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Columnar Joints

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Definition

A planar, extensional rupture surface of a larger network of polygonal fractures that delimits a set of columns, the entire system resulting from contraction of the material.

Note

The term *columnar joint* is rarely used in singular as columns are delimited by a network of fractures.

Category

A type of joint system.

Synonyms

Basalt column; Basalt organs; Columnar lava; Organ pipes

Description

A network of joints, which forms mostly hexagons and pentagons, but polygons with three to nine sides have all been observed. Statistics on 3,033 columns measured at 50 different sites on Earth has found that half of the columns are hexagonal, one third are pentagonal, and the average polygon side is 5.71 (Hetényi et al. 2012).

Morphometry

Columnar-jointed lavas usually exhibit elongated columns (cm to m wide, m to 10 m high), with a height-to-side length ratio in general between 10 and 100 (Hetényi et al. 2012). The width of the columns has since long been linked to the cooling rate of the body, slower cooling resulting in wider columns and faster cooling in narrower columns (e.g., small, 3- to 4-sided polygons in the tagamites of the Jänisjärvi impact crater, Karelia (Masaitis 1999)). Cooling rate was recently decomposed into two independent determining factors of columnar joint scales (Hetényi et al. 2012; see below at

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section "Formation"). Scales of columnar jointing in sedimentary rocks have not been compiled, but relatively short columns are not uncommon.

Subtypes

Official classification does not exist but is possible to make according to composition of the lava (or magma) as well as the geological setting of its emplacement (lava flow, lava lake, dyke or sill, volcanic plug or conduit, lava dome, impact melt sheet, etc.).

Interpretation

These usually form in contracting materials, most often in cooling igneous bodies (lavas, magmas, impact melts (e.g., Osinski 2006)), and also in dehydrating sedimentary rocks. The joints propagate perpendicularly to the cooling (resp. dehydrating) surface. Traces of each inward propagating fracture, called "chisel marks," can be visible in cases devoid of erosion (Degraff and Aydin 1993).

Formation

Columnar joints form when thermal stresses due to cooling cannot be relaxed by the viscous behavior of the material, and their difference overcomes the tensile stress of the material leading to rupture. This set of processes is strongly dependent on temperature. The advance of individual cracks proceeds perpendicularly to the cooling surface. The network of joints becomes polygonal below the cooling surface. Its characteristic spacing depends on the cooling rate, which is determined by two factors: chemical composition of the magma and geological setting of the emplacement. (1) There is a continuous transition in column width from large sizes in felsic lavas (phonolite), through intermediate sizes in intermediate compositions (andesite), to narrow columns in mafic lavas (basalt). (2) The geological emplacement of the igneous body (see above at *Subtypes*) is even more important in influencing column width, as it determines the boundary conditions to cooling and the thickness of the material to cool. Cooling rate at the surface can be accelerated by direct contact with water or ice (Saemundsson 1970; Spörli and Rowland 2006) and hence yield narrow, slender columns.

Degradation

Erosion first rounds down the edges of individual columns (leading to the folksy "organ" name), then may fracture the columns horizontally and further into lamellae to finally dismantle the columns piece by piece.

Surface/Structural Units

Well-preserved, thick lava flows may contain a bottom and a top set of respectively stouter and slenderer columns, labeled *colonnade* and *entablature* (Budkewitsch and Robin 1994 and references

Fig. 1 Lava flow filling a paleo-relief at Saint-Arcons, France, with colonnade and entablature. Man is 1.9 m tall (Photo by F. Garel)

therein). Their different size characteristics are due to the different cooling regimes (boundary conditions) to bedrock and respectively to air. Potential interaction with water or ice at the surface can also affect the cooling rate.

Composition

Columnar jointing is observed in a large variety of igneous rocks (basalt, tephrite-basanite, trachybasalt, basaltic andesite, basaltic trachyandesite, trachyandesite, trachyte, and phonolite) as well as in ignimbrites. The most common occurrences are mafic in composition, as these are the most common effusive lava types. Sedimentary examples include loess, baked clay, and sandstone.

Distribution

Columnar jointing is very common on Earth, the most famous probably being the Giant's Causeway in Northern Ireland. Numerous examples have been studied in the Columbia River Valley (USA), as well as in the Massif Central (France) (Figs. 1 and 2), in the Pannonian Basin (Hungary) (Fig. 3), and in Iceland (Hetényi et al. 2012). Further examples can be seen in Argentina, Armenia, Australia, Chile, Czech Republic, Germany, India, Israel (Fig. 4), Italy, Japan, Korea, La Réunion, Madagascar, Mexico, Namibia, New Zealand, Paraguay, Romania, Russia (Kuril Islands), Scotland (Fingal's

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Fig. 2 Lava flow filling a paleo-river valley at Prades, France, with colonnade and entablature. Total thickness is up to 100 m (Photo by E. Médard)

Fig. 3 Curved basalt columns in the neck of a former maar crater at Somoskő, Hungary. Square scale is 40 cm (Photo by B. Taisne)

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Fig. 4 Meter-large basalt columns at the Golan Heights, Israel (Photo by A. Lukashov 2010)

Cave), Sicily, Turkey, Ukraine, USA (California: Devil's Postpile, Hawaii, Oregon, Washington: Mt. St. Helens, Wyoming: Devil's Tower), and likely in all former or active volcanic zones. In impact craters, columnar jointing was observed in impact melt rocks e.g., in Jänisjärvi, Karelia (Masaitis 1999) and in Discovery Hill, Mistastin impact structure, Canada (Osinski 2006).

Significance

The characteristic length of joints might have been influenced by water that was eventually present during the emplacement of lava.

Planetary Analogs

Hints of columnar jointing on Venus from a polygonal fracture network (Johnson and Sandwell 1992); a set of entire columns with entablature seen on Mars, in the wall of a pristine, 16-km-diameter impact crater (Milazzo et al. 2009; Fig. 5) and other fresh impact craters (Fig. 6).

History of Investigation

Columnar jointing has already been the topic of indigenous oral traditions, e.g., at the Kiowa Indians. Scientific publications on columnar jointing date back to the first description of Giant's Causeway in 1693, rapidly followed by several others at the end of the seventeenth century (Tomkeieff 1940 and references therein). The origin of columnar jointing was an important issue that opposed neptunists and plutonists. Neptunists argued that all rocks, including the columnar-jointed basalt at the castle of Stolpen, Germany, were deposited from water. The volcanic origin of basalt was later demonstrated by Desmarest at the end of the eighteenth century, after a careful observation of columnar-jointed lava flows in the Massif Central, France. Proposed physical

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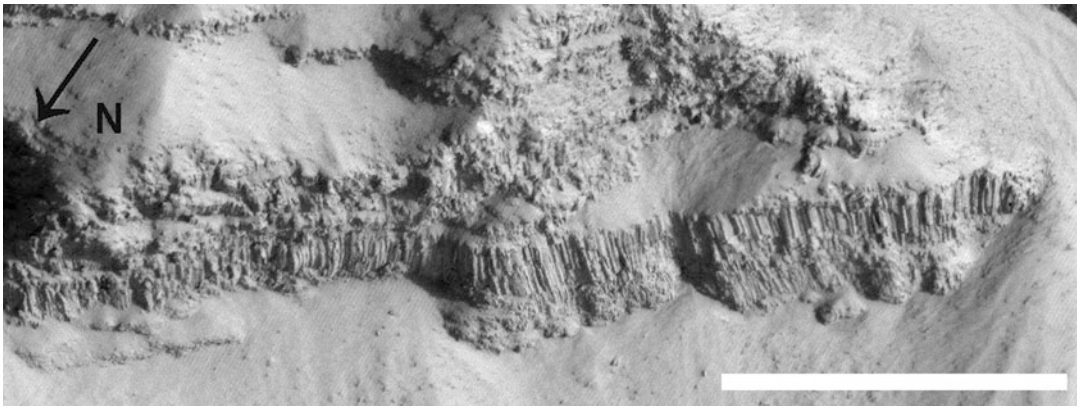

Fig. 5 Sixteen- to nineteen-meter-high columns in the wall of a pristine 16-km-diameter lobate ejecta central peak crater Near Marte Vallis, at 21.5°N, 184.3°E. Scale bar 100 m. HiRISE PSP_005917_2020. (NASA/JPL/University of Arizona)

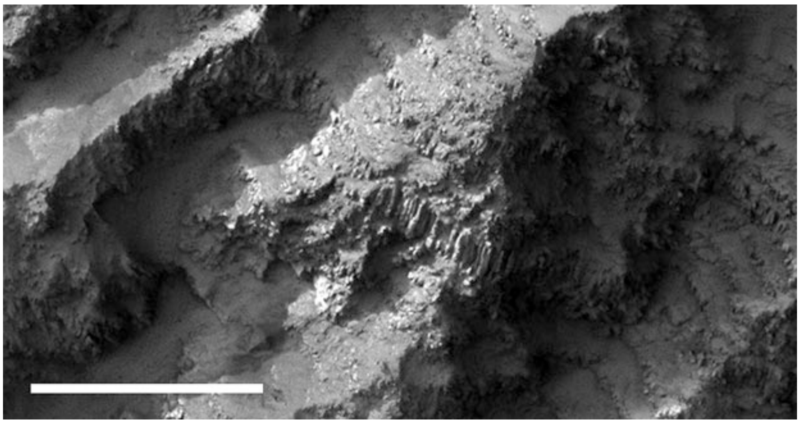

Fig. 6 Columnar joints in the wall of a fresh crater in Northeast Hellas at 33.2°S 86.6°E. Scale bar 50 m. HiRISE PSP_009863_1465. (NASA/JPL/University of Arizona)

mechanisms for columnar joint formation include crystallization around nucleation centers (concretion), convection cells, contractional cooling (Tomkeieff 1940 and references therein, Spry 1962 and references therein), and large-scale constitutional supercooling (Guy and Le Coze 1990). The currently most widely accepted view for columnar jointing, viz. contractional cooling, was first proposed by Raspe in 1776. It had a hard time to become accepted as Raspe has also written down the famous adventures of the very real Baron de Münchhausen.

See Also

► Joint

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