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ROCK MASS STRENGTH AND THE FORM OF SOME INSELBERGS IN THE CENTRAL NAMIB DESERT

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ABSTRACT

A rock mass strength classification, involving eight parameters, has been applied to selected inselbergs in the Namib Desert. The inselbergs are formed of schists, gneiss, granite and marble. Their slope inclinations are in a strength equilibrium with their rocks. The study suggests that the strength classification is consistent and has a general validity, and that rock slopes, undergoing uniform weathering, retreat to form slopes which are adjusted to their rock mass strength: this is a more general statement than the common hypothesis of parallel retreat. The favoured hypothesis of slope evolution in the Namib is one of retreat rather than downwearing.

KEY WORDS Rock mass strength Strength equilibrium Inselberg slopes Slope retreat Namib

INTRODUCTION

Study of the inselbergs of the central Namib Desert has been undertaken for two reasons: (1) to provide a further test of the method of assessing rock mass strength already described by Selby (1980); (2) to evaluate established theories of the evolution of rock slopes in a desert environment.

The central Namib provides an excellent field study area because it is reasonably accessible by air and road transport; it has an extremely arid climate which has not undergone any significant change during the last two glacials and interglacials at least (Selby, Hendy and Seely, 1979); and it has many rock slopes on numerous inselbergs, isolated mountain ranges, and parts of the escarpment, and the spurs extending from it, which forms the inland edge of the desert.

The Namib Desert extends from 15°S in Angola, southwards for nearly 2000 km to the mouth of the Olifants River, 32°S, in Cape Province, South Africa. The central Namib lies north of the Namib erg and the canyon of the Kuiseb River (Figure 1). Descriptive accounts of the geomorphology of the area are provided by Besler (1972), Beaudet and Michel (1978), and by Hövermann (1978). The geology of the area is described by Martin (1965) and has been mapped at a scale of 1 to 1 million (Geological Survey of the Republic of South Africa and South West Africa/Namibia, 1980).

Inselbergs of the central Namib Desert all possess only one main slope element: that is a rock slope, nearly bare of debris, standing above a pediment which has a slope of 2°–6°. Talus or debris slopes are rare and, where they do exist, are of limited extent; they seldom consist of more than a veneer of debris over a bedrock slope. Slope angles on the inselbergs vary from 90° to as little as 14°: changes in inclination are usually associated with a change in lithology or some structural control. The most common lithologies are granite, schist, gneiss and marble. All of the rocks are of Late Precambrian age, except for some Cretaceous granite forming large intrusive bodies in the northern part of the central Namib.

The inselbergs discussed in this paper are composed of metamorphic and igneous rocks which are either well jointed or foliated; massive intrusive granites are excluded because their slope forms are structurally controlled and may be unrelated to the mass strength of the rock. With this exception the

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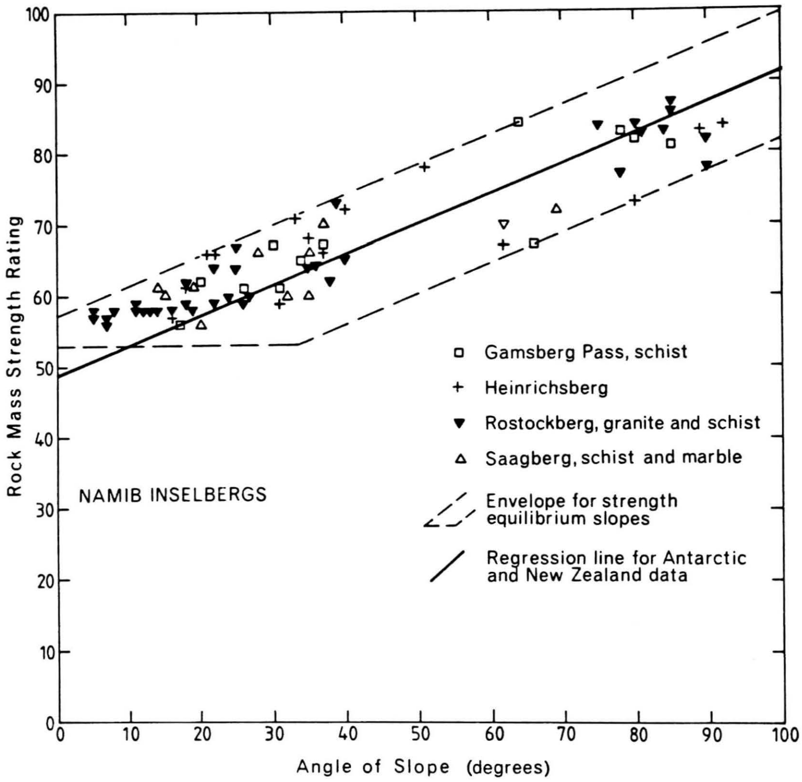


Figure 2. The relationship between rock mass strength and slope angle for all rock units studied in Namib

THE INSELBERGS

Three inselbergs—Saagberg, Rostockberg and Heinrichsberg—and a profile of a spur from the main escarpment above the Gamsberg Pass have ben chosen as representatives of the main lithologies and slope forms of the central Namib. Measured profiles indicating the main features of the partings, the characteristic slope inclinations and (in bold type) the rock mass strength for each unit are shown in Figure 3; an example of the data obtained is given in Table I. The profile for Rostockberg is broken because many slope units are repetitive in their features and the total height of the hill, 280 m, cannot be depicted on a small drawing.

Saagberg is a ridge aligned approximately north to south with its scarp facing east towards the main escarpment. Its rocks are schists and marbles. They dip at about 30° into the scarp which is sufficiently free of talus debris for measurements of mass strength to be made on all rock units except one bed of finely laminated marble. This laminated marble was largely obscured by debris and its rock so closely fractured that Schmidt hammer readings could not be made. The dip slope of Saagberg is covered by talus resting at about 17°.

This schists have very weak intact strengths with an 'N' type Schmidt hammer reading of between 15 and 26; joints and planes of schistosity are 100 to 400 nm apart, few of them are continuous and they are 1–3 mm wide; weathering is slight and, as with all sites in the Namib, there is no groundwater flow. Mass strength ratings are consequently relatively low at 56, 60 and 66 units with the differences being primarily caused by variations in spacing of partings.

The marbles have higher intact strength than the schist, with Schmidt hammer readings of 30–52, but the finely laminated rock units have such closely spaced partings, 80–100 mm, that their mass strengths, with ratings of 61–66, are similar to those of the schist. Only the more massive marble has relatively high mass strength ratings of 70 and 72.

because it is within the metamorphic aureole of the Donkerhoek granite (H. Martin personal communication). As a result of contact metamorphism the Heinrichsberg schist has a slightly higher intact strength (20–30) than other Namib schists, with the highest readings being obtained from rock units containing many quartz veins. Some of the schist units have relatively wide joint spacing (e.g. units F, L) with consequent high mass strengths of 71–72 and steep slope inclinations, of 33° and 40°, for this type of rock. The steepest slopes on schist occur where the rock is rich in quartz and has few joints: unit N, for example, has an intact strength of 40, joint spacing of 1500 mm, closed joints and a mass strength of 84. The slopes of Heinrichsberg are crossed by several pegmatite and aplite dykes. These rocks have moderate intact strengths and few or very widely spaced joints with resulting high mass strengths, and hence the ability to support steep slope angles of 51° and 80° (units E, J).

Gamsberg Pass follows the headwaters of the Kuiseb River and lies between spurs extending towards the Namib from the escarpment. A slope on one of these spurs was selected as being representative. The spur is composed of schists. The rock appears to be altered flysch and has variable composition: quartz-rich rock units are interbedded with weaker biotite-rich beds which are highly sheared and have closely-spaced foliations. Boudins and pockets of quartz reinforce some of the foliated schist. In the stronger units spacing between foliations is 100 to 150 mm, but in the weaker units only 50–90 mm. The strongest rock units are welded by secondary quartz and/or calcium carbonate which fills the joints, thus producing an effective joint spacing of 1 to 2 m.

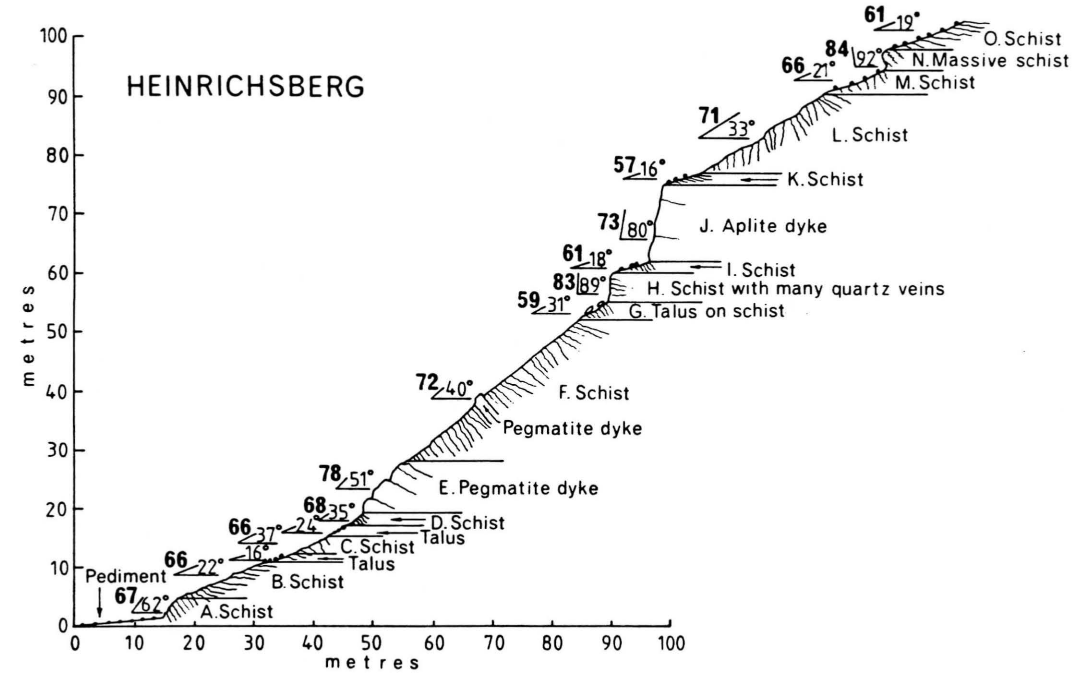
As a result of the interbedding of weak and strong units the slopes have stepped profiles with the quartz vein-reinforced rock having mass strength ratings of 81–83 and slope angles of 78°–85°, while the weaker rock units have ratings of 61–67 and slopes of 26° to 37°. The weakest schist has a mass strength of 56 and slope of 17°. Because the Gamsberg Pass is in the slightly more humid zone, with an average of 100–200 mm of rain per year, inland of the most arid part of the Namib, it can support some vegetation. The talus material which lies upon the lower angle hillslope units is thus mostly fixed in place by grasses and thorn bushes, and some chemical weathering is obviously contributing to soil formation in place. In spite of this the soil profile is so thin, and the rock outcrops so numerous that the slope may still be regarded as a rock slope rather than a soil-covered slope. The presence of soil does, however, make measurement of rock features impossible and consequently the measurements for soil-covered rock units shown on the profile (Figure 3) were derived from rock exposed in a gully floor, while the profile is of a spur between two gullies. Mass strength measurements for outcrops were obtained from the spur profile.

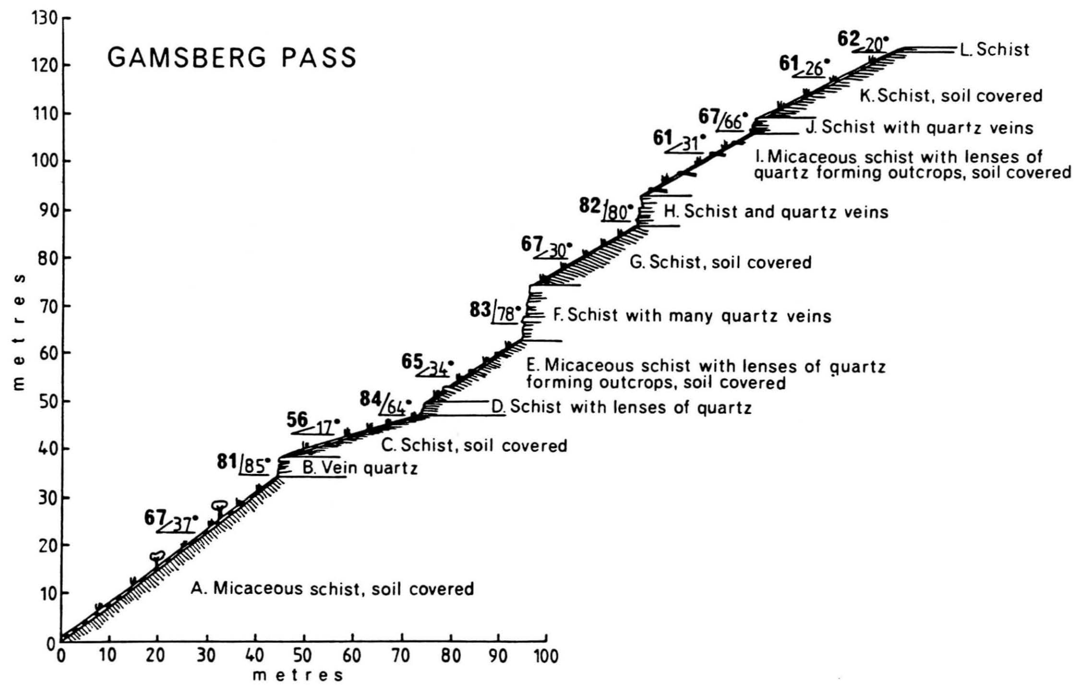
SLOPE PROCESSES

The nature and rate of operation of processes on rock slopes is difficult to determine. Weathering causes exfoliation of small (10–200 mm) platey rock fragments in fine-grained rocks and granular disintegration on coarse-grained rocks: the opening of joints and separation of joint blocks may lead to rock falls from steep outcrops or slow creep of blocks on gentler slopes. Debris comes to rest on slopes of less than about 35° and remains there until weathering processes break it down to pea-size gravel, which can be moved by rare (once in 10 years) sheet wash, or to sand which can be moved by wind. Talus deposits on rock slopes are usually one or two particles thick; they occur most commonly below a steep slope unit. The weaker rocks are thus protected from further weathering, and recession of a weak rock unit to undercut a stronger rock mass is rare. With the single exception of some rills etched into massive granite domes no channels were seen cut into the rocks of inselbergs.

Surrounding each inselberg is a pediment, cut across bedrock, bearing a pea-sized gravel veneer that is usually 0·5 to 1·0 m thick. This veneer is sometimes calcreted and may be rilled with channels which cut down to the bedrock. Talus does not accumulate at the upslope margin of the pediment. The pediment is commonly 20–200 m long and grades into the main desert plain which has a slope of 0·5° to 3°.

Only close to the inland escarpment where rainfall occurs in most years and mean annual precipitation is 100 to 200 mm can soil formation and vegetation cover have an effect on slope processes. In such areas gully and rill development occurs on slopes, and the abundance of terracettes suggests that soil creep, perhaps greatly accelerated by animal treading, is a common process.





angles and mass strength rating (in bold type) for rock units partings is also very disturbed; and the data are inadequate for statistical tests. Obtaining further data will be very difficult as so much of the pediment gravel is calcreted.

In the absence of evidence to the contrary scarp retreat appears to be a preferred hypothesis for the origin of the inselbergs and escarpment, but evidence is still inadequate and equivocal.

CONCLUSIONS

The rock mass strength classification gives consistent results in a variety of climatic zones, and on a range of lithologies. Its application to inselbergs in a desert environment demonstrates that rock slope inclinations are adjusted to the resistance of their rock masses. The widely-held hypothesis that rock slopes, on which weathering is uniform across the exposed rock face, retreat parallel to themselves is true only if the resistance of the rock does not change with depth into the rock mass. Even a small change in joint spacing can produce a change in rock mass strength and the hypothesis would, therefore, be more appropriately stated in the form–rock faces undergoing uniform weathering retreat to form slopes which are in conformity with the mass strength of their rocks.

The widespread occurrence of strength equilibrium slopes in the Namib Desert, on a variety of lithologies, suggests that slope change involves slope retreat rather than a general downwearing or mantle-controlled planation process.

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REFERENCES

Beaudet, G., and Michel, P. 1978. *Recherches Géomorphologiques en Namibie Centrale*, Association Geographique D'Alsace, Strasbourg.

Besler, H. 1972. 'Klimaverhältnisse und Klimageomorphologische Zonierung der zentralen Namib (Südwestafrika)', *Stuttgarter Geographische Studien*, **83**, 1–209.

Bryan, K. 1940. 'The retreat of slopes', *Annals of the Association of American Geographers*, **30**, 254–268.

Fair, T. J. 1947. 'Slope form and development in the interior of Natal', *Transactions of the Geological Society of South Africa*, **50**, 105–120.

Fair, T. J. 1948. 'Slope form and development in the coastal hinterland of Natal', *Transactions of the Geological Society of South Africa*, **51**, 37–53.

Geological Survey of the Republic of South Africa and South West Africa/Namibia 1980. '*South West Africa/Namibia Geological Map, 1:1000 000*', Geological Survey Office, Pretoria.

Hövermann, J. 1978. 'Formen and Formung in der Pränamib (Flächen-Namib)', *Zeitschrift für Geomorphologie Supplementband*, **30**, 55–73.

King, L. C. 1951. *South African Scenery*, (2nd edn), Oliver and Boyd, Edinburgh.

King, L. C. 1953. 'Canons of landscape evolution', *Bulletin of the Geological Society of America*, **64**, 721–751.

King, L. C. 1962. *Morphology of the Earth*, Oliver and Boyd, Edinburgh.

Mabbutt, J. A. 1966. 'Mantle-controlled planation of pediments', *American Journal of Science*, **264**, 78–91.

Martin, H. 1965. *The Precambrian Geology of South West Africa and Namaqualand*, The Precambrian Research Unit, University of Cape Town.

Moon, B. P., and Selby, M. J. in prep. 'Rock mass strength and scarp forms in southern Africa'.

Ollier, C. D. 1978. 'Inselbergs of the Namib desert processes and history', *Zeitschrift für Geomorphologie Supplementband*, **31**, 161–176.

Penck, W. 1924. *Die morphologische Analyse Ein Kapitel der physikalischen Geologie*, Engelhorns, Stuttgart.

Selby, M. J. 1977. 'Bornhardts of the Namib desert', *Zeitschrift für Geomorphologie*, **21**, 1–13.

Selby, M. J. 1980. 'A rock mass strength classification for geomorphic purposes: with tests from Antarctica and New Zealand', *Zeitschrift für Geomorphologie*, **24**, 31–51.

Selby, M. J. in press. 'Form and origin of some bornhardts of the Namib Desert', *Zeitschrift für Geomorphologie.*

Selby, M. J., Hendy, C. H., and Seely, M. K. 1979. 'A Late Quaternary lake in the central Namib desert, southern Africa, and some implications', *Palaeogeography, Palaeoclimatology, Palaeoecology*, **26**, 37–41.

Wood, A. 1942. 'The development of hillside slopes', *Proceedings of the Geologists' Association*, **53**, 128–140.