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1.3.2. Measuring rock hardness in the field

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ABSTRACT: Rock surface hardness is often used as an indicator of the degree to which a rock surface has weathered. As the surface deteriorates the loss of cohesion results in crumbling of the surface, increased pore water circulation and dislodging of sections such as flakes. It is widely assumed that this results in a lowering of rock surface hardness. However, hardness can also increase if weathering leads to cementation of the surface due to the deposition of solutes such as quartz, clays and small quantities of carbonates. A number of different instruments are available to map out hardness distributions and changes over time. This chapter outlines the use of a simple field test (Moh's hardness test), three rebound devices (Picolo, Equotip and Schmidt Hammer) and resistance drilling as possible methods for assessing rock surface hardness.

KEYWORDS: weathering, field methodology, surface hardness

Introduction

Landscape development and rock weathering go hand in hand; whether it is through weakening and removal of material creating new landforms, the rate of sediment production, accumulation and removal dictating the flow of rivers, or the supply of sediment for sand dunes. All of these are heavily influenced by the ability of material to withstand weathering processes. Understanding the rate of weathering, and associated source and rate of production of sediment, is therefore paramount when investigating wider landscape development.

Geomorphological investigations often are complicated by issues of scale, process rates, and a disconnect between laboratory and field observations. Rock weathering studies are no exception to this, as field measurements and laboratory measurements often don't corroborate (see for example Matsuoka, 2001; White and Brantley, 2003) and questions arise when extrapolating the small scale observations of granular disintegration to larger scale rock face development, or even landscape development (Viles, 2001). Moreover, non-linearity, threshold development and changing environmental conditions add further to the complexities experienced by researchers. Figure 1 illustrates the multitude of scales on which weathering operates and the presence of positive and negative feedback systems.

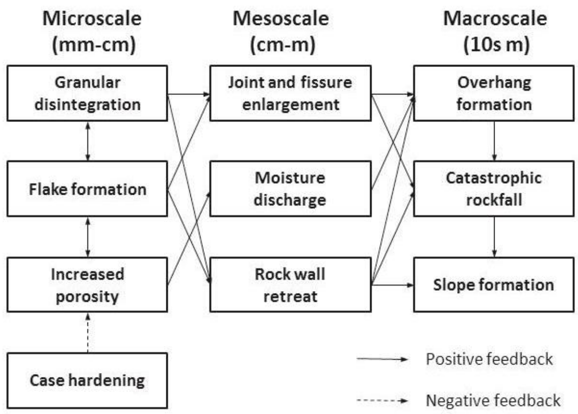

Figure 1: A simple representation of some of the complex feedback mechanisms within weathering. (Adapted from: Mol and Viles, 2012a, p.224).

However, these challenges do not mean that we should not attempt to understand rock weathering rates, quite the contrary as the vast body of published research indicates that the methodology is rapidly becoming more sophisticated, and diversifying, enabling researchers to approach weathering studies from a multitude of angles such as the impacts of temperature (Smith *et al.*, 2011) and precipitation ingress (McCabe *et al.*, 2013). In addition, methodological precautions such as taking repeat measurements of surface hardness (Coombes *et al.*, 2013), and carrying out chemical analysis to monitor changes in the rock (Buj *et al.*, 2011) aid in reducing the uncertainties caused by the complexities outlined previously. We can therefore use rock surface hardness to pinpoint areas of accelerated weathering. As surface weathering progresses the bonds between minerals weaken, allowing for more moisture absorption and general loss of surface hardness. Hardness can therefore be used as a tool for mapping weathering progression as well as dating exposure of rock surfaces (see Goudie, 2006 for an overview). This chapter discusses some of the methods available to measure rock hardness in situ and their advantages and drawbacks.

Rock weathering and surface hardness measurements; theory

Rock weathering is influenced by many different factors such as: (1) the amount of thermal stress a rock face is subjected to; (2) the presence or absence of water; (3) the development of microbial activity on or under the surface; and, (4) the cycling of chemicals and salts which cause disintegration of the mineral matrix. All of these factors have a net result in common; weakening of the rock surface and subsequent susceptibility to erosion. As surface deterioration sets in, cementation between grains gradually weakens, individual grains disintegrate, and surface volume loss becomes evident. This deterioration can take a number of forms, such as flaking, blistering and accumulation of biological activity (such as algal colonies) and moisture beneath the surface (Mol, 2014), all of which reduce the hardness of the rock surface as subsurface weathering influences porosity and changes the compressive strength and elasticity of a rock (Moses *et al.*, 2014). We can therefore use rock hardness to estimate the progression of weathering processes and specific areas of weakness.

However, there are three complicating factors that should be monitored. Firstly, increasing weakness can lead to an increase in surface roughness, which in turn affects rebound values (McCarroll, 1991), thereby creating a slightly distorted image of rock weathering variations. Secondly, weathering processes could strengthen a rock surface through case hardening. This is created through cementation of the surface by the precipitation of elements such as iron and magnesium within the subsurface. This then leads to a thin, discoloured hardened skin (see for example Viles and Goudie, 2004). Thirdly, variability within the strength of bedding planes in sedimentary rock can lead to differential weathering that can only partially be contributed to outcrop exposure.

Figure 2: Active weathering along the coastal road, Longyearbyen (Svalbard). Clearly visible are the harder sandstones which have not weathered at the same rate as the weaker shale. Also visible is the post-deposition folding of the facies.

When assessing weathering rates you should therefore take into account both external factors such as temperature fluctuations and precipitation levels as well as predisposition to weathering of the individual bedrock bedding planes in a heterogeneous outcrop. Especially in areas where sea level has fluctuated significantly over millions of years the stratigraphy across a rock face can change dramatically vertically. This then leads to complex weathering features, such as found along the coastal road in Longyearbyen, Svalbard (see Figure 2). In this section not only do the depositional phases result in very different weathering rates, the subsequent tectonic activity has created a fold that has altered the physical structure of the shale, leading to crumbling of the section rather than flaking which dominates the rest of the section. Rock surface hardness should therefore be taken as a relative measurement of weathering and placed within the geological and environmental context of the site.

A simple field method: Moh's test

Moh's test is a very simple procedure in the field that can provide an initial assessment of rock hardness. All that is needed to hand is a rock sample, whether a loose hand sample or an exposed rock surface, and one of a small array of potential objects; a coin, a piece of glass or even your nail. Moh's test uses a scale of known hardness (see Table 1), which you can then compare to the impact of an object when scratched over the surface of the rock (see Table 2). Glass also is commonly used, where a piece of rock that scratches the surface of the glass is considered hard (H=5.5 or above), whereas a piece of rock that does not impact the glass surface is considered soft (H=5.5 or below). This field test can be used to give a first indication of the hardness of the test site and, if multiple samples are used, variability of hardness within a limited area. Though this test is often used to distinguish between minerals, it can also be used to test various sections of a homogenous material to determine which sections are most badly affected by weathering processes. It is however, only semi-quantitative and does not provide an exact figure for hardness.

Table 1: Mineral hardness according to Moh's test

1. Talc (H=1)	2. Gypsum (H=2)	3. Calcite (H=3)	4. Fluorite (H=4)	5. Apatite (H=5)
6. Orthoclase (H=6)	7. Quartz (H=7)	8. Topaz (H=8)	9. Corundum (H=9)	10. Diamond (H=10)

Table 2: Commonly available materials and their hardness index

1. Finger nail (H= 2.5)	2. A copper coin (H=3.0)	3. Steel blade (H=5.5)

Rebound devices

One group of equipment available are 'rebound devices', a group of devices that use a spring-loaded mechanism to measure rebound of a metal object against a rock face.

The principle is very simple and can be compared to throwing a ball against a wall (though ball velocity in flight towards the wall would be constant); if a wall is very hard the ball will bounce back fast and quite far. Now imagine that same wall covered in a layer of pillows; the ball will bounce back much more slowly and not as far. Rebound devices work on exactly the same principle – the 'cushioning' effect of a reduction in surface hardness dampens the return of the impact device, thereby slowing the arrival time and thus lowering the value measured (Sumner and Nel, 2002). There are a number of different devices available. In particular, the Schmidt Hammer and the Equotip are commonly used as they are quick, simple, relatively cheap and portable (Goudie, 2013), and non-destructive. They should all be calibrated before the fieldwork takes place using a calibration block, which can be obtained from the supplier.

Schmidt Hammer

The Schmidt Hammer is a rebound device first used in the 1950s but gained momentum in the 1960s (see for example Rusakov and Mavrodi, 1968), and since then has been extensively used in geomorphological research for example in dating rock surface exposure time (Kellerer-Priklbauer *et al.*, 2007) and estimating the effect of environmental controls such as aspect on rock weathering (Hansen *et al.*, 2013). The device contains a spring-loaded piston which is pressed against the rock surface. The dial on the side of the device indicates the rebound value (R-value) on a scale from 0 to

100. The higher the rebound value, the harder the rock surface. To use the device in the field you simply need to press the metal rod against the surface until it is fully compressed within the main chamber (see Figure 3). By pressing the button (on the analogue version there is only 1!) you release the spring mechanism and the rebound is measured on the dial on the side. Care needs to be taken that the device is placed perpendicular to the rock surface, as placing it at an angle will result in the metal impact rod glancing off the surface during rebound instead of measuring the rock surface hardness.

Figure 3: Schmidt Hammer in action.

This device is particularly good for harder rock surfaces such as granite. When using a Schmidt Hammer on softer sedimentary rock care needs to be taken when selecting the model: the N-type works with high impact energy and could actually be damaging to the point of leaving a mark where it has actively indented the surface. An example of this can be seen in Figure 4 where the white marks on the rock face indicate N-type Schmidt Hammer readings. If there is a risk of this type of damage then the user might want to consider using an L-type Schmidt Hammer instead, which has a low impact energy and is suitable for brittle objects or structures less than 100mm thick. This is important also if the Schmidt Hammer is used in the laboratory to monitor small test blocks. To further reduce the impact a research can attach a mushroom plunger which decreases point-specific impact and instead spreads the impact over a larger area. The outlined advantages and limitations of the different models therefore need to be taken into account when selecting the rock hardness method for the measurement of a specific site or sample.

Figure 4: Impact damage from Schmidt Hammer (photo: Lisa Mol).

Equotip

The Equotip (Figure 5) is essentially the 'little brother' of the Schmidt Hammer. Rather than a loaded piston the Equotip uses a small rebound 'bullet' made of carbon tungsten which is fired by first compressing and then releasing the coil within the impact device (seen to the right in Figure 5). When this bullet rebounds into the device it recompresses this coil, thereby generating a measurements of both impact and rebound velocity. The software then uses the following formula to calculate Leeb value:

$$L = Vr/Vi \times 1000$$

where L is Leeb value, Vr is rebound velocity and Vi is impact velocity (Aoki and Matsukura, 2008). Higher values indicate higher rock surface hardness.

It can be programmed for the appropriate rebound test (i.e. concrete or steel) and impact angle, or used on a fully automatic setting. It can, however, store hundreds of measurements which eliminates the need to painstakingly copy over every measurement by hand in the field, which is not an option on the older Schmidt Hammer models. Care has to be taken when comparing Equotip to Schmidt Hammer as the scales used for measurement are different (R-value vs Leeb-value).

One of the drawbacks of the Equotip is that the piston can collect dust when used repeatedly on heavily weathered surfaces which affects the readings. In addition, because of the lower impact the Equotip is more sensitive to small scale irregularities such as edges and cracks, which needs to be taken into account when surveying either small test blocks or larger surfaces that are heavily cracked.

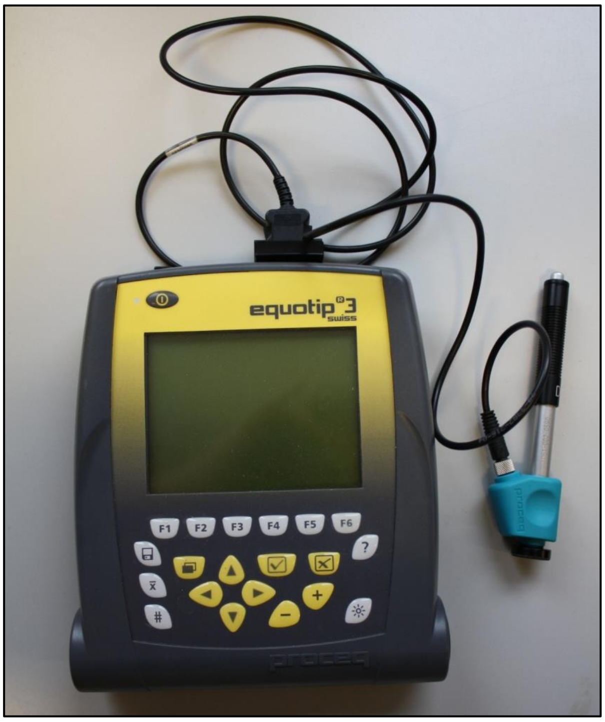

Figure 5: Equotip with impact device (right). Photo: Lisa Mol.

However, this technique has been successfully applied in a number of studies (see for example Aoki and Matsukura, 2008; Hansen et al, 2013; Matsukura *et al.*, 2007). Figure 6 illustrates this type of research. Here you can see a plot of Equotip data gathered on concave sandstone surfaces in the Golden Gate Highlands National Park, where variability and development of rock surface hardness was combined with internal moisture distributions to quantify the role of case hardening in tafoni development over time.

Piccolo

The Piccolo is the smallest of the impact devices and, as it is part of the Equotip family, also measures hardness on the Leeb scale allowing for direct comparison of measurements. Due to its size it is even more sensitive to changes in the surface and could equally create noise in the dataset. However, because of its sensitivity it is very suited to small scale investigations into hardness loss such as small building blocks or small samples in environmental simulations. It is also ‘pocket sized’ which makes it very useful for fieldwork where mobility is a primary concern due to long hikes or difficult terrain.

Drawbacks and limitations of rebound devices

One of the biggest issues with rebound devices is the ‘edge effect’, where the measurement registered is influenced by the proximity of a rock edge or major crack. This effect is extensively discussed in Viles *et al.* (2011) where it was shown that the smaller the device the less influence the edge effect has. However, the smaller devices (such as the Piccolo) are more sensitive to surface irregularities, leading to potentially a large variability in the data set. When selecting a particular rebound device one has to keep in mind the size of the rock structure (i.e. outcrop vs small laboratory sample) and the surface structure as changes in surface smoothness can lead to variability in the measurements (McCaroll, 1991).

In addition, the user can also influence the readings; small changes such as the pressure exerted on the piston during the rebound measurements and angle of impact can cause fluctuations in the readings, especially if multiple researchers work on the same data set. These small inconsistencies can be traced through statistical analysis of the data set and repeat measurements by multiple users on the same site (see Viles *et al.*, 2011 Figure 4 for an illustration of these small inconsistencies).

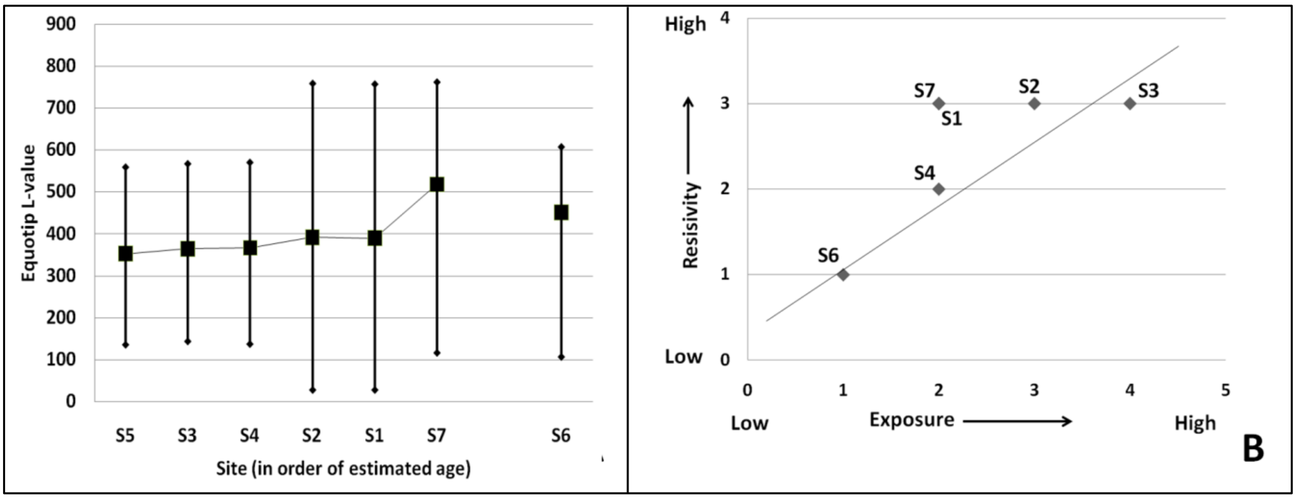

Figure 6: Rock surface hardness and resistivity distributions in relation to tafoni development over time. From: Mol, L and Viles, H. (2012b).

Drilling resistance

Resistance drilling is a method frequently used to asses for example the condition of a building stone or wall. A drill is placed against a stone surface and controlled pressure is applied (Figure 7). The time it takes for the drill to travel a pre-determined distance into the stone surface can be plotted against force used to create a resistance plot, outlining variations in rock hardness through the subsurface. However, even though resistance drilling is classified as 'non-destructive', it leaves a rather noticeable hole in the surface of the stone. This makes it unsuitable for sensitive sites such as heritage and listed buildings if the test specimen is to be returned to the original structure. All tests have to be carried out in the laboratory as the drill is computer controlled, as shown in Figure 6. To minimise the risk of wear and tear of drill heads influencing measurements only diamond-tip drill can be used.

Microdrilling equipment is also available for in situ measurements, which measure up to 50mm depth (see for example Török *et al.*, 2007 and Cnudde *et al.*, 2009 for more information) and can be used to map the presence of weathering crusts. This technique works on the same principle as the larger scale laboratory based equipment, where are small drill head is placed against the rock surface and progression through the stone vs pressure exerted is measured via specialised software connected to the drill.

Figure 7: Resistance drilling in action. Photo: Laboratorio de Petrofísica del Instituto de Geociencias IGEO (CSIC-UCM).

Rock surface hardness and weathering rates; a word of caution

While it is possible to make a straightforward correlation between weathering and surface hardness, as many studies (such as the ones referenced in this article) have successfully shown, a word of caution is needed. There are a number of factors that influence rock surface hardness readings that need to be taken into consideration. For example, water content, flake formation and hardening and the presence of microbial colonies can all dampen the impact in which case the readings are as much a representation of the environmental conditions (such as a recent rainfall) as the actual deterioration of the surface. Researchers should therefore always take note of any irregularities observed on the rock surface that could influence hardness readings and combine rock surface hardness measurements with, for example, saturation measurements.

Concluding remarks

This chapter gives a brief overview of rock surface hardness methods and theory. The tools highlighted in this chapter are very suitable for monitoring and mapping rock surface weathering, though the drawbacks have been outlined. It has to be stressed that the selection of the method is of utmost importance in light of acceptable noise in the data set, size of the sample area and fragility of the surface. If applied properly, these methods can give a good insight into weathering processes and their impact on surface deterioration.

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