GEOLOGY OF THE BALMAT ZINC REGION

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The Balmat-Edwards district zinc orebodies are located in the northwest Adirondack Lowlands of northern New York State (Fig. 1). The Adirondacks are an extension of the Canadian Shield into New York State via the Frontenac Axis/ Thousand Islands region located along the St. Lawrence River and are underlain by poly-deformed rocks metamorphosed to a high grade during the Grenvillian orogeny about 1.1 bya. Zinc orebodies of the Balmat district occur in an eight mile long strip of rocks comprised of dolomitic marbles and calc-silicate rocks referred to as the Balmat-Edwards marble belt. The Balmat-Edwards marble belt cores a nappe-scale, doubly plunging, recumbent fold referred to as the Sylvia Lake syncline (Fig. 1). Lithologically similar silicated dolomitic marble host rocks, sulfide ore, and structure reappear 28 miles/45 km to the northeast of Balmat at Pierrepont, NY (Fig.1).

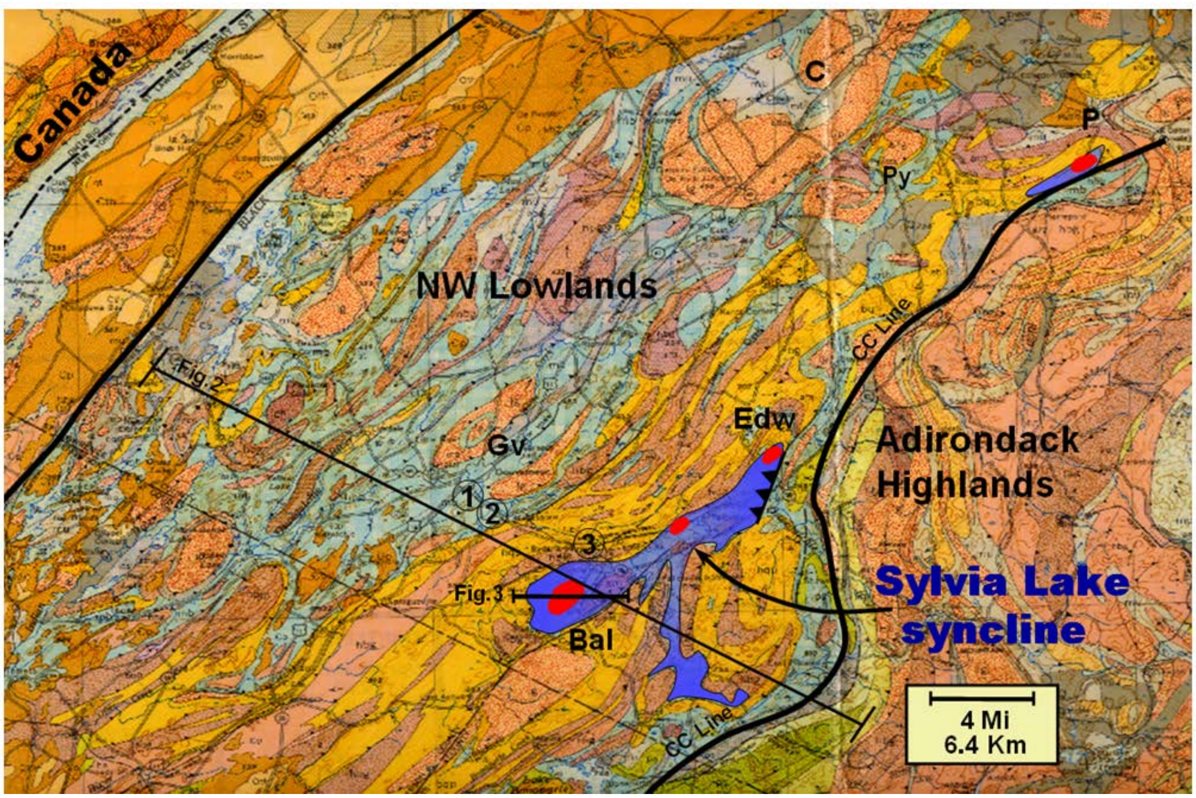

Figure 1. NYS geologic map (Adirondack Sheet of Isachsen and Fisher, 1970) of the NW Adirondack Lowlands. Locations of Zinc deposits shown in red at Balmat (Bal), Hyatt (Hy), Edwards (Edw), and Pierrepont (P). Zinc deposits in upper marble, darker shaded blue areas. Village of Gouverneur labeled "Gv", Village of Canton labeled "C".

On this field trip we will make a NW-SE transect across the Lowlands beginning in Gouverneur and ending at Balmat, NY. We will examine, in a general sense, the structural architecture and tectono-stratigraphic setting of what has been referred to as the "Trans Adirondack Back-Arc Basin" (TABB) comprising the NW Adirondack Lowlands between the Highlands and the Black Lake region (deLorraine and Carl, 1993; Chiarenzelli et al., 2012). As we progress from Stop 1 to Stops 2 and 3 we'll gradually move up section.

Stops 1 and 2 in calcitic lower marble record rift and drift phase chemogenic sedimentation in the (TABB) whereas up section at Stop 3 Popple Hill gneiss records basin fill turbididic sedimentation initiated by convergence (Chiarenzelli et al., 2012). Stop 4 takes us to dolomitic upper marble at the top of the section. Host rocks record cyclic dolomitized and silicified algal mat carbonate and evaporite deposition in shallow restricted marine seas during the final stages of backarc basin fill. Overall objective will be to take a look at the different high grade metamorphic rock types and mineral assemblages, styles of folding, relate minor folds to major folds, and to gain an appreciation for why the tectono-stratigraphic setting of the NW Adirondack Lowlands as a back-arc basin might be the ideal setting for the formation of SEDEX ore deposits such as the Balmat-Edwards-Pierrepont deposits

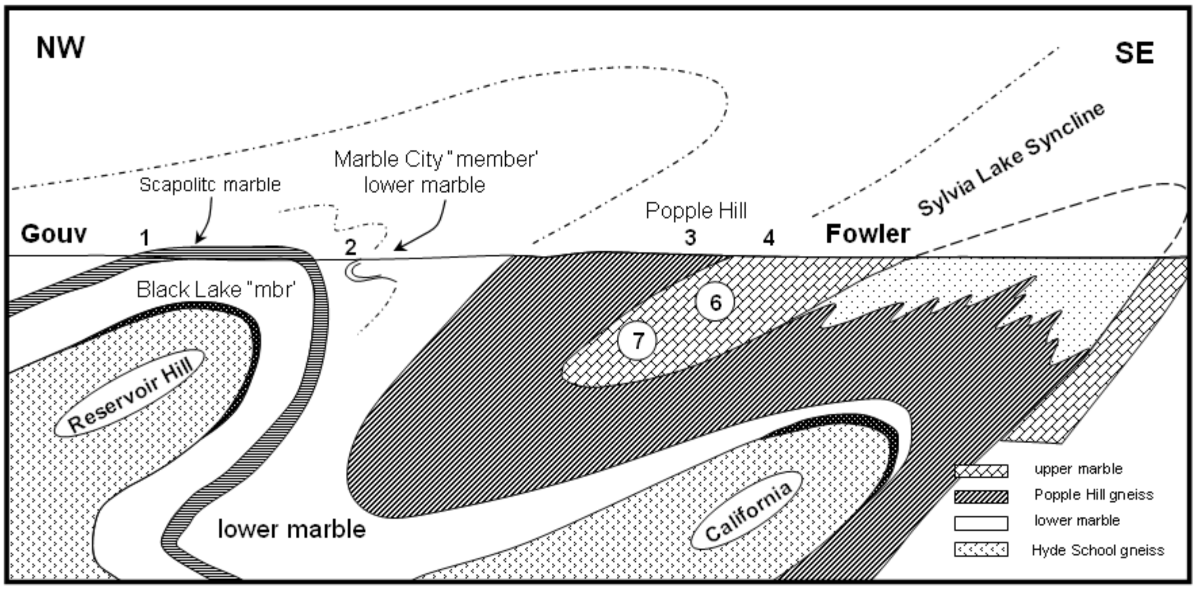

Figure 2. Vertical NW-SE section along Rt. 58/812, Gouverneur to Fowler, NY. Numbers refer to stops. Section line shown on Fig. 1.

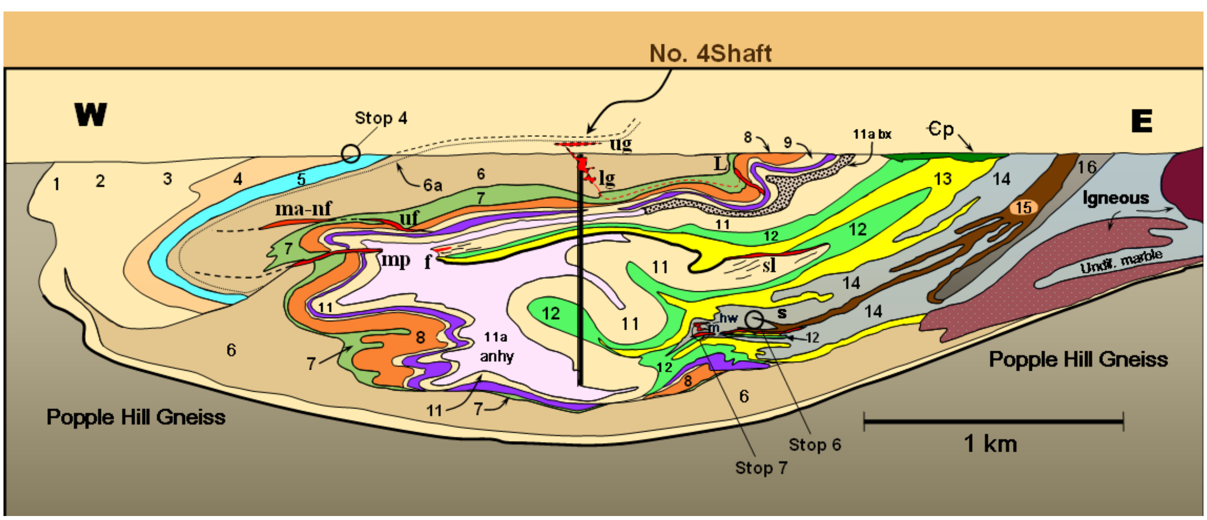

Figure 3. W-E vertical section through the Sylvia Lake Syncline. Section line shown on Fig. 1. Relative structural position of stops shown on section.

Zinc orebodies are believed to have originated as Mesoproterozoic seafloor exhalations that accumulated as conformable sedimentary massive sulfide lenses and layers deposited some 1.25 bya in the TABB within a sequence of dolostones, thinly layered stromatolitic cherty dolostones, and evaporites (Fig. 4). Sphalerite and pyrite accompanied by very minor galena are the principal sulfide minerals. Host rocks and orebodies attained burial depths of 20 km or more during Grenvillian orogenesis when they underwent polyphase deformation. Upper Amphibolite grade peak metamorphic conditions generated migmatites and anatectic melts in surrounding rocks and mobilized significant sulfide fractions within and away from the orebodies. In a few places, sheet-like, aerially extensive, nearly pure sphalerite "dikes" segregated from their parent lenses and intruded macrofracture surfaces where these large cracks intersected parent sulfide masses. Macrofractures evolved into thrust faults at a high metamorphic grade during deep-seated regional ductile shearing. Sheetlike "daughter" orebodies thus formed are found on three major ductile fault surfaces that are refolded by the Sylvia Lake syncline. Most of the intruded sphalerite segregated along the fault surfaces into tabular lozenges elongated in the direction of associated fold hinges. A typical daughter orebody "footprint" is several hundred feet wide by 6000 ft/1800 m long by perhaps 1.8-2.5 m thick on average. Tonnages average up to 6 million.

Daughter orebodies are inherently lower grade and finer grained because of their locations on fault surfaces making them inherently more susceptible to recurrent deformational strains. Ductile faulting abraded and rounded admixed adjacent wall rock inclusions in the ore thereby imparting their signature deformational texture referred to as "Durchbewegung" texture. "Parent" ore lenses from which the daughter orebodies are derived can be 1500 ft/450 m or more in length, 450ft/150 m wide, and up to 80ft/25 m or more thick. Parent ore is coarse grained and twice the tenor of daughter ore. Presently there are several daughter orebodies in production or have been drilled whose predicted source bed or parent massive body awaits discovery.

Parent orebodies originally deposited in more ductile carbonate lithologies that flowed rather than faulted during deformation did not necessarily give rise to daughter offshoots. Rather, those stratabound sulfides remobilized within and parallel to fold hinges associated with the Sylvia Lake syncline. The largest of these orebodies, the Main and Hanging Wall, are located at No. 2 mine within the core of the Sylvia Lake syncline in Unit 14 (Fig. 3).

Individual orebodies exhibit good continuity and are quite predictable in the down-plunge dimension, though the details of host structure change and evolve from section to section in the mine. This leads to a variety of dips of ore shoots from flattish to vertical hence requiring an array of different mining methods, from inclined room and pillar to long-hole extraction.

Multiple lines of evidence suggest differentiation of sphalerite from stratiform massive sulfide ore lenses occurred during the Upper Amphibolite grade Shawinigan (Grenville) Orogeny (ca. 1.20-1.15 Ga) prior to development of the host Sylvia Lake Syncline. Syntectonic macrofractures impinged upon massive lenticular, polymetallic stratiform orebodies forming subsidiary ores as sheet-like radial dikes. Several of the monomineralic sphalerite daughter orebodies remain linked to parents by thin, refolded, "durchbewegt" ore sheets that cross-cut stratigraphy and metamorphic fabrics (Fig. 3, daughter orebodies L and lg linked to UG near No. 4 mine). Long after intrusion of daughter sphalerite dikes, admixed xenolithic fragments of wall rock contained within the initially massive, coarse-grained, sphalerite became rounded by tectonic milling resulting from recurrent strains partitioned along macrofracture surfaces. Daughter orebodies thereby acquired distinctive durchbewegung textures while nearly doubling their thicknesses but halving their tenors as macrofractures evolved into tectonic slides -- some with km-scale displacements.

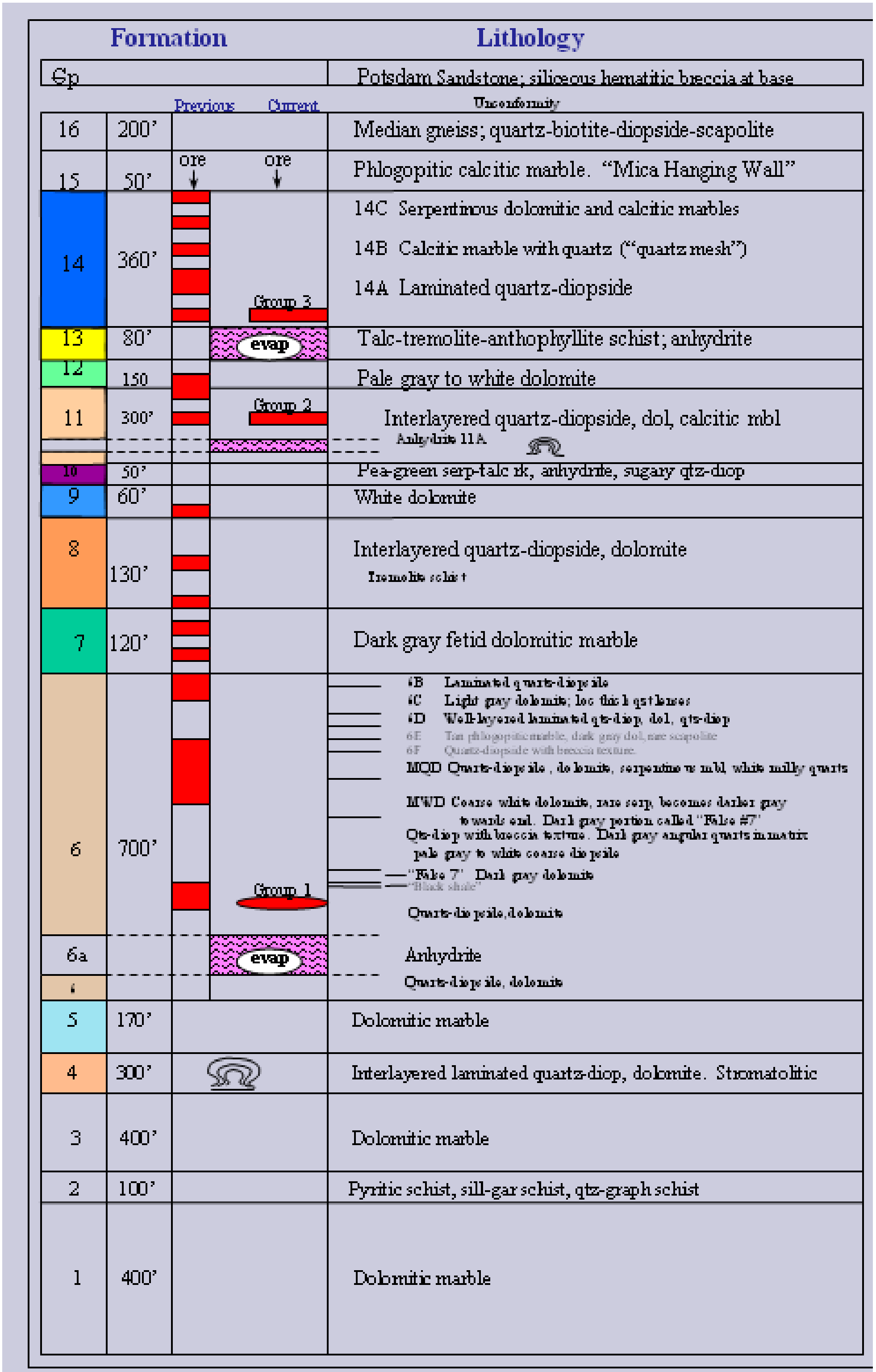

Figure 4. Stratigraphic Column through the Balmat District. Black bars represent stratigraphic horizons at which zinc mineralization has been found. Column marked "Previous" shows locations of sulfide ore formerly interpreted as (Fig.4 cont'd) conformable, stratabound occurrences but known to occur along cross-cutting metamorphic faults therefore have no stratigraphic significance. Column marked "Current" shows confromable, stratiform sulfide ore horizons (after deLorraine (2001); deLorraine and Sangster (1997).

Polyphase deformation culminated with superposition of the nappe-scale Sylvia Lake syncline accompanied by refolding and inversion of parent-daughter ore complexes on its upper limb. This complex fold displays elements of both passive flow and concentric geometries due to extremes of ductility contrast induced by intercalation of marble, exceedingly ductile anhydrite strata, and competent quartz-diopside-rich units. Long thought to have been the driving force or "tectonic engine" responsible for large scale sulfide mobilization to dilatent sites within its major and minor fold hinges, the Sylvia Lake syncline is now known to refold durchbewegt "daughter" ore sheets and thus is a late stage feature in the evolution of orebodies of the district. Mobilization of originally disseminated sulfides from throughout the Upper Marble section to dilatent structural sites either within fold hinges or along syn-kinematic faults via metahydrothermal fluid phases is precluded by direct linkage of daughter ore to parent source beds. As well, the emplacement of daughter mineralization along synmetamorphic faults that transgress metamorphic foliations and recrystallized bedding suggests emplacement <u>after</u> cessation of major devolitization reactions under "dry" ambient metamorphic conditions.

Geochemical groupings of orebodies are consistent with three "SEDEX" horizons (Fig. 4). Significantly, three major epochs of evaporite deposition in that interval coincide with the three epochs of stratabound sulfide deposition such that anhydrite sedimentation shortly precedes sulfide deposition in each case. Resulting from this are three "evaporite—ore" couplets within units 6, 11, and 14 (Fig. 4). Stratiform massive sulfide source bed lenses or layers specifically occur in those units. The association of evaporites and ore is an indirect, but important one that is common to other important sulfide deposits.

Deciphering the origin of the Balmat zinc deposits is made somewhat problematic by the effects of high grade metamorphism, polydeformation, and post-metamorphic annealing recrystallization. Nevertheless, the following scenario can be pieced together from petrological, geochemical and isotopic data, underground mapping and photographs, deposit-wide and regional structural geology, and deposit and regional stratigraphy. Orebodies fall into three geochemical groupings, each of which appears in the section not long after major evaporative epochs. Orebodies lowest in section are highest in Hg and vice versa, consistent with the interpretation that earliest SEDEX orebodies precipitated from saline brines that stripped most of the available Hg from the volcano-sedimentary pile in the Back-Arc basin repository during the first SEDEX cycle. In so doing less and less Hg was left for successive ore-forming cycles. This interpretation places evaporites immediately available to SEDEX ore fluids as a source of saline brines capable of leaching metals and presumes depletion of halide reservoirs after each SEDEX depositional epoch. Consequently SEDEX ore deposition is precluded until after the end of the next evaporative sedimentation epoch pending restoration of anhydrite and halite reservoirs.

An interpretation consistent with available data is that Balmat Zn deposits are ultimately of late Proterozoic, vent-distal, carbonate-hosted, SEDEX origin and that metamorphogenic "Daughter" orebodies spawned from massive "Parent" orebodies during Upper Amphibolite grade metamorphism as differentiated offshoots in the form of sheetlike sphalerite "dikes". Local preservation of flow banding, sulfur isotope gradients, color gradations in sphalerite and mineralogic differentiation <u>ZnS+Py>ZnS>PbS</u> in the direction of transport suggests that plastic flow or fluid-aided plastic flow was the dominant mechanism of mass transfer. Distances of migration are truly epic with readily demonstrable, km-scale, cross-stratal flow.

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ROAD LOG FIELD TRIP A-5: GEOLOGY OF THE BALMAT ZINC REGION

Start location: Aubuchon Hardware parking lot, 32 Clinton Street, Gouverneur, NY, just down the street from Jumbo's restaurant, across the street from Kinney Drugs at the intersection of Rt. 11 and Rt. 58N.

0.00 mi. Aubuchon parking lot exit: turn left on 58 S toward Edwards. (At traffic light route becomes 58/812 S). Proceed straight through light.

0.91 mi. Stop 1 Scapolite marble roadcut, lower marble. Dips to south at end of Reservoir Hill leucogneiss dome. Note black, N60ºE trending, late dike. Near the base of the lower marble section. Scapolite may be evidence for early evaporative chemogenic sedimentation in the Trans-Adirondack Back-Arc Basin (TABB).

1.58 mi. Stop 2 "Train Wreck" road cut, lower marble. "Graph-phlogo-cal" marble with brown tourmaline. Stratigraphically overlies the scapolitic marble. "Rift and Drift" phase of development of the TABB. Large blocks represent dismembered mafic dike fragments rotated and "strewn" about in the marble like a derailed train. This is the marble quarried extensively in the late 1800's to early 1900's making Gouverneur famous as "Marble City". It is a prominent local building stone which is a major component of churches, post offices, and other buildings in the region. 1274 +/- 9 Lu-Hf .

5.16 mi. Stop 3 Popple Hill migmatite gneiss road cut. Plag-qtz-biot gneiss; ca 1220. Migmatite-agmatite roadcut. Look for refolded migmatitic leucosomes, ptygmatic folds, folds with "S" asymmetric sense appropriate for structural position on upper limb of the Sylvia Lake Syncline and many that aren't... ? Basin Fill stage metasediments; here a poly-deformed migmatite-agmatite exposure. 1180-1160ma anatectic zircons. Local sill-gar-biot gneiss layers; rare carbonate seams. Currently nterpreted as immature turbiditic sediments, plag-rich wackes, qtz-arenites to Al-rich shales fining upward toward contact with upper marble as the back arc basin evolved into a foreland basin. Sourced from the Southern Adirondack terrane (Chiarenzelli et al, 2012).

6.15 mi. Rt. turn on 812 S towards Balmat at caution light.

6.40 mi. Rt. turn onto Sylvia Lake Road

7.48 mi. Arrive at front gate, St. Lawrence Zinc Co. No. 4 Mine. Do a "U" turn, park well off on the right-hand side of Sylvia Lake Road.

7.48 mi. Stop 4 . Units 4/5 Contact, No. 4 Mine. Upper marble Ca. 1210 ma. Upper limb of the Sylvia Lake syncline. Contact between silicated Unit 4 and overlying dolomitic marble, Unit 5. Unit 4 is stromatolitic. How are they identified? Look for laminated qtz-diopside rocks locally retrograded to serp-talcose-diop. What is stratigraphic "tops"? How do you think stroms formed and what might be their mode of preservation? How did theysurvive Upper Amphibolite grade metamorphism and polydeformation? "Footprint" of one inverted strom slightly elongated N10º W parallel to major and minor fold hinges.

8.57 mi. Intersection of Sylvia Lake Road and 812 S. Turn right on 812 toward Balmat.

10.40 mi. Balmat. Turn right at 4 corners on CR 24 (Russell Turnpike Road).

11.25 mi. Stop 5. Langevin Lane (private drive). Turn right, drive up paved driveway to top of hill.

11.44 mi. Private residence. Permission required. South end of Sylvia Lake, viewing N. Sweeping northerly vista of the lake with Balmat No. 4 mine headframe in right background. Topographic expression of the lake is a reflection of the geometry of the hourglass-shaped core of the Sylvia Lake syncline. Filled with Unit 11A anhydrite, the core of the fold was easily eroded so that the shape and great depth of the lake of over 150 feet in places is attributable to this unusual lithology.

11.62 mi. Return to CR 24, turn left and return to Balmat.

12.46 mi. Balmat. Turn left onto Rte. 812 N toward Fowler.

12.78 mi. Stop 6. Turn left onto short, dead-end paved road segment leading downhill toward abandoned open pit mine. Permission Required. Gouverneur Minerals Co. (formerly referred to as Gouverneur Talc Co); Vanderbilt Corp. Exposed in the east sidewall of the pit facing Rte. 812 is a spectacular isoclinal fold hinge in Unit 15 "Mica Hanging Wall" in the core of the Sylvia Lake syncline. Look for axial planar schistosity and transposed bedding in this tightlyappressed hinge. Good examples of boudinage. Are the long axes of the boudins parallel to the fold axes?

Turn around, return to 812, turn left onto 812 N.

13.21 mi. Turn left onto Pumphouse Road, entrance to Gouverneur Minerals Co.

13.38 mi. Drive past "Dead End" sign; Gouverneur Minerals Co. office and mill complex on right.

13.58 mi. RR tracks. Cross tracks, take immediate left-hand turn onto narrow paved lane.

13.72 mi. Stop 7. Gate to No. 2 mine. (Gate is locked, access by appointment only St. Lawrence Zinc Co.). We'll proceed into the No. 2 mine grounds, past the inclined shaft and hoist house, to the No. 2 open pit. The shaft and hoist are kept in good running condition on a stand-by basis serving as a second way out, escape route for the No. 4 mine. High tenor zinc ore is exposed in the pit along with numerous examples of high temperature cross-cutting relationships with host rocks. Numerous minor folds, examples of surficial oxidation of the massive sulfide ore resulting in "gossan", examples of bird's eye alteration texture, numerous different rock types and mineral parageneses. A suite of high grade carbonate metamorphic minerals for the student mineralogist and retrograde assemblages as well.

Return to intersection of Pumphouse Road and 812 N.

~14.21 mi. Turn left onto 812 N.

15.36 mi. Left turn onto Sylvia Lake Road

16.44 mi. Stop 8. St. Lawrence Zinc Co., No. 4 Mine entrance. Turn left into parking lot. Stop to view mine models, maps, core logging facilities, diamond drill core displayed on core racks, ore specimens, recap trip and discuss genetic models.

End of Trip