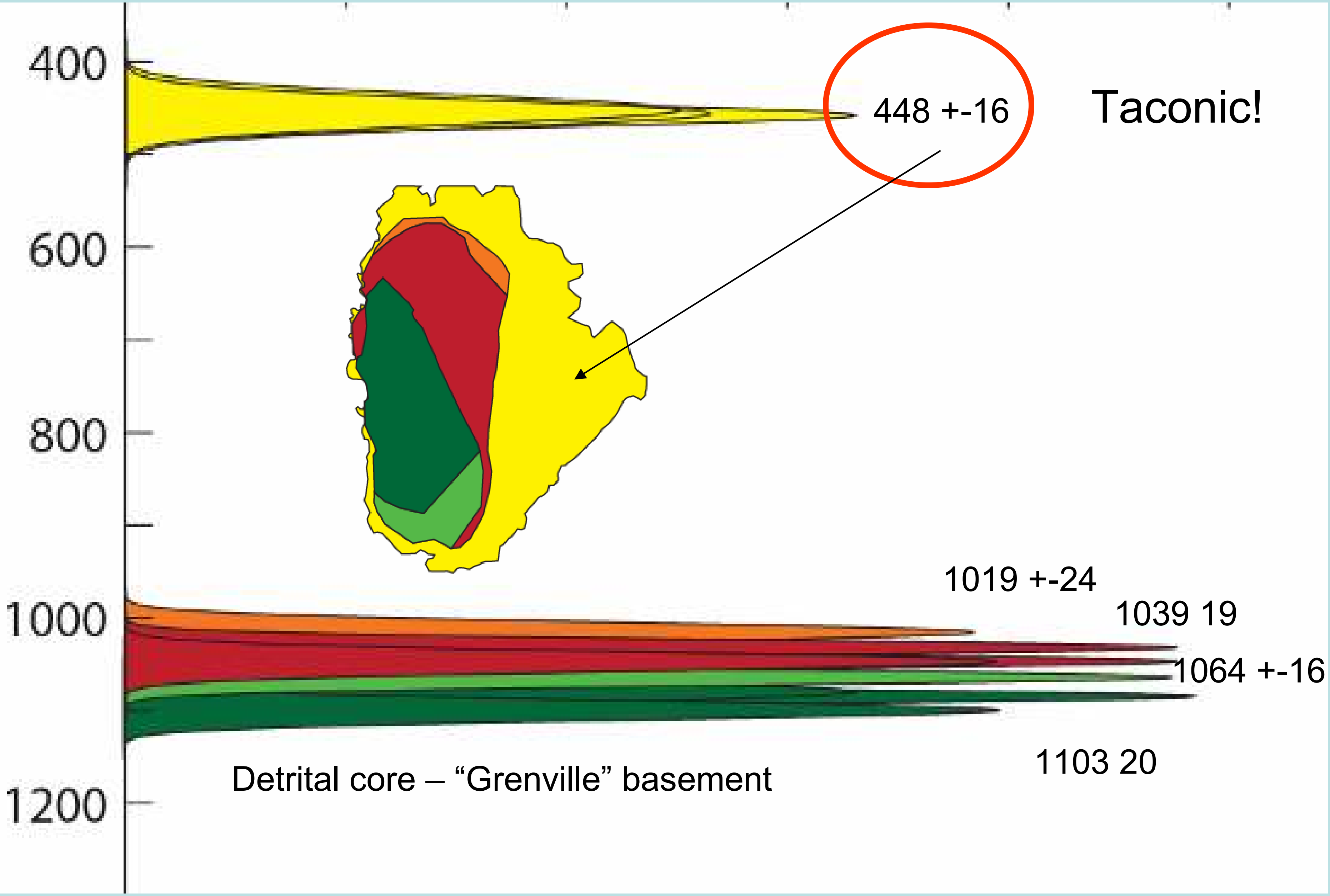


PC6-m1





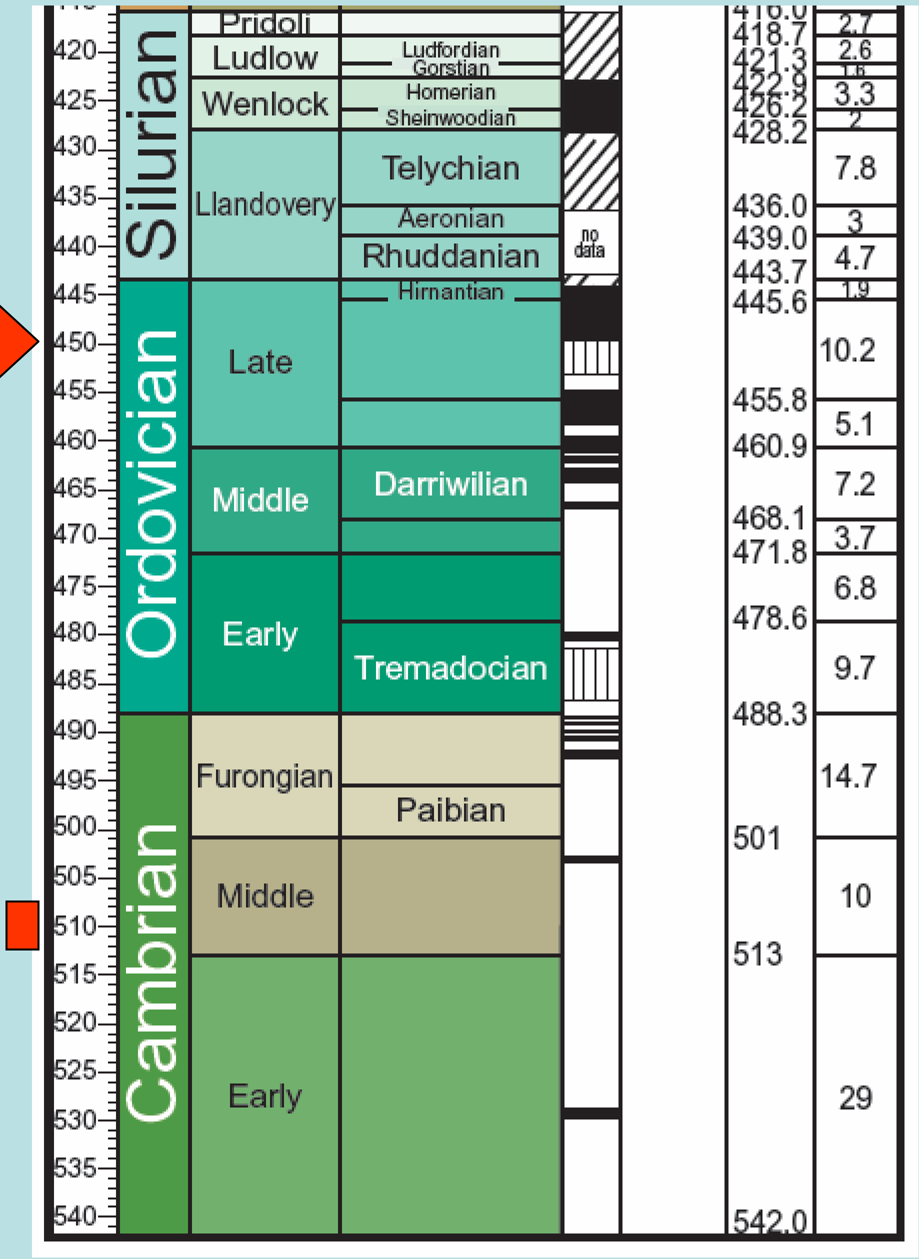
Ausable Member of Potsdam Formation near Ticonderoga, NY



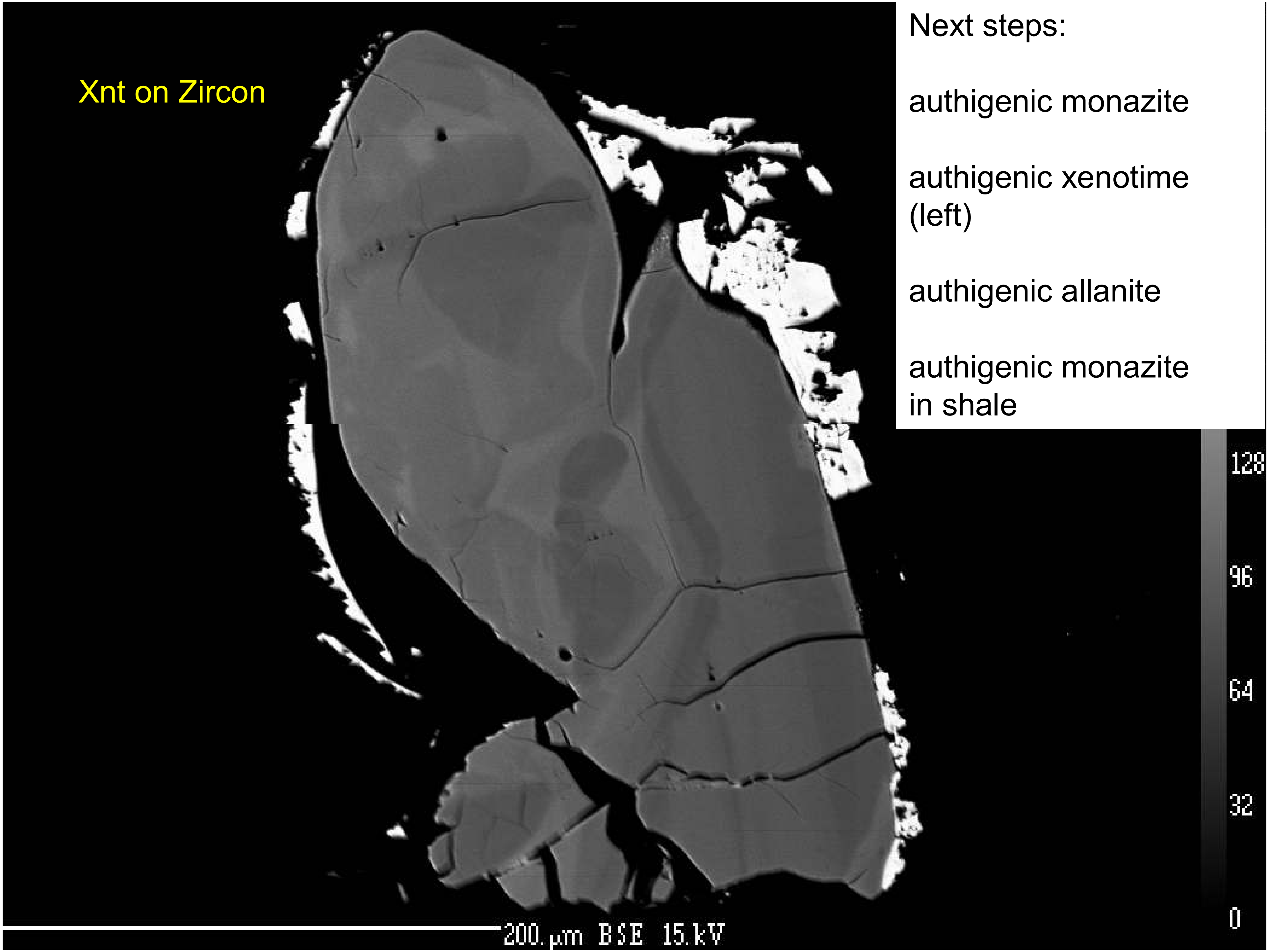
Taconic!

Detrital core – “Grenville” basement

Growth of authigenic monazite in Potsdam Formation



Likely age of deposition of Ausable Mbr



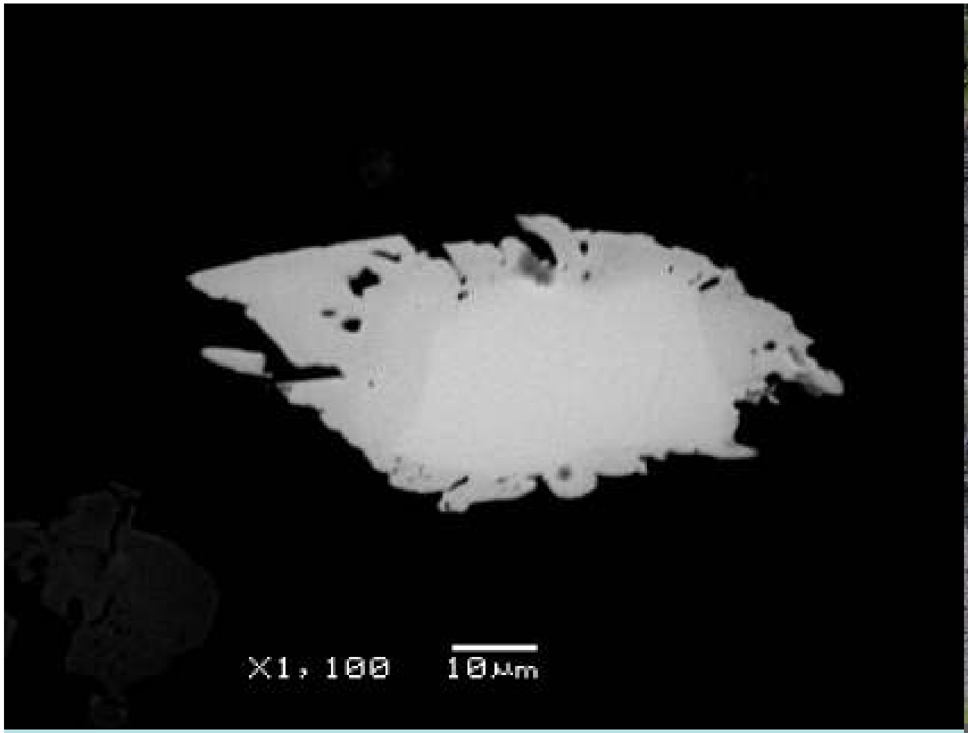
Next steps:

authigenic monazite

authigenic xenotime (left)

authigenic allanite

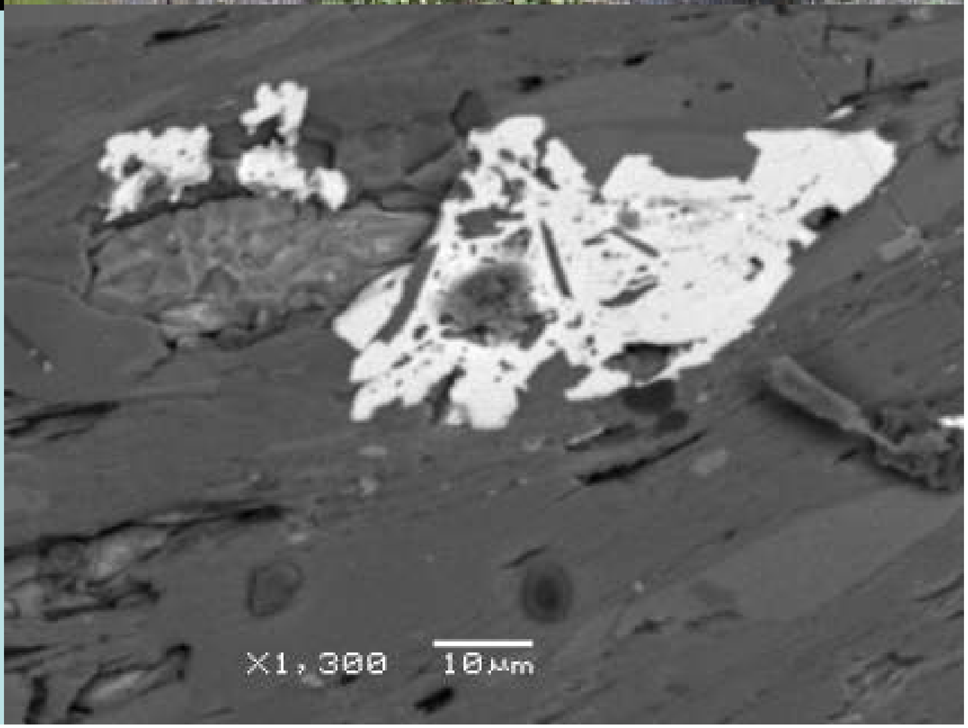
authigenic monazite in shale




Utica Shale at Northwestern, NY

Above: Authigenic monazite overgrowth on detrital grain; calcareous mudstone - Utica Shale.

Right: Authigenic monazite, Taconic Slate near Granville, NY



Colgate UNIVERSITY

Seismic pumping—a hydrothermal fluid transport mechanism

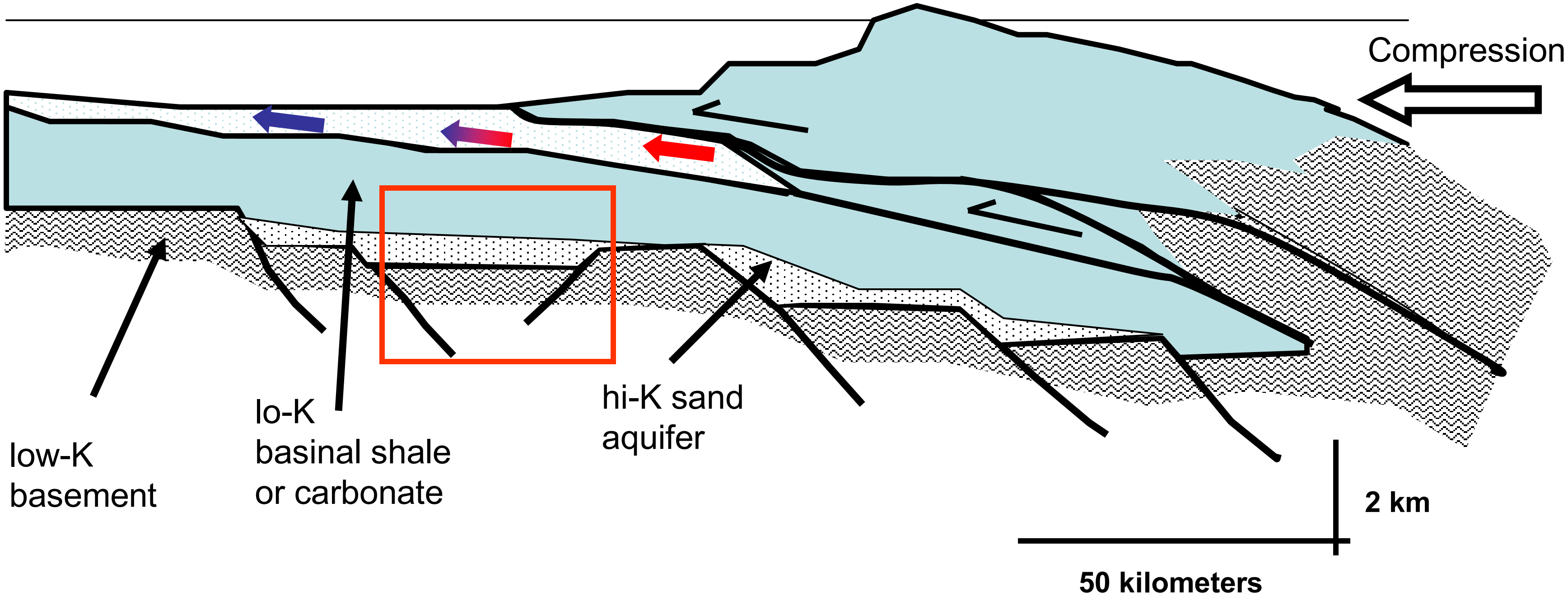
R. H. SIBSON, J. Mc. M. MOORE & A. H. RANKIN

A consequence of the dilatancy/fluid-diffusion mechanism for shallow earthquakes is that considerable volumes of fluid are rapidly redistributed in the crust following seismic faulting. This is borne out by the outpourings of warm groundwater which have been observed along fault traces following some moderate (M5–M7) earthquakes. The quantities of fluid involved are such that significant hydrothermal mineralisation may result from each seismically induced fluid pulse, and the mechanism provides an explanation for the textures of hydrothermal vein deposits associated with ancient faults, which almost invariably indicate that mineralisation was episodic

Journal of the Geological Society; 1975; v. 131; issue.6; p. 653-659;

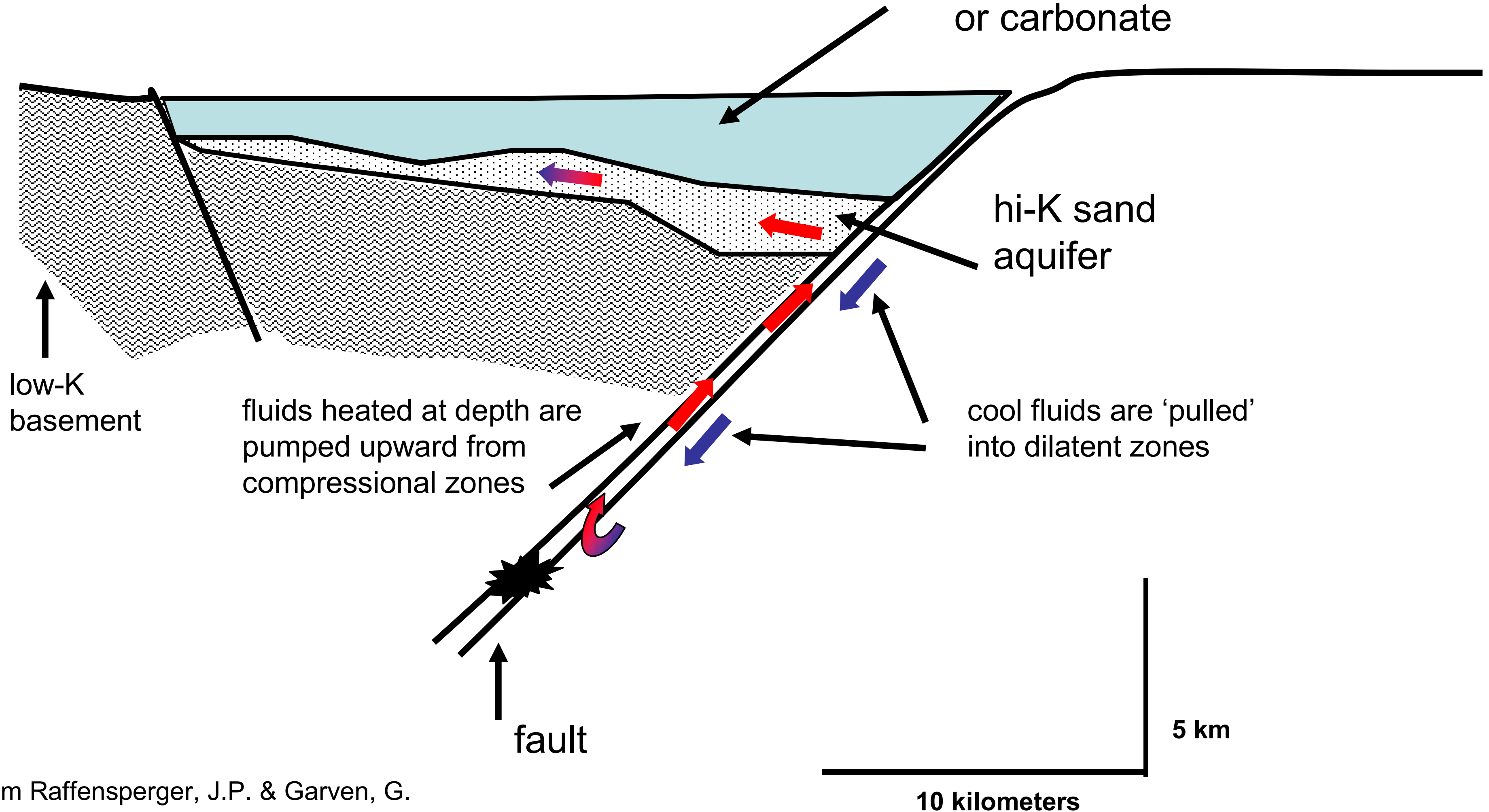
THRUST TERRANE

Maximum flow rate 0.1-1 m/yr



after Raffensperger, J.P. & Garven, G.
SEG Pre-conference workshop A, SEG Conf. On Carbonate-Hosted Lead-Zinc Deposits, St. Louis, 2 June 1995

Seismic Pumping – flow rates of 100’s of meters/day; 10^6 -10^7 m^3 per event



lo-K
basinal shale
or carbonate

hi-K sand
aquifer

low-K
basement

fluids heated at depth are
pumped upward from
compressional zones

cool fluids are ‘pulled’
into dilatent zones

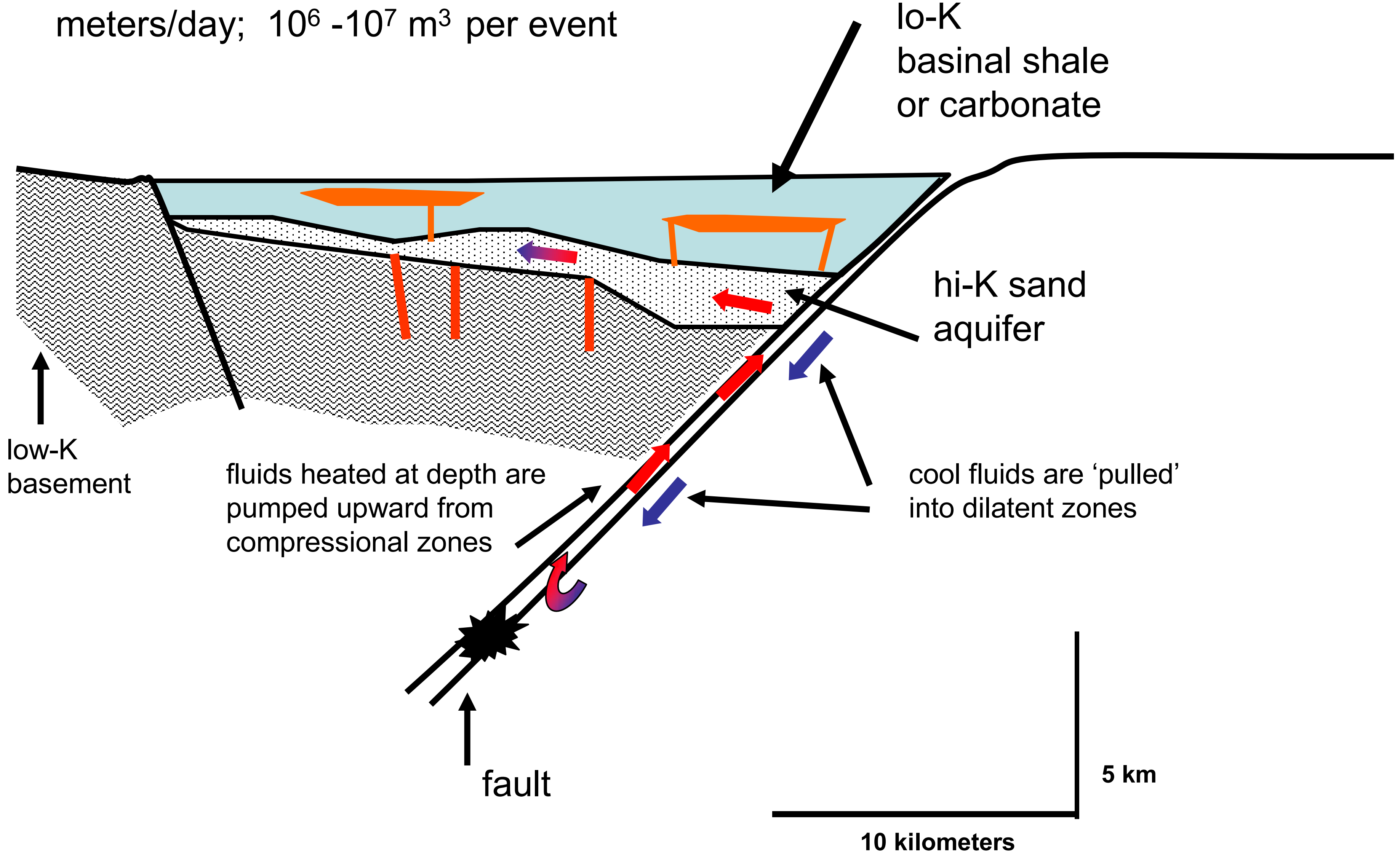
fault

5 km

10 kilometers

from Raffensperger, J.P. & Garven, G.
SEG Pre-conference workshop A, SEG Conf. On Carbonate-Hosted Lead-Zinc Deposits, St. Louis, 2 June 1995

Seismic Pumping – flow rates of 100's of meters/day; 10^6 -10^7 m^3 per event



lo-K
basinal shale
or carbonate

hi-K sand
aquifer

low-K
basement

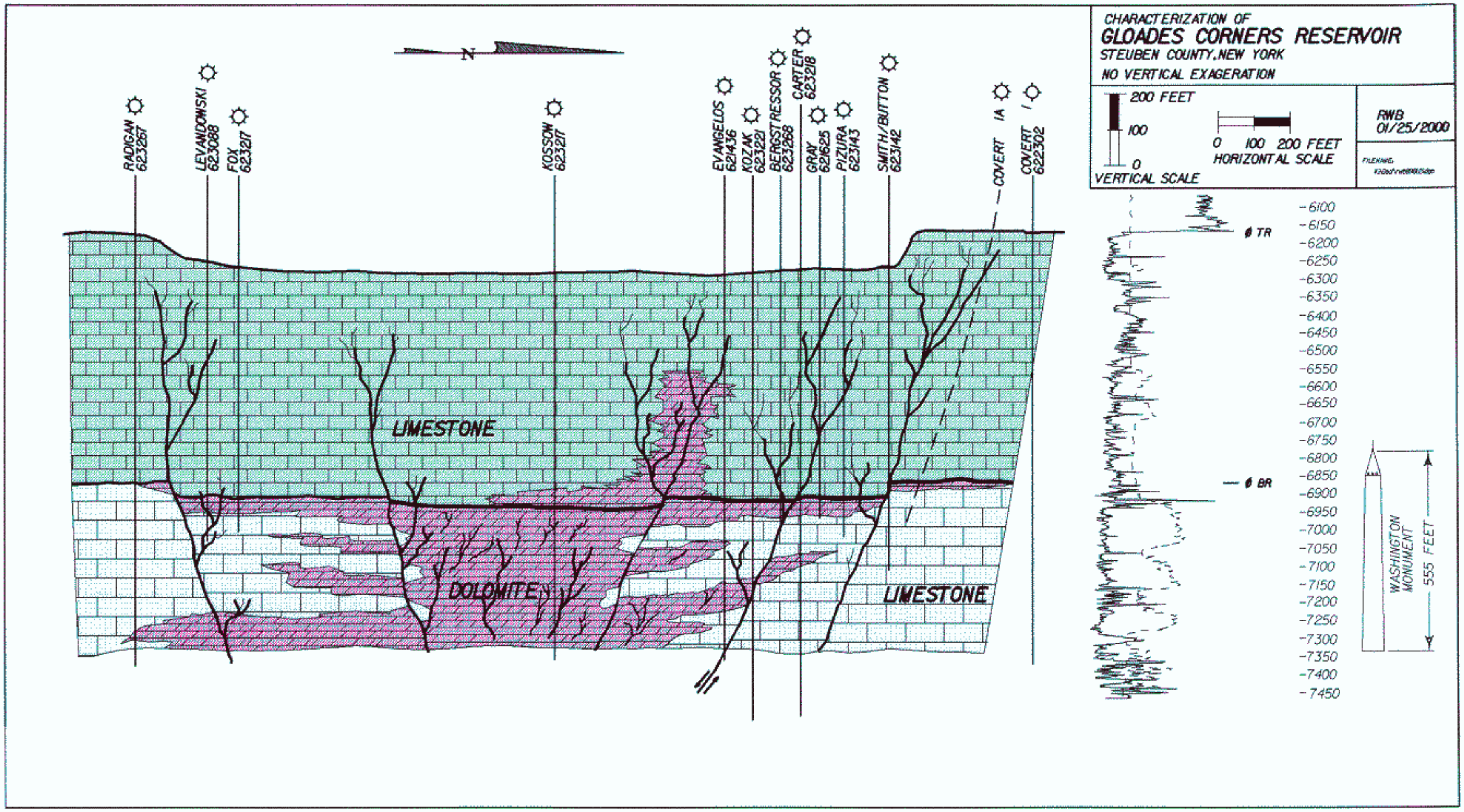
fluids heated at depth are
pumped upward from
compressional zones

cool fluids are 'pulled'
into dilatent zones

fault

5 km

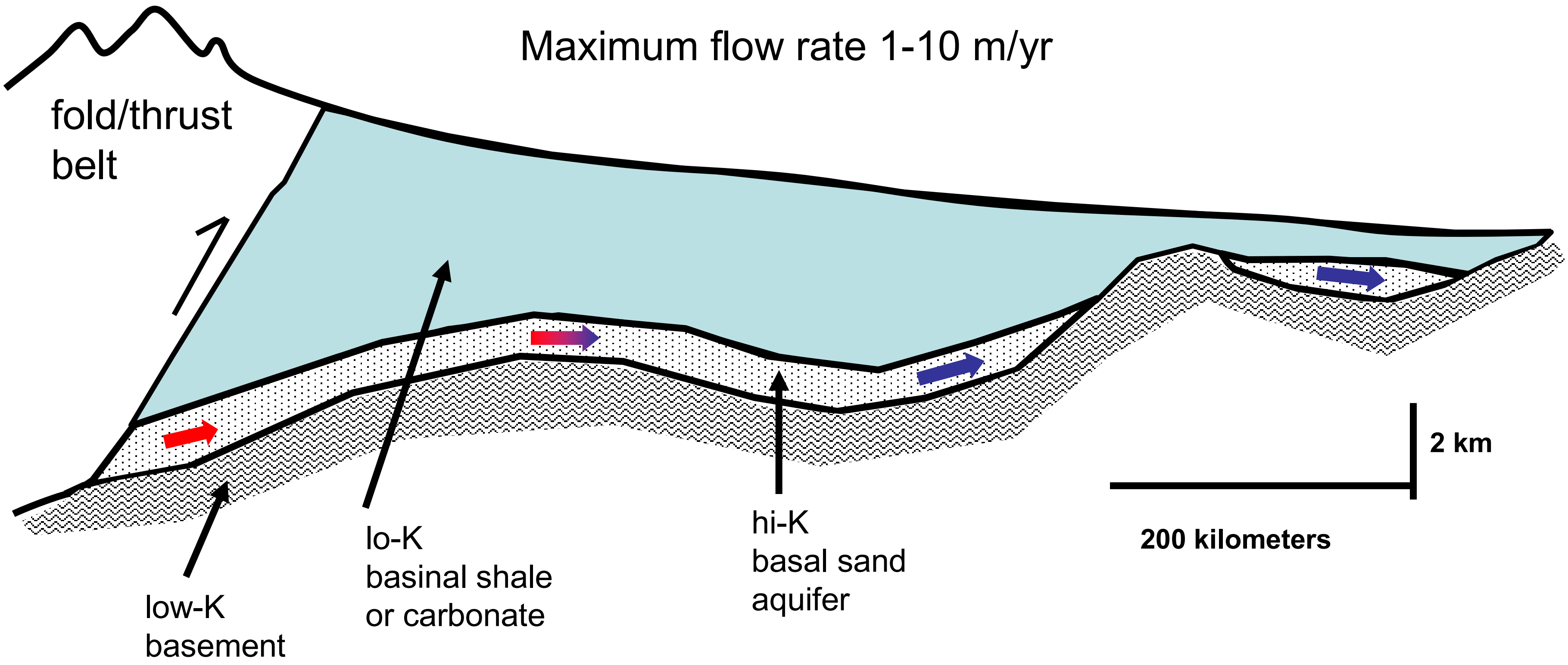
10 kilometers



http://www.uky.edu/KGS/emsweb/trenton/gloadesxsection.gif

Uplifted foreland basin

Maximum flow rate 1-10 m/yr



fold/thrust
belt

low-K
basement

lo-K
basinal shale
or carbonate

hi-K
basal sand
aquifer

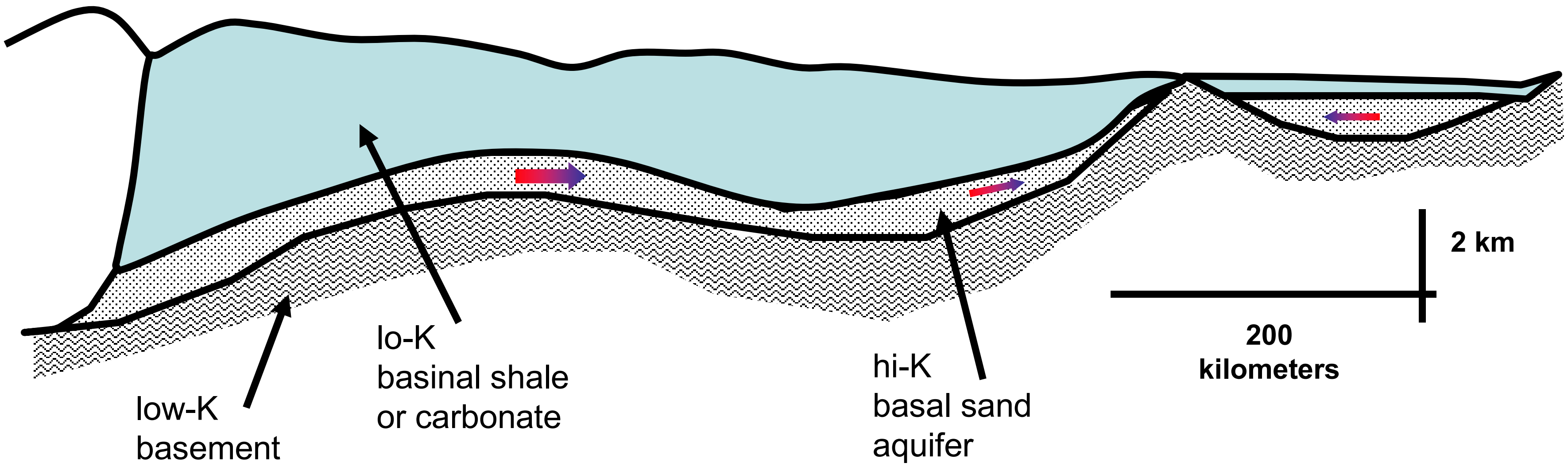
2 km

200 kilometers

All images are after Raffensperger, J.P. & Garven, G.
(SEG Pre-conference workshop A, SEG Conf. On Carbonate-Hosted Lead-Zinc Deposits, St. Louis, 2 June 1995)

web.uct.ac.za/depts/geolsci/hef/Metam/fluid1.html

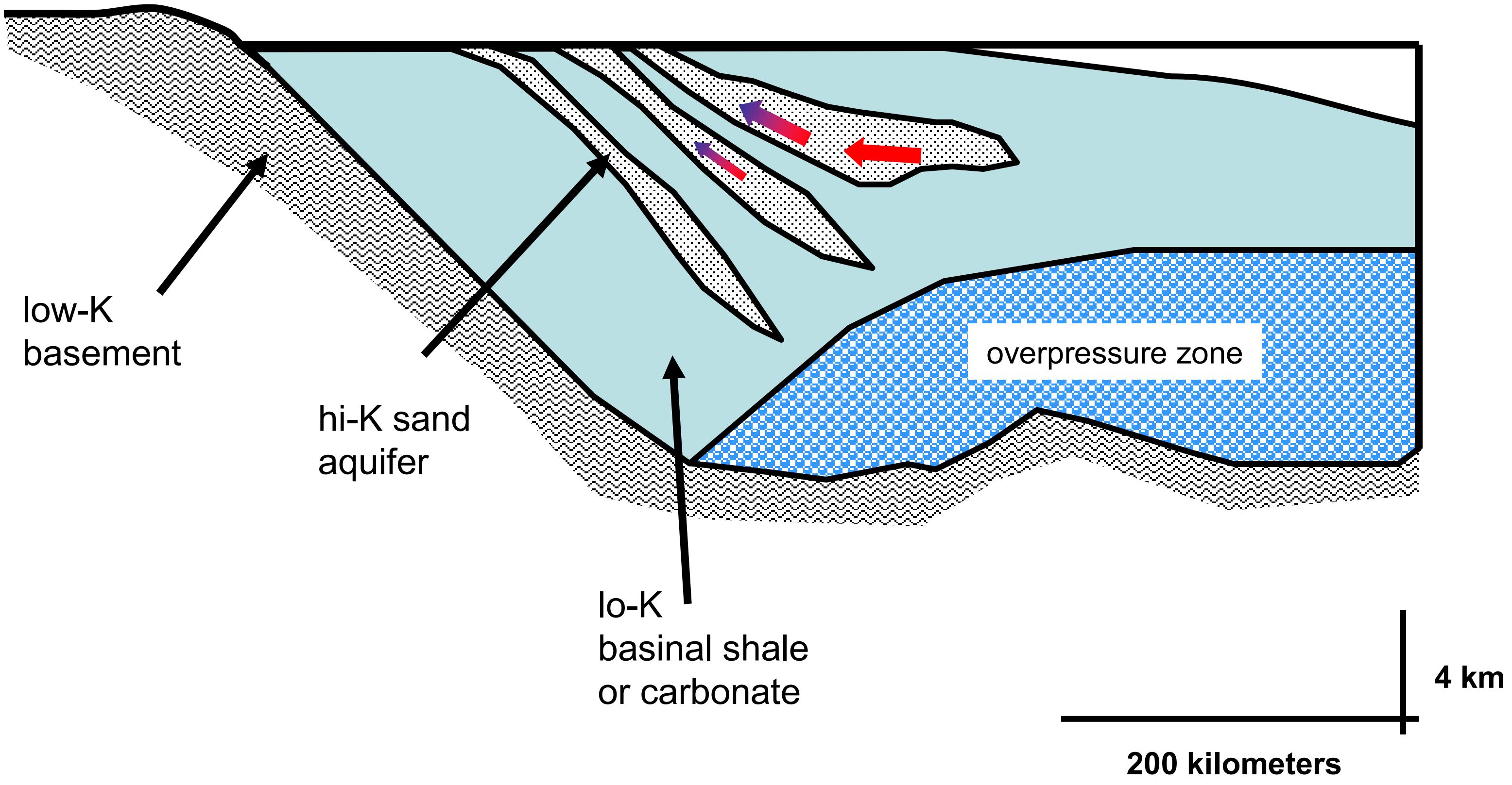
Foreland Basin (Eroded)



Maximum Flow Rate 1-100 m/year

Rapidly subsiding margin

Maximum flow rate 0.1-1 cm/yr



low-K
basement

hi-K sand
aquifer

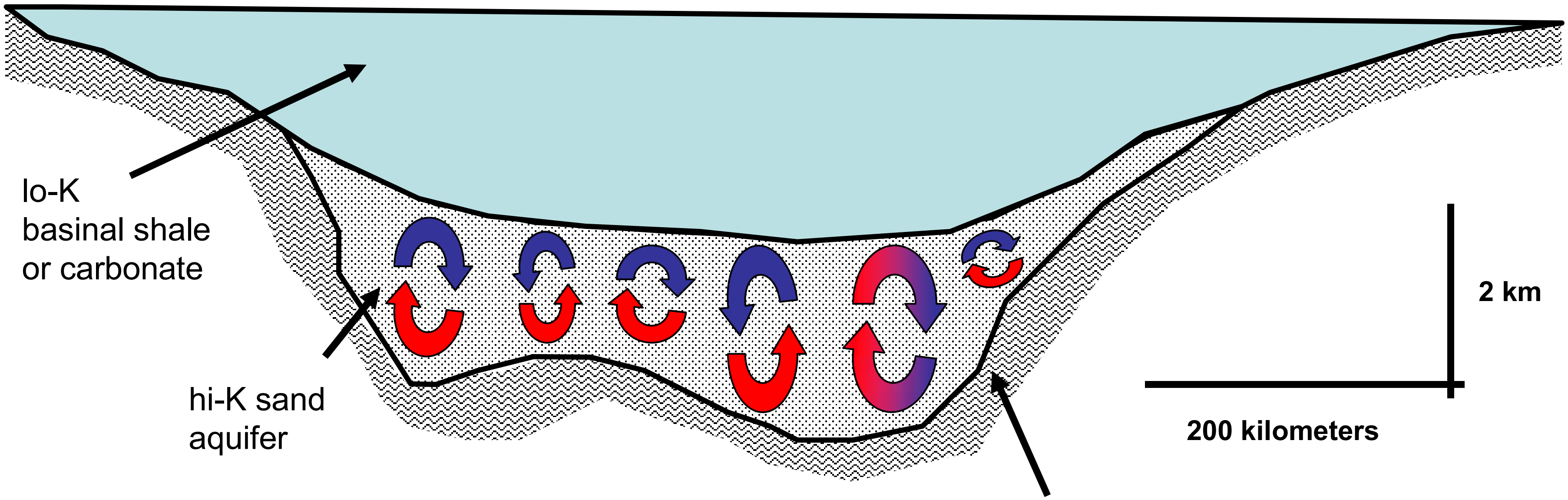
lo-K
basinal shale
or carbonate

overpressure zone

4 km

200 kilometers

Rift Basin/Intracratonic Sag Basin



Maximum Flow Rate: 0.1-1.0 m/yr