MORPHOLOGICAL EVOLUTION OF DOMES AND TORS IN DUMKA UPLAND, JHARKHAND, INDIA

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Abstract
Prominent among discussion of the granitic landscapes are the accounts of domes and tors. Domes typically rise as monoliths and exceed several hundred metres in height. Tors are characterised by group of spheroidally weathered boulders rooted in bedrock. They rarely exceed few tens of metres in height. Smaller domes may be completely hemispherical but larger domes show much complexity in morphology. Granitic landscapes are also characterised by boulder strewn domes and castellated domes. These morphological variations are often interpreted in terms of climatic geomorphology. However, their coexistence in Dumka Upland supports structural hypothesis for their genesis. Domes and tors are interpreted in terms two competing theories. One holds that domes and tors evolve due to scarp retreat and pediplanation and the other involves subsurface weathering of granitic terrain followed by stripping of regolith and subsequent exposure of the residual forms. In Dumka Upland, circumstantial evidences are in favour of sub-surface genesis of domes and tors.

Keywords: *domes; tors; Dumka; Jharkhand*

Introduction

Granite landscapes are characterized by the presence of residual hills rising abruptly from the surrounding plain. The term ‘inselberg’ has been proposed by Bornhardt in 1900 to describe hills or group of hills rising abruptly from a peneplain as an island rises from the sea (Willis, 1934). But the term widened to include a variety of hill forms. In order to distinguish the inselberg that consists of a massive granite or quartz rich gneiss or schist intruded by granite Willis (1934) proposed the adoption of discoverer’ own name i.e. Bornhardt. Therefore, a bornhardt is characterised by ‘bare surface, precipitous sides, becoming steepeer towards the base, an absence of talus, alluvial cones, soil, a close adjustment of form to structure’ (Willis, 1934, p. 124). The terms ‘dome’ and ‘domed inselberg’ are orther synonyms available in literature.

Apart from the domes, granite landscapes are also characterized by the presence of boulder-strewn domes and castleted domes. Morphologically the three forms are so distint that the three forms have acquired distictive names. Boulder strewn domes consists of a chaotic mass of boulders. They are also known as nubbins (Twidale, 1981), block and boulder-strewn domes (Twidale, 1998) bouldely inselberg/ block-strewn inselberg (Migoń, 2006). The third type is charactersed by presence of orthogonal fracture pattern and it is known as castle koppies (Twidale, 1981) and castellated inselberg (Migoń, 2006).

Geomorphologist have long debated whether three distinct granitic landforms developed in response to different geomorphic processes or are they genetically related forms. The imprint of strucure on the morphology of the three forms, the global distribution and the coexistence of these landforms in many areas are strong evidences in favour of structural control in the morphological evolution of domes and tors.

Domes have fascinated geomophologists since the inception of the subject and several explanations have been offered for them. Previously, inselbergs including the domed types were cosidered to be typical of semiarid or savannah climate. But this view is no tenable.

Inselbergs particularly the domed type are reported from different morphoclimatic regions. Inselberg are considered as an example equifinality in geomorphology (Migoń, 2006, p. 125). Broadly speaking, there are two cases in which domes develop. Firstly, if there is petrological difference i.e. rocks which constitute the domes are younger in age than the surrounding palin like the inselbergs of the Namib desert which are built of Jurassic granite, whereas the surroundong plain is cut across Salem granite of Precambrian age. Hence, they can be explained in terms of the ongoing differential denudation without taking recource to past deep weathering (Migoń, 2000, p. 21). Secondly, if there is no petrological difference i.e. there is no difference between the rocks which constitute the domes and the surrounding plain. In this case two classic models dominats geomorphological thinking. One is based on subsurface weathering of granitic terrain guided by structure and subsequent exposure of the weathering front. Empahsis is laid on structure. While in term of the other, inselbergs evolve due to scarp retreat and pedimention. Inherent in the later model is the concept of time and stage.

In the context of the ongoing debate, this research considers the case of origin and evolution of domes and tors and their relation to landscape settings in Dumka Upland, Jharkhand, India.

Study area

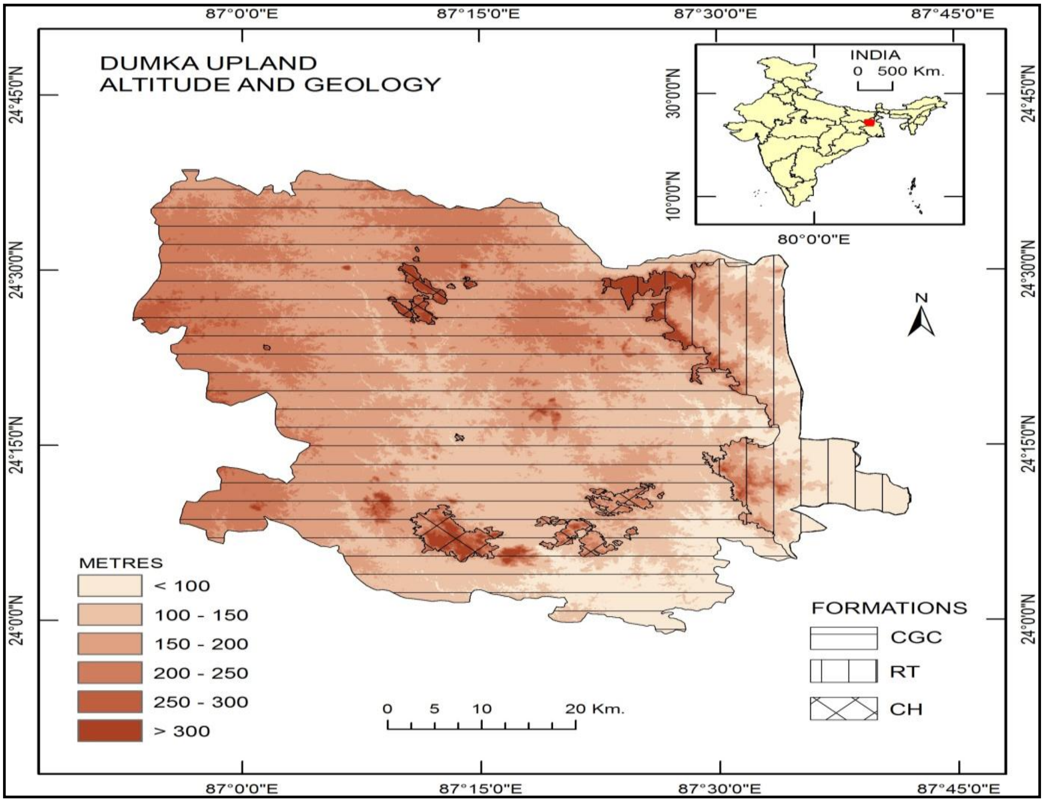

Figure 1. Showing alititude and geology in Dumka Upland.

CGC, RT and CH stands for Chotanagpur Granite Gneiss Complex, Rajmahal Trap and Charnockite Series respectively

Dumka Upland is a part of the earlier super continent Gondwanaland. It lies between latitude 23^0 $59^/$ N- 24^0 $40^/$ N and longitude $86^0 55^/$ E - $87^0 45^/$ E. It belongs to the state of Jharkhand, India.

In Dumka Upland, 150 - 200 metres is the most dominant altitudinal category. It prevails in the northern, western part. The second most dominant category ranges from 100 - 150 metres. This category is scooped out by the dominant rivers of Dumka Upland viz. the Mayurakshi, the Brahmani, the Dwarka, the Bansloi. Therefore, this category is confined to the valleys of these rivers. The remaining categories of 200 - 250 metres, 250 – 300 metres, above 300 metres are associated with residual hills. In the east it is represented by the Rajmahal and Ramgarh hills and in the south by the Masanjor-Satgarh-Sapchala hills. The lowest category of less than 100 metres is confined in the valley of the Mayurakshi river below the Masanjor dam and in the valley of the Brahmani river.

The rainfall is concentrated between the months of June to September. Maximum rainfall is recorded in the month of August (301 mm). Minimum rainfall occurs in the month of December (4 mm). High temperature is recorded in the month of April and May reaches its maximum in the month of May (31.5 ^{o} c). Minimum temperature is recorded in the month of January (18^o c).

Dumka upland is chiefly represented by the rocks of the Chotanagpur gneissic Complex, intruded by batholithic granites of Archaen to Proterozoic age. Within the granites and gneisses, patches of Archaen charnockite, granulite and Khondalite/ garnet-silimanite-biotite gneiss are located. Acid and basic charnockite granulite and Khondalite are intrusive in field relation, usually coarse grained and have subsequently been metamorphosed. Chhotanagpur Gneissis Complex is represented by garnet-biotite gneiss, augen gneiss, banded gneiss, migmatites, silimanite-biotite gneiss and porphyritic gneissic granite with enclaves of meta-sedimentary and meta-igneous rocks. The meta-sedimentary rocks are represented by quartz schist. Meta-igneous suite consists of mainly amphibolites, meta-dolerite, meta-gabbro and also pyroxenite, pyroxene granuite, occasional anorthosite and norite /meta-norite. Syenite and other younger intrusive granite occur in the form of small to large bodies within the gneiss. Pegmatites and veins of quartz traverse all these rocks during different tectonic regimes (G.S.I., 1998).

The most obvious morphological features which denote a dome are their domical form with summit convexity, steep slopes consisting of bare rocks and a clear differentiation from the surrounding terrain. These features are often associated with curvilinear joint patterns leading to the formation of sheets. It is because of these characteristics that this particular type of inselberg is also known as ‘exfoliation domes’ (Thomas, 1974, p. 173). Curved joints which are associated with ‘unloading’ exercise considerable influence on the external form of bornhardts. However, they do not play decisive role on the initiation of bornhardts (King, 1948). The boundaries of domes are often fracture controlled and occasionally show circular plans. However, in most cases rectilinear plans are noted (Twidale, 1964).

There is great variety in the morphology adopted by the domes and tors. They may be composed of one solid, virtually unjointed, rock mass standing in isolation above the adjacent slopes. They manifest curvilinear fracture pattern. They are also known as Bornhardt (Fig 2). Another type consists of a pile of boulders and is referred as boulderly inselberg/ block strewn inselberg or block and boulder-strewn dome (Fig 4). A third type manifests orthogonal fracture pattern and referred as castellated inselberg (Fig 6). Tors are generally comprised of one or more spheroidal blocks and rarely exceeds 30 m in height (Fig 7).

Figure 2. Dome developed in garnet-biotite gneiss near Kunji, Dumka. The small hill is nearly symmetrical and shows curvilinear fracture pattern. It shows evidence of both sub-surface weathering and tensional collapse. A talus of joint blocks can be seen at the base of the hill.

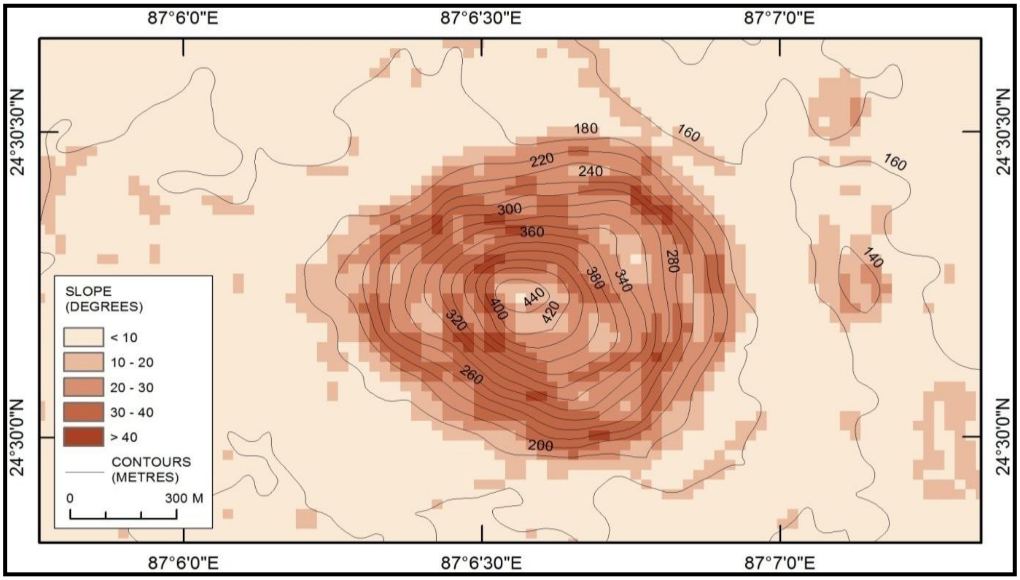

Figure 3. Slope of a boulder strewn dome near Lagwa, Nunihat

Figure 4. Dome developed in garnet-biotite gneiss with dense fracture patterns, near Lagwa, Dumka. The fracture pattern is obscured under the veneer of boulders. It seems that the present shape of the hill is derived from a large radius dome with closely spaced fractures

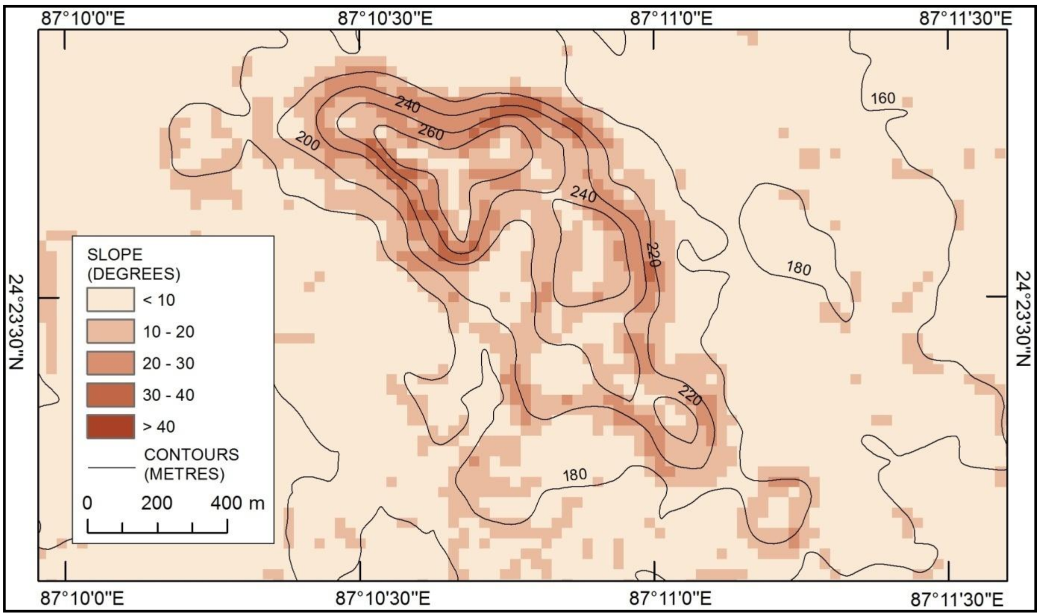

Figure 5. Slope of a dome near Sirsa, Maharo

Figure 6. Dome developed in garnet-biotite gneiss with orthogonal fracture patterns near Sirsa, Dumka. It seems that the present form of the hill is the shattered remnant of a primitive dome with much larger radius. Orthogonal fracture pattern can be seen in the main mass

Figure 7. Tor reduced to a group of residual corestones due to long continued weathering followed by removal of regolith

Morphological evolution of domes and tors

It was Falconer (1911) who worked in Nigeria, gave the first account on the origin of domes by exhumation: 'A plane surface of granite and gneiss subject to long continued weathering at base level would be decomposed to unequal depths, mainly according to the composition and texture of the various rocks. When elevation and erosion ensued the weathering crust would be removed, and an irregular surface would be produced from which the more resistant rocks would project' (p. 246).

Holmes and Wray (1913) working in Mozambique, suggested that the dome – like intrusions are the primary cause in determining the sites of the inselberg. The morphological diversity is brought by the weathering and erosion which in turn are guided by internal structure (pp. 146-147).

Willis (1934) noted four prerequisites for the formation of inselberg: They are: '1, a terrain chiefly composed of gneiss or schist, intruded granite and traversed by veins of aplite and quartz; 2, Vertical or steeply dipping schistocity and jointing which in general facilitates the decomposition of the rock and which serves to give precipitous faces to more massive or more quartzose bodies; 3, a climate characterised by warmth and humidity, favourable to abundant vegetation and rock decay, 4, notable uplift which in usual case will found to have progressed...with marked variation in the rate of elevation' (p. 127).

King (1948) argued that 'no single thing, structure or process is responsible for the development of bornhardts. Bornhardts are due to the twin process of pediplanation (scarp retreat and pedimentation) acting upon suitable rock types, following a geological history which involves stream rejuvenation.' (p. 83). He goes on to state that bornhardt cycle is cycle of pediplanation. The youth stage is characterised by incision of local streams diving the whole country into number of incipient bornhardts. The distribution of bornhardts is guided by the spacing of rectangular joint system. At maturity bornhardts disappear under erosion and pediments coalesce to form a wide pediplain. The remaining bornhardts often form striking features of the landscape. They may occasionally tower 1500 feet or more above surrounding pediplain. In extremely old age the bornhardts are reduced to piles of rock rubble. The landscape remains with little variation until fresh rejuvenation initiates a new bornhardts cycle (p. 87).

The subsurface weathering of rock and subsequent exposure of the residuals is also known as the 'Two-stage model' and is commonly associated with name of Linton (1955). While explaining the origin and evolution of Dartmoor tors, Linton (1955) remarked, '...Tors, core-stones and probably other residual rock forms are result of a two-stage process, the earlier stage being a period of extensive sub-surface rock rotting whose pattern is controlled by structural considerations and the later being a period of exhumation by removal of fine-grained products of rock decay' (p. 472).

Mabbut (1961) suggested 'domes originated as resistant, unweathered structural kernels within belts of more massive granite forming the interfluves' (p. 110). Similar ideas of dome formation have been advanced by Twidale (1964), Thomas (1965), and Doornkamp (1968).

The polyphase development necessary to explain high domes and the mechanism of stripping were the principal problems encountered by this exhumation hypothesis (Thomas, 1974, p. 191). The solution to this problem was offered by (Twidale & Bourne, 1975) who advanced a model of episodic exposure of inselbergs.

Morphological evolution of domes and tors in dumka upland

The Archaen gneissic terrain of Dumka Upland was subject to long continued erosion at the base level. Since Dumka Upland escaped orogenic deformation since the Cambrian period, process of denudation operated virtually unhindered for a long interval of time. The terrain was decomposed to unequal depths mainly according to the structural properties. Long continued erosion exposed these residual forms. Domes and tors are chiefly distributed over the garnet-biotite-gneissic belt. Within this belt, fracture pattern play decisive role in the genesis of domes, tor and topographic depressions. Hence, there is no petrological difference between the domes and the adjoining plains. The appearance of the individual landforms is guided by the pattern of fractures developed at surface or shallow subsurface in response to pressure release. The curvilinear fracture pattern gives rise to a typical bornhardt or dome. Dome developed in garnet-biotite gneiss near Kunji (Fig. 2) is an example of this category. In the second case a dome with dense fracture pattern will ensure greater subsurface weathering along the partings and individual blocks will be subject to spheroidal weathering. When weathering will remove the regolith, a boulder-strewn dome will appear. Boulder-strewn dome developed in garnet-biotite gneiss near Lagwa (Fig. 4) is an example of this category. In the third case a dome with orthogonal fracture pattern will culminate into a castellated dome. It is an intermediary situation between the two categories discussed above. Individual blocks will be more angular than boulder strewn dome but will also lack massive sheets which distinguish a typical bornhardts. An orthogonally fractured dome near Sirsa, Dumka has been cited as an example of this category (Fig. 6).

Therefore domes, boulder strewn domes and castellated domes are genetically related forms. A dome culminates into a castellated dome and boulder strewn dome due to long continued erosion. Boulder strewn domes often have massive unweathered compartments at their base. These massive compartments may again evolve in domes in due course of time. Frequent association of domes, tors and corestones in Dumka Upland indicate their common formational history (Fig. 7). Therefore, the morphological evolution of domes and tor in Dumka Upland supports structural hypothesis for their genesis. Climatic factors, particularly the availability of moisture facilitates subsurface exploitation of structural weaknesses.

Evidences for a sub-surface origin of domes and tors in dumka upland

The relation between weathering pattern and joint systems on one hand and relation between dome margins and fracture directions support structural control in the morphological evolution of domes and tors. Domes show highly variable morphology in terms of slope, variable morphology at the junction between hill slope and plain (Plate 3, 5). All these argue against a simple application of the theory of parallel retreat to account for origin of domes. The extent, depth and thoroughness of weathering over wide areas of the Dumka Upland support such a theory as the structurally controlled sub-surface weathering is the first stage in the subsurface formation of domes and tors. Frequent association of domes and tors and the merging of the two forms indicate their common origin. The spatial distribution of domes and tors of varying morphology with regard to major rivers and divides indicate randomness in their disposition and do not belong to a certain stage of geomorphic evolution of the landscape.

Conclusion

The Archaen gneissic terrain of Dumka Upland was subject to long continued erosion at the base level. Since Dumka upland escaped orogenic deformation since the Cambrian period, process of denudation operated virtually unhindered for a long interval of time. The terrain was decomposed to unequal depths mainly according to the structural properties. Long continued erosion exposed these residual forms. In Dumka Upland, varied morphology of domes such as high degree of asymmetry, variable height, variable slope at the junctions of hill and plain can be seen. The extent and depth of weathering is closely related with fracture patterns. Further, the correspondence of dome margins and the direction of fracture can also be noticed. All these circumstantial evidences are in favour of structural control on denudational processes and subsequent exposure and evolution of domes and tors. Domes can be regarded as a basic form from which castellated domes and boulder-strewn domes evolve due to subsurface weathering. The morphological evolution of such residuals can be explained in terms of fracture patterns. These morphological variations are often interpreted in terms of climatic geomorphology and hence, domes, castellated domes and boulder-strewn domes are considered to be typical of humid tropical, arid and seasonally humid tropics respectively. However, the worldwide distribution of the three types, and their co-existence in many areas as in Dumka Upland, favours structural hypothesis for their genesis.

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