Clastic dikes in the Parachute Creek Member

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Abstract

Clastic dikes penetrate the upper Parachute Creek Member (the main oil shale sequence) in the Piceance Creek Basin, northwest Colorado. These were formed by seismic liquefaction of tuffaceous sands in the middle of the Parachute Creek Member. They reach over 100 m to the base of the Uinta Formation, which invaded the lake as sand wedges shed from rising basin margins. Nowadays, dikes may carry significant vertical leakage of groundwater across aquitards such as the Mahogany zone, which was once described as a confining layer between upper and lower aquifer systems.

Introduction

While the word *dike* typically connotes an igneous intrusion, clastic or sandstone dikes, where cracks are filled with sediments, have been described in early geologic literature. Diller, in the very first GSA Bulletin (1889) is an early reference, but contains references in turn to descriptions of injected clastic dikes in Patagonia by Darwin, and in Oregon by Dana. Each of these authors distinguished top-filled and bottom-filled or injected forms. An example at small scale of a top-filled form is sand-filled dessication cracks, and of an injected form, irruptions of mud (mud volcanoes) due to tidal loading in estuarine sediments. Levi et al (2006) recently described both top-filled and bottom-filled dikes of larger size in Pleistocene lacustrine marls near the Dead Sea, and distinguished the two varieties by magnetic susceptibilities. Their top-filled dikes are tension cracks formed by diapiric doming, and filled with sediments similar to those found on the surface. Injected dikes intrude to surface from loose sandy beds at least 10 m deep, and are presumed to have been triggered by seismicity on the Dead Sea transform. Larger clastic dikes such as these require liquefaction of a loose bed by an earthquake, and follow the pressure gradient through overburden to the surface, or to some horizon in which they can dissipate.

Locations of sandstone dikes in the Piceance basin described below are shown in Figure 1. Some of these have previously been noted in Piceance Basin outcrops, underground and in a few core holes. Those evi-

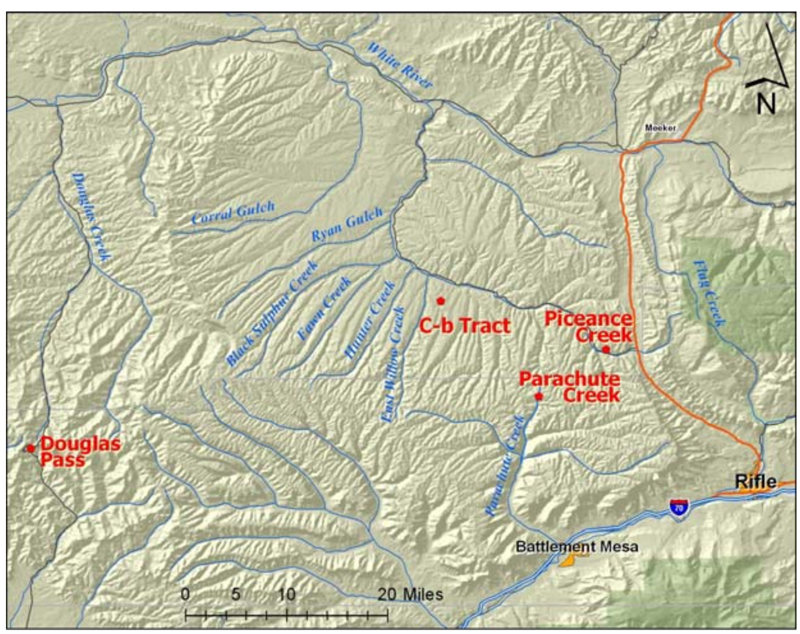

Figure 1. Map of locations described in this paper

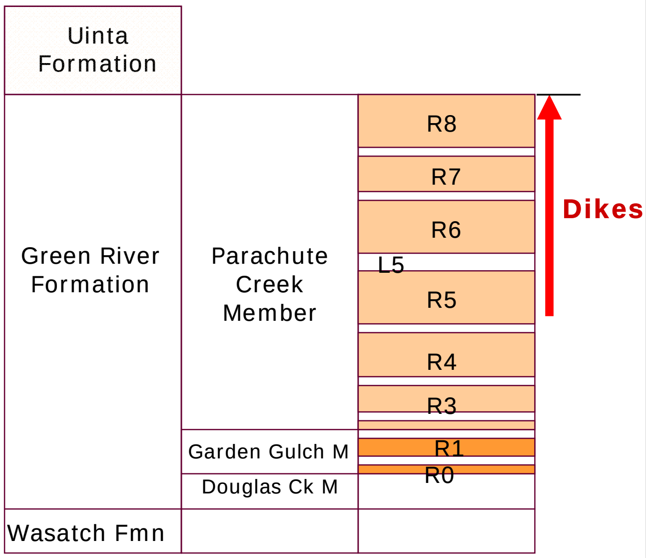

Figure 2: Stratigraphic location of dikes

dent in face-ups at the head of Parachute Creek have not previously been described. There, they riddle the upper oil shales.

Figure 2 summarizes the stratigraphy of the oil shale sequence, and the intervals penetrated by these dikes. The Green River Formation accumulated in Eocene Lake Uintah. Kerogenous "oil shale" was deposited initially as illitic shale (the Garden Gulch Member), and then, when the lake became very alkaline, as dolomite-dawsonite marlstones. Tuffaceous (air fall ash) beds occur throughout the sequence, and dating of these beds has shown the lake persisted over some six million years (Yuval Bartov, pers com). Cashion and Donnell (1977) divided the oil shale sequence into richer and leaner (R, L) zones; the L6, R7 and L7 were previously known (and are still referred to) as B-groove, Mahogany, and A-groove, respectively. Dikes in upper Parachute Creek penetrate the section from at least the base of the R5 zone to the base of the Uinta.

McAlpin (1996) stated that it is unusual for fluidized dikes to be injected higher than 20 m. The Parachute Creek was, however, an unusual overburden-host, the deposit apparently remaining quite unlithified with organic-rich marls trapping water for the life of the lake. At least some of the dikes described below are over 100 m high. The intruded mass was thus quite soft, and the fluidized bed probably had high pore water pressure.

Dewatering veins formed a different type of dike on the west margin of the basin, where barren silts permitted water escape.

Dikes in upper Parachute Creek

In 1982 there was extensive preparation for a Mahogany mine bench and access roads in upper Parachute Creek. The fresh exposures of face-ups revealed numerous sandstone dikes. Locations and strikes of these dikes are shown in Figure 3, superposed on older topography. At least some of these appear to be more than a kilometer long, and more than 100 m in vertical extent.

Figure 4 shows a dike approximately 10 cm thick cutting from the mid Mahogany to the base of the Uinta (sandstone shoulder at upper right of photo). Although no actual

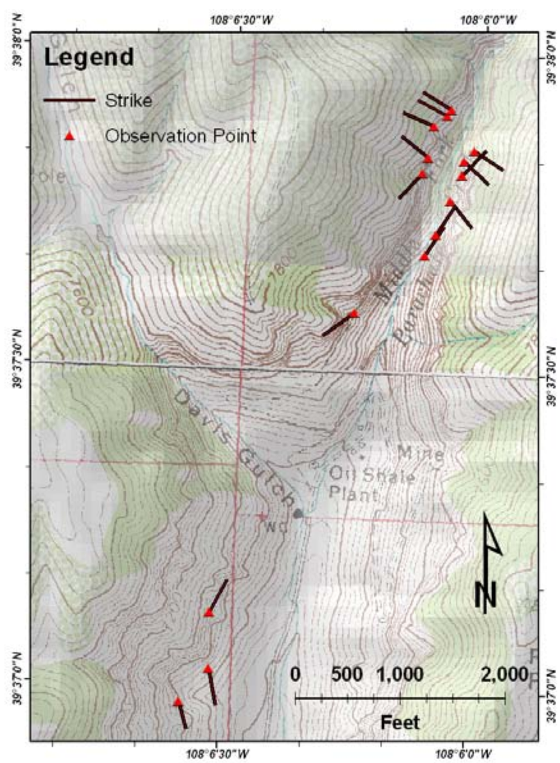

Figure 3: Map of dike occurrences in upper Parachute Creek

top to any dike has been observed, they are known to terminate within a meter of the typically talus-covered contact between Green River and Uinta Formations. Figure 5 shows the southern-most dike in Figure 3,

Figure 4: Dike extending from mid-Mahogany to Uinta

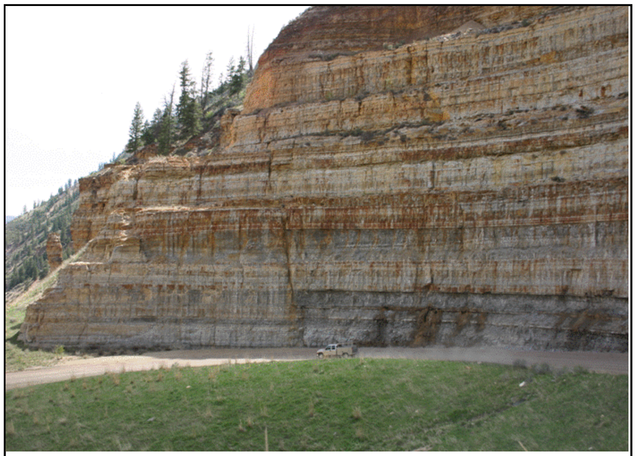

Figure 5: Dike in front of pickup at base of R5

Figure 6: Close-up of previous figure, with dike splaying downward

in the lowest R5 zone, and Figure 6 shows a close up of this dike. The latter splays downward at this location, an unusual mode for clastic dikes, which commonly branch upward as confining pressure decreases. It is suggested this may indicate proximity to the root of the dike, that here several ruptures developed and converged, and largely re-closed after passage of the fluidized mass.

Dike in Piceance Creek

Figure 7 shows a small dike in a road cut in the upper Piceance Creek canyon, in the R8 interval. The dike zigs and zags up the bluff. In close-up (Figure 8) a section of this dike is seen to be contorted with the oil shale host. The vergence of the folding is counter-clockwise, the same sense as the faulted monocline of the Grand Hogback, three kilometers to the east (right in the photo).

Figure 7: Dike in upper Piceance Creek

Figure 8: Close-up of previous figure, with folded dike

This dike tells the story of its injection in still-soft oil shale, and subsequent deformation within it through the early marginal uplift. Although thin and erratic in this outcrop, this dike can be traced over 500 m to the south, and through talus up to the first Uinta sandstone.

Dikes at C-b tract

Stellavato (1982) described branching clastic dikes (he called them tuff dikes) in mine openings at the former C-b federal lease tract. These are mapped onto an isometric of the mine openings in Figure 9. They were mapped in levels above and below the A-groove, but not in the lower level ("intermediate void level") at the base of the Mahogany (R7). It is not clear that the dikes were looked for in lower entries; they may have drifted to east, or may be rooted at a higher level at C-b than in Parachute Creek. Stellavato suggested the source material might be the Curly tuff bed at the base of the Mahogany.

Dikes on Douglas Pass

A different type of clastic dike occurs in lake-marginal, lower Green River Formation on the south side of Douglas Pass. Dozens of these features are evident in a new exposure in marly siltstones with stromatolite and ostracod beds, in a section believed to be equivalent to the R4 (Bartov, pers com). This is very close to the level of the lowest dike observation in upper Parachute Creek. In Figure 10 one of these features is seen to consist of laminated silt crossing the host siltstone. The Douglas Pass dikes are irregularly shaped, up to 20 m high, and 15 cm wide in the marlstone, but pinch where they cross sandstone and limestone beds. They suggest a dewatering origin where periodic water venting occurred along these features as burial progressed. Here the silts allowed drainage and venting of water from silts under accumulating burial load.

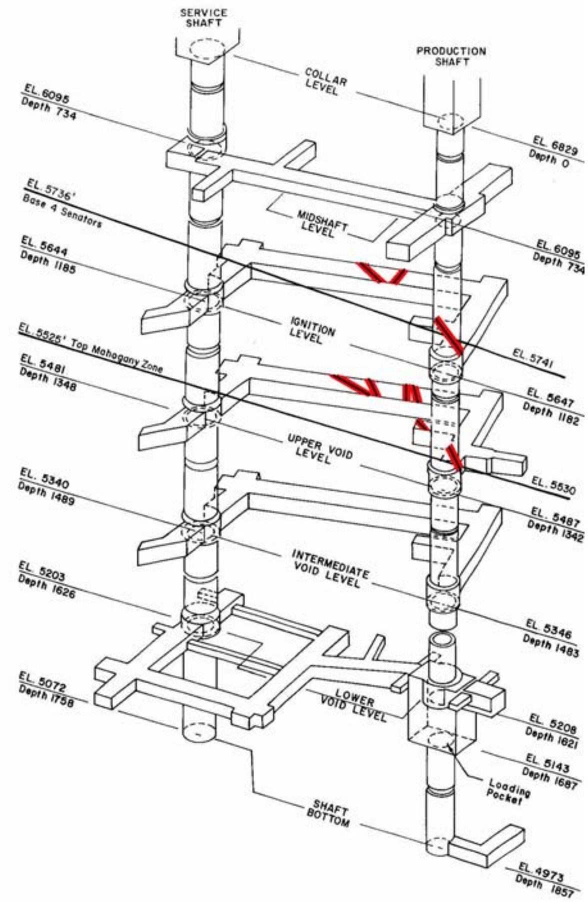

Figure 9: Dikes mapped at C-b by Stellavato (long entries run N-S; shaft centers are 230 feet apart)

Dike mineralogy

Dikes in Parachute Creek and Piceance Creek are dense, massive, silty fine sandstone. A piece of the Piceance Creek dike was examined in thin section and by X-ray diffraction (XRD) by DSM Science Lab, in Wheat Ridge, Colorado. Figure 11 shows the mineral composition disclosed by point counting the thin section. The specimen is from outcrop, and so likely altered by weathering.

Figure 10: Douglas Pass dike

About 60% of the thin section is dolomite and analcime. The dolomite must be marl entrained from beds adjacent to the source tuff bed, or the rock would have had an initial porosity of 60%. Analcime is the main cement, and chert is a later overgrowth on analcime. The other constituents are quartz, some of it highly rounded, felspars, mafic minerals and basaltic rock fragments, indicating a mixed provenance dominated by tuff (volcanic ash fall). The thin section shows less than 1% porosity.

The XRD shows 4% clay, of which 1% is illite and 3% smectite. This very minor clay content is likely to be due to weathering of silicates in the tuff source, rather than the illitic shale of the Garden Gulch Member.

Hydrologic expressions

Dikes may have several hydrological expressions, in native groundwater flow and in pumping tests.

In the native groundwater regime, they may tend to both dam lateral flow in water bearing zones, and to carry vertical leakage across aquitards between them. Higher dike permeability favors more vertical leakage, and lower permeability tends to form lateral barriers. In the mapped face-ups in upper Parachute Creek, the summed widths of dikes compares with the saturated thickness of the A-groove, so that they must allow significant leakage across the Mahogany zone. Historically, the Mahogany has been described as the isolating aquitard between upper and lower aquifer systems in the basin. Weeks et al (1974) remarked that, while no vertical connection could be discerned across the Mahogany in pumping tests at the Rio Blanco site in the central Piceance Creek basin, the potentiometric surfaces of Uinta, A-groove and B-groove aquifers deviated so little from one another

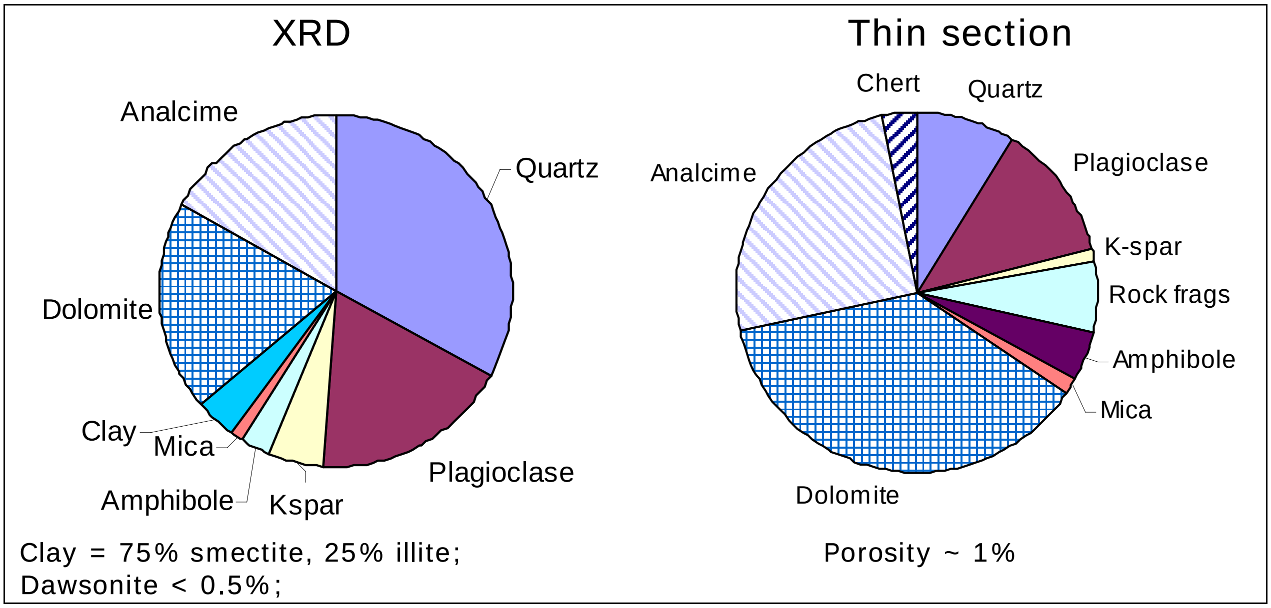

Figure 11; Mineralogy of Piceance Creek dike specimen

over tens of miles and thousands of feet elevation change from recharge to discharge areas, that they had to believe they were hydraulically connected.

Dikes may show up in long-term pumping tests through boundary effects. When a drawdown cone propagating outward from a pumping well open in, say, the A-groove encounters a lower permeability boundary in the form of a dike, the flow is less from that quarter and the drawdown thus exaggerated. This would cause a departure from the initial time-drawdown trend; and if there are observation wells it may even be possible to deduce the location of the dike from the various trend deviations.

On the other hand, differences in drawdown between various observation wells in the vicinity of a dike might cause an unwary test data analyst to posit anisotropic permeability in the pumped interval, when the variability is in fact due to heterogeneity.

Faults may cause some of the same effects, and a swath of northwesterly striking faults including the Dudley Bluffs graben is well known in the central basin. It is not known what form any of these faults have at depth, or what effect they have on groundwater. There are crushed breccias in faults cutting Uinta outcrop in Ryan Gulch and Fawn Creek, and some calcite veining suggesting they have carried high carbonate waters from depth.

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