



## *The enigmatic Late Cretaceous mcDermott Formation*

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# THE ENIGMATIC LATE CRETACEOUS McDERMOTT FORMATION

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**ABSTRACT**—The Late Cretaceous McDermott Formation is a distinctive maroon to purple unit that is exposed on the northwest margin of the San Juan Basin. Previous workers have argued that this unit is composed of volcanoclastic deposits that were derived from a volcanic complex in the vicinity of the La Plata Mountains. There is no evidence for any volcanic features or events associated with the intrusive complex in the La Plata Mountains, and definitive field and petrologic evidence for volcanic deposits within the McDermott Formation has not been documented. The igneous material in the McDermott Formation is dominated by pebble- to boulder-sized fragments of diorite and monzonite that are similar to intrusive rocks exposed in the La Plata Mountains laccolithic complex. The deposits in the McDermott Formation mostly fine upward, and were deposited as debris flows and hyperconcentrated flows along with minor dilute stream flows.

An alternative hypothesis for the origin of this controversial unit is that dome collapse of the La Plata Mountains intrusive complex was created by magmatic inflation and roof-flank detachment creating gravity slides that were remobilized by streams flowing to the south and southeast. Reduction in lithostatic pressure may have also allowed for sudden release of pressure on the underlying magma body which could have produced minor volcanic-flank eruptions. This model is consistent with the dominant type of igneous material in the unit, and the fluvial-dominated systems that are preserved in these rocks.

## INTRODUCTION

South of Durango, the Cretaceous-Tertiary boundary on the northwest margin of the San Juan basin lies near the top of maroon to purple strata in the uppermost Cretaceous McDermott Formation (Figures 1 and 2). How these eye-catching deposits came to be is a question that geologists have pondered and debated for over 100 years. Understanding the origin of the McDermott Formation is important for gaining insight into the geologic and tectonic processes in the Four Corners region at this point in time.

The issue at the heart of the debate over the McDermott Formation is the source of the abundant igneous material contained within these rocks. Many previous workers have interpreted the igneous-rich deposits in the McDermott Formation as volcanoclastic (Reeside, 1924; McCormick, 1950; Barnes et al., 1954; Kottowski, 1957; Sikink, 1987). More recently, O'Shea (2009) concluded that the McDermott Formation was a "braided river" system that was interrupted by the deposition of lahars, and interprets some of the finer-grained facies in the unit as pyroclastic flow and base surge deposits.

That the McDermott Formation contains material of igneous origin is without question, but definitive evidence in support of a volcanic connection has been elusive. O'Shea (2009) reported wavy- and low-angle cross stratification, local normal graded beds, and rare and inconclusive "ghosts" of glass shards as evidence of a pyroclastic origin for her lithofacies 11, 12, and 13, which make up a small portion of the total deposits in the McDermott Formation. McCormick (1950) even suggested the presence of unaltered glass in these ~70 Ma deposits (Newman, 1987). Those parts of the unit interpreted as pyroclastic flow or surge deposits (McCormick, 1950; O'Shea, 2009), however, lack signature features such as internal erosion surfaces and antidunes, cooling units with columnar-jointed margins, vesicles or gas pockets, and fiamme and lithophysae. These types of volcanic features have not been documented by any previous worker.

The source and history of the McDermott Formation thus is enigmatic. We are left with several interesting and seemingly disparate pieces of evidence that have to be explained within the

context of a fluvial-dominated depositional system. Any interpretation of the origin of the deposits in the McDermott Formation has to accommodate several key observations. In any scenario the McDermott Formation was deposited on the Upper Cretaceous Kirtland Shale. There is clear and substantial evidence the McDermott Formation is composed dominantly of debris-flow and fluvial deposits. Plutonic rock fragments from the La Plata Mountains make up an important, if not dominant, proportion of the igneous material in these deposits. The strength of the arguments for a volcanic connection remains spurious, and there is no definitive evidence for a substantial contribution of volcanic material during deposition of the McDermott Formation. The possibility, however, that some of the rock layers in these deposits contain volcanic material, even though this is not well supported by evidence, must be considered, especially for the fine-grained deposits where it is difficult to determine between a volcanic or plutonic source. In this paper, an alternative hypothesis is proposed for the origin of the deposits in the McDermott Formation that takes into account the main attributes of this unit which do not support a dominantly volcanoclastic origin.

## HISTORY OF THE NOMENCLATURE OF THE McDERMOTT FORMATION

Upper Cretaceous to Paleocene deposits exposed on the southern flanks of the Laramide San Juan uplift (Figure 1) were first named the Animas River beds by Emmons et al., (1896). These rocks were later referred to as the Animas Formation (Lee, 1912; Lee and Knowlton, 1917), which Reeside (1924) divided into the lower McDermott Formation and upper Animas Formation. Barnes et al., (1954) assigned member status to the two formations, the McDermott Member and upper member of the Animas Formation. Fassett (2009) proposed that the unit nomenclature established by Reeside (1924) be restored due to the fact that this unit is a distinct and mappable unit. In this paper, the name McDermott Formation as applied by Reeside (1924) and Fassett (2009) is used (Figure 2).

The contact between the McDermott Formation and Animas Formation has been interpreted as either gradational and con-

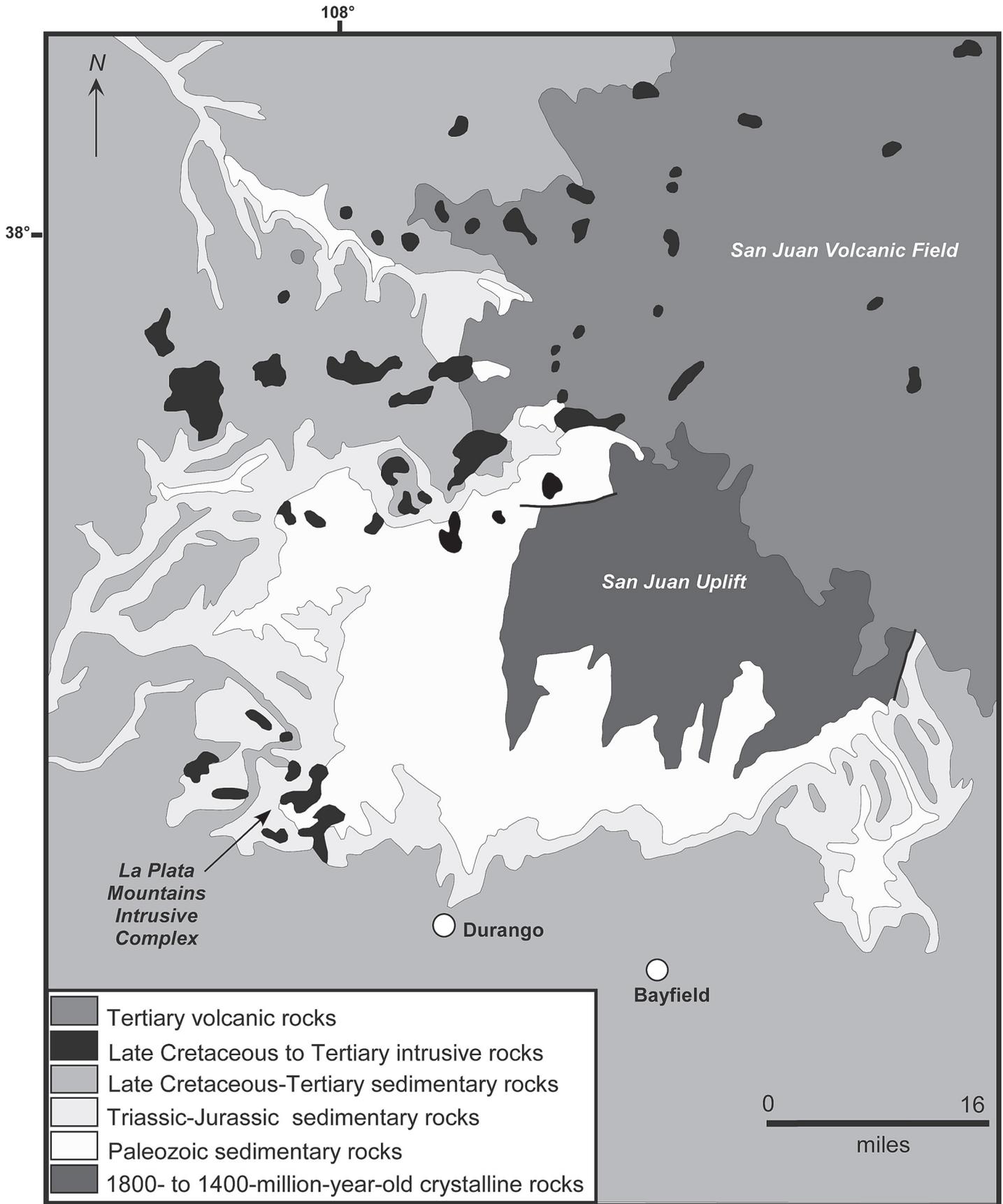


FIGURE 1. General geologic map of southwestern Colorado showing the dominant rock groups in the area.

formable (Zapp, 1949; Baltz, 1953; Barnes et al., 1954; Carroll et al., 1997, 1998) or an unconformity representing a time gap of approximately ~6 million years (Reeside, 1924; Fassett, 1985, 1988, 2009; Newman, 1987; Kirkham and Navarre, 2003).

Fossil fauna and flora (Granger, 1917; Reeside, 1924; Knowlton, 1924; Simpson, 1935a, b, c; Barnes, 1953) and palynomorphs

(Newman, 1987) identified in rock samples from the Animas Formation are mostly interpreted as Paleocene in age. Fossils and pollen samples documented in the McDermott Formation provide evidence that the unit is Early Maastrichtian (Reeside, 1924; Newman, 1987; Kirkham and Navarre, 2003).

#### PALEOCURRENT DATA, PROVENANCE, ENVIRONMENT OF DEPOSITION & LITHOFACIES

Both the McDermott and Animas Formations were deposited on an alluvial apron that developed on the southern margin of the San Juan uplift at the end of the Cretaceous. Paleocurrent measurements (Sikkink, 1987) indicate that material in these units was transported from the uplifted highlands to the north of the San Juan Basin by streams that flowed to the southeast (mean direction of S15° E) and southwest (mean direction of S10° W).

The provenance of detritus in the McDermott Formation and Animas Formation are distinct. Conglomeratic facies of the McDermott Formation (Figure 2) contain a high proportion of rounded to subangular boulder- to pebble-sized fragments of porphyritic monzonite and diorite along with lesser amounts of quartz, sandstone, petrified wood, and siltstone. Grains of perthitic microcline were also found in some samples from this unit (Lorraine and Gonzales, 2003). The dominant minerals identified in the igneous fragments are augite, biotite, orthopyroxene, hornblende, and oligoclase-andesine plagioclase. The types of igneous-rock fragments, and minerals contained in them, are indicative of rocks exposed in the La Plata Mountains laccolithic complex to the northwest (Figure 1).

Conglomerates and sandstones in the Animas Formation (Figure 2) contain rounded to subangular granules and pebbles of quartz, quartzite, chalcedony, chert, jasper, reddish brown to brown sandstone and siltstone, and grayish white sandstone. Some lenses and beds contain abundant angular fragments of perthitic microcline up to an inch in length. Granules to pebbles of volcanic fragments, granite, petrified wood, charcoal fragments, and limestone comprise a minor component of the clasts in the unit. (Gonzales et al., 2008). The volcanic fragments in the Animas Formation are porphyritic-aphanitic rhyolite to andesite commonly with laths of plagioclase (Gonzales et al., 2008). Some of the volcanic fragments have a distinct mineral-flow lamination and crystal-free groundmass that may be devitrified glass. The volcanic fragments in the Animas Formation are distinctly different from the igneous material in the McDermott Formation. The granite clasts and fragments of perthitic microcline in the upper Animas Formation were derived from Proterozoic granite that is exposed in the San Juan uplift to the north (Figure 1). Either before or during deposition of the material in the alluvial fan complexes (Sikkink, 1987) of the Animas Formation, however, there were eruptions of intermediate to felsic volcanic material in the region of the San Juan Mountains (Harraden and Gonzales, 2007).

Lorraine and Gonzales (2003) documented six major lithofacies and several intraformational erosion surfaces in the McDermott Formation exposed in the Animas River valley south of Durango (Figure 1). A more extensive study of the McDermott

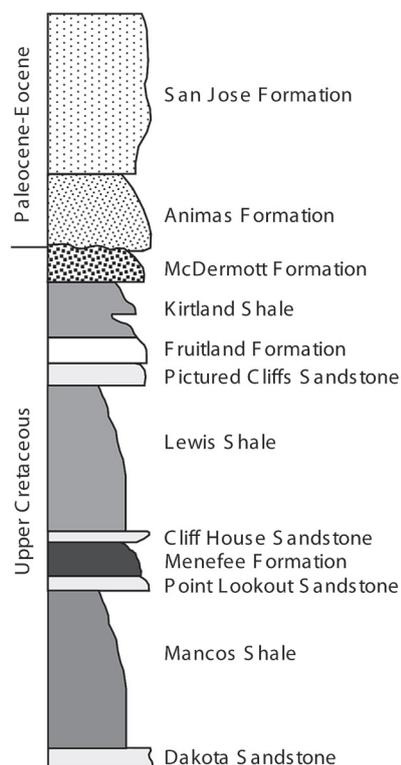
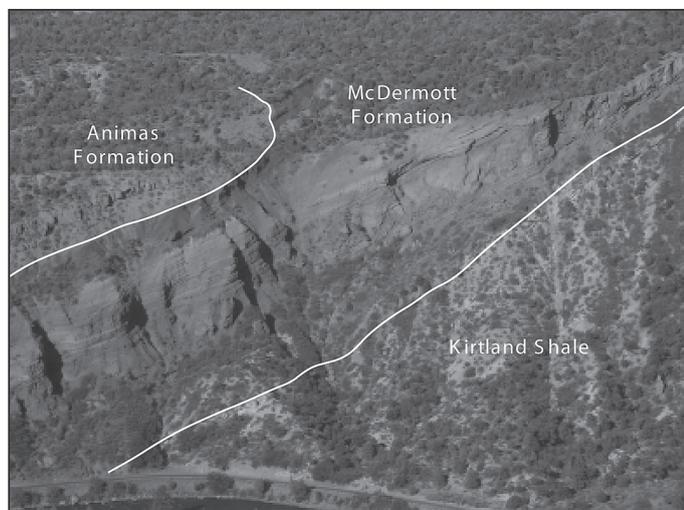


FIGURE 2. A generalized stratigraphic section showing the Upper Cretaceous to Eocene sedimentary units exposed on the southern rim of the San Juan uplift. The photograph is an aerial view of the McDermott Formation exposed south of Durango as viewed looking west (photograph provided by Gary Gianniny). The approximate lower and upper boundaries of the McDermott Formation are indicated by the solid white lines.

Formation by O'Shea (2009) recognized 13 different lithofacies, several of which were interpreted as volcanic tuff or breccia deposits. The lower two-thirds of the McDermott Formation is dominantly matrix- to clast-supported boulder to cobble conglomerate and conglomeratic sandstone which grades upward into interbedded beds of coarse-grained sandstone, siltstone, and shale (McCormick, 1950; Kirkham and Navarre, 2003; Lorraine and Gonzales, 2003; O'Shea, 2009). Alluvium in the McDermott Formation was mostly deposited in debris flows and hyperconcentrated flows although dilute stream flows were probably dominant for the upper, finer-grained lithofacies. The Animas Formation also contains a thick succession of interbedded stream and lacustrine deposits, but tends to have a much lower proportion of the boulder- to cobble-rich debris flow deposits found in the McDermott Formation.

### THE IGNEOUS CONNECTION

The volcanic connection for the McDermott Formation has always rested on the poorly supported presumption that the La Plata Mountains laccolithic complex was a site of volcanism in the Late Cretaceous. Extensive work by the author in the La Plata Mountains and other laccolithic complexes in the region provides no evidence of any such volcanic events. Erosion would have removed much of any volcanic record that may have existed, but there is no evidence that lends support to the idea that a volcanic cap existed in the La Plata Mountains such as vents areas that breach the sedimentary section or remnant volcanic rocks (not even in the ancient to modern stream deposits derived from these mountains).

Several pieces of evidence that have been used to argue that igneous materials in the McDermott Formation are volcanic in origin is the distinctive maroon color of these deposits, and fact that they contain mineral constituents that are common in intermediate volcanic rocks. There is virtually no documentation of features in the McDermott Formation, however, that are definitive only of volcanic deposits. O'Shea (2009) reported a single "glass ghost shard" completely replaced by an opaque mineral. This fragment was interpreted as a glass shard because of its overall shape, but in a photograph of this feature in O'Shea (2009) the characteristic features of broken glass bubbles are not visible; it instead appears to be a cluster of several opaque crystals.

An observation that complicates the interpretation of the volcanic source of igneous debris in the McDermott Formation is the presence of blocks and boulders of porphyritic diorite and monzonite, especially the lower conglomeratic deposits of the unit (Lorraine and Gonzales, 2003; Kirkham and Navarre, 2003). These large fragments are identical in mineralogy and texture to the plutonic rocks exposed in the La Plata Mountains. Furthermore, McCormick (1950) reported the presence of garnet in some of the detritus which probably came from garnet-epidote-hematite skarns in the La Plata Mountains complex. O'Shea (2009) reported extensive hydrothermal alteration of igneous minerals in the McDermott Formation which she attributed to in situ hydrothermal activity within the deposits. These alteration assemblages, however, are ubiquitous and diagnostic of deuteric-

altered plutonic rocks in the La Plata Mountains.

A detailed petrographic examination of igneous clasts in the McDermott Formation by the author determined that they are dominated by porphyritic monzonite and diorite that are similar in texture and mineral assemblages to the dominant plutonic igneous rocks in the La Plata Mountains. The trachytic to pilotaxitic textures documented in igneous-rock clasts of the McDermott Formation in some studies, and offered as evidence of volcanic origin (McCormick, 1950; O'Shea, 2009), are common features in hypabyssal intrusive rocks in the La Plata Mountains.

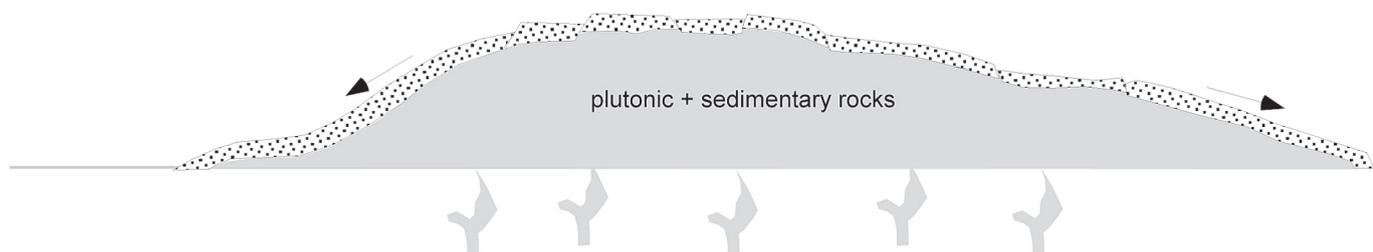
### AN ALTERNATIVE HYPOTHESIS

Most previous workers have argued that volcanic eruptions associated with the 65 Ma to 75 Ma La Plata Mountains laccolithic complex produced the igneous fragments and detritus in the McDermott Formation. There is no evidence that magmas associated with the La Plata Mountains complex breached the Upper Cretaceous sedimentary section that covered it. The competing hypothesis is that the hypabyssal plutonic rocks in the La Plata Mountains were the source of most of the igneous detritus in the McDermott Formation. This scenario requires that the intrusive complex was exposed in a rather short period of time in order for it to contribute material into the debris flows and streams that flowed south and southeast off of the uplifted highlands.

One possible analog that is consistent with a plutonic-dominated scenario is found in Tertiary laccolithic complexes in western Utah. The Miocene laccoliths exposed in this area were proposed to have formed by emplacement of extensive sill-shaped masses that inflated and extended the upflexed roof of the complexes (Hacker et al., 2002, 2007). This inflation of the roof is thought to have triggered catastrophic collapse of some of the flanks of the laccolithic domes. Gravity slides in the upper parts of the magmatic dome caused the transport of large blocks of sedimentary and igneous rocks down along the flanks of the laccolith. In some instances, it is proposed that the reduction in lithostatic pressure allowed for sudden release of pressure on the underlying magma body which might have produced minor volcanic-flank eruptions of ash deposits and lava flows (Figure 3). The deposits found around the flanks of these Miocene intrusive complexes in Utah have a striking resemblance to those in the McDermott Formation, in terms of the distribution and types of lithofacies.

Lorraine and Gonzales (2003) proposed a similar mechanism to explain the formation of the material in the McDermott Formation. Their model proposed that the southern margin of the La Plata Mountains laccolithic complex was oversteepened and collapsed; the south flank of the La Plata Mountain is steeper and marked by numerous steep faults that developed during uplift of the complex. Intrusive and sedimentary rocks released by this flank collapse were then transported and deposited by debris and hyperconcentrated flows. In this model, small amounts of volcanic material could have been generated by lateral eruptions (Figure 3), but a large flux of plutonic rock material would also be included in the mix. This scenario might also explain the lack of eruptive vents in the La Plata Mountains. Small flank erup-

## Magma Injection, Dome Development &amp; Inflation of Roof



## Extension of Cover Rocks &amp; Gravity Slides

minor flank eruptions

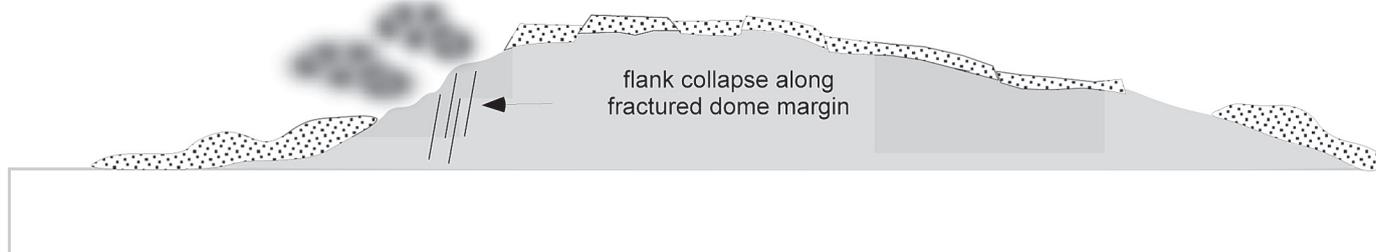


FIGURE 3. Cartoon interpretation of the sequence of events that is hypothesized to have caused the flank collapse of the La Plata Mountains dome. Exposure of the dome would have provided a source of igneous detritus in the debris flow and stream deposits that make up the McDermott Formation. The gray color represents intrusive and sedimentary rocks in the domed complex. The stippled blocks at the top of the complex are detached blocks that undergo gravity slide off of the dome due to magmatic inflation and oversteepening. Local flank collapse may have led to minor volcanic eruptions during these events.

tions would not originate from distinct vent areas, but rather from depressurization of magma along zones in the detached flanks. A model of laccolith formation that led to an oversteepening and detachment of cover rocks that were remobilized by debris flows and streams (Figure 3) is consistent with all of the major observations noted for the McDermott Formation.

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