Earth and Planetary Science Letters 411 (2015) 199–207

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Catastrophic emplacement of giant landslides aided by thermal decomposition: Heart Mountain, Wyoming

Thomas M. Mitchell[a,b,*], Steven A.F. Smith[b,c], Mark H. Anders[d], Giulio Di Toro[b,e], Stefan Nielsen[f], Andrea Cavallo[b], Andrew D. Beard[g]

[a] *Department of Earth Sciences, University College London, Gower Street, London, UK*
[b] *Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italy*
[c] *Department of Geology, University of Otago, Dunedin, 9054, New Zealand*
[d] *Department of Earth and Environmental Sciences and Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, United States*
[e] *Dipartimento di Geoscienze, Università di Padova, Padova, Italy*
[f] *Earth Sciences Department, University of Durham, South Road, DH1 3LE, UK*
[g] *Department of Earth and Planetary Sciences, Birkbeck, University of London, Malet Street, London, WC1E 7HX, UK*

ARTICLE INFO

Article history:
Received 9 June 2014
Received in revised form 18 October 2014
Accepted 21 October 2014
Available online 23 December 2014
Editor: P. Shearer

Keywords:
landslide
thermal decomposition
Heart Mountain
thermal pressurization
high velocity friction

ABSTRACT

The Heart Mountain landslide of northwest Wyoming is the largest known sub-aerial landslide on Earth. During its emplacement more than 2000 km^3 of Paleozoic sedimentary and Eocene volcanic rocks slid >45 km on a basal detachment surface dipping 2°, leading to 100 yr of debate regarding the emplacement mechanisms. Recently, emplacement by catastrophic sliding has been favored, but experimental evidence in support of this is lacking. Here we show in friction experiments on carbonate rocks taken from the landslide that at slip velocities of several meters per second CO_2 starts to degas due to thermal decomposition induced by flash heating after only a few hundred microns of slip. This is associated with the formation of vesicular degassing rims in dolomite clasts and a crystalline calcite cement that closely resemble microstructures in the basal slip zone of the natural landslide. Our experimental results are consistent with an emplacement mechanism whereby catastrophic slip was aided by carbonate decomposition and release of CO_2, allowing the huge upper plate rock mass to slide over a 'cushion' of pressurized material.

1. Introduction

In the early 1900s, a low-angle detachment was recognized at Heart Mountain and initially attributed to thrusting of Paleozoic rocks onto Eocene rocks (Dake, 1916). In the 1940s the detachment was shown to be a landslide (Bucher, 1947), and in the late 1950s and early 1960s its enormous areal extent (Fig. 1, Fig. 2a) was first established (Hauge, 1985, 1990, 1993). Since then, debate has centered on whether emplacement was catastrophic (Anders et al., 2011; Beutner and Gerbi, 2005; Beutner and Hauge, 2009; Craddock et al., 2000, 2009; Pierce, 1960, 1973; Voight, 1973) or incremental (Hauge, 1985) and by which mechanisms such a massive volume of upper plate rock could have moved across a basal surface with an average regional dip of only 2° (Anders et al., 2011; Craddock et al., 2000; Hughes, 1970; Melosh, 1983). Central to the debate is the character of deformation at the landslides base (Anders et al., 2010; Beutner and Craven, 1996; Craddock et al., 2009; Hauge, 1990). Consensus amongst workers today is that emplacement was catastrophic, taking on the order of minutes to hours, and that initial movement of the landslide was triggered by Eocene volcanic activity (Aharonov and Anders, 2006; Anders et al., 2010; Beutner and Craven, 1996; Craddock et al., 2009; Goren et al., 2010a, 2010b; Hughes, 1970; Malone et al., 2014; Melosh, 1983).

Although long-runout landslides are known to occur on high-angle surfaces (e.g. Brian Dade and Huppert, 1998), one of the long-standing paradoxes in geomechanics is how large landslides are able to move great distances on low-angle surfaces when frictional resistance demands that they not. There have been a number of hypotheses to explain this phenomenon (e.g. Pudasaini and Miller, 2013 and references therein), but almost no empirical data to support one model over another. Suggested mechanisms to account for the >45 km long runout

---

* Corresponding author.
E-mail address: tom.mitchell@ucl.ac.uk (T.M. Mitchell).

http://dx.doi.org/10.1016/j.epsl.2014.10.051

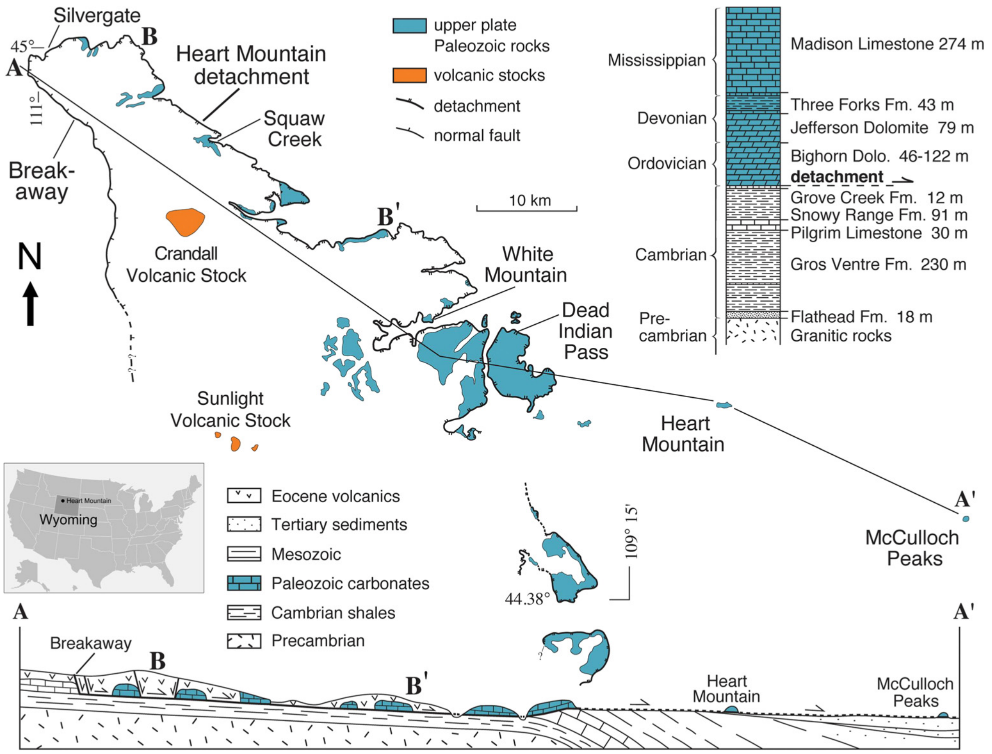

Fig. 1. Map of the Heart Mountain slide block located in northwestern Wyoming and southeastern Montana, showing the sampling areas referred to in the text. Modified from Anders et al. (2010).

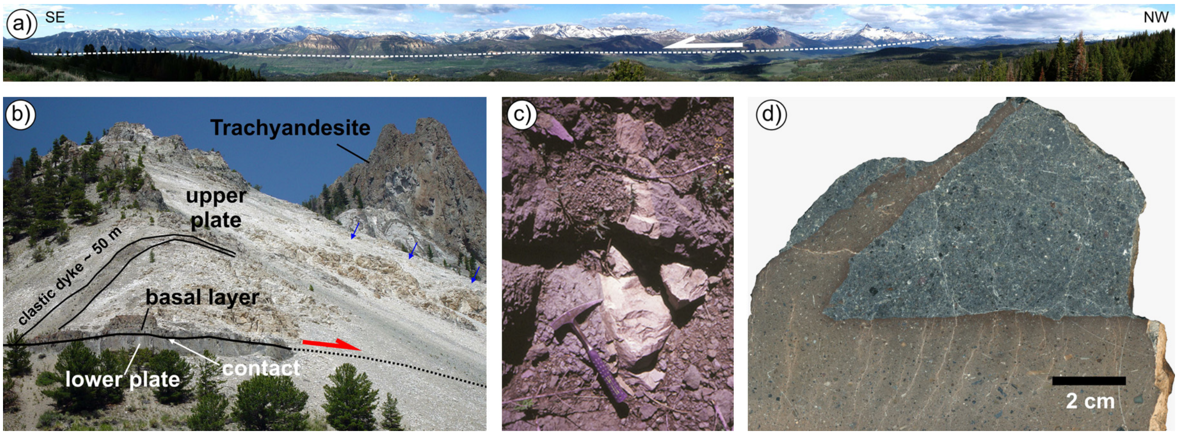

Fig. 2. (a) Photograph of ∼30 km of the Heart Mountain slide block (B to B′ in Fig. 1). View looking southwest from south flank of the Beartooth Mountains. Photograph is by Anna Foster with her permission. (b) White Mountain sampling site. White rocks are upper plate marbleized Ordovician Bighorn Dolomite and Mississippian Madison Limestone. The gray horizontal layer is the ∼3 m-thick basal layer overlying a thin sliver of the lower plate Bighorn Dolomite and Cambrian Snowy Range Formation. The dark trachyandesite peak in the upper right is an Eocene stock of the Absaroka Group Volcanics. Marbleization is due to stock igneous intrusion prior to slide emplacement. Modified from Anders et al. (2010). (c) A clastic dike/injectite at Silvergate, Montana (light colored injectite is intruded into dark Eocene Absaroka Volcanic rocks). This dike is located within a meter of the basal contact. At this location carbonized Eocene wood was found in the dike (see Anders et al., 2010, their Fig. 3f). (d) Cut slab of clastic dike/injectite from Silvergate, Montana location.

of the Heart Mountain landslide include hydroplaning on cognate waters (Voight, 1973), injection of pressurized volcanic gases at the slide's base (Beutner and Gerbi, 2005; Hughes, 1970), earthquake acoustic fluidization (Melosh, 1983), granular dynamic fluidization (Anders et al., 2000), hydrothermal overpressuring (Aharonov and Anders, 2006; Goren et al., 2010a, 2010b) and, more recently, overpressuring from generation of CO_2 gas caused by thermal decomposition of the basal carbonates (Anders et al., 2010; Beutner and Gerbi, 2005).

Here we present experimental results that support the unique role of carbonate decomposition in the long-runout of large terrestrial landslides. We show that hypotheses of landslide fluidization by CO_2 gas generation, hitherto speculated at, are well supported by a combination of our experimental results and field observations.

2. Natural observations

One of the best exposures of the basal section of the HM landslide is at White Mountain (Figs. 1, 2b). At this locality a Paleozoic section of marbleized Ordovician Bighorn Dolomite to Mississippian Madison Limestone in the upper plate was emplaced (Fig. 1)