A Cryptic Miocene Occurrence of an Ultramafic Dike in the Interior of the San Juan Basin: Composition, Age, and Tectonic Interpretations

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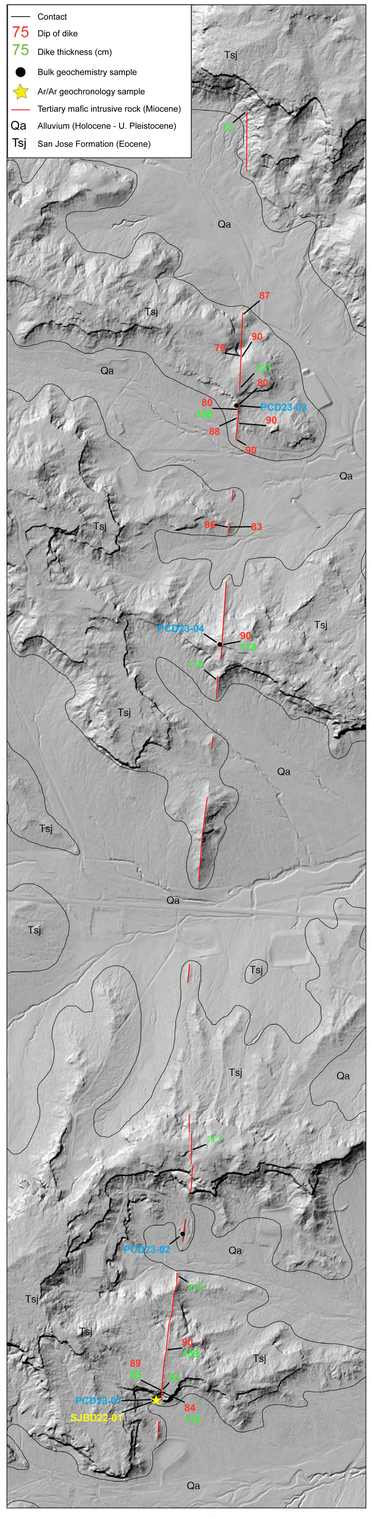
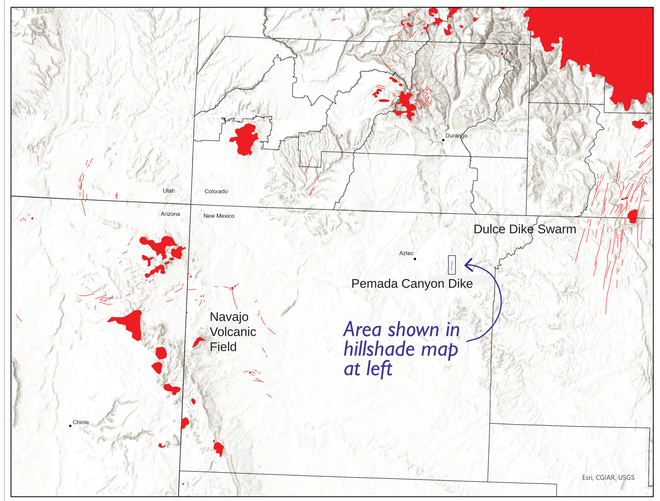




Above: Regional map of known Cenozoic volcanic and shallow intrusive features in the Four Corners region. The Pemada Canyon dike is located among the Dulce dike swarm, the San Juan volcanic field, and the Navajo volcanic field. Sources: Haynes et al. (1972); NMBGMR (2003); Nowell (1994); Tweto 1979; and Wilson et al. (1960).

Key Points

- The Pemada Canyon dike is a small (~1 m wide, ~4 km long) dike intruding Eocene siliciclastic rocks in the north-central San Juan basin near Aztec, New Mexico.

- The Pemada Canyon dike is geographically isolated: the next nearest known igneous features are ~50 km to the east (Dulce dike swarm) or ~90 km to the west (Navajo volcanic field).

- The dike's top is preserved at its northernmost outcrop exposure.

- The dike's composition is ultramafic, with ~37 mass% SiO_2.

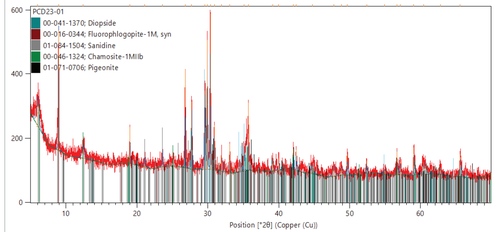
- The first attempt at $^{40}Ar/^{39}Ar$ dating of dike groundmass yielded imprecise results due to a disturbed spectrum, but likely indicate an early to middle Miocene age (~20 to 12 Ma).

- There is little evidence of alteration along the dike's margins or in the surrounding wall rock.

- Fractures associated with the dike follow similar orientations to regional fracture sets in the San Juan basin.

Mineralogical Composition of the Pemada Canyon Dike

XRD analysis of a powdered whole-rock sample (PCD23-01) indicates a dike composition of diopside (a clinopyroxene), fluorophlogopite (a Mg-rich biotite), a potassium feldspar (best match is sanidine), chamosite (an Fe-Mg phyllosilicate), and pigeonite (a clinopyroxene). Thin section petrography is forthcoming.



Above: X-ray diffractogram of Pemada Canyon dike sample PCD23-01.

Field photograph of dike exposure. The outer ~dm of the dike is more aphanitic than the interior, leading to "garden path" pavement outcrops like this. Hammer is 32 cm long. Loc: 36.79589°, -107.82128°.

Field photograph of emplacement contact between dike (left) and feldspathic arenite (right) of the San Jose Formation. There is a notable lack of obvious alteration in the wall rock at all exposures. Loc: 36.79262°, -107.82156°.

Field photograph of dike wall. Where dike intruded mudstones of the San Jose Formation, it forms prominent outcrops like this. Where it intruded arenites, it is more recessive. Hammer is 32 cm long. Loc: 36.79355°, -107.82146°.

Abstract

This field study presents the physical, geochemical, geochronological, and mineralogical properties of the informally named Pemada Canyon dike that is found 15 km east of Aztec, New Mexico. The geographical isolation of this dike merits investigation into its relationship to nearby igneous features and Cenozoic stress orientations in the San Juan basin. Surface exposures of this 3.8 km-long dike are found intruded into arenites, wackes, and mudstones of the Eocene San Jose Formation. It is 76 to 173 cm thick, has measured outcrop strikes ranging from 355° to 012° (average strike 003°), and dips ranging from 83° to 90°. There are at least two left-stepping en echelon features in the dike. Bulk geochemical analysis of the dike indicates a low silica (37%), low alumina (9.5%), and high magnesium (12%) composition similar to some transitional minette/katungite dikes of the Navajo volcanic field (Nowell, 1994) but dissimilar to nearby dikes of the Dulce dike swarm (Lipman and Zimmerer, 2019). XRD analysis indicates a primary mineral composition of diopside, phlogopite, sanidine, and pigeonite with minor chamosite, hinting at more mineralogical affinity to the Navajo volcanic field than to the Dulce dike swarm. $^{40}Ar/^{39}Ar$ dating of dike groundmass suggests an early to middle Miocene age (20 to 12 Ma).

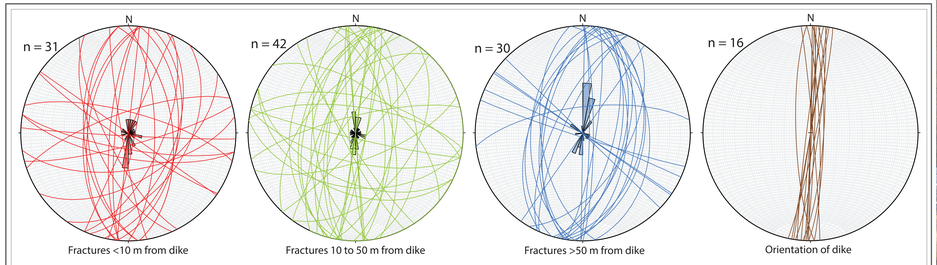
The Pemada Canyon dike's accordance with regional fracture patterns in the San Jose Formation and subjacent formations, along with its likely Miocene age, give new insight into the history of stress orientations in the San Juan basin—it shows that the least compressive stress at the time of emplacement was east-west and horizontal. This study's dataset allows further interpretation of the timing and development of documented north-south fracture sets within stratigraphy of the San Juan basin including the Dakota Formation and Mesaverde Group (e.g., Lorenz and Cooper, 2003), Mancos Shale/Niobrara Formation (e.g., Nelson and Sonnenberg, 2021), and Ojo Alamo Formation (e.g., Hobbs and Thacker, 2021). The age and composition of the Pemada Canyon dike suggests relation to late-stage Navajo volcanic field magmatism as opposed to magmatism from the Platoro caldera complex and associated Dulce dike swarm of the Southern Rocky Mountain volcanic field. This interpretation of the Pemada Canyon dike extends the eastern boundary of the Navajo volcanic field approximately 50 km to the east into the interior of the San Juan basin.

Table 1. Bulk geochemical composition of San Juan basin dikes

	Pemada Canyon dike (this study)				*Nowell, 1994 (Navajo V.F.)*		*Lipman and Zimmerer, 2019 (Dulce dike swarm)*			
	PCD23-01	PCD23-02	PCD23-03	PCD23-04	AWL-5-86	BOL-8-84	15L-58	15L-57	16L-11	16L-9A*
Component										
SiO_2	30.90	36.70	36.30	37.60	36.94	34.81	48.48	50.33	49.27	37.26
TiO_2	3.19	3.23	3.14	3.30	3.29	4.34	2.66	2.48	2.45	1.81
Al_2O_3	8.56	9.27	8.97	11.00	5.45	6.01	14.72	14.75	14.65	14.44
Fe_2O3	14.10	14.30	14.50	14.80	13.22	12.91	10.89	9.62	10.25	12.90
MnO	0.28	0.28	0.35	0.36	0.19	0.18	0.24	0.22	0.20	0.25
MgO	10.40	12.80	11.30	12.00	22.59	18.45	4.34	5.98	5.98	11.00
CaO	17.40	15.60	19.10	15.30	9.28	11.21	10.42	7.33	8.64	15.95
Na_2O	0.36	1.58	1.72	1.01	1.33	1.17	4.20	4.08	3.67	0.40
K_2O	2.02	1.72	1.73	1.75	1.26	2.56	1.45	2.77	2.95	4.17
P_2O_5	1.23	1.41	1.38	1.54	1.10	1.19	1.00	1.15	1.20	0.71

Bulk Geochemical Composition

Based on silica oxide percentages, the Pemada Canyon dike is ultramafic. There are several ultramafic dikes in the Navajo volcanic field near Newcomb, New Mexico (approximately 90 km southwest of the Pemada Canyon dike) classified as transitional between katungites and minettes by Nowell (1994). Dikes and sills of the Dulce dike swarm and Platoro complex of Lipman and Zimmerer (2019) are mafic to intermediate, with the exception of one Dulce dike (sample 16L-9A) which was excluded from interpretation by those authors.



Measured orientations of the Pemada Canyon dike and nearby fractures

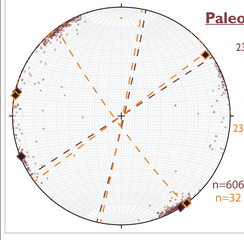
Structural Interpretation

We measured the orientation of fractures at and near the Pemada Canyon dike, as well as orientation of the dike itself where it was well exposed.

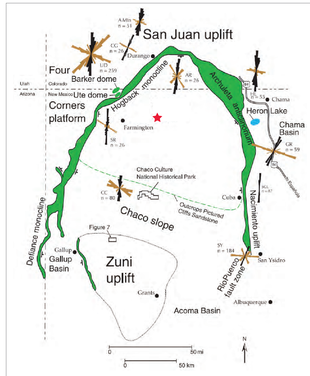
The Pemada Canyon dike strikes at an average of 003°, similar both to well-documented fracture sets in Cretaceous through Eocene bedrock throughout the San Juan basin (Lorenz & Cooper, 2003; Hobbs & Thacker, 2021; Nelson & Sonnenberg, 2021) as well as many dikes of the southern Dulce dike swarm (Lipman & Zimmerer, 2019) and the Navajo volcanic field (Nowell, 1994; Gonzales et al., 2010).

The orientation of the Pemada Canyon dike indicates that the least compressive stress direction at the time of emplacement (Miocene?) was oriented east-west and horizontal. Further study is needed to determine if this stress orientation is the σ_2 of Laramide compression sensu Lorenz & Cooper (2003) with a horizontal north-directed σ_1, or the σ_3 of Rio Grande rift extension with a vertical σ_1 .

The age of the dike, its relationship to stress orientations at the time of emplacement, and its correlation with basin-wide fracture patterns potentially informs interpretation of timing of fracture development in the basin.



Left: Fracture orientations in the Eocene San Jose Formation (the same unit which hosts the Pemada Canyon Dike) and the Paleocene Ojo Alamo Formation from the eastern and central San Juan basin. One of three dominant fracture orientation sets is parallel to the Pemada Canyon dike. Data from Hobbs & Thacker (2021).



Above: Map from Lorenz & Cooper (2003) showing fracture orientations from Proterozoic and Phanerozoic rock units around the San Juan basin. North-striking extensional fractures related to the Pemada Canyon dike are in accord with these data. Pemada Canyon marked by red star.

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