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Polygonal cracking in coarse clastics records cold temperatures in the equatorial Fountain Formation (Pennsylvanian–Permian, Colorado)

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ABSTRACT

Sand- and granule-filled polygonal fractures are present on bedding surfaces within the equatorial Fountain Formation (Pennsylvanian–Permian, Colorado). The surfaces are areally extensive (>120,000 m^2) and occur within inferred braided braided-river deposits. The fractures penetrate downward into coarse sandstone to granule conglomerate and range from 3–55 cm to 13–>220 cm in width and depth, respectively. At one locality (Manitou Springs), both fracture fill and polygon interiors display a grain-supported texture and contain <14% clay; additionally, the fracture fill is microbrecciated. At the other locality (Loveland), both the fracture fill and polygon interiors display a grain-supported texture and contain <3.5% clay.

The polygonal fractures formed as frozen ground experienced thermal contraction induced by repeated cooling events. Owing to the equatorial location of the Fountain Formation, we suggest that diurnal, rather than seasonal, temperature variations provided the repeated cooling mechanism. Alternative causes of polygonal fracturing, such as desiccation of clay-rich sediments or thermal contraction of evaporite minerals, are untenable because the hosting strata contain minimal clay (<14%) and are framework supported, indicating that there was insufficient space for either clay or evaporite minerals. A thermal contraction origin for these features implies that the equatorial Fountain Formation experienced at least two episodes of remarkably cold conditions. Furthermore, using maximum reasonable stream gradients (~0.02) between the polygonally fractured surfaces and the shoreline (gauged from shallow-marine deposits of the Denver basin), the fractures formed at relatively low elevation (≤1800 m).

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1. Introduction

Polygonal cracking on bedding planes in mud-rich continental strata is common and typically attributed to desiccation. A desiccation origin for polygonal cracks in coarse clastics (>50% sand), however, is untenable because the framework grains lack the contractive and cohesive qualities necessary for formation of desiccation cracks (Fellows, 1951; Neal, 1978; Weinberger, 2001). Other processes implemented to account for polygonal fracturing in coarse-grained clastic strata include ice- and sand-wedge formation (e.g. Lachenbruch, 1962; Black, 1976; Johnson, 1990), seasonal frost cracking (e.g. Katasonov, 1973; Black, 1976; Seppälä, 2004; Vliet-Lanoë et al., 2004), diurnal thermal contraction cracking (e.g. Hastenrath, 1981, 1984; Maloof et al., 2002) and thermal contraction of evaporites (e.g. Goldberg, 1967; Evans et al., 1969; Watson, 1985; Kocurek and Hunter, 1986). These processes take place on a stable land surface that undergoes thermal contraction in the presence of a binding medium (i.e. frozen interstitial water, or salts) that maintains cohesion within the polygon.

Different mechanisms of polygonal cracking have different paleoclimatic implications. For example, polygonal fractures containing evaporite minerals indicate a deficit of effective moisture (e.g. Parrish, 1998), whereas modern polygonal fracturing at high latitudes is the result of seasonal temperature swings (e.g. Lachenbruch, 1962; Black, 1976; Washburn, 1980a,b). Additionally, fracture-fill lithology and structure is different for a cold–humid (i.e. ice wedges) or a cold–arid (i.e. sand wedges) climate (Black, 1976).

In this paper, we describe polygonal fractures within coarse clastic strata of the Pennsylvanian–Permian Fountain Formation (western U.S.; Fig. 1). Our analysis indicates that these features formed as a result of repeated thermal contraction, reflecting discrete episodes of remarkably cold temperatures in this equatorial setting.

2. Geologic setting

The Pennsylvanian–Permian Fountain Formation consists of coarse arkosic sandstone and conglomerate deposited on the east flank of the ancestral Front Range (Fig. 1), one of a series of uplifts within the Ancestral Rocky Mountains (ARM). The ARM were an intracontinental array of Precambrian-cored uplifts and intervening basins situated in western equatorial Pangaea (Kluth and Coney, 1981). Latitudinal position of the study site ranged from 0 –5 N in the mid to late Pennsylvanian (Golonka et al., 1994; Scotese, 1999).

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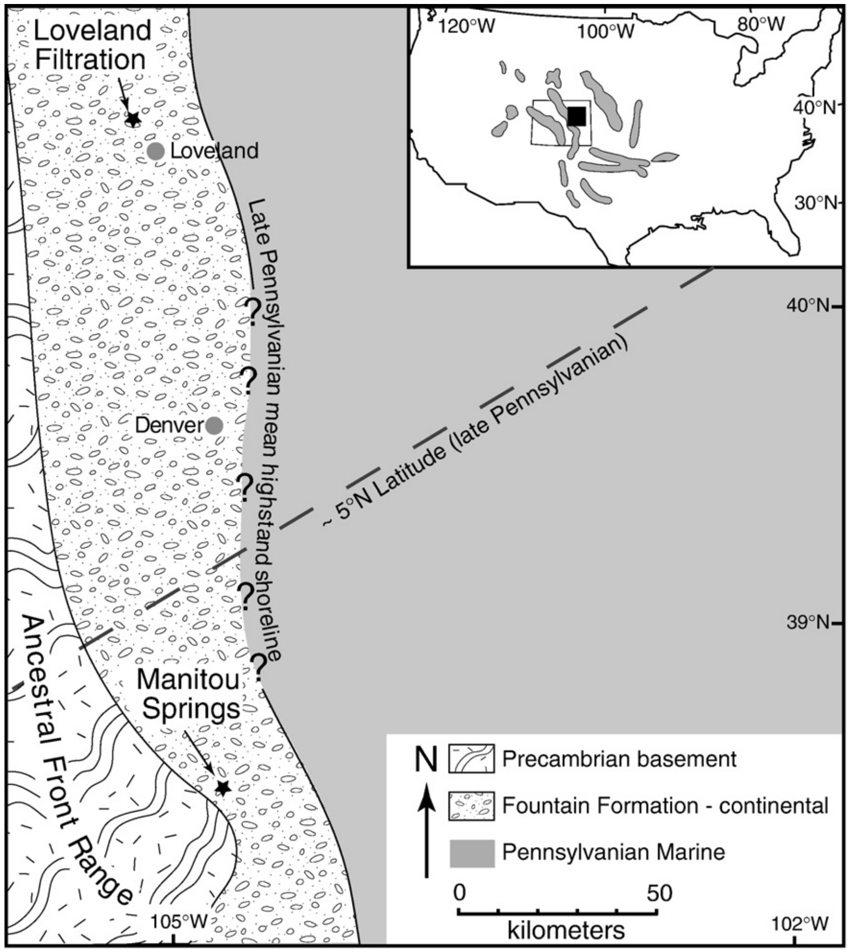

Fig. 1. Late Pennsylvanian paleogeographic map along the east flank of the ancestral Front Range uplift. Manitou Springs and Loveland study sites are denoted by black stars. The average highstand shoreline is estimated from subsurface data of Maughan and Ahlbrandt (1985) and Maher (1953). Latitudinal position estimated from Scotese (1999). Inset: Displays the outline of Colorado within the United States interior and location of ARM uplifts (*in* gray; modified from Kluth and Coney, 1981). Black box is the approximate area of enlarged view.

At Manitou Springs, Colorado (Fig. 1), the lower Fountain Formation is characterized by intertonguing of continental facies with lagoonal to shallow shallow-marine facies (Glen Eyrie Member; Langford and Fishbaugh, 1984; Suttner et al., 1984), whereas the upper Fountain Formation is entirely continental (Langford and Fishbaugh, 1984). Our interval of interest is within the upper "Balanced Rock interval" of Suttner et al. (1984) which they have interpreted as a braided fluvial succession. Here the lower Fountain Formation has been assigned a Morrowan–Atokan (Bashkirian) age on the basis of marine invertebrate and plant fossils found in the Glen Eyrie Member (Chronic and Williams, 1978; Suttner et al., 1984), and the upper Fountain Formation is presumed to be of Wolfcampian (Asselian–Sakmarian) age as constrained by the overlying Lyons Formation of probable Wolfcampian to Leonardian (Sakmarian–Artinskian) age (Thompson, 1949; Fig. 2).

Near Loveland, Colorado (Fig. 1), the Fountain Formation consists of coarse arkosic sandstone and minor granule conglomerate interpreted as braidplain deposits (Hubert, 1960; Schatz, 1986). The upper Fountain Formation represents a transition zone between fluvial deposition below and eolian deposition of the overlying Ingleside Formation (Schatz, 1986). Our interval of interest occurs within the uppermost Fountain Formation (Fig. 2). North of Loveland, thin limestone beds containing Virgilian (Gzhelian) fusulinids interfinger with the upper Fountain Formation (Maughan and Ahlbrandt, 1985) suggesting that the unit is entirely Pennsylvanian in the northern study site (Fig. 2).

3. Methods

Stratigraphic sections were measured with a Jacob Staff and Brunton compass and described at 1:25 scale. Fracture trends were measured with a Brunton compass on three-dimensional exposures. Samples of both the polygon interior and fracture fill were collected for sedimentary and X-ray diffraction (XRD) analyses.

Samples were disaggregated for grain-size and sand microtextural analyses by immersion in a dilute sodium carbonate dispersant solution followed by gentle sonication for 3 h. Calcite cement was then removed by submersion in 1 N hydrochloric acid at 50 °C until effervescence ceased. Lastly, iron oxide cement was removed by the citrate–bicarbonate–diothionite (CBD) method (Mehra and Jackson, 1960; Janitzky, 1986). The resultant disaggregated sample was analyzed for grain-size distribution by wet sieving with a 4 φ mesh (62.5 μm) to separate the sand+gravel from mud fractions. The mud fraction was analyzed with a Beckman-Coulter LS-230 laser particle size analyzer. The sand+gravel fraction was dry-sieved into granule (>2000 μm), very coarse to coarse sand (500–2000 μm), medium sand (250–500 μm) and fine to very fine sand (63–250 μm) fractions. Randomly selected quartz grains from the coarse and medium sand fractions were selected for scanning electron microscopy (SEM) analysis as outlined by Mahaney et al. (1988). The atlases of Krinsley and Doornkamp (1973) and Mahaney (2002) were used for identification of microtextures.

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