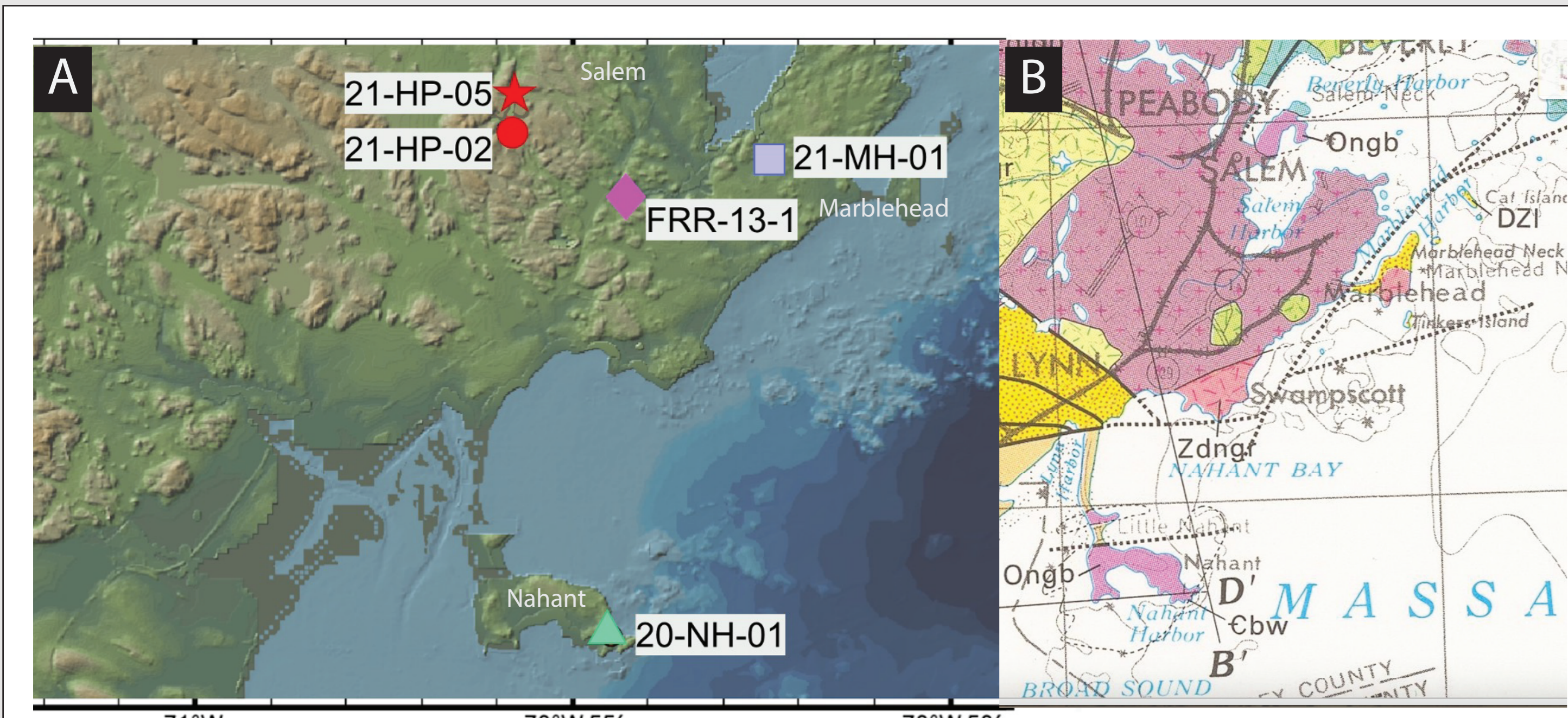


## INTRODUCTION

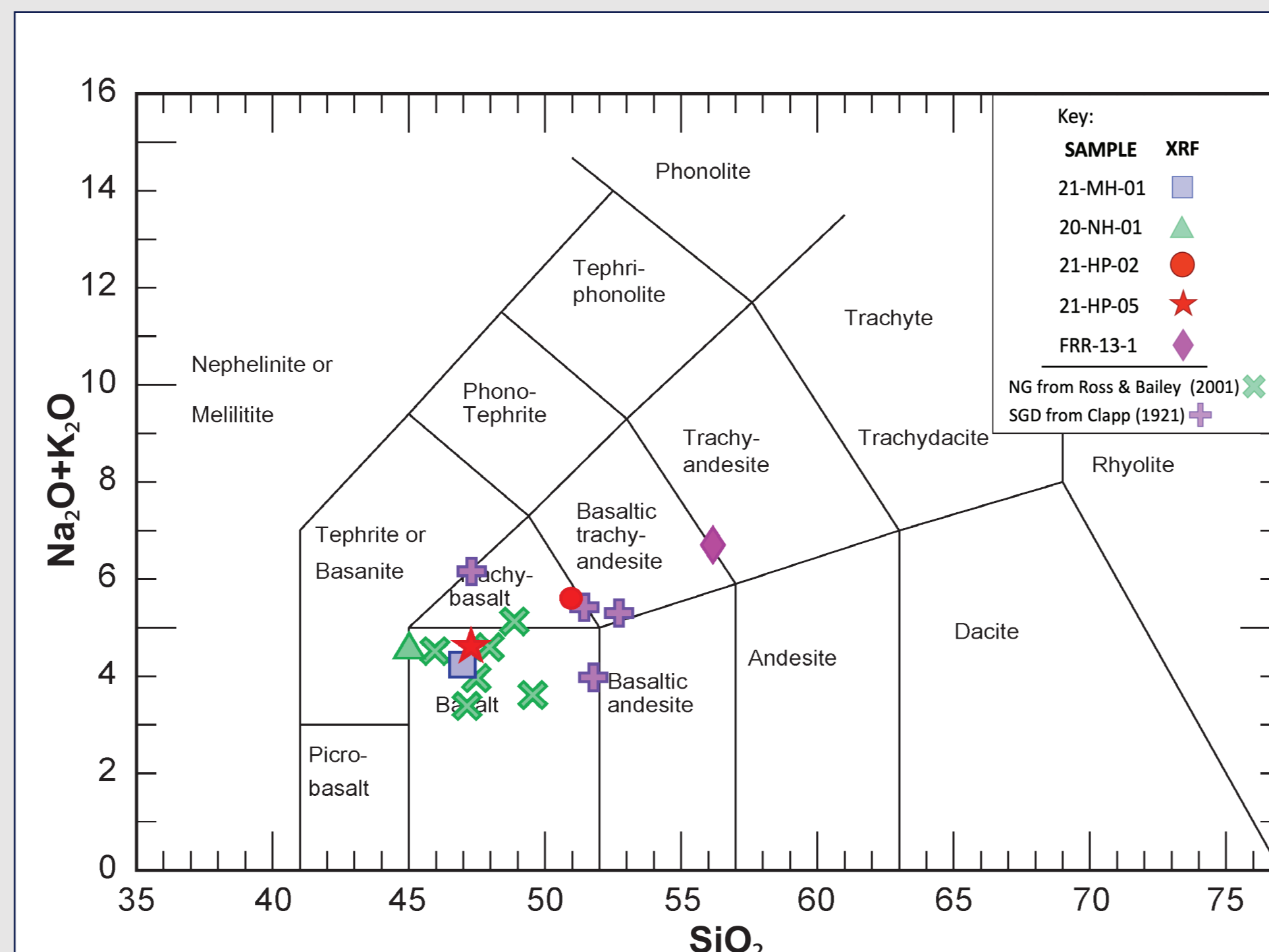
The Avalon Terrane formed during the late Proterozoic as a volcanic arc that was originally part of Gondwana and later rifted away from the supercontinent. During this rifting process, the Nahant Gabbro (NG) formed ~488 Ma, and later stages of rifting within Avalon led to the intrusion of the Salem Gabbro-Diorite (SGD; 431-425 Ma) and other plutons as part of the Mid-Paleozoic plutonic belt. Avalon gradually made its way across the Atlantic and collided with the modified margin of Laurentia, contributing to the formation of the Appalachian Mountains. The SGD and the NG outcrops are adjacent and due to their similarities in rock types, they can be hard to distinguish in the field. In this study, we collected five samples in four different localities to establish possible differences in petrology and geochemistry between the SGD and the NG.



**Figure 1:** (A) Map of the region being studied, which encompasses Salem, Nahant, and Marblehead (MA). (B) Geologic map of the region showing the lack of a direct contact between the Salem Gabbro Diorite and the Nahant Gabbro suggesting unit assignment difficulties. Nahant is labeled "Ongb" or Ordovician Nahant Gabbro. The other samples are plotting within the field mapped as the Salem Gabbro-Diorite.

## ROCK TYPE

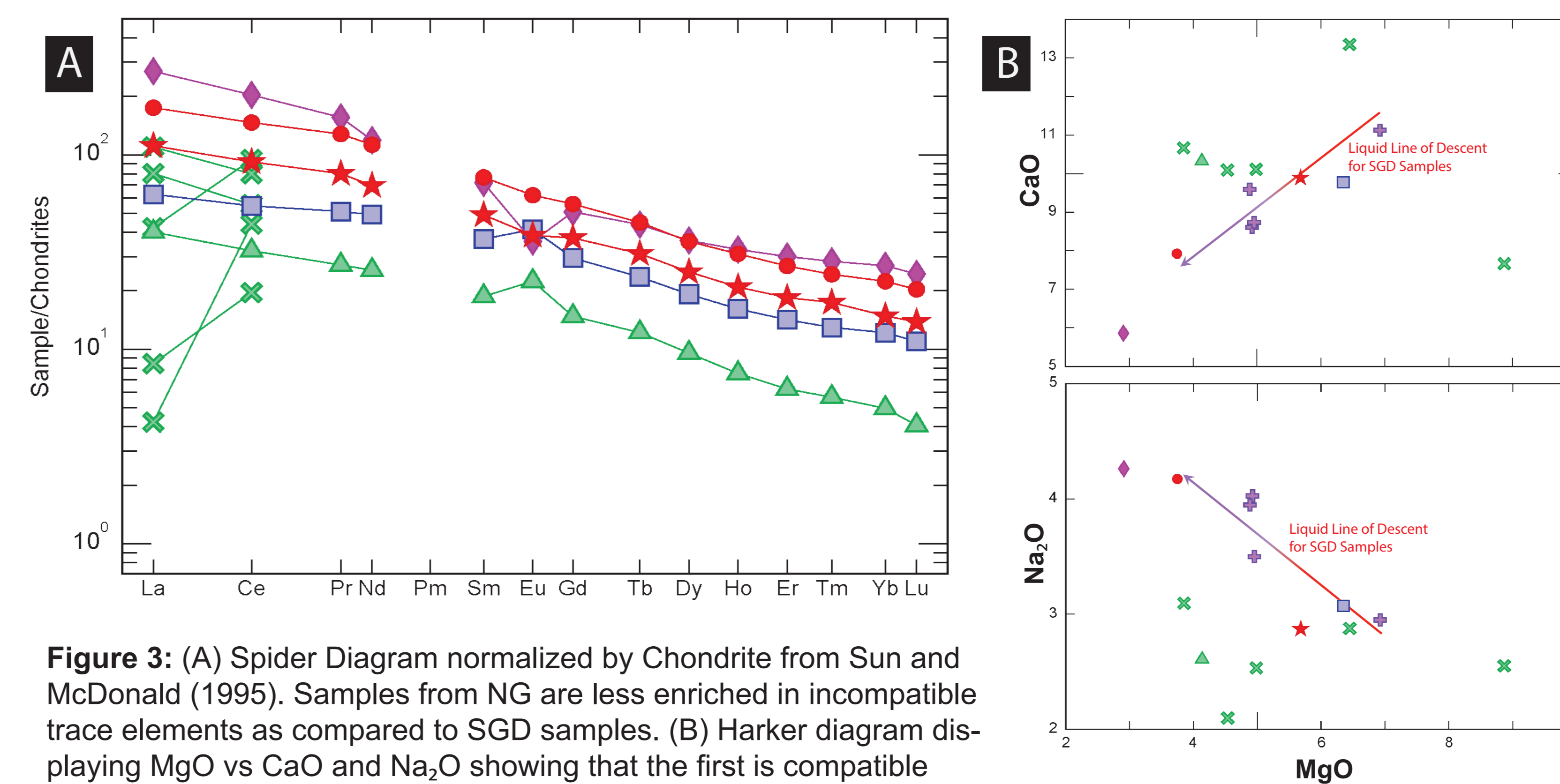
When plot on a TAS diagram the samples show a trend from basalt to basaltic andesite, and from trachybasalt to trachyandesite. The Nahant samples are consistently more primitive and overlap with the Marblehead sample, while the Salem Gabbro Diorite field expands towards more evolved compositions. Major and trace elements were ascertained via XRF and LA-ICP-MS.



**Figure 2:** TAS diagram modified from Le Maitre et al. (1989) of igneous rocks from Salem, Marblehead, and Nahant (Clapp, 1921, Ross & Bailey 2001, this study).

## MAGMA CHARACTERIZATION

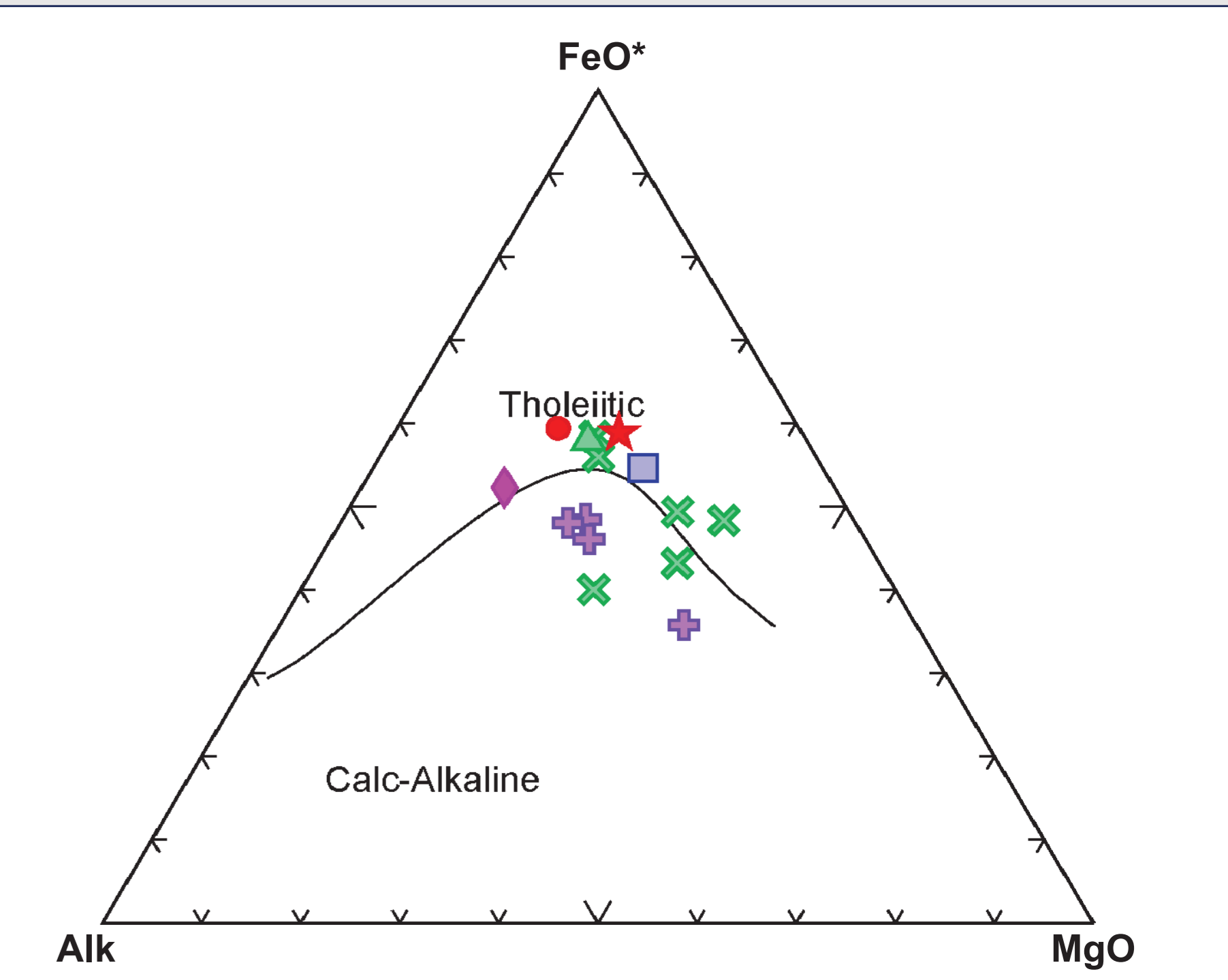
Samples from Nahant, Marblehead, and the dalmatian sample (21-HP-05) from the Highland Pluton are consistently more primitive with high MgO, low SiO<sub>2</sub> and are depleted in incompatible trace elements as compared to the SGD. Enrichment of incompatible elements can be derived from various degrees of fractional crystallization and/or lower degrees of partial melting. The sample from Marblehead plots in between the NG and the SGD samples and appears to be most similar to the trend of the NG thanks to the presence of an Eu positive anomaly. Since Eu is fractionated by plagioclase, this positive anomaly reflects an enrichment/ accumulation of plagioclase within the magma in the NG. If modelling the SGD flows as one magma undergoing fractional crystallization we notice that CaO is compatible, while Al<sub>2</sub>O<sub>3</sub>, Na<sub>2</sub>O, and K<sub>2</sub>O are incompatible confirming that plagioclase is not a major phase fractionating during the formation of the SGD.



**Figure 3:** (A) Spider Diagram normalized by Chondrite from Sun and McDonald (1995). Samples from NG are less enriched in incompatible trace elements as compared to SGD samples. (B) Harker diagram displaying MgO vs CaO and Na<sub>2</sub>O showing that the first is compatible while the latter is incompatible.

## TECTONIC SETTING

The AFM tectonic discrimination diagram used to distinguish between tholeiitic and calc-alkaline diagram. The SGD and NG samples consistently plot along a tholeiitic curve, thus none of them originated in a subduction zone. This means that they likely originated from an intraplate setting (hotspot) or even a divergent plate setting.



**Figure 4:** AFM Diagram modified from (Irvine and Baragar, 1971). This tectonic setting diagram denotes that none of the samples originated in a subduction zone since they plot along a tholeiitic curve

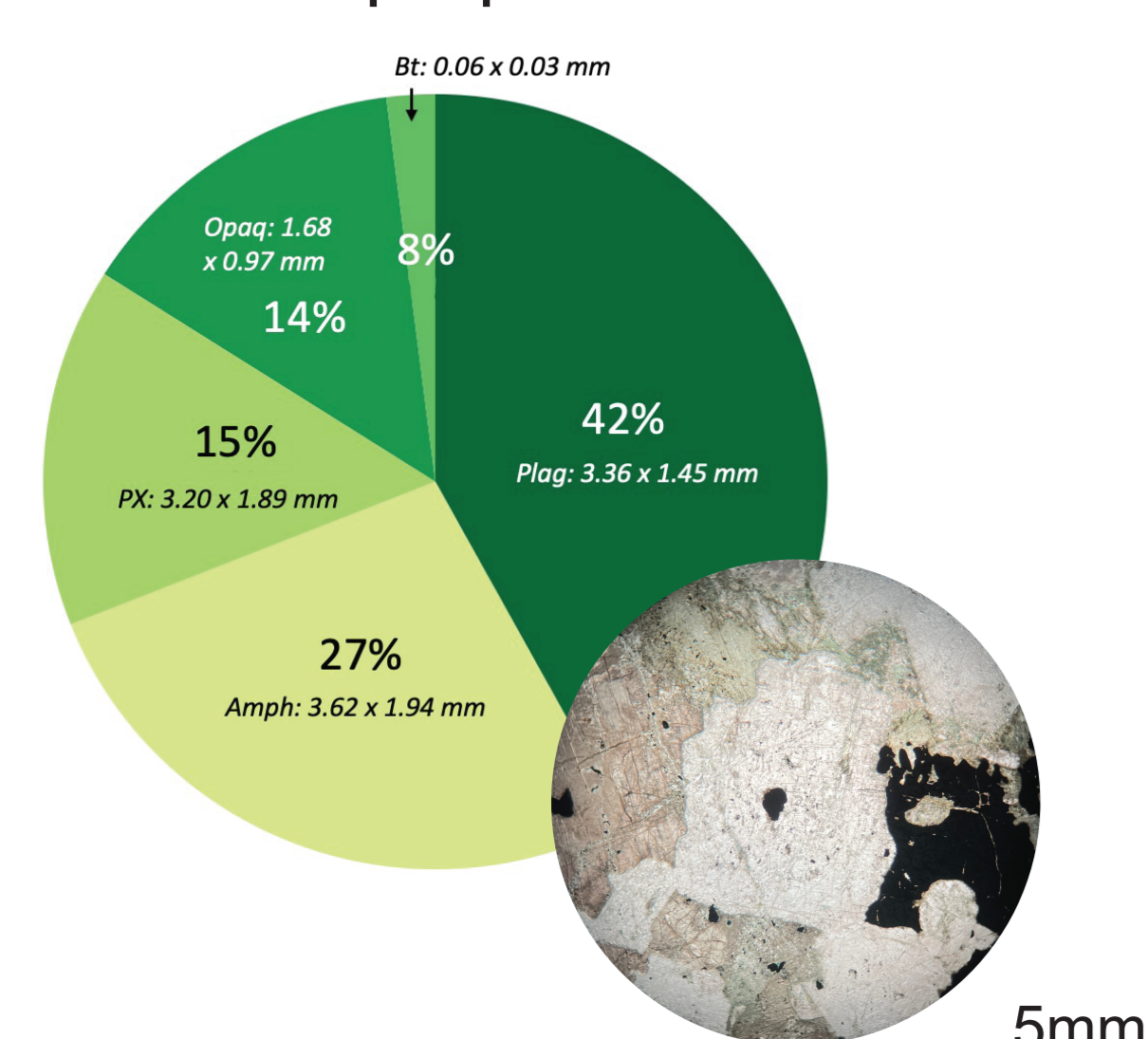
## MODAL & TEXTURAL ANALYSIS

When analyzed under the microscope, the Nahant Gabbro is phaneritic with coarse plagioclase, pyroxene, and amphibole. Samples collected from Marblehead, Highland Pluton, and Forest River display a porphyritic-phaneritic texture with plagioclase phenocrysts. Finally, a component of the Highland Pluton is phaneritic, although fine-grained, and displays a "dalmatian" pattern with clusters of mafic minerals.

KEY: ■ Plagioclase ■ Opaques ■ Biotite ■ Pyroxene ■ Amphibole ■ Feldspar

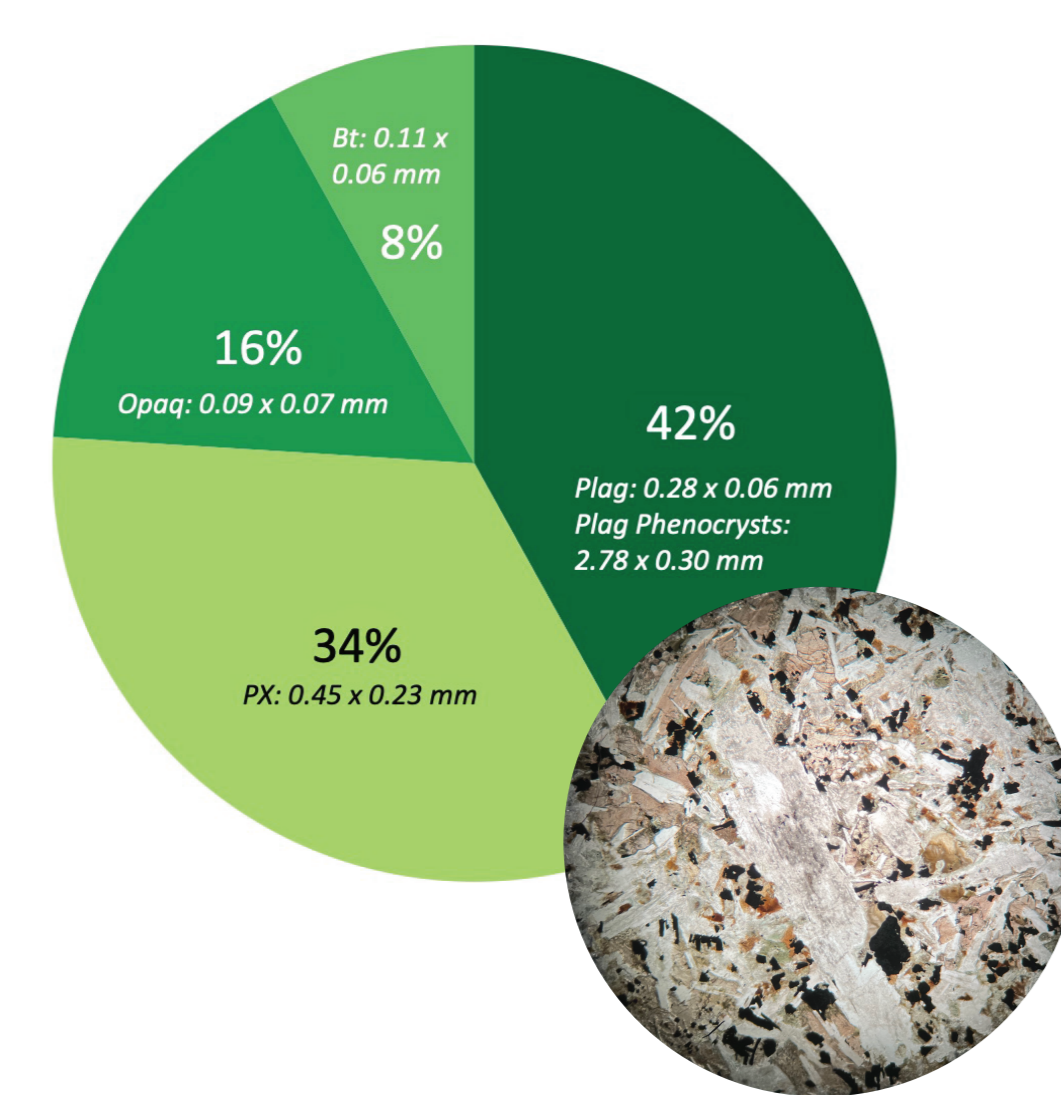
### 20-NH-01 ▲

Composed of plagioclase, opaques, biotite, pyroxene, and amphibole. It has a phaneritic texture with <0.01 mm inclusions and larger sized grains of an opaque mineral.



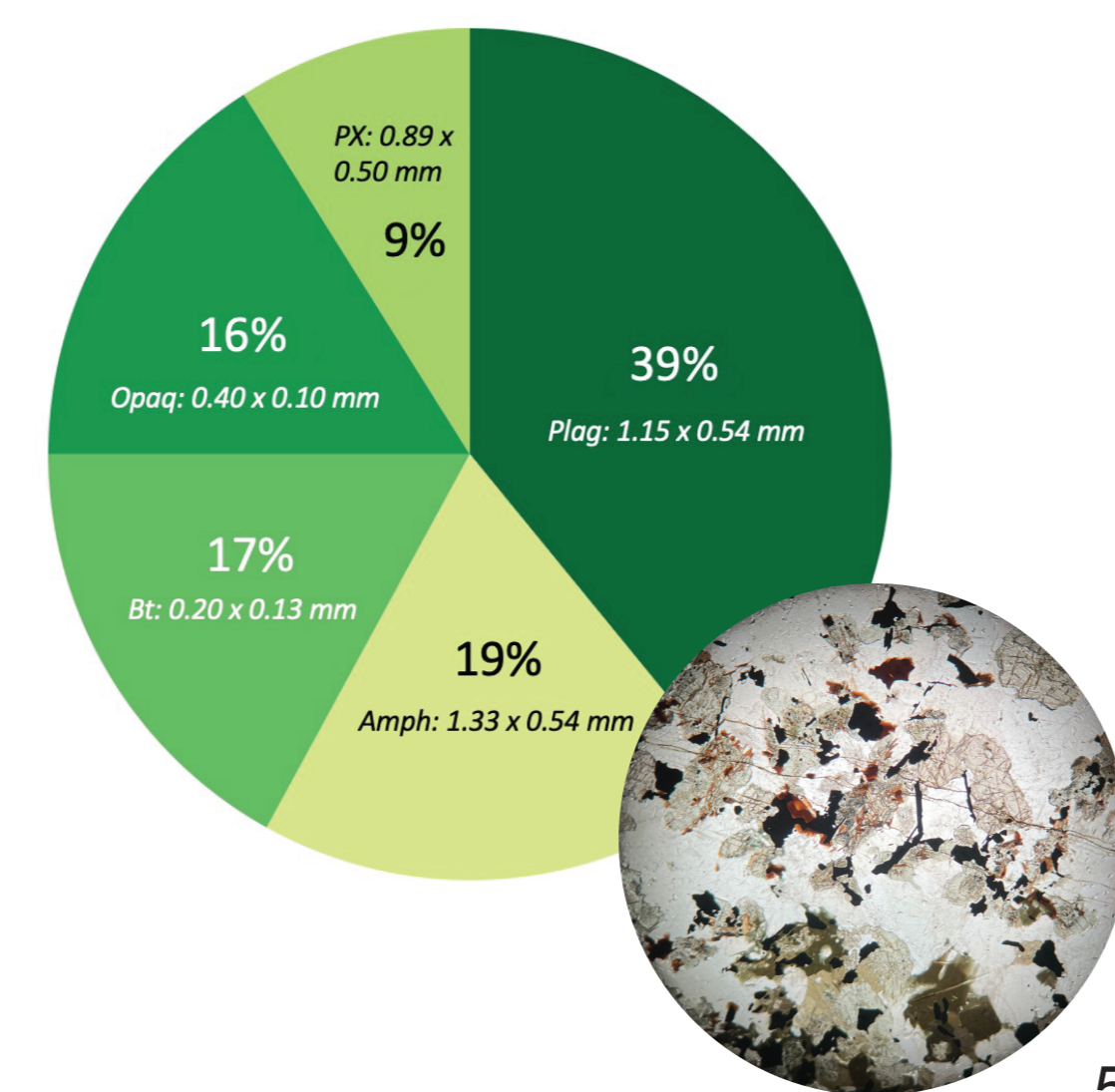
### 21-MH-01 ■

Composed of plagioclase, opaques, biotite, and pyroxene. Exhibits a porphyritic phaneritic texture with larger plagioclase phenocrysts.



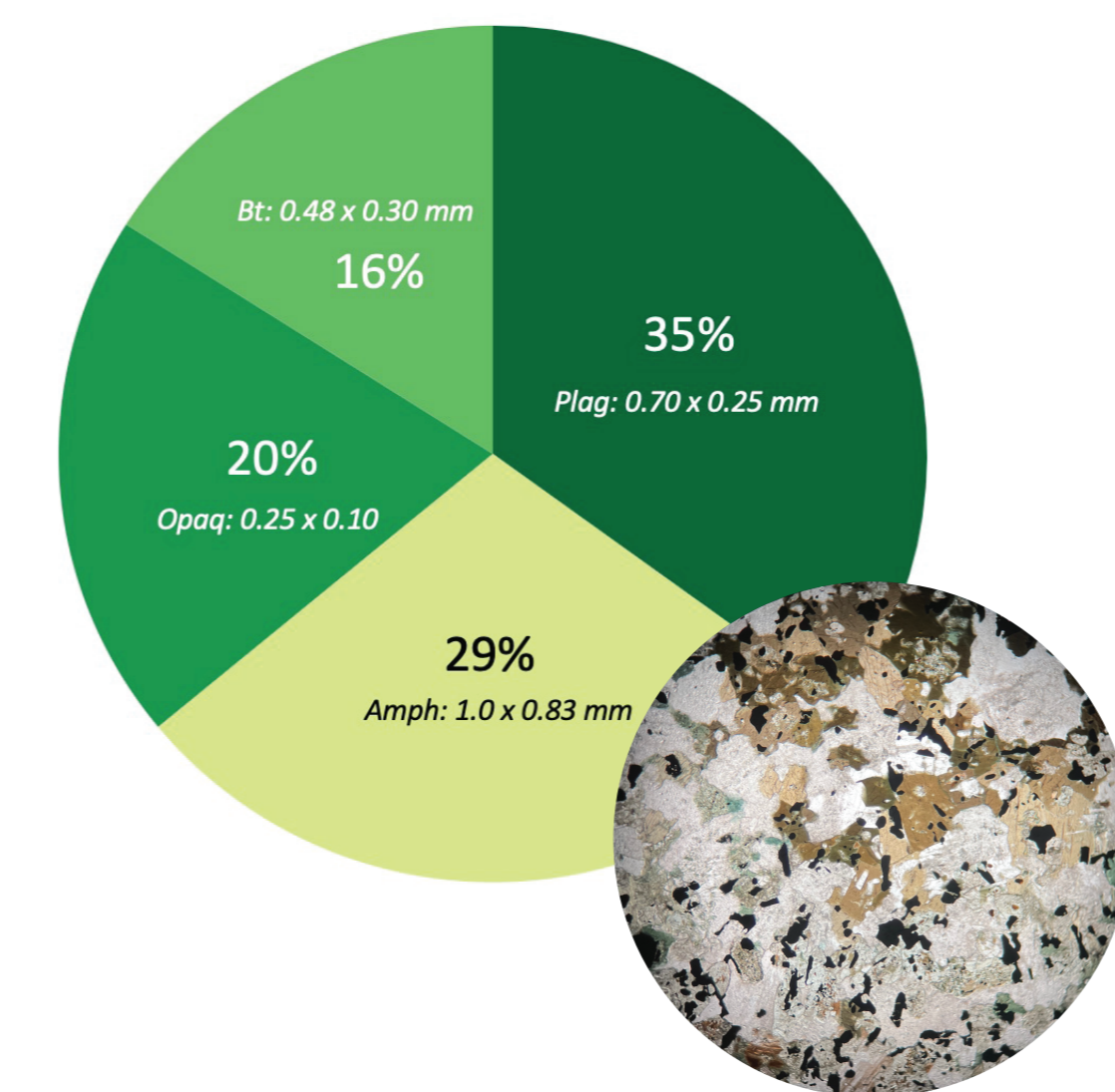
### 21-HP-02 ●

Composed of plagioclase, opaques, biotite, pyroxene, and amphibole. It has a phaneritic texture with <0.02 mm opaques and biotite inclusions as well as larger sizes of these minerals.



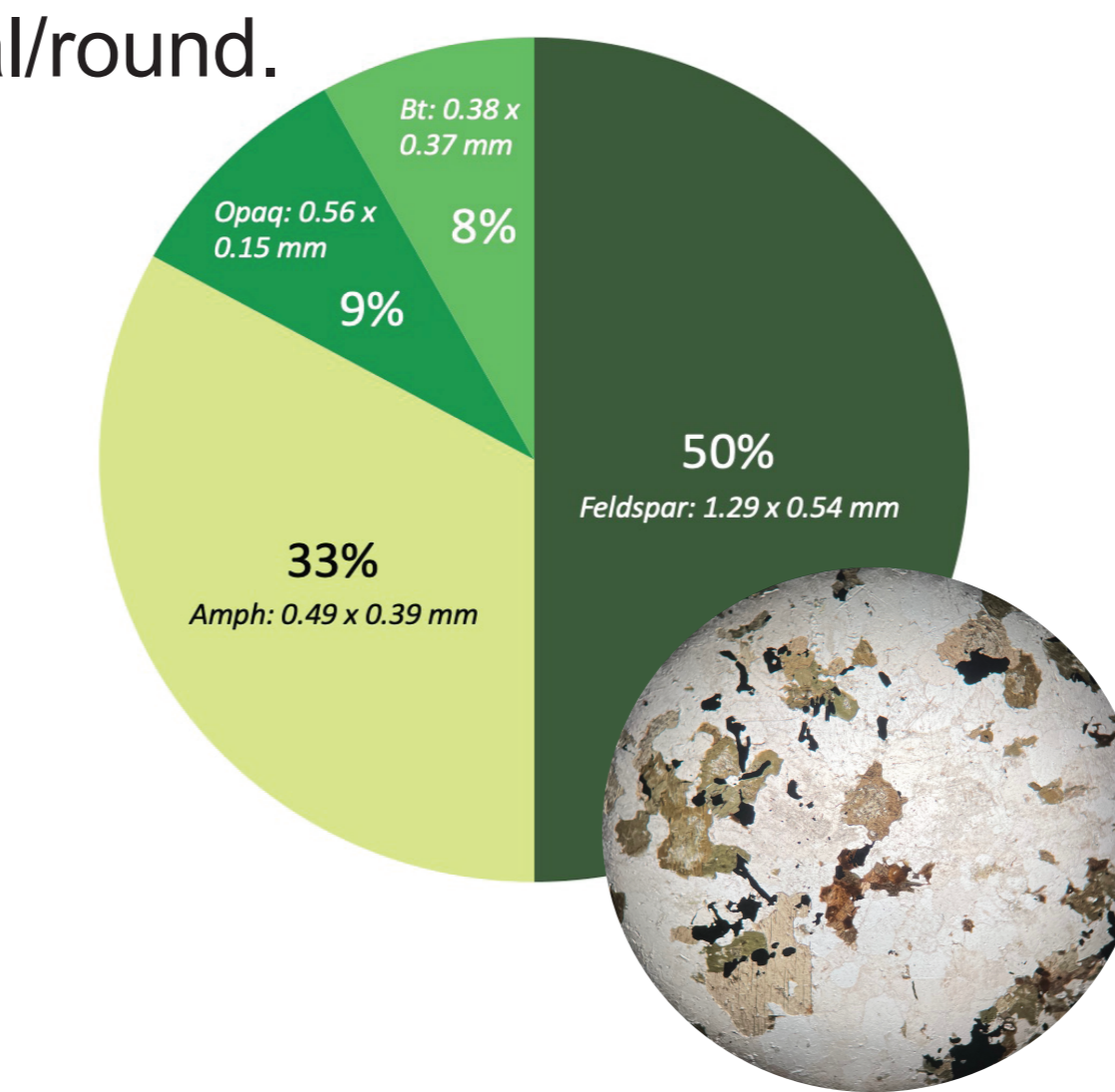
### 21-HP-05 ★

Composed of plagioclase, opaques, biotite, and amphibole. It has a phaneritic texture with <0.02 mm opaques inclusions as well as larger sizes of these minerals.



### FRR13-1 ◆

Composed of feldspar, opaques, biotite, and amphibole. Feldspar mainly appears to be plagioclase, but there is possibly another feldspar mineral, it has a smaller size and is subhedral/round.



## CONCLUSION

Geochemical analyses can be used to accurately attribute gabbroic samples to local units that have thus far assigned simply based on their vicinity to the SGD.

Based on its major and trace element abundances, the gabbroic specimen sampled in Marblehead (21-MH-01) is geochemically more similar to the Nahant Gabbro sample (20-NH-01) as opposed to the Salem Gabbro-Diorite samples. Although, it cannot be said for certain that the Marblehead exposures are in fact related to the NG this study underlines the possibility of errors in the current unit identifications.

Magmas from both the NG and the SGD are tholeiitic and not related to subduction zone magmatism. Therefore, they can be attributed to either an intraplate tectonic setting (hotspot) or a rifting environment.

## REFERENCES

Clapp, C. H. (1921). Geology of the igneous rocks of Essex County, Massachusetts. US Government Printing Office. Irvine and Baragar (1971). AFM Diagram. Le Maitre et al. (1989). TAS Diagram. Ross, M. E., Bailey, R. H., & West, D. P. (2001). Igneous and sedimentary petrology of East Point, Nahant, Massachusetts. Guidebook for geological field trips in New England: Boulder, Colorado, Geological Society of America, O1-O29. Sun and McDonald (1995). Spider Diagram.