Avon Volcanic District Field Trip, June 10, 2014

by
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INTRODUCTION

This field trip was organized to enable researchers interested in studying mid-continent alkaline and ultramafic magmatism to meet and share ideas and experiences. It is hopeful that future collaboration and research will be able to solve some of the intriguing questions associated with these rocks.

The Avon Volcanic District

The Avon volcanic district (AVD) is primarily composed of approximately 80 known diatremes, dikes and possible sills. More intrusions are certainly yet to be discovered. The primary lithology consists of olivine melilitite, alnöite and carbonatite based on observed mineralogy (Bridges and Hogan, 2008) and available geochemical work (Mansker, 1974). The AVD covers a roughly elliptical area of approximately 195 km^2 east of Farmington, Missouri (Fig. 1). This area lies on the south limb of the Farmington anticline. The Farmington anticline is also known as the Jonca dome (Rust, 1937) or Avon block (Graves, 1938). Outcrops are poorly exposed and most are extensively altered. A majority of the outcrops exhibit a very heterogeneous composition and texture. These challenges have plagued researchers for nearly 100 years. Known outcrops occur in late Cambrian sedimentary deposits (Figs. 1B and 2). Based on Devonian fossils found in chert xenoliths and K-Ar and Rb-Sr age dating (Zartman et al., 1966), a middle to late Devonian age of intrusion is suggested.

Previous Work

A few of the igneous outcrops of the AVD were mapped as Tertiary conglomerates by Weller and St. Clair (1928) during their geologic mapping of Ste. Genevieve County between 1913 and 1920. The first published occurrence of post-Precambrian igneous volcanic activity in Missouri was by Spurr (1926). Two of the intrusions were subsequently described by two papers in the *Journal of Geology* (Singewald and Milton, 1930; Tarr and Keller, 1933). The first comprehensive survey of the AVD was completed by George W. Rust in the summer of 1935 and subsequently published (Rust, 1937). Rust increased the known number of intrusions from five to seventy one. Rust believed the intrusions were a result of gaseous eruptions from a laccolithic body. In 1947, Albert L. Kidwell's monumental work, *Post-Devonian Igneous Activity in Southeastern Missouri* was published by the Missouri Geological Survey and Water Resources. Kidwell not only completed a survey of outcrops but provided a comprehensive description of 56 intrusives that he visited. The Kidwell intrusive numbers used in this field guide come from this work. A major finding for the AVD came in 1966, when Zartman et al. (1966) published an abstract reporting a radiometric age of 390 ±20 Ma using the mineral phlogopite. Two theses related to the AVD were published in the early 1970s (Mansker, 1973; Rinehart, 1974). Little AVD research has been reported since.

Lithological Characterization

Due to poor exposure and extensive alteration, the AVD intrusions have been poorly characterized. They have been described as **peridotite** (Spurr,1926; Tarr and Keller, 1933; Koenig, 1956; Zartman et al., 1967); **olivine peridotite** (Weller and St. Clair, 1928); **augite-free alnöite** (Singewald and Milton, 1930); **lamprophyre**

(Grohskopf, 1955; Koenig, 1956); **basalt** (Snyder and Gerdemann, 1965); **mica peridotite** (Zartman et al., 1966); **kimberlite** (Watson, 1967; Zartman et al., 1967; Heyl, 1972; Mansker, 1973; Mansker et al., 1976; Kisvarsanyi and Kisvarsanyi, 1976a and 1976b; Zartman, 1977; Basu and Tatsumoto, 1980; Basu et al., 1984; Hills et al., 1991; Ryckman and Hogan, 1999); **carbonatite** (Brookins, 1969; Rinehart, 1974; Bridges and Hogan, 2007); **alkalic peridotite** (Heyl, 1972); **alnöite** (Kisvarsanyi and Kisvarsanyi, 1976a and 1976b; Mitchell, 1986; Bridges and Hogan, 2007); "**kimberlitic**" (Kisvarsanyi et al., 1981); **ultramafic lamprophyre** (Rock, 1986); **melnoite** (Mitchell, 1996); **melilitite** (Mitchell, 1997; Bridges and Hogan, 2007); and **olivine melilitite** (Bridges and Hogan, 2008; Callicoat et al., 2008). Based on current understanding, the AVD is classified as a **melilitite-carbonatite suite**. Kidwell intrusion #24 is an **alnöite**. A majority of the intrusions of the AVD are simply classified as **olivine melilitites** according to the IUGS classification (Tappe et al., 2005).

Kidwell (1947) divided the intrusions into three types: 1) non-explosive type consisting primarily of igneous material with very few xenoliths, 2) sedimentary and igneous xenolithic breccia cemented by ultramafic igneous material and 3) large brecciated sedimentary inclusions and granite fragments cemented by calcite or ultramafic igneous material that has been altered to calcite, chlorite and serpentine. Kidwell's type 1 matches with the root zone of Mitchell's (1986) diatreme model (Fig. 3). This zone hosts a hypabyssal facies and likely serves as the transition locus for the diatreme facies. Although Mitchell's diatreme model was originally intended to illustrate emplacement morphology of kimberlitic diatremes, based on field relations in the AVD, it appears to be applicable to melilitite diatremes. This is further supported by morphologies described in other and better exposed melilitite volcanic fields such as Hegau, Urach, Eshowe and Namaqualand (Mitchell, 1996). Crystallized hypabyssal melilititic magma is referred to a melnoite (Mitchell, 1996). Stop #4 provides the opportunity to examine this type of intrusive. Kidwell's intrusive type #2 is the most common type. Thirty-five of the fifty-six described intrusives described by Kidwell (1947) are this type. This type conforms with the diatreme facies of Mitchell's (1986) diatreme model. The diatreme facies is found where much of the pelletal lapilli formed simultaneously with the brecciation and redistribution of the country rock within the diatreme. Kidwell (1947) reports finding xenoliths from 4000 ft of vertical stratigraphic section within the diatremes. The currently exposed relief between exposures is 600 to 700 ft, and all currently known intrusives are restricted to Upper Cambrian strata. The least common of Kidwell's intrusion types is #3. This may be due to the lack of obvious igneous material combined with the large juxtaposed country rock boulders that are not conspicuous in the field. This type would likely be found vertically higher than type #2 in Mitchell's diatreme model or a portion of the diatreme closer to its contact with the country rock. Of final note, the current exposure level in the AVD has removed any evidence of pyroclastics or crater facies—if they existed (Figs. 3 and 4).

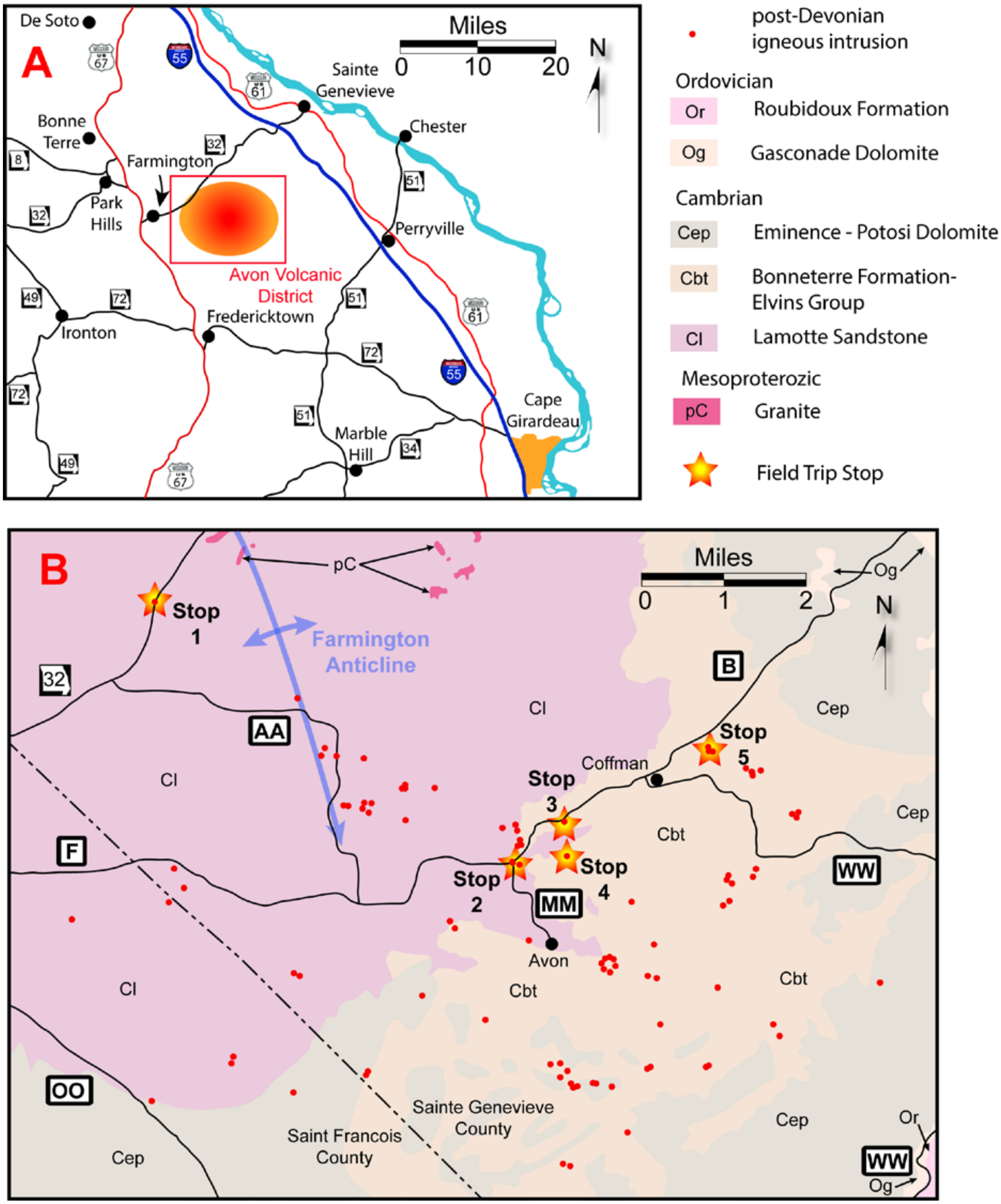
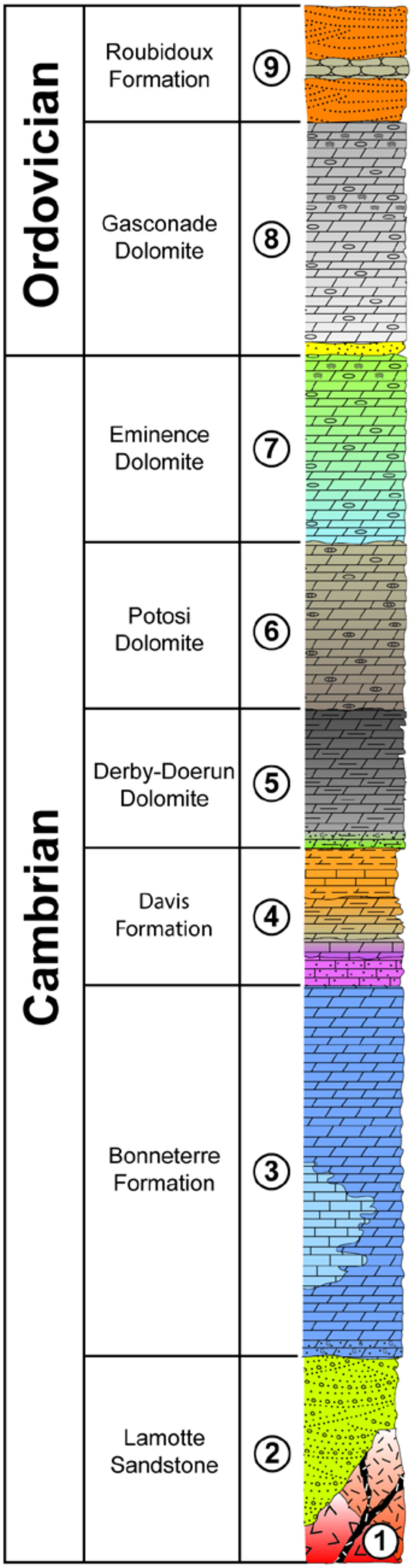


Figure 1. *The Avon volcanic district (AVD).* **(A)** *Map showing location in southeastern Missouri.* **(B)** *Geologic map.*



Generalized Geologic Column for the Avon Volcanic District

9. Roubidoux Sandstone
Thickness - 60'. The Roubidoux formation consists of sandstone and chert. The basal and upper portions consist of a medium grain sandstone, commonly reddish brown. The middle section is often massively bedded chert.

8. Gasconade Dolomite
Thickness - 250'. The Gasconade is composed of dolomite and chert. It is primarily a coarsely crystalline light to medium gray dolomite.

7. Eminence Dolomite
Thickness - 50'? The Eminence dolomite is poorly characterized in the Avon Volcanic District. It consists of a gray crystalline dolomite and chert.

6. Potosi Dolomite
Thickness - ~300'. The Potosi is a medium-grained dolomite light gray to chocolate brown in color. The formation is characterized by abundant quartz druse.

5. Derby-Doerun Dolomite
Thickness - 10' to 40'. The Derby-Doerun is primarily dolomite. The upper part consist of an argillaceous buff-colored dolomite with quarts druse. The lower part is primarily a finely crystalline, dark dolomite that is irregularly fractured.

4. Davis Formation
Thickness - 80' to 100'. The Davis is comprised of intercalated dolomite and shale beds. The dolomite is usually dense and gray to buff color, medium to fine-crystalline. The shale is typically fissile and greenish-gray.

3. Bonneterre Formation
Thickness ~400'. The Bonneterre is primarily dolomite with some shale and limestone present. It is dense and dark brown in the upper part and light gray, porous and glauconitic in the lower part.

2. Lamotte Sandstone
Thickness - 110' to 220'. The Lamotte Sandstone is a medium to coarse grained sandstone with a well developed basal conglomerate and many intraformational conglomerates. It is most commonly yellow but varies from white to brown.

1. Mesoproterozoic Volcanics and Intrusions
Thickness unknown. Granite and basic dikes. The granite consist of a red to pink and gray varieties. The granites are fine to coarsely grained. The gray variety contains more ferromagnesian minerals.The basic dikes are dark greenish gray with equigranular to porphyritic textures.

Figure 2. *Geologic column for the Avon volcanic district (AVD).*

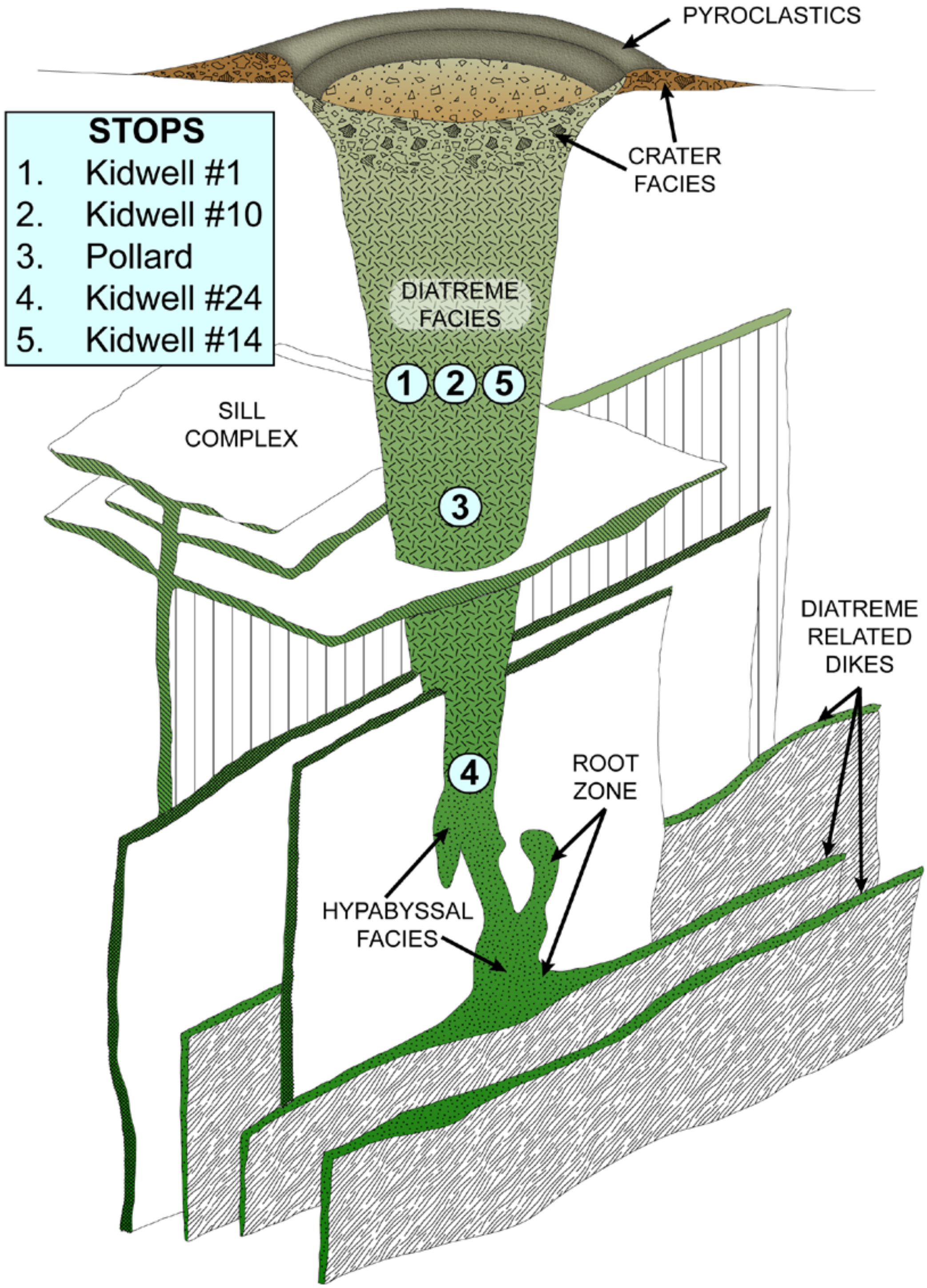


Figure 3. *Model for diatreme morphology modified after Mitchell (1986). Numbered circles indicate the field trip stops. The relative depths of emplacement of the diatreme rocks at the stops are indicated.*

Mineralogy

Kidwell (1947) reported the following minerals occurring in the melilitite and carbonatite intrusions: **olivine**, **phlogopite**, **biotite**, **magnetite**, **calcite**, **augite**, **melilite**, **hornblende**, **diopside**, **pyrite**, **apatite**, **perovskite**, **chromite** and **garnet**.

Mansker (1973) completed a thorough geochemical study of Kidwell intrusive #24 including some microprobe work. Mansker reported the occurrence of the following minerals in intrusion #24: **olivine**, **phlogopite**, **magnetite**, **calcite**, **xonotlite**, **diopside**, **salite**, **serpentine**, **chromite**, **apatite**, **melilite** and **perovskite**. Based on Mansker's (1973) microprobe work, the olivines are forsteritic Fo_{88}. Mansker believed that the salite is associated with metamorphism at the intrusion–dolomite contact. Mansker (1973) found two generations of phlogopite. If the older generation of phlogopite was the one dated by Zartman et al. (1967), then the Devonian age would not be indicative of when the volcanism associated with AVD actually occurred. Chromite exhibits rims that have been replaced by magnetite. Based on EDS analysis performed by the author, the rims are also titanium enriched.

Emplacement and Tectonic Framework

The tectonic framework and thus emplacement of the various intrusives of the AVD is poorly understood at this time. Pieces in this puzzle likely include the Ozark Dome, St. Francois Mesoproterozoic igneous activity, the breakup of supercontinent Rodinia (thus the Reelfoot graben), southeastern Missouri mineralization, Ste. Genevieve fault system and the Farmington anticline. The melilitite volcanism is ultimately sourced from a metasomatized mantle 80–120 km depth by partial melting of dolomitic garnet lherzolite (Mitchell, 1996). Figure 4 is a cartoon that illustrates the manner in which the diatremes may have been emplaced. The doming of the Farmington anticline and the concentration of the intrusions of the AVD seems more than coincidental. More isotopic and microprobe work is needed to provide clues as to how the pieces fit together. It is the author's belief that the different pieces are all interconnected in some intimate fashion. It is our job to put the puzzle together!

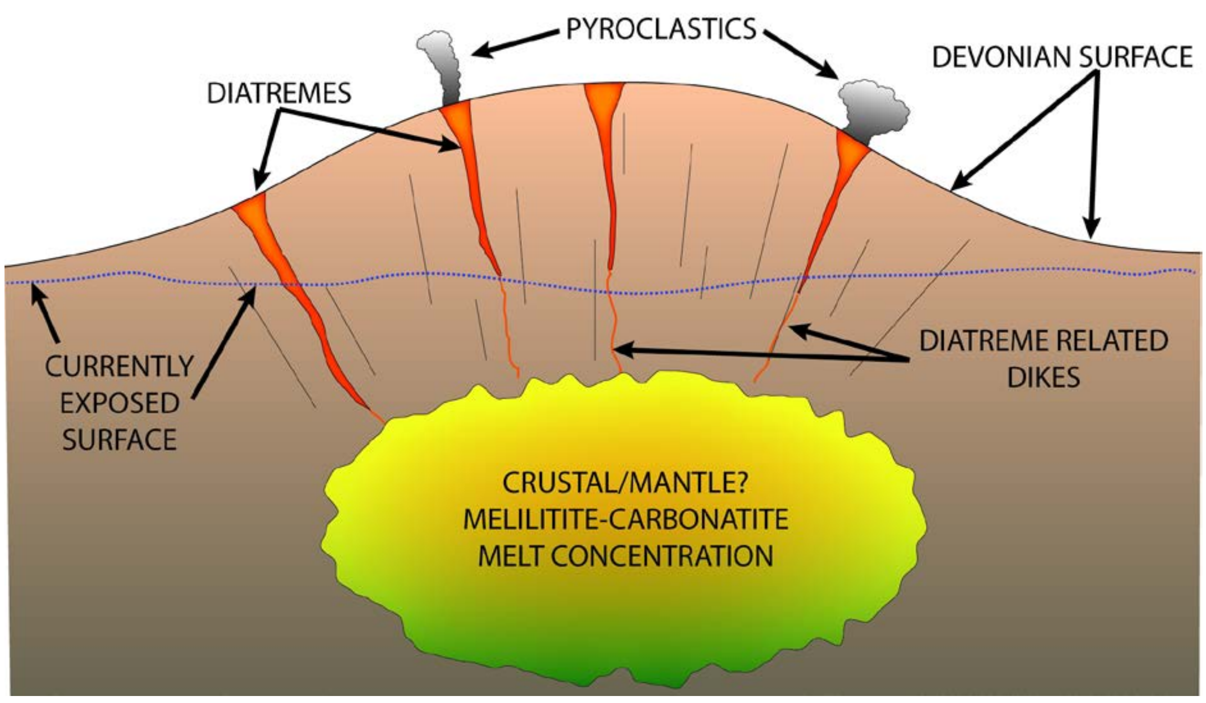


Figure 4. *Schematic cartoon showing possible AVD emplacement configuration. Doming is suggested by the presence of the Farmington anticline.*

STOP #1

Kidwell #1 - Missouri Route 32

Figure 5. *Kidwell #1 is poorly exposed and highly weathered. The visible rock near the center is highly fractured Lamotte Sandstone suggestive of faulting or a direct result of volcanism. To the right (south) of the exposed rock, beneath the vegetated slope is igneous material that has largely been weathered to a saprolitic material. Missouri Route 32 is on left. Photo direction is northeast.*

Kidwell intrusive #1 was extensively described by Tarr and Keller (1933). This intrusion was initially uncovered during construction of Missouri Route 32 during the summer of 1932. The site was subsequently visited by Tarr and Keller in January and May of the following year. The intrusion is 275 ft wide and covered with vegetation. The northernmost contact with the Lamotte Sandstone is sharp (Fig. 5) while the southernmost contact is covered. Tarr and Keller reported that the intrusion has an elliptical morphology 175 ft in width and 600 to 700 ft long. The part of the intrusion that can be seen along the road represents the northernmost edge of the pipe. Although most of the material is highly weathered, fresh material may be had by considerable searching and digging. The rock is composed primarily of pelletal lapilli in a fine grained matrix (Fig. 6). The fresh material is dark gray in color and yellowish when extensively weathered (Fig. 6). The lapilli range in size from 0.5 mm to in excess of 10 mm. Most pelletal lapilli cores are carbonate mineral that has replaced an originally mafic mineral (likely olivine). The pelletal lapilli weather to a dark greenish color. The groundmass is mostly carbonate mineral with some rounded sand grains present. A remarkable characteristic of this exposure is the variety of xenoliths present. These xenoliths are typically angular and can be boulder-sized (4 ft). Tarr and Keller reported the presence of sandstone, chert, granite, gneiss, flint, conglomerate, shale, dolomite and some other undeterminable igneous rocks. Devonian fossils in the chert at this locality allowed earlier researchers to determine that the intrusions are post-Devonian age. Later dating by Zartman (1977) yielded a middle Devonian age based on K-Ar and Rb-Sr dating of biotites. Tarr and Keller were able to make a few thin sections from a less weathered boulder. Mineralogy includes carbonate, quartz, serpentine, magnetite, chlorite, epidote (?), phlogopite, chromite (?) and rare clinopyroxene. Kidwell (1947) noted a similar mineralogy. Kidwell (1947) described the exposure as a type #2 intrusion. The former presence of olivine is suggested by euhedral "ghosts" of serpentine visible in many of the pelletal lapilli. Melilite was likely present as small laths in the groundmass that surround the cores of the pelletal lapilli based on crystal morphology and occurrence.

Figure 6. *Close view of saprolitic material typical of the Kidwell #1 intrusive body.*

STOP #2

Kidwell #10 - Intersection of State Routes F and MM

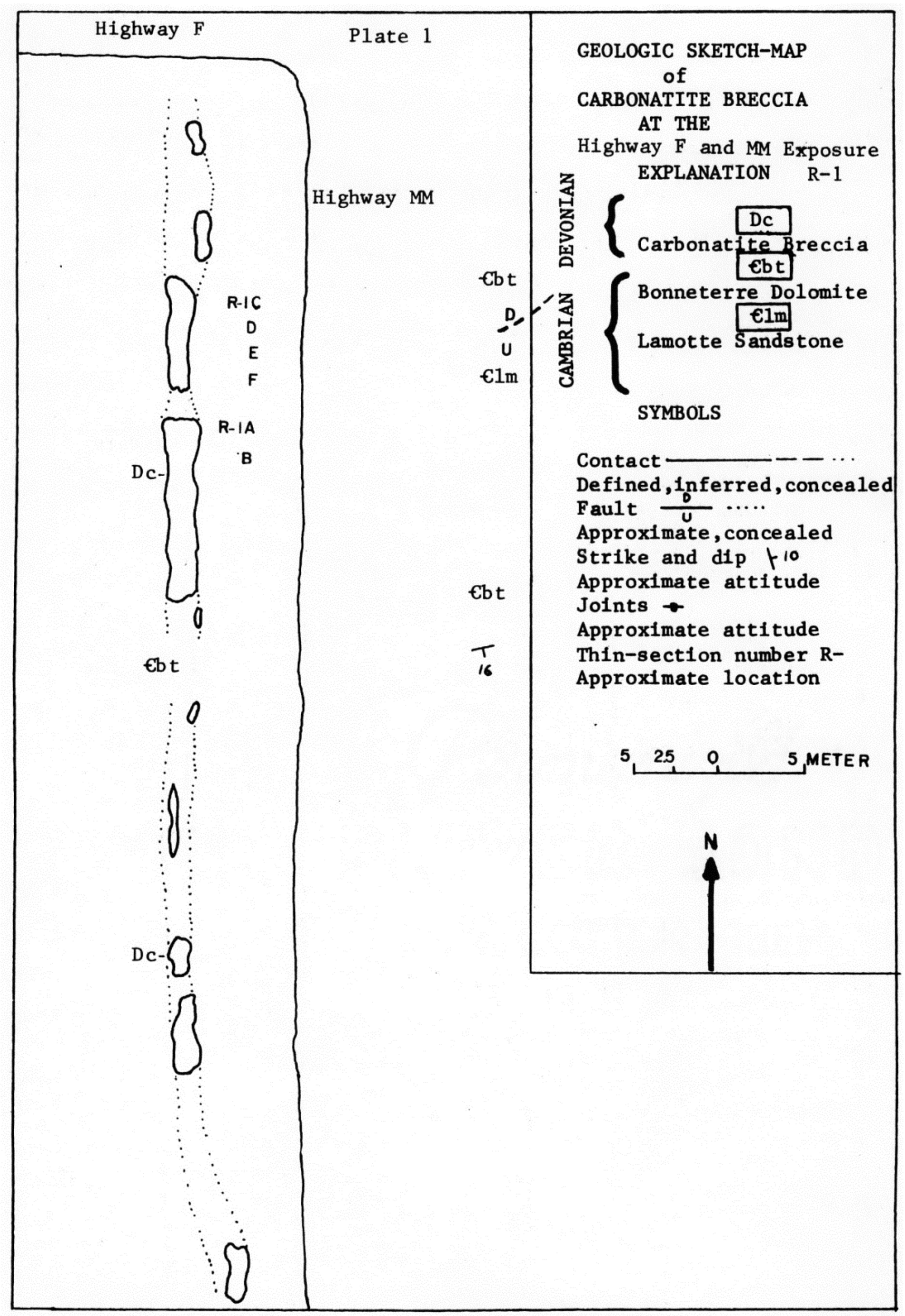


Figure 7. *Outcrop map of Kidwell #10 intrusive from Rinehart (1974).*

Kidwell intrusion #10 (Fig. 7) was one of the first described intrusions of the AVD. Weller and St. Clair (1928) described this exposure as a Tertiary conglomerate. Kidwell (1947) described the exposure as one of his type #2 intrusions. The intrusion was visited during a Geological Society of America field trip in 1965 (Snyder and Williams, 1965). Kidwell #10 was described by Heinrich (1966) in his popular book *The Geology of Carbonatites* (Fig. 8).

Figure 8. *Kidwell #10 from Heinrich (1966).*

Although Rinehart (1974) suggested that this exposure is elongated along a north–south trend (Fig. 7), the present author believes that this is merely an artifact of having been exposed during utility and road work. Similar rock is present in the yard and in the floor of the barn across the road to the east. A rounded exposure of Bonneterre Formation dolomite is visible on the east side of Missouri Route MM. The outcrop has a conglomerate appearance with some homogenous igneous material also present. The rock is essentially a xenolithic breccia supported in a pelletal lapilli groundmass. The xenoliths are primarily dolomite, limestone, shale, granite, fossiliferous chert and sandstone (Rinehart, 1974; Kidwell, 1947). The igneous material has a dark greenish gray appearance when fresh and a yellowish-brown color upon weathering. The pelletal lapilli are generally less than 3 mm in diameter (Kidwell, 1947). The mineralogy consists of calcite, serpentine, magnetite, quartz (secondary) and andradite garnet.

Figure 9. *Kidwell #10 on west side of Missouri Route MM and immediately south of T-intersection with Missouri Route F. This exposure has become overgrown; however, dense, massive igneous material can still be collected.*

Figure 10. *View of sawed specimen shown in Figure 9. This specimen is composed of brecciated county rock surrounded by a groundmass of pelletal lapilli. The pelletal lapilli typically consist of a core surrounded by dark, chloritized igneous material.*

STOP #3

Pollard Exposure

Figure 11. *Dense igneous material found at the Pollard exposure.*

This exposure was found by Eric Pollard, a student from Indiana University, during a 2010 field trip led by Missouri Geological Survey geologist Patrick S. Mulvany. Little work has been done to characterize this exposure. The outcrop was recently visited by the author and samples collected for thin sections and geochemistry. The igneous material appears to be massive with little to no xenolithic clasts or xenocrysts. The weathered outcrop appears yellowish-brown in color with fresh material exhibiting a greenish gray color. The rock is comprised mostly of pelletal lapilli less than 2 mm diameter; nevertheless, some lapilli up to 7 mm diameter are present, along with occasional crystal and lithic fragments.

STOP #4

Kidwell #24

Figure 12. *Kidwell intrusive #24 is characterized by rounded exposures of dense hypabyssal igneous rock.*

Kidwell intrusive #24 is perhaps the most studied of all the known igneous intrusions of the AVD. This intrusion also has the distinction of being the first AVD intrusion to be described in peer reviewed literature (Singewald and Milton, 1930). The intrusion was first described by Spurr (1926) and Ball (see Singewald and Milton, 1930). The outcrop was described as a pipe with a slightly elongated axis about 220 ft in length. The diatreme intrudes Bonneterre Formation dolomite which is contact-metamorphosed to a small degree. One diamond drill hole near the center of the outcrop penetrated 305 ft of igneous material. Singewald and Milton (1930) published a paper in the *Journal of Geology* in which they described this exposure and called it an augite-free alnöite. This article is one of the most widely cited papers related to the AVD. Two types of igneous material are present, one being a dark greenish gray porphyritic rock (Figs. 12 and 13) and a pelletal lapilli-rich rock found near the contact with the Bonneterre Formation dolomite country rock (Fig. 14). The latter type appears to be a late stage hypabyssal intrusion that occurred inside the pelletal lapilli-filled diatreme pipe. The porphyritic nature of this hypabyssal rock is due to the presence of large olivine megacrysts up to 10 mm in diameter. Many of the megacrysts has been replaced by serpentine; however, some pristine relic olivine is still present (Figs. 13 and 16). Very few intrusions in the AVD exhibit pristine olivine. The groundmass of the porphyritic igneous rock contains phenocrysts of phlogopite. Many seem to mantle the olivine megacrysts and may be secondary in nature. Large phenocrysts of phlogopite are visible in hand specimen as golden brown tuffs of vitreous mineral. The groundmass contains calcite, melilite, perovskite and garnet. The groundmass appears turbid in places with little discernable crystallinity. In thin section, under cross polars, the groundmass exhibits little to no birefringence. This perhaps results from the presence of large amounts of anhedral melilite or anomalous color blocking true birefringence such as commonly exhibited by chlorite and serpentine minerals. Singewald and Milton (1930) reported the following mineralogy: olivine, serpentine, phlogopite, melilite, apatite, magnetite, chromite and perovskite. The author has observed a similar mineralogy with the addition of garnet. The garnet appears honey-yellow to brown in plane light and isotropic in crossed polars.

Figure 13. *Samples collected at Kidwell #24. Sample in center exhibits marbelization of Bonneterre Formation dolomite country rock. Sample to right shows olivine megacrysts (dark) surrounded by alnöitic groundmass.*

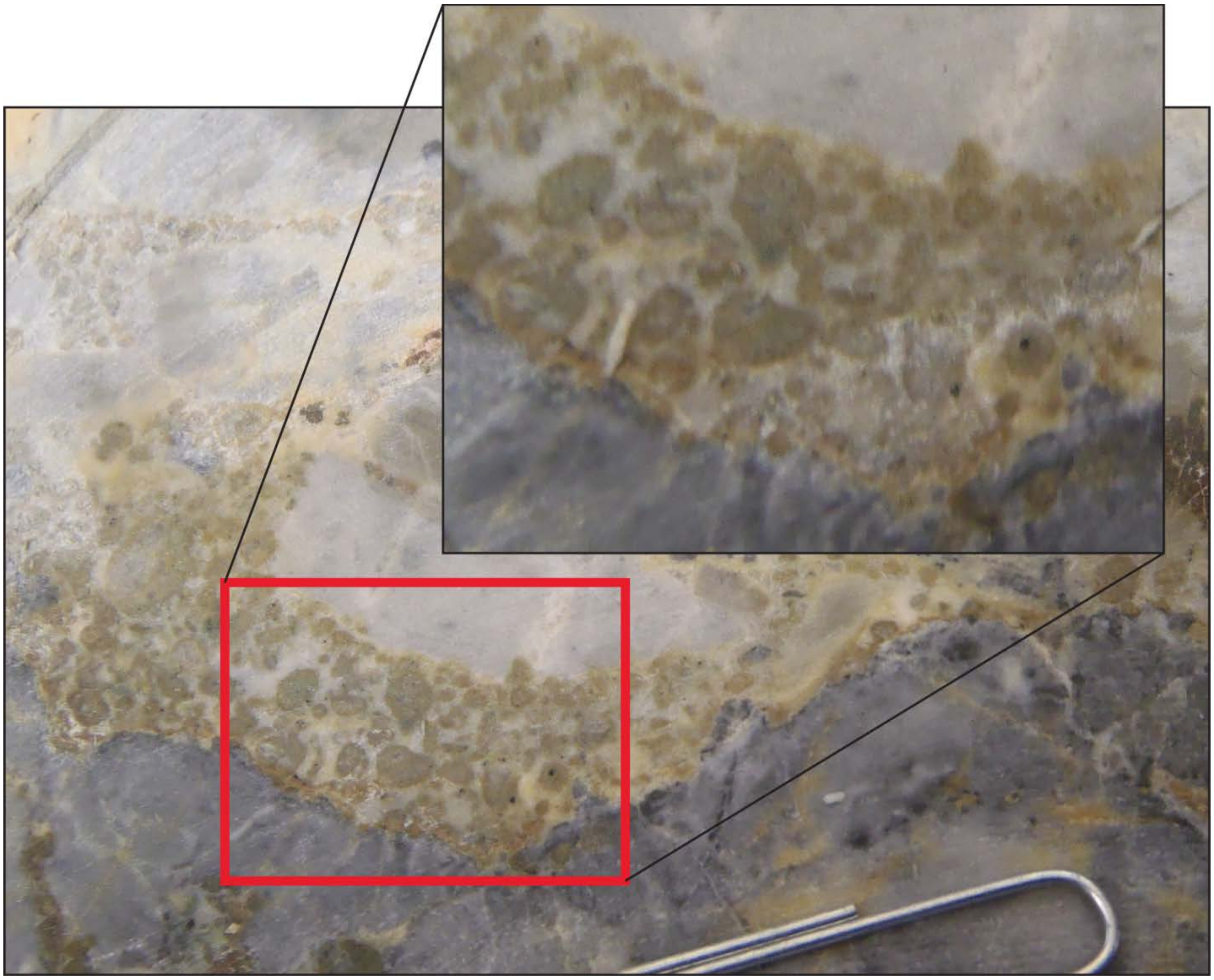


Figure 14. *Bonneterre Formation–intrusion contact at Kidwell #24. Note the pelletal lapilli within a primary carbonate groundmass. The carbonate was emplaced at a later stage than the pelletal lapilli.*

Of particular interest at Kidwell intrusion #24 is the contact of the diatreme pipe with the Bonneterre Formation country rock (Fig. 14). This portion of the diatreme reveals a time sequence of events that occurred during emplacement of the diatreme. The initial intrusion appears to be gas driven. This is supported by the limited extent of contact-metamorphism with the country rock and the presence of the pelletal lapilli. During this early stage, the country rock was fractured and transported vertically towards the surface. At the same time, a small amount of igneous material from depth was incorporated into the gas jet thereby emulsifying the igneous material into tiny droplets that formed the pelletal lapilli. These pelletal lapilli are most commonly cored; however, some appear to be droplets of igneous melt only. It also appears that some carbonatite liquid may have been incorporated in the emulsified gas column or jet within the diatreme. The pelletal lapilli appear to have a coating of carbonatite (Fig. 15) that is optically distinctive from the surrounding groundmass carbonatite. The second major event was the intrusion of the hypabyssal alnöite into the lapilli-choked diatreme. The alnöite melt pushed much of the lapilli to the sides of the diatreme and into the fractures of the surrounding Bonneterre Formation dolomite. Either syn- or post-hypabyssal emplacement intrusion of carbonatitic fluid (gas or liquid) filled the spaces between the pelletal lapilli, hypabyssal intrusion and country rock. Singewald and Milton (1930) also reported xonotlite ($Ca_3Si_3O_9 \cdot H_2O$)

associated with the contact metamorphism. Late stage sulfide mineralization appears to be last major emplacement event for Kidwell intrusion #24. A magnetic survey (Fig. 17) completed by Kidwell (1947) further supports the pipe model.

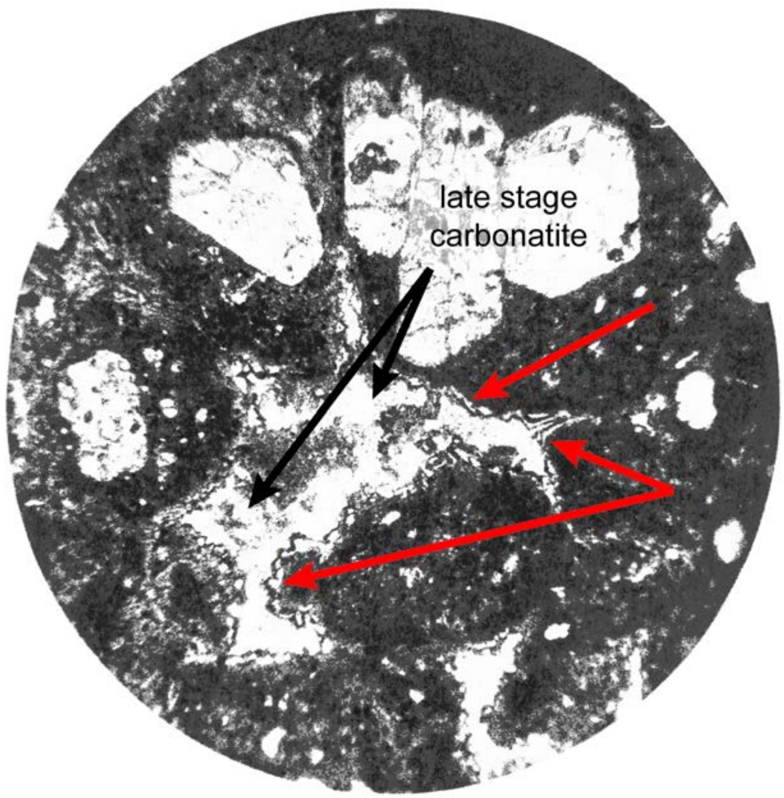


Figure 15. *Photomicrograph of Kidwell #24 from Singewald and Milton (1930, fig. 4) that shows carbonatite and pelletal lapilli. Red arrows point to coatings of suspected carbonatite deposited contemporously on pelletal lapilli during emplacement.*

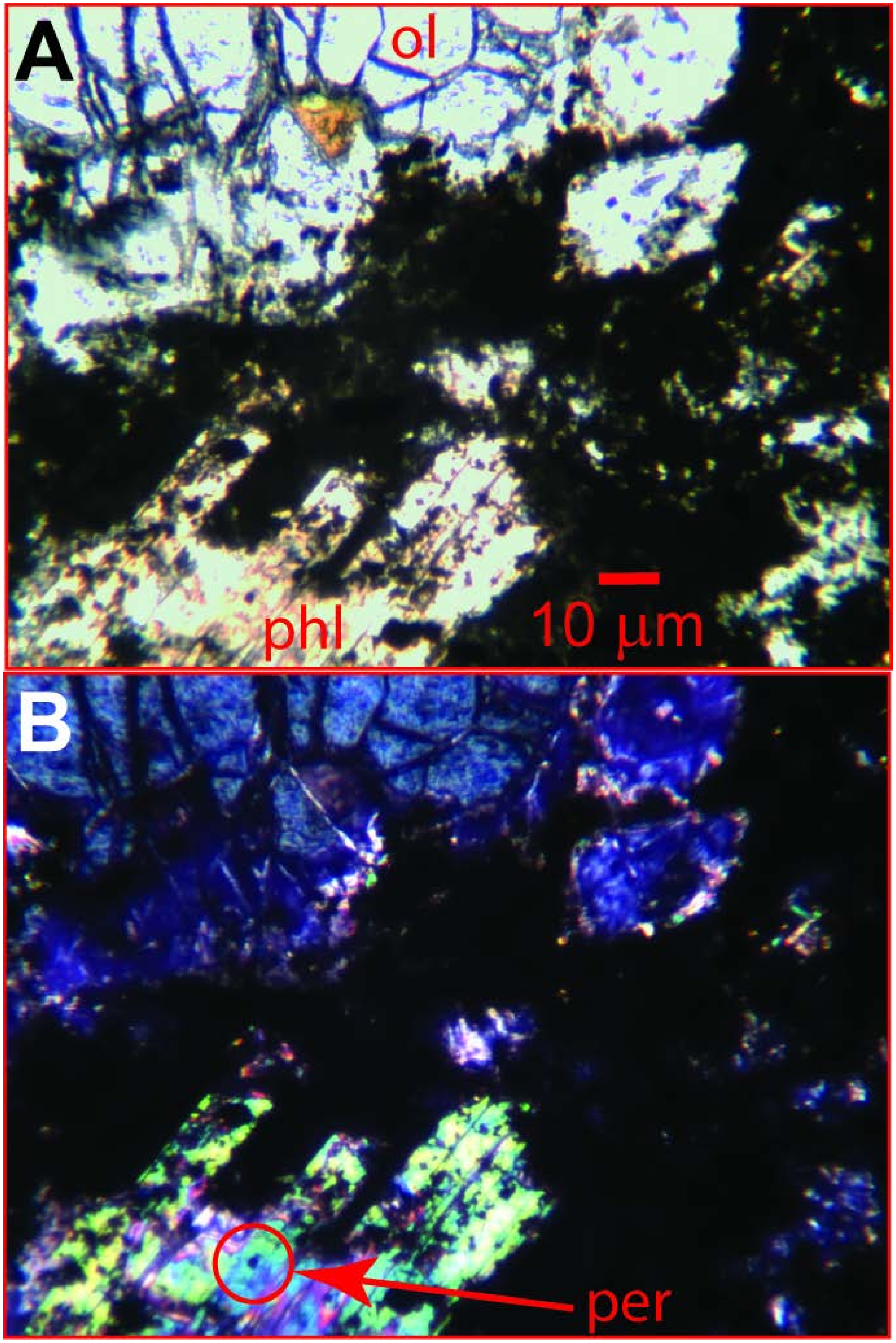


Figure 16. *Hypabyssal alnöite from Kidwell intrusive #24.* **(A)** *plane light.* ***(B)*** *crossed polars. ol=olivine; per=perovskite; phl=phlogopite.*

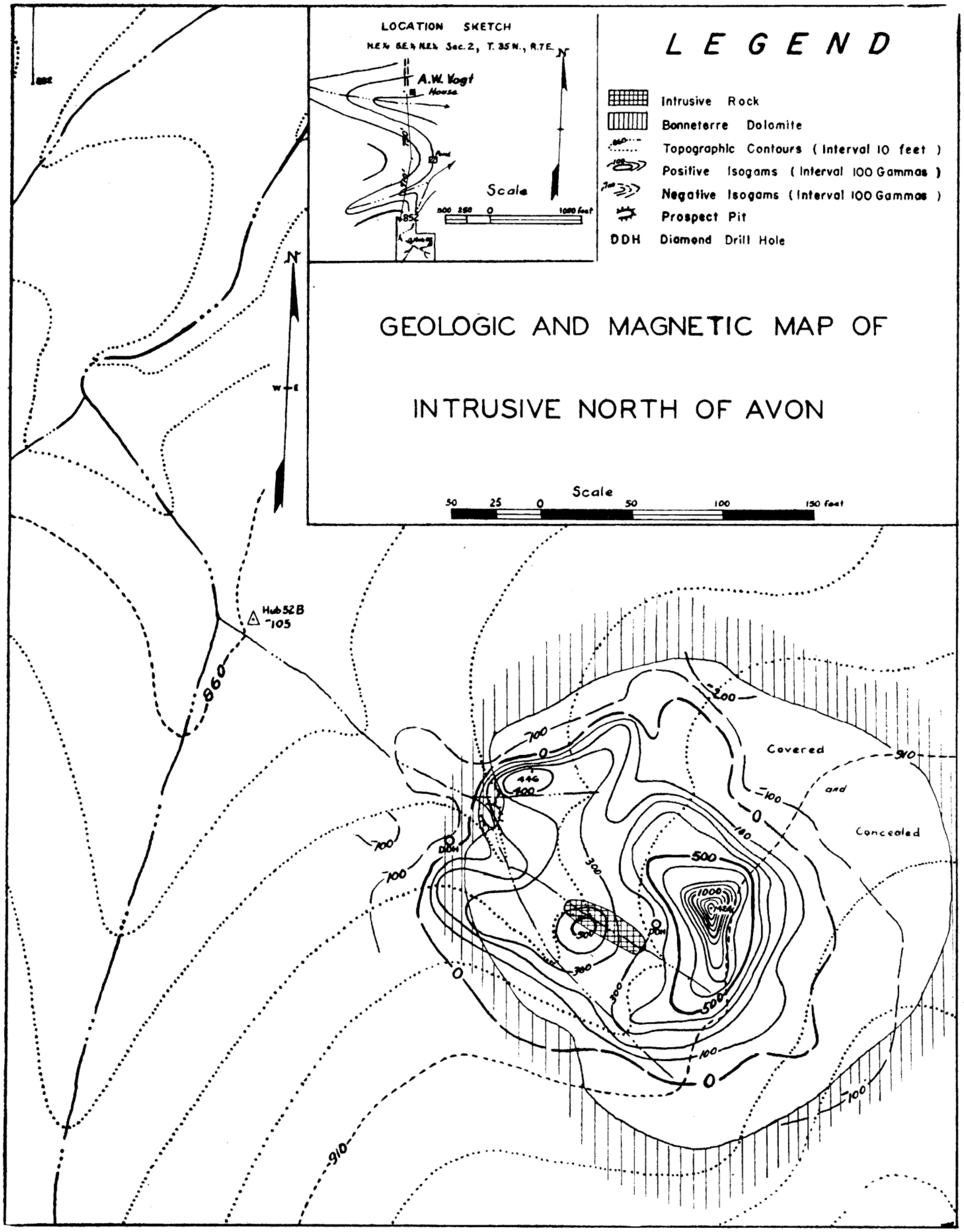


Figure 17. *Magnetic map of Kidwell intrusive #24 from Kidwell (1947).*

STOP #5

Kidwell #14

Figure 18. *Kidwell intrusive #14 is exposed in a creek bottom. Dr. John Encarnacion, St. Louis University, is studying a boulder.*

Kidwell intrusive #14 is located in a streambed about three-quarters of a mile east of Coffman (Fig. 1). Rust (1937) reported this intrusion as two in his compilation but was later shown to be one intrusion by Kidwell (1947). The southern exposed portion of the intrusion is 225 ft long and the northern exposed portion is 100 ft long. Kidwell (1947) reported that the exposures are orientated in N 60^o W. A magnetic investigation suggests that the intrusion is actually about 400 ft north-south and 600 ft east-west (Fig. 21). Similar to stops #1 and #2, xenoliths are abundant in this intrusion (Figs. 19 and 20). In decreasing order of abundance, the minerals are: dolomite, quartzite, sandstone, granite, limestone and chert. Kidwell (1947) reported identifiable fossils in the limestone. Much of the groundmass and pelletal lapilli of this intrusion has been replaced by calcite (Kidwell, 1947). Sand grains, quartz fragments and feldspar fragments (from the granite) are also present in the groundmass. Some pelletal lapilli are nearly one-inch in their long axis. Magnetite is most commonly found within the lapilli. Kidwell (1947) also noted lath-shaped crystals surrounding the cores of the pelletal lapilli. These are likely melilite laths that have since been replaced by calcite.

Figure 19*. Close view of Kidwell intrusive #14 showing granite xenolith imbedded in lapilli groundmass.*

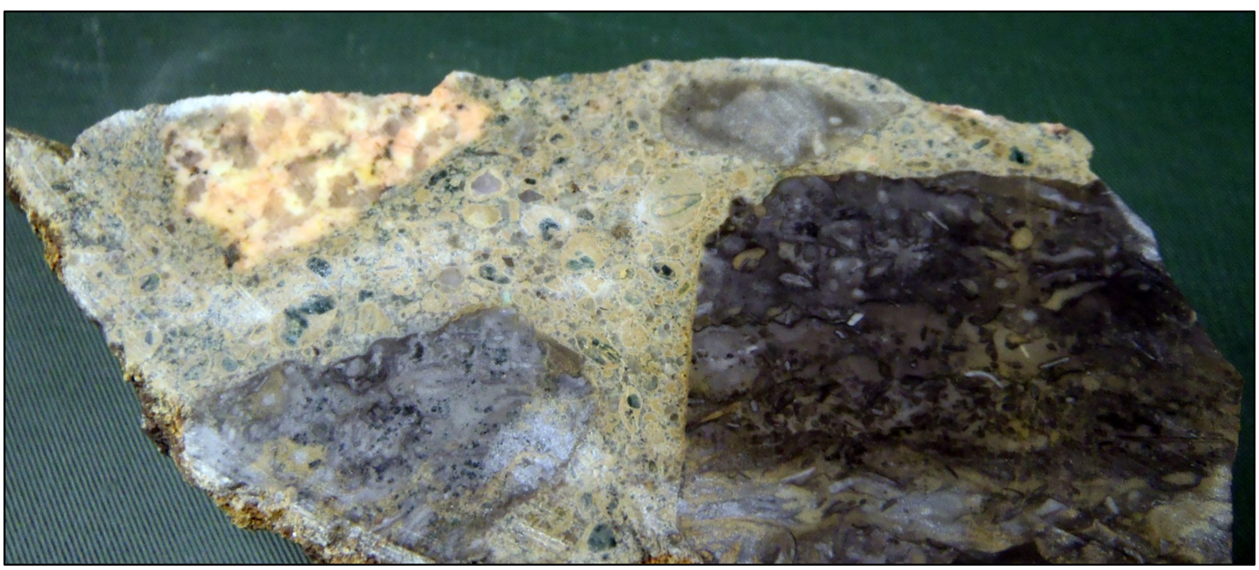
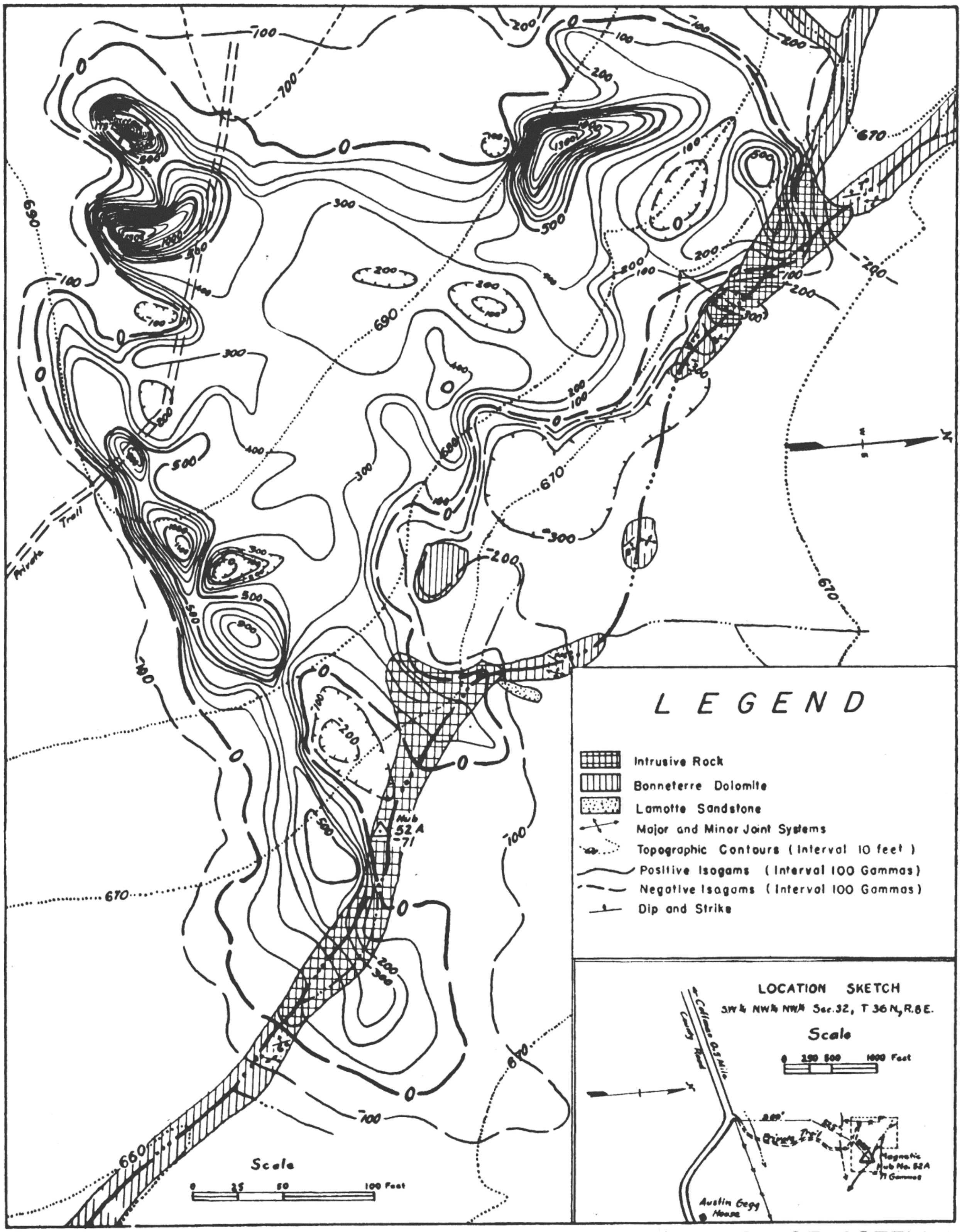


Figure 20*. Sawed specimen of Kidwell intrusion #14. Numerous xenoliths of granite, dolomite and fossiliferous limestone are visible.*



GEOLOGIC AND MAGNETIC MAP OF INTRUSIVE EAST OF COFFMAN

Figure 21. *Magnetic map of Kidwell intrusive #14 from Kidwell (1947).*

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