Ten diatremes in three days in the Navajo volcanic field, Navajo Nation, Arizona and New Mexico, USA

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Extended abstract

The Navajo volcanic field (NVF) covers about 14,000 km^2 (this study) in the central part of the Colorado Plateau; it spans portions of Arizona, Colorado, New Mexico and Utah (Figs. 1, 2). Over 80 Oligocene to Miocene (28-19 Ma) volcanoes and intrusive features are known in the NVF (Semken 2003). Dikes and diatremes ("necks") are the main exposed features due to significant post-emplacement erosion; shallower features such as maars and lava flows are only preserved in a few areas such as Narbona Pass (Brand et al. 2009). Scoria cones are not known but are likely represented by dikes at the current erosion level.

The predominant magma type in the NVF is minette, a potassic mica lamprophyre with about 50% SiO_2 (phenocrysts of dark mica, clinopyroxene, olivine in a dark aphanitic groundmass; Roden 1981). Nine of the ten volcanoes visited by the authors in March 2014 were formed by explosive eruptions of the minette magma (Fig. 3).

A few diatremes of the NVF instead consist of "serpentinized ultramafic microbreccia" (SUM), which was formerly called "kimberlite". According to Semken (2003) these rocks contain "xenocrysts of olivine, enstatite, chrome diopside, chlorite, garnet, titanoclinohumite, oxide minerals, and apatite, as well as abundant crustal and mantle xenoliths" in a fine matrix, but no identifiable juvenile particles (Fig. 4). Green Knobs, the tenth site visited by the authors, is a good example.

The most famous minette diatreme in the NVF is the 480 m-tall Ship Rock, NM (Delaney 1987) (Fig. 5). The 450 m-high Agathla Peak, another minette diatreme near Kayenta, AZ, is also an important landmark (Fig. 6), visible from a distance of 80 km (Williams 1936); both are considered sacred by the Navajo people and were only examined from a distance. Due to space constraints only two of the ten visited sites will be briefly described here: Cathedral Cliff and Green Knobs, in the New Mexico part of the field.

Cathedral Cliff (Fig. 2: **CC**) is a minette diatreme >250 m in diameter (Fig. 7). We found no information on this volcano in the literature. It is located 14.5 km SE of Ship Rock, where Delaney and Pollard (1981) estimate ~1 km of erosion to the current land surface (Mancos Shale). The Cathedral Cliff diatreme infill is dominated by pyroclastic rocks with very minor coherent minette. The pyroclastic rocks range from bedded to non-bedded, from coarse tuff to tuff breccia (lapilli tuffs dominate), and from lithic-rich to juvenile-rich (Figs 8-12). The lithic population includes abundant loose quartz grains. The bedded pyroclastic rocks dip steeply (~75°) inward on the E and S sides of the diatreme; these beds display low-angle cross bedding and are interpreted mostly at base surge deposits.

A sub-vertical column of non-bedded pyroclastic rocks, ~9 m in width, cuts disrupted bedded rocks on the SW side of the diatreme (Fig. 13). This column is interpreted to reflect the passage of one or several debris jets through the existing diatreme fill (see White and Ross 2011). The N and NE sides of the diatreme expose mostly non-bedded pyroclastic rocks, locally with large sedimentary megablocks. Country rock breccias occur on the S side (Fig. 14). The inferred erosion level of ~1 km indicates deep subsidence of the bedded pyroclastic rocks within the diatreme.

The Green Knobs (Fig. 2: **GN**) SUM diatreme (Allen and Balk 1954; Akers et al. 1971; Smith and Levy 1976) is approximately 800 m in diameter and circular in map view (Fig. 15). The pale green rocks are clearly to cryptically bedded with inward dips ranging from ~80-85° near the margins of the diatreme to sub-horizontal toward the centre (Figs. 16-18). The grain-size is mostly lapilli tuff. The average constituents are 12% lithic fragments, 43% crystal fragments (mostly olivine, pyroxene, quartz, and feldspar), and 45% fine matrix (Smith and Levy 1976). The main types of lithic fragments are gneiss, granite, sandstone, shale and peridotite (Akers et al. 1971) (Figs 19-20).

The reported absence of juvenile clasts in this and other SUM diatremes is very intriguing. Volatiles apparently rose from the mantle and carried the olivine and other xenocrysts, also sampling the crust along the way. The gas-solids mixture finally erupted explosively to form a diatreme (and presumably an ejecta ring and crater). SUM diatremes occur in areas where minettes are also found (sometimes in the same diatreme, e.g. Buell Park, BP on Fig. 2), suggesting an association. According to Roden (1981), the volatiles that created the SUMs were either liberated from the garnet peridotite mantle during intrusion of minette magma into it, or they dissociated as a supercritical phase from the minette magma. Alternatively, the juvenile fraction in the SUMs may be "hiding" in the 45% optically irresolvable matrix.

Acknowledgements

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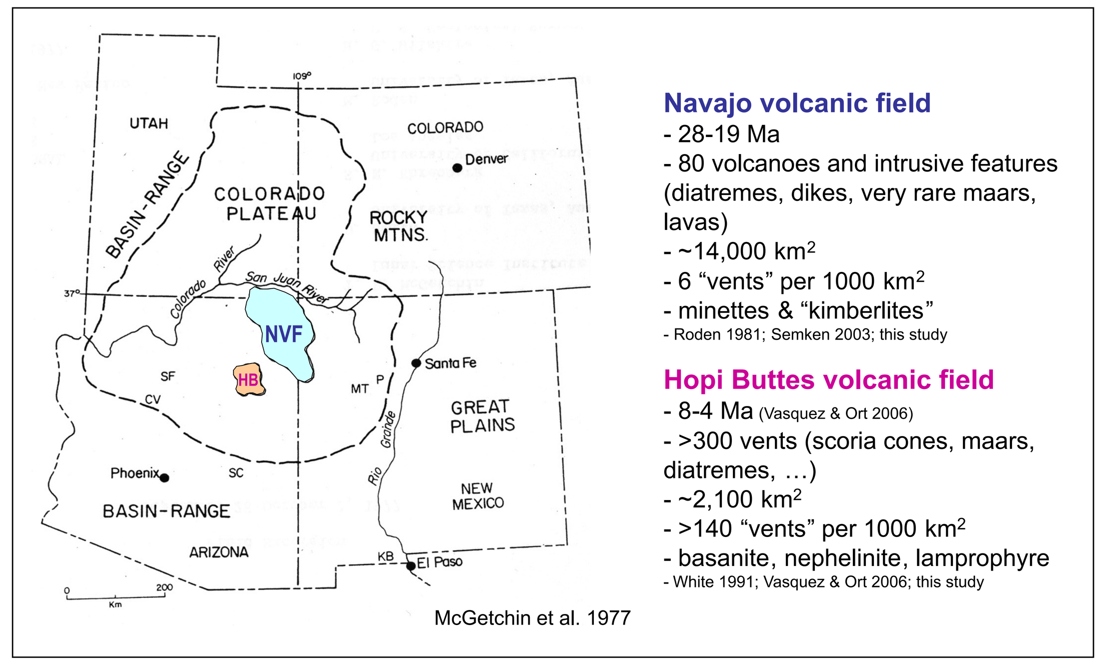

Fig. 1 Location of the Navajo Volcanic Field (NVF) in the Four Corners area of the Colorado Plateau, USA. The better-known Hopi Buttes Volcanic Field (HB) is to the south-west.

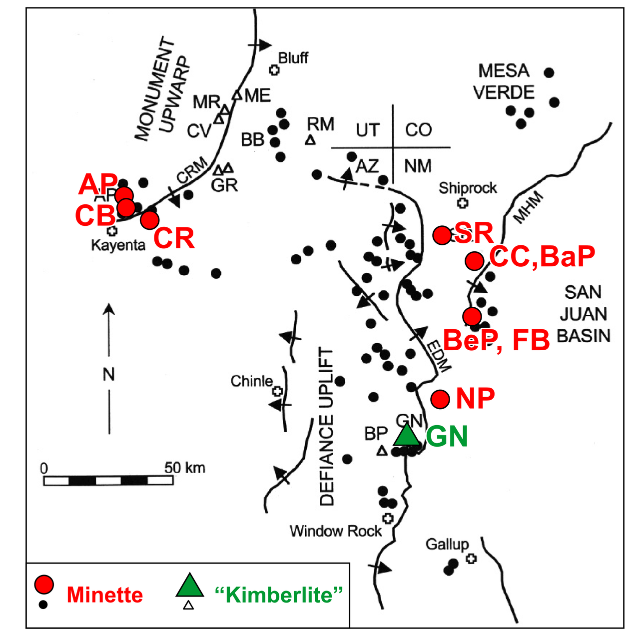

Fig. 2 Sketch map of the NVF, modified from Semken (2003). Sites visited: AP = Agathla Peak, BaP = Barber Peak, BeP = Bennett Peak, CB = Chaistla Butte, CC = Cathedral Cliff, CR = Church Rock, FB = Ford Butte, GN = Green Knobs, NP = Narbona Pass, SR = Ship Rock.

Fig. 3 Large minette juvenile pyroclast (with a lithic fragment inside) at Chaistla Butte diatreme, AZ.

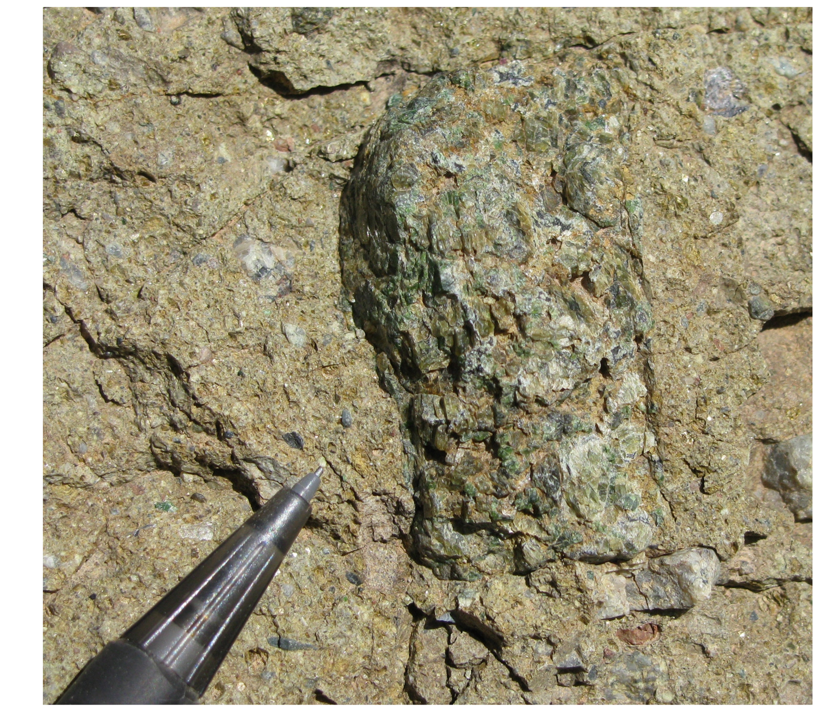

Fig. 4 "Serpentinized ultramafic microbreccia" at the Green Knobs diatreme, NM. The photo shows a peridotite xenolith in a volcaniclastic rock rich in olivine crystals and granitic lithics.

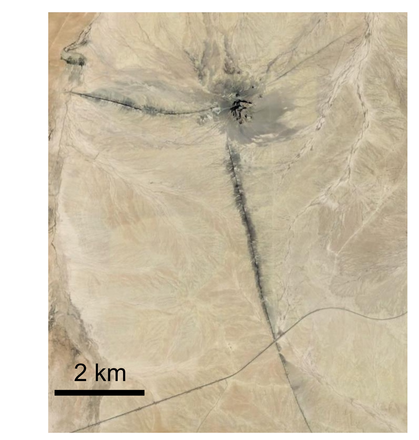

Fig. 5 The famous Ship Rock diatreme in NM and the three surrounding dikes. The main massif is 480 m tall (Delaney 1987), and ~500 m diameter. The surrounding plain consists of Mancos Shale. Photo: Wikipedia; satellite image: Google Earth.

Fig. 6 Agathla Peak viewed from the west. The neck (eroded diatreme) sits on a pedestal of Chine Formation.

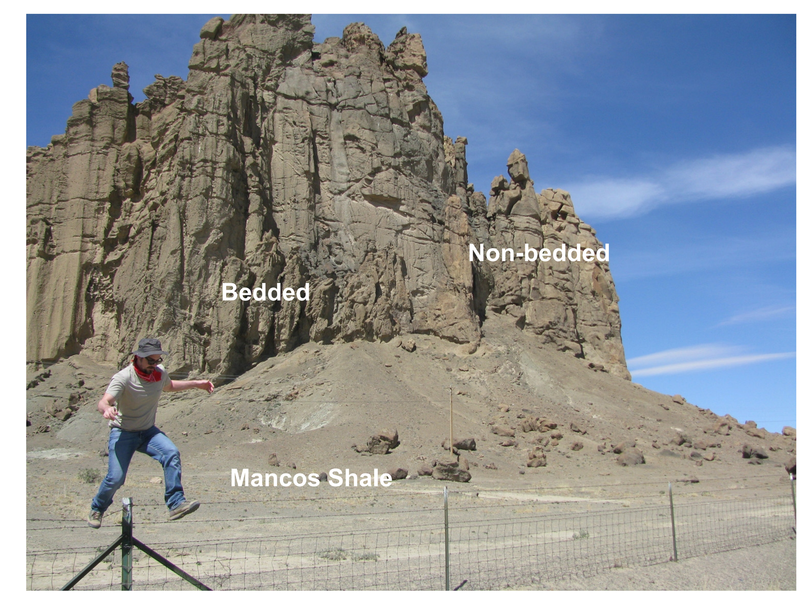

Fig. 7 The Cathedral Cliff diatreme, NM. One side is bedded (with steep dips) and the other side is non-bedded.

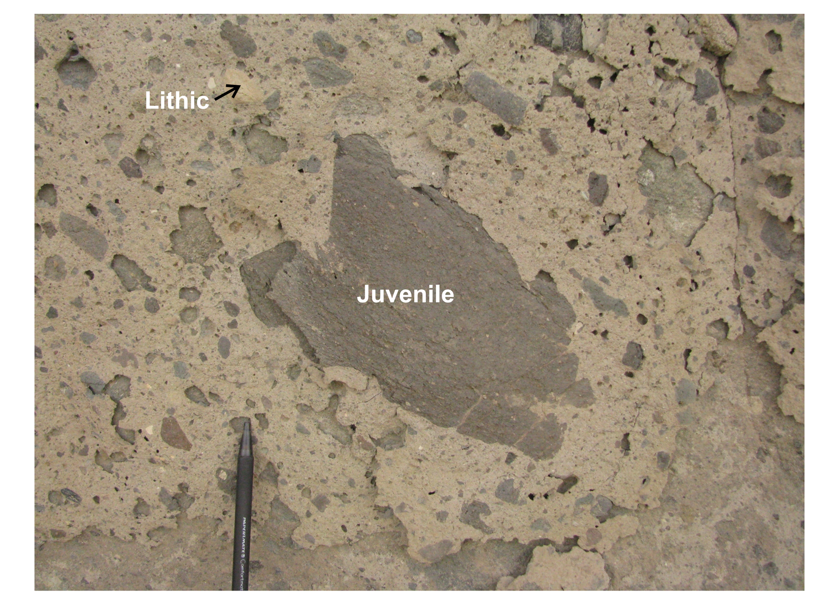

Fig. 8 Non-bedded lapilli-tuff at Cathedral Cliff (NE side). The lapilli here are mostly juvenile minette clasts, whereas the matrix looks quartz-rich.

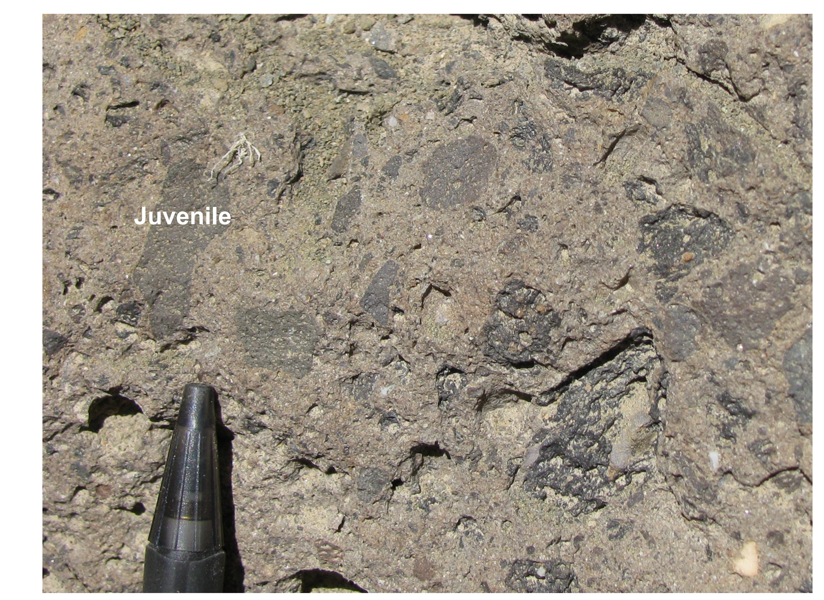

Fig. 9 Non-bedded lapilli-tuff at Cathedral Cliff (east side). This facies is particularly juvenile-rich, with vesicular clasts.

Fig. 10 Steeply dipping bedded volcaniclastic rocks in the Cathedral Cliff diatreme (SE side).

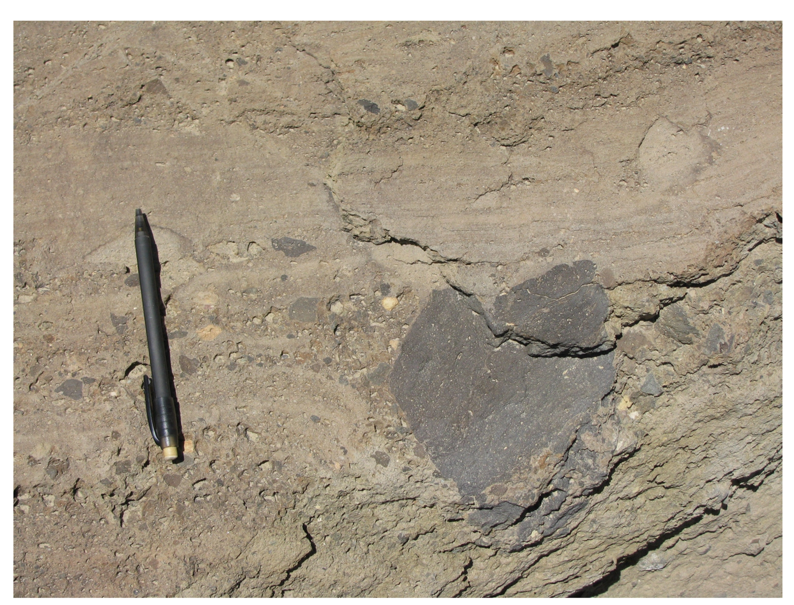

Fig. 11 Bomb sag in juvenile-rich pyroclastic beds from Cathedral Cliff (SE side).

Fig. 12 Low angle cross-beds and channels in lithic (quartz)-rich bedded volcaniclastic rocks from the south side of Cathedral Cliff. These are interpreted as base surge (dilute PDC) deposits.

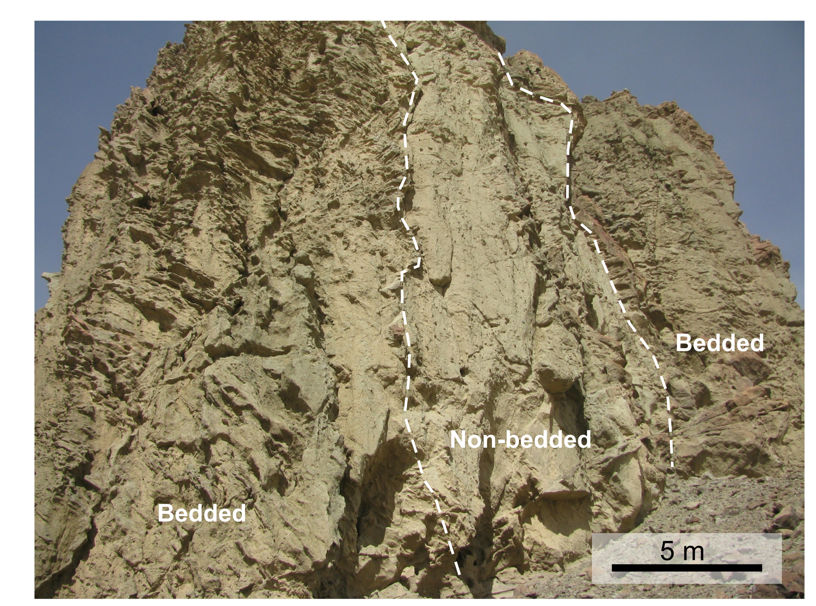

Fig. 13 Column of non-bedded volcaniclastic rocks cutting bedded volcaniclastic rocks at Cathedral Cliff (SW side).

Fig. 14 Country rock breccia near the diatreme margin from the south side of Cathedral Cliff.

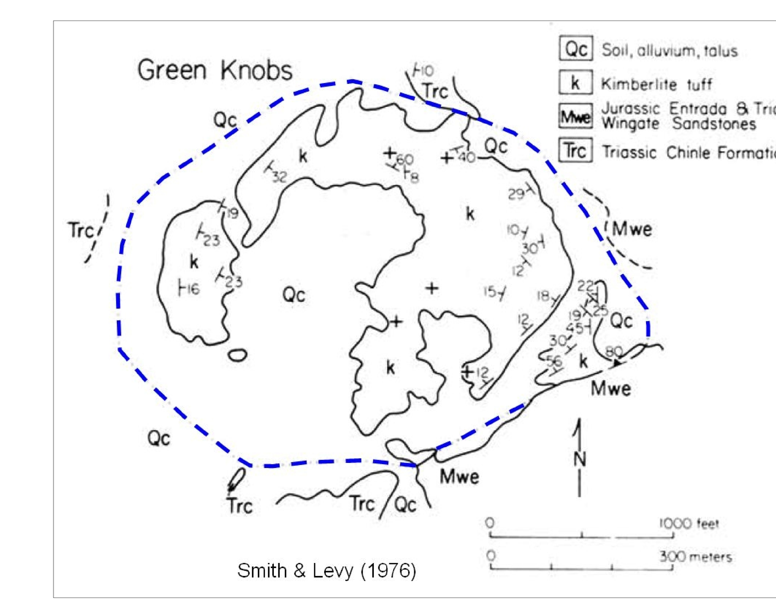

Fig. 15 Map of the 800 m diameter Green Knobs diatreme, NM after Smith and Levy (1976). Note the centroclinal dips of volcaniclastic layers.

Fig. 16 Overview of the Green Knobs diatreme in NM. The (bedded) diatreme rocks are green and the country rocks are red.

Fig. 17 Gently dipping volcaniclastic beds in the centre of the Green Knobs diatreme.

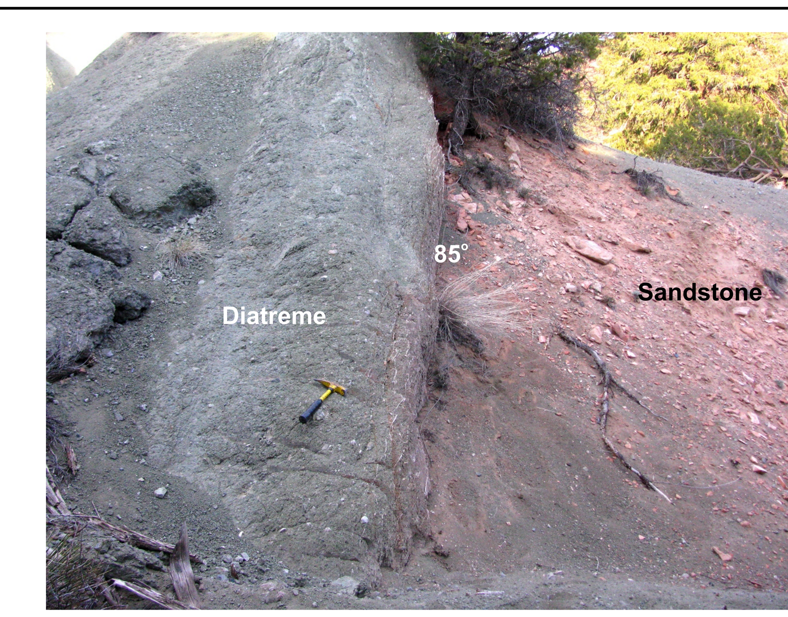

Fig. 18 Near-vertical contact between the Jurassic-Triassic country rocks and the Green Knobs diatreme (E side).

Fig. 19 Close-up view of volcaniclastic rocks at Green Knobs. Note the abundance of green olivine and granite xenoliths.

Fig. 20 Typical granitic xenolith (lithic block) in the Green Knobs diatreme.