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Exfoliation Joint and Its Origins

Pitsanupong Kanjanapayont

Department of Geology, Faculty of Science, Chulalongkorn University, Bangkok 10330, Thailand
Corresponding author e-mail: pitsanupong.k@hotmail.com

Abstract

Exfoliation joint is generally used in various terms such as sheet joint or sheet structure. The topography of it is domical hills or bornhardts which is in a dome shape. The origins of exfoliation joint are commonly explained by four theories; pressure release, thermoelastic strain, chemical weathering, compressive stress and extensional fracture. Pressure release theory has many inconsistencies with field and observations, while thermoelastic strain and chemical weathering can not explain for the large scale or deep exfoliation joint. The compressive stress and extensional fracture seems to be the most suitable theory to explain the origin of exfoliation joint.

Key words: Exfoliation joint, pressure release, thermoelastic strain, chemical weathering, compressive stress

1. Exfoliation joint

1.1. Definition

Exfoliation have been used in various terms i.e. exfoliation joint, sheet joint, sheet structure (Bahat et al., 1999; Holzhausen, 1989). Collins dictionary of geology (MacDonald and Burton, 2003) gives the meaning of it as "Exfoliation is the separation of successive thin, onion-like shells (spalls) from bare surfaces of massive rock, such as granite or basalt", while the new penguin dictionary of geology (Kearey, 2001) defines that "The degradation of boulders by the spalling of surface layers, millimeters to a few metres in thickness, probably arising from the release of lithostatic pressure on exhumation, by weathering or the growth of salt crystals just below the surface of the rock". The larger-scale exfoliation was expressed by Holzhausen (1989) as "Sheet structure, or large-scale exfoliation, is the division of rock mass into lenses, plate or "sheet" approximately parallel to the earth's surface". However, exfoliation shows fracture surface which is imperceptible movement, so it is typically classified as a kind of joint.

1.2. General characteristics of exfoliation joints

Exfoliation typically shows a dome shape and expresses in domical hills or bornhardts following the topography (Gilbert, 1904; Goodman, 1993; Romani and Twidale, 1999). It divides the rock into sub-planar slabs which can have concave and convex upward curvatures (Gilbert, 1904; Goodman, 1993; Romani and Twidale, 1999) (Fig. 1). It often associated with secondary compressive forms such as arching, buckling, and A-tents (buckled slabs) (Romani and Twidale, 1999). The spacing of exfoliation joint increases with depth from a few centimeters to a few meters (Dale, 1923; Goodman; 1993; Jahns, 1943). The deeper joints have a larger radius of curvature, which tens to round the corners of the landscape as material is eroded (Dale, 1923; Gilbert, 1904; Goodman; 1993; Jahns, 1943). The maximum depth of observed occurrence is around 100 meters (Dale, 1923; Goodman; 1993; Holzhausen, 1989; Jahns, 1943). Exfoliation joint occurs in many

different lithologies and climate zones, not unique to glaciated landscapes (Badley 1963; Goodman; 1993; Twidale, 1973). The host rock is generally sparsely jointed, fairly isotropic, and high compressive strength (Gilbert, 1904; Jahns, 1943; Twidale, 1973). The fracture mode is tensile fracture mode (mode I) (Bahat et al., 1999; Mandl, 2005).

Figure 1. Exfoliation joint illustrates sub-planar slabs in the Eastern Granite Belt of Thailand at Nakhon Sawan region.

2. Origins of exfoliation joint

The origin of exfoliation joint has been debated by various investigators because of different landscapes (Bahat et al., 1999; Gilbert, 1904; Holzhausen, 1989). The general theories of its origins are summarized below;

2.1. Pressure release

The original theory of exfoliation, known as unloading, was first proposed by geomorphologist Grove Karl Gilbert in Bulletin of the Geological Society of America in 1904. Gilbert explains that the erosion of overburden and exhumation of deeply buried rock to the ground surface allows previously compressed rock to expand radially, creating tensile stress and fracturing the rock in layer parallel to the ground surface. The description of this mechanism has led to alternate terms of exfoliation joints, including pressure release or offloading joints.

Although this theory is widely found in many geology text, there are many inconsistencies with field and observations such as; exfoliation joint can be found in the unburied rocks; laboratory studies show that fracturing is not caused by simple compression and relaxation of rock samples under realistic conditions; exfoliation joint is most commonly found in the surface-parallel compressive stress region (Holzhausen, 1989; Twidale, 1973; Wolters, 1969). One theory of unloading matching with the compressive

stress theory expresses that the exhumation of deeply buried rocks relieves vertical stress, but horizontal stresses can remain in a competent rock mass since the medium is laterally confined (Goodman, 1993). The horizontal stresses align to the current ground surface as the vertical stress drops to zero at this boundary, thus large surface-parallel compressive stresses can be generated through exhumation leading to tensile rock fracturing (Goodman, 1993).

2.2. Thermoelastic strain

Thermoelastic strain theory is about the expansion/contraction of rock by thermal stress. The different rock-forming minerals which have variable thermal expansion/contraction rate are the reason to the expansion/contraction of rock under heating and cooling condition. The large daily temperature variation at rock surface can be created stresses causing the rock surface expansion and thin slabs detachment (e.g. Wolters, 1969). Fire-induced or large diurnal temperature fluctuations can be created thin lamination and flaking at rock surface (Blackwelder, 1927).

However, due to rock's low thermal conductivity, diurnal temperature fluctuations can only reach a few centimeters depth in rock. Therefore, this theory can not apply to exfoliation jointing that may reach 100 meters depth (Gilbert, 1904; Goodman, 1993; Holzhausen, 1989; Twidale, 1973).

2.3. Chemical weathering

Chemical weathering which is concerns to exfoliation is hydration. Flaking of thin shells of rock since the volume of some minerals increases upon hydration cause mineral weathering (Twidale, 1973). Mineral hydration involves the rigid attachment of H+ and OH- ions to the atoms and molecules of a mineral. The increased volume creates physical stresses within the rock when rock minerals take up water.

Not all mineral hydration results in increased volume, while field observation of exfoliation joints show that the joint surfaces have not experienced significant chemical alteration, so mineral weathering can not be explained for the origin of large scale, deeper exfoliation joint.

2.4. Compressive stress

The large compressive stresses parallel to the earth's surface can create tensile fracture mode (mode I) in rock, where the direction of fracture propagation is parallel to the principle compressive stress and the direction of fracture opening is perpendicular to the free surface (Bahat, 1999; Bradley, 1963; Brunner and Scheidegger, 1973; Holzhausen, 1989; Mandl, 2005; Twidale, 1973; Wolters, 1969). Tensile fracture mode can form in a compressive stress field due to the influence of pervasive microcracks in the rock lattice and extension of "wing cracks" from near the tips of preferentially oriented microcracks, which then curve and align with the direction of the principle compressive stress (Hoek and Bieniawski, 1965; Fairhurst and Cook, 1966). These fractures are sometimes called axial cleavage, longitudinal splitting, or extensional fractures, and are commonly observed in the laboratory during uniaxial compression tests. High horizontal or surface-parallel compressive stress can be a result of regional tectonic or topographic stresses.

3. Conclusions

There are many theories for explain the origin of exfoliation joint in many scales. The most common pressure release theory still has many inconsistencies with field and observations at the present day. Thermoelastic strain and chemical weathering can not explain for the large scale or deep exfoliation joint. The compressive stress and extensional fracture seems to be the most suitable theory to explain the origin of exfoliation joint considering to the field evidence and observations of occurrence, fracture mode, and secondary forms.

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