Rock breakdown in extreme environments: from Namibia to Mars

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Opening with the comment that rock breakdown involves an important set of processes, the speaker explained the title of the talk. Extreme environments include areas like Namibia, an extreme desert, volcanic areas, glaciated valleys and Mars. All are hostile to life, have lots of bare rock and thin soils. Conditions are extreme in terms of temperature ranges, both diurnal and seasonal, rock temperatures and a shortage or over-abundance of moisture. The talk concentrated on the arid extremes. Rock breakdown involves all the processes causing surface rocks to disintegrate, including weathering (an in situ process) and Aeolian erosion. In reality they are very integrated so the term rock breakdown is used.

The study of rock breakdown

The 3 reasons we need to study rock breakdown are that:

- it explains the landscape, being a very fundamental process to provide material for transport, erosion and deposition;
- it assists in understanding the geological record; and
- it affects building materials etc.

Rock breakdown is studied using methods which at one extreme have greater realism and at the other have greater control by the researcher. They include field observations, sampling for laboratory analysis, field monitoring of agents and processes, field experiments, laboratory experiments and computer modelling. Much of the study involves inferring the process from the form through abductive reasoning.

Field observations are the most realistic measure of rock breakdown but the processes take a long time. In consequence, weathering data and process data are collected from field experiments involving leaving c. 10 x 3 x 3cm blocks of various rock types in the area for a year or two and observing what happens to them.

Exposure testing of blocks of different rock types

The processes

Rock breakdown in extreme environments involves mainly physical processes (thermal, frost, salt), chemical (carbonation, hydrolysis, dissolution) and Aeolian abrasion. Thermal weathering leading to exfoliation arises because of the extreme temperature ranges, which can be as much as 40-50ºC in 24 hours, with thermal shock when the rate of change exceeds 2ºC per minute. Frost weathering is very important but it needs water to enter the rock and freeze, expanding as it does so and stressing the rock. Salt weathering operates in a similar fashion and requires a great range in temperature and moisture containing salt. Dissolution is still important in deserts. While rainfall is low, there is often no shortage of moisture from fog and condensation. Rocks are abraded by sand grains carried in the wind. Biochemical and biophysical breakdown also occurs as well as biological protection. Lichens create grooves in the rock to cling on to it and also cause physical breakdown of the rock through hydration and dehydration. Lichens, while still alive, can also shelter the rock from wind abrasion. Generally, where there is life, it can only grow because it involves the rock. The processes are very diverse over small areas, as illustrated by the absence of lichens on the east side of rocks because the main wind is from the east. The processes are much more diverse than expected and we do not know the relative importance of the processes.

Thermal weathering

Frost weathering

Salt weathering

Dissolution

Wind abrasion *Bio-protection by lichens*

The speed of rock breakdown

There are differing views on the rate of rock breakdown in extreme environments. Peltier (1950) plotted temperature against precipitation for cold arid areas and hot arid areas and concluded that weathering was very slight due to the lack of moisture. The more modern view is that there are weathering hotspots where rock breakdown can be very rapid. Hotspots in the Namib Desert are the coastal salt pans, and field experiments carried out with blocks of different rock types for 2+ years showed that the rate of breakdown depends on the rock type. Granite shows no breakdown, marble has the corners rounded and is starting to turn to rock sugar and Bath limetone almost totally breaks down to sand grains. This rapid breakdown is illustrated by dust hotspots giving rise to dust plumes off the Namib coast, as in August 2002.

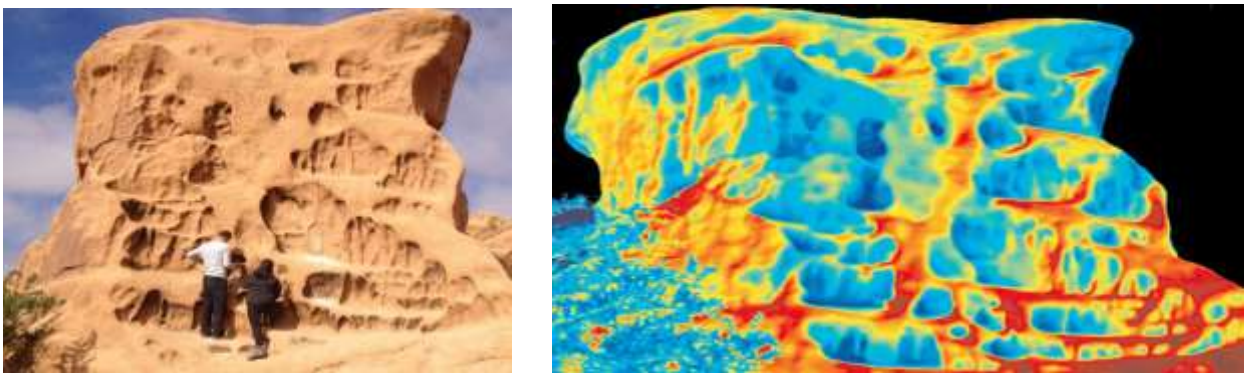
How does rock breakdown contribute to the development of landforms?

A landform is any form of surface sculpturing, which can be from micro- to mega-scale. Tadrart Acacus, in Libya, a World Heritage site because of its rock art, illustrates the response of various sandstones to processes, while Spitzkoppe, in Namibia has weathering features that can be viewed on Google Earth.

Tafoni are cavernous weathering features, as seen in granite in Corsica and the Namibian desert. Key questions are how do they form? And what are the processes and rate of formation? The approach to answering these questions involves monitoring weathering, investigating the processes of weathering, dating of the tafoni, quantifying their sizes and distribution and modelling.

Tafoni in granite, Corsica ***Tafoni in granite, Namib Desert***

Monitoring the agents of weathering has been done with non-contact spot measurements of temperature and the use of a hand-held moisture meter, measuring every 4 hours. The same thing can be done automatically using i-buttons. Rock hardness is measured as a proxy for the degree of weathering using a Schmidt hammer and internal rock moisture is measured with 2-dimensional resistivity surveys. Using an infra-red camea on tafoni in Morocco, with a photograph every hour for 24 hours in February 2014 showed a diurnal temperature range from 10 to 30 – 40ºC. A good suite of techniques are available so we are starting to understand how quickly the processes act.



Morocco tafoni infra-red camera results showing temperature differences over a duirnal cycle, February 2014-06-30

Mars

Rock breakdown seen on Mars is not alien to that seen in extreme environments on earth but there are very important differences in climatic/atmospheric conditions. It is important to understand rock breakdown on Mars as a key to interpreting the landscape, as a part of the search for water and as part of the assessment of habitability. This is done by observations from Mars-orbiting craft and rover vehicles, by experiments under near-Mars conditions and by earth-analogue studies.

The Martian surface

The Rock Breakdown Laboratory at Oxford University is working with Dr Mary Bourke from the Planetary Science Institute in Arizona on a NASA-funded project on rock breakdown on Mars. This has involved the use of a physical simulation chamber with control of temperature and pressure and a 98% CO_2 environment, normally used to test equipment for landing craft and and earth simulation chamber. Pre-stressed blocks and blocks with salt have been tested for runs of 36 cycles. Simple temperature cycles can cause rock breakdown similar to that on earth if not higher.

Mars-analogue field experiments have been carried out at sandy and windy sites and at a salt-pan site using gypsum prototypes of basalt boulders to speed up the rates. Basalt blocks show Aeolian pitting on the chemically softened surface and incipient salt weathering exploiting microcracks.

Summary

Rock breakdown in extreme environments is

- faster and more complex than previously thought;
- a key factor in producing landforms such as tafoni and inselbergs;

- a vital source of debris, from dust to boulders, which contributes to the geomorphic system; and
- becoming better studied thanks to new techniques.