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# BORNHARDT TERRAIN ON GRANITIC ROCKS IN ZIMBABWE: A PRELIMINARY ASSESSMENT

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Presents results of a reconnaissance survey of bornhardt terrain in Zimbabwe. This is based on a country-wide systematic sampling of 1:50 000 topographic map sheets combined with air photo analysis of select areas and cross-checking to type areas examined in the field. Examines in particular the relationship of bornhardt terrain to the erosion surfaces mapped by Lister (1976), and to granitic rock types. Concludes that the scarp retreat hypothesis does not provide an adequate explanation of origins and that there is a need for more detailed study involving a range of hypotheses. Variations in structure and lithology exert a clear influence on terrain type and bornhardt form.

## INTRODUCTION

About 45 per cent of Zimbabwe is underlain by granitic rocks which make up the greater part of an ancient, massive craton extending some 600 km in a north-east to south-west direction across the central part of the country (Phaup, 1973a). Much of the granitic terrain is characterized by flat to gently sloping plateau surfaces broken in places by residual boulder-strewn hills. More spectacular landscapes (Plate 1) also occur in the form of areas of steep-sided convex domes or bornhardts; such landscapes occupy about 30 per cent of the regions underlain by granitic rocks. The bornhardt terrain forms a distinctive but discontinuous arc varying in width from 90 to 130 km on the southern margin of the craton body (see Fig. 5).

Relatively few geomorphological investigations have been carried out on this terrain in Zimbabwe. For example, King (1948) refers to erosion cycles and bornhardt development in the Matopos Hills south of Bulawayo, and Lister (1973) has described selected micro-geomorphological features on three domes in the north-east of the country. More recently, Twidale (1981) has commented briefly on domed and castellated inselbergs in central Zimbabwe, and Whitlow (1980a) has described the implications of extensive rock outcrops in relation to land use and population pressures in communal farming areas. Apart from these studies, certain of the Geological Survey memoirs (especially the earlier reports) provide limited accounts of the bornhardt terrain (e.g., MacGregor, 1930; Tyndale-Biscoe, 1933). Systematic regional studies of bornhardt landscapes, however, have been lacking. In this respect the examination of bornhardts in Zimbabwe would seem to offer an ideal opportunity for testing some of the many hypotheses on the origins of rock domes and minor landform features associated with them (e.g., King, 1966, 1975; Doornkamp, 1972; Thomas, 1974a, 1978; Twidale & Bourne, 1975a, 1978; Brook, 1978; Twidale, 1980). Furthermore, considerable advances have been made in recent years by geologists examining the nature and modes of development of the granitic and related rocks of the ancient craton in Zimbabwe (e.g., Phaup, 1973a; Wilson, 1979). The structural characteristics of the craton have been described by Stowe (1980). Clearly, geomorphological studies could draw upon and greatly benefit from this research. Systematic studies of individual granitic bodies, such as the Chinamora Batholith north of Salisbury (Viewing & Harrison, 1973), have also been carried out and would enable more detailed examination of rock domes at a meso- and micro-scale. From an educational point of view the bornhardt landscapes offer tremendous scope in demonstrating basic geomorphological principles and methods of field observation (Whitlow, 1981a).

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The purposes of this paper are as follows:

a) to present the results of a preliminary investigation of the bornhardt terrain in Zimbabwe; and

b) to comment on some of the implications of the nature and distribution of rock domes with respect to hypotheses on their development.

The study should be treated as exploratory not definitive, and the need for more detailed systematic research should be stressed; this paper might serve to indicate where such research might most profitably be carried out. However, before discussing the methods and results of the present survey, it is useful to make some brief comments regarding the origins and development of bornhardts and factors influencing them with particular reference to Southern Africa.

## BACKGROUND ON BORNHARDT LANDSCAPES

In Central and Southern Africa, the traditional explanation of rock domes has been in terms of scarp retreat, involving active exfoliation, and pediment formation (King, 1948, 1966, 1975). This view has been accepted, often uncritically, for many years to the extent that few alternative hypotheses have been considered, let alone tested. Evidence from East Africa (Ollier, 1960; Doornkamp, 1968), West Africa (Thomas, 1965; Faniran, 1974) and more recently from Southern Africa (Giardino, 1973; Brook, 1978) suggests that an alternative mode of formation involving exhumation of deeply weathered rocks,following rejuvenation of river systems may be more realistic than this traditional explanation of bornhardts. Twidale (1980), in a review of a wide range of evidence concerning bornhardt evolution, has argued that "many bornhardts have not formed as a direct consequence of scarp retreat" (p. 206) and that the "two-stage [exhumation] hypothesis offers the most cohesive and comprehensive general account of bornhardts" (p. 206). There is, therefore, reason to believe that a deep weathering and erosional stripping sequence might also be applicable in Zimbabwe. Nevertheless, the varied and complex character of bornhardt terrain in this country (see Plates 5 to 8) may frustrate attempts to explain dome features in terms of any single hypothesis, and one should be aware of statements by Selby (1977) who invokes the concept of equifinality to account for the development of bornhardts, whereby the same forms might result from different suites of processes. This means that the scarp retreat hypothesis may prove acceptable under certain conditions, but until other hypotheses have been considered properly this traditional viewpoint can not be taken as having universal application to bornhardt terrain in Zimbabwe.

There are several factors that need to be taken into account with respect to the current study and future research on bornhardts in Zimbabwe. Firstly, the country has been influenced by several cycles of erosion which have given rise to a number of planation surfaces (see Dixey, 1938). Although the origins and methods of recognizing such erosion surfaces are sometimes disputed (e.g., Thomas, 1969; Pitty, 1971), it is generally accepted that bornhardts are commonly associated with such multi-cyclic landscapes (Twidale, 1976). In this respect Twidale & Bourne (1975b) have presented evidence suggesting episodic exposure of domes: features such as flared slopes and tafoni, which appear to be initiated under subsurface weathering conditions, have been found to occur at different levels on domes above present-day hill-plain junctions and seem to indicate gradual exposure of the domes. Since comparable features occur on bornhardts in Zimbabwe (Whitlow, 1981a) and the notion of episodic exposure is not inconsistent with the occurrence of erosion cycles as described by Dixey (1938), King (1951) and Lister (1976), it may be that observation of meso- and micro-scale landform features might provide evidence to test the validity of the exhumation and related hypotheses. Secondly, the association between boulder and dome inselberg features needs to be evaluated in terms of their spatial occurrence and possible genetic links (e.g., Thomas, 1974b; Brook, 1978; Twidale, 1981). Such associations are common in certain parts of Zimbabwe but have not been explained adequately. Related to this is a third factor, that of the significance of rectangular and curvilinear jointing patterns; these would influence the nature of both subsurface and subaerial physico-chemical weathering processes. Also the regional fracture patterns, themselves a result of crustal geophysical processes (Stowe, 1980), are likely to influence the general disposition of domes in the landscape. Finally, there is the question of the apparently greater frequency and size of bornhardts in rocks that have a high proportion of potash feldspars or which have undergone potash metasomatism (Brook, 1978). This may be particularly relevant in Zimbabwe where bornhardts are common on the potash-rich adamellites, a fact noted by many field geologists (Wilson, 1980).

## METHODS OF MAPPING BORNHARDT TERRAIN

Topographical maps, despite their inherent limitations, are useful in reconnaissance surveys of different landscape types (e.g. Swan, 1970; Faniran, 1974). Bornhardt terrain is readily identifyable on maps on the basis of its distinctive contour and drainage patterns (Whitlow, 1981b); in the present survey 1: 50 000 topographical maps, mainly metric editions with a 20 metre contour interval, were used. Whilst the interpretation of bornhardt terrain was somewhat subjective, errors were reduced through frequent cross-check-

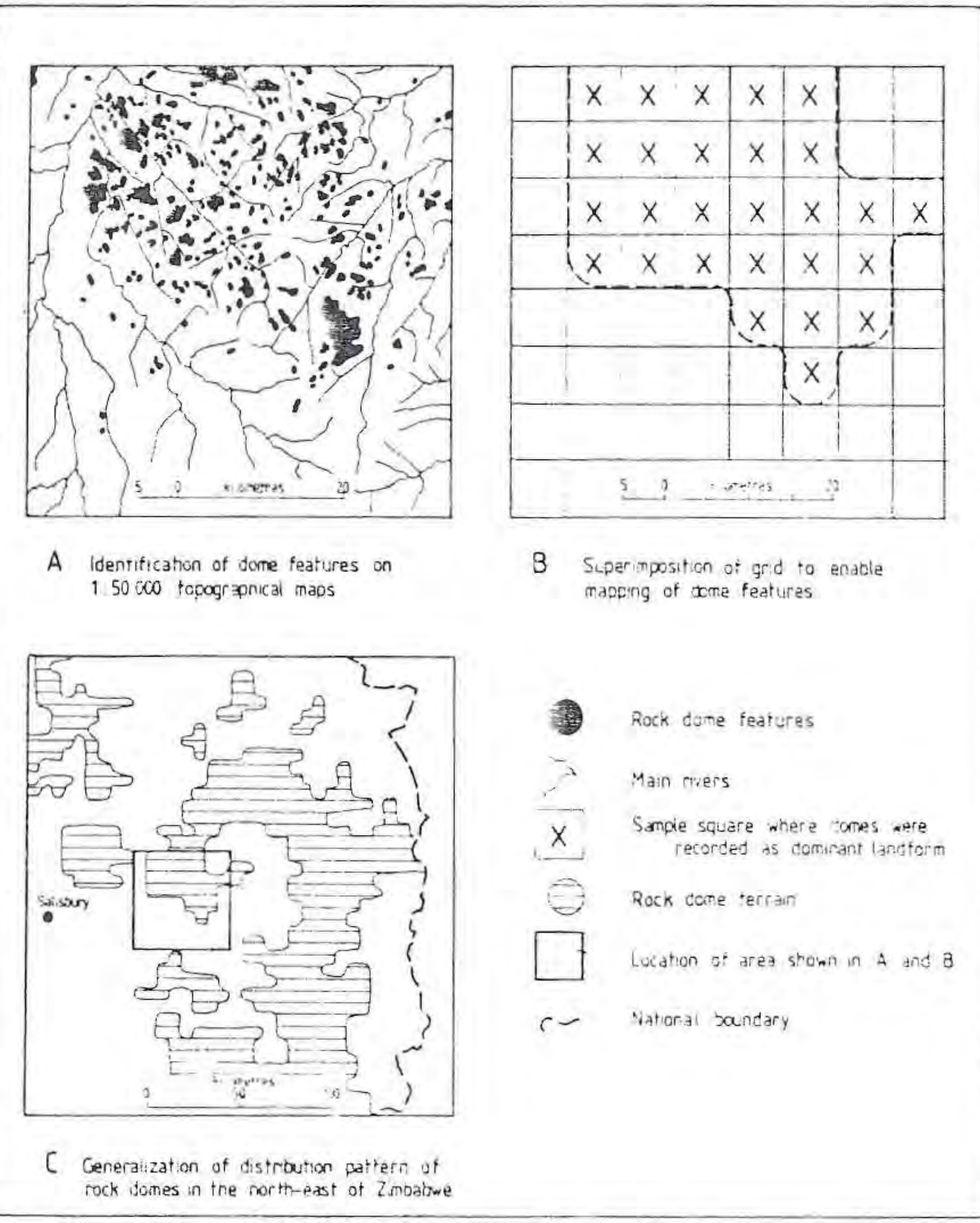


FIG. 1. PROCEDURE FOR MAPPING BORNHARDT LANDSCAPES IN ZIMBABWE

ing with 'type-areas' which had been visited in the field several times in the past. The subsequent availability of 1:80 000 panchromatic aerial photography covering the entire country enabled confirmation and modification of the mapping

The mapping procedure is shown in Fig. 1. Sampling was based on a grid framework whereby each topographical map sheet was divided into 16 squares of equal area approximating to 45 $km^2$ on the ground. The dimensions of the grid squares represented a compromise between the accuracy of the topographical maps, the scale of the features under investigation, and the time and effort involved in sampling. Systematic sampling within areas underlain by granitic rocks involved the examination of over 350 map sheets, with the presence and absence of bornhardt terrain being noted for each sample square (Figs. 1A and B). Presence was only recorded where the bornhardt landscape occupied at least half of a given grid square. This terrain type was recorded in over 1 270 sample squares out of the 4 040 squares examined, thus accounting for about 30 per cent of the granitic landscapes as noted earlier. Within a given grid square the actual area of rock domes, bared or regolith-covered, was typically in the order of 20 to 35 per cent of the land, although locally the proportion could be considerably higher; these figures are based on mapping from aerial photography (e.g. Fig. 3 below). The final plotting was carried out on a 1:1 000 000 base map of Zimbabwe and the boundaries of the bornhardt terrain were generalized as shown in Fig. 1C.

Once the general distribution of the bornhardt terrain had been established it was necessary to obtain data on the granitic rocks and erosion surfaces in the areas where the domes occurred. Two maps were used for this purpose: the provisional geological map of Zimbabwe (1977), seventh edition (see Stagman, 1978), and an erosion surfaces map of the country compiled by Lister (1976). Both maps were on a scale of 1:1 000 000 and data extraction was carried out using the same grid as that used for plotting the distribution of the bornhardt terrain. Similar procedures and difficulties involved in this operation have been outlined elsewhere (Whitlow, 1980b). Other data sources are explained at a later stage with respect to more localised sampling in areas of bornhardt terrain.

## RESULTS AND DISCUSSION

The results are presented in two main sections, as follows:

a) Relationship of bornhardt terrain and erosion surfaces;

b) Relationship of bornhardt terrain and granitic rocks.

The question of erosion surfaces is discussed first since this relates to the traditional scarp retreat hypothesis which, as argued above, may no longer provide an acceptable explanation of bornhardts. The aim here is to establish whether this applies to all types of bornhardt terrain in Zimbabwe, as has been assumed in the past, or whether other hypotheses need to be explored. The second part concerns the variations in the lithology and structure of the granitic ricks on which bornhardts occur; it will be argued that these result in differential weathering and erosion of granitic rocks and, by implication, provide some support for the exhumation hypothesis. Thorough validation of such ideas would, however, require more detailed study than that carried out in this reconnaissance survey.

### a) RELATIONSHIP OF BORNHARDT TERRAIN AND EROSION SURFACES

The fact that much of south-central Africa has undergone several phases of planation followed by active stream incision in response to periodic uplift and tilting of the earth's crust has been recognized for some time (e.g., Dixey, 1938, 1955; King, 1951). The resultant erosion surfaces have been explained in terms of "pediplanation . . . which governs the destruction of the older landsurfaces by encroaching younger surfaces operating at a lower level by the method of scarp retreat" (Lister, 1976, p. 6). The occurrence of erosion surfaces associated with bornhardt terrain is indicated in Fig. 2 and Table 1.

The Post-African surface has been mapped as two sub-regions to delimit an upper zone, corresponding to the headwater areas of rivers draining the central watershed, and a lower zone. This division was made arbitrarily for purposes of examining general topographical variations in the upper and lower portions of this extensive erosion surface.

Table 1. RELATIONSHIP BETWEEN EROSION SURFACES AND BORNHARDT TERRAIN

| EROSION SURFACE | GEOLOGICAL PERIOD | APPROX. AGE (mill. yrs.) | PROPORTION OF GRANITIC ROCK | PROPORTION OF BORNHARDT TERRAIN a) between surfaces | b) within surfaces |
|---|---|---|---|---|---|
| African | mid-Cretaceous/end-Oligocene | over 20 | 9.0% | 2.1% | 8.6% |
| Post-African | Miocene | 5 to 20 | 72.6% | 79.2% | 34.7% |
| Pliocene | Pliocene | under 5 | 18.4% | 18.7% | 32.2% |

The results are discussed under three headings:

1. distribution of bornhardt terrain on different erosion surfaces;
2. occurrence and nature of bornhardts on a given erosion surface;
3. topographical variations of bornhardt terrain.

## 1. Distribution of Bornhardt Terrain on Different Erosion Surfaces

Both Fig. 2 and Table 1 indicate a greater prevalence of bornhardt terrain on the Post-African erosion surface than on the other surfaces. This is primarily due to the fact that over 70 per cent of the granitic rocks in Zimbabwe occur in areas affected by the Post-African erosion cycle. In these areas the bornhardt terrain accounts for nearly 35 per cent of the granitic landscapes, but in the lower zone of the Post-African surface this increases to over 50 per cent. On the African erosion surface the bornhardt terrain was more localized (Table 1) and accounted for less than 10 per cent of the granitic landscapes; this erosion surface is generally characterized by gentle slopes broken occasionally by hill features. On the Pliocene erosion surface the bornhardt terrain was more widespread than on the ancient central plateau accounting for nearly 20 per cent of the bornhardt terrain and occurring in nearly one-third of this surface underlain by granitic rocks.

The high proportion of bornhardt terrain in areas influenced by the Post-African erosion cycle may reflect the operation of headward erosion and scarp retreat as envisaged by King (1948), but equally it could represent the exhumation of domes from a differentially and deeply weathered planation surface (e.g., as described by Doornkamp, 1968). Two issues need to be resolved with respect to the occurrence of bornhardt terrain and erosion surfaces. Firstly, bornhardt landscapes often cut across the erosion surface boundaries and within a given surface may form discrete islands (Fig. 2); these distribution patterns are more clearly related to geological factors and are discussed at a later stage. Secondly, although rock domes are common features on the Post-African surface, other granitic landscape types characterized by gently undulating terrain with residual boulder-strewn hills and low domes are also common. To what extent these are simply a reflection of 'different stages' of the same erosion cycle (King, 1948; and Plate 2), or a result of some other mode of development is not clear. The situation is complicated further by the influence of geological factors which modify the nature of weathering and erosional processes on the granitic rocks and hence the resulting landscapes.

## 2. Occurrence and Nature of Bornhardts on a Given Erosion Surface

Variability seems to be the rule rather than the exception on bornhardt terrain in Zimbabwe. This includes variations in the spatial occurrence of domes in the landscape, differing degrees of exposure of bornhardts and differences in the relief of domes. The first two aspects are discussed here with respect to randomly selected sample area occurring on adamellites on the African erosion surface north-east of Rusape and the Post-African erosion surface near Bikita (Fig. 3). The third aspect is discussed in the next section, although relief of domes is also mentioned below.

The Rusape and Bikita areas are not necessarily 'typical' of bornhardt terrain on the two surfaces, especially given the contrasting types of bornhardt landscapes which are found in Zimbabwe (see Plates 5 to 8). However, they do serve to illustrate some of the characteristics of domes which have undergone differing periods of weathering and exposure irrespective of the actual mode of development of the terrain. Mapping of the two areas was carried

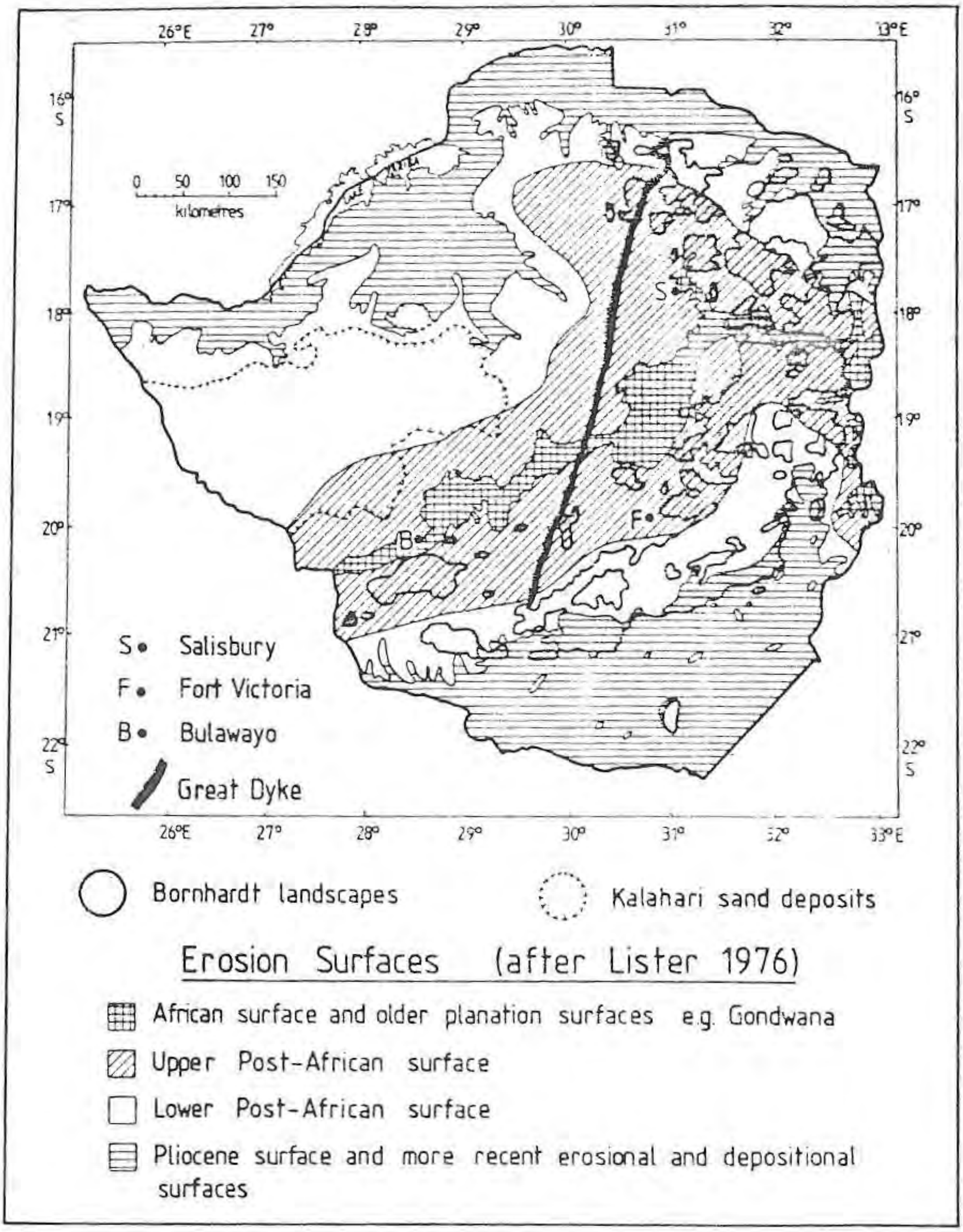


FIG. 2. DISTRIBUTION OF BORNHARDT LANDSCAPES IN RELATION TO EROSION SURFACES IN ZIMBABWE

out using panchromatic aerial photography on a scale of 1:25 000; plotting was based on 1:50 000 topographical maps. Before describing the two areas, the aspects of distribution and exposure of domes need some elaboration. Firstly, although domes might occupy any position in the landscape (Doornkamp, 1972), scarp retreat logically should result in clustering of domes on interfluve sites, although this would depend on jointing patterns in the bedrock (Faniran, 1974). In contrast, an irregular distribution of bornhardts conforms more readily with the exhumation hypothesis (Thomas, 1974b). Secondly, the occurrence of stripped, partially stripped and regolith-covered domes within an area affected by the same stage of a given erosion cycle is more easily accounted for in terms of exhumation than scarp retreat, although this does not necessarily preclude the latter (Thomas, 1974b).

In the Rusape area (Fig. 3A) there is an irregular distribution of domes on the gently sloping plateau surface, although the influence of large-scale jointing on the form of the

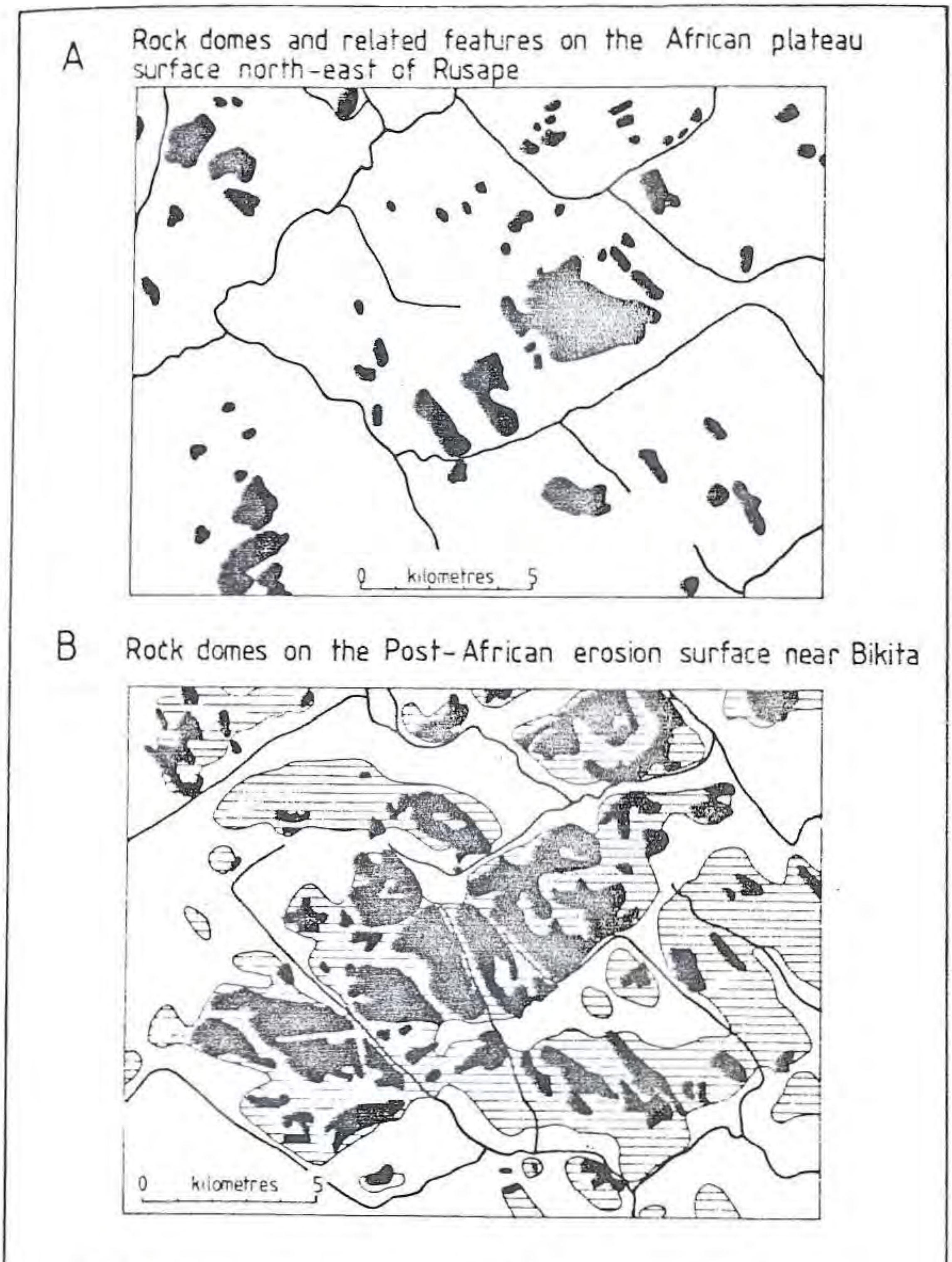


FIG. 3. DISTRIBUTION OF ROCK DOMES IN THE LANDSCAPE

PLATE 1. MASSIVE GNEISSIC DOMES TO THE SOUTH OF FORT VICTORIA *(Ministry of Information)*

domes and the stream network is evident. The domes typically rise abruptly from the regolith-covered plateau and vary in height from 20 to 120 m; the larger domes (Fig. 3A) are generally greater than 80 m in height. Virtually all the domes have been stripped of any regolith that once might have concealed them. In the Bikita area (Fig. 3B) the bornhardts are more extensive and range in height from 120 to 240 m. Unlike the bared domes of the Rusape area which have undergone a much longer period of denudation (possibly in the order of several million years), the Bikita bornhardts have not been completely stripped of their regolith. Weathered material in this area varies from a residual mantle on the crests or flanks of the domes to complete blanketing of a dome. There is clearly a much greater structural influence on the form and distribution of the domes in this area compared with the Rusape area.

From these sample areas there is certainly evidence to support the possibility of the exhumation hypothesis, whereas the varying distribution of domes and differing degrees of exposure cast doubts on certain aspects of the scarp retreat hypothesis. Observations in other areas, such as that shown in Plate 3, provide further confirmation of the difficulties of explaining variations in bornhardt terrain in terms of the latter hypothesis.

.3. Topographical Variations of Bornhardt Terrain

Variability in the heights of domes in restricted sample areas on the African and Post-African erosion surfaces has been described above. These differences might be accounted for either in terms of varying periods of exposure to subaerial denudation processes or progressive weathering and erosion of rocks surrounding bornhardts which, through successive erosion cycles, might gradually accentuate the relief of the domes (see Twidale, 1971; Thomas, 1974b). In order to examine the variations in the relief of the bornhardt terrain between and within the erosion surfaces defined by Lister (1976), data were obtained on a random sample basis from 1:50 000 topographical maps. Fifty squares were sampled within areas of born-


PLATE 2. SOUTHERN MARGIN OF THE MATOPOS HILLS WITH YOUNGER GRANITES BEING CHARACTERIZED BY LARGE, SOMETIMES STRONGLY FOLIATED, DOMES RISING TO HEIGHTS OF UP TO 200M ABOVE THE SURROUNDING AREAS. THE RELATIVELY FLAT TERRAIN TO THE SOUTH OF THESE DOMES IS UNDERLAIN BY MORE DEEPLY WEATHERED TONALITES.

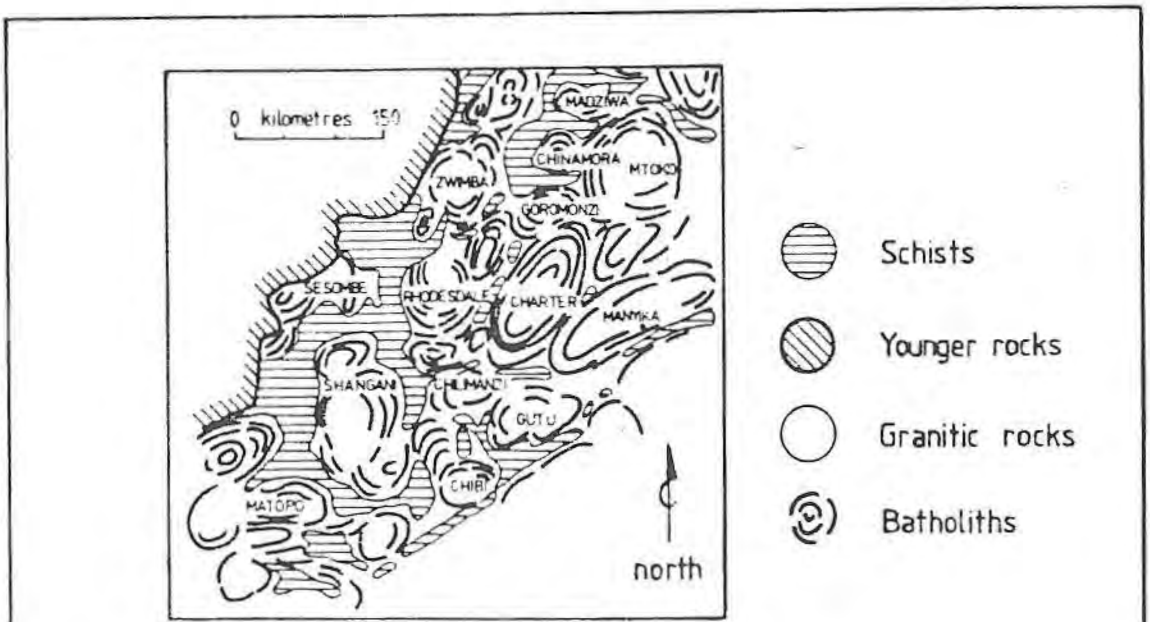


FIG. 4. GENERALIZED STRUCTURE OF THE ZIMBABWEAN ARCHAEN CRATON ACCORDING TO THE 'GREGARIOUS BATHOLITH' HYPOTHESIS *(MacGregor, 1951)*

hardt terrain on the upper and lower Post-African and Pliocene surfaces; only 32 grid squares were classified as having bornhardt terrain on the African surface, therefore all of these were included. Relative relief (highest elevation minus lowest elevation) was recorded in each sample square and the results are presented in Table 2. It should be noted that the relief of the domes themselves would be less than the figures shown in this table, although these might represent maximum relief of the bornhardts in some cases.

The varying distribution of bornhardt terrain between the relief classes from the oldest (African) surface to the youngest (Pliocene) surface suggests a general increase in relief from the former through to the latter. The mean relief on the Post-African and Pliocene surfaces is in the order of 90 m greater than that of the African surface, with perhaps a slight tendency for greater relief on the Post-African surface. In general the average attainable height for the progressive accentuation of dome relief by exhumation or scarp retreat seems to be in the order of 300 m; this is not an absolute maximum as values over 500 m were not uncommon, but it does give an indication of the sizes of the dome feature.

**Table 2. RELATIVE RELIEF OF BORNHARDT TERRAIN AND EROSION SURFACES**

| RELATIVE RELIEF (metres) | AFRICAN | UPPER POST-AFRICAN | LOWER POST-AFRICAN | PLIOCENE |
|---|---|---|---|---|
| | | (percentage of sample on different erosion surfaces) | | |
| under 100 | 4 | — | — | 2 |
| 100–199 | 36 | 18 | 10 | 14 |
| 200–299 | 44 | 44 | 38 | 36 |
| 300–399 | 16 | 12 | 32 | 40 |
| 400–499 | — | 20 | 14 | 6 |
| 500+ | | 6 | 6 | 2 |
| Squares sampled | 32 | 50 | 50 | 50 |
| Mean relative relief | 208.9m | 300.3m | 318.2m | 299.9m |
| Standard deviation | 69.7m | 138.7m | 98.8m | 83.8m |
| Maximum relief | 380 m | 720 m | 545 m | 520 m |
| Minimum relief | 95 m | 130 m | 150 m | 140 m |

Of greater significance is the considerable variation in relief within areas on a given erosion surface (see Table 2, standard deviations, maximum and minimum relief). Scarp retreat does not provide an explanation for this except in terms of varying stages of retreat which are difficult to prove or disprove. On the other hand, exhumation of massive rock compartments at different depths within the granite offers a reasonable alternative explanation (Twidale, 1976). In the latter case the nature of bedrock jointing and the duration of weathering and erosional processes would give rise to more varied topography such as seems to occur in the areas of bornhardt terrain in Zimbabwe.

In terms of the objective of this comparison of bornhardt terrain and erosion surfaces it can be concluded that whilst erosional stripping of the landscape is a necessary part of the development of rock domes, there are several sources of evidence that support hypotheses other than the scarp retreat hypothesis. Moreover, there are certain aspects that are difficult to reconcile with the latter hypothesis. Clearly, there is a case for evaluating a range of hypotheses to arrive at a more rational and accurate account of the development of bornhardts in Zimbabwe.

b) RELATIONSHIP OF BORNHARDT TERRAIN AND GRANITIC ROCKS

In Zimbabwe it is evident that the nature and disposition of the granitic rocks have exerted a major influence on the development of the bornhardt landscapes. MacGregor (1932), for example, noted that smaller batholiths and stocks, which he referred to as 'Daly Batholiths' gave rise to broken terrain of domes and kopjes. Later he described the large ovoidal granitic masses within the ancient craton as being 'gregarious batholiths', some of which had a massive sheet-like structure (MacGregor, 1951; and Fig. 4). Comparison of

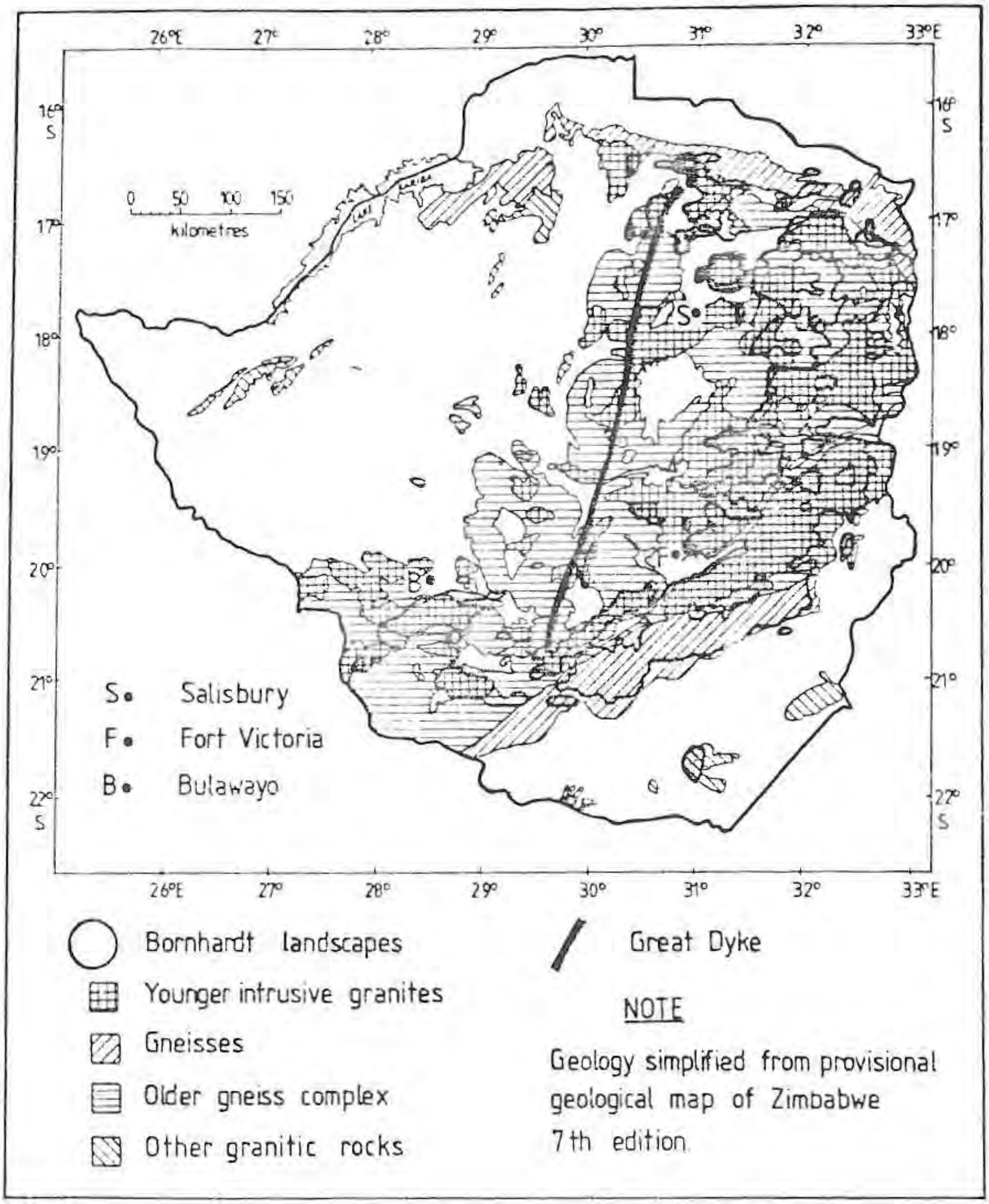


FIG. 5. DISTRIBUTION OF BORNHARDT LANDSCAPES IN RELATION TO GRANITIC ROCK TYPES IN ZIMBABWE

Figs. 4 and 5 reveals that only certain of the major batholiths are characterized by bornhardt terrain; these include the Chinamora, Mtoko, Manyika, Chilimanzi, Gutu, Chibi and Matopo batholiths. Domes are generally absent from batholiths which have a sheet-like structure. This requires more detailed examination.

Before discussing the relationships between the granitic rocks and the bornhardt terrain, it is necessary to provide a brief description of the granitic rocks which have been indicated in Fig. 5. The granitic rocks in general are "coarsely crystalline rocks composed of quartz, oligoclase and microcline with variable though small amounts of the dark coloured minerals, biotite and hornblende" (Stagman, 1978, p. 21). Several granitic rock types have been differentiated on the recent (1977) geological map of the country, although in some cases a given type might contain rocks of varying lithology and ages (Stagman, 1978).

A simplified classification of these granitic rocks is given below:

| | | |
|---|---|---|
| Younger Granites | – | mainly adamellites with some tonalites; |
| Older Gneiss Complex | – | mainly rocks of tonalitic composition; |
| Gneisses | – | foliated rocks of varying composition forming part of the mobile belts associated with the major craton; |
| Others | – | less extensive granitic rocks including granophyse and syenite. |

These rocks are mainly Pre-Cambrian in age. Two general periods of granitization have been identified nominally within the ancient craton; the older gneiss complex and the gneisses of the mobile belts seem to have formed some 3 500 million years ago and the younger granites formed about 2 600 million years ago (Phaup, 1973a). This is a grossly over-simplified account for purposes of general background only; more detailed information on the current state of knowledge regarding the granitic and greenstone rocks in Zimbabwe is given by Wilson (1979). The question of the varying composition of the main rock types is outlined at a later stage.

The distribution of the bornhardt terrain according to the main granitic rocks is indicated in Fig. 5 and Table 3. The occurrence of flat to gently sloping landscapes with residual kopjes is included for comparison in Table 3; such terrain occupies nearly 26 per cent of areas

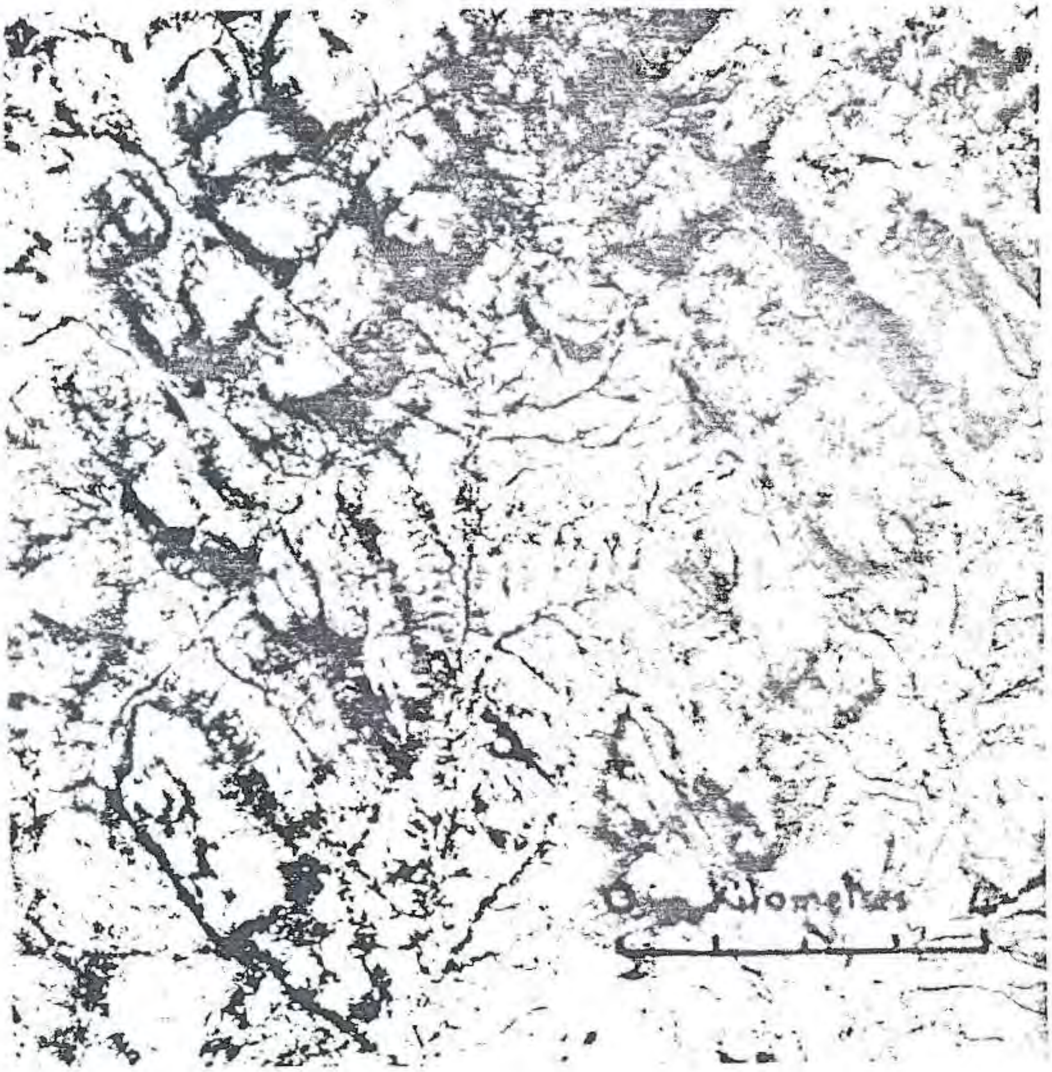


PLATE 3. MASSIVE GRANITIC DOMES, SOME IN EXCESS OF 300M IN HEIGHT, EXPOSED THROUGH DEEP INCISION OF RIVERS INTO THE PLATEAU SURFACE EAST OF RUSAPE. NOTE THE VARYING AMOUNTS OF REGOLITH COVER, MORPHOLOGY AND DISTRIBUTION OF DOMES IN THE AREA.

underlain by granitic rocks and is common on the central plateau region of Zimbabwe (Whitlow 1981b). Whilst the younger granites constitute less than half of the total granitic rocks, nearly 70 per cent of the bornhardts occur on these rocks. In contrast, the gently sloping terrain is most widespread on the older gneiss complex occurring in nearly 60 per cent of regions underlain by these rocks, although they constitute just over one third of the granitic rocks (Table 3). Examination of larger scale geological maps (e.g., Inyanga 1:100 000; Stocklmayer, 1977), where finer divisions of the granitic rocks have been made, suggests that there is a strong association between certain types of granitic rocks (especially the ada-

PLATE 4. MAJOR JOINTS AND FRACTURE PATTERNS OCCUR IN THE YOUNGER GRANITES IN THE MTOKO AREA, THESE HAVE INFLUENCED THE GENERAL DISPOSITION OF DOMES IN THE AREA.

Table 3. RELATIONSHIP OF ROCK TYPE AND TERRAIN TYPE

| ROCK TYPE | BORNHARDT TERRAIN | GENTLY SLOPING TERRAIN | PROPORTION OF GRANITIC ROCKS |
|---|---|---|---|
| Younger granites | 69.8 | 30.4 | 45.9 |
| Older gneiss complex | 19.2 | 60.0 | 35.9 |
| Gneisses | 10.2 | 5.2 | 14.1 |
| Other | 0.8 | 4.4 | 4.1 |

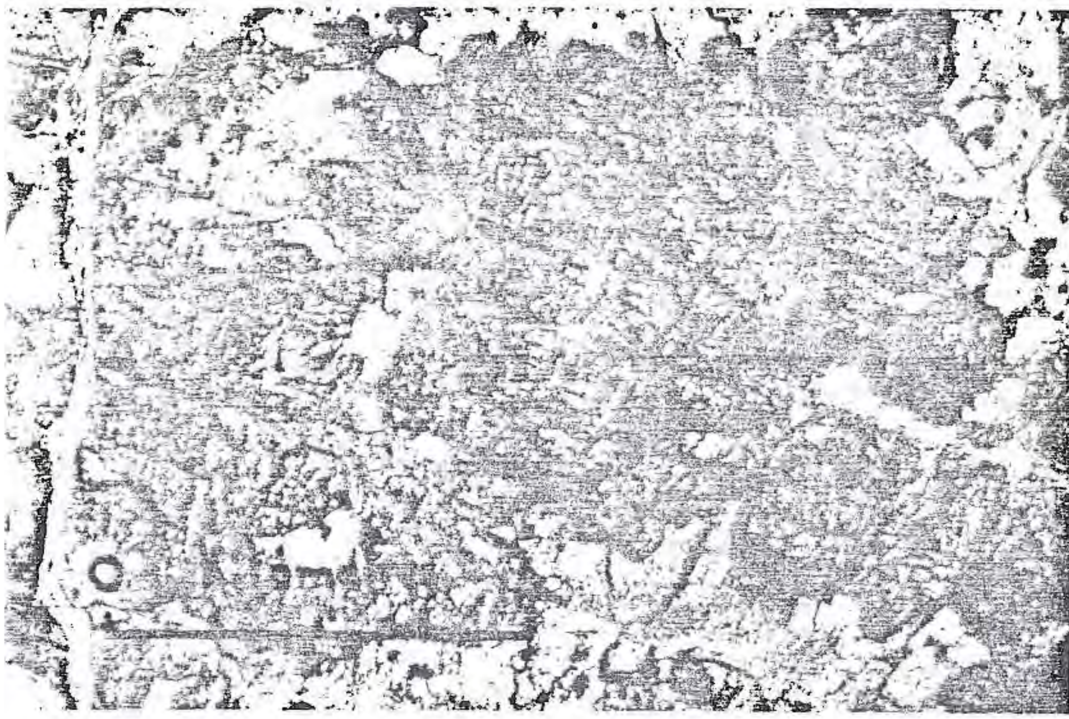

PLATE 5. CLOSELY SPACED AND STRONGLY FOLIATED DOMES OCCUR TO THE EAST OF THE NYAZVIDZI RIVER IN THE BUHERA DISTRICT.

mellites) and the bornhardts. This association is related to the variations in the mineralogy and jointing patterns of the granitic rocks, as described by Thomas (1974b), Brook (1978) and others.

Although the distinction between granitic rocks on the basis of the composition remains problematic (see Stidolph & Stocklmayer, 1976), as can be appreciated from the figures given in Table 4 (Phaup, 1973b), the main differences seem to relate to the varying proportions of potash and hence of potassium feldspar. For example, adamellite contains an average 4.5% by weight of potash and is normally defined as having between 35 to 65 per cent of the total feldspars as being potassium feldspars (Stagman, 1978). In contrast, the tonalites have a much lower proportion of potash (1.9%) and less than 15 per cent potassium feldspars. Since the younger granites on which bornhardt terrain is most prevalent are mainly dominated by adamellites this would support Brook's contention of an association between the potassium-rich

Table 4. AVERAGE COMPOSITION OF GRANITIC ROCKS

| COMPOUNDS | TONALITE | GNEISS | GRANODIORITE | ADAMELLITE |
|---|---|---|---|---|
| $SiO_2$ | 69.9 | 72.4 | 71.5 | 71.8 |
| $Al_2O_3$ | 14.7 | 14.2 | 14.5 | 14.0 |
| MgO | 1.2 | 0.8 | 0.8 | 0.6 |
| CaO | 3.4 | 2.3 | 2.5 | 1.7 |
| $K_2O$ | 1.9 | 2.4 | 2.8 | 4.5 |
| $Na_2O$ | 4.1 | 3.9 | 3.9 | 3.4 |
| Iron | 2.9 | 2.3 | 2.6 | 2.6 |
| Others | 1.9 | 1.7 | 1.7 | 1.4 |
| Number of samples | 41 | 32 | 49 | 44 |

(Source: compiled from Phaup, 1973b)

rocks and bornhardts (Brook, 1978). However, it has not been established whether this possible relationship is a function of the jointing patterns or different responses to weathering and erosion in the adamellites and related rocks. This requires further investigation.

The significance of jointing in crystalline rocks has been described by Thomas (1965) who likens the jointing system to "a rectangular lattice, varying in its texture both spatially and in depth, so that larger joint blocks may occur not only in different locations, but also at different depths below the landsurface of the time" (p. 66). In Zimbabwe it would be necessary to examine the macro-scale jointing and fracture patterns of the different batholiths as well since these seem to have exerted a major influence on the orientation of domes and river systems (see Plate 4). A good example of this is the Chinamora Batholith about 40 km north of Salisbury (Fig. 6). Viewing & Harrison (1973) have described the origins of this granitic body as follows: "It is probable that the batholith was originally a mantled gneiss dome mainly composed of tonalite, which was modified by the addition of potassium to form granodiorite, and in turn to form a granite core". They go on to say that "the com-

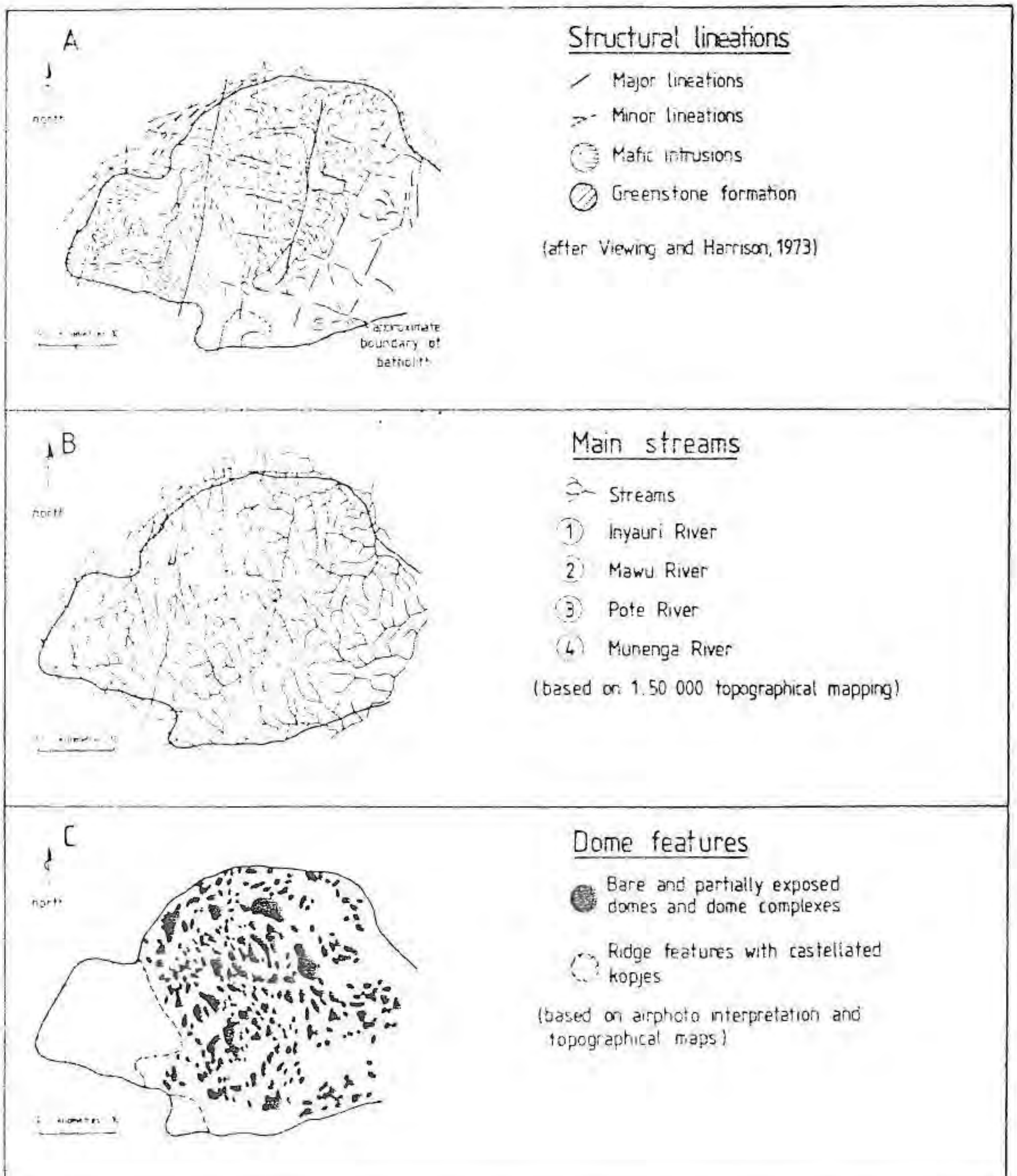


FIG. 6 SOME GEOMORPHOLOGICAL CHARACTERISTICS OF CHINAMORA BATHOLITH

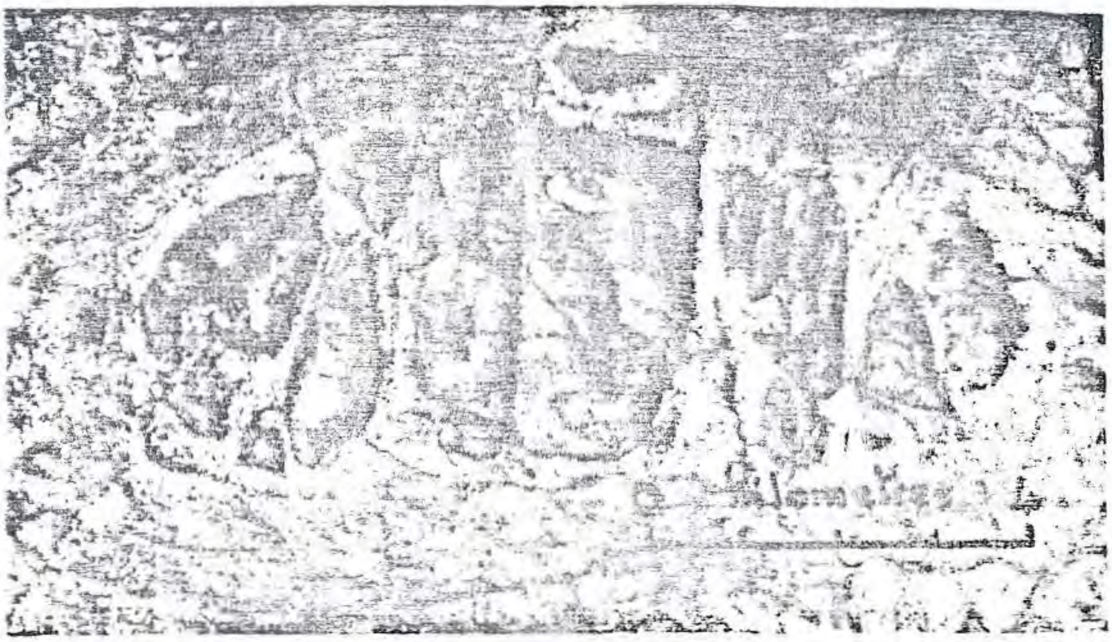

PLATE 6. THE DOMES OF THE RUNGAI HILLS RISE ABRUPTLY FROM THE PLATEAU SURFACE SOUTH OF FORT VICTORIA. MOST OF THE DOMES HAVE BEEN STRIPPED OF REGOLITH AND VARY IN HEIGHT FROM 100 TO 300M.

PLATE 7. EXPOSED DOMES ON THE OLDER GNEISS COMPLEX ROCKS TO THE SOUTH OF BULAWAYO THE DOMES ARE IRREGULAR IN MORPHOLOGY AND ARE IN THE ORDER OF 100 TO 120M IN HEIGHT.

plex structure and the presence of large xenoliths in the central portion (of the batholith) are taken to indicate that the present erosion surface is close to the roof of the batholith" (p. 419).

This batholith has been exposed under the influence of the Post-African erosion cycle (Lister, 1976), but the strong relationship between structural lineations, stream patterns and bornhardts (Fig. 6) suggest that exhumation rather than scarp retreat has taken place. For example, the main structural lineations (Fig. 6A) in the Chinamora Batholith, themselves a result of regional geophysical stresses, have exerted a major influence on the larger rivers such as the Inyauri and Mawu, and their tributaries. The contacts between the batholith and the adjacent greenstone belts are followed more or less by the Pote and Munenga Rivers. The actual pattern of domes, in terms of their size, shape and orientation (Fig. 6C) is clearly related to the stream network which in turn is related to the joint lattice. The more irregular domes are generally associated with portions of the batholith where the jointing patterns are more contorted. Relief variations ranging from 75 to over 300 m for the main domes as well as differing degrees of exposure of domes provides further evidence of the possibility of exhumation being a more plausible explanation of the development of the bornhardt terrain than the scarp retreat hypothesis. It is interesting to note that the summits of several of the larger domes in the central part of the batholith are at the same altitude as the African erosion surface plateau around Salisbury, a fact which suggests the progressive accentuation of relief as described earlier.

By way of a conclusion on the relationship of bornhardt terrain and granitic rocks in Zimbabwe, it is clear that variations in structure and lithology of the rocks have exerted a major influence over the development of bornhardts, and that geological factors provide a more satisfactory account of the distribution of such features than a simple association with erosion surfaces. Certain authors (e.g., Thomas, 1974b; Twidale, 1976) have stressed the importance of differential weathering and erosion depending on the degree of jointing in the granitic rocks. There seems no reason why this should not apply to bornhardts in Zimbabwe.

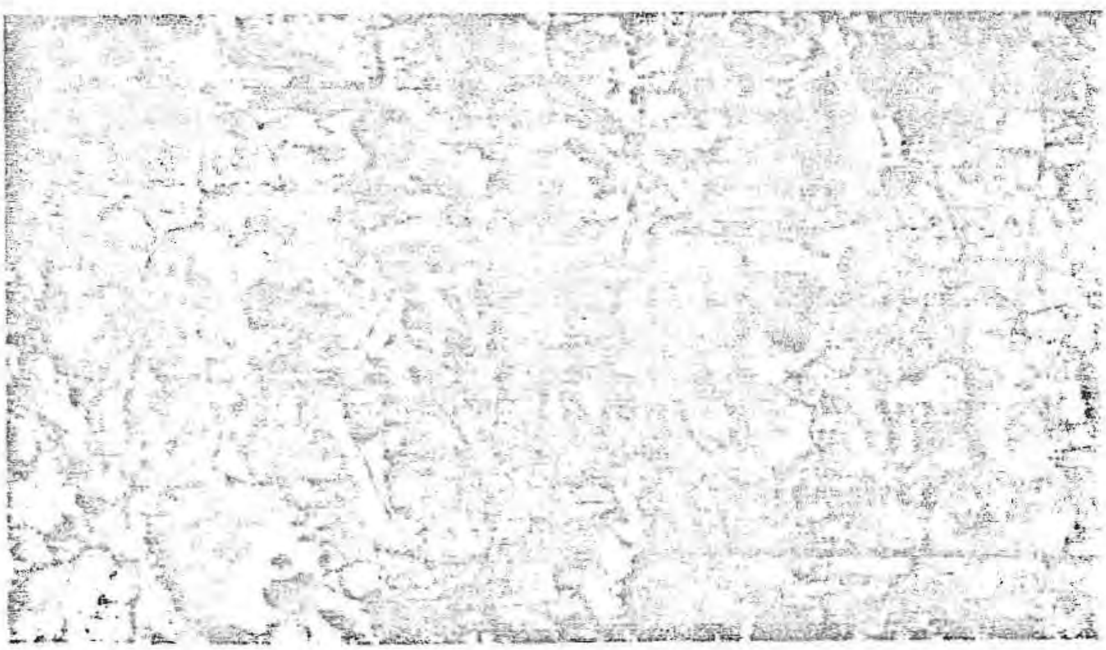

PLATE 8. DOME FEATURES RISING TO ABOUT 60M ABOVE THE SURROUNDING AREAS TO THE NORTH-EAST OF FORT VICTORIA.

## CONCLUSION

Apart from presenting the results of a preliminary survey of bornhardt terrain in Zimbabwe, the objective of this paper was to show that the traditional scarp retreat hypothesis no longer seems to be tenable in view of research findings from elsewhere and the evidence presented here. In the absence of more rigorous analyses, however, the scarp retreat hypothesis cannot be entirely discounted. What is required is a more systematic study involving testing of a range of hypotheses. Apart from examination of individual batholiths such as the Chinamora Batholith, an investigation of features including flared slopes, microvalleys, etc. (see Whitlow, 1981a) might provide clues as to the origins of the bornhardts. As suggested earlier, it may be that there is no universal hypothesis as far as the origins of bornhardt terrain in Zimbabwe is concerned. This is partly because of the wide range of geological conditions within the granitic rocks and a long history of bornhardt development during which environmental conditions, especially climate (e.g., Bond, 1968), have been continually changing. Some indication of the resultant variability of the bornhardt terrain is demonstrated in Plates 5 to 8. To unravel the origins of such complex landscapes will require considerable skill and effort.


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