Geochemistry of the Banded Iron Formations and their Host Rocks in the Eastern Desert of Egypt

Session 92:T3. Sigma Gamma Epsilon Undergraduate Research (Posters)
Paper # 92-54

BACKUS, Ethan L.[1], GAGNON, Kelli E.[1], EL-SHAZLY, Aley K.[1], and KHALIL, Khalil Isaac[2]
(1)Geology Department, Marshall University, Huntington, WV 25755
(2)Geology Department, Faculty of Science, Alexandria University, Egypt

Sponsored by NSF-OISE-1004021

THE GEOLOGICAL SOCIETY OF AMERICA®
2012 GSA ANNUAL MEETING & EXPOSITION
4-7 November | Charlotte, North Carolina, USA

Abstract

Thirteen deposits of banded iron formations occur in an area extending over 30,000 km^2 in the central Eastern Desert of Egypt. The deposits most resemble Algoma-type iron formations, but have higher Fe/Si ratios that vary from one deposit to another and are of Neoproterozoic age, whereas most Algoma type banded iron formations are Archean. Variations in the Fe/Si and Fe^{2+}/Fe^{3+} from one deposit to another allow for their subdivision into "fresh" (Fe^{2+}/Fe^{3+} > 0.1; Fe/Si < 3) and altered (Fe^{2+}/Fe^{3+} < 0.1) BIFs. The banded iron formations are also interbedded with metasediments, as well as mafic to acidic metapyroclastics and metavolcanics, suggesting proximity to an active arc. All deposits are dominated by oxide and silicate facies; carbonates are minor, whereas sulfides are rare. Some deposits are characterized by the assemblage andradite-rich garnet-epidote-quartz-magnetite-hematite-calcite. Textures suggest that fine-grained Si-bearing magnetite ± hematite dust formed during diagenesis. The presence of abundant andraditic garnets and epidote suggests that the deposits underwent calcium-metasomatism. Both magnetite and hematite underwent grain coarsening/recrystallization during metamorphism. Abundant late veins of epidote and calcite suggest a second stage of calcium-metasomatism after the metamorphism. Supergene alteration resulted in the formation of goethite and lepidocrocite and an overall enrichment of Fe.

Whole rock geochemical data show that all the BIFs have REE patterns similar to that of ocean water. Major and trace element discriminant diagrams show that the host metavolcanics and metapyroclastics are calc-alkaline to tholeiitic, with N-MORB to island arc signatures. These data suggest that the BIFs were deposited by hydrothermal vent activity in some type of ocean basin close to an island or volcanic arc. Suboxic conditions necessary for BIF formation were maintained through the delivery of ash and dust to the small ocean basin. During the Pan-African orogeny. Accretion and obduction led to ophiolite emplacement and subsequent regional metamorphism under epidote-amphibolite facies conditions.

Introduction

The banded iron formations (BIFs) of the Egyptian Eastern Desert are represented by thirteen deposits that occur in an area ~ 30,000 km^2 (Fig. 1). These deposits, which have characteristics similar to Algoma type BIFs, contain 53,000 M tons of iron ore (Dardir 1990), and are intercalated with volcano-sedimentary units within the basement of the Egyptian Eastern Desert. These units, amalgamated during the Neoproterozoic Pan-African Orogeny, reveal a six – stage tectonic history: (Fig. 2; e.g. El-Gaby et al., 1990; Stern et al., 2006): (i) rifting and breakup of Rodinia 900 – 850 Ma; (ii) sea floor spreading (870 – 720 Ma); (iii) subduction and development of arc – back-arc basins (750 – 650 Ma); coupled with episodes of intrusion of "Older Granitoids" (iv) accretion/ collision marking the culmination of the Pan-African Orogeny (630 – 600 Ma) with continued intrusion of older granitoids; (v) continued shortening coupled with escape tectonics and continental collapse (600 – 570 Ma) ; and (vi) intrusion of alkalic, post-orogenic "Younger Granites" (570 – 475 Ma) (Fig 3G).

The iron formations are Neoproterozoic in age with characteristics that most closely resemble Algoma-type BIFs, although they have significantly higher Fe contents. Many are laminated and deformed (Fig. 3D & E). Rock units intercalated with and hosting the BIFs include volcaniclastics, dolerites, andesites, siltstones, mudstones (Fig. 3F), and mafic volcanics (Fig 3C), all part of the "ophiolitic/ island arc succession" (e.g. Egyptian Geological Survey, 1981; El-Gaby et al., 1990; Ali et al., 2009; Basta et al., 2011) metamorphosed under epidote amphibolite to greenschist facies conditions. In most areas, these units were intruded by felsic dikes, sills, or plugs (Figs. 3A-B).

To fully understand the origin and tectonic setting of the BIFs, a detailed study of their host rocks is needed. Many of the hornblende – rich rocks that have traditionally been mapped as mafic metavolcanics are characterized by a wide range of mineral assemblages (some with more than 30% quartz; Fig. 4B) suggesting a variety of protoliths. A better understanding of the acidic intrusions, both dikes and plutons (Figs. 1 F and E respectively), is also needed. This study therefore focuses on the geochemistry of the host rocks and their felsic intrusions from the Um Nar area in an attempt to better understand their origin and tectonic setting.

Objectives

❖Identify the geochemical nature of the samples mapped as "metavolcanics", and classify all host rocks

❖Determine the tectonic setting of the host rocks intercalated with the banded iron formations.

❖Gain insight into the history of the banded iron formations from the host rocks.

❖Establish the tectonic setting of the granites intruding the banded iron formations and host rocks.

Petrography

Banded Iron Formations

❖Banded Iron Formation (Fig. 4A): Magnetite + Hematite + Quartz + Garnet + Epidote ± Calcite ± Stilpnomelane ± Actinolite ± diopside ± Goethite

Host Rocks

❖Hb-Qz Schist (Fig. 4B & C): Hornblende + Quartz ± Plagioclase ± Biotite ± Epidote ± Chlorite ± K-Feldspar ± Titanite ± Rutile

❖Meta-Andesite(Fig. 4D): Plagioclase + Chlorite ± Clinozoisite/Epidote ± Actinolite ± Sphene

❖Meta-Gabbro/Meta-Dolerite (Fig.4E & 4F respectively): Plagioclase + Actinolite ± Quartz ± Chlorite ± Clinozosite

❖Metatuff (Fig. 4G): Quartz + Muscovite ± Plagioclase ± Epidote + Magnetite + Hematite ± Chlorite ± Calcite

❖Garnet mica schists (Fig. 4H): Garnet + Biotite + Muscovite + Quartz ± Chlorite

Felsic Intrusions

❖Dacite/Rhyodacite (Fig. 4I & J respecitvely): Quartz + Plagioclase + Muscovite + Biotite + Epidote +Hematite ± Rutile ± Titanite ± Apatite

❖Rhyolite (Fig. 4K): Quartz+Plagioclase+Kspar±Biotite±Garnet ±Epidote + Hematite ± Rutile ± Titanite ± Apatite

❖Granite (Fig. 4L): Quartz + Plagioclase + Mircocline + Biotite ±Hornblende ± Titanite ± Zircon

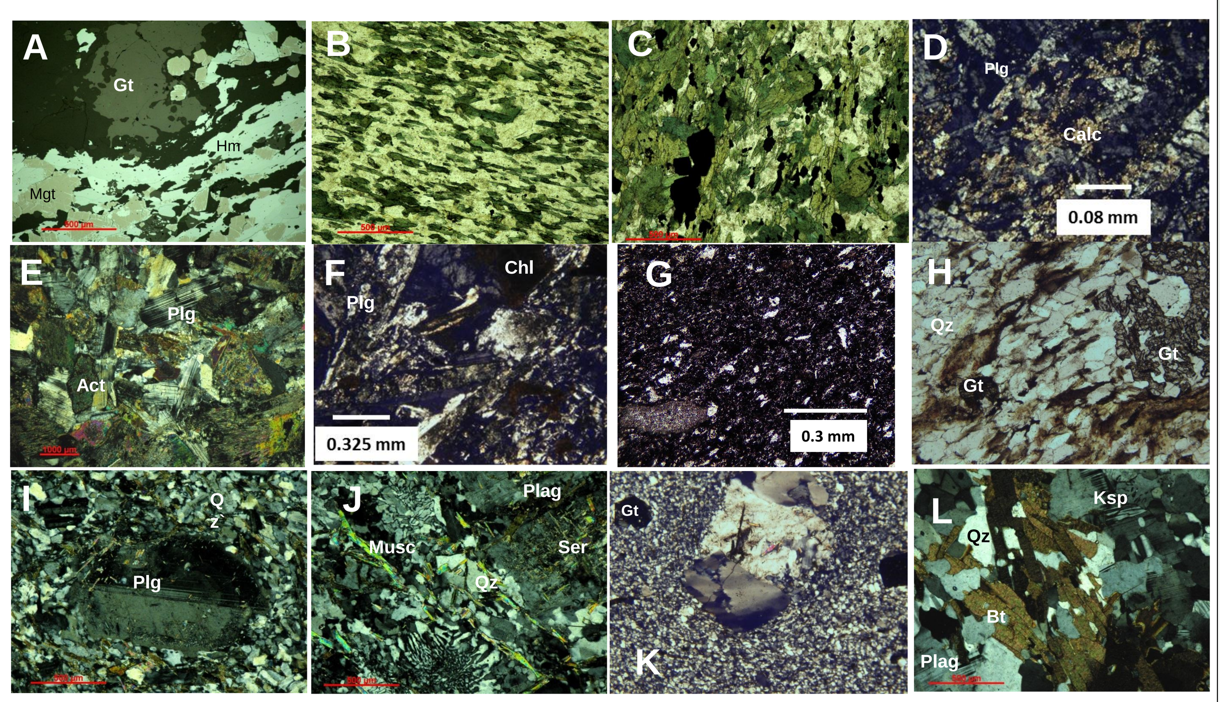


Figure 4: **A)** BIF showing Mgt, Hm and Gt (reflected light, ppl, Um Nar) **B)** Hb-Qz Schist (transmitted light, ppl, Um Nar) **C)** Hb – Plg schist (ppl; Um Nar), **D)** Andesite with calcite (transmitted light, xpl, Wadi El Dabbah) **E)** Gabbro showing randomly oriented grains and actinolite replacing Cpx? (transmitted light, xpl, Um Nar) **F)** Dolerite (transmitted light, xpl, W. El-Dabbah) **G)** Metatuff with lithic fragments and Qz replacing glass shards; xpl, W. El-Dabbah; **H)** Metapelitic schist with Gt showing rotational texture (transmitted light, ppl, Um Nar) **I)** Meta-Dacite with large plagioclase phenocryst in a groundmass of Plg, Qz, and Musc (transmitted light, xpl, Um Nar) **J)** Rhyolite dike showing sericitized Plg and a granophyric texture (transmitted light, xpl, Um Nar) **K)** Rhyolite dike with phenocrysts of Qz and garnet, xpl; Um Nar; **L)** Older granite (transmitted light, xpl, Um Nar)

Abbreviations: Gt-Garnet; Hm-Hematite; Mgt-Magnetite; Ksp: K-feldspar; Plg-Plagioclase; Hb-Hornblende; Ep-Epidote; Chl-Chlorite; Qz-Quartz; Calc-Calcite; Act-Actinolite; Musc-Muscovite; Ser-Sericite

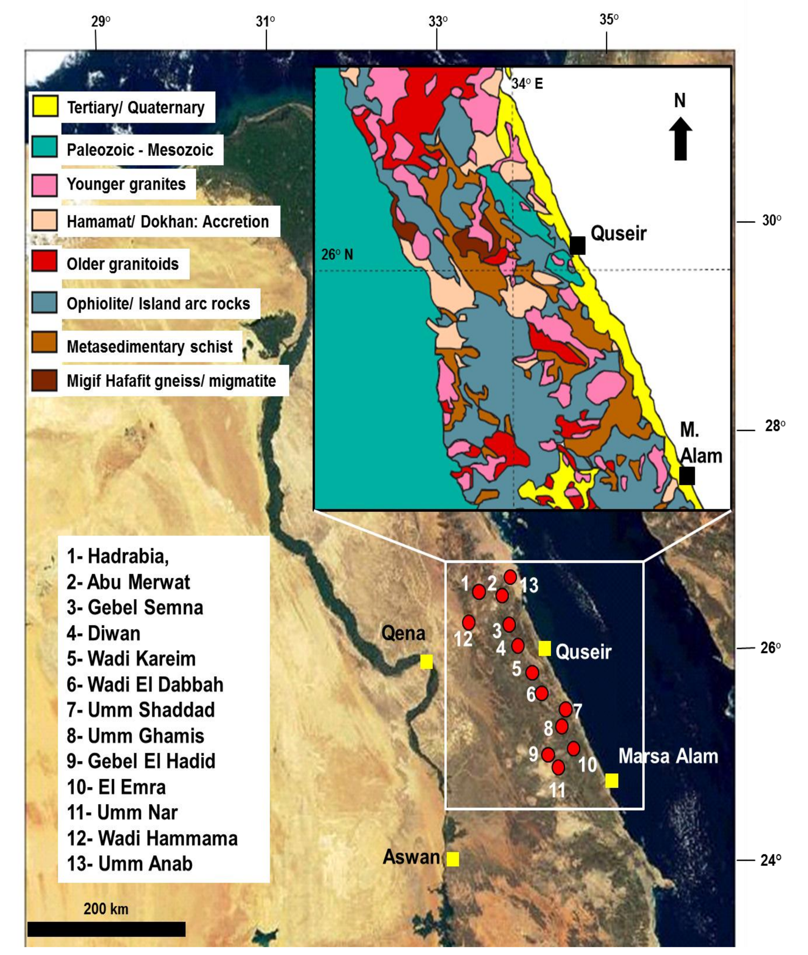


Figure 1: Thematic Landsat image of Egypt showing the location of banded iron formations classified as altered (dark blue circles), "fresh" (red circles), and undifferentiated (green). Inset is a simplified geological map of the area outlined in the box (from Egyptian Geological Survey, 1981)

Eon/ Era	Tectonic Stage		Age Ma	Rock Types/ Associations		Granitoid intrusion
Phanerozoic	Post-Orogenic		< 570	Younger Granites (post-tectonic, alkalic): Granite, granodiorite, monzonite.		Gattarian (570 – 475 Ma)
Neoproterozoic	PanAfrican	Accretion/ Collision	650 - 570	Dokhan metavolcanics (andesite, rhyolite, rhyodacite, pyroclastics) intercalated with Hammamat metasediments (breccias, conglomerates, greywackes, arenites, and siltstones)		
		Subduction	750 - 650	Island Arc	Shadhli Metavolcanics (rhyolite, dacite, tuff); Volcaniclastic metasediments; Diamictites (Strutian: 680 – 715 Ma). **Banded Iron Ores**	Meatiq (710 – 610) Hafafit (760 – 710)
		Spreading	850 - 750	Ophiolite	Tholeiitic basalt, sheeted dykes, gabbros, serpentinites, all weakly metamorphosed	Shaitian Granite (850 – 800 Ma)
Archean?/ Paleoproterozoic	Pre-Pan-African		<1.8 Ga	Metasedimentary schists and gneisses (Hb-, Bt-, and Chl- schists), metagreywackes, slates, phyllites, and metaconglomerates **Some BIF? Umm Nar?**		
				Migiff – Hafafit gneiss (Hb and Bt gneiss) and migmatite		

Figure 2: Geologic History of the ANS (Sources: Egyptian Geological Survey (1981); El-Gaby et al. (1990); Hassan and El-Hashad, 1990; Stern et al. (2006); Avigad et al. (2007); Moussa et al. (2008)).

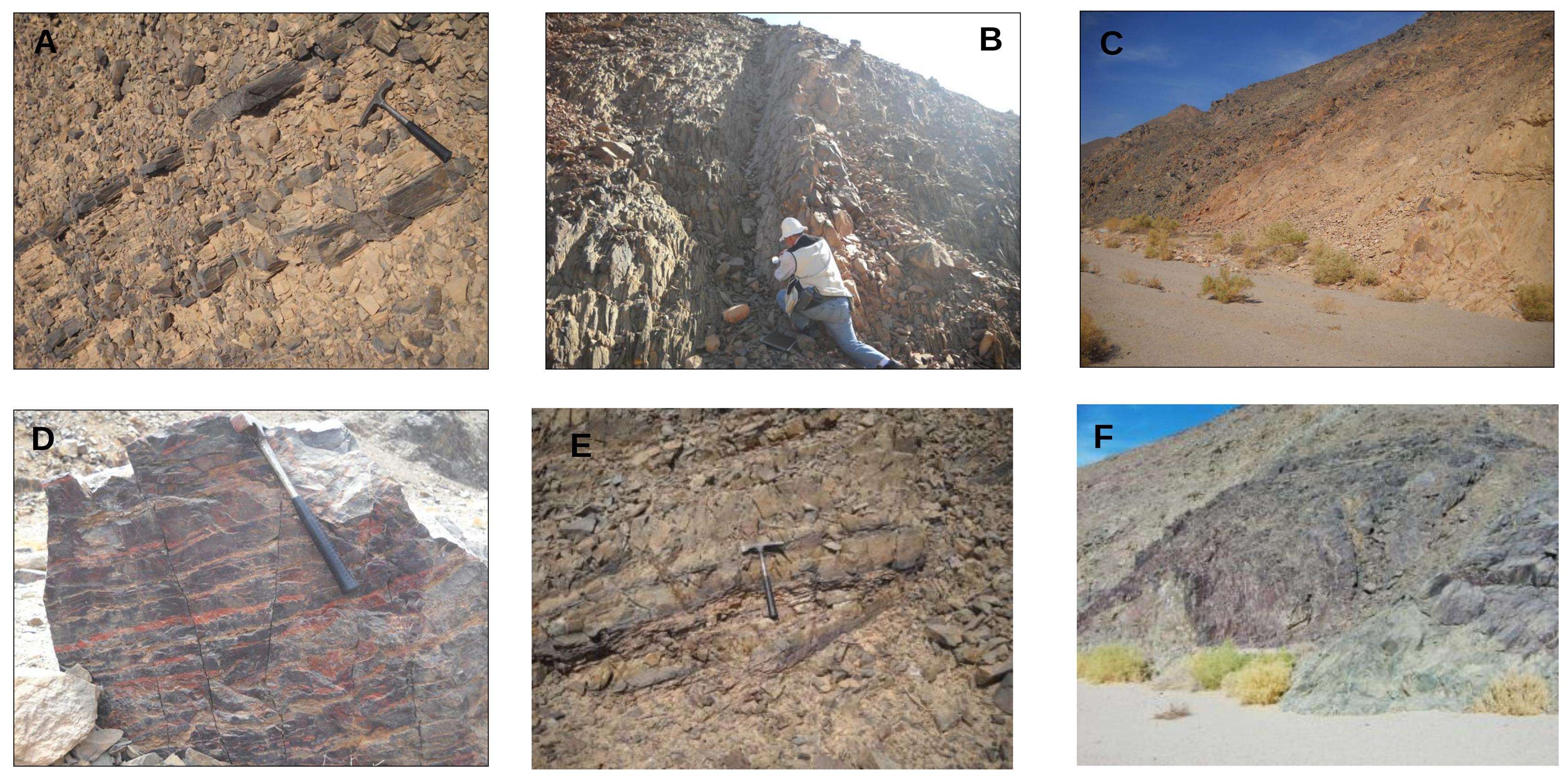


Figure 3: **A)** BIF intercalated with aplite in a sill (Um Nar) **B)** Rhyolite dike intruding into the metavolcanic (Um Nar) **C)** Contact between a granitic unit and the metavolcanics (Wadi El Dabbah) **D)** BIF wit japer laminations (Wadi El Kariem) **E)** Contact between the "younger granite" and a later dolerite dike (Um Nar) **F)** Granitic Intrusion into mudstone (Wadi El Kariem) **G)** Outcrop of the "younger," post-tectonic granite (Um Nar) **H)** Andesite dike (Um Ghamis)

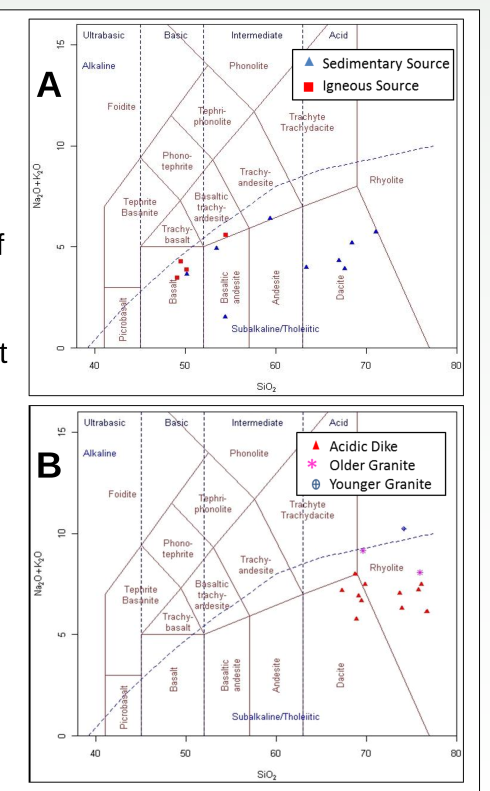
Results

❖ **Host Rocks**

- ❖ Five of the host rocks samples were petrographically determined to have an igneous origin; nine of the samples were determined to have a sedimentary signature.
- ❖ Samples have SiO_2 values ranging from 47.33-68.99 wt%
- ❖ When geochemical data was plotted on the TAS diagram of LeBas (1984) (Fig. 5A) all of the samples plotted as subalkaline/tholeiitic.
- ❖ The samples plotted over 6 different rock types: dacite (5 Samples), trachy-Andesite (1 sample), basaltic trachy-andesite (1 sample), basaltic andesite (3 samples), trachy-basalt (2 samples), and basalt (3 samples).
- ❖ The majority of the sedimentary samples plot as dacites, while most of the igneous samples plot as basalts.

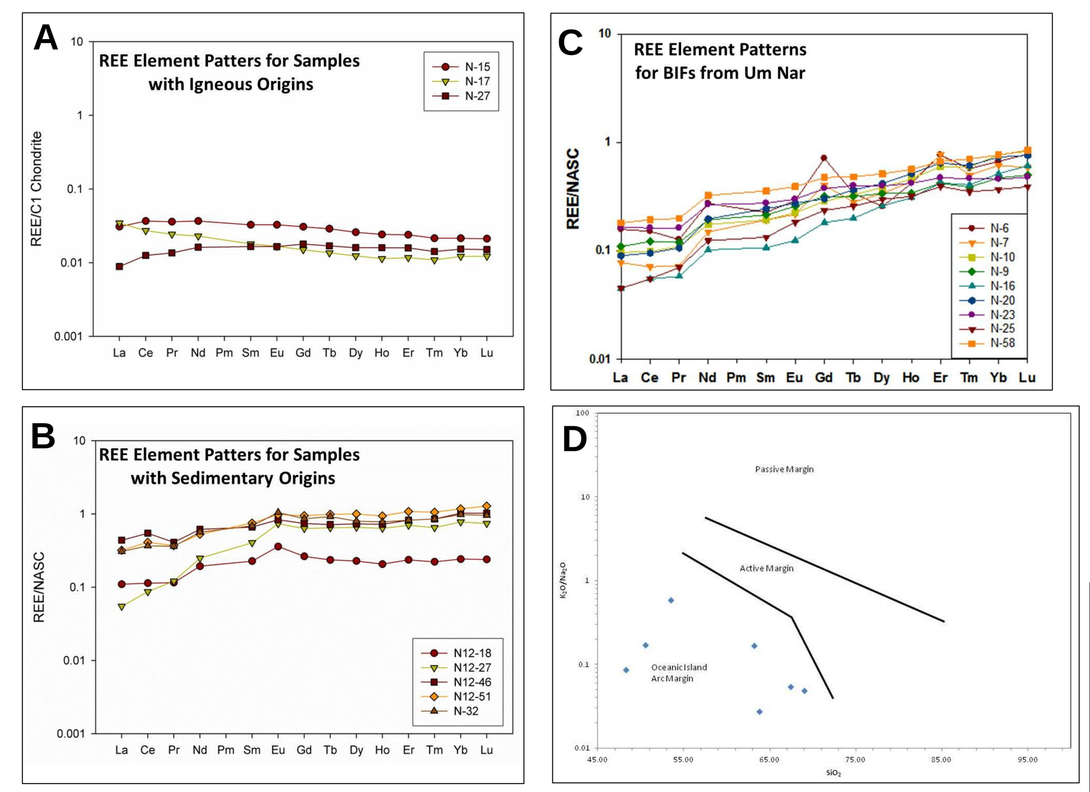
❖ **Granitic Intrusions**

- ❖ SiO_2 values of 66.99 to 75.84 wt % were observed for all of the samples.
- ❖ All samples but the younger granite plot as subalkaline/tholeiitic
- ❖ According to the TAS diagram (Fig. 1B) the acidic intrusions plot as three rock types: dacite (4 samples), rhyolite (6 samples), and trachyte/trachydacite (1 Sample).
- ❖ All of the granitic samples plot in the rhyolitic field.
- ❖ The younger granites plot as subalkaline/tholeiitic, while the younger granite didn't.
- ❖ All of the acidic intrusions plot in a cluster, suggesting a similar source.



Tectonic Setting: Host Rocks

- ❖ Among the amphibolites with a volcanic protolith, N-15 and N-17 have chondrite normalized REE patterns similar to those of E-MORBs, whereas N-27 has a signature that mimics that of an N-MORB (Fig. 6A).
- ❖ The amphibolite samples with a sedimentary protolith all show a similar trend when their REE values are normalized to the North American Shale Composite (NASC); LREE depletion and HREE enrichment with a positive Eu anomaly (Fig. 6B). The positive Eu anomaly is likely due to the accumulation of plagioclase feldspar in these samples.
- ❖ When the REE pattern for the metasedimentary amphibolites is compared to the BIF samples from Um Nar (Fig 6C), there is a strong correlation in the LREE depletion and HREE enrichment.
- ❖ Plotting the samples with a sedimentary protolith on a plot for K_2O/Na_2O vs. SiO_2 (Fig 6D) suggests that all of the samples originated in an oceanic island arc setting.
- ❖ Figure 6E shows a wide variety of tectonic settings for the samples with an igneous protolith, suggesting multiple sources/ tectonic settings that range from arc related basalts to E-MORB. None of the samples plot in the back arc basin basalt field. Many "sedimentary" amphibolites plot in the E-MORB field.
- ❖ The samples with a sedimentary protolith plot in the arc tectonic setting on Figure 6F, whereas the "volcanic" amphibolites plot mostly as MORBs. This is consistent with the discrimination diagrams of Green (2007), Pearce et al. (1977), and Shervais (19XX) all of which indicate E-MORB to arc signatures.
- ❖ Whereas most of the amphibolites have continental arc Th/Yb and Nb/Yb signatures, some have signatures characteristic of oceanic arcs (Fig. 6G).



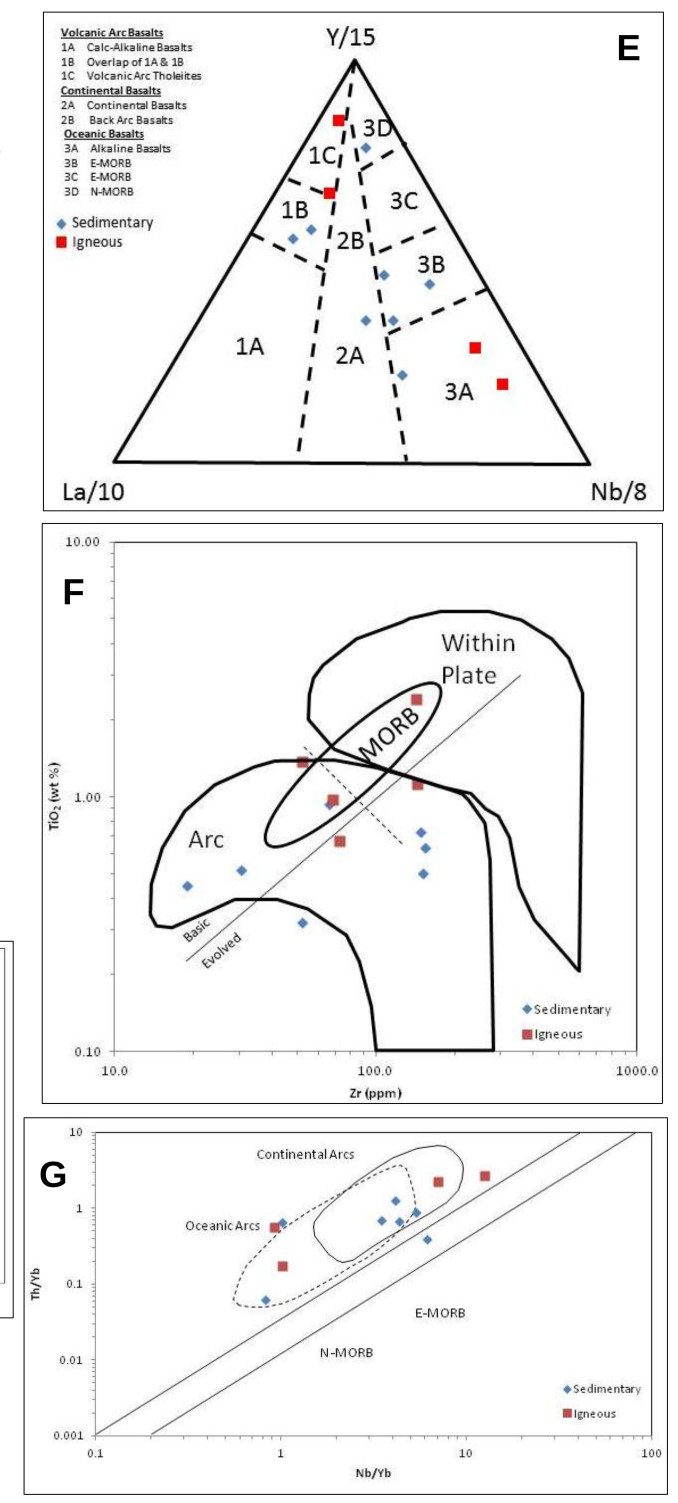
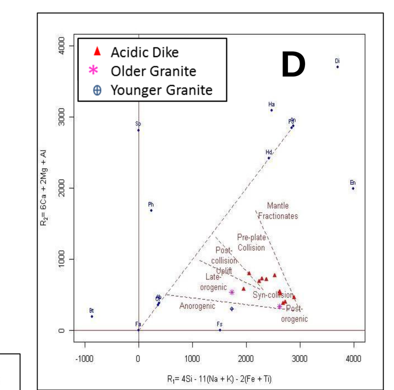


Figure 6: **A)** REE patterns of host rock amphibolites with an igneous origin (normalized to C1 Chondrite) **B)** Amphibolites with a sedimentary origin normalized to the North American Shale Composite **C)** BIF samples from Um-Nar normailized to the North American Shale Composite **D)** Plot of K_2O/Na_2O vs. SiO_2 for the determination of tectonic setting for sedimentary samples (Roser and Korsch, 1986) **E)** Ternary of Y/15-Nb/8-La/10 showing a lack of correlation among the tectonic setting of the samples' protolits (Cabanis & Lecolle, 1989) (* Samples with a sedimentary protolith plotted for comparison only) **F)** TiO_2 (wt %) vs. Zr (ppm) to determine the setting of the protolith (Pearce and Gale, 1977) **G)** Th/Yb vs. Nb/Yb to determine arc type (Pearce and Peate,1995)

Tectonic Setting: Felsic Intrusions

- ❖ All samples are either metaluminous or peraluminous, with the younger granite showing the highest alkali signatures plotting along the boundary between peralkaline and metaluminous rocks (Fig. 7A).
- ❖ The acidic dikes and the older granite have identical chondrite normalized light REE enriched patterns, whereas the younger granite has a flat REE pattern with a pronounced negative Eu anomaly (Fig. 7B).
- ❖ According to the Rb vs Y+ Nb plot of Pearce et al. (1984), all acidic dikes and older granites have a volcanic arc signature, whereas the younger granite is shown to have intruded within the plate (Fig 7C).
- ❖ Figure 7D shows that most of the dikes are syn-collisional to post-orogenic, whereas the older granites are late- and post orogenic. The younger granite plots in the field of anorogenic granites.
- ❖ The strong negative Eu anomaly for the younger granite suggests that they evolved through the fractionation of significant amounts of plagioclase feldspar.



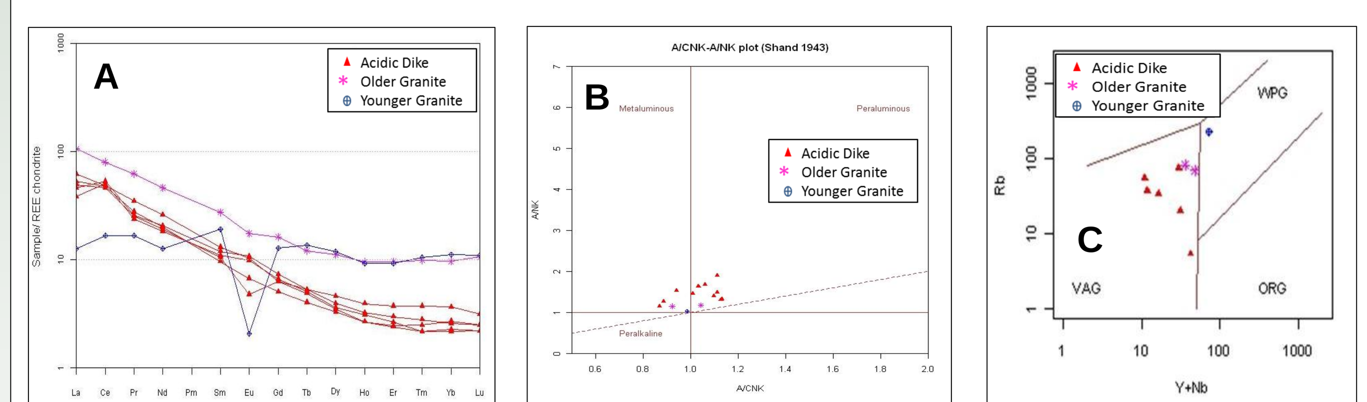


Figure 7: **A)** REE patterns for graniitic samples normalized vs. REE chondrite (Boynton, 1984). **B)** A/CNK vs. A/NK (Shand, 1943). **C)** Rb vs. Y+Nb diagram for tectonic origin of granitic intrusion (Pearce et al., 1984). **D)** Plot for determination of tectonic timing of granitic intursions (Batchelor and Bowden, 1985).

Conclusions

- ❖ Many of the hornblende schists represent metamorphosed calcareous sediments/ tuffs, whereas some represent metamorphosed mafic volcanics.
- ❖ Samples that were petrographically determined to have a sedimetnary protolith most likely formed in an oceanic island arc setting, although some have signatures characteristic of continental arcs.
- ❖ The REE pattern of the samples with a sedimentary source and the BIFs they are intercalated with are characterized by a NASC – normalized LREE-depleted, HREE – enriched pattern. This suggests a similar tectonic setting for the deposition of the two groups.
- ❖ Most of the amphibolites with a volcanic protolith range in composition from N-MORBs to E-MORBs, although some have volcanic arc signatures.
- ❖ Acidic dikes and the "older granites" have similar chemical characteristics and identical REE patterns that suggest formation in a volcanic arc setting, whereas the "younger "granites have a within plate chemical signature.
- ❖ The dikes and granitic plutons intruded in the later stages of the Pan-African Orogeny, whereas the younger granites are anorogenic.
- ❖ Volcanic/ island arc activity took place at the same time as oceanic crust was being generated in intra-arc basins with considerable hydrothermal activity. Ash deposited in these basins imposed anoxic conditions that suppressed biotic and photosynthetic activity, keeping hydrothermal Fe dissolved. During periods of arc quiescence, oxidation of Fe led to the deposition of BIFs, which were intercalated with MORBs and volcaniclastics.
- ❖ During the Pan-African orogeny (640 Ma), the entire sequence was thrust onto the continental/ arc margins, and were intruded by syntectonic I-type older granites. Post-orogenic, within plate granites intruded the sequence 610 - 475 Ma.

Analytical Methods

Twenty-one samples from Umm-Nar were analyzed for major and selected trace elements using a Liberty 110 ICP-AES at Marshall University. For major element analysis, rock powders were fused with a flux and dissolved in H_2SO_4 using the single solution method of Ingamells (1966). For the trace elements Ba, Ce, La, Nb, Rb, Sr, Th, Y, Yb, and Zr, the samples were dissolved in HF, HNO_3, and HCl using the acid digestion technique of Briggs (2002). REEs and other trace elements were analyzed for at ALS Minerals using an ICP-MS (MEMS-81 method). The geochemical data was processed and then plotted on various discrimination diagrams using GCDKit 2.3 (Janousek, 2008).

Acknowledgements

This research was funded by the National Science Foundation (Grant NSF-OISE-1004021). The authors would like to also thank Natural Resource Partners, L.P. for printing the poster, Matthew Kestner for his help in preparing the samples, and the Marshall University Geology Department for its ongoing support.