Phytokarst and Photokarren in Ireland

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Abstract: Light oriented phytokarst pinnacles, or photokarren, have been found adjacent to unroofed sections in several ancient cave passages along the Burren coast, Co. Clare, Ireland. This is the first record of photokarren in a temperate marine setting. The preservation of scalloping, formed when the cave was originally active and sea level was lower, in the darkest parts of the caves demonstrates that direct solution of limestone by sea water in intertidal situations is negligible. The destruction, by development of photokarren, of the scalloping adjacent to unroofed sections of passage shows that most erosion of limestones in temperate intertidal situations can be ascribed to the actions of algae. Comparison of karst forms found within the cave with those on the adjacent intertidal and supralittoral ledges indicate that the role of algae is greatest in the Littorina and Verrucaria Zones but is moderated by other biotic factors in the Barnacle and Mussel-Echinoid Zones. In Britain and Ireland photokarren has been found only in caves with a significant marine influence.

On visits to the Burren, Co. Clare, Ireland, light-oriented pinnacles (photokarren of Brook & Waltham, 1978) have been observed in parts of several fossil cave passages which now lie partly in the intertidal zone between Doolin and Fanore. Photokarren are erosional features produced by the boring and/or solution action of algae and have previously been noted only in tropical cave entrances (Bull & Laverty, 1982). Their discovery in temperate caves is in itself of some interest but of greater significance are the implications which their absence from the darkest parts of the cave has for theories on the erosion of all limestone now lying within, or immediately adjacent to, the marine environment in temperate regions.

Limestones exposed along temperate marine coastlines often display a characteristic suite of erosional and solutional features quite distinct from those found in freshwater or subaerial situations. The extent to which solution alone has influenced the development of these karst forms has been a source of speculation. Since sea water is saturated with respect to calcium carbonate, no solution of limestone should occur in normal marine environments. Respiration of marine organisms in intertidal situations, particularly at night when there is no photosynthetic absorption of respiratory carbon dioxide, has been suggested as a mechanism for raising the pH of sea water and hence causing solution of limestone (Folk et al., 1973; Holbye, 1989). However, it is now recognised that the activities of many marine organisms may have a more direct influence on rates of limestone erosion in the intertidal and subtidal zones.

Intertidal karst zonation

A clear zonation of karst forms has been documented on the Burren coast (Lundberg, 1977; Trudgill, 1977, 1985), extending from just below Low Water Mark (LWM) into the splash zone above High Water Mark (HWM). The karst morphology characteristic of each zone has been assumed to reflect the bioerosional effects of the dominant marine organisms at that level. The Mussel-Echinoid Zone, just above LWM, has sharp fretted pinnacles, often encrusted with mussels, surrounded pools crowded with echinoids (Paracentrotus), each of which occupies a small cavity which it has excavated in the floor of the pool. The Barnacle Zone, around mid-tide level, is characterised by rounded pinnacles heavily encrusted with barnacles. Extending from around HWM up to 2-3m above, are the Littorina and Verrucaria Zones, with shallow sharp-edged depressions, small pinnacles and a sharply pitted surface. In addition to the obvious macrofauna and algae of each zone, Trudgill (1977, 1985) found that microscopic boring algae form a significant element of the total biota and make an important contribution to limestone erosion.

In many tropical situations, both terrestrial and marine, algae have been recognised as an important component of the development of particular karst forms, particularly types of pinnate karst (Bull & Laverty, 1982). In temperate climates, however, less is known about the role of algae in karst development. Furthermore, although it is recognised that algae are important in the development of intertidal karst, the presence of other bioeroders renders it difficult to assess the relative contribution to erosion provided by the algae.

The presence of tidal conduit cave passages, now partly invaded by the sea, provides an opportunity to assess how important algae are in producing these intertidal karst forms. Solutional features found on passage walls must have developed when the cave was active and sea level was lower. Since algae require light to photosynthesise, and hence cannot survive in darkness, the extent to which these original solutional features have been modified in the darkest parts of the cave provides a measure of the extent of non-algal erosion of the limestone since the cave was inundated by the sea.

PHOTOKARST ON THE BURREN COAST

Photokarren pinnacles have been observed in several marine-inundated caves along the Burren coast between Doolin and Fanore. Of these sites the most readily accessible are the 39 m long section of vadose canyon on the north side of Poulsallagh Bay (Self, 1981) and the partly unroofed vadose canyon, known locally as 'Hell', on Doolin Point (Boycott & Wilson, 1986; Jones, 1988). Since photokarren are better developed and more readily accessible at the latter site than elsewhere, only that site is described.

The main part of 'Hell' accessible to non-divers comprises a straight section of ancient cave passage developed along a major north-south joint. Remnants of four small elliptical phreatic tubes with minor vadose trenching, all developed on a single bedding plane, can be seen to meander across the surface of Doolin Point, roughly along strike. The two northern inlets enter high in the
walls at the southern end of ‘Hell’, which here is a tall vadose canyon up to 1.5m wide and about 6m high, while the two southern inlets unite before entering the vadose passage at its extreme southern end. Scalloping is well developed on the walls in places. Elsewhere, eroded remnants of flowstone can be seen adjacent to where the phreatic tubes enter. ‘Hell’ is unusual among Burren caves in having drained northwards against the dip, which is here about 2-3° to the south. Towards its southern end part of this vadose canyon has been unroofed. Northwards the roof descends at a shallow angle so that even at low tide much of the northern part of the passage is accessible only to divers. At its northern end the passage is considerably smaller and appears to be a vertically elliptical phreatic tube with a small vadose trench in the floor (Tim Fogg, pers. comm.). Other passages lead off to the east and west. The main passage is now truncated by a submarine cliff, from which it emerges at a depth of about 5m (Boycott & Wilson, 1986). Almost certainly it operated originally as an inlet to the major conduit of Mermaid Hole which lies a short distance to the north (Jones, 1988).

Photokarren are well developed in ‘Hell’ in the area adjacent to the unroofed section of passage. Precise morphology varies both with distance above sea level and position relative to the local light source (the unroofed section).

From LWM up to about 3m above LWM the limestone surface is fairly rounded, without pinacles, and encrusted by red algae, particularly the encrusting Lithothamnion. The transition to the photokarren pinacle zone is fairly abrupt, generally occurring over a distance of less than 0.5m, though Lithothamnion crusts may persist locally up to about 1m above this level on chert bands. The lowest pinacles are rather coarse and blunt and often coated with pale Lithothamnion crusts. Above this the pinacles are sharper and almost vertical. They are best developed about 3.5-4m above LWM, where they may be up to 60mm or more in length, tapering from a base about 20-30mm wide. They decrease in size upwards but are still found more than 5m above LWM, beyond which they give way to a black crust of the lichen Verrucaria. Locally, small photokarren pinacles may occur up to 8m above LWM where the Verrucaria crust is absent, particularly where a coating of ancient flowstone is present. Pinacles are best developed on steep, dimly-lit faces. On gentle slopes and horizontal surfaces the pinacles grade into an irregular pitted surface (Figure 1). Overhanging surfaces have no pinacles.

On fairly well-lit surfaces within the cave the pinacles are sharply conical and usually less than 10mm long. Moving away from the light source pinacles become larger and more blade-like and are oriented towards the light at angles of 20-35° from the vertical. Still further from the light source these blade-like pinacles merge into elongate flakes and ‘terraces’ (Figure 2). Relief on these flakes may reach 40mm or more while individual ‘terraces’ can be traced along the walls for a metre or more, with a vertical separation of 50-150mm between ‘terraces’. In still darker parts of the cave these terraces and pinacles become less distinct until, in the darkest areas, the original scalloping of the passage walls is clearly visible.

Pinnacles in the more dimly lit parts of the cave have a strong surface coloration, presumably due to the presence of the algae responsible for the formation of the pinacles. The relatively smooth vertical or steeply angled faces of pinacles have a dark greenish-black hue while the pits and gentle slopes between pinacles have a distinct purple coloration and a more corroded texture. Close to the surface in the better lit parts of the cave the pinacles are much smaller and these colours are much fainter. The observed fauna in the intertidal and immediately supratidal part of ‘Hell’ where the photokarren pinacles are developed is restricted to small numbers (<5m²) of patellid and littorinid gastropods (limpets and winkles) and a few balanid barnacles. Neither echinoids nor mussels have been seen at any level and there is no evidence in the cave of any of the distinct zones which have been recognised on the intertidal platform immediately outside.
DEVELOPMENT OF THE PHYTOKARST

The solutional scallops on the walls of 'Hell' clearly formed when the cave was active prior to its inundation by the sea. Hence their preservation, virtually unchanged in the darkest parts of the cave over probably more than 10,000 years, since the end of the last glacial maximum, testifies to the negligible dissolution of limestone directly by sea water. In contrast to these intact scallops, the walls adjacent to unroofed sections of passage display varying degree of modification by the development of phytokarst. The size and shape of phytokarst pinnacle is related both to local light levels and to their position relative to tidal levels. Together these factors determine the degree of desiccation which the pinnacles experience during each tidal cycle. The phototropic orientation of the pinnacles proves conclusively that they are due to the action of algae, as demonstrated for tropical photokarren (Bull and Laverty, 1982).

The conclusion to be drawn from the preservation of solutional scallops in the darkest parts of the cave, the absence of typical intertidal zonation and the development of phototrophic phytokarst pinnacles adjacent to a local light source, is that the boring and/or corrosional effects of marine algae represent the major component of karst development in intertidally exposed limestones. As such it is responsible for the distinctive suite of karst forms found on temperate limestone coasts. In temperate regions photokarren appears restricted to sites with a strong marine influence. It has not been found around any cave entrances further inland on the Burren or elsewhere but has recently been found in several ancient conduit caves developed in Ordovician limestones on the coast of Portrane, in north County Dublin.

Comparison with intertidal karst

The characteristic pitted surfaces of small pools and depressions in the Verrucaria and Littorina Zones bear striking similarity to the karstic features developed on gently sloping or sub-horizontal surfaces adjacent to the unroofed section of 'Hell' and suggest that most erosion of limestones in the splash zone occurs through the agency of bioerosive algae. The more rounded pinnacles characteristic of the Barnacle Zone probably reflect the way in which the encrustation of limestone surfaces by successive generations of barnacles prevents the development of typical phytokarst forms. Bioerosive algae may be able to colonise small areas of limestone exposed in the gaps between adjacent barnacles but are quite likely to be smothered subsequently by the settlement of later generations of barnacles. Any initial angularities in the limestone which are unfavourable for barnacle settlement will inevitably be subjected to more prolonged attack by bioerosive algae, causing the preferential removal of angularities and thereby accelerating the development of the rounded pinnacles typical of this zone. The complex fretted pinnacles and pools of the Mussel-Echinoid Zone clearly have a strong algal component to their formation but it is clear that echinoids are also major bioeroders of limestone in this region. Where present it is probable that echinoids are of considerably greater importance for limestone erosion that are algae, though where they are absent then algae probably assume the dominant role in this zone also, with various borers and grazers comprising only a subsidiary element.

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REFERENCES


