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Morphological impacts of low magnitude seismic events on granite: Viewing certain landforms with new eyes

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ABSTRACT

Several landforms developed in massive brittle rocks located in cratonic settings, and formerly thought to be caused by external agencies, are now attributed to low magnitude seismic events or earth tremors. Field observations and particularly monitoring of specific sites have shown that the frequent joggling of shield areas has given rise to miniature scarps that define dislodged segments. Furthermore, sheeting fractures, previously well known as offloading joints, are planes of dislocation and are initiated during low energy earthquakes. A-tents or pop-ups were in past times widely attributed to insolation and less commonly to offloading, but they too, and like sheet structures and rock wedges, are formed by compressive stress applied either instantly during earth tremors or gradually, over decades. Many of these forms develop after exposure but some A-tents are almost certainly initiated at the weathering front. Wedges also develop in the subsurface. Rock bursts and slabs and blocks are displaced or split during earth tremors. It is not suggested that lithostatic pressure can be overlooked but applied compression as well as reduced lithostatic loading are necessary for the development of sheet fractures and the other forms cited.

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1. Introduction

The landscape changes wrought by major earthquakes associated with plate junctions are well documented (Lawson and Reid, 1908–10; Davison, 1931; Grantz et al., 1964; Ikeda, 1996, 2012; Lay

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et al., 2005). The resultant landforms vary in scale. They include escarpments bordering horsts and graben, or delimiting irregular blocks; diverted and blocked rivers and blocked or freshly initiated springs; and uplift or subsidence sufficient to cause changes in the distribution of land and sea.

In addition, and if only because plates comprise elements of varied composition, structure, and hence rheology, stresses are generated during migration, causing intraplate disruptions. For example, Australia is located distant from any plate junction and is migrating 7–10 cm p.a. to the north or northeast (Hillis and Müller, 2003). Earthquakes of medium to low magnitude are frequent both in time and space, generating relatively minor dislocations. Some associated changes are obvious, others so minute as to be almost imperceptible. Some are instantaneous, others gradual and developed over decades, centuries, and longer. All, however, are responses to crustal stress (Harris, 1939; Denham, 1988; McCue, 1990; Bowman, 1992; Twidale and Bourne, 2003; Twidale, 2011).

Low magnitude earthquakes or earth tremors most obviously affect brittle rocks, and particularly crystalline materials like granite. Two categories of minor forms initiated by crustal stress can be identified. First, several common landforms, such as rock blisters and A-tents, formerly attributed to external agencies like insolation or pressure release, are now known to be associated with tremors. Field evidence indicates that they owe their origin principally to horizontal compression generated in low magnitude earthquakes (e.g. Terzaghi, 1950). Second, as is shown in this review it is now realized that a small number of features, such as triangular rock wedges and even sheet fractures are of tectonic origin.

2. Displaced slabs

Faulting has caused both vertical and lateral displacements, the former involving scarps at various scales with associated rock splinters, re-crystallization, steps, and slickensides, the latter, wedges and displaced slabs. The compressive forms cited develop where and when applied stresses outweigh lithostatic forces.

2.1. Vertical dislocation

Fault scarps are a common and widely distributed product of crustal stress. Those developed in lithified rocks are enduring landscape features, whereas recurrent uplift and renewed stream dissection of unconsolidated rocks have produced wine-glass valleys (goblets in cross-section shape), so-called for their wider, open, upper valley and a narrow gorge incised in that valley floor. They separate triangular facets on fault scarps (Fig. 1). Such valleys occur where the dissected block has been uplifted relative to that adjacent, causing stream rejuvenation and channel incision. Differential movement has been generated in compressional as well as extensional environments. Examples of wine-glass valleys occur in the Mojave Desert of the American Southwest where strike–slip faults developed in relatively youthful unconsolidated materials are dominant. They vary between gravity and reverse regionally and along strike (e.g. Wright and Troxel, 1954). In such arid regions the occasional rains and runoff have excavated evenly spaced valleys that have been repeatedly revived. In more humid environments and consolidated rocks subjected to long-term tectonism the outlines of such complex valleys are subdued by weathering, as for example, on the scarps of the Mt Lofty Ranges, South Australia, which is a horst defined by old but recurrently active and predominantly reverse faults.

Other ruptures are underprinted from basement distortions and transmitted to overlying strata or regolith as ephemeral dirt scarps formed in unconsolidated materials (e.g. Hills, 1961). Thus, en echelon dirt scarps formed during the 1968 Meckering earthquake on the Yilgarn Craton of Western Australia (Gordon and Lewis, 1980) were soon eliminated by weathering and erosion (Figs. 2 and 3).

Fault scarps vary in scale from the regional to the local. A minor shallow earthquake (measuring 2.7 on the Richter scale) with an epicenter some 80 km to the east affected Minnipa Hill, northwestern Eyre Peninsula, South Australia, at 1137 h local time on 19 January 1999. It caused numerous superficial changes (Twidale and Bourne, 2000). The event was identified on the basis of its time of occurrence as recorded on seismographs and by eyewitness accounts. Fault traces were readily recognized because they exposed clean surfaces in the fresh orthoclase-rich pink granite that contrasted sharply with the pre-existing gray surfaces

Fig. 1. Wine-glass valleys at Stovepipe Well, California, where the face of the uplifted block was dissected by episodic desert streams. Each eroded a valley that developed an open V-shape in cross-section. After further uplift the streams cut down to the new base level, eroding a narrow gorge-like younger valley in the floor of the old (to form the stem of the imagined wine glass). Bleached weathered rock was exposed in the new basal sector of the scarp.