Magnetostratigraphic constraints on the Bouse Formation in the Blythe Basin—existing evidence

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Possible constraints on age and correlation of the early Pliocene stratigraphic record of Colorado River integration in the Blythe Basin (Fig. 1) are suggested by review of preliminary pre-2016 magnetostratigraphic information. The data invite comparison to the magnetostratigraphy of Colorado River-derived strata in the Fish Creek–Vallecito Basin of the Anza Borrego area in the western Salton Trough (Fig. 2). Figure 3 illustrates a conceptual stratigraphy of the Bouse Formation, whose marine vs. lacustrine environments remain debated. New studies in the Blythe Basin in 2016 are expected to resolve and greatly improve the magnetostratigraphy and its constraints on the duration and timing of deposition of the Bouse Formation. This may in turn help inform possible histories of how and when Colorado River water and sediments connected the Blythe Basin to the sea.

A section 165 ft (50 m) thick of the Bouse Formation near Mesquite Mountain (Fig. 1) was sampled a decade ago by Daniel Malmon in a pilot USGS study to investigate the feasibility of establishing a magnetostratigraphy of the Bouse Formation (Fig. 4). Preliminary determinations (by Malmon and Hillhouse) tentatively suggest a polarity transition, at an elevation about 500 ft (about 150 m) above sea level (asl), from magnetically normal below to reversed above (Malmon et al., 2011a[1]).

This result needs to be tested with further sampling and measurement but seems consistent with generalized information on outcrop samples reported by Kukla and Updike (1976). According to their paleomagnetic study, six outcrop samples from the Bouse in the general vicinity of Malmon's sampled section ("between Bouse Wash and Quarry Mountain") showed normal polarity. But outcrop samples from the *upper part* of the formation, both nearby in the Parker Valley area and to the southwest in the Palo Verde area (Fig. 1), were described as dominantly reversed.

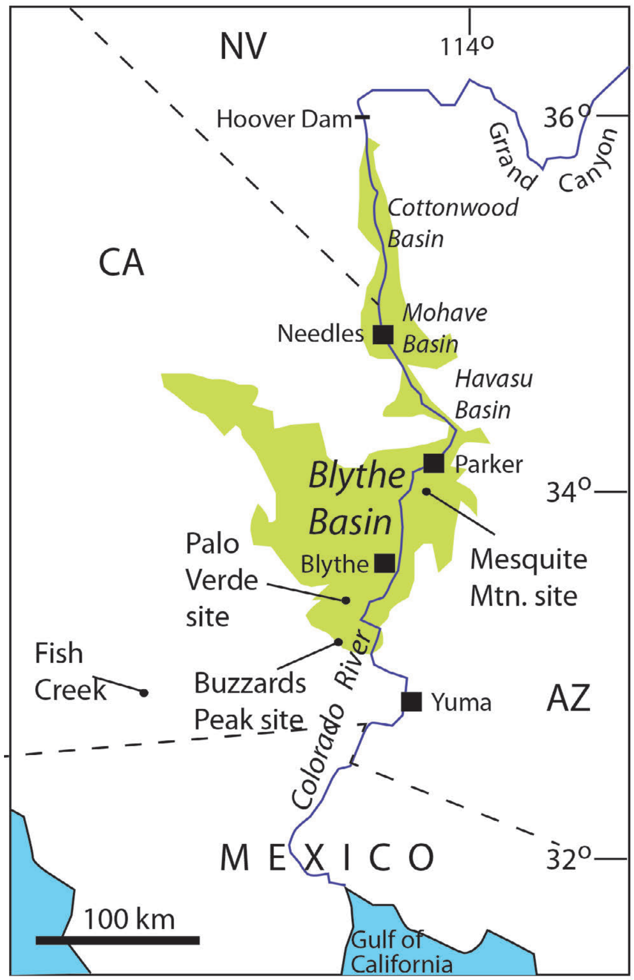

Figure 1. Map of Bouse Formation former extent (in green), showing the Buzzards Peak, Mesquite Mountain, Palo Verde, and (Anza Borrego) Fish Creek sites. Reconstructing 5 myr of San Andreas fault offset would restore the Fish Creek site to the Gulf of California .

Kukla and Updike (1976) also sampled 14 drill cores in the Blythe Basin for polarity determinations. They reported reversed and normal polarities in both the Bouse Formation and the overlying "unit QTrb," which we identify as the Bullhead Alluvium. They also reported

1 The polarity transition at 500 ft asl was inadvertently misreported (by KAH) in Malmon et al. (2011a) as at 500 m asl.

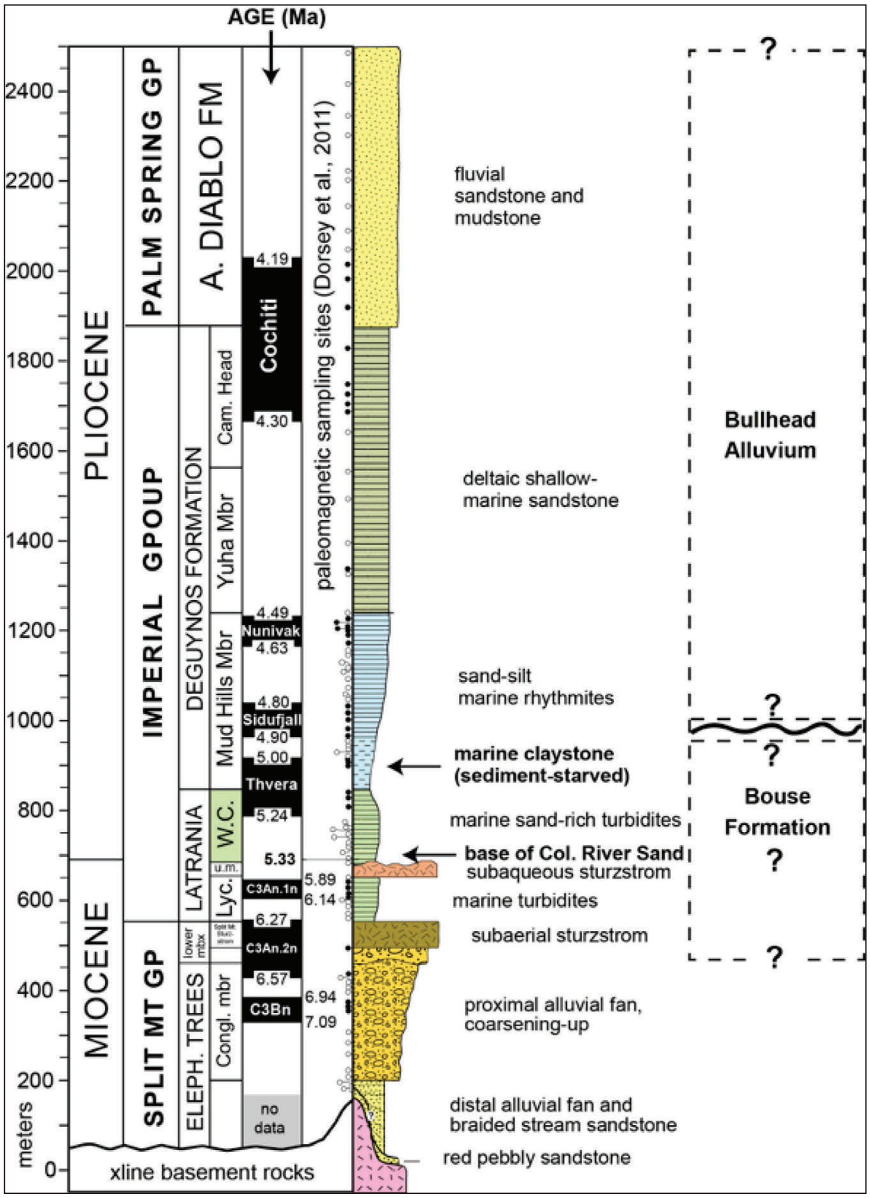

Figure 2. Magnetostratigraphy for part of the Fish Creek-Vallecito Basin (modified from Dorsey et al., 2011), and (on the right) tentative correlations to two key units in the lower Colorado River corridor. The Fish Creek-Vallecito section, containing a record of sediment delivered by the Colorado River to the sea and the river's delta plain, is constrained by 77 polarity determinations using 3-10 samples at each site, and tied to the Miocene-Pliocene marine faunal boundary and to 2 dated tephras in the upper part of the section. Existing paleomagnetic measurements of the Bouse Formation in Blythe Basin are from upper, likely Pliocene, parts of the formation.

dominantly normal (but locally reversed) polarity in the younger "unit QTrd," which mostly correlates to the Chemehuevi Formation, for which Malmon et al. (2011b) reported a 70-ka tephrocorrelation age.

The top of the Bouse Formation in two cores (Fig. 5) was recognized at 10–31 ft (3–6 m) above sea level (asl.) based on lithology (Fugro, 1976) and at 2–5 ft (1–2 m) below sea level (bsl.) based on the highest indigenous Bouse foraminifera (Fritts (1976). Neither drill hole reached the basal limestone of the Bouse Formation identified at greater depths by Metzger et al. (1973).

The near-sea-level top of the cored Bouse sections lies hundreds of feet below outcrops of the Bouse. Three cores were reported to have dominantly reversed polarities in the Bouse Formation clays although one of the cores (B-DH-50) reportedly contained a 30-ft-thick (9-m) interval of normal polarities at the same elevation as reversed samples in nearby core B-DH-51 (Kukla and Updike, 1976). These assignments are less clear when the individual determinations are plotted (Fig. 5).

The Bouse Formation and part of the Bullhead Alluvium are subsided in parts of the Blythe Basin, sagging towards the basin axis and affected by an uncertain degree of faulting (Metzger, 1973; Fugro, 1976; Homan and Dorsey, 2013; Howard et al., 2015). Because of the uncertain amount and sites of deformation, any direct correlations between the measured Palo Verde and Mesquite Mountain sites are tentative at best. The data in Figure 5 indicate more than 180 m of relative elevation difference between reversed-polarity parts of the Bouse Formation between the two sites. While more work is needed to test the possibility of this much deformation of a reversed-polarity interval, we suggest it is more likely that the Palo Verde reversed interval in the Bouse lies stratigraphically below the normal-polarity part of the much higher-elevation Mesquite Mountain section. If so, the Bouse Formation's interbedded unit tentatively contains at least one normal interval sandwiched between two reversed intervals.

The 4.83-Ma Lawlor Tuff (Fig. 2) has normal magnetic polarity as measured in northern California by Sarna-Wojcicki et al. (2011), who assigned it to the Sidufjall Normal Polarity Subchron (C3n.3n) of the

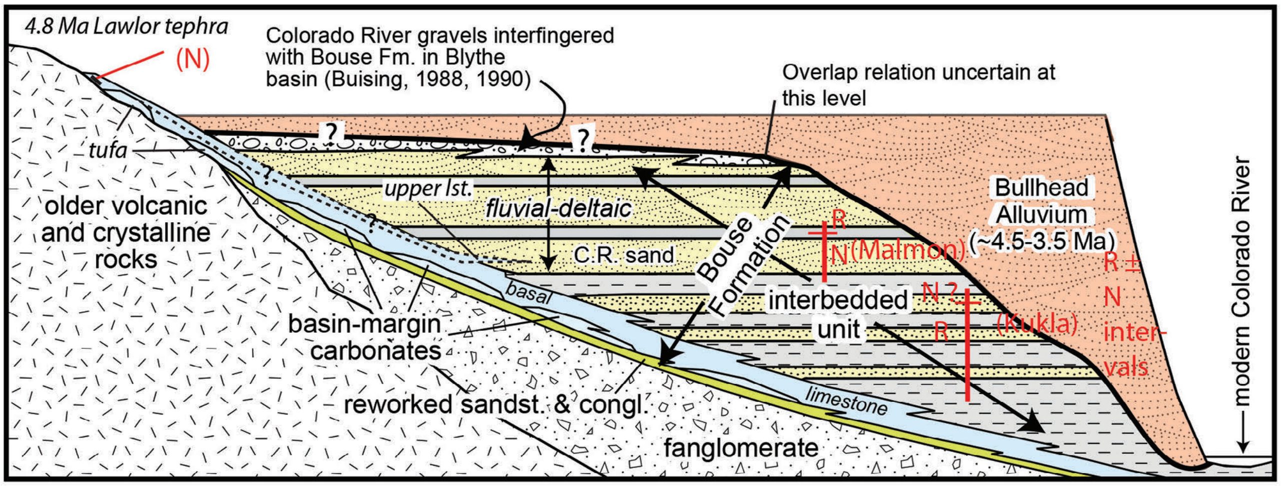

Figure 3. Estimated tentative positions of magnetically normal (N) and reversed (R) sections in the Bouse Formation and Bullhead Alluvium as interpreted from data of Sarna-Wocjicki et al (2011), Kukla and Updike (1976), and this report. Conceptual stratigraphic architecture revised from Howard et al. (2015) and Homan (2014); the relative position of an upper limestone unit (Dorsey et al., this volume) is uncertain.

Gilbert Reversed Polarity Chron, which has a calibrated age of 4.799 to 4.896 Ma (Gradstein and others, 2004). How the Lawlor tephra in the Bouse Formation in the Blythe basin correlates to the sections of the interbedded unit of the Bouse Formation that were studied for magnetic polarity (Figs. 3) remains unresolved. Dorsey et al. (this volume) propose that the Lawlor tephra near Buzzards Peak (Fig. 1) rests on thin basal carbonate of the Bouse Formation and is overlain by an upper limestone unit of the Bouse Formation. These possible stratigraphic correlations remain to be tested. Those authors interpret the upper limestone unit as recording a second inundation of the southern part of the Blythe Basin following initial entry of cross-bedded Colorado River sands.

In summary, the Bouse Formation contains at least one and likely two or more polarity boundaries, and likely at least one full subchron, within the Gilbert Polarity Chron. Normal polarity rocks include Lawlor tephra assigned to the Sidufjall Normal Polarity Subchron (Fig. 2). The interbedded unit of the Bouse Formation includes both reversed and normal polarity rocks, but how these may correlate between sections and to the Lawlor tephra remain uncertain. McDougall and Miranda-Martinez (this volume) report faunal evidence suggesting that parts of the Bouse basal carbonate are Miocene, older by at least two polarity subchrons than the Sidufiall. As no subchron between 3.6 and 6.9 Ma is less than 100 kyr long, the parts of the Bouse Formation sampled for polarity likely span more than 100 kyr. This apparently minimum length of time for deposition of the formation much exceeds the roughly 30–40 kyr that Spencer et al. (2008, 2013) modeled for the predicted filling and spillover of a model Bouse Formation lake in the Blythe Basin.

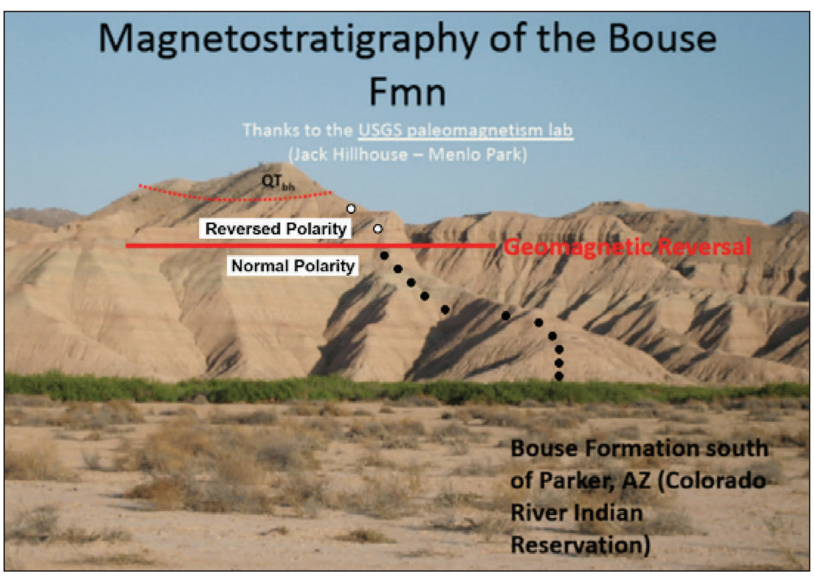

Figure 4. Annotated outcrop photo of a section of the interbedded unit of the Bouse Formation near Mesquite Mountain, where Malmon's preliminary results from elevations 374 to 483 ft. asl. (114 to 147 m) suggest normal polarity and 2 higher sites in the formation at 509 and 523 ft asl (155 and 159 m) suggest reversed polarity.

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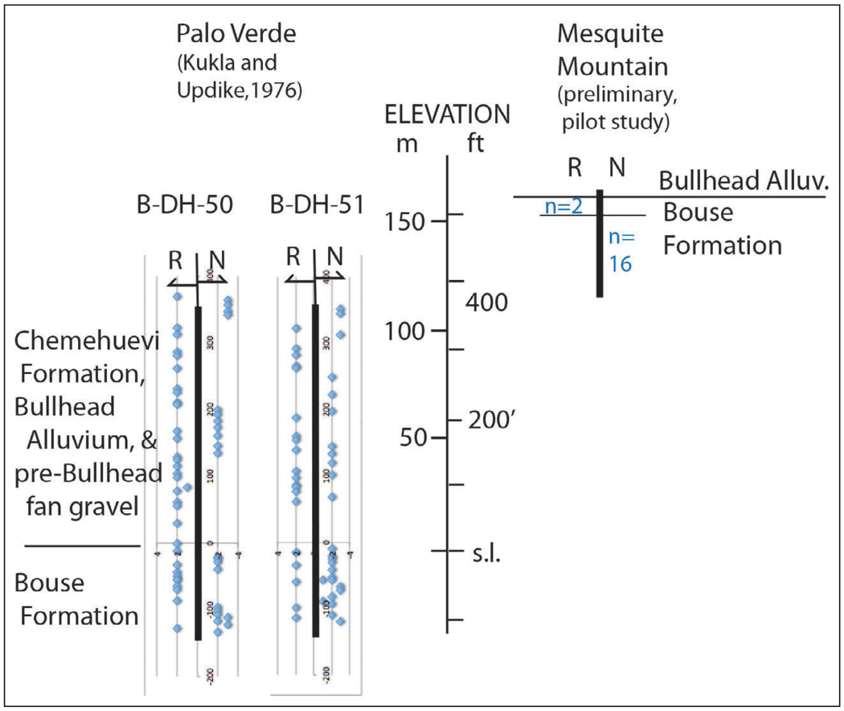

Figure 5. Polarity determinations (in blue) shown by elevation (in feet). Right—Tentative results near Mesquite Mountain (Fig. 1) shown in Figure 4. Left— Determinations in drill holes B-DH-50 and nearby B-DH-51 at a site west of Palo Verde (Fig. 1; Kukla and Updike, 1976). The quality of reversed (R) and normal (N) determinations increases away from the ordinate dividing R from N.

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