PRIMARY FLOW FOLDS ON THE NORTH MARGIN OF THE JONES CAMP DIKE: EVIDENCE FOR EASTERLY DIKE PROPAGATION AND MAFIC MAGMA TRANSPORT

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"The remarkably prevalent, simplistic, idea of only vertical movement of magma in dykes must be abandoned" P.C. Rickwood, 1990

The primary objective of this note is to present photographic evidence (Fig 1.45) for lateral magma flow and easterly dike propagation during the initial mafic phase of intrusion that formed the Jones Camp dike in late Oligocene time. It should be acknowledged that the interpretation of lateral magma transport, as presented here, is contrary to previous studies of the Jones Camp dike (cf. Kelley, 1949; Jochems, 1987), which tacitly assumed or overtly presumed only vertical ascent of magma within the Jones Camp dike. Notably the key exposure of the chilled dike margin that exhibits primary flow folds (Fig. 1.45) appears to be moderately tilted and down warped. This makes the interpretation of magma flow direction less straight forward and requires additional structural analysis to determine the original geometry of the flow folds.

A bulldozer cut near the west end of the strip mine area at Jones Camp provides a rare glimpse of the northern chilled margin of the Jones Camp dike, also fortunately where it is relatively unaltered (Fig.1.45). The chilled margin of the dike consists of dark gray, aphanitic, basaltic andesite with rare small phenocrysts of plagioclase. A sample from the chilled margin yields an analysis of 53.6 wt. % SiO2 and 4.6 wt. % MgO (Chamberlin et al., this guidebook). Hand specimens of the chilled margin are moderately magnetic, which supports the field observation that the outcrop is unaltered (cf. Jochems, 1987).

The chilled contact of the dike with a massive gypsum bed of the Yeso Formation is well exposed in the dozer cut. The overall trend of the exposure is N 65 W and the well exposed surface of the chilled margin is distinctly curviplanar, dipping from 57° SSW to about 22° WSW. On first impression, the west end of the exposure looks very much like the chilled base of a southwest dipping sill. Three lines of observation negate this initial impression: 1) the southwest dipping "sill-like' exposure is contiguous and continuous with the 100m-wide main body of the Jones Camp dike; 2) where well exposed along a road bed (50m to the west), the same aphanitic dike margin (albeit altered) strikes N 75 W and grades southward into fine- to medium-grained pyroxene diorite and pyroxene-hornblende diorite near the center of the dike; and 3) mafic sills on the north margin of Jones Camp dike dip 25-55° northward (Jenkins, 1985), not southward , as observed here.

Most basaltic dikes in central New Mexico are relatively narrow (1-10m wide), near vertical, and typically display two parallel, aphanitic, chilled margins (cf. Chamberlin et al., 2008). Thus, in contrast to most basaltic dikes, it seems likely that this flow folded mafic dike margin — a rare phenomenon (Liss et al., 2002) — is also unique in that it has apparently been moderately deformed (tilted and warped) after solidification of the initial basaltic dike. Paleomagnetic directions determined from dike samples collected near the key bulldozer cut are suggestive of strong tilting and vertical axis rotation of the dike after it cooled below the Curie point of 570° C (Jochems, 1987, PM-6), but this interpretation is not unique.

The curviplanar chilled margin is well buttressed by a thick mass of gypsum at its eastern end. Here, the dike contact strikes N 67° W and dips 57° SSW; and a relatively small weathered patch of the contact displays near parallel fold axes that plunge about 48° to 165° (S15°E). To determine the original orientation of the flow fold axes, the dike contact was assumed to have been originally vertical with the same strike presently exhibited. Note that the fold axes (crest lines) are treated here as linear elements even though in cross section the folds clearly display closely spaced, imbricate axial surfaces (Fig. 1.45B). Using a stereographic net, rotation of the contact to vertical shows the original fold axes (crest lines) plunged about 65° to the ESE (113). By analogy with pahoehoe lava flows (Fink and Fletcher, 1978), magma flow in the dike was presumably at right angles to the steeply plunging drag folds (cf. Rickwood, 1990, fig. 7). Assuming an upward component of flow, then magma flow was to the ESE at a shallow angle of about 25° to the horizon. Although less likely, downward flow to the WNW is also possible.

Narrow, millimeter-high, drag folds can be more broadly examined toward the west end of the bulldozer cut where the less weathered contact distinctly overhangs the adjacent gypsum bed at the base of the road cut (Fig.1.45A). When viewed orthogonal to the overhanging face (Fig. 1.45A) the millimeter high fold crests tend to be subparallel and appear to be at a high angle to the horizon. However, the narrow fold crests are also gently curved, presumably by continuing drag in the viscous shear layer shortly after initial intrusion (left side of Fig. 1.45A). In other portions of the chilled margin (not shown here), relatively wide spaced and deep furrows (centimeter-scale) locally cut across the more numerous millimeter-scale folds to form noses and long gently plunging troughs. These secondary flow folds may represent mini-thrusts and tear faults formed during a relatively brief transition from ductile to semi-brittle shear. The more variable orientation of the secondary folds implies that they are less reliable in determining the original direction of magma flow.

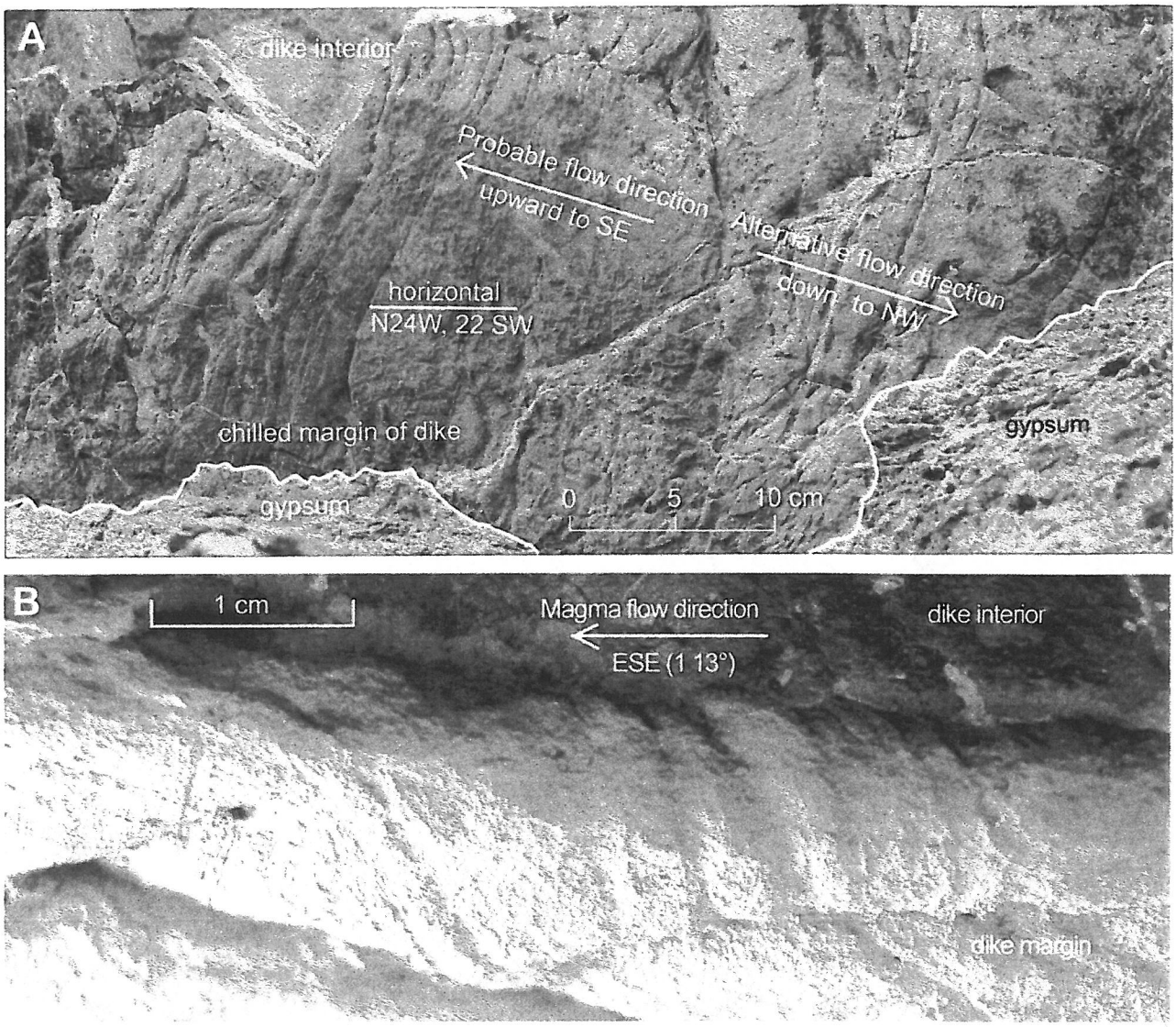

FIGURE 1.45. Primary viscous flow folds (drag folds) exposed in bulldozer cut on the north margin of the Jones Camp dike (UTM: 0391099E, 3747894N, 1927 NAD). **A**. Orthogonal view of overhanging mafic chilled margin of Jones Camp dike where it strikes N24W and dips 22° SW. Pahoehoe-type flow folds provide evidence of viscous shear between the stationary dike wall and flowing magma in a rapidly cooling boundary zone. Assuming an upward component to magma flow along the propagating dike, then the orientation of fold axes suggest flow from right to left (to SE), but downward flow to the northwest is also possible. See text for restored orientation of flow fold axes. **B**. Oblique view of flow folds in an oriented sample of the chilled dike margin showing asymmetry of imbricate fold axes, as they would appear in map view along the dike margin at the mine area, where the dominant strike of the dike is ESE (~113). Bending of axial surfaces near the hotter and more mobile interior of the dike (dark gray) is consistent with continuing magma flow from right to left (west to east) during the mafic phase of dike injection. Note that the chilled margin has been bleached by weathering or minor alteration. See text for additional details.

The curviplanar dike margin is convex to the southwest. The marked curvature of the chilled surface and fractured nature of the adjacent dike interior suggests that the overhanging contact has been down warped to the north and rotated clockwise, perhaps after the bulldozer cut was made. An oriented sample of the dike margin was collected near the western end of the curved surface, where the contact strikes N24°W and dips 22° to the WSW (246). The oriented sample exhibits closely spaced fold crests that are gently curved and cut by a few deep furrows. The predominant closely spaced fold crests plunge at 18-20° to the SW between azimuths of 211 and 216. The original orientation of the flow fold axes is determined by a two step rotation:1) the gently dipping sample is rotated to vertical along the present strike and 2) the vertical plane (N24W) is then rotated counterclockwise to N67W (293), which is the observed strike of the chilled contact at the east end of the cut. Azimuth 293 is also the axial trend of the Jones Camp dike in the mine area (Kelley, 1949, fig. 44). The two step rotation shows that the original fold axes plunged between 56 to 62°to the ESE (113). With magma flow perpendicular to fold axes, and again assuming an upward component

of flow, then magma flow was to the ESE from an angle of 28-34 degrees below the horizon. A statistical analysis of magma flow inclinations preserved in this outcrop would most likely show a larger variance than determined here (25-34°), but the average flow inclination would probably still be in the range of 20-40° from the horizon.

A second oriented sample of the chilled margin clearly shows bending of imbricate axial surfaces of the flow folds near the interior of the dike (Fig.1.45B). The observed asymmetry of flow folds eliminates the ambiguity inherent in assuming an upward component of magma flow and confirms west-to-east flow of basaltic magma during initial intrusion of the Jones Camp dike (Fig.1.45B).

Evidence of west-to-east basaltic magma flow at Jones Camp (Fig.1.45) and a new high precision $^{40}Ar/^{39}Ar$ age of 28.88 ± 0.22 Ma for the Jones Camp dike (Chamberlin et al., this guidebook) strongly support the previous interpretation that the Jones Camp dike is part of the Magdalena radial dike swarm of Oligocene age (Chamberlin et al., 2002; Chapin et al., 2004). The Magdalena radial dike swarm is broadly focused on the Oligocene Socorro-Magdalena caldera cluster (32.3-24.5 Ma) of the early Rio Grande rift (Chamberlin et al., 2007).

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