Comparative morphology and weathering characteristics of sandstone outcrops in England, UK

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Abstract

Free-standing, inland exposures of sandstone cliffs are found in four regions of England: the Central Weald in the southeast; the Welsh Borders, North and West Midlands; the Pennines and Peak District of North Central England, and the North-East. Each of these groups of exposures is developed in sandstone of different age and geological characteristics. In the Weald the exposures are found in fine grained Cretaceous sandstones; in the Midlands and Welsh Borders, they occur in Triassic red-bed sandstones; in the Pennine uplands and the North-East they are developed in Carboniferous sandstones and gritstones. Despite their geological variation, sandstone exposures in these four regions exhibit considerable similarities in morphology and weathering. However, there are also significant differences in the dominance and frequency of different weathering features. This paper compares the morphological features of the different outcrops, the prevalence of different weathering phenomena and discusses their origin in relation to the geological characteristics of the sandstones, their environmental history and present day conditions.

Introduction

This paper examines the distribution of weathering and erosive features on inland sandstone cliffs and crags in England. It is not concerned with coastal cliffs, or actively eroding river cliffs. England has a broad range of sandstones varying in age from Devonian to Tertiary, but only the more massive and/or strongly cemented form cliffs and crags.

Inland cliffs and crags are restricted to four sandstone formations. The oldest sandstone that gives rise to inland cliffs is the Fell Sandstone, of Lower Carboniferous (Dinantian) age. It outcrops over a small area in the extreme north east of England (Fig. 1), and consists of a series of massive, deltaic, often cross-bedded sandstones (Sparks 1971; Turner & Smith 1995). The formation reaches a maximum thickness of around 330 m and forms impressive west-facing, often crag-topped escarpments, that reach a maximum elevation of 430 m OD.

Fell Sandstone is quartz-rich, but generally with < 10% feldspar and < 5% mica (Bell 1978). It is mostly fine to medium grained, with a mean grain size of 0.3 - 0.4 mm (Hodgson 1970; Bell 1978), though coarser, gritty and pebbly layers are found occasionally. It is a relatively strong sandstone (Table 1) with a moderately low porosity.

Further south and west, a later series of Carboniferous (Namurian) sandstones, known collectively as the Millstone Grit, also form cliffs and crags. They outcrop over a large area of the Pennine Uplands and the Peak District (Fig. 1). In the Pennines they reach a maximum thickness of 1800 m, in the Peak District their maximum thickness is about 1100 m.

The Millstone Grit sandstones alternate with finer-grained, argillaceous rocks. The argillaceous rocks dominate the lower part of the succession, the sandstones are more frequent towards the top. Some of the sandstones are fine grained and "flaggy", but most are medium or coarse-grained. Known locally as "grits" or "gritstones", their past use as millstones gave name to the formation. Many are feldspathic, and the feldpar contents may reach 27.5%, making them sub-arkosic or in extreme cases arkosic (Aitkenhead *et al*. 1985: 92). Cross-bedding is often present, sometimes on an impressively large scale.

The sandstones show marked lateral variations in thickness, and some persist only for short distances, passing laterally into shales. Physical properties vary, but generally they exhibit relatively high strength and low porosity (Fig. 1). Because of their resistance to weathering the sandstones often cap plateaus and escarpments, frequently outcropping as bold cliffs and crags. Isolated pinnacles, tor-like masses, block fields and clitter slopes are also quite common (Palmer and Radley 1961; Linton 1964). Most outcrops are angular to sub-angular, but more rounded crags and boulders can also be found. Apart from use as millstones, they have been exploited extensively for building stone.

The third group of cliffs are formed in the Triassic New Red Sandstone. Laid down under desert conditions, the predominant red coloration is due to haematite coatings around the grains (Hains & Horton 1969). Individual beds vary from well sorted, fine grained sandstones to poorly sorted, coarse grained pebble beds. Generally less well cemented, weaker and more porous (Table 1) than the Carboniferous sandstones, they form rather rounded or sub-rounded, discontinuous cliffs and crags, often capping low cuestas, that run south from the Mersey estuary through Cheshire and the North Midlands to the West Midlands and the Welsh Borders (Fig. 1). Occasionally they form pillars and low isolated masses resembling the stumps of tors.

The fourth group of cliff-forming sandstones, the Ardingly and Ashdown Sandstones, are early Cretaceous in age and outcrop as discontinuous lines of rather rounded valley-side crags and cliffs, occasional pillars and tor-like masses in central southeast England (Robinson & Willams 1976). The sandstones are poorly cemented and porous but exhibit sufficient strength (Table 1) to be used locally as a building stone. On exposure to the weather, the sandstone develops a crust which, as on many other sandstones, strengthens the surface and reduces porosity (Robinson & Williams 1987).

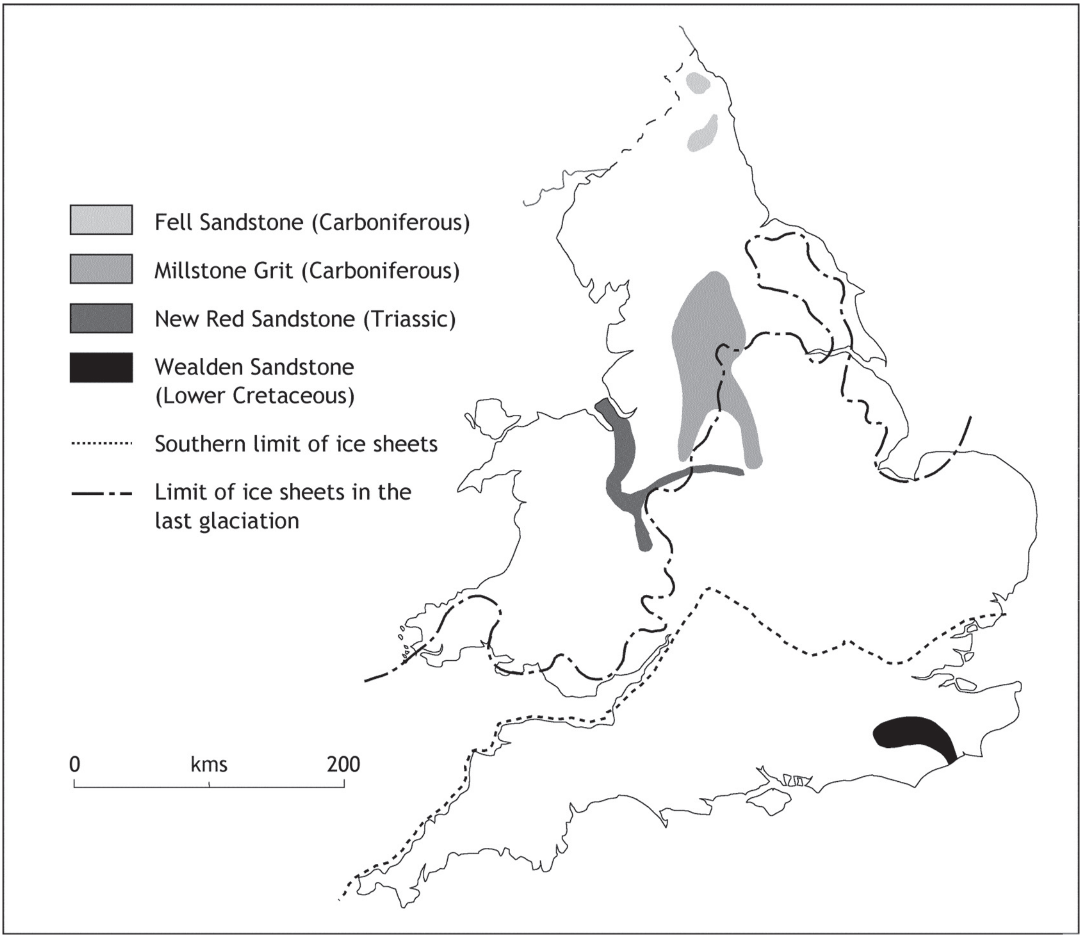

Fig. 1: Distribution of sandstone strata forming inland cliffs and crags in England.

Weathering features

The sandstones display a range of weathering features characteristic of temperate sandstone outcrops (Robinson & Williams 1994), but the extent to which individual features are developed varies between the four sandstones (Table 1). However, there is no clear relationship between the distribution of features and their glacial history. The Fell sandstone outcrops entirely within the area covered by the Devensian ice sheets (Fig. 1); the Millstone Grit and the New Red Sandstone outcrop on either side of the Devensian ice limit, but entirely within the area covered by earlier Quaternary ice sheets; the Wealden sandstones outcrop far to the south of the maximum limit of glaciation. Despite this, bare sandstone platforms or pavements are uncommon and limited in extent on all four sandstones, whilst relatively fragile, pillars and tors occur within the areas covered by Devensian ice. All four sandstones were subject to severe periglacial conditions during the Quaternary, and clitter slopes and blockfields most probably result from freeze-thaw processes under a periglacial climate. They are most common on the Millstone Grit which was immediately peripheral to the ice limits for much of the Devensian. Angularity of the cliffs and blockfields appears to be more closely related to rock hardness than to glacial or periglacial history, as evidenced by the rounded or sub-rounded forms of many of the glaciated outcrops of New Red Sandstone compared to the angularity of the Millstone Grit.

The development of honeycomb weathering depends on the porosity and mechanical strength, developing only rarely in the Millstone Grit compared to the more porous, and weaker Wealden, New Red and Fell Sandstones. In contrast, tafoni-like weathering is less clearly linked to these two properties. The world distribution of polygonal cracking suggests strongly that it develops best on rocks with a marked surface rind or crust (Williams & Robinson 1989). The lesser development of polygonal cracking on the Millstone Grit agrees with this conclusion. In contrast, weather pits and runnels, which require storage and flow of water on and over the surface of the sandstone, are both developed best on the relatively impervious Millstone Grit and are almost entirely absent from the porous Wealden sandstones. They are quite well developed also on the Fell Sandstone and on some New Red Sandstone exposures.

The ease with which rock surfaces suffer granular disintegration and abrasion is clearly related to cementation and surface strength. The New Red and Wealden Sandstones suffer significant losses whenever their protective surface crust is lost. There appears to be a cycle of crusting and spalling which periodically exposes a weakened sub-surface to granular disintegration. However at some sites, especially in the Weald, the process is accelerated by climbers and climbing ropes, and by foot traffic.

Undercutting is most common on the Wealden outcrops where cliffs outcrop on steep valley sides. Widened joints are best developed on these outcrops also, where they are believed to result from cambering under periglacial conditions. Caves are uncommon on all outcrops.

The role of climate and vegetation change is uncertain. The Millsone Grit and Fell Sandstones outcrop on high moorland and suffer significant winter snowfalls and frequent frosts but splitting of any rock is rare. The Wealden and New Red Sandstone outcrops are extensively wooded, but were probably less so at times in the past. Increased shade and dampness may reduce the incidence of honeycomb weathering which appears to develop best on surfaces subject to wetting and drying cycles. The most marked influence appears to be on some New Red Sandstone outcrops, where afforestation with conifers during the 20th century seems to be causing accelerated spalling and granular disintegration of the surface.

Table 1: Rock properties and weathering features of the four sandstones.

	Fell Sandstone	Millstone Grit	New Red Sandstone	Wealden Sandstone	Controlling Factor(s)
ROCK PROPERTIES[1]					
Dry strength (MPa)	74.1	39-104	11.6	31.5-51.9	
Wet strength (MPa)	52.8	24.3	4.8	13.4-51.4	
Porosity (%)	9.4-14.0	7.0-17.0	8.9-25.8	26-27	
Water saturation		0.51-0.74	0.62	0.67-0.72	
LARGE SCALE FEATURES					
Basal undercutting	rare	occasional	occasional	fairly frequent	Rock Strength Slope erosion
Pedestal rocks	rare	occasional	very rare	occasional	Undercutting
Pillars	rare	fairly frequent	very rare	occasional	Erosion of joints Cambering
Pavements	rare and limited in extent	rare and limited in extent	occasional	occasional, but limited in extent	Erosion of soil cover, not associated with glaciation
Widened joints	rare	fairly frequent	occasional	abundant	Cambering Gelifluction
Caves	rare	rare	rare	very rare	Widened joints and undercutting
Tors	absent	fairly frequent	very rare	very rare	Deep weathering? Freeze/thaw and gelifluction
Blockfields/ clitter slopes	fairly frequent	fairly frequent	very rare	rare	Gelifluction Cambering
SMALLER SCALE FEATURES					
Surface crust	inconspicuous	inconspicuous	conspicuous	conspicuous	Porosity
Surface abrasion and granular disintegration	limited	limited	common and widespread	common and widespread	Rock Strength Loss of crust
Rock basins	fairly frequent	fairly frequent	occasional	very rare	Porosity
Flutes	fairly frequent	fairly frequent	occasional	absent	Porosity/salts
Honeycombs	fairly frequent	occasional	fairly frequent	abundant	Porosity/ Exposure to wetting/drying cycles
Polygonal cracking	fairly frequent	very rare	occasional	fairly frequent	Crust development Wet/dry, heating/ cooling cycles?
Tafoni	very rare	very rare	very rare	absent	Porosity/salts
Surface spalling	rare	rare	fairly frequent	occasional	Cyclical Crust development Vegetation change

[1]Data collated from Bell (1983), Leary (1986), Natural Stone Directory (1991).

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Résumé de la présentation

Comparaisons des caractéristiques de la morphologie et de la désagrégation des affleurements de grès en Angleterre, R-U

Des affleurements naturelles de grès à l'intérieur de l'île existent dans quatre régions distinctes de l'Angleterre: le District de Wealden dans le sud-est; le pays de Galles et l'Ouest des Midlands; le haut pays des Pennines au nord de l'Angleterre centrale, et le Nord-est. Chacun de ces paysages gréseux est développé dans des strates de grès d'âge différent et de caractéristiques géologiques différentes. Dans le District de Wealden affleure un grès fin fin d'âge crétacé. Dans l'ouest des Midlands et le pays de Galles, on rencontre avant tout des formations rouges de grès permo-triassique. Dans le haut pays de Pennine et dans le Nord-est les affleurements elles sont dans des grès et des gritstones plus durs d'âge carbonifère.

Pendant la période quaternaire les affleurements gréseux ont subi des conditions environnementales et des oscillations sensiblement différentes. Ceci a continué au cours de la période historique jusqu'à nos jours. Chacun des quatre secteurs était sujet à des périodes intenses d'activité périglaciale et de tous sauf celui du Sud-est, subissaient les glaciers qui recouvraient la grande Bretagne au moins pendant une des périodes froides des dernières glaciations. Cependant, l'intensité de ces processus et de la fréquence du couvert de glace change d'une région à l'autre. Pendant l'Holocène, l'ampleur d'une couverture forestière et d'une végétation plus dégagée a différé sensiblement d'une région à l'autre, tout comme l'utilisation économique des grès pour la construction et pour les loisirs.

En dépit de ces différences, les expositions de grès dans ces quatre régions montrent de grandes similitudes dans leur morphologie et dans leur altération. Cependant, il existe des différences significatives, en particulier dans la dominance et la fréquence de certains phénomènes d'altération.

Cet article compare les phénomènes morphologiques visibles sur les différents affleurements, la prédominance de différents processus d'altération et discute leur origine par rapport aux caractéristiques géologiques des grès, de leur histoire environnementale et des conditions actuelles.