BEDROCK GEOLOGY OF THE LAKE SUNAPEE AREA, WEST-CENTRAL NEW HAMPSHIRE

by

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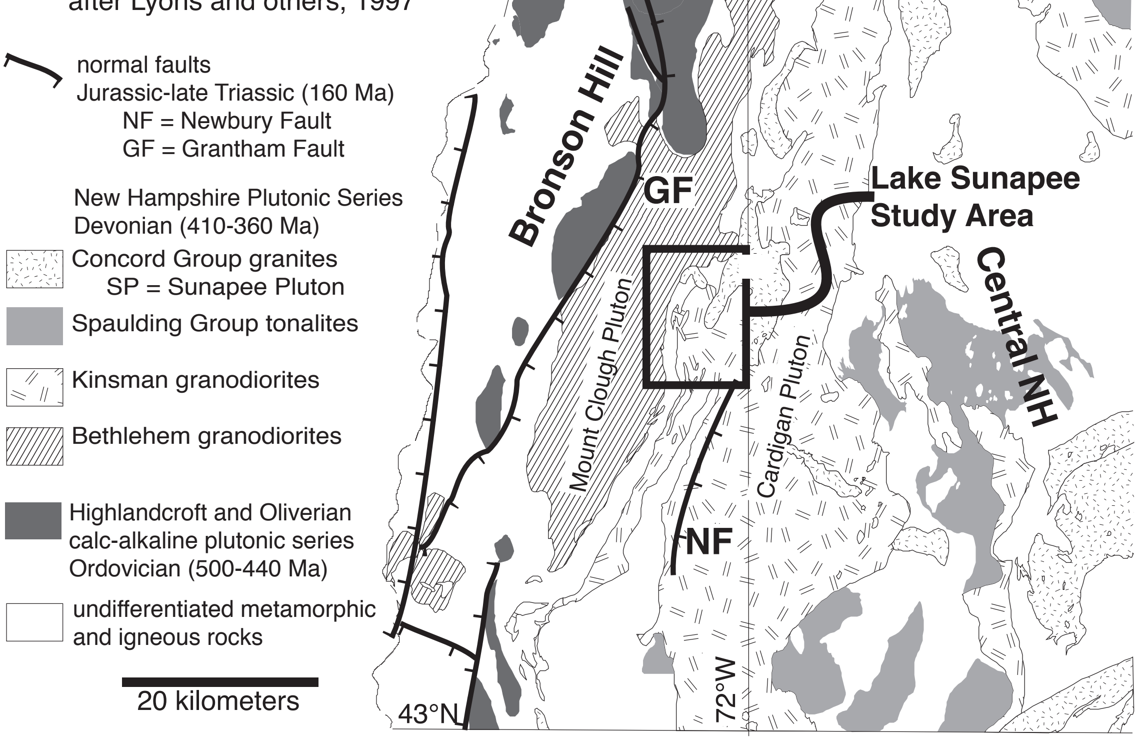
INTRODUCTION

The Lake Sunapee area lies at the intersection of the regions mapped by Jim Thompson and his students to the west, and by John Lyons and his students to the east, and I am indebted to both men (and their students) for their mentorship. This field trip was originally run as trip A4 at the 2003 NEIGC meeting; the road log and order of stops has been re-organized for the 2012 NEIGC meeting.

The regional geology of west-central New Hampshire (e.g. Allen, 1997) includes: (1) fold nappes which transported highly metamorphosed deep-basin sediments from the east towards the west over less-metamorphosed shelf sediments and volcanics (Bronson Hill, Figure 1), (2) large syn-kinematic anatectic plutonic sheets (the Mount Clough and Cardigan Plutons, Fig. 1), whose emplacement may have been intimately involved with the formation of the nappes, (3) a series of gneiss domes (Oliverian Plutonic Series, Fig. 1) which subsequently deformed (and metamorphosed) the nappes, and (4) late and post-kinematic magmatism.

The Mount Clough and Cardigan plutonic sheets are both heterogeneous granitoids, but being predominately granodiorite. The rocks making up the Mount Clough Pluton are known as the Bethlehem Gneiss, while those making up the Cardigan Pluton are called the Kinsman, which is renowned for its megacrystic texture. Although they differ in texture and mineralogy, the Bethlehem Gneiss and the Kinsman are chemically very similar (Billings & Wilson, 1964) and cannot be distinguished from one another on the basis of detailed isotopic studies (Lathrop et al., 1994, 1996). Thus it has been suggested that the magmas

Figure 1: Geologic Setting West-Central New Hampshire
after Lyons and others, 1997



forming these plutons originated from the same parent material. The mineralogical differences may result from different environmental conditions during crystallization (e.g, Dorais, 2003), or post-crystallization metamorphism (Chamberlain & Lyons, 1983). Lathrop and others (1994, 1996) suggested that the magmas were formed by anatectic melting of the adjacent metamorphosed sedimentary rocks, with slight geochemical differences attributable to differences between the original deep-basin sediments to the east (central NH) and the shelf sediments and volcanics to the west (Bronson Hill). Dorais (2003) argues that while the metasedimentary rocks are important sources, the magmas forming these plutons (particularly the Kinsman), could not have been produced without some input (of both heat and material) from mantle sources. Differences in texture could be related to the degree to which the plutons were involved in nappe-stage deformation, the Mount Clough Pluton being the further west and thus perhaps more closely involved with the west-vergent fold nappes (Allen, 1997).

In the Sunapee area, the Mount Clough and Cardigan Plutons are narrowly separated by a belt of metamorphosed sedimentary rock (Figure 2), known as the "Sunapee Septum" (Dean, 1976). In addition, small plutons and sheets of quartz diorite (Spaulding Group of the New Hampshire Plutonic Series, or NHPS, Lyons et al., 1997) and 2-mica granites (NHPS Concord Group) are unusually abundant within the septum in the Lake Sunapee area. In fact, previous maps show the septum of metasedimentary rocks being truncated by the Sunapee Pluton of 2-mica granite (Fig. 1). The Spaulding and Concord Group rocks are found more extensively in central NH (Fig. 1; Lyons et al., 1997), where they may be associated with migmatite zones (Eusden, 1988; Allen, 1996) and are perhaps a key to understanding relationships between structural development, magmatism, and metamorphism in the mid-crust during the Acadian orogenic event (Dorais, 2003).

Previous geologic maps of the Lake Sunapee area include one by Chapman (1952) at 1:62,500, limited partial coverage by Dean (1976) at 1:24,000, and unpublished manuscript maps by C. P. Chamberlain, cited by Thompson and others (1990). My students and I undertook detailed 1:24,000-scale geological mapping in this area in an attempt to help address questions about the relationships between the Mount Clough and Cardigan Plutons, their role in nappe-stage and subsequent deformation, and the significance of plutons of the Spaulding and Concord Groups in the overall structure of the orogen.

We have found that the Cardigan and Mount Clough Plutons may grade into one another, but that ductile structures have "sandwiched" the Sunapee Septum in between the two, obscuring their original relationship. The structure of the septum was exploited by late syn-tectonic Spaulding Group magmas, and the later post-tectonic Concord Group magmas seemed to follow some of the same conduits. But perhaps most importantly, we discovered that previously un-recognized brittle faulting dominates the geology of the area—Lake Sunapee is a graben!

METASEDIMENTS

The sediments which were metamorphosed into the lower-sillimanite grade rocks of the Sunapee Septum were deposited during Silurian and earliest Devonian time somewhere on a transition between a shallow shelf environment to the west, and the rapidly deepening basin of the Central Maine Terrane to the east. While our map (Fig. 2) does not yet differentiate among the metasedimentary rock units, we have recognized the following rock types, as found elsewhere in NH (Allen, 1997; Lyons et al., 1997): rusty schists and related rocks associated with the Silurian Rangeley Formation, very-rusty rocks we think of as the Silurian Smalls Falls Formation, calc-silicates likely part of the Silurian Madrid Formation, quartzites and related rocks of the Silurian Clough Formation, as well as aluminous turbidite schists of the Devonian Littleton Formation.

All of these rock types are exposed in tight steeply inclined (to the east) upright folds underlying the summit ridges of Mount Sunapee (Figure 3). As with other important mountains in NH, the main summit of Mount Sunapee is made up of Littleton Formation. These folds, northeastward fingers of Dean's (1976) Sunapee Septum (Fig. 2), appear to plunge moderately to the south-southwest. Foliation is generally parallel to bedding (or compositional layering), except in fold noses. The Kinsman plutonic sheet underlying these metasediments may be caught up in the folding on Mount Sunapee; locally it develops a strong foli-

FIGURE 2: BEDROCK GEOLOGY OF THE LAKE SUNAPEE AREA, NH

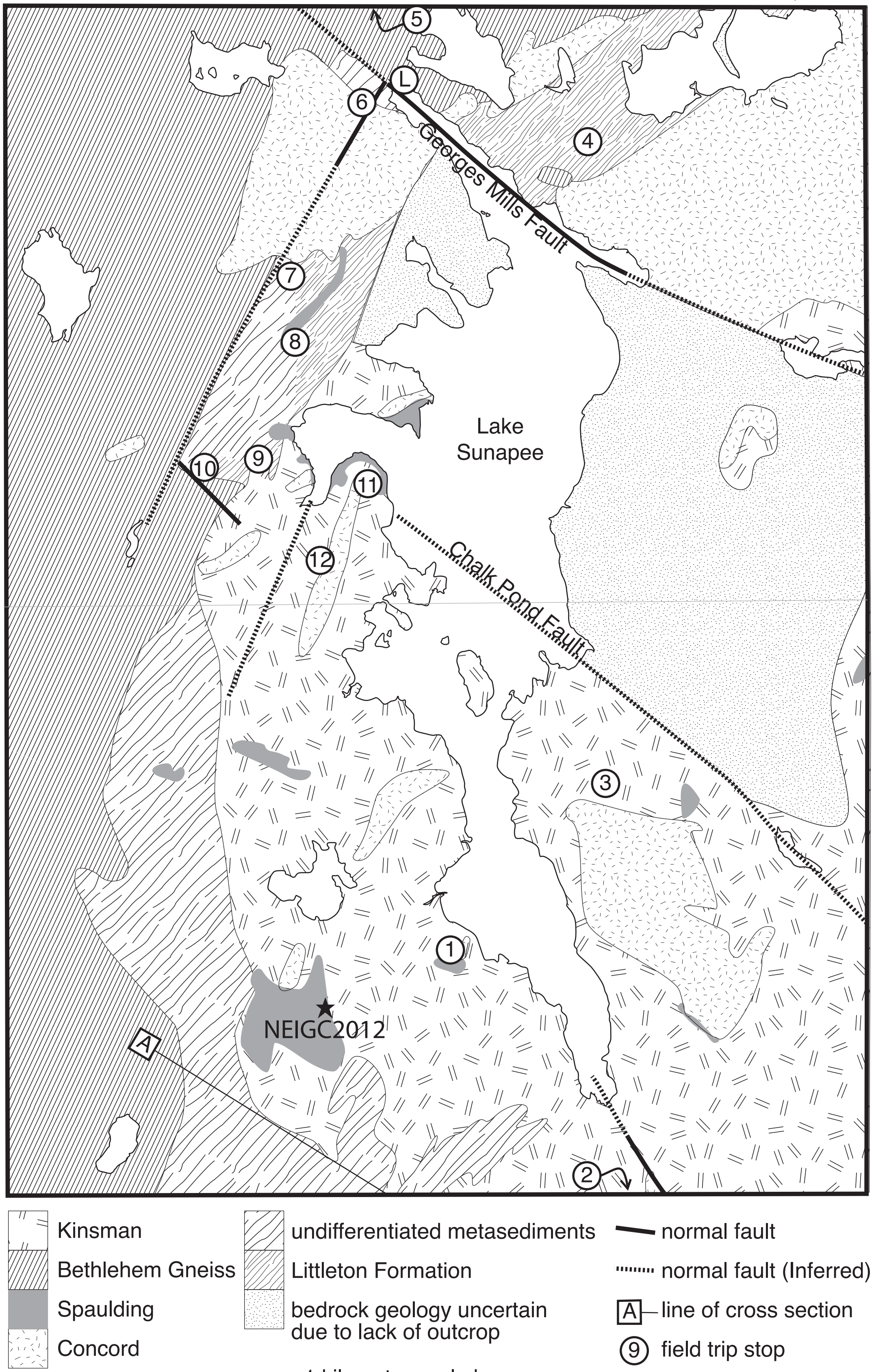
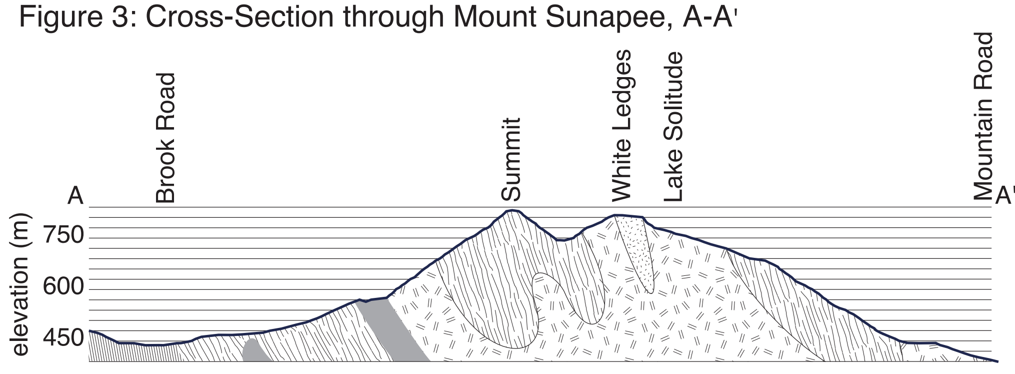


Figure 3: Cross-Section through Mount Sunapee, A-A'



1kilometer horizontal scale bar
vertical exageration = 2.5X
rock unit patterns are the same as in Figure 1

ation consistent with the fold axial planes. Local inter-fingering of the Kinsman with the metasediments could possibly be a consequence of folding rather than intrusion.

In the central part of the map area, the bedding and foliation are steeply inclined to the east-southeast (Figure 4), in what appears to be an upright stratigraphic sequence. While there are some small-scale (intra-formation?) folds (Stop 10), we have not identified any larger scale structures in this part of the septum. The metasediments appear to be "sandwiched" between the Bethlehem Gneiss (below) and the Kinsman (above). It is possible, however, that one (or both) of these contacts is in the form of a late brittle fault (Fig. 2), and/or a ductile shear zone (Figure 5, Stop 10), obscuring the original relationship.

Contact aureoles are developed in the metasediments adjacent to intrusions of hot Spaulding Group magmas (Stop 8). Northeastward of Lake Sunapee, the regional metamorphism of the rocks has produced a migmatitic gneiss (Stop 4), which suggests to us that this portion of the septum was buried to a greater depth than the other sections, vertically offset by the Georges Mills Fault (Fig. 2; see discussion below).

INTRUSIVE ROCKS

The Kinsman of the Cardigan Pluton (413±5 Ma; Lyons et al., 1997) is a foliated granodiorite (varying from granite to tonalite in composition), with abundant and characteristic potassium feldspar megacrysts in a coarse groundmass of quartz, plagioclase, biotite, muscovite and garnet. At several locations, it is cut by later dikes of curious "mini-kinsman" porphyritic granite (Stops 1, 3). While the Kinsman generally has a crude foliation and some alignment of feldspar megacrysts throughout the area, we have not recognized any pattern to these orientations, which are not particularly uniform, except in the western-most margins of the pluton, and underlying the folds on Mount Sunapee. In the western margins, the foliation—a gneissosity—becomes pronounced (perhaps even extreme), pervasive and relatively uniform as the characteristic megacrystic texture disappears (Stop 10). To the southwest of the Lake Sunapee area, the Huntley Mountain Spur of the Cardigan Pluton is inter-fingered with the metasediments of the Sunapee Septum, and has been mapped as the sole of the Fall Mountain Nappe (Chamberlain et al., 1988)—its texture, too, is distinct from the typical Kinsman (Allen, 1997).

The Bethlehem Gneiss of the Mount Clough Pluton (407±5 to 410±5 Ma; Lyons et al., 1997) is a well foliated (gneissose), biotite granodiorite (varying from granite to tonalite in composition). Generally lacking the feldspar megacrysts characteristic of the Kinsman, its appearance is relatively more homogeneous, and its foliation is pervasive and fairly uniform (Stop 5). Fresh surfaces often have a distinctive blue cast, recognizable even in drill cuttings (Stop 10). The pervasive foliation may be due to magmatic flow, or perhaps solid-state flow during westward nappe transport.

Figure 4: Stereonets of structural orientations within the Sunapee Septum

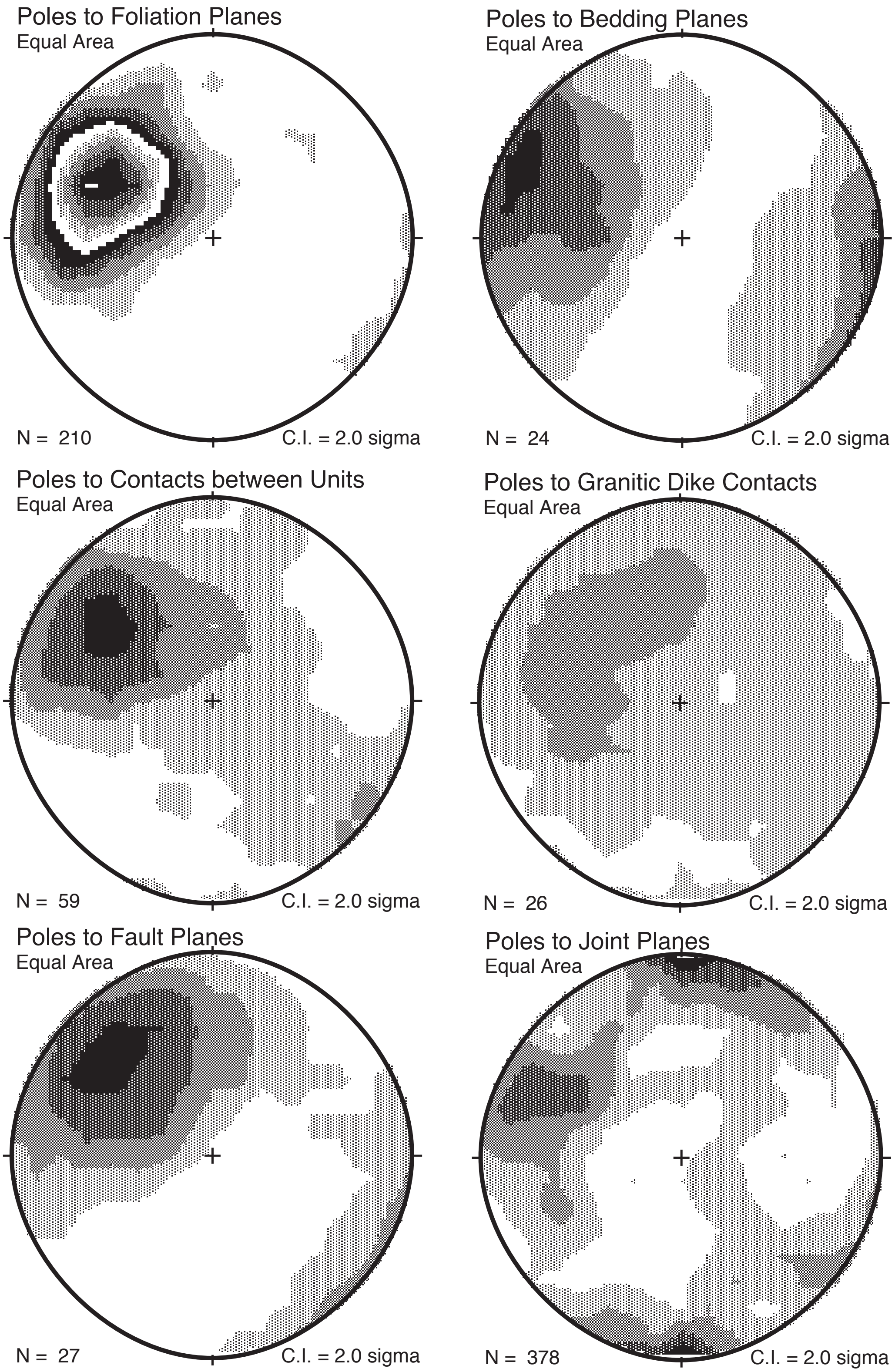
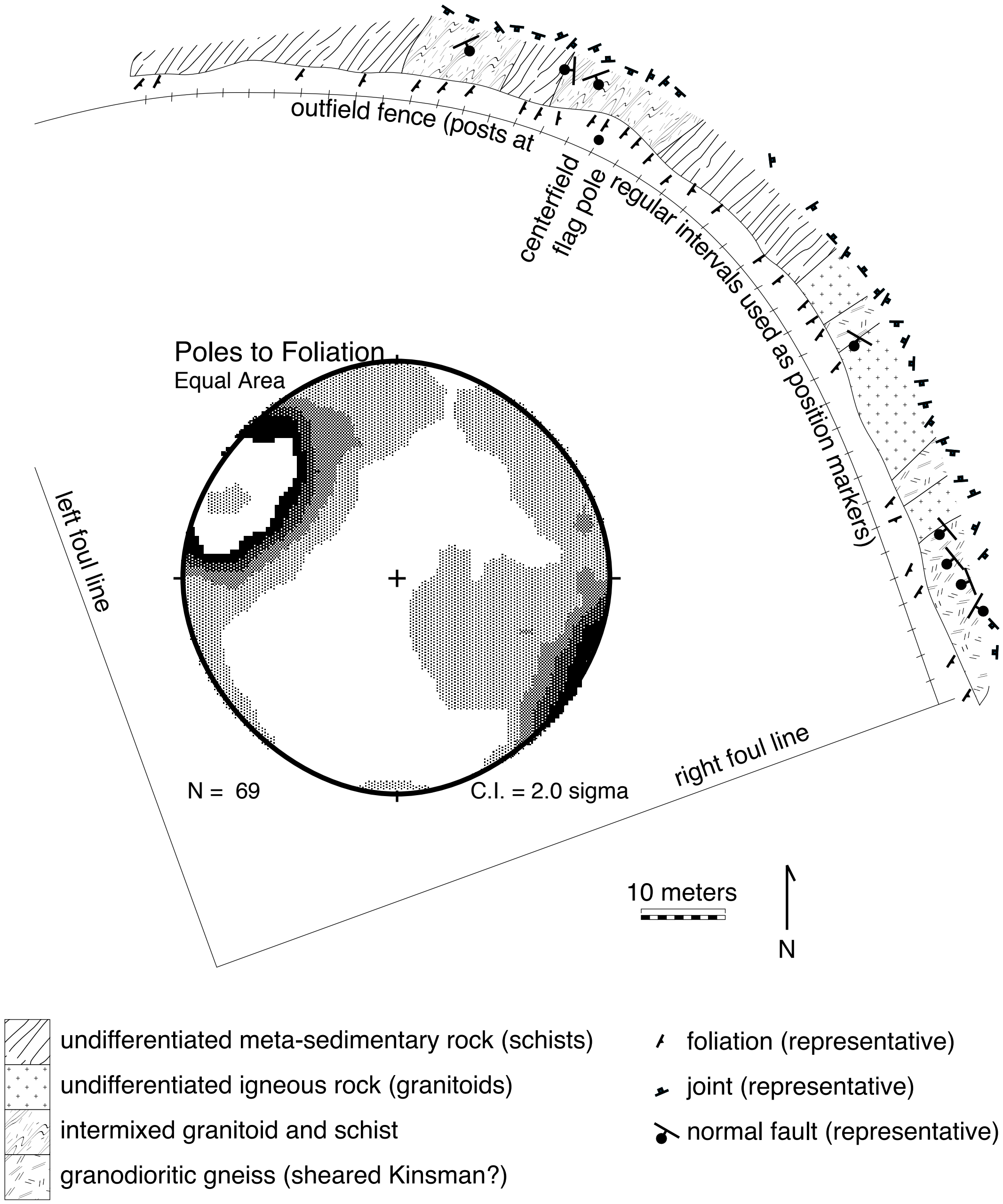


Figure 5: Sunapee Ballfield Outcrop (Stop 10) Detail



The Bethlehem Gneiss is typically easily distinguished from the Kinsman based on textural differences, but we have seen Kinsman-like feldspar megacrysts in what otherwise looks like Bethlehem Gneiss within the Mount Clough Pluton (albeit near the eastern margin). Thus at it's eastern edges, the Bethlehem Gneiss starts to look a bit like the Kinsman, and the Kinsman, at it's western edges looks a bit like the Bethlehem Gneiss. In the town of Sunapee, outcrops of the two rock types occur very close to one another. Compositionally, the two rock types are indistinguishable from one another (Billings & Wilson, 1964; Lathrop et al., 1994, 1996); and their ages overlap—Dorais (2003) has debunked field evidence elsewhere that required the Kinsman to be older than the Bethlehem. We have shown the two plutons in gradational contact on our map (Fig. 2), although we could use a few more outcrops to confirm that!

The Spaulding Group (392 Ma; Lyons et al., 1997) includes magmatic rocks ranging from diorite to granite in composition, but predominantly quartz diorite and tonalite. Often magmas from both ends of the composition range co-mingled to produce very interesting rocks (Stops 1, 8, 9, and 11!). At its contacts, Spaulding Group rocks often incorporate xenoliths of country rock, having disaggregated them, producing an igneous breccia with flow foliation resulting from explosion venting of fluidized magma. (J. B. Lyons, pers. comm., 1988). Common in the Lake Sunapee area is a relatively fine-grained dark quartz diorite "flecked" with biotite-hornblende clusters. This rock, too, is distinctive and recognizable in drill cuttings. We think many of the Spaulding Group plutons in the area are in the form of intrusive sills or sheets. Dorais (2003) suggests that Spaulding Group magmas were significantly hotter than ambient metamorphic temperatures in the Acadian orogen, in excess of 850°C, consistent with the contact aureoles we have observed (Stop 8).

The Concord Group granites (354±5 Ma; Harrison et al., 1987, Lyons et al., 1997) occur as light gray to white two-mica granites. While many interesting flow features can be found within these rocks, they clearly post-kinematic. The age of these rocks, about 30 to 50 Ma after the orogeny, puts them at about the right timing to be the result of anatectic melting following thermal relaxation after tectonic loading during the Acadian Orogeny (Chamberlain & England, 1985).

Occasionally we find a 2-mica granite with a porphyritic texture of feldspar phenocrysts, for example at the White Ledges on Mount Sunapee (Fig. 3). These occurrences are typically in close proximity to the Kinsman. Often we find Concord Group granites "following" intrusions of the Spaulding Group (e.g. Stop 1). Are these magmas using the same conduits to travel through the crust nearly 40 million years apart? These conduits must be important features in the structural development of the orogen. We find the concentration of these rock types together along the Sunapee Septum unique, which suggests that the septum is related to an important crustal-scale structure.

In the Sunapee area, the Concord Group granites are noted for being highly radioactive. There are anecdotal reports of domestic water wells in the area with radon concentrations greater than 30,000 pico-curies per liter! A roadcut through the Sunapee Pluton, on Interstate-89 just south of Exit 12 in New London, was especially notorious. After the road was opened, it was discovered that the rock was highly radioactive. The joint surfaces in the rock were covered with a heavy coating of ore-grade Uranium phosphate mineral deposits. Most of this valuable ore had been used as fill for the roadbed (R. Lane & E. Boudette, oral comm., 1995). This mineralization presumably represents late hydro-thermal mobilization, and is focused on fractured zones (note that this outcrop is in close proximity to the Georges Mills Fault, as discussed below). Zircons from this rock show little evidence of inheritance, but do show Uranium loss, with an age of crystallization of 354±5 Ma (Harrison et al., 1987).

The I-89 roadcut was re-stabilized in the mid-1990's. The entire height of the cut was blasted in a single lift, for which special permission was needed from the Federal Highway Administration (R. Lane & E. Boudette, oral comm., 1995). During the road-cut re-stabilization effort, great care was taken to keep the dust down, due to its potential radioactivity, and the material removed from the cut was landfilled in the median strip of the highway 2 miles to the southeast ("Mount Radon"). That location was chosen in part because it was hoped that any Uranium leached from the rock would be fixed in the highly-reducing environment of the organic sediments of the Messer Pond/Clark Pond bog system down gradient (along the trace of the Georges Mills Fault, see Fig. 2). However, much of the Uranium had already been leached from these rocks due to the lowering of the water table resulting from the initial road cut (R. Lane & E. Boudette, oral comm., 1995).

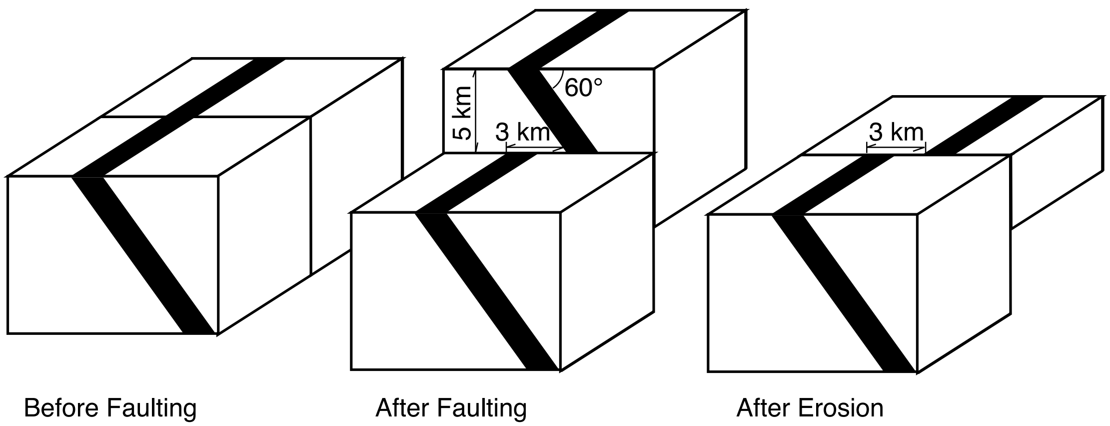
White to gray granitic pegmatites are abundant throughout the region, particularly associated with the Bethlehem Gneiss and the Concord Group granites. These pegmatites have been mined for feldspar and especially mica.

BRITTLE FAULTS

Extensional rifting during the Mesozoic produced several large brittle normal faults in western New Hampshire, including the Newbury Fault and the Grantham Fault (Fig. 1, Lyons et al., 1997). In our mapping, we have observed numerous brittle faults trending NNE-SSW and WNW-ESE (e.g. Figs. 4 and 5). The faults are variously recognized by burnished surfaces, often with steeply-plunging slickenlines, calcite-quartz-Iron hydroxide mineralization, gouge and/or brecciation, and/or hydrothermal alteration zones. We have not been able to determine amount of offset on any of the faults we've observed in outcrop, but none of these strike us as terribly big. However, small offsets on numerous *en echelon* faults could add up to significant displacements. The faults shown on Figure 2 are somewhat schematic and do not necessarily represent all of the faults observed in outcrop.

The Georges Mills Fault is not exposed in outcrop anywhere, but is marked by a very prominent lineament (Clark et al., 1998) defined by the arms at the north end of Lake Sunapee as well as the drainage pattern beyond the limits of the lake. In addition, the fault produces an apparent horizontal offset in the metasediments of the Sunapee Septum of about 3 kilometers—probably not due to horizontal motion, but rather due to vertical displacement of dipping strata (northeast up, southwest down; Figure 6). If the fault is vertical and perpendicular to the strike of the septum, and the metasediments of the septum are dipping at about 60° (see Fig. 4), then a 3 kilometer apparent horizontal offset could be produced by a 5 kilometer vertical offset (Fig. 6)! A vertical displacement of that scale seems unlikely, but such a vertical displacement could perhaps account for apparent differences in the metamorphic grade of the metasediments on either side of the fault—those to the northeast are well developed migmatites (Stop 4), while those to the southwest are only in the lower-sillimanite zone (Stop 7). The relief at the northern shore of the lake is

Figure 6: Schematic Illustration of Possible Georges Mills Fault Displacement



rather steep, consistent with it being a remnant fault scarp. South of the fault, particularly on the eastern side of the lake, there are essentially no bedrock outcrops, as the land appears to be wearing a thick mantle of glacial till (Fig. 2).

The Chalk Pond Fault also is not (yet) recognized in outcrop anywhere. Its existence is inferred from lineaments (Clark et al., 1998), bathymetry (Lake Sunapee Protective Association, 2002), and the distribution of bedrock outcrops. The deepest point in the lake, a hole 142 feet deep, lies just north of the inferred fault, and bathymetric contours define a linear scarp in the lake along the line of the fault. Symmetrically with the Georges Mills Fault, north of the Chalk Pond Fault and east of the lake we have not found many bedrock outcrops (Fig. 2; south of the fault they are abundant). In addition, the eastern shore of the lake between the two faults is marked by sandy shoals not generally present elsewhere in the lake (Lake Sunapee Protective Association, 2002), consistent with infilling of the graben by glacial drift. Thus we infer the motion on the Chalk Pond Fault to be NE side down, SW side up. This makes the main body of Lake Sunapee a graben! And some of the hills in the town of Sunapee may be horsts; Mount Sunapee itself could be a horst.

The NNE-SSW trending faults on the western side of the lake between the Georges Mills Fault and the Chalk Pond Fault are marked by small-scale faults in outcrop, many of which are consistent with mapped lineaments (Clark et al., 1998; Clark et al., 1996), although certainly not all mapped lineaments are necessarily faults. These faults appear to be NW side up and to the north, SE side (the lake) down and to the south, based on slickenlines on the fault surfaces

While the main body of the lake is in a graben, it is also possible that the southern arm of the lake may also be fault-controlled. In fact, the southern tip of the lake has the appearance of a U-shaped glacial trough, similar to the many notches in the White Mountains, which are also structurally controlled (Allen et al., 2001).

CONCLUSIONS

The Cardigan and Mount Clough Plutons grade into one another, but that relationship has been obscured by ductile structures that have "sandwiched" a septum of metasedimentary rocks between the two. The late syn-tectonic Spaulding Group magmas took advantage of these ductile structures to get up through the crust into the septum. The later post-tectonic Concord Group magmas appear to have followed some of these same conduits. The Sunapee Septum is a unique and important crustal-scale structure. Significant vertical displacement along late brittle normal faults has produced a horst and graben topography, the major graben now being occupied by the main body of Lake Sunapee.

ROAD LOG

The trip begins at the Mount Sunapee Ski Area off State Route 103 in Newbury, New Hampshire. Several of the stops we will make are on private property—please be respectful. Parking is limited at most stops. For this and other reasons, please carpool as much as possible—the trip *will* end up at back at the beginning. The area is covered by the following maps: the southern half of the USGS Sunapee Lake North, NH, 7.5-minute quadrangle, and the northern half of the USGS Sunapee Lake South, NH, 7.5-minute quadrangle, or the southeast quarter of the USGS Sunapee, NH, 7.5x15-minute metric quadrangle and the northeast quarter of the USGS Newport, NH, 7.5x15-minute metric quadrangle.

0.00		The mileage log begins at he Mount Sunapee Traffic Circle; follow Route 103 east/south towards Newbury
0.40	0.40	turn right into North Peak Village (private road)
0.80	0.40	keep right (uphill)
0.90	0.10	turn around at cul-de-sac and park along road

STOP 1. CLOUGH QUARTZITE, KINSMAN, SPAULDING, AND CONCORD GROUP ROCKS (45 minutes). The rocks here exhibit some very interesting and complex relationships, showing multiple magmatic episodes, co-mingled magmas and disaggregated xenoliths. We collected some material that we *thought* might be a felsic phase of the Spaulding co-mingled magmas. Two zircon crystals and three monazite grains separated from this rock were dated by U-Pb techniques, yielding an age of approximately 360 Ma (S. A. Bowring, written comm., 2001). This suggests that what we collected was in fact a cross-cutting intrusion of Concord Group granite, although it does not seem to have well-defined sharp contacts with the surrounding material.

1.00	0.10	return from whence you came
1.90	0.90	turn right, back onto Route 103 (east/south)
2.30	0.40	the outcrops all along this stretch of Route 103 are as complex as those at Stop 1.
3.40	1.10	Village of Newbury Harbor. During the retreat of glacial ice, this was the spillway for Lake Sunapee—draining into the Merrimack watershed—until Sunapee Harbor opened up and the lake could drain into the Connecticut watershed.
3.50	0.10	intersection with Route 103-A, continue on Route 103 (east/south)
4.00	0.50	road cut through the height of land. Several fault surfaces can be seen on the west side of the road.
4.25	0.25	turn right onto Mountain Road
4.80	0.55	park along the shoulder of Mountain Road— be careful not to go over the edge!

STOP 2. NEWBURY FAULT (15 minutes). The Kinsman has been brecciated and subjected to strong hydrothermal alteration along this major structure. Kaolinite gouge from this locality has yielded a K–Ar age of 160 Ma (J. B. Lyons, pers. comm., 1988).

5.45	0.65	turn around in the parking area for the Andrews Brook Trail, which is a nice hike up to Lake Solitude and the White Ledges on Mount Sunapee (see Fig. 3).
6.10	0.65	back at Stop 2 (we could have turned around here but the road is pretty narrow)
6.75	0.55	turn left onto Route 103 (uphill, west/north)
7.55	0.80	turn right onto Route 103-A (north)
9.70	2.15	The Fells was the summer retreat for several generations of the Hay family, including Secretary of State John M. Hay, who also served as private secretary to President Abraham Lincoln. The estate is now open to the public and protected as a part of the John Hay National Wildlife Refuge (http://www.thefells.org/). There is a hiking trail from here to top of Sunset Hill, which is made up of granitic pegmatites in the Kinsman.
9.80	0.10	Follow Route 103-A around a sharp right.
10.00	0.20	park on *left* shoulder of Route 103-A or on side of Ramblewood Drive, also on the left

STOP 3. KINSMAN OF THE CARDIGAN PLUTON (15 minutes) The rock here is a good example of the typical Kinsman, but this outcrop has been cross-cut by a dike of curious "mini-kinsman" porphyritic granite. This outcrop also exhibits a burnished fault surface (we are near the inferred Chalk Pond fault).

10.40	0.40	Follow Route 103-A around to the left; the road to the right is Chalk Pond Road
12.00	1.60	There appears to be kettle hole and some kame deposits on the right. We have not found any bedrock outcrops anywhere on the hill we have just driven over.
12.90	0.90	Follow Route 103-A around to the left at intersection with County Road (straight ahead) and Stony Brook Road (right)
13.90	1.00	A view over the trees ahead of the infamous radioactive roadcut on I-89.
14.10	0.20	Herrick Cove, Lake Sunapee
15.10	1.00	turn right into the Park-and-Ride lot

STOP 4. MIGMATITIC LITTLETON FORMATION (45 minutes). Walk over to and cross Route 11 to outcrops along the I-89 southbound Exit 12 off-ramp. There are numerous small brittle fault features here, as we are in proximity to the Georges Mills Fault. In addition, the deep basin sediments of the Littleton Formation are here metamorphosed to migmatites. Contrast the metamorphism of these rocks with those that we will see on the other side of the Georges Mills Fault.

		leave the Park-and-Ride lot by turning right onto Route 103-A (north)
15.15	0.05	Turn left onto Route 11 (west)
16.60	1.45	turn right onto Springfield Road (toward I-89) in the Village of Georges Mills
17.20	0.60	turn left onto Stoney Brook Road, just before the intersection with I-89
17.70	0.50	park on the left just under the highway.

STOP 5. BETHLEHEM GNEISS OF THE MOUNT CLOUGH PLUTON (10 minutes). The rock is a well foliated (gneissose) biotite granodiorite, relatively homogeneous in appearance.

		turn around and return the way we came
18.20	0.50	turn right onto Springfield Road back towards Georges Mills
18.80	0.60	there is a market at this intersection if you need supplies for lunch, otherwise continue across Route 11 onto Cooper Street heading down to Lake Sunapee for lunch.
18.90	0.10	park at Georges Mills landing

STOP L. LUNCH on the shores of Lake Sunapee at the Georges Mills landing (30 minutes).

		return to Route 11, taking the west branch (left) of Cooper Street across the river.
19.00	0.10	turn left onto Route 11 (west)

19.20	0.20	turn left onto Jobs Creek Road and turn right immediately to park around the Sunapee Fire Department garage—DO NOT block the firetruck! Carefully cross Route 11 to outcrop on west side of the highway.

STOP 6. GRANITE OF THE SUNAPEE PLUTON (15 minutes). There are several large outcrops between here and the top of the hill which at first glance appear to be granites. While much of the rock is granite and pegmatite, there are zones of schist and quartzite (probably Clough Formation). There are also several burnished fault surfaces with slickenlines, and manganese and iron oxide as well as calcite mineralization. Sense of motion is east side down and to the south. Many of the joints show evidence of early hydrothermal alteration to the granite.

19.35	0.15	turn left, back onto Route 11 (west, uphill)
20.90	1.55	turn right onto Sunny Lane (or you can park for STOP 7 off the shoulder of Route 11, without entering Sunny Lane).
21.20	0.30	turn around at cul-de-sac and return to intersection with Route 11
21.45	0.25	park in a shady spot along the shoulder of Sunny Lane; do not block any driveways.

STOP 7. SILURO-DEVONIAN METASEDIMENTS (15 minutes). Carefully cross Route 11 to outcrops on east side of highway opposite the entrance to Sunny Lane. Of particular interest here is the contrast in metamorphic grade between these rocks and those at Stop 4.

21.50	0.05	turn right, back onto Route 11 (west); view of Mount Sunapee to the south.
21.70	0.20	more outcrops of Littleton schists on the right; graded beds show tops to SE.
22.00	0.30	turn right onto Old Grandliden Road
22.10	0.10	turn around at intersection with Old Route 11, and park

STOP 8. INTRUSIVE CONTACT OF SPAULDING (30 minutes). Starting at the SW corner of the intersection we find typical Littleton-type schists. Crossing to the NE corner and proceeding N along the outcrop, the schist becomes progressively more migmatized as we approach a contact with a sill of Spaulding Group rocks. Dorais (2003) has estimated the temperatures of Spaulding Group magmas to be in excess of 850°C, well above the ambient metamorphic temperature. The Spaulding magma here is clearly heterogeneous in texture and composition, containing linearly oriented "flecky" biotite-hornblende clusters at different scales and concentrations, needle-shaped feldspar phenocrysts, and injection of and brecciation by more felsic material. In addition there are several *en echelon* slicken-lined and mineralized fracture surfaces oriented N-S, dipping steeply east. Sense of motion is east side down and to the south.

22.20	0.10	turn right, back onto Route 11 (west)
22.60	0.40	another outcrop of Littleton schists
23.00	0.40	park on the right shoulder just past Sargent Rd.

STOP 9. AUTOLITHS OF SPAULDING QUARTZ DIORITE AND PEGMATITE (15 minutes): Quartz diorite of the Spaulding Group is cut by pink pegmatites (with perthitic feldspar), but you can see "autoliths" of the pegmatite within the Spaulding and vice-versa. Thus the pegmatite and the quartz diorite must be magmatically related.

23.10	0.10	continue on Route 11 (west)
23.30	0.20	turn right onto Lower Main Street
23.80	0.50	turn right onto North Road
23.95	0.15	turn right into the Sunapee Middle-High School north parking lot, park in the north-east corner close to the athletic fields.

STOP 10. THE BALLFIELD OUTCROP (60 minutes): Behind the outfield fence is an extensive outcrop, depicted in detail in Figure 5. The contact between the Kinsman and the metasediments of the septum has seen extreme ductile shear. This contact was also a locus for igneous intrusion, and subsequently for late brittle normal faulting. Outcrops exposed along Lower Main Street also reveal the progressive shearing of the Kinsman, transitional to the textures observed in the Bethlehem, up to the contact with the metasediments.

		return whence we came back to the center of town
24.60	0.65	cross Route 11 onto Main Street (heading uphill)
24.90	0.30	Sunapee Harbor, continue ahead on Lake Avenue
25.20	0.30	turn right into Indian Cave Landing (private road)
25.30	0.10	left toward the Outlook, past the outcrops of Kinsman
25.40	0.10	left toward the Outlook, through the outcrops of Kinsman with several possible fault surfaces
25.60	0.20	turn right at circle and find a spot to park off to the side. Try not to damage any lawns.

STOP 11. MAGMATIC TEXTURES IN THE SPAULDING (20 minutes) This sill of Spaulding Group rocks—with Kinsman above and below it (as well as some 2-mica granite nearby)—shows multiple pulses of magmatism. This sill may be an extension of a sill that outcrops at lake level just north of Sunapee Harbor, vertically offset by normal faulting (Chalk Pond Fault?).

		return back down the way we came in
25.90	0.30	turn right
26.00	0.10	bear right
26.10	0.10	turn right, back onto Lake Ave
26.80	0.70	At this point, we are driving along the Chalk Pond fault scarp. The deepest point in the lake (142 feet) is off this shore.
27.70	0.90	Note the waterfront house on the left (with 3 bay garage) and the matching 6 bay (4 in front, 2 on each side in back) garage opposite on the right.
27.90	0.20	turn right onto Burkhaven Hill Road
29.10	0.20	the road takes a sharp left, continue following it
29.40	0.30	turn right onto Harbor Hill road
29.70	0.30	turn around at cul-de-sac and return to intersection with Burkhaven Hill Road. Park along the shoulder of Harbor Hill Road

STOP 12. CONTACT BETWEEN KINSMAN AND 2-MICA GRANITE (15 minutes) The granite on top of Harbor Hill is locally porphyritic, with feldspar phenocrysts up to 2 cm long. The granite occurs in a narrow structure within the Kinsman, extending to the south where it is more homogeneous and fine-grained. There (to the south) it has been and still is being extensively quarried. At this stop, we see a contact relationship where the granite is intruding the Kinsman.

30.00	0.30	turn right, back onto Burkhaven Hill Road
30.45	0.45	turn left on Main Street (back in Sunapee Harbor)
30.50	0.05	turn left onto River Road
30.65	0.15	turn left onto Maple Street (uphill)
30.85	0.20	turn right onto Beech Street (Maple Street ends)
30.90	0.05	turn left onto Route 103-B (south) and keep to the left
31.10	0.20	Sunapee Granite Works
33.90	2.80	junction of Route 103-B with Route 103 at the Mount Sunapee Traffic Circle.

END OF TRIP

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