Geochemistry of Ediacaran-Ordovician diabase, lamprophyre and phonolite dikes in southern Colorado, possibly related to rifting in the Southern Oklahoma Aulacogen

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Abstract

The Southern Oklahoma aulacogen is a northwest-trending structure containing abundant igneous rocks representing the remains of a major Cambrian rift zone. Previous geologists have mapped numerous igneous intrusions in Colorado that follow the same trend, ranging from Ediacaran to Ordovician in age, and have speculated that these intrusions may be a part of the same rift. These intrusions include abundant igneous dikes of various compositions that originated from deeper magmatic bodies, filling fracture systems in older igneous rocks and Precambrian gneisses. This study involves the geochemical analysis of samples we collected from different dike types, including diabase, lamprophyre, phonolite, and nepheline syenite. The dikes include a prominent diabase dike swarm in the Gunnison area as well as abundant dikes of several types in the Wet Mountains and Front Range farther east. On the discrimination and REE diagrams, fifteen representative dike samples from both sample regions plot tightly together, indicating the clustered dikes share a petrogenetic history of E-MORB-type magma that interacted with intercontinental lithosphere.

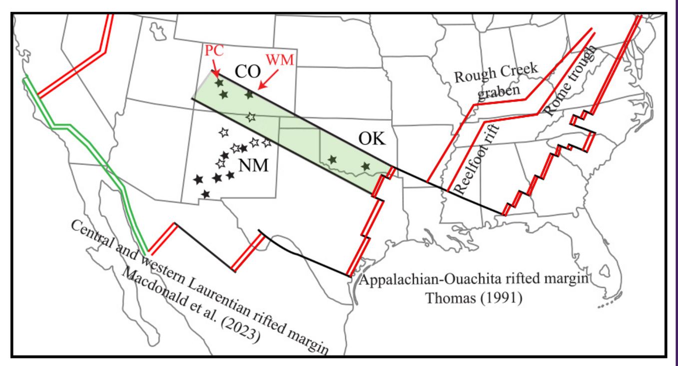
We have not yet found diabase dikes in the Wet Mountains suitable for geochemical studies. However, five samples from NW- to NNW-trending diabase dikes in the Front Range, ~80 km north of the Wet Mountains, are among the fifteen diabase samples that cluster together on the geochemical diagrams. This raises the intriguing possibility that dikes related to Ediacaran-Ordovician intraplate magmatism in Colorado may be more extensive than previously thought.

Samples of four lamprophyre dikes in the Wet Mountains exhibit uniform patterns in REE diagrams and plot within the same field on the Winchester and Floyd (1977) classification diagram. Three dikes classified as trachytes by other workers cluster in the phonolite field on this diagram, suggesting some of these dikes were previously misclassified. These three dikes also show similar REE patterns with prominent negative Ba, Sr, Eu and Ti anomalies, implying prolonged fractional crystallization.

Geologic Background

Cambrian igneous rocks in southern Oklahoma and adjacent parts of Texas, mostly present in the subsurface, define a northwest-trending rift zone extending from the ancient continental margin (Hanson et al., 2013; Wall et al., 2021). Numerous Ediacaran to Ordovician igneous intrusions ranging from large plutonic intrusions to smaller dikes occur along the same trend in Colorado, primarily in the Powderhorn District in western Colorado and the Wet Mountains and other parts of the Front Range of the Rockies farther east (Figs. 1 and 2). It is possible that all these rocks form a single major rift, where North America began to split apart (Larson et al., 1985). This project deals with abundant dikes present in the Gunnison region and the Wet Mountains and parts of the Front Range farther east (Olson et al., 1977; Pivarunas and Meert, 2019; Magnin et al., 2023). We have sampled a range of dikes mapped by previous workers that consist of diabase, lamprophyre and what was thought to be trachyte (see unnumbered field photos to lower left and upper right), as well as one much younger basaltic dike, in order to compare it with the older dikes. Associated plutons (Fig. 2) include the Powderhorn Complex, which contains dolomitic carbonatite, nepheline syenite, and other alkalic rocks. The McClure Mountain Complex in the Wet Mountains consists of a layered mafic-ultramafic complex, syenite, nepheline syenite, and a pyroxene-nepheline rock.

Fig. 1 Northwest-trending Southern Oklahoma Aulacogen from Magnin et al. (2023).



Methods and Sampled Units

We collected samples in Colorado during the summers of 2022 and 2023. These samples are from diabase dikes in the Gunnison area, and diabase, lamprophyre, and phonolite dikes scattered throughout the Front Range and Wet Mountains region (Fig. 2). We also collected a Cenozoic basalt dike in the Wet Mountains for purposes of comparison with our other samples. Samples were prepared at TCU and then sent to the GeoAnalytical Lab at Washington State University. Major and trace elements were analyzed by X-ray fluorescence spectrometry and inductively coupled plasma-emission mass spectrometry.

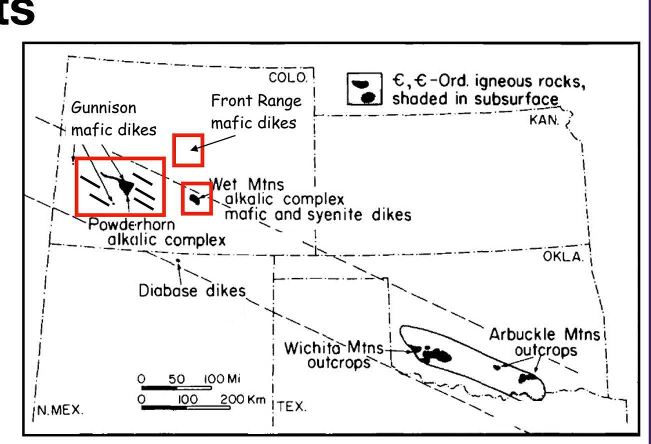


Fig. 2 Map indicating the locations of igneous complexes and dikes in Colorado thought to be associated with the Southern Oklahoma aulacogen in Oklahoma. Modified from Larson et al. (1985).

Red phonolite dike traced across the road. Sample CO23-19 was taken from the outcrop in the foreground.

Comparison between margin (left) and center (right) of red phonolite dike. Samples CO23-19c and CO23-19 were taken from this outcrop, respectively. Pencil for scale.

Geochemistry

Legend

- Diabase (Wet Mts/Front Range)
- Diabase (Gunnison area)
- Lamprophyre
- Phonolite
- Mafic-rich Nepheline Syenite
- Cenozoic Basalt

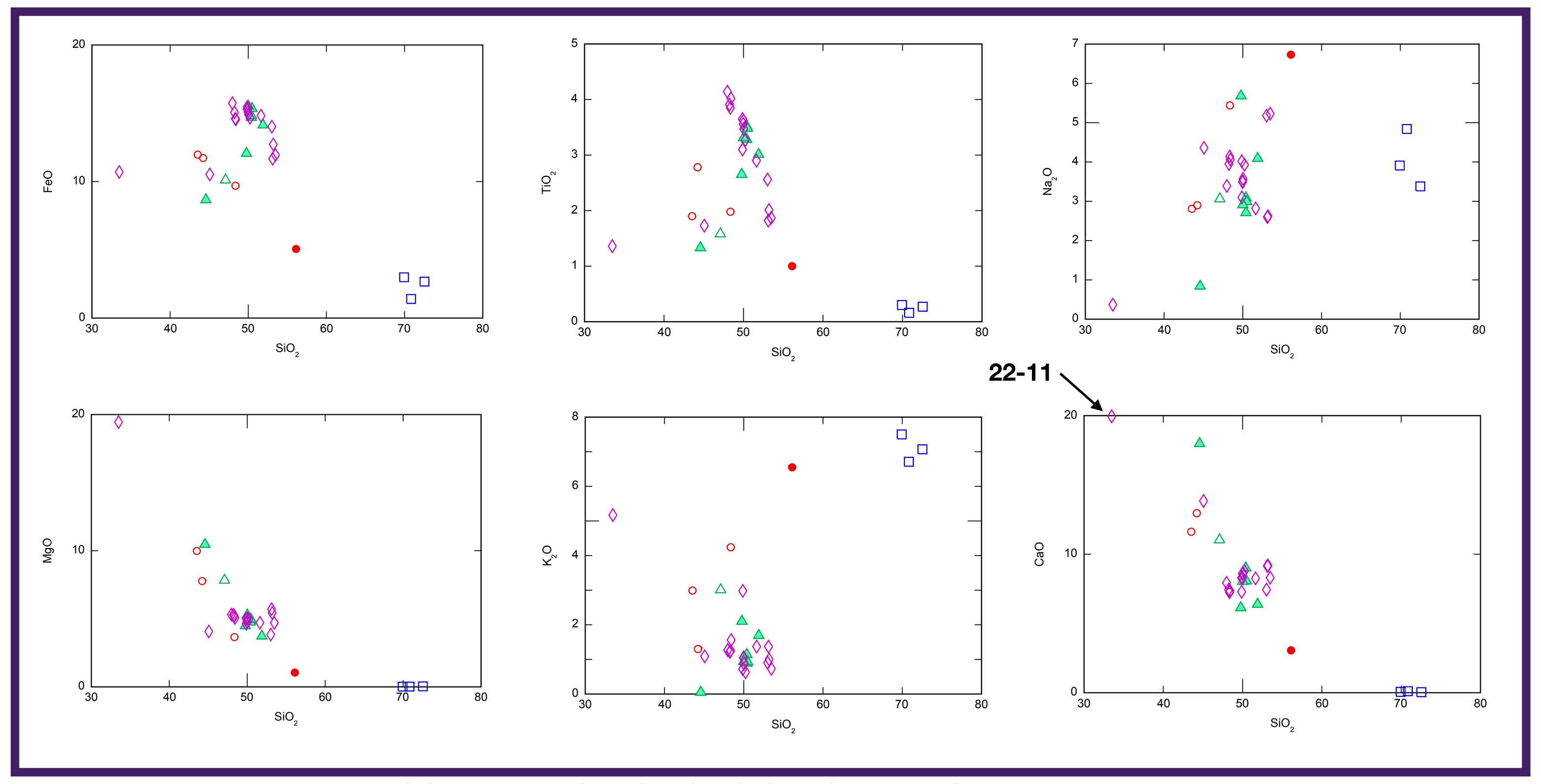


Fig. 3 Harker variation diagrams of SiO2 versus MgO, FeO, TiO2, CaO, K2O, and Na2O.

Harker Variation Diagrams

We used Harker variation diagrams to demonstrate the variety in compositions among the sampled dikes (Fig. 3). No observable trend exists between the sampled dikes because 1) the samples originated from petrogenetically unrelated magmas and 2) most of the dike samples exhibit some degree of alteration. Some notable examples of the effects of alteration include secondary quartz in the phonolite dike samples and diabase dike (22-11), which is overprinted by replacement carbonatite (e.g., Armbrustmacher, 1979).

Winchester and Floyd Classification Diagram

We used the Winchester and Floyd (1977) classification diagram for igneous rocks (Fig. 4) because it uses ratios of highly immobile elements that tend to resist secondary alteration. Most of the diabase samples fall within the subalkaline basalt field. However, three diabase samples fall within alkaline fields. Two of these samples fall within the alkaline basalt field, and another sample falls within the basanite/nephelinite field. Another sample (23-12) plots far to the left of the sub-alkaline basalt field, which matches its erratic behavior in other diagrams. The lamprophyre dike samples plot within the alkaline basalt and basanite/nephelinite fields, as does the mafic-rich nepheline syenite dike. Samples from dikes that were previously classified as red trachytes by other workers plot within the phonolite field, suggesting these dikes were previously misidentified.

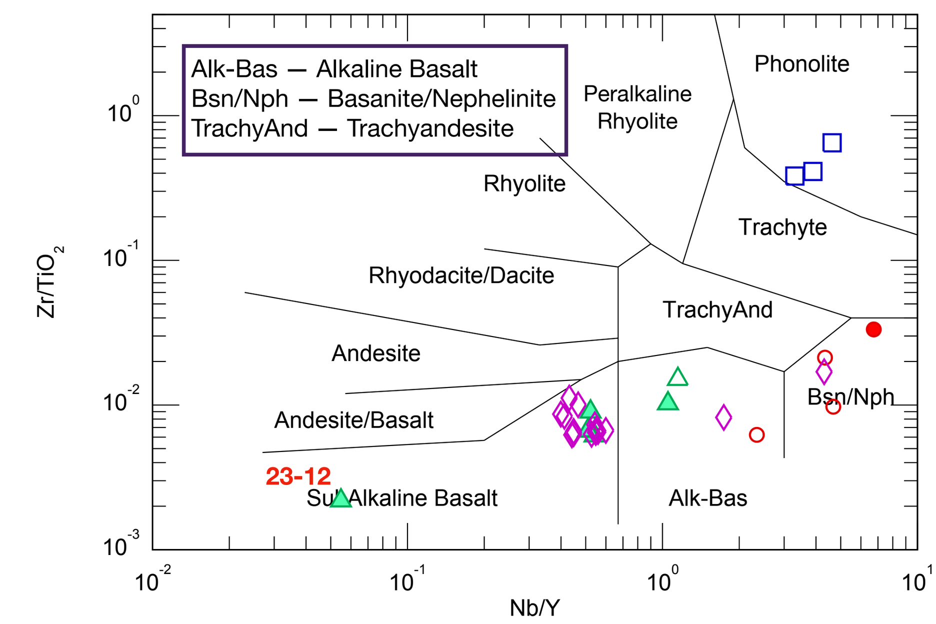


Fig. 4 Igneous rock classification diagram from Winchester and Floyd (1977).

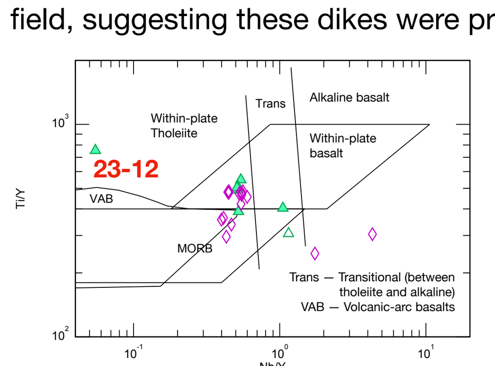


Fig. 5 Discrimination diagram for basalts, from Pearce (1982).

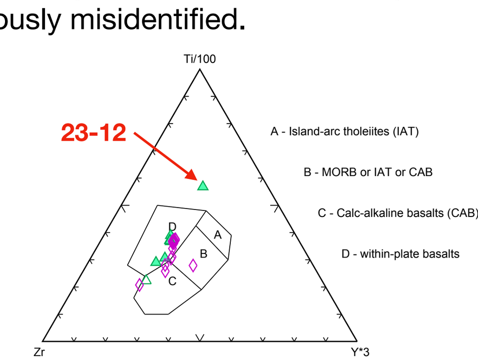


Fig. 6 Discrimination diagram for basalts, from Pearce and Cann (1971).

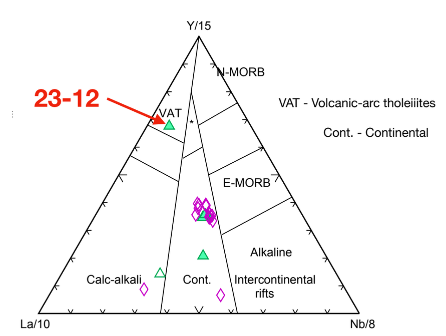


Fig. 7 Discrimination diagram for basalts, from Cabanis and Lecolle (1989).

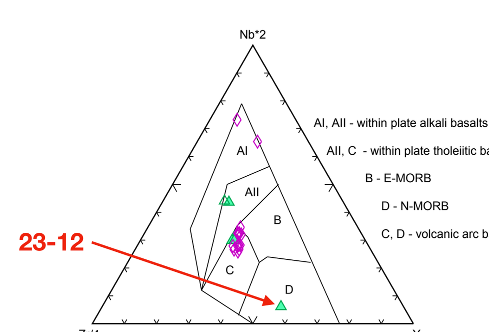


Fig. 8 Discrimination diagram for basalts, from Meschede (1986).

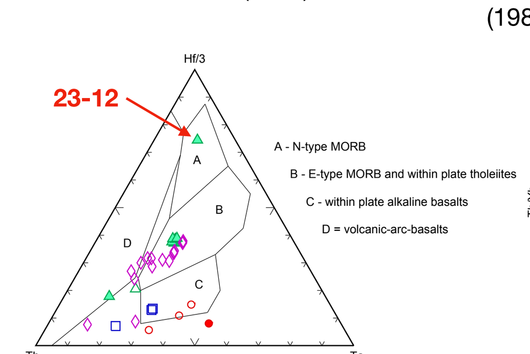


Fig. 9 Discrimination diagram from Wood (1980).

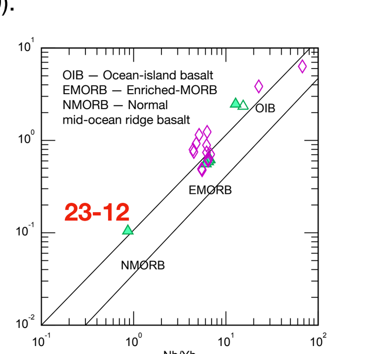


Fig.10 Discrimination diagram from Pearce (2008).

Discrimination Plots

Various discrimination plots employing immobile trace elements show most of the diabase samples from the Gunnison area and the Wet Mountains/Front Range falling within the fields for tholeiitic, within-plate, continental basalts (Figs. 5-8). Samples that plot within the alkaline fields in the Winchester and Floyd (1977) diagram also tend to fall within alkaline fields in Fig. 8. In Fig. 9, most of the diabase samples have E-MORB-type affinities. This is consistent with the results shown in Fig. 10, which indicates the magmas are E-MORB-type, asthenospheric partial melts that interacted with continental lithosphere previously modified by subduction. Three alkaline basalt samples have OIB-type affinities. The anomalous sample (23-12) continues to behave erratically.

REE (Rare-Earth Element) Diagrams

The majority of the Gunnison area and Wet Mountains/Front Range diabase samples cluster closely together with moderately light REE-enriched patterns in the upper graph of Fig. 11, typical of E-MORB-type basalts. The three alkaline basalt samples show stronger light REE enrichment typical of alkaline magmas. The anomalous sample (23-12) shows an unusual REE pattern that we do not understand. In the lower graph of Fig. 11, the phonolite dike samples show a well-defined europium anomaly along with a flat heavy REE pattern. The negative europium anomaly indicates fractional crystallization from a parental magma. This pattern contrasts with the trends of the lamprophyre and mafic-rich nepheline syenite dike samples, all of which show a much steeper light REE-enriched pattern. In Fig. 12, the diabase dike samples from the Gunnison area and the Wet Mountains/Front Range mostly show similar patterns. The phonolite dike samples show strong negative anomalies in barium, strontium, and titanium, suggesting these dikes are the product of prolonged fractional crystallization. The phonolite dike samples also show enrichment of many of the incompatible elements on the left side of the diagram, which is typical of alkaline rocks. The diabase sample (23-12) is completely anomalous.

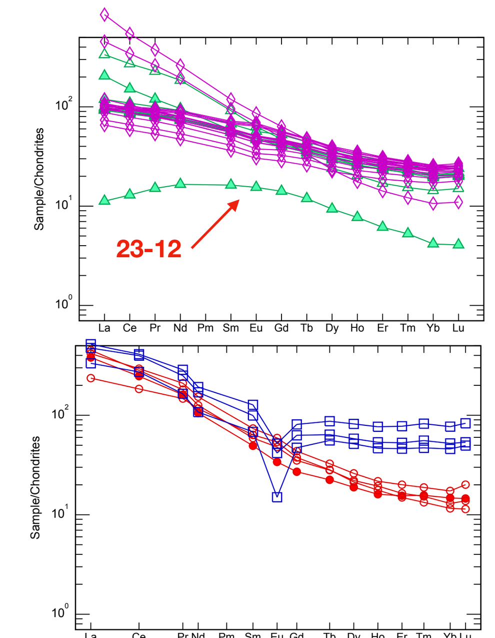


Fig. 11 REE diagrams of dike samples normalized to chondrites (Sun and McDonough, 1989)

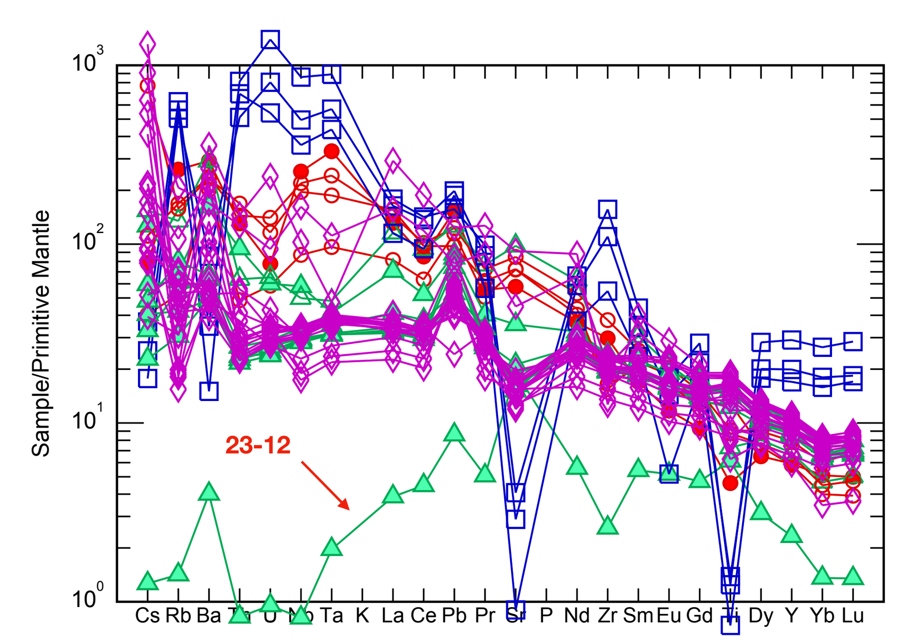


Fig. 12 REE diagram of all dike samples normalized to primitive mantle (Sun and McDonough, 1989).

Lamprophyre dike intruding Precambrian gneiss. Sample CO23-13 was taken from this outcrop. Figure for scale.

Lamprophyre dike in cliff side. Sample CO23-18 was taken from this outcrop. Figure for scale.

Conclusions

1. The samples fall within the sub-alkaline basalt, alkaline basalt, basanite/nephelinite, and phonolite fields in Fig. 4. This diagram indicates that the dike samples previously classified as trachyte dikes by other workers are, in fact, phonolites.
2. All these rock types are typical of intraplate rift environments. Figs. 5-8 show that the majority of the diabase dikes plot within fields for tholeiitic, within-plate, continental basaltic magmas. Figs. 9 and 10 show that the parental magmas of the dikes were E-MORB-type, asthenospheric melts that interacted with continental lithosphere previously modified by subduction.
3. The lack of any observable trends in the Harker variation diagrams (Fig. 3) at least partly reflects the fact that we are plotting samples that have different petrogenetic histories as well as the fact that the samples have been altered to various degrees. One diabase sample (23-12) shows erratic and anomalous behavior across the various geochemical diagrams, and this must also reflect secondary alteration, although the cause of that alteration is unclear.
4. Figs. 11 and 12 show that most of the diabase samples exhibit E-MORB-type patterns, and the alkaline basalts show light REE enrichment. However, the anomalous diabase sample (23-12) shows a very unusual REE pattern. The phonolite dike samples all show well-defined, negative europium anomalies as well as negative anomalies in barium, strontium, titanium, indicating the parental magmas underwent prolonged fractional crystallization. The lamprophyre and mafic-rich nepheline syenite dike samples show very similar REE patterns with pronounced light REE enrichment and appear to be unrelated to the phonolites.
5. The compositions of the Colorado dikes conflict with the dominant rock types in the Southern Oklahoma aulacogen, which include large volumes of rhyolite and granite. The diabase dikes with E-MORB-type affinities in Colorado are geochemically very similar to diabases in the Southern Oklahoma aulacogen (e.g., Eschberger et al., 2014), which could argue for a direct connection between the two igneous suites. However, lamprophyres, phonolites, and nepheline syenites do not occur in the aulacogen. If the aulacogen does directly continue into Colorado, then it must have had a different petrogenetic history. Isotopic dating is now in progress to determine if there is a direct connection between the two regions.

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