Volcanology and Geochemistry of Cambrian Rift-Related Rhyolites in the East Timbered Hills, Arbuckle Mountains, Southern Oklahoma

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Abstract

The Carlton Rhyolite Group forms part of a Lower Cambrian bimodal igneous assemblage emplaced during formation of a major intracontinental rift in southern Oklahoma. The rhyolites occupy an area of ~ 40,000 km^2 in the subsurface, with outcrops in the Wichita Mountains of southwest Oklahoma and in the East and West Timbered Hills in the Arbuckle Mountains, ~ 130 km to the southeast. Rhyolites in the Wichitas were emplaced as thick cooling units without obvious pyroclastic textures and may represent parts of extensive sheet-like lava flows erupted non-explosively. Rhyolite flows in the Arbuckles have not been studied in detail previously.

Our new mapping in the East Timbered Hills, close to the northern margin of the rift, shows that two rhyolite flows make up most of the volcanic sequence in that area. The total extent and thickness of the flows are unknown because they are truncated by faulting and partly hidden by younger cover. The largest exposed flow can be traced for 3.6 km and is at least ~ 600 m thick. It contains feldspar and quartz phenocrysts typically set in a massive felsitic groundmass with randomly oriented to radiating tridymite crystals (now inverted to quartz). Well-developed columnar jointing is perpendicular to the flow base, with delicate flow lamination and peperite present in the lower few meters. We infer that this unit is a remnant of a more extensive lava flow of the same type as documented in the Wichitas.

The upper flow is separated from the lower flow by volcaniclastic sedimentary rocks ~ 60 m thick that include planar-laminated vitric tuff with zones of soft-sediment folding, and planar-bedded tuff, mudstone and siltstone interbedded with rhyolite conglomerate and sandstone. The lower rhyolite flow is aphyric and shows flow banding and abundant spherulites throughout, perlitic texture, and vesicle-rich zones. Open to isoclinal flow folds deform the flow banding, and flow breccia up to 50 m thick is present in the upper part of the flow. This flow can only be traced ~ 700 m but is > 300 m thick. A complex series of hypabyssal felsic intrusions form irregular contacts against the two main flow units and can be divided into four types based on phenocryst content. The abundance of these subvolcanic intrusions suggests that the study area may be close to a rhyolite source vent. Geochemical studies thus far show the lava flows and hypabyssal intrusions to have within-plate, A-type compositions that are comparable with Carlton Rhyolite in the Wichitas.

Introduction

An Early Cambrian rift zone in southern Oklahoma forms an elongate, partially inverted rift that extends from the ancient continental margin in south-central Oklahoma northwest into the Texas Panhandle (Fig. 1). This rift zone represents a failed rift arm associated with the opening of the Iapetus Ocean to the present southeast. The Cambrian Carlton Rhyolite Group and related Wichita granites (Fig. 2) are widely distributed within the rift zone (Ham et al., 1964). The rhyolites occupy an area of ~ 40,000 km^2 in the subsurface, based on geophysics and drilling. This makes the Carlton Rhyolite Group a major volcanic field that is comparable in scale to the Miocene to Holocene Snake River Plain/Yellowstone magmatic system.

The Carlton Rhyolite is only exposed in the Wichita Mountains of southwestern Oklahoma and the Arbuckle Mountains of southern Oklahoma (Fig. 1). Much work has been done on rhyolites in the Wichitas by TCU workers (Philips, 2002; Burkholder, 2005; Finegan et al., this meeting; Frazier et al., this meeting). Rhyolites in the Arbuckles were first described by Uhl (1932), and brief additional information was given by Ham et al. (1964). The present project is the first modern study of the rhyolites in the Arbuckle Mountains.

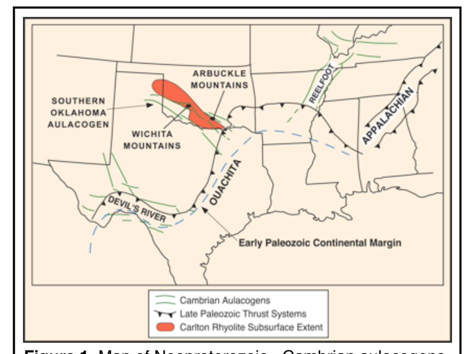

Figure 1. Map of Neoproterozoic - Cambrian aulacogens in southeastern North America (modified from McConnell & Gilbert, 1990; subsurface rhyolite extent from Ham et al., 1964; early Paleozoic margin from Keller & Stephenson, 2007; figure drafted by David McCleery, 2010).

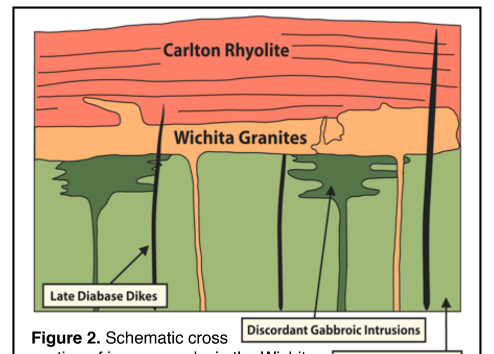

Figure 2. Schematic cross section of igneous rocks in the Wichita Mountains province (modified from Hogan & Gilbert, 1998; subsurface data from Ham et al., 1964, and Keller & Stephenson, 2007; figure drafted by David McCleery, 2010).

Geologic Background

Regional Geologic Setting

The southern Oklahoma rift zone is one of several rift zones that formed during the breakup of the Laurentian supercontinent in Neoproterozoic to Early Cambrian time. In Oklahoma, the igneous rocks associated with this rifting event were buried by up to 5 km of sediments during the Late Cambrian to late Paleozoic (Johnson et al., 1988; Gilbert, 1992). During late Paleozoic compression, the rift fill was partially inverted, with the igneous rocks uplifted as fault-bounded blocks. Igneous rocks associated with the southern Oklahoma rift zone are bimodal and include a layered mafic intrusive complex, gabbroic intrusions, and basaltic volcanic rocks (present only in the subsurface). The Carlton Rhyolite Group was deposited on an angular unconformity developed on the layered complex (Fig. 2). Sheet granites of the Wichita Granite Group that intrude the base of the Carlton Rhyolite are inferred to be comagmatic with it (Ham et. al., 1964; Gilbert, 1982). Diabase dikes crosscut all the other units, especially in the Arbuckle Mountains, where they are mostly parallel to the northwest structural grain of the rift (Taylor, 1915; Denison, 1995). These dikes are termed the "late diabases" (Powell et al., 1980).

Geologic Setting of the Study Area

In the Arbuckle Mountains, the Carlton Rhyolite is exposed in two main areas in the core of the Arbuckle anticline. These areas are called the East and West Timbered Hills (Fig. 3). My studies to date have been restricted to the East Timbered Hills (Figs. 6 and 7), which include the highest point in the Arbuckle Mountains. In the southwestern part of the East Timbered Hills outcrop, the rhyolite is overlain disconformably by the Upper Cambrian Timbered Hills Group (consisting of the Reagan Sandstone overlain by the Honey Creek Limestone). In the east and northeast, the rhyolite is thrust on top of the Arbuckle Group (which consists of a number of different formations). Several faults cut the rhyolite and are inferred to have formed during late Paleozoic deformation.

Brittle shear zones have been mapped in the upper rhyolite flow and in some of the hypabyssal felsic intrusions (Fig. 6). These zones are up to 80 m across and have closely spaced, sub-parallel, steeply dipping fractures that locally grade into pockets of fine-grained cataclastite (Fig. 4). Cataclastic breccias up to 1 m wide are locally associated with fine-grained foliated cataclastite, and are generally found near or along the major thrust fault on the northeast side of the study area. Limestone in the Arbuckle Group in these regions also shows cataclastic disruption (Fig. 5). These brittle shear zones are inferred to have formed during Pennsylvanian deformation.

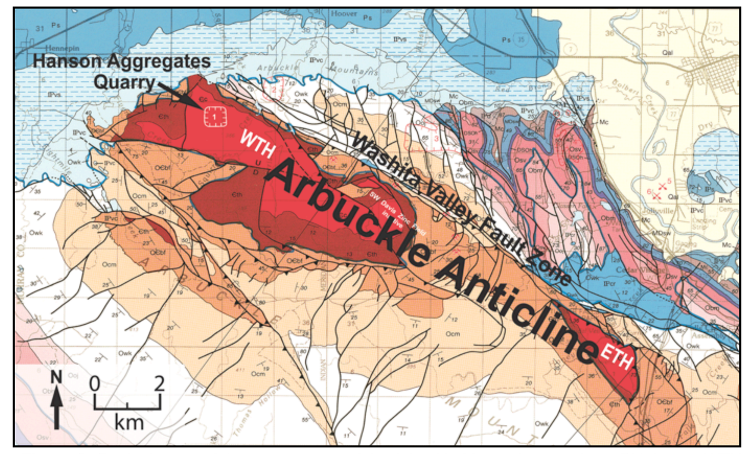

Figure 3. Geologic map of the western part of the Arbuckle Mountains, southern Oklahoma. WTH = West Timbered Hills; ETH = East Timbered Hills (modified from Johnson, 1990).

Figure 4. Fine-grained cataclastite in Type III felsic intrusion.

Figure 5. Fine-grained cataclastite in limestone from the Arbuckle Group (in same region as Figure 4).

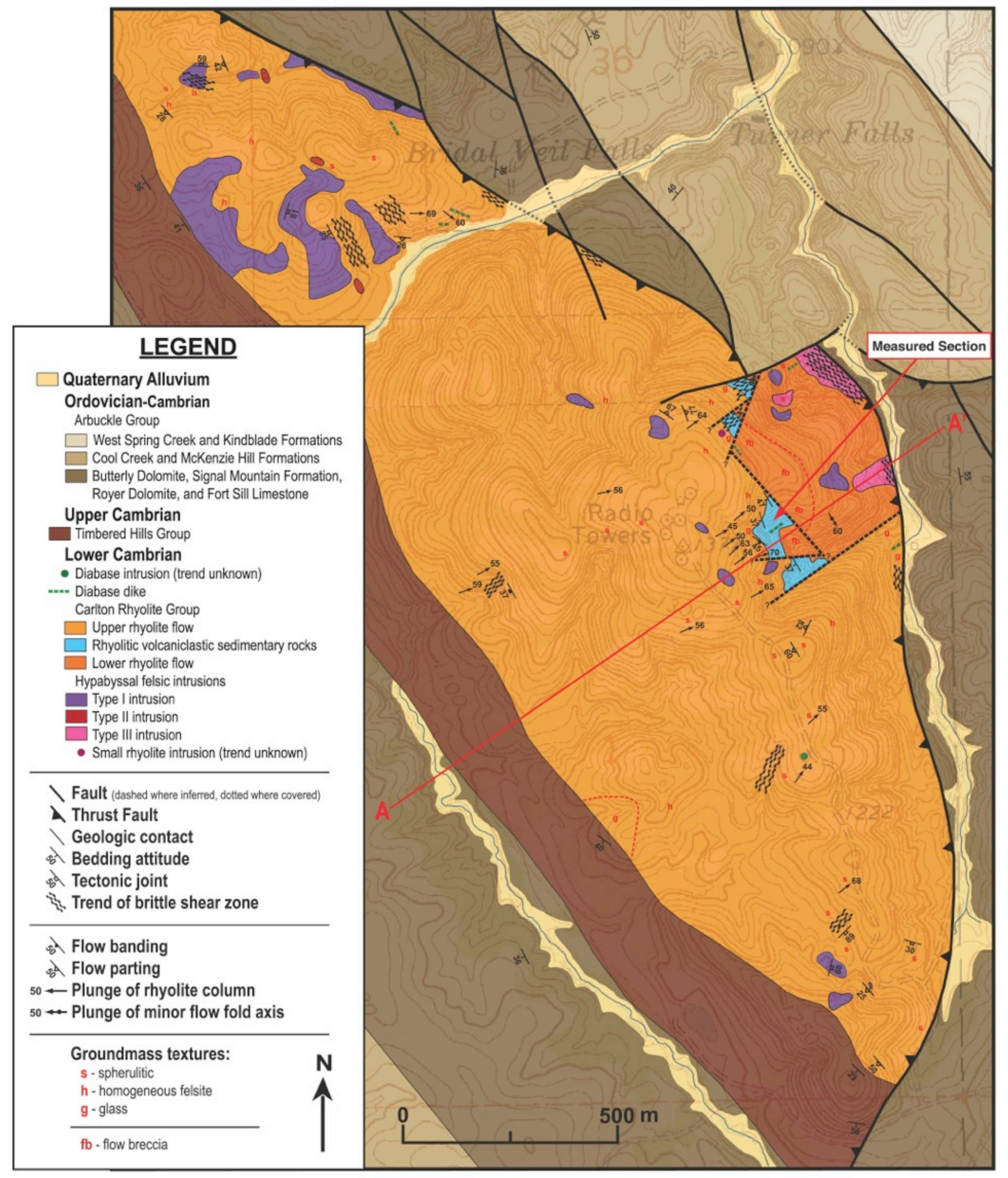

Figure 6. Geologic map of the East Timbered Hills in the western part of the Arbuckle Mountains. Upper Cambrian-Ordovician geologic units and faults cutting them from Johnson (1990). Cross section A-A' (Fig. 7) is indicated in red. Red arrow points to location of measured section (Fig. 16).

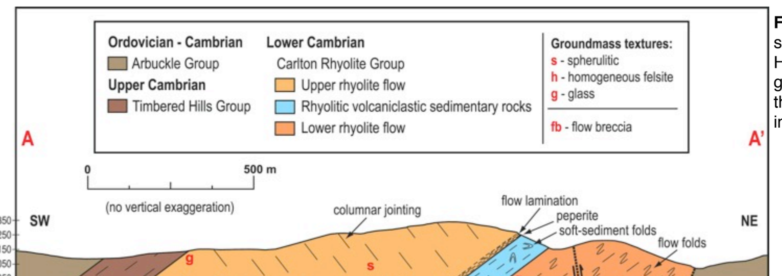

Figure 7. Geologic cross section of East Timbered Hills showing prominent groundmass textures in the lava flows. A to A' is indicated on Fig. 6.

Carlton Rhyolite Group in the East Timbered Hills

Our mapping to date (Fig. 6) shows two rhyolite flows, an intervening sequence of volcaniclastic sedimentary rocks, and a complex series of hypabyssal felsic intrusions that can be divided into four main types based on phenocryst content. The felsic intrusions form irregular contacts against the two rhyolite flows. Diabase dikes in the study area tend to be poorly exposed, and are up to a few meters across, with northwest or northeast trends.

Lower Rhyolite Lava Flow

This unit is only present in the eastern part of the study area and is in fault contact to the east with the Arbuckle Group. The lower rhyolite flow is > 300 m thick, but since the base of the unit is faulted, the actual thickness may be much larger. The lava is aphyric and pervasively flow-banded down to the thin-section scale (Figs. 8 and 9). Some flow bands contain abundant, elongate, small vesicles oriented in the direction of flow (Fig. 10). Open to isoclinal flow folds deform the flow banding in many places (Figs. 11a and 11b). Flow breccia is present in the upper part of this unit and is up to 50 m thick (Fig. 12). Spherulites are abundant and range from < 1 mm to 1.5 cm in diameter (Figs. 13 and 14). The spherulites are set in a dark gray groundmass, and are inferred to represent early, high-temperature devitrification of glassy lava. Parts of the groundmass that did not develop spherulites preserve relict perlitic texture (Fig. 15), which formed during hydration of glass following early devitrification.

Figure 8. Flow banding in lower rhyolite flow.

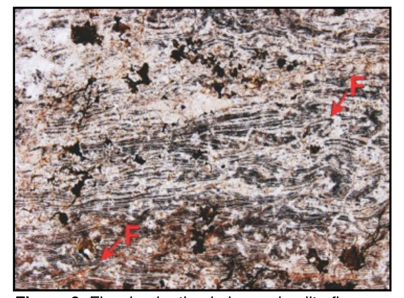

Figure 9. Flow lamination in lower rhyolite flow overprinted by secondary silicification. Plane-polarized light; field of view ~ 2.5 mm across. F=flow fold.

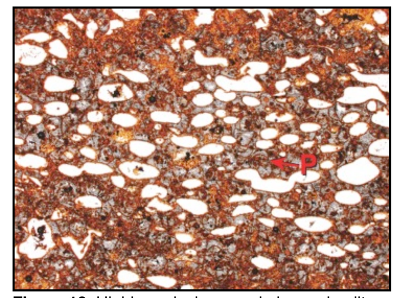

Figure 10. Highly vesicular zone in lower rhyolite flow. Vesicles are filled with quartz. Plane-polarized light; field of view ~ 5 mm across. P=perlitic texture.

Figure 11a. Flow folding in lower rhyolite flow.

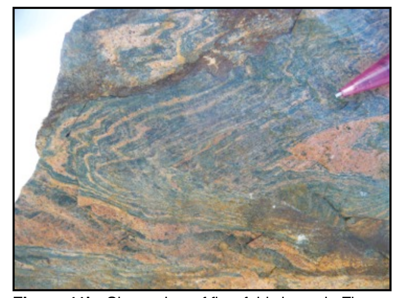

Figure 11b. Closer view of flow fold shown in Fig. 11a.

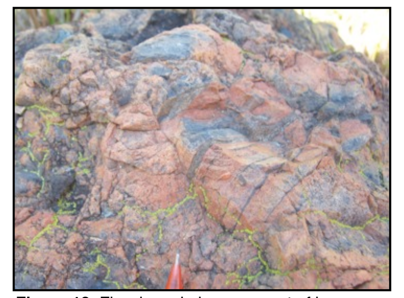

Figure 12. Flow breccia in upper part of lower rhyolite flow. Notice some clasts are outlined by yellow lichen.

Figure 13. Spherulites in lower rhyolite flow showing concentric growth zones.

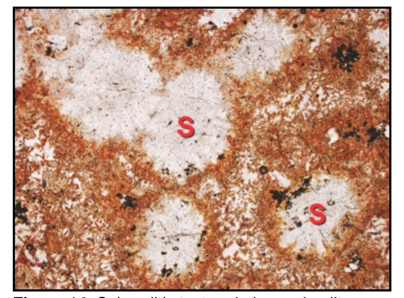

Figure 14. Spherulitic texture in lower rhyolite flow. Plane-polarized light; field of view ~ 5 mm across. **S**=spherulite.

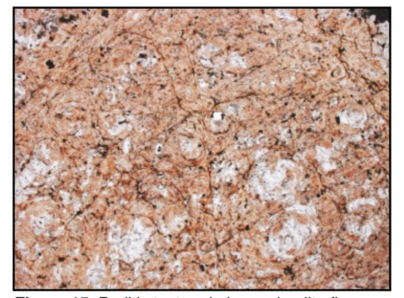

Figure 15. Perlitic texture in lower rhyolite flow. Plane-polarized light; field of view ~ 5 mm across.

Rhyolitic Volcaniclastic Sedimentary Rocks

The lower rhyolite is overlain by a rhyolitic volcaniclastic sedimentary sequence ~ 60 m thick (Fig. 16). Planar-laminated, very fine-grained siliceous tuff and tuffaceous mudstone (Figs. 17a and 17b) make up the lower part of the sequence and show zones of intense soft-sediment disruption. Meter-scale soft-sediment folds in these zones range from upright to recumbent (Fig. 18). These fine-grained rocks are succeeded by a poorly sorted, massively bedded polymict rhyolite cobble and boulder conglomerate containing clasts of aphyric rhyolite up to 30 cm long and showing coarse-tail normal grading. Planar-bedded tuff, mudstone and siltstone interbedded with rhyolite pebble conglomerate and sandstone make up the rest of the interval (Fig. 19). In the eastern part of the study area, this sequence is offset by several faults trending mostly northeast-southwest, and is completely faulted out against the upper rhyolite flow to the northwest and southeast.

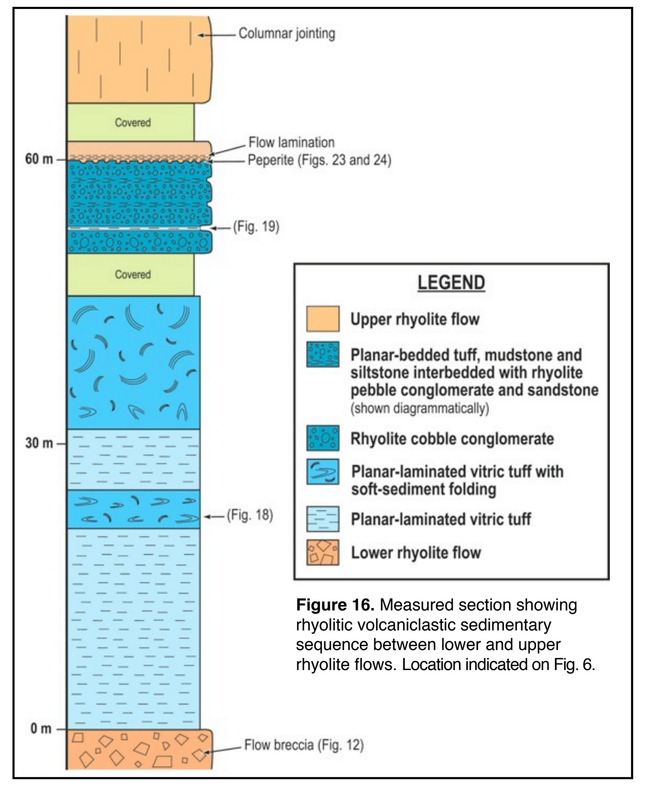

Figure 16. Measured section showing rhyolitic volcaniclastic sedimentary sequence between lower and upper rhyolite flows. Location indicated on Fig. 6.

Figure 17a. Planar lamination in very fine-grained siliceous tuff and tuffaceous mudstone.

Figure 17b. Planar lamination in very fine-grained siliceous tuff and tuffaceous mudstone.

Figure 18. Soft sediment fold in planar-laminated vitric tuff.

Figure 19. Contact between planar-laminated tuff interbed and rhyolite pebble conglomerate.

Upper Rhyolite Lava Flow

The volcaniclastic sedimentary rocks are overlain along a planar contact by the upper rhyolite flow. This flow is the most extensive unit in the study area, and can be traced up to 3.6 km along strike, with a thickness of at least ~ 600 m; however, the total extent and thickness of the flow are unknown since the unit lies against a major thrust fault to the east and northeast. In addition, offset between different parts of the flow along Pennsylvanian faults cutting it has not yet been quantified.

This flow is very different from the lower rhyolite flow. The upper flow is a porphyritic rhyolite with abundant phenocrysts (mostly of alkali feldspar with minor quartz), and the main part of the flow has a pinkish-gray, homogeneous, felsitic groundmass in contrast to the dark-colored spherulitic and flow-banded groundmass in the lower rhyolite flow. However, in the upper part of the upper rhyolite flow, where cooling was more rapid, the unit has a more heterogeneous groundmass, with locally pervasive flow parting (Fig. 20) and small spherulites visible in hand sample and well-displayed in thin section (Fig. 21).

In the uppermost part of the flow, beneath the unconformity against the Reagan Sandstone, the groundmass is locally dark gray to black representing altered and devitrified glass. This suggests the unconformity surface is close to the original top of the flow. The groundmass is also dark gray to black near the base of the flow (Fig. 22), and shows delicate flow lamination in places. Peperite formed along the flow base by quench fragmentation of rhyolite and intermixing with underlying wet, unconsolidated tuffaceous sediments (Figs. 23). This peperite zone consists of dark-colored, mostly blocky, subangular rhyolite fragments separated by disrupted, light gray-colored tuffaceous mudstone. Smaller rhyolite fragments show characteristic jigsaw texture (Fig. 24), which documents non-explosive, *in situ* quench fragmentation of rhyolite lava as it flowed across the wet tuffaceous sediments.

Figure 20. Upper rhyolite flow showing pervasive flow parting near top of flow.

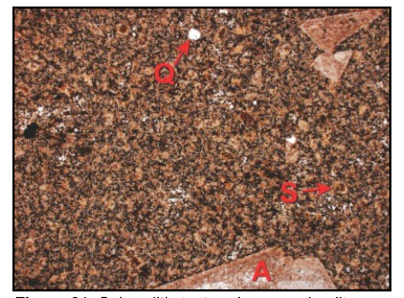

Figure 21. Spherulitic texture in upper rhyolite flow. Plane-polarized light; field of view ~ 5 mm across. **A**=alkali feldspar phenocryst; **Q**=quartz phenocryst; **S**=spherulite.

Figure 22. Upper rhyolite flow showing dark groundmass near base of flow. Pink alkali feldspar and gray quartz phenocrysts are visible.

The main part of the upper flow is characterized by uniformly developed columnar jointing (Fig. 25), indicating that it is a single cooling unit. The columns are up to 1 m wide (Fig. 26) and plunge steeply (mostly 50° to 70°) to the northeast, perpendicular to the base of the flow.

In thin section, the groundmass shows an increase in the size of tridymite needles (now replaced by quartz) upward in the flow (Figs. 27 and 28). Similar tridymite textures have been documented in the Wichitas by TCU workers (Philips, 2002; Burkholder, 2005; Finegan et al., this meeting; Frazier et al., this meeting).

Figure 23. Peperite located at base of upper rhyolite flow.

Figure 24. Peperite located at base of upper rhyolite flow, showing jigsaw texture.

Figure 25. Columnar jointing in upper rhyolite flow. Columns are ~ 1 m across.

Figure 26. Columnar jointing in upper rhyolite flow. Hammer rests on surface at high angle to jointing.

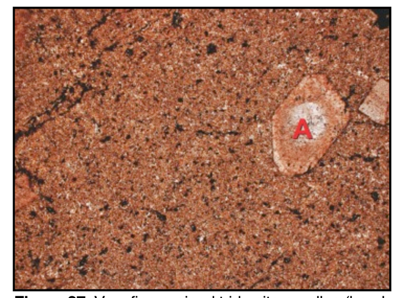

Figure 27. Very fine-grained tridymite needles (barely visible; now replaced by quartz) in groundmass near base of upper rhyolite flow. Plane-polarized light; field of view ~ 5 mm across. **A**=alkali feldspar phenocryst.

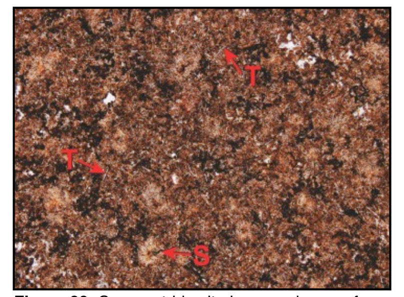

Figure 28. Coarser tridymite in groundmass of interior of upper rhyolite flow. Plane-polarized light; field of view ~ 2.5 mm across. **S**=spherulite; **T**=tridymite (now replaced by quartz).

Hypabyssal Felsic Intrusions:

Type I Intrusions

This unit is a series of rhyolite intrusions up to ~ 160 m across, which cut both the upper and lower rhyolite flows (Figs. 6 and 29). The Type I rhyolite intrusions are similar to the upper rhyolite flow in that they contain abundant alkali feldspar phenocrysts in a felsitic groundmass, but they are differentiated by their distinctive dipyramidal quartz phenocrysts up to ~ 3 mm across, and by the presence of micrographic texture in the groundmass (Fig. 30). In addition, Type I intrusions show only local regions of crude columnar jointing, and no flow banding. However, locally they contain lithophysae up to 1.5 cm across (Fig. 31). The presence of these gas cavities indicates that the Type I rhyolite intrusions were emplaced at very shallow levels where gas bubbles could exsolve readily during cooling and devitrification.

Figure 29. Contact between upper rhyolite flow (bottom) and Type I intrusion (top). Hammer head rests on contact (outlined in red). Note the crude columnar jointing in the intrusion.

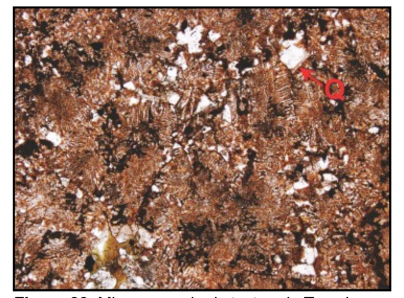

Figure 30. Micrographic texture in Type I rhyolite intrusion. Plane-polarized light; field of view ~ 2.5 mm across. **Q**=dipyramidal beta-quartz phenocryst.

Figure 31. Lithophysae in Type I rhyolite intrusion, up to 1.5 cm across.

Type II Intrusions

This unit consists of small orange-brown rhyolite intrusions that cut the upper rhyolite flow and are up to ~ 35 m across. So far, only three such intrusions have been mapped in the study area, all in the northwestern part. The only phenocrysts are small mafic crystals replaced by iron oxide and clay. These are set in a very fine-grained felsite groundmass.

Type III Intrusions

This unit includes three felsic intrusions up to 100 m across that intrude the lower rhyolite flow in the eastern part of the study area. The Type III intrusions are pinkish- to reddish-gray in color and aphyric, with a homogeneous groundmass that is barely phaneritic, making the term microgranite appropriate for these rocks.

In thin section (Fig. 32), the groundmass shows spherulitic texture, and coarse, randomly oriented tridymite needles up to 1 mm long, much coarser than the tridymite needles found in the upper rhyolite flow (Fig. 28). Micrographic texture occurs between the tridymite needles.

Type IV Intrusion

This unit has so far only been found as locally derived float in a small area, where the base of the upper rhyolite flow is in contact with tuffaceous sedimentary rocks in the eastern part of the study area (Fig. 6). The Type IV intrusion is a pinkish-red rhyolite, with alkali feldspar phenocrysts up to 2 mm across. The groundmass shows well-developed spherulitic texture (Fig. 33). The unit may represent a poorly exposed dike.

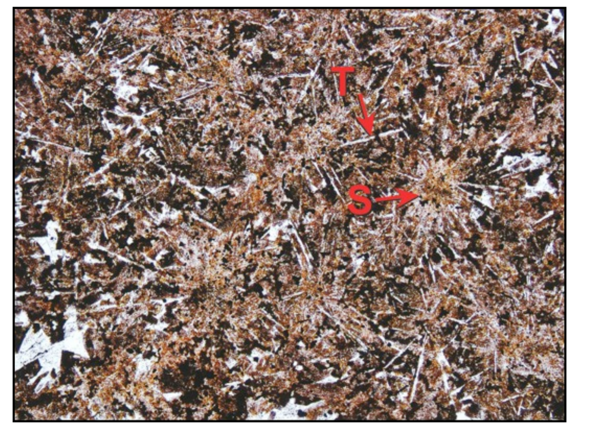

Figure 32. Groundmass textures in Type III intrusion. Plane-polarized light; field of view ~ 2.5 mm across. **S**=spherulite; **T**=tridymite (now replaced by quartz).

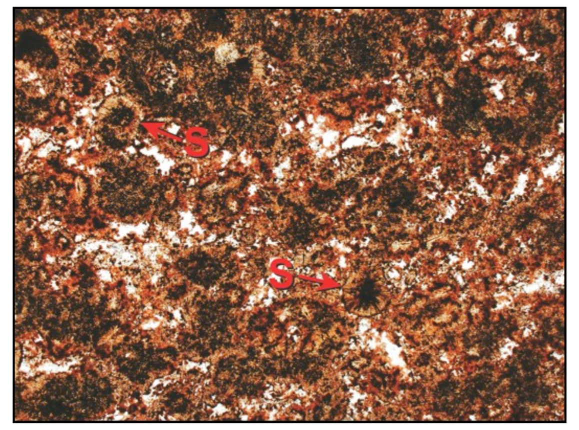

Figure 33. Spherulitic texture in rhyolite dike. Plane-polarized light; field of view ~ 5 mm across. **S**=spherulite.

Geochemistry

We have so far analyzed three samples from the upper flow, two samples from the lower flow, and a total of eight samples from the hypabyssal intrusions. Only two representative Harker diagrams are shown here (Figs. 34 and 35). Other major oxides on Harker diagrams tend to be scattered, probably as a result of element mobility during secondary alteration. Some of the variation in silica contents in Figs. 34 and 35 is also due to secondary silicification.

Figures 36 and 37 are standard discrimination diagrams that use trace elements that are resistant to secondary alteration. In Fig. 36, the samples generally fall in fields for rhyolite and peralkaline rhyolite. They uniformly plot within fields for within-plate, A-type felsic rocks (Figs. 37 and 38) and compare fairly closely to fields for Carlton Rhyolite in the Wichita Mountains.

Overall, the samples show highly fractionated patterns on the multi-element (spider) diagram (Fig. 39), which is typical of A-type felsic rocks. The samples show a strong depletion in Sr, P, and Ti, reflecting fractionation of plagioclase, apatite, and titanomagnetite, respectively. They also show a marked negative Ba anomaly, indicating significant fractionation of alkali feldspar. These patterns are comparable to those in Carlton Rhyolite of the Wichitas, except that the hypabyssal intrusions show a more pronounced negative Ba anomaly.

In Figs. 40 and 41, which again use immobile trace elements, all but one of the samples consistently plot within three distinct groups. The upper and lower lava flows, as well as a few of the hypabyssal intrusions occupy one group, whereas the other intrusions occupy two different groups. These three geochemical groups may represent distinct magma reservoirs or source regions, although the available data set is too limited to make any firm conclusions along these lines at the present time.

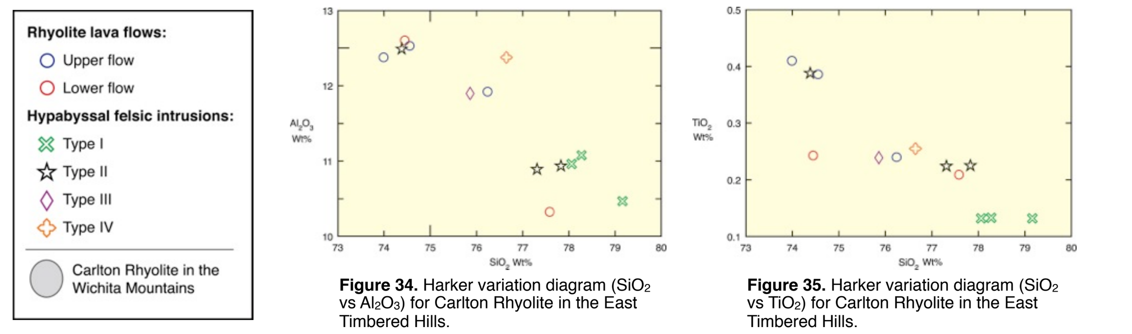

Figure 34. Harker variation diagram (SiO_2 vs Al_2O_3) for Carlton Rhyolite in the East Timbered Hills.

Figure 35. Harker variation diagram (SiO_2 vs TiO_2) for Carlton Rhyolite in the East Timbered Hills.

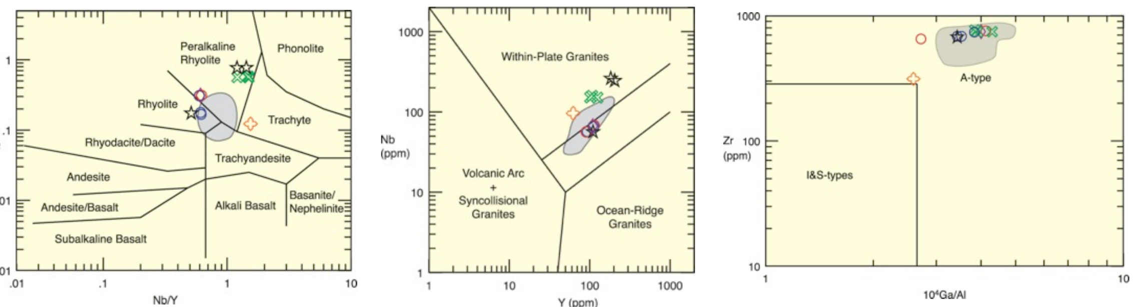

Figure 36. Carlton Rhyolite in the East Timbered Hills plotted on the diagram of Winchester and Floyd (1977).

Figure 37. Carlton Rhyolite in the East Timbered Hills plotted on the diagram of Pearce et al. (1984).

Figure 38. Carlton Rhyolite in the East Timbered Hills plotted on the diagram of Whalen et al. (1987).

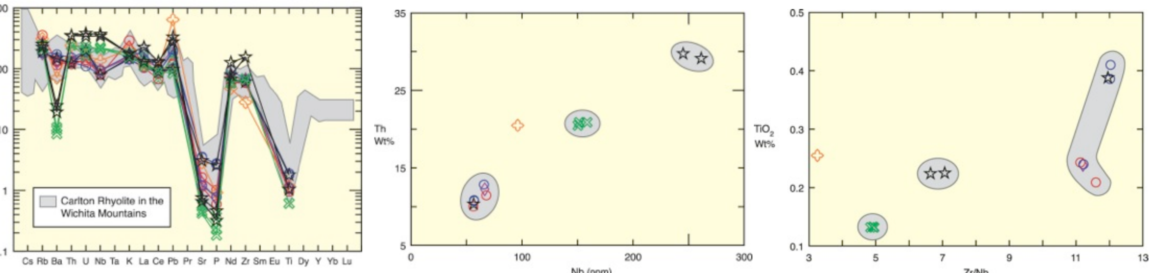

Figure 39. Multi-element diagram for Carlton Rhyolite in the East Timbered Hills. Normalized to primitive mantle according to Sun and McDonough (1989).

Figure 40. Nb vs Th showing three distinct geochemical groups of Carlton Rhyolite in the East Timbered Hills.

Figure 41. Zr/Nb vs TiO_2 showing three distinct geochemical groups of Carlton Rhyolite in the East Timbered Hills.

Conclusions

- Our work in the Arbuckles has so far documented one extensive rhyolite flow unit (upper flow) with a thickness of at least ~ 600 m. This is greater than the maximum rhyolite flow thickness (400 m) documented in the Wichitas (Pollard and Hanson, 2000).
- Another rhyolite lava flow (lower flow) is thinner and less continuous than the upper rhyolite flow, with a thickness > 300 m. This lower flow may represent a rhyolite dome that has not travelled far from the vent.
- Four types of hypabyssal felsic intrusions have been recognized. Their abundance suggests that the study area is relatively close to one of the rhyolite source vents. This makes the area different from the rhyolite outcrops studied in the Wichitas, where mapping by TCU workers has found only a small number of felsic hypabyssal intrusions (Philips, 2002; Finegan et al., this meeting).
- A rhyolitic volcaniclastic sedimentary sequence occurs between the two lava flow units. This sequence records a pause in eruption activity and serves as a stratigraphic marker.
- Preservation of significant thicknesses of finely laminated tuff suggests that deposition occurred in a lacustrine setting. Similar lacustrine deposits between flows have been documented in the Wichitas (Frazier et al., this meeting).
- Geochemical studies of samples taken from rhyolite flows and hypabyssal felsic intrusions in the study area, show them to be highly fractionated, within-plate, A-type felsic rocks, very similar to the Carlton Rhyolite in the Wichita Mountains. This indicates that rhyolites in different parts of the rift have similar petrogenetic histories.

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