Z. Geomorph. N. F.	26	1	1–15	Berlin · Stuttgart	März 1982

Form and origin of some bornhardts of the Namib Desert

by

M.J. SELBY, Hamilton

with 7 figures and 5 photos

Zusammenfassung. Hinweise werden mitgeteilt, die einen früheren Bericht über einige Inselberge in der Namib bestätigen, nämlich daß ihre Glockenbergform verursacht wird durch die Domform des aufgedrungenen Granits. Die Hinweise umfassen: konforme Faltung des unverwitterten kristallinen Schiefers um und über dem Dom, Durchdringen von Pegmatit- und Aplitgängen vom Granit in den Schiefer, Einflüsse von Schieferstücken im Dach des Granits. Abschalungen erhalten die Domform, bis sich kreuzweise Klüfte öffnen, während der Granit Hänge entwickelt, deren Neigungen im Gleichgewicht sind mit der Widerstandsfähigkeit des Gesteins. Die Steuerung der Entstehung und Entwicklung von Namib Bornhardts durch die geologische Struktur ist eindeutig und unterstützt die Meinung, daß Theorien, die eine klimatische Steuerung verlangen, mit Vorsicht betrachtet werden müssen, aber es ist klar, daß Domformen auf viele verschiedene Arten entstehen können.

Summary. Evidence is presented which confirms an earlier report that some bornhardts in the Namib desert owe their dome form to that created during emplacement of the granite. The evidence includes: conformable folding of unweathered schist around and over the domes; penetration of pegmatite and aplite dykes through the granite and into the schist; survival of schist xenoliths in the roofs of the domes. Sheeting of granite perpetuates the dome form until cross joints open when the granite slopes develop inclinations which are in equilibrium with the mass strength of the rock. The control of geological structure on the origin and development of Namib bornhardts is unequivocal and supports the contention that theories invoking climatic controls should be treated with caution, although it is clear that domed landforms can be produced in many different ways.

Résumé. De nouvelles informations confirment des conclusions antérieures selon lesquelles l'aspect en cloche des inselbergs de Namibie résulte de la forme en dôme des granites. Ces données comprennent: plissement conforme des schistes cristallisés, non-altérés, autour et au-dessus du dôme, injection de filons pegmatitiques et aplitiques de granite dans le schiste, influences de fragments de schiste dans le toit du granite. L'écaillement maintient la forme en dôme jusqu'à ce que les fissures s'ouvrent en croix pendant que le granite développe des versants dont la pente est en équilibre avec la résistance de la roche. La régulation de la naissance et de l'évolution des "Namib Bornhardts" par la structure géologique est évidente. En conséquence les théories d'une régulation climatique doivent être considérées avec prudence, mais il est clair que des formes en dôme peuvent apparaître de diverses façons.

0372-8854/82/0026-0001 $ 3.75

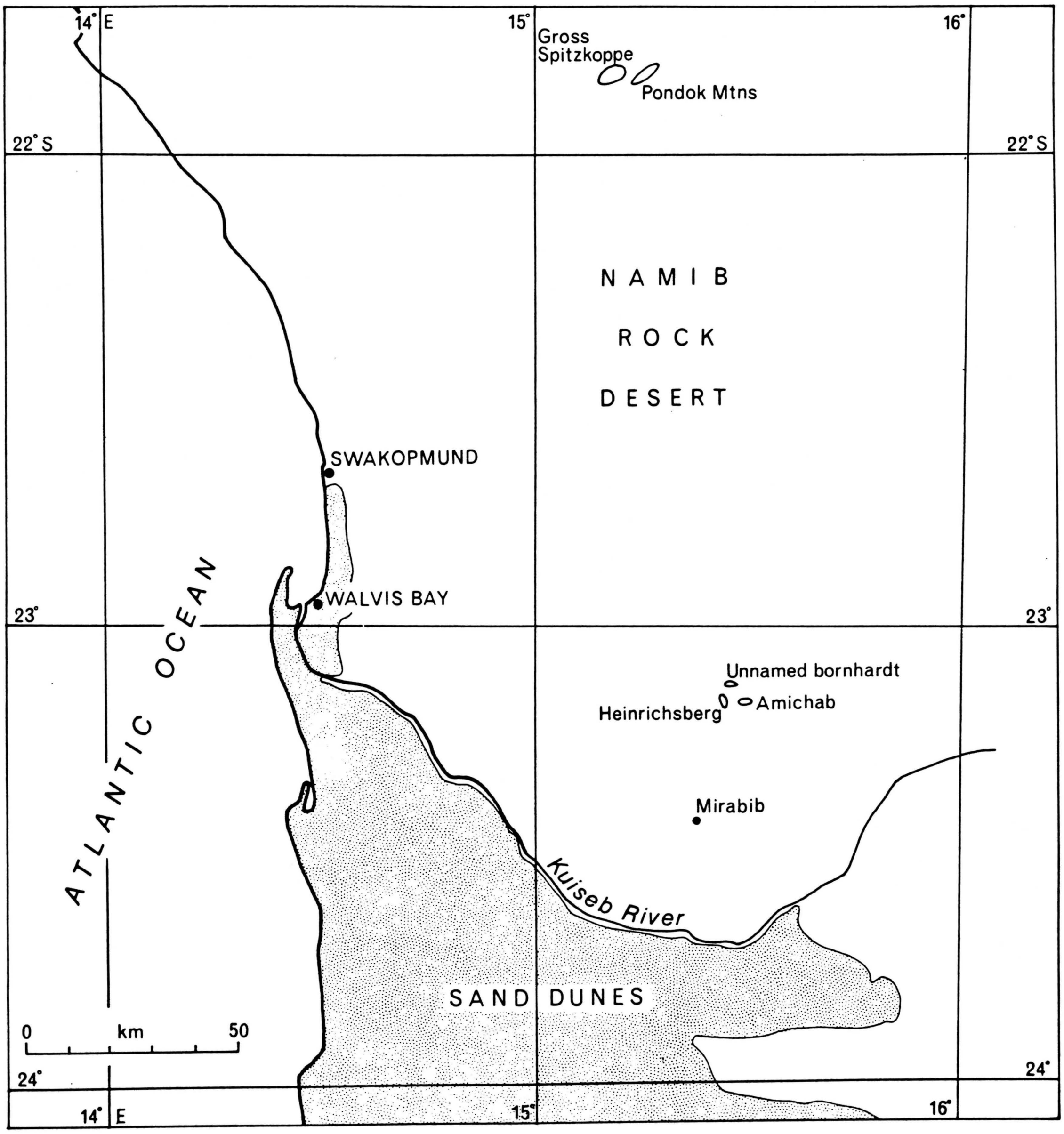

Fig. 1. The central Namib with locations of the bornhardts studied.

This group is composed of Donkerhuk granite of Namibian age (late Precambrian). The granite is generally pale pink to grey porphyritic biotite granite which contains large phenocrysts of orthoclase and microcline feldspar. The approximate composition of the rock is: quartz 20%; plagioclase 45%; orthoclase 22%; mica 13% (SELBY 1977b: 175). The northern group contains the very large bornhardt of Gross Spitzkoppe (or Spitzkop) and the adjacent ridge, surmounted by domes, which is locally known as the Pondok Mountains. Gross Spitzkoppe is composed of Erongo Granite of Cretaceous age which has been intruded into Old Granite of the Damara Sequenwater outflow and no infill in the joints. The dip of the joints is shown diagrammatically in the profile drawings (fig. 2, 3); joint widths vary from less than 1 mm to more than 20 mm; joint continuity is very variable.

The mass strength-slope angle relationships for Mirabib and Amichab are shown in fig. 4. On Mirabib the steep flanks of the domes are strength equilibrium slopes because they have few and widely spaced joints, and consequently a high mass strength rating. The upper surfaces of both the large and small domes have lower angles of slope, but their mass strength rating is as high as that of the flanks, so they have considerably lower slope angles than, theoretically, could be supported

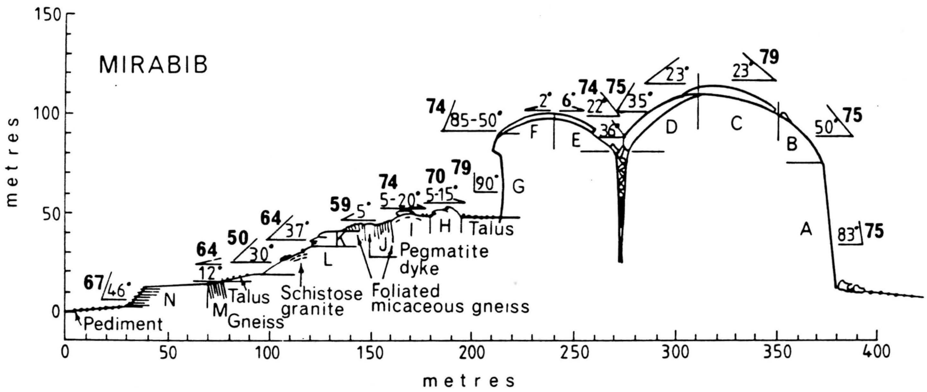

Fig. 2. A profile across the bornhardt Mirabib with characteristic angles of the slope units and rock mass strength ratings given in bold type.

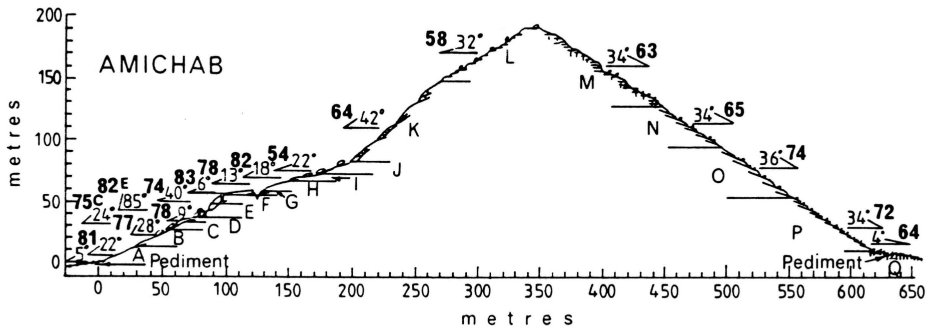

Fig. 3. A profile across Amichab.

by their mass strength. On Amichab the slope units A to I forming the lower part of the east facing slope appear to be the outcrop of sheet structures with a low angle of dip. Unit E is an exception as it results from a steeply dipping cross joint forming the face of the slope unit. As a consequence units A to D and F to I have slope angles which are lower than those which could be supported by their mass strengths. Higher on Amichab units J, K and L are formed in the outcrop of sheet structures which are being broken down by the development of an orthogonal joint set. The presence of these joints cutting across the sheets reduces the mass strength, and their data points plot within the strength equilibrium envelope. On the western face of

Amichab units M, N and P are composed of granite in which the joints are closely spaced (300–400 mm) and continuous, hence any controlling influence of sheet structures on slope angles has been lost. Only unit O retains the influence of sheet structure through its widely spaced joints and it is marginally stronger than needed for strength equilibrium with its slope angle. The pediment at the base of the western slopes is composed of gneiss with a joint spacing of only 80 mm. This produces a rock of only moderate strength but because of its low slope angle its data points plot above the strength equilibrium envelope.

Unnamed dome

About 5 km north of Amichab and 3 km north of Heinrichsberg (fig. 1) lies a domical granite outcrop with a vertical relief of about 100 m. This feature has such

Photo 1. The upper surface of the unnamed bornhardt showing schist lying conformably on the granite.

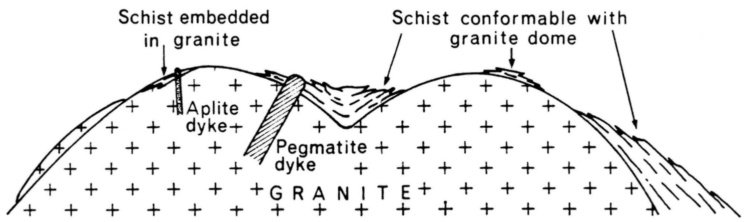

Fig. 5. A diagrammatic cross–section of the unnamed bornhardt, north of Heinrichsberg, showing the various lines of evidence which indicate that granite has been intruded as a dome into the schist.

gnment of the domes in an east-west direction is controlled by two joint sets which tend to converge towards the east and so cause narrowing of the Pondok domes in that direction. The Pondok domes appear to have attained their present form after the opening of the dominant joints as their individual shapes are confined within the joints. Gross Spitzkoppe, by contrast, was apparently a multi-domed feature whose eastern side was later cut by the development of the north-south trending set of joints which have spacings of 10–30 m (photo 4). The lower dome cut by this set now has a relief and suite of minor landforms dominated by these joints.

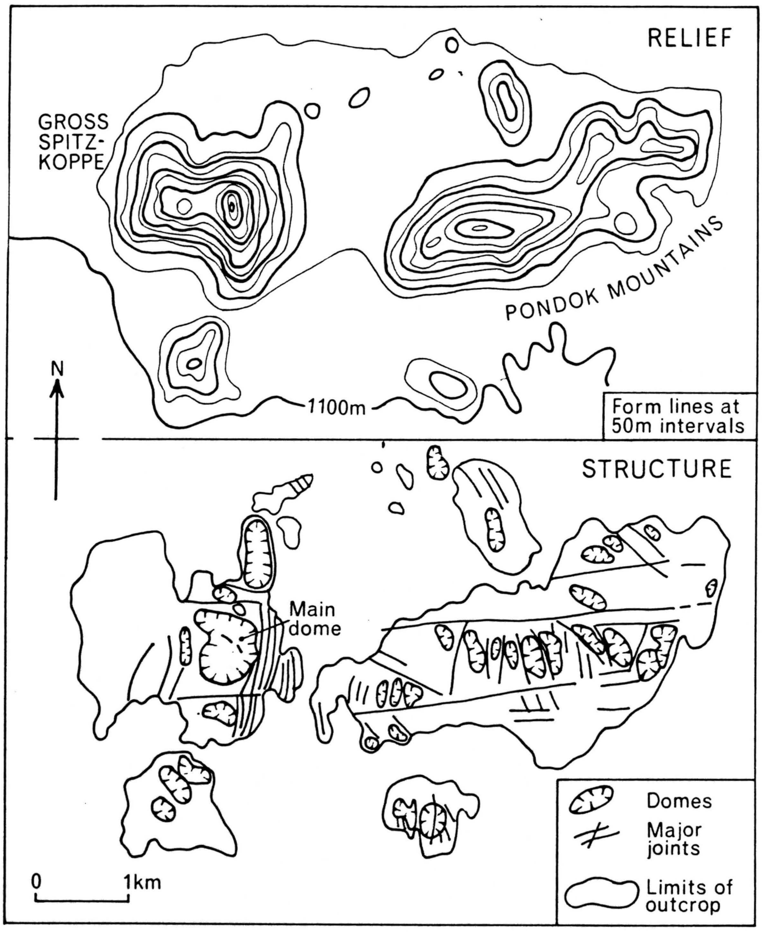

Fig. 6. The relief, domes and dominant joints of Gross Spitzkoppe and the Pondok Mountains.

Nowhere on these mountains have outcrops or residuals of the country rock, into which the granite was intruded, been seen or reported. It is, consequently, not possible to ascertain whether the domes owe their outline to original emplacement forms or to subsequent development of sheeting joints developing on the massive compartments of granite between the major linear joint sets.

All of the large domes have well-developed sheeting joints which are nearly parallel with the dome surface where the sheeting rock units are thin (1–10 m), but a massive talus or, of the joints produce a stepped slope profile, it becomes a strength equilibrium slope.

The process of joint block reduction proceeds in the arid environment of the Namib by granular disaggregation of coarse grained rocks. The Erongo Granite is particularly susceptible to this kind of weathering and the surfaces of all joint blocks, and of the domes, are characterised by this process. Its mechanism is still obscure but involves the partial alteration of biotite, the release of ferric hydroxides and loosening of individual quartz and feldspar crystals (Selby 1977b: 176). No alteration of feldspar crystals was evident in hand specimens. The upper surfaces of the large vertical rock slices forming the eastern edge of Gross Spitzkoppe show the results of this weathering very clearly (photo 5). The upper surfaces of each slice are subdivided by joints which are either parallel to the faces of the slice or cut into them at right angles. The edges of each joint block are rounded by spalling and the ultimate result is the separation of partly rounded blocks from the parent slice. Thus joint blocks of many sizes and shapes are being formed on the faces of the mountains. Similar weathering forms of crystalline rocks in an arid environment have been reported by Mensching (1978: 12, photo 4).

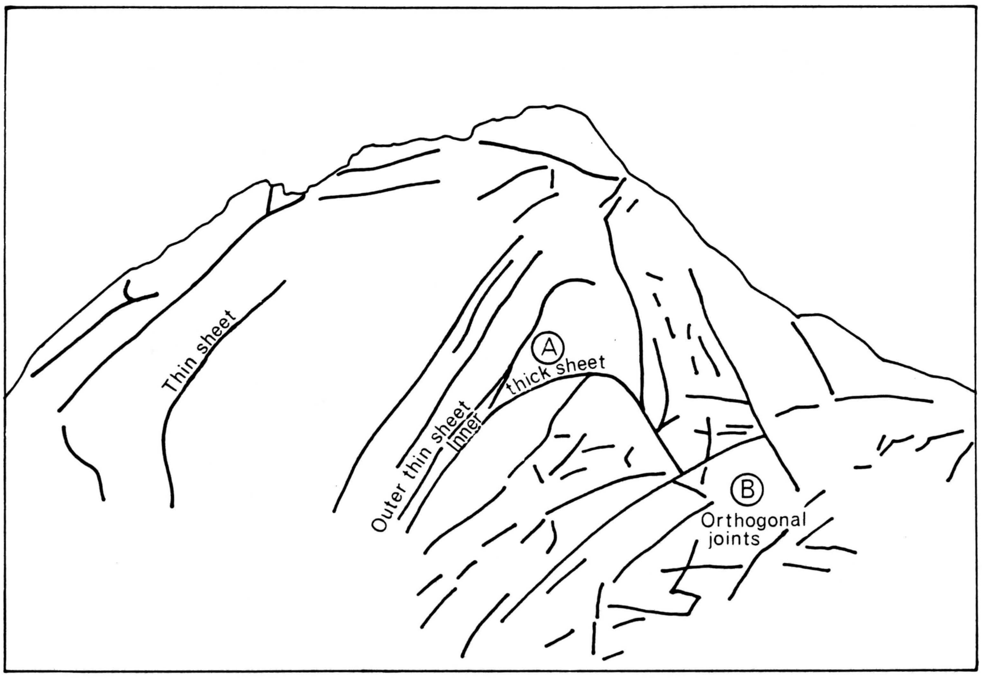

Fig. 7. The main structural features of the southwest face of Gross Spitzkoppe.

Conclusions

The evidence from Mirabib and Amichab shows that bornhardts may, initially, have slope angles controlled by structure and perpetuated by the opening of sheeting

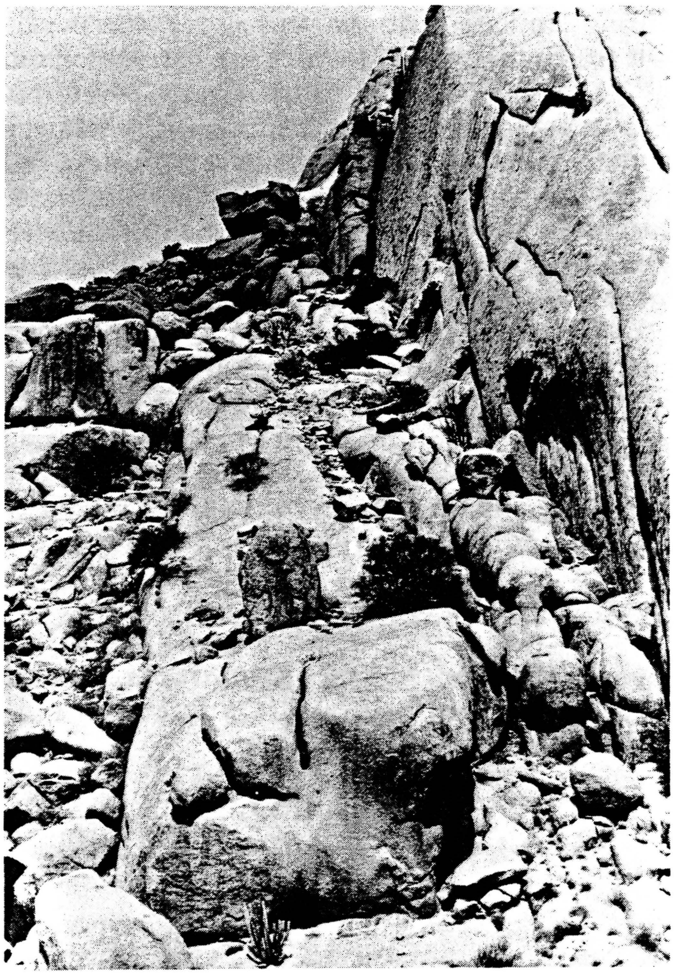

Photo 5. The weathering of granite on Gross Spitzkoppe by joint opening and granular disaggregation to form rounded boulders.

joints. As an orthogonal set of joints open the mass strength of the rock is reduced and slope profiles are adjusted so that the slope angle is in a strength equilibrium with the rock. Studies of inselbergs on metamorphic and sedimentary rocks elsewhere in the Namib (SELBY in prep.) have shown that strength equilibrium slopes are widespread and may be universal in the absence of talus deposits. It is probable, therefore, that continued evolution of the granite slopes preserves strength equilibrium so that, in the virtual absence of groundwater and weathering, slope angles are controlled by the joint pattern through its influence on mass strength.

The significance of the finding that some Namib Desert granite domes achieved that form at the time of their emplacement is difficult to evaluate. It does, of course, stress the significance of original structural control, but cannot be compared with assumptions about origins of domes elsewhere because in few other places is similar strong evidence of emplacement forms preserved. Wherever the country-rock above the granite has been removed by erosion or altered by weathering the original form can only be inferred and is never certain. The unequivocal evidence from the Namib cannot be used to infer similar origins for bornhardts elsewhere. It is evident, of course, that some bornhardts cannot owe their form to that created