Journal of Volcanology and Geothermal Research 177 (2008) 755–759

Contents lists available at ScienceDirect

Journal of Volcanology and Geothermal Research

journal homepage: www.elsevier.com/locate/jvolgeores

Surge deposit misidentification at Spor Mountain, Utah and elsewhere: A cautionary message for Mars

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ARTICLE INFO

Article history:
Accepted 25 January 2008
Available online 7 June 2008

Keywords:
surge deposit
history
Mars
impact
volcanic

ABSTRACT

Before base surges were described in association with nuclear blasts and explosive volcanic eruptions (especially, the 1980 eruption of Mount St. Helens, Washington), laminar and cross-bedded volcanogenic surge deposits were commonly misinterpreted as being of fluvial or aeolian origin. One well-documented example involves the "water-laid tuffs" in and near the Spor Mountain beryllium mine, Utah; other examples abound. In light of how frequently volcanogenic surge deposits have been misinterpreted on Earth, extreme caution is urged for Mars studies. Contrary to what has been claimed, the markedly cross-bedded, salty deposits at Meridiani Planum on Mars need not have been formed by a combination of aeolian and aqueous processes, and their contained hematitic spherules need not have formed as aqueous concretions. Given the lack of indications of volcanism in the vicinity, and the planet-wide abundance of impact craters, deposition by surges associated with distant impact targets consisting of brine-soaked, locally sulfidic regolith is a reasonable explanation for all features observed, especially if diagenesis and weathering are considered. The uniformly sized and shaped, Ni-enriched blue-gray hematitic spherules would then be some type of vapor condensation spherules (including accretionary lapilli). A similar interpretation is possible for deposits in the Home Plate area, Gusev Crater. Unlike on the dry and atmosphereless Moon, salty impact surge deposits containing spherules should be common, and well-preserved, on Mars.

1. Introduction

Layered, cross-bedded, sulfate-rich sediments observed by the Opportunity rover (MER-B) at Meridiani Planum, Mars, were initially (Squyres et al., 2004) interpreted as having formed from flowing and standing water related to an evaporating acid sea or lake and, later (Squyres and Knoll, 2005; Squyres et al., 2006), as having been deposited by aeolian processes acting on a vanished playa, modified by late flowing (but not standing) surface water (Grotzinger et al., 2005), and multiple inflows of variably acid and salty groundwater brines (McLennan et al., 2005). The "vanished playa" aeolian interpretation, like the "vanished lake" fluvial interpretation before it, appears unusually complex and filled with internal contradictions. It could well represent a serious misinterpretation (Burt et al., 2005, 2006), because a much simpler, more logical explanation, impact-related surge followed by diagenesis and weathering, accounts for everything imaged and measured to date by the Opportunity rover (Knauth et al., 2005, 2006), without contradictions.

At Meridiani, hematite mineralization is contained in disseminated, uniformly-sized blue-gray spherical nodules first called "blueberries" (Squyres et al., 2004). Their origin, and the origin of the hematite itself, is controversial: sedimentary concretions or oxidized impact-related vapor condensation spherules. Their uniform shape, strict size limitation to about 5 mm, general lack of clumping or flattening, and puzzling enrichment in Ni as well as Fe (Yen et al., 2005), strongly suggests that they are not sedimentary concretions (Knauth et al., 2005). In addition, they appear to be made largely or wholly of the high-temperature specular form of hematite, not found in concretions.

Layered, cross-bedded, altered rocks appearing somewhat analogous to those of Meridiani Planum on Mars have been mined for beryllium since the 1960s at Spor Mountain, west central Utah. Uranium, leached from overlying silicic volcanic tuffs, and dark purple fluorite replacing Paleozoic dolomite in volcanogenic breccia pipes have also been mined in the district.

At Spor Mountain, beryllium as bertrandite is dissemined in purple nodules of fluorite and silica replacing dolomite clasts (e.g., Lindsey, 1977; Burt et al., 1982) at the top of cross-bedded volcanic base surge deposits preserved beneath a lava flow of topaz rhyolite. As with the hematite mineralization at Meridiani Planum, the origin of this beryllium mineralization remains controversial: low temperature

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0377-0273/$ – see front matter
doi:10.1016/j.jvolgeores.2008.01.044

hydrothermal fluids derived from an underlying pluton or direct release of metals from devitrification of overlying high-fluorine lava. The fact that beryllium mineralization is lacking in fluorite-mineralized brecciated volcanic vent areas, is only present just beneath the lava flows, and is associated with enrichment in other incompatible lithophile elements such as Sn, W, and Nb, suggested the latter possibility (a sort of "extrusive skarn" type of contact deposit: Burt and Sheridan, 1981).

For about 15 years from the late 1960s, the mineralized rocks of Spor Mountain and similar-appearing unmineralized rocks in the nearby Thomas Range (Topaz Mt.) and adjacent ranges, were labelled "water-laid tuff" in various U.S. Geological Survey (USGS) publications. Such mistakes in interpretation were relatively common at that time, because the differences between volcanic surge deposits and normal aeolian or fluvial sedimentary deposits can be subtle. More importantly, the typical characteristics of volcanic surge deposits, including bomb or impact sags, which are present at Spor Mountain, were not described until about 1970 (e.g., Fisher and Waters, 1970) and were not widely publicized until after the 1980 Mount St. Helens volcanic eruption in Washington state. Even today, these deposits remain relatively poorly understood, and their nomenclature remains inconsistent (compare, e.g., Wohletz, 1998 with Branney and Kokelaar, 2002).

Fig. 2. Exposure of cross-bedding in mineralized tuff of beryllium ore zone directly beneath a topaz rhyolite lava flow, Spor Mountain, Utah. Hammer at the contact gives scale. Slide photo by D.M. Burt.

2. Spor Mountain history

In the early 1960s, the first government geologist to study the Spor Mountain Be deposits simply referred to the layered tuffaceous rocks as "vitric tuff" (Staatz, 1963). In this early investigation, it was not realized that the district had experienced two episodes of F-rich volcanism, at about 21 Ma (Spor Mt.) and 6 Ma (Thomas Range, including Topaz Mountain). Except for miarolitic gem topaz and red beryl in young lava at Topaz Mountain, plus uraniferous opal in fractures, only the older Spor Mountain volcanism formed economic Be-, U-, and F-mineralization. In a later study (Shawe, 1966), the cross-bedded rocks were named "water-laid tuff" and this genetic misinterpretation was repeated in the book "Ore Deposits in the United States" (Shawe, 1968). Over the next several years numerous articles and Professional Papers appeared on mineralization related to the "water-laid tuffs" of Utah (e.g., Lindsey, 1975a,b, 1977), at Spor Mountain and at nearby occurrences.

Fig. 1. Exposure of unmineralized, near-vent volcanic surge at Antelope Ridge, Thomas Range, Utah. Slide photo by D.M. Burt.

This situation changed during a joint ASU/USGS field trip in March, 1979, when one of us (Sheridan, on first viewing an exposure of unmineralized, near-vent "water-laid tuff" at Antelope Ridge near Topaz Mountain) exclaimed, "Why, those are surge deposits!" His criteria were the coarse angular clasts, the lack of sorting, the laminar bedding and cross bedding, bomb sags, and position beneath a rhyolite dome complex, next to a known volcanic vent. See Figs. 1 and 2 for examples of unmineralized and mineralized tuff, respectively. Thereafter, the unmineralized and mineralized tuffs of central Utah became "stratified tuff" (e.g., Lindsey, 1979, 1982) as it was finally recognized that they were formed directly by explosive volcanism. The possible relation of such deposits to topaz rhyolite volcanism in general was first summarized by Burt et al. (1982) and later, in more detail, by Christiansen et al. (1986).

3. Other examples

There are many localities, other than Spor Mountain, where volcanic surge deposits have been mistaken for normal sedimentary deposits, either subaqueous or aeolian. Several other examples are listed below, primarily from localities where at least one of us has considerable field experience. After 1980, many researchers recognized the difficulties inherent in discriminating surge deposits from sediments (e.g., Bull and Cas, 2000 and references therein).

3.1. Kilbourne Hole maar and Zuni Salt Lake maar, New Mexico

Fine-grained, cross-bedded basaltic surge deposits were initially interpreted as the products of aeolian reworking, presumably owing to the presence of high-angle cross-beds (Fig. 3). Interestingly, this early misinterpretation was made by Gene Shoemaker (in a 1957 meeting abstract), who was then a young man working as a uranium geologist for the USGS. He had not yet studied the geology of Meteor Crater, Arizona for his Princeton doctoral dissertation, let alone become world-famous for his studies of impacts and cratering.

3.2. Hopi Buttes volcanic field, Arizona

Hack (1942) studied sedimentation in this area and attributed the layered tephra deposits within maar crater rims and surrounding diatremes as water-laid. Wenrich (1989) continued to interpret many of the surge deposits as lacustrine sediments that collected in craters