Two Bridges Quarry

S. Campbell

Highlights

Two Bridges Quarry provides an excellent example of the 'decomposed' Dartmoor granite, and is one of the best sites in Britain for understanding the formation of tors.

Introduction

Two Bridges Quarry is one of the most important geomorphological sites in South-West England, and is particularly noted for its association with D.L. Linton's classic theory of tor formation (Linton, 1955). The site shows heavily decomposed granite juxtaposed with masses of harder, less altered granite, and was used as a field model by Linton to illustrate the first stage of tor formation by differential weathering. The site has also featured widely in subsequent studies supporting, challenging or modifying Linton's model (e.g. Palmer and Nelson, 1962; Brunsden, 1964, 1968; Gregory, 1969; Green and Eden, 1971, 1973; Eden and Green, 1971; Green and Gerrard, 1977), and the roles of pneu-matolysis (alteration of the granite by mineralizing fluids from deep within the Earth), subsurface chemical weathering and physical weathering by frost-action, in the formation of the altered granite (growan) have all been examined using evidence from this site (e.g. Doornkamp, 1974; Dearman and Baynes, 1978; Cullingford, 1982; Durrance and Laming, 1982). A summary of the site's scientific importance and conservation value was given by Campbell (1991).

Description

Two Bridges Quarry [SX 609 751] lies near Princetown on Dartmoor, and *c.* 6 km east of Merrivale. The floor of this small disused quarry is now occupied by a car park, but the curved working face (*c.* 20 m long by 6 m deep) still provides an excellent section through the granite and associated weathering products (Figure 4.13). Both ends of the exposure are occupied by relatively solid and intact masses of grey, coarse-grained granite, including intrusions of fine-grained aplite (Green and Gerrard, 1977; Dearman and Baynes, 1978). The largest of these masses (to the north) measures some 6 m wide by 4 m deep: it shows both vertical joints (at *c.* 1–2 m intervals) as well as subhorizontal sheet jointing or 'pseudo-bedding' (at *c.* 0.5 m intervals).

Growan or decomposed granite, up to 6 m in thickness, occurs between the more coherent granite masses (Figure 4.13) and (Figure 4.14). Thin quartz-tourmaline veins are present in this material: the structure of the original granite is undisturbed and the primary rock-forming minerals are readily identifiable (Green and Gerrard, 1977). This pattern, however, breaks down within *c.* 1 m of the ground surface. Here, the growan is commonly mixed with large angular granite clasts (head) and, in one or two places, the growan shows colour banding which indicates downslope bedding.

Interpretation

Linton (1955) regarded the growan at this pit as the product of subaerial chemical weathering, and the masses of more solid rock as unexhumed tors. Indeed, he considered that the field evidence from Two Bridges Quarry showed that the Dartmoor tors, in general, had formed in response to differential sub-surface weathering, with the decomposed granite (growan) having formed as the result of deep weathering by percolating groundwaters under warm conditions in the late Tertiary (the Neogene). This, he argued, developed a thick regolith with corestones occurring only where joint planes were widely spaced and where the granite was least susceptible to chemical alteration (Figure 4.2). The products of this weathering (the regolith or growan) were subsequently stripped by mass-wasting, probably by periglacial processes in the Pleistocene. Two Bridges Quarry was therefore fundamental for demonstrating an *in situ* example of the selective, deep chemical weathering necessary in Linton's model of tor formation: in most of the more exposed locations the weathering products had subsequently been removed, destroying the critical association of weathered and

non-weathered rock.

Palmer and Neilson (1962) disagreed, and related the breakdown of the granite at Two Bridges Quarry (and elsewhere) to pneumatolytic processes, arguing that the decomposition was not a prerequisite for tor formation. They argued that the tors had evolved in response to Pleistocene periglacial processes, and that granite had been removed from around the tors by physical frost-shattering and solifluction. A principal line of reasoning was that the altered granite material was found in valley bottoms and not around the tors themselves.

Alternatively, Brunsden (1964, 1968), also using evidence from Two Bridges Quarry, argued that characteristics of all three forms of rock alteration and breakdown (subaerial chemical weathering, pneumatolytic alteration and physical breakdown) could be found together at individual sites on Dartmoor. He argued that the bulk of evidence from Two Bridges Quarry showed that the decomposed granite there had originated from chemical weathering, most of the weathered deposits belonging to the 'pallid zone' in his classification (see Kaolinization or Tertiary chemical weathering?). He cited, in particular, the pronounced eluviation of clay minerals (found coating joint faces lower in the profile) and the progressive stages of physical disintegration shown by the deposits, and the spheroidal weathering and grus formation found in the lowest parts of the section adjacent to the corestones and 'solid' rock (Brunsden, 1964). Since some of the joint faces are marked by thin veins of tourmaline (cf. Green and Gerrard, 1977), the sections at Two Bridges also probably show evidence for pneumatolytic alteration. However, Brunsden suggested that tourmalinization could only be confirmed if the zone of decayed granite increased and widened with depth, if a widespread cover of solid unaltered granite could be proven and if there was an upward decrease in the frequency of alteration products. Since the depth and extent of alteration at Two Bridges Quarry (and elsewhere) cannot be seen, the role of pneumatolysis remains uncertain in this instance.

The evidence for physical processes in the profile at Two Bridges Quarry, however, was believed to be more sound (Brunsden, 1964): the weathering profile was capped by a thin, 'migratory' layer of head (Brunsden, 1968), and the observed leaching of minerals in solution and the eluviation of clays was also seen as consistent with frost-assisted physical weathering (Brunsden, 1964).

Eden and Green (1971) undertook a detailed mineralogical and grain-size study of the growan at Two Bridges Quarry and from comparable sites elsewhere on Dartmoor. They concluded that the growan was in fact characterized by a relatively low silt and clay content and by a high feldspar residue. These findings were not in keeping with those of Brunsden (1964) who had argued, partly on the basis of the evidence from Two Bridges Quarry, that the granite was 'well rotted' and 'incoherent' and consisted of as much as 90% quartz residue. Neither was there evidence, according to Eden and Green, for the leaching and eluviation of weathering products claimed by Brunsden. Instead, they argued that the high feldspar content and persisting rock texture of the growan showed that there had been only slight chemical weathering and a limited removal of weathering products: the low clay content of the growan was attributed to limited weathering rather than to leaching and eluviation. Although some translocated clay could be found in the profile near the ground surface and along joint planes, they argued that this had originated from the pedogenic zone since there was little evidence for its translocation deeper within the growan profile (Eden and Green, 1971). In conclusion, Eden and Green suggested that the growan at Two Bridges Quarry was only moderately decomposed, contrasting markedly with the alteration products caused by pneumatolysis (kaolinization) found elsewhere in the region. As such, they argued that it was unlikely that the growan had formed in the hot, humid environment perhaps implied by Linton (1955). Rather, it may have originated under conditions somewhat warmer than at present, perhaps akin to a 'meso-humid subtropical climate'.

Further detailed work was carried out at Two Bridges Quarry by Doornkamp (1974) and by Dearman and Baynes (1978). Doornkamp studied the micromorphological characteristics of detrital quartz grains taken from head deposits, bedded growan and *in situ* growan at the site, and from other locations on Dartmoor. He demonstrated that only the growan material at Two Bridges Quarry showed significant evidence for chemical alteration, most of the deposits elsewhere were strongly affected by the processes of mechanical weathering. Indeed, the various facies of head deposits could not be distinguished on the basis of quartz grain micromorphology, and even the bedded growan and *in situ* growan at most sites showed similar quartz grain surface features dominated by mechanical weathering. Quartz grains from the growan at Two Bridges Quarry, however, showed quite different characteristics, with solutional and etch features highly indicative of chemical weathering in a more humid and hotter environment than that found on Dartmoor today (Doornkamp, 1974).

He concluded that the evidence of chemically decomposed granite in Two Bridges Quarry alone could be construed to support Linton's hypothesis that a climate of a 'more tropical' nature had occurred on Dartmoor, and that it effectively produced a sub-surface differential weathering of the granite (Doornkamp, 1974; p. 81). Such evidence also supported Eden and Green (1971) who had concluded that there were only relatively few present-day remnants of any pre-existing widespread cover of a chemically weathered mantle. Either, most of this regolith had been removed during the Pleistocene or, more likely, the deep weathering described by Linton had been much more localized in the first place (Eden and Green, 1971; Doornkamp, 1974). A cautionary note should, however, be added: Doornkamp admitted that the evidence from Scanning Electron Microscopy (SEM) was probably insufficient to differentiate between the products of chemical weathering under a hot humid climate, and the effects of metasomatic (hydrothermal/pneumatolytic) alteration.

Dearman and Baynes (1978) further attempted to distinguish the relative effects of hydrothermal alteration, chemical weathering and frost-shattering on the formation of the rotten granite on Dartmoor, and also used evidence from Two Bridges Quarry. By mapping the distribution of equal intensities of granite decomposition at a number of sites, Dearman and Baynes constructed a model to allow differentiation between chemical weathering (characterized by an overall increase in intensity upwards to the ground surface) and hydrothermal alteration (characterized by an even distribution of alteration products with depth) at any given outcrop.

At Two Bridges Quarry, they demonstrated that only small proportions of the granite had been weathered to grade D in their engineering classification, most of the *in situ* growan belonging to their grade C. Since decomposition of the granite could therefore be demonstrated to increase in intensity upwards, they argued that the origin of the growan was attributable, at least partly, to chemical weathering. However, the precise structural controls on the extent and distribution of chemical weathering, like veins and joints, were also those which had controlled the original distribution of the hydrothermal alteration. Thus, although a dominant set of characteristics (chemical weathering or hydrothermal alteration) could be determined for any given profile, the precise contribution of each in exposures like those at Two Bridges Quarry, where both were believed to be present, was very difficult to ascertain (Dearman and Baynes, 1978). These workers also noted that nearly all of the granite weathering products (head, bedded growan and *in situ* growan) at the site had been substantially affected by frost-action, tending to support Brunsden's earlier argument.

Evidence from Two Bridges Quarry has important implications for landscape evolution in the Dartmoor region and, particularly, a major bearing on the genesis of granite landforms including tors. According to Eden and Green (1971) and Green and Gerrard (1977), it is clear that the growan at Two Bridges closely resembles, and is indeed typical of, weathered granite found elsewhere on Dartmoor and in other parts of Europe. The material is quite unlike the products of pneumatolytic alteration also present on Dartmoor and which are quarried from the southern part of the moor as china clay (Green and Gerrard, 1977). It is significant that substantial depths of the growan are confined, apparently, to the present-day valleys: they are not found on interfluve summits, and this condition may be the principal determinant in the distribution and formation of the tors themselves which are also found in similar locations and not on plateaux surfaces or the higher interfluves (Eden and Green, 1971; Green and Gerrard, 1977).

Although the general principle of a two-stage mechanism in the formation of tors was accepted by Eden and Green, they argued that the weathering process on Dartmoor was likely to have been much less effective and widespread than previously envisaged. Linton (1955), for example, implied the previous existence of weathered granite (growan) up to 20–30 ft (6–9 m) in thickness on Dartmoor, from which the tors were subsequently exhumed. Since the extensive plateaux surfaces of the region are largely devoid of tors and growan, it would appear likely that the weathering process was indeed more localized. Eden and Green (1971) argued that the tors had been exhumed from a sandy and not clayey weathering zone located principally in or adjacent to the main river valleys. These authors also recognized that many of the Dartmoor tors had been exhumed and modified by periglacial processes.

Two Bridges Quarry has furnished evidence for all the theories put forward to explain the altered or decomposed granite or growan of Dartmoor. As such, it is a key site for the understanding of longterm landscape evolution in the region, and holds one of the principal keys to explaining the origin, long-debated, of local and other British tors. There is no doubt that the origin of the decomposed granite on Dartmoor is critical to understanding how tors, such as those at Merrivale, formed. Two Bridges Quarry shows a profile considered by some to be typical of the Dartmoor growan, and one which has been used by many workers to demonstrate proposed mechanisms for granitic decomposition including chemical

weathering, pneumatolytic alteration as well as physical disintegration and weathering. Since the weathering products at Two Bridges Quarry are closely juxtaposed with more intact granite masses, which strikingly resemble unexhumed tors, the site has become a reference locality in theories of tor formation and granite landscape evolution. However, it must be stressed that the quarry does not provide a three-dimensional picture. The latest evidence from the site is probably the most convincing and suggests that weathering of the Dartmoor granite was selective and that it probably occurred under a warm and mildly humid climate. Major difficulties still remain, however, in assessing the relative effects of hydrothermal alteration and chemical weathering where they occur together in one section. Although the granite alteration scheme recently proposed by Floyd *et al.* (1993) for the St Austell Granite does not aid in this discrimination, it does provide an appropriate model and time-frame for geomorphologists working on the evolution of granite terrains and landforms.

Whereas nearby Merrivale exhibits one of the finest assemblages of tors (and associated periglacial landforms) anywhere in Britain, it does not provide the detailed juxtaposition of sedimentary evidence necessary to elaborate and test theories of the longer-term aspects of tor formation: this is provided at Two Bridges and Believer quarries. Although these quarries share some common characteristics, the evidence is complementary, and Bellever Quarry provides an altogether different insight into the geomorphological evolution of Dartmoor, showing particularly detailed evidence for periglacial slope processes and head formation. Together, these sites form a network indispensable to any detailed reconstruction of long-term geomorphological evolution.

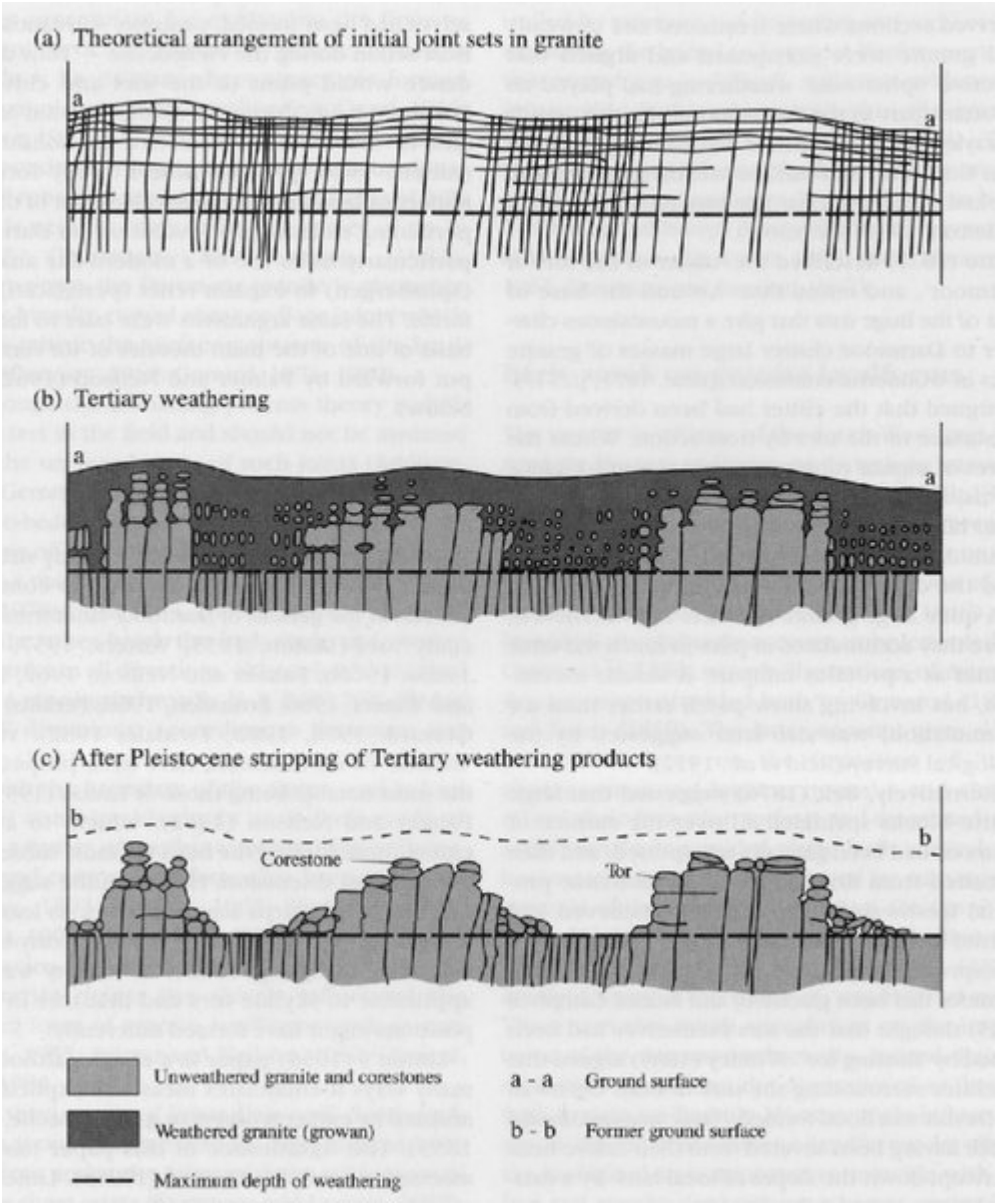
Conclusion

Two Bridges Quarry is one of the most important sites in Britain for understanding processes of granite alteration. The site shows relatively sound, unaltered masses of granite surrounded by softer, decomposed granite or growan. This association of rock and alteration products was central to D.L. Linton's proposal that many British tors had formed by differential chemical weathering of the granite in the Tertiary, followed by a stripping of the weathering products by periglacial processes in the Pleistocene. Many of the subsequent studies which have either challenged or modified Linton's classic theory, have also used Two Bridges Quarry as critical field evidence. In particular, the site has been central in establishing the relative roles played in alteration of the granite by pneumatolysis (alteration by mineralizing fluids from deep within the Earth) and chemical and physical weathering processes. The importance of Two Bridges Quarry, in conservation terms, can be summed up simply: its 'embryonic' tors juxtaposed with granitic alteration products will remain central to debates on the origin of British granite terrains and landforms.

References

(Figure 4.13) A cross-section through the granite and associated alteration products at Two Bridges Quarry, Dartmoor, adapted from Campbell (1991).

(Figure 4.14) The section at Two Bridges Quarry, showing large intact granite masses, the unexhumed tors and adjacent deeply altered granite. (Photo: S. Campbell.)



(Figure 4.2) Linton's (1955) classic two-stage model of tor formation.