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FIELD RELATIONS, PETROGRAPHY AND PROVENANCE OF MAFIC DIKES, WESTERN MAINE.

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INTRODUCTION

In his 1965 report on the Geology of the Bryant Pond quadrangle, Maine, C.V. Guidotti mapped some 65 mafic dikes within this field area. However, his rather enigmatic map (see Figure 2 of his report) served only to inspire a group of undergraduates and their advisor to further investigate these intrusions. Guidotti (1965) assigned a preliminary Triassic age to these intrusions but to date no accurate age determinations have been performed on these rocks. Since publication of Guidotti's report many other researchers have reported and mapped petrographically similar dikes that intrude further to the south into the Sebago Lake region.

The mafic dikes of the study area intrude a variety of rock types that are found in the general area of high-grade metamorphism in western Maine (Figure 1). Specifically, these dikes intrude the Devonian Songo granodioritic pluton (Stop1 on this field trip), the 293±2 Ma Sebago (*sensu latto*) two-mica granite (as displayed at Stops 3 and 4) and the metamorphic country rock envelope that surrounds both these intrusions. Mafic dikes are also observed intruding several of the pegmatities that form a distinct zone in western Maine, such as the Bumpus, Tamminen and Havey quarries.

In general the spatial and temporal occurrence of numerous dikes (forming a dike swarm) is a strong indication of extensional tectonics. Many other examples of dikes swarms are observed along the Maine coast such as the exceptional exposures around the Schoodic peninsula, but others are also observed throughout New England and in Maritime Canada. Therefore there are a number of possible sources for the western Maine mafic dike swarm. They could be related to the Eastern North American (ENA) magma series, which are remnants in N. America of the Central American Magmatic Province (CAMP). These are assumed to be ~ 200 Ma and are predominantly tholeiitic in composition. However, they might also be related to the older (~ 225 – 230Ma) Coastal New England (CNE) magma series, which have a definite alkaline affinity and maybe related to a deeper "plume" source. There are distinct geochemical parameters (as discussed below) that can be utilized to distinguish between these magma series. In addition, the western Maine dike (WMD) suite could be related to the White Mountain Magma Series, a group of mostly plutonic rocks of alkaline affinity. The latter are represented in western Maine by small stocks, e.g. Rattlesnake Mountain, that intrude the Sebago granite and have described by Creasy in the Jackson volumes (1989).

Our field trip today is a north to south traverse that will enable examination of the range of dikes that constitute the WMD series. The main objectives are to examine -

a) the petrography of these dikes in an extended area from Bethel in the north, to Sebago Lake in the south (see Figure 9),
b) their field relationships, specifically their orientations and any cross cutting evidence that may pertain to one or more sets of dikes(?),
c) any relationships between the host rock and dike petrography,
d) the provenance of the WMD swarm, specifically their major and trace element composition to assess if they have a geochemical affinity with other dike swarms that occur regionally (as outlined above).

GENERAL GEOLOGY OF THE STUDY AREA

The igneous and metamorphic geology of western Maine has been the focus of many NEIGC field trips over the years and therefore we will highlight only the salient details in this section. Readers are referred to the following NE GSA and NEIGC field trip guides for more comprehensive information – Guidotti et al. (1986 and 1996), Solar et al. (2001, 2009 and 2016). The main rock units that host the mafic dikes are the Songo pluton, the pegmatitic intrusions and the Sebago "batholith" (*sensu latto*).

The Songo pluton is a post-Acadian intrusion that covers approximately 350 km^2. It is a medium grained, equigranular granodiorite that displays some textural and compositional variation. Initial age dates for the pluton

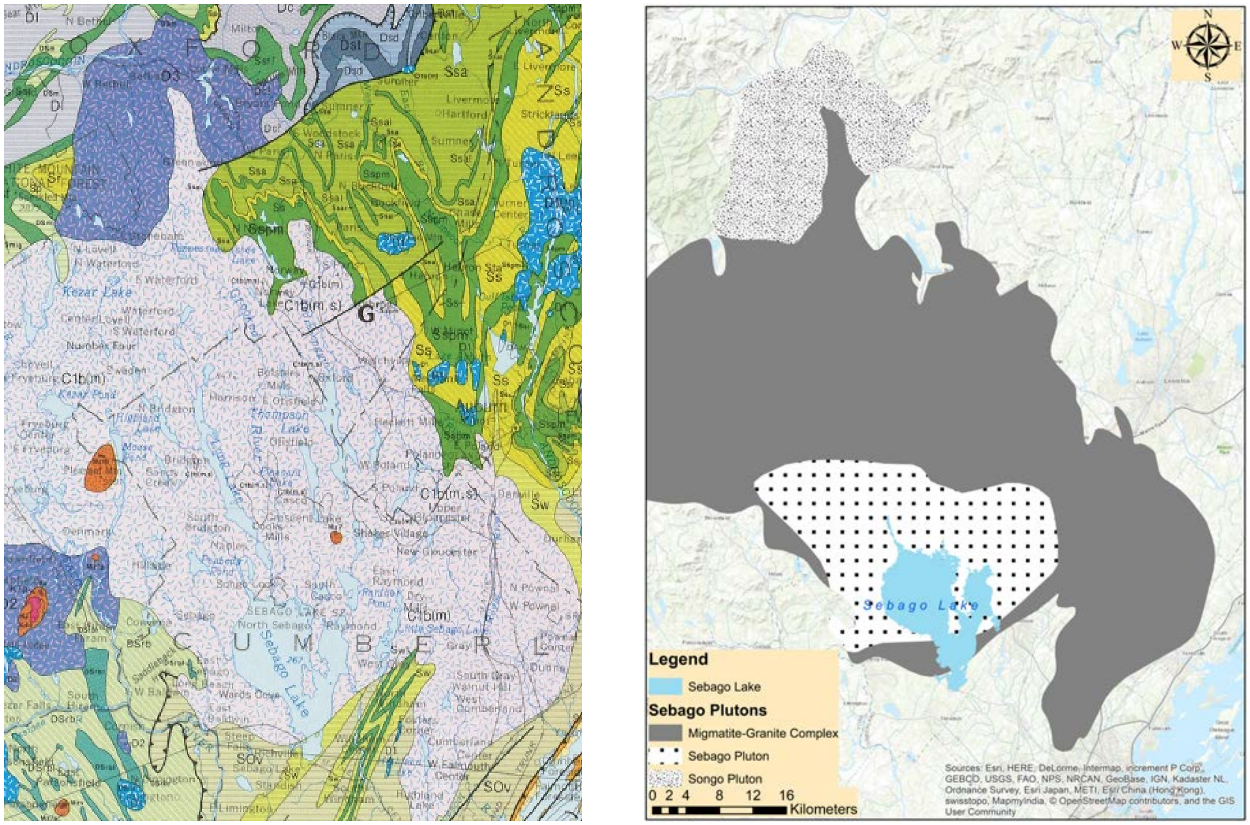


FIGURE 1. Bedrock map of western Maine as displayed on the 1985 State map (Osberg et al. 1985) compared to current map of the major rock units (after Solar and Tomascak 2009).

suggest a crystallization age of ~ 380 Ma. However, new LA ICP-MS zircon data reveal a much younger age of 364 ± 1.3Ma for the Songo (pers comm. van Rooyen, 2017). For the most part the pluton is an unfoliated granodiorite with biotite ± hornblende ± sphene, a typical I-type granite mineralogy (Chappell and White, 2001). However, in other (mappable) areas (see Figure 2 of Gibson and Lux, 1989) the Songo pluton lacks hornblende, the biotite has a distinctive red/brown sheen often indicative of high TiO_2 contents and can be strongly foliated (Stop 1). The latter areas are coincident with the proximity of the Sebago granite and/or pegmatitc bodies that also often contain sheet-like bodies of leucocratic granite not dissimilar to the Sebago itself. In addition, $^{40}Ar/^{39}Ar$ dating of hornblende from the Songo pluton (Lux and Aleinikoff, 1985 and Lux et al. 1989) yielded significantly younger ages than the crystallization age of the pluton. These younger, reset hornblende ages led Guidotti et al. (1985) to suggest that this metamorphic event was related in time and space to the emplacement of the Sebago pluton. However, subsequent research has cast doubt on this idea.

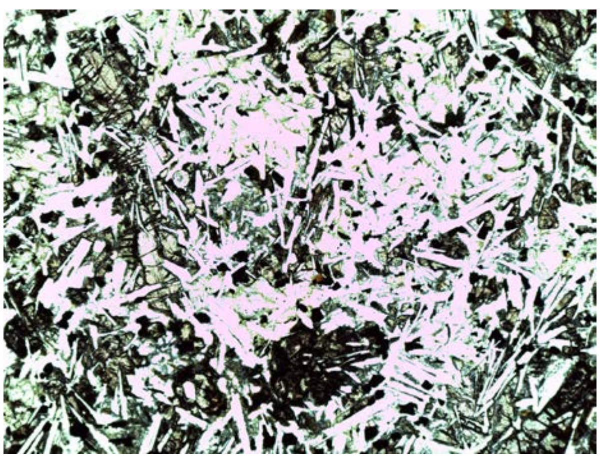
Pegmatitic intrusions are ubiquitous throughout western and south-western Maine and are often associated with the Sebago granite in the southern part of the Oxford pegmatite field. Wise and Francis (1992) classified them as LCT REE-granite pegmatites and they fall into three categories – 1) simple pegmatites that are composed of K-feldspar, quartz, muscovite and bitoite and often display classic graphic intergrowths, 2) beryl-type pegmatites containing beryl along with albite (cleavlandite), and 3) Li-enriched pegmatites of the spodumene subtype. In many of these pegmatitic intrusions mafic dikes are observed, e.g. Songo Pond, Bumpus, Tamminen, and Havey.

The Sebago batholith/pluton et al. Although originally mapped as a single intrusion, as shown on the 1985 bedrock map of Maine (Osberg et al. 1985), the Sebago "batholith" has been shrinking in size ever since[1]! The detailed research of Gary Solar and Paul Tomascak (2001, 2009 and 2016), and their students, have shown that the Sebago granite pluton covers an area of only 400 km^2 which roughly encircles Sebago Lake. They subdivided the previously mapped batholith into a more homogeneous core of two-mica, fine to medium-grained granite, the Sebago granite pluton, and a heterogeneous area surrounding it. The latter area is highly variable composed of two-mica granite and granodiorite, schleiric granite, pegmatite dikes, metapelitic pelites and diatexites. This rock "smorgasbord" surrounds the Sebago granite and is referred to as the Sebago Migmatite Domain or more recently the Migmatite-Granite complex (Solar and Tomascak, 2016). We will see some of these rocks at our final stop on the field trip.

FIELD RELATIONSHIPS AND PETROGRAPHY OF THE MAFIC DIKES

The mafic dikes that intrude all the above country rocks are variable in size, petrography and orientation. They can be broadly subdivided intro three main types – 1) Thin, < 1m wide, basaltic dikes, 2) Larger , > 1m wide, basaltic to basaltic andesites, and 3) Trachy basalts which have a distinctive glomeroporphryitic texture.

TYPE 1 DIKES – These basaltic dikes are usually between 60 cm to a few cms in width and have narrow chilled margins (< 1cm) with the host rocks. They are most commonly aphyric in texture, but some examples are porphyritic with small, ~ 1cm long, plagioclase lathes. Photomicrographs showing the textures of these basaltic rocks are shown in Figures 2, 3 and 4, which also show the abundance of plagioclase lathes often arranged in a pseudo-radiating texture indicating quenching. In addition, abundant pyroxene is present with the distinctive reddish/brown color of titanaugite. Future mineral chemistry studies should help confirm their detailed mineralogy. They are vertically inclined and trend from NNE – SSW to NE – SW. We will see examples of the Type 1 dikes at Stops 1 and along the large road cut of Stop 5. At the latter locality some of the thin vertical dikes are displaced by minor sub-horizontal faults although they display ample evidence to confirm that they are post deformation.



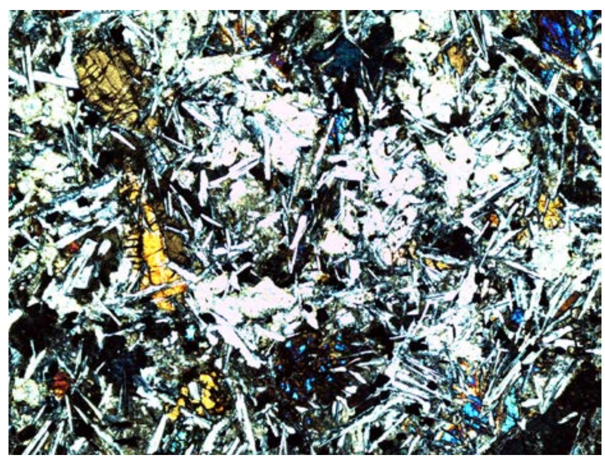


FIGURE 2. Photomicrographs of WMD-2 showing aphyric texture with semi-radiating plagioclase lathes and possible titan augite. PPL on the left; CPL right. Field of view 3.5mm.

[1] Which in fact is a good thing as the Sebago "batholith" was considered as a potential repository for nuclear waste!!

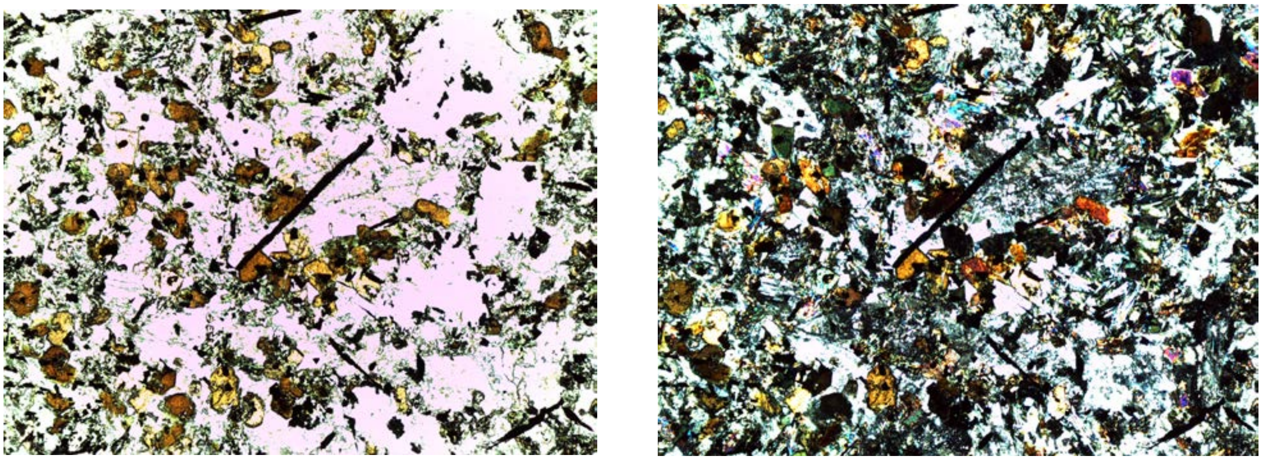


FIGURE 3. Photomicrographs of WMD-4 showing aphyric texture with abundant possible titanaugite and skeletal opaques indicative of quenching. PPL on the left; CPL right. Field of view 3.5mm.

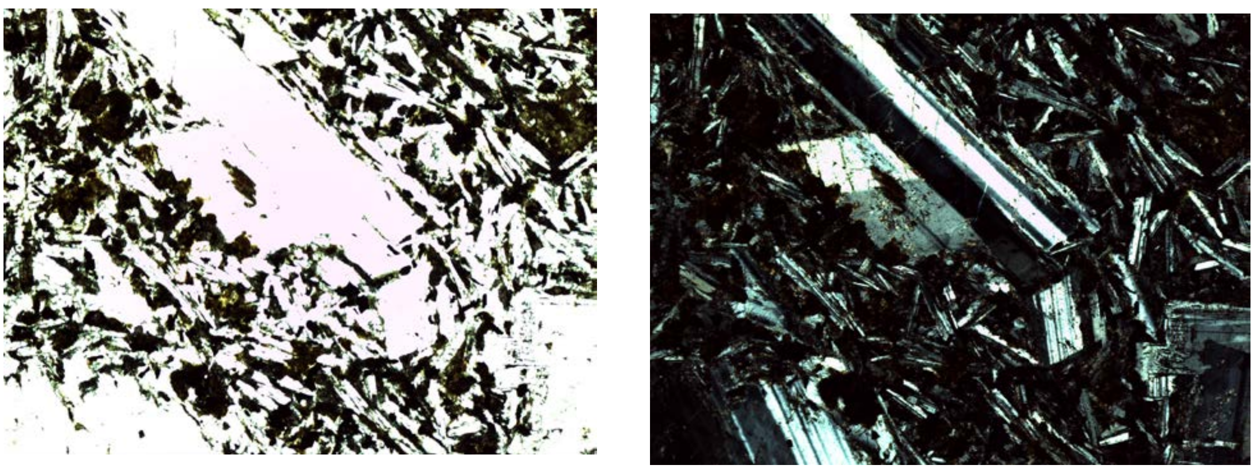


FIGURE 4. Photomicrographs of WMD-6 showing plagioclase-phyric texture. PPL on the left; CPL right. Field of view 3.5mm.

TYPE 2 DIKES – The larger basaltic to basaltic andesite dikes have a distinct chilled margin with the host rocks, as shown in Figure 5. Away from their margins they have a coarser-grained texture appearing more diabasic and can display ophitic and subophitic textures, Figure 5. The larger Type 2 dikes commonly contain xenoliths of their host rock and also larger selvages of granite, as we will observe at Stop 5. These dikes vary in inclination and orientation. Most of them are vertical but some notable exceptions dip steeply, generally to the SE. They also have a more consistent trend to the NE – SW.

TYPE 3 DIKES – These dikes are distinct from the other two types as they are lighter in color with clusters of minerals forming a glomeroporphyritic texture. These areas are 2 – 3cm across and possibly contain Na-rich pyroxenes, Figure 6. The groundmass is fine-grained with abundant plagioclase, pyroxene and some olivine. These dikes are vertically inclined but have a more definite E – W trend.

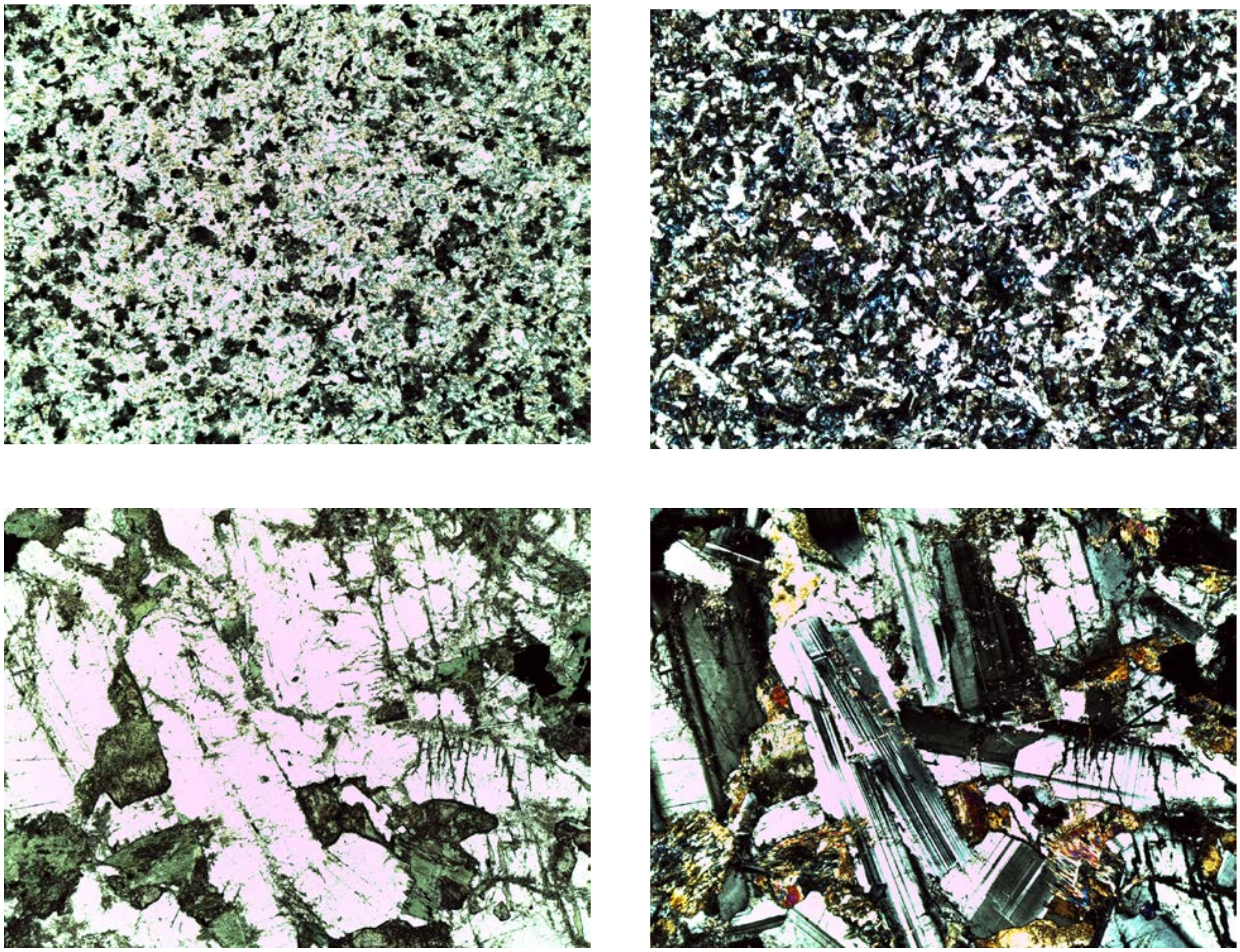


FIGURE 5. Photomicrographs of WMD-7. Top set show the chilled margin of this dike in contrast with the coarser-grained diabase interior, bottom set. PPL on the left; CPL right. Field of view 3.5mm.

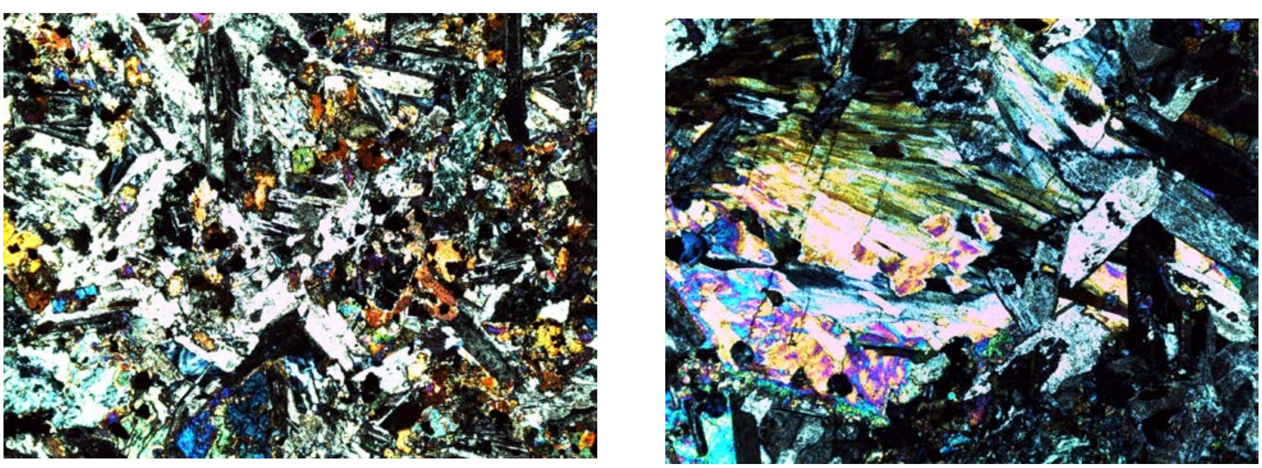


FIGURE 6. Photomicrographs of WMD-9a, the glomeroporphyritic trachy basalt. On left the groundmass texture of this dike; on the right one of the glomercrysts. PPL on the left; CPL right. Field of view 3.5

GEOCHEMISTRY

As this is a ***field trip*** we will not delve too much into the geochemistry of these dike rocks. However, given their fine-grained textures it is necessary to utilize geochemical data in order to classify them. Geochemical discrimination diagrams (Pearce and Cann, 1973) can aid in examining the tectonic setting of these intrusions. In addition, several geochemical parameters can be employed to discriminate between dikes of potential magma sources, i..e. the Coastal New England (CNE) suite and the Eastern North America (ENA) suite (Dorais et al., 2005 and McHone, 1992). In particular the levels of TiO_2 and Zr are higher in the CNE series compared to the ENA, and the CNE dikes are enriched in Nb whereas the ENA series have Nb and Ti anomalies

25 samples have been collected from western Maine and analyzed for 18 major, minor and trace elements, Analyses were performed in the UMF XRF laboratory using standard procedures of sample preparation and analysis, including USGS standard materials. Only those samples that are definitely post deformation have been plotted on the following diagrams.

Figure 7 demonstrates that the WMD are predominantly alkaline although some subalkaline compositions are evident. The other bivariate diagrams show the WM dike compositions in comparison with the fields for dikes of the CNE and ENA series. It would appear that the WM dikes are more closely related to the CNE suite than the ENA dikes. The discrimination diagrams, Figure 8, not surprisingly demonstrate that the WM dikes are within plate basalts with a spread of alkali and tholeiitic compositions

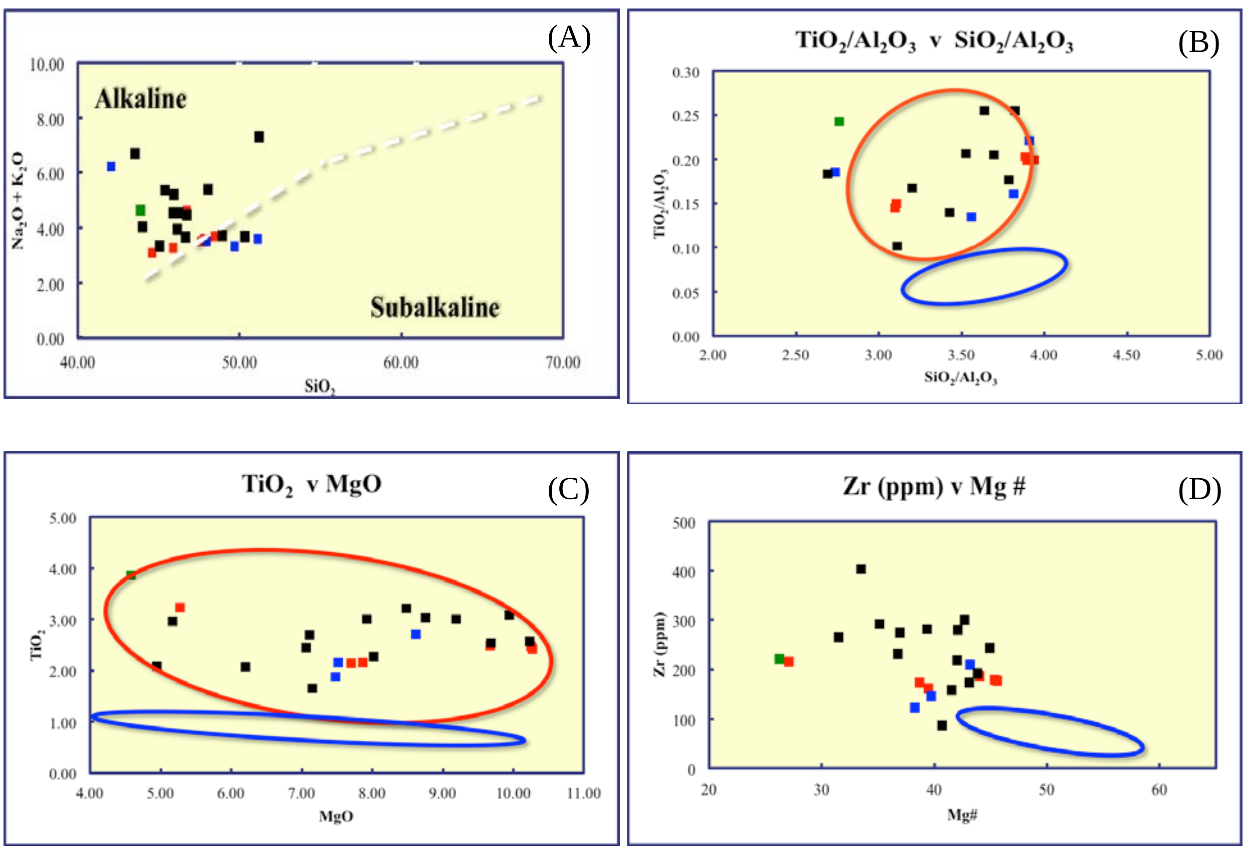


FIGURE 7. Bivariate diagrams showing the range of compositions for the WM dikes. (A) Plot of total alkalis V SiO_2 wt.% ; Plots (B), (C), and (D) plot geochemical parameters, suggested by McHone (1992) and Dorais (2005), to discriminate between the CNE (red field) and ENA (blue field) dike suites.

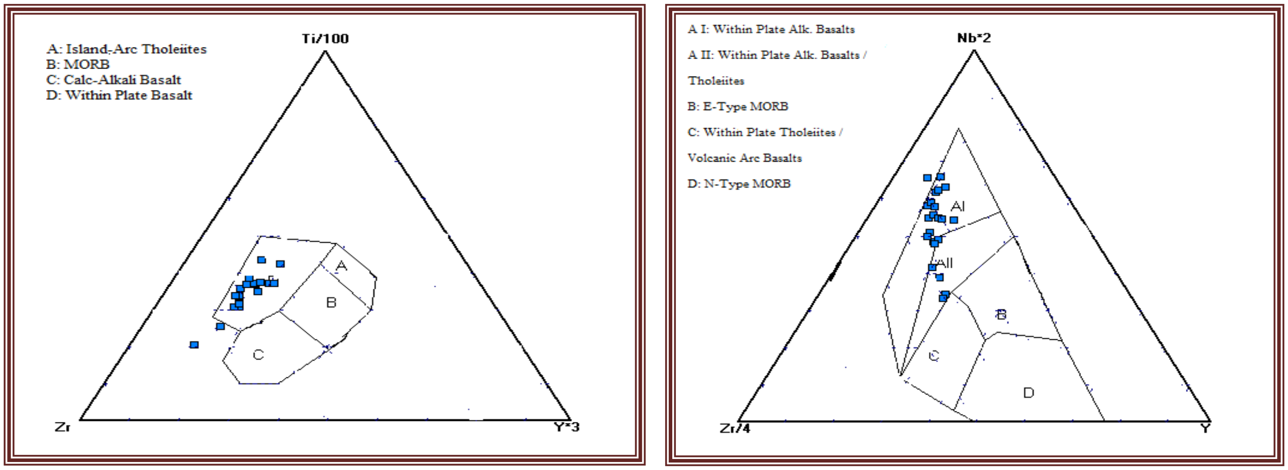


FIGURE 8. Basaltic tectonic discrimination diagrams (Pearce and Cann, 1973) showing the within plate signature and alkalic nature of the WMD series.

SUMMARY

The WMD series are predominantly aphyric basalts and diabases although some have higher amounts of the alkali elements and are trachy basalts. These are most likely related to the alkaline Mesozoic intrusive series as described by Creasy (op cit). They are predominantly post deformation although some may have experienced late stage faulting. Many examples may contain titaugite though this needs to be confirmed by electron microprobe analysis. They have higher TiO_2 contents than the ENA series and display greater affinity to the CNE suite of dikes. Their trace element concentrations place them in the within-plate fields on the standard basaltic discrimination diagrams. In conclusion, the majority of western Maine dikes have a close geochemical affinity with the Coastal New England magma series and this extends the geographic area over which this series is observed.

ACKNOWLEDGEMENTS

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ROAD LOG

MEETING POINT: Meet at the Casablanca Cinema 4 parking lot on Cross Street in Bethel (44º 24’ 40.73” N; 70º 47’ 30.64” W) at 8:30am on Sunday, October 1st. This parking lot is beside the Bethel Area Chamber of Commerce. There will be limited opportunities to get food so you might consider bringing lunch with you. The trip will end close to access roads for I 95 north and south. The road map for this field trip, from Bethel to near Gray, is displayed in Figure 9.

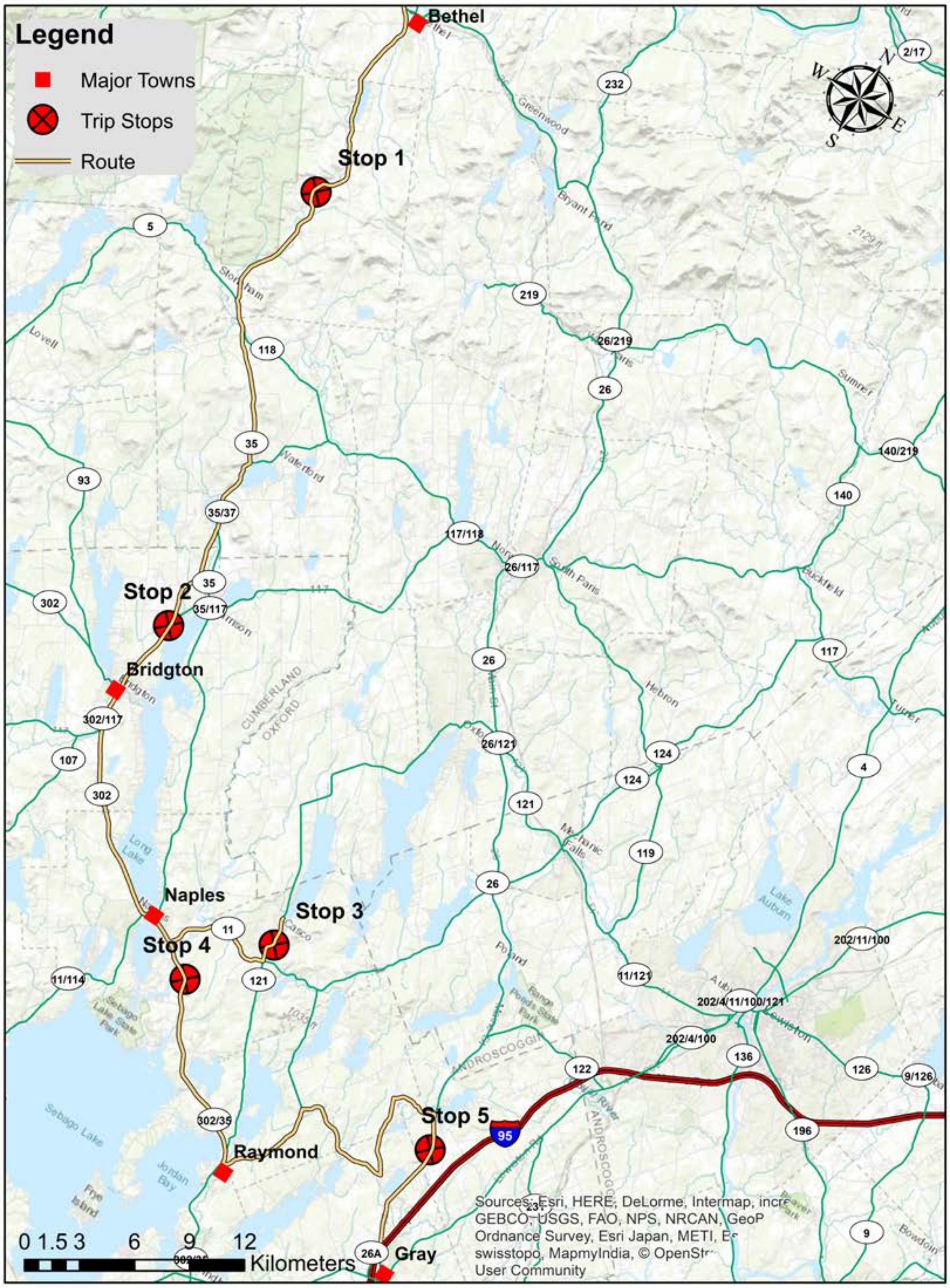

FIGURE 9. Map of the route taken on this field trip.

MILEAGE

0.0 Turn right out of the parking lot onto Cross Street and then take next right onto Mechanic Street. Take another right after crossing the railway tracks onto Railroad Street. The road then goes under Rte 2, and merges in 0.7 miles with Rte. 2 W. In 0.1 miles turn left onto Rtes 5 & 35, Songo Pond Road. Continue S passing Songo Pond on your left.

8.0 Park on shoulder. (NOTE: this is a solid hard shoulder but others on the field trip are not. Please try to ensure you always keep two wheels on more solid surfaces)

STOP 1. DOUGLASS QUARRY. PETROGRAPHY OF THE SONGO GRANODIORITE, PEGMATITE AND LEUCOGRANITE SHEETS ALL INTRUDED BY MAFIC DIKES.

Access to the quarry is by permission only and if you wish to revisit this locality you must get permission from the owners.

At this locality we can observe a couple of thin, < 1m, mafic dikes intruding highly foliated Songo granodiorite, a leucogranite sheet and pegmatite. The Songo here is typical of the deformed petrographic variant and the red/brown sheen of the biotites can be clearly observed. The mafic dikes are aphyric basalts with narrow chilled margins. The field relationships clearly show that the mafic dikes are younger than the other rock types in this quarry, Figure 10.

FIGURE 10. Stop 1 Douglass quarry showing thin basaltic intruding the Songo granodiorite (at back wall of quarry) and cutting leucocratic sheets and pegmatite. Insert shows close up of contact with chilled margin.

Continue S on Rtes 5 & 35.

13.0 Turn left onto Rte 35 S. (NOTE: Interesting signpost at this intersection, a Maine peculiarity!)

14.0 Jct. with Rte. 118 stay on Rte. 35.

18.0 Jct of Rte. 35 with Rte. 37, continue on Rte. 35.

21.0 Right hand turn onto combined Rtes. 37 and 35 to Bridgton. Stay on Rte. 37 after Bear Pond on right Reduced speed zone going through N. Bridgton passing Bridgton Academy on right.

25.0 Pull off onto shoulder just beyond the junction with Rte. 117.

STOP 2. MAFIC DIKES INTRUDING THE SEBAGO GRANITE.

At this locality two mafic dikes are observed intruding Sebago granite like country rock. Even though the main area of the Sebago pluton is observed further to the south isolated areas of similar rocks are found within the Migmatite-Granite complex. Chilled margins to the dikes and granite xenoliths within them clearly demonstrate the intrusive nature of the dikes.

FIGURE 11. Stop 2 - examples of basaltic dikes with chilled margins, xenoliths of country rock and apophyses.

Continue heading S on Rte. 117

28.0 Jct. with Rte. 302 turn right and continue on Rte. 302.

29.0 Major intersection in Bridgton. Stay on Rte. 302 E to Naples (Maine that is !).

43.0 Intersection with Rtes. 35 and 11 south of Naples. Turn left.

47.0 Turn L onto Rte. 121.

48.0 Park at second layby on right hand side and walk up to the outcrop opposite Birch Terrace.

STOP 3. GLOMEROPORPHYRITIC TRACHY BASALT DIKE.

At this locality there is an excellent example of a trachy basalt dike intruding the Sebago granite. Notice the crystal clusters that dominate the texture of this rock. Are these glomerocrysts or could they be small xenoliths? Further along the outcrop look for a thin basaltic dike like other examples we have observed on this field trip.

Return to vehicles and reverse direction going S on Rte. 121.

49.0 Junction with Rtes. 35 and 11, turn right.

53.0 Turn left onto Rte. 302. Take care this is a very busy junction.

56.0 Park on shoulder just beyond Rabbit Lane and before Varney Hill Road.

STOP 4. A VARIETY OF DIKES INTRUDING SEBAGO GRANITE.

At this locality there are three dikes that intrude the Sebago granite. Our objectives at this outcrop are to locate the dikes at this locality; secondly examine their petrography. Are they all the same? Thirdly, are there any cross cutting relationships that could give relevant information regarding the timing of these intrusive events?

FIGURE 12. Two types of "porphyritic textures observed in the dikes at Stop 4.

Continue south on Rte. 302 E.

61.0 Jct. with Rte. 121.

62.0 Jct. with Rte. 85, pull into rest area on right.
This will be our lunch stop.

62.0 Exit rest area and proceed straight across intersection onto Rte. 85.

66.0 Turn right onto Egypt Road.

70.0 Turn left onto N. Raymond Road.

73.0 Turn right onto Pond Road.

74.5 Park approximately 50 meters up from intersection with Rte. 26.

STOP 5a. RTE. 26 SECTION - N. NUMEROUS MAFIC DIKES AT THE EASTERN MARGIN OF THE MIGMATITE-GRANITE COMPLEX.

CAUTION: Rte. 26 is a very busy road and we must exercise extreme caution here. Please cross the road in the designated area and only when you are told it is clear to do so.

At this locality numerous mafic dikes intrude the leuco- and melano-somes of the migmatitic envelope of the Sebago pluton as defined by Solar and Tomascak (2016). Firstly examine the dikes on the west side of the road and then the eastern side. Several questions need to be addressed here - the variations of dike petrography, number of intrusive events and the disappearance of dikes from one side of the road to the other?
Return to vehicles, turn right onto Rte. 26 and continue south. As we drive south passengers note the numerous mafic dikes intruding this exceptionally well exposed migmatitic zone. Drivers keep your eyes on the road !

76.2 At the bottom of the hill turn left onto Sabathday Road (apropos!) and in a few meters turn left into the Gray Park ‘n Ride. We will walk back up the hill to Stop 5.

STOP 5b. RTE. 26 SECTION S. MULTIPLE GENERATIONS OF MAFIC DIKES INTRUDING THE EASTERN MARGIN OF THE SEBAGO/MIGMATITE DOMAIN.

At this locality there are different generations of dike intrusion. Cross cutting relationships can be definitely inferred if not observed directly. Again examine the petrographic variations of the dikes, their orientations and relationships with the migmatitic country rocks, see Figures 13 and 14 below.

FIGURE 13. Large mafic dike intruding the leucosome and melanosome of the migmatitic margin to this complex.

FIGURE 14. Dike intruding migmatite but it itself offset by late stage faulting.

This concludes our fieldtrip. Turn left out Sabbathday Road onto Rte. 26 and 26a to access I 95 N and S.

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