Field Studies 7 (1988), 239–279

INTEGRATED GEOMORPHOLOGICAL AND ECOLOGICAL STUDIES ON ROCKY SHORES IN SOUTHERN BRITAIN

STEPHEN TRUDGILL
Department of Geography, The University, Sheffield, S10 2TN

ABSTRACT

The relationship between landforms and organisms on rocky shores is often a two-way one. The shape and distribution of intertidal landforms, such as pinnacles and pot-holes, can substantially modify exposure conditions, giving rise to micro-habitats for both plants and animals. On many shores, and especially on calcareous rocks such as limestone, landforms can be produced or modified by the erosive actions of plants and animals—actions collectively termed *bioerosion*. This paper first discusses the principles involved in an integrated geomorphological and ecological study of rocky shores and then describes specific case studies.

INTRODUCTION

ON rocky sea shores, plants and animals have been able to colonise a wide range of conditions of exposure to wave action and drying. In many situations, the shapes of the landforms on the shore have considerable effects on the conditions influencing plant and animal life. In particular, the existence of rock pools, crevices and rock pinnacles affords shelter and protection which encourage the colonisation of plants and animals in these positions. Thus, for example, organisms which are adapted to sheltered or moist conditions are able to grow more widely on dissected shore surfaces than on a simple rock surface without pools or other features. Landforms can have a considerable influence on the local distributions and activities of intertidal organisms by modifying exposure conditions.

On the other hand, certain plants and animals influence the evolution of landforms. The solid substratum may be subject to boring, abrasion or chemical weathering processes through the activities of organisms. The processes whereby organisms may directly or indirectly cause rock erosion are collectively termed "*bioerosion*" (as described by Trudgill, 1983, Ch. 4.8; 1985, Ch. 9; 1987; Trudgill & Crabtree, 1987; Trudgill *et al.*, 1987). Such processes are common on a wide variety of substrates, particularly the softer rocks, (such as the poorly cemented sandstones, shales, mudstones and clays) but they also occur on chalk, some schists and volcanic rocks. They are particularly marked on limestone coasts. As limestones can be dissolved by acids, it is often concluded that much of the biological attack is chemical—involving the production of acids by organisms. This is sometimes the case, but it is not necessarily so as many processes are solely mechanical while others involve the combined actions of physical and chemical processes.

By contrast, some plants and animals cover the rock so that they actually protect it from other erosional processes, such as wave action. Individual plants or animals may attach themselves to the rock surface in isolated locations or they may form a complete covering. The protection of the rock is not necessarily assured, however, because some organisms may be torn away in storms, taking some of the rock with them.

In these ways, the landforms of the rocky shore and the organisms growing on and in them can have complex inter-relationships—landforms producing exposed and sheltered sites and organisms contributing to the erosion or protection of rock. Careful observation is required to reveal the nature of these relationships.

Biologists studying intertidal distribution patterns traditionally focus on plants and animals and neglect to consider the evolution of substrate morphology, although they commonly stress the effect of morphology on zonation and species distributions. Geomorphological study also has its own focus, especially in the survey of rock platforms and on beach profiles. In this case, there is less reference to biota but attention is paid to the evaluation of the dominant erosion processes at particular points on the shore, including wave action, abrasion, salt weathering and bioerosion.

This paper attempts to bridge the gap between these two approaches and to stress that on all rocky coasts there exist opportunities for the integrated study of the plants, animals and intertidal landforms. Guidelines are suggested and case studies on British shores are described, but before this, the principle organisms involved in bioerosion and protection are discussed. If these are already known, the reader can turn to the summary and study guidelines on p. 251.

BIOEROSION

The major groups of biological influences upon landform evolution are first outlined briefly and then further detail is given for each group.

1. *Boring algae and lichens* are widely found on many surfaces but are most common on limestone. They may penetrate the rock surface, leaving networks of fine tubes and small pits about 5–15 μm in diameter. Algae which occur below the rock surface may either be *endolithic* and bore directly into the rock grains, or *chasmolithic* and exist in the pore spaces between the rock grains. Those algae which occur on the rock surface are termed *epilithic*.

2. *Boring sponges* are common in carbonate-rich rocks, such as chalk, limestone and calcareous sandstone. They excavate slits in the rock about 1–2 mm long, 0.5 mm wide and up to 1–2 mm deep.

3. *Boring annelid worms* are found in limestone and soft calcareous rocks. They excavate tubular borings about 1 mm in diameter.

4. *Boring molluscs.* Some bivalves bore into limestones and softer substrates, including chalk and clay, leaving small flask-shaped excavations, often 5–10 mm wide and up to 50–100 mm deep. Boring molluscs should be distinguished from burrowing molluscs which excavate temporary holes in loose, unconsolidated, soft sediments such as sand and mud.

5. *Boring sea urchins* excavate shallow depressions or pits in the rock surface, often up to 50–100 mm deep. Boring species are not widely distributed in the UK, but are locally common on limestone in western Ireland.

6. *Grazing molluscs* are the most widespread erosive organisms and are found on virtually all rocky shores. Many molluscs graze on epilithic and subsurface algae, often removing appreciable quantities of rock as they do so. Some limpets also excavate a ring shaped

"home scar" with their shell to which they return by day. Grazing molluscs of many species can be found on consolidated shores in the UK.

7. *Encrusting organisms.* These include widely distributed species of annelid worms, barnacles, mussels, lichens, coralline and other algae. As mentioned above they often protect the rock but they can become bioerosive agents if removed in storms with rock material attached. This is especially true of the larger algae.

At this stage, details of the groups above will be described; this can be read for future references or the reader could proceed to p. 251 for guidelines to field study, referring back to this section for points of detail if necessary.

Boring Algae, Fungi and Lichens

Boring algae are commonly found on limestone shores where they are widely distributed below the upper intertidal zones. They can also be found on other shores, especially where the rock is soft, porous or carbonate-rich, such as a calcareous sandstone. Fungal threads may penetrate rock surfaces, usually in association with lichen colonies. The extent of algal colonisation in limestone can be very widespread but it is often not readily apparent unless the rock is split open. Sections of rock can reveal a green stain just below the surface, though these are often non-boring chasmoliths.

From a conservation point of view, it is preferable not to destroy areas of rock by hammering and so surface examination is more desirable. From the surface, a hand lens is necessary to see the borings, and, even then, only the larger ones will be seen—most are only apparent by microscope examination.

However, despite their small size, the importance of these plants in landform evolution is undoubted. This is revealed by examination at high magnification which can show that as much as 50% of an apparently sound surface is, in fact, void space. Compare Fig. 1, which shows a limestone surface at low magnification, with Fig. 2 which shows the same surface at high magnification. In the latter photograph, the network of rounded algal borings is clearly seen, with a "lacework" of rock material remaining.

The algae are filamentous and are mostly blue-greens = Cyanophytes (now also termed Cyanobacteria), but green and red algae may also be involved. All are difficult to identify, as their morphology is strongly dependent upon their environment—one species may appear in different forms under contrasting environmental conditions and different species may appear very similar in the same environment. Because of this problem, Drouet and Daly (1956) suggested the blanket use of the name *Entophysalis deusta* for boring algae, but differentiation has since been made by Carr and Whitton (1973) and by Schneider (1976). Common forms identified are the genera:

Hormathonema: short, thick, blue-black threads.

Kyrtuthrix: double-loop threads with "U" shaped bifurcations; deep blue-green colour.

Mastigocoleus: fine, branching threads.

Scytonema: with small "false" branches, sharp bends and turns.

In the field it is virtually impossible to differentiate the genera (let alone species) and even under microscopical examination it is difficult; often all that can be seen are the borings which connect to the surface and which are empty of their former occupants—the living algae being present some millimetres below the surface.

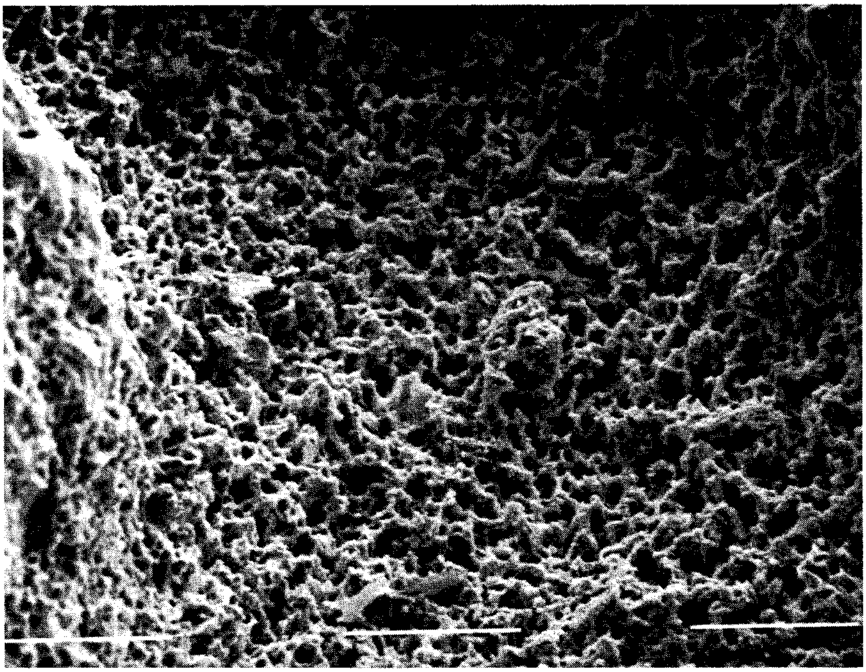


FIG. 1.
Photograph of the surface of intertidal limestone, Co. Clare, Eire, showing an apparently sound surface (× 160).

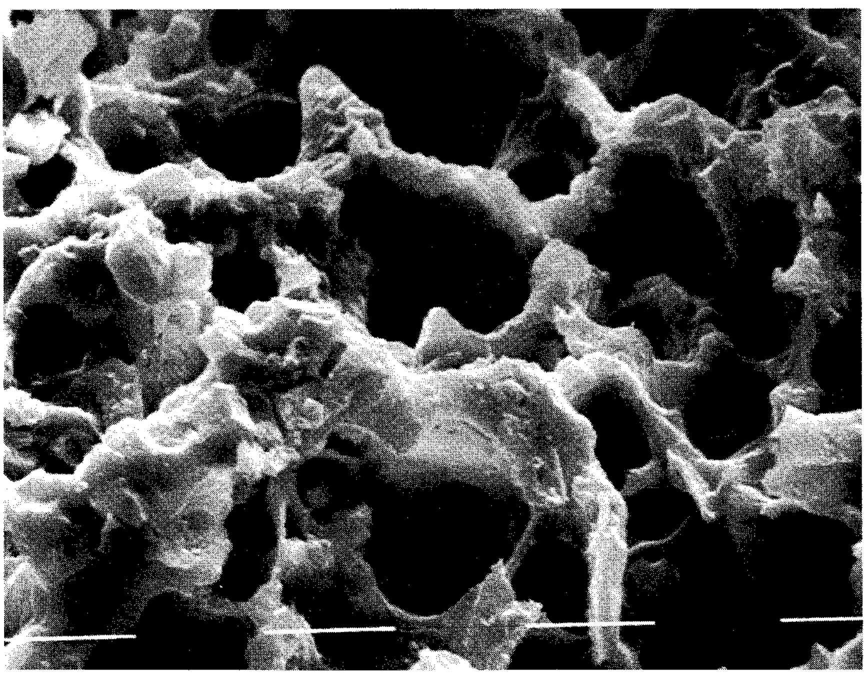


FIG. 2.
The same surface at high magnification (× 1250) showing algal borings.

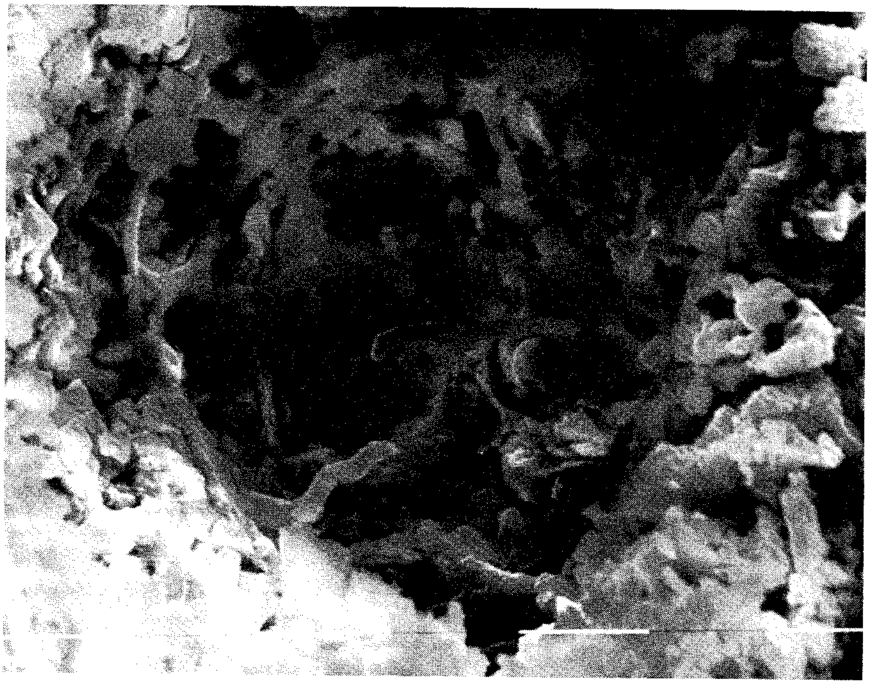


FIG. 3.
Photomicrograph of a lichen pit in intertidal limestone surface, Co. Clare, Eire (× 1250).

The algae normally penetrate 1–2 mm into the rock. They are positively hydrotropic and penetrate away from the drier surface. However, they are also phototrophic in the sense that they cease to photosynthesise if they bore too deep. Thus, their depth in the rock is a balance between the surface where it is too dry but sunlight is available (or too intense) and the deeper rock which, although moist, is too far removed from the surface for photosynthesis. This may mean that they bore deeper in the upper intertidal zone where the surface is more prone to drying out and sunlight more intense and less deep lower down the intertidal where it is moister and the sunlight is less intense because of deeper water or the presence of other shade-giving organisms.

Algal borings are difficult to differentiate from fungal borings and small perforations in the rock are as likely to be fungal, as they are to be algal, in origin. Fungal penetration of terrestrially exposed limestone surfaces in association with lichens is documented by Jones (1965).

The fungi bore deeper than the algae but usually live by functional contact with the algae. They invade the rock most intensively when it is moist. Endolithic lichen colonisation can also be marked, notably by *Amphoridium calcisedum* (Schneider, 1976), leaving a mass of small pits at the surface, spaced out at about 10–15 mm^{-2}. A high magnification of a lichen pit from an unidentified species is shown in Fig. 3. A readily observed boring lichen is *Arthopyrenia* sp. which can commonly be seen in shells of limpets (*Patella*) as small black dots (Fig. 4).

Boring Sponges

The boring sponge *Cliona* excavates small cavities in limestone surfaces and shells. The holes are clearly visible to the naked eye as slits about 1–2 mm long (Fig. 5). The sponge

FIG. 4.
Small black dots of the lichen *Arthopyrenia* in a limpet shell (× 10).

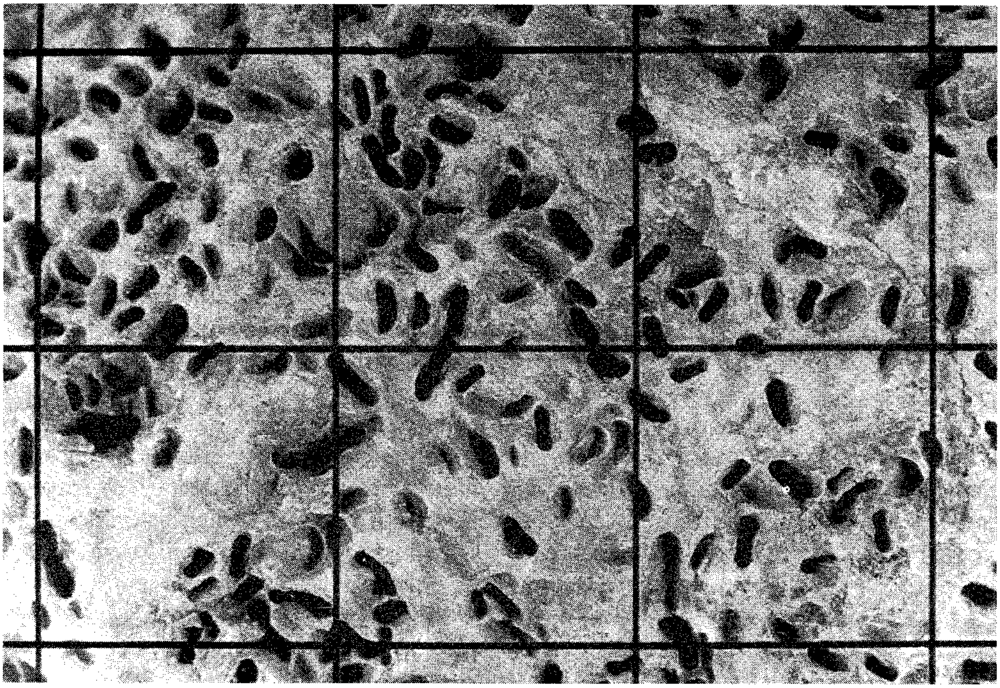


FIG. 5.
Slits of the boring sponge, *Cliona* from Penmon, Anglesey, N. Wales the grid is of 1 cm squares.

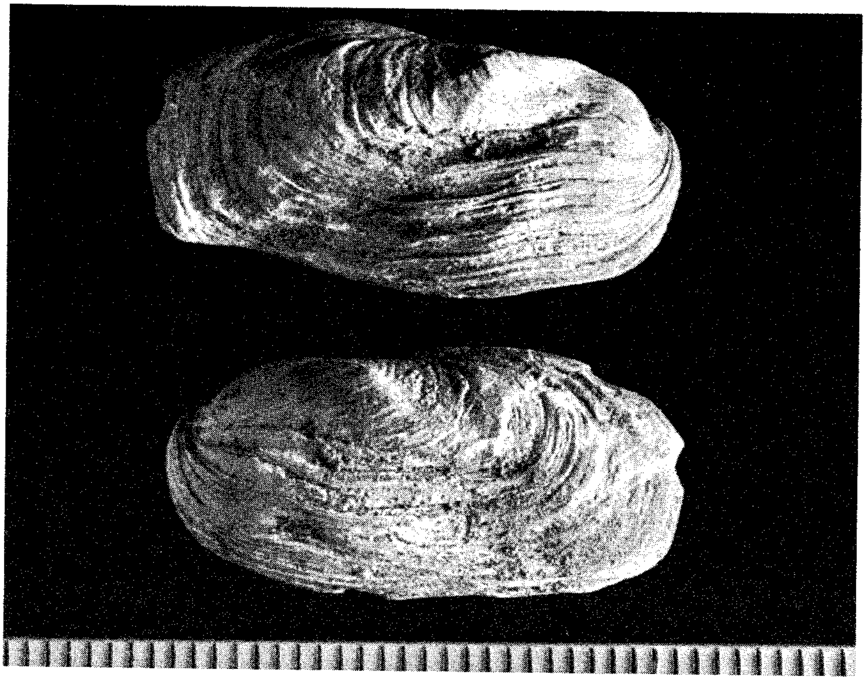


FIG. 6.
Shell valves of the boring bivalve, *Hiatella arctica*. Scale in mm.

bores for protection and feeds on microscopic debris and organisms using currents of water. Occupied slits are normally confined to the base of pools and permanently moist surfaces in the lower intertidal zone and below. In life, the sponge appears as small yellow blobs in the rock. Most commonly, the empty slits may be seen in rock fragments, pebbles and shells thrown up during storms. In non-limestone areas they are most often observed in shells from the lower intertidal and subtidal zones, especially those of oysters (*Ostrea edulis*) and whelks (*Buccinum undatum*).

During excavation, part of the sponge (called an etching amoebocyte) extends into the calcite crystals, removing small semi-circular chips. This process leaves small semi-circular cavities in the crystal, readily seen under high magnification (Cobb, 1969). Several kilogrammes of material may be removed per square metre by this means; for example, Neumann (1966), working in Bermuda, recorded a maximum rate equivalent to 18–25 kg m^{-2} a^{-1}* during the initial stages of colonisation of limestone substrate.

Boring Annelid Worms

Most boring worms are polychaete (many bristled) annelid segmented worms. *Polydora ciliata* is very common in limestone on some parts of the UK coast. The "U"-shaped tubes, 0.5–1.0 mm across, are sinuous and may extend for 10 mm into the rock.

Boring Molluscs

Several genera of bivalve molluscs bore into wood, peat, clay and other soft rocks. The piddocks (*Barnea*, *Pholas* and *Zirphaea* spp. and some other locally distributed genera) bore into soft substrates such as clay and peat but are also found in mudstones, chalk and limestone. In harder rocks, the principal borer in Britain is the wrinkled rock borer,

*kg m^{-2} a^{-1} = kilogrammes per square metre per year.

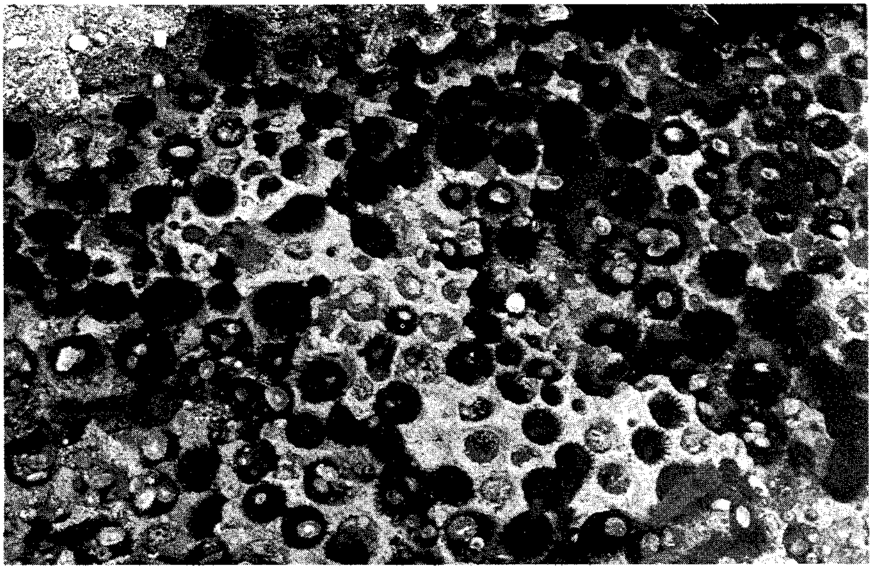


FIG. 7.
Excavations by the sea urchin *Paracentrotus lividus*, Co. Clare, Eire.

Hiatella arctica (Fig. 6) which is commonest on limestone (there has been some taxonomic confusion over this species, with older references to *H. arctica, H. striata* and *H. gallicana* and to the genus *Saxicava*; current usage adopted here is to refer solely to *Hiatella arctica*). The flask shell, *Gastrochaena dubia* also bores in hard rocks locally in the south west. *Sphenia binghami* lives in crevices but may also bore.

The method of excavation used by *Hiatella* is a matter for debate and was discussed at some length by Hunter (1949). It is clear that further research is necessary to clarify this topic but it is possible that both mechanical and chemical processes are involved. However, mechanical wear on shells is not clearly visible, neither are acid secretion glands evident; it is possible that respiratory carbon dioxide or mucous secretions with a chelatory enzyme may be involved in a chemical process and that rock fragments may be dislodged by movements of the shell achieved by muscular contraction and expansion. The rates of boring by bivalve molluscs are difficult to determine, but estimates of age using growth rings indicate that they may be as high as 10 mm a^{-1}. The rates are lower in the harder rocks and they decrease with the age of the individual borer (Trudgill, 1985, Ch. 9; Trudgill & Crabtree, 1987).

Boring Sea Urchins

The sea urchin *Paracentrotus lividus* excavates cavities in limestones, apparently in response to exposure, boring deeper for protection under conditions which are more exposed to wave action (Otter, 1932, Trudgill, 1985, Ch. 9; Trudgill *et al.*, 1987). Its distribution in the British Isles is limited but it is locally widespread on Irish limestone coasts, notably in Bantry Bay and on the south side of Galway Bay. *P. lividus* is largely confined to rock pools in the mid-intertidal zone but also occurs in the lower intertidal zone.

The excavation is mechanical and is achieved by the abrading action of the teeth and spines, leaving behind a smooth-sided hemispherical pit (Fig. 7). From studies of growth

FIG. 8.
Two limpets (*Patella vulgata*) and an unoccupied limpet scar. Watchet, Somerset. (photo J. H. Crothers).

rings, it has been estimated that the rate of excavation may approach 10 mm a^{-1} (Trudgill, 1985, Ch. 9; Trudgill *et al.*, 1987).

Grazing Molluscs

Many gastropod molluscs, and almost all chitons, graze on algae. Those which graze on the algae growing close to, or within, rock surfaces often remove appreciable amounts of rock during grazing. Others, graze or browse on purely epilithic algae, and have little geomorphological effect. It is those which ingest endolithic and chasmolithic algae which have the effect of modifying the surface form.

Limpets of the genus *Patella* commonly wear away a "home scar" site. This is a small ring-shaped depression to which the limpet returns by day after grazing during darkness (Fig. 8). In soft rocks the depression can be several millimetres deep but on harder rocks, a close fit to the surface is achieved more by the variable growth of the shell, than by abrasion of the rock.

The principal grazers which have geomorphological effects on British shores are:

Mollusca: Placophora: Chitons: (12 British species not very effective at rock erosion)

Lepidochitona cinereus	widespread and abundant
Tonicella rubra	widespread but not very evident
Acanthochitona crinitus	widespread in the South and West

Mollusca: Gastropoda: Limpets: (effective at rock erosion, especially on softer rocks), (Fig. 9)

Patella vulgata	widespread and common
Patella aspera	Southwest, West, extreme Northeast

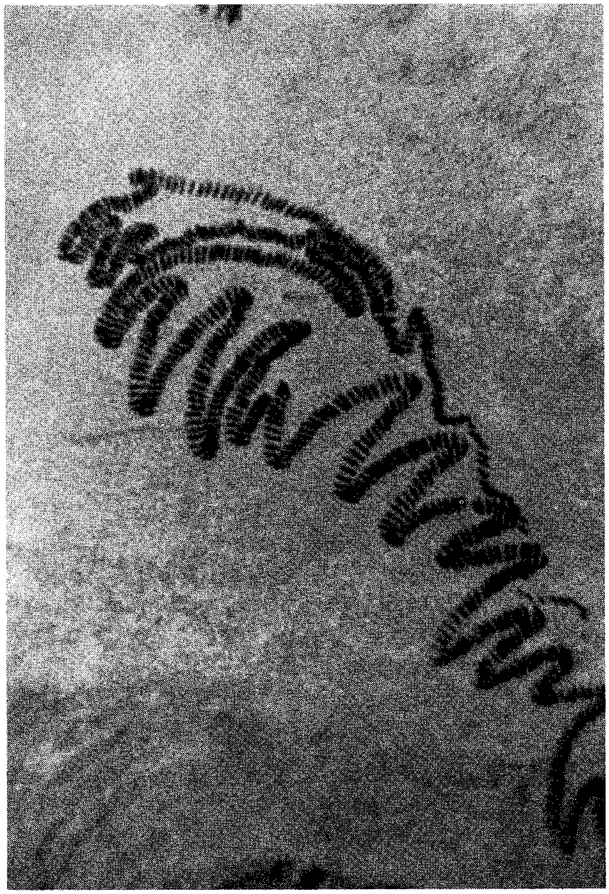


FIG. 9.
Limpet grazing trail. Watchet, Somerset. (photo J. H. Crothers).

Patella intermedia Southwest
(*Acmaea* sp. most evident in North Britain, graze on red algae).

Mollusca: Gastropoda: Winkles: (effective at rock erosion, especially on softer rock)

Littorina neglecta and *Melarhaphe neritoides* upper and mid intertidal zone (small periwinkles)

Littorina saxatilis and *L. arcana* upper to mid intertidal (rough periwinkles)

Littorina nigrolineata mid intertidal (rough periwinkle)

Littorina littorea mid intertidal and below (edible periwinkle)

Littorina obtusata
mid intertidal (mostly on fucoid seaweeds and only occasionally on rock surfaces (flat periwinkle)

Littorina mariae low intertidal (flat periwinkle) (as above)

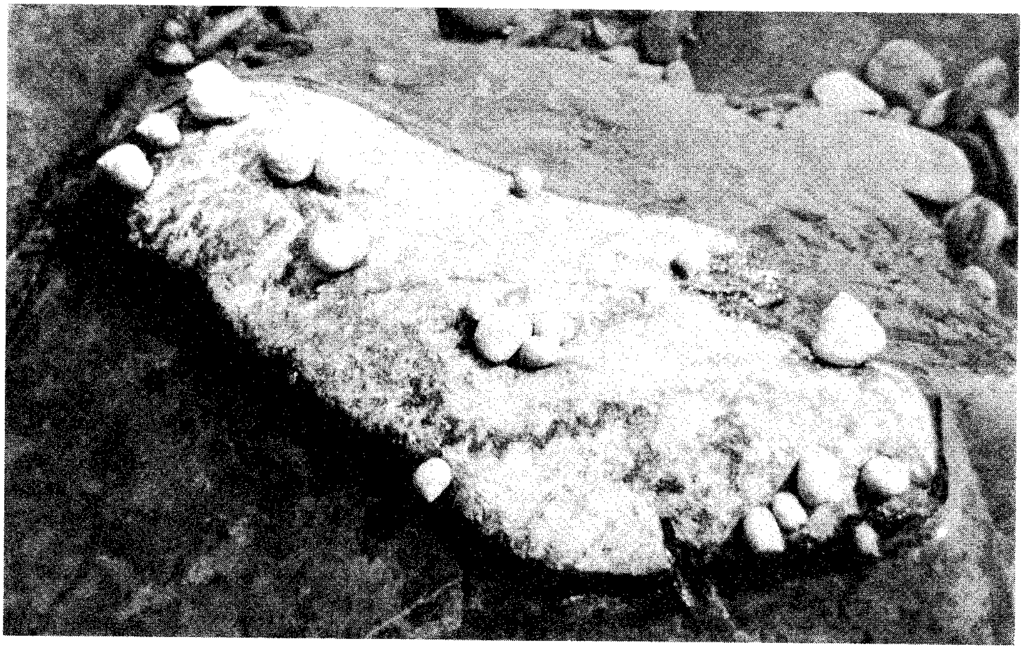


FIG. 10.
Grazing tracks of common topshells (*Monodonta lineata*) and edible winkles (*Littorina littorea*) at Porlock Weir, Somerset. (photo J. H. Crothers).

Monodonta lineata (Fig. 10) — upper intertidal (common topshell) South and West only

Of these species, *Patella vulgata* and *Littorina littorea* are the most important, removing up to 0.25–0.5 mm of rock during grazing if the rock is soft; the other species (including those not mentioned above) are either less widespread or they ingest little rock material during feeding. This is especially true of the British chitons which have little effect compared with those larger species which occur in the tropics and which are a major source of erosion of intertidally exposed limestone there (Trudgill, 1976).

In all cases, the geomorphological effects vary with the hardness of the rock and the degree to which the rock surface is penetrated by the algae on which the grazers feed. It is the softer, more porous rocks, such as the softer sandstones, limestones and shales, where algal colonisation and grazing with rock ingestion are most marked.

Seaweeds

The whiplash effect of the larger seaweeds (Fig. 11), produced by the waves sweeping the fronds over the rocks, is a powerful abrasive agent. More delicate plants and newly-settled animals are swept away and, on soft rocks, some of the surface as well.

Encrusting Organisms

These include the pink encrusting algae: *Lithophyllum* spp. and *Lithothamnion* spp. (Fig. 12) and the barnacles (Crustacea: Cirripedia) (Fig. 13), *Balanus* spp., *Elminius*

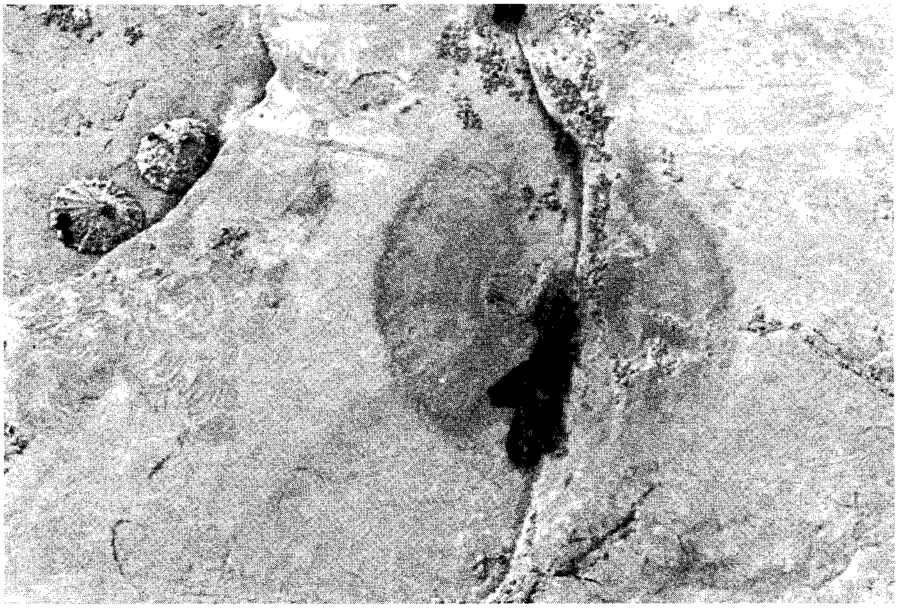


FIG. 11.
Abrasion of the rock through the "whiplash effect" of fucoid algae. Watchet, Somerset. (photo J. H. Crothers).

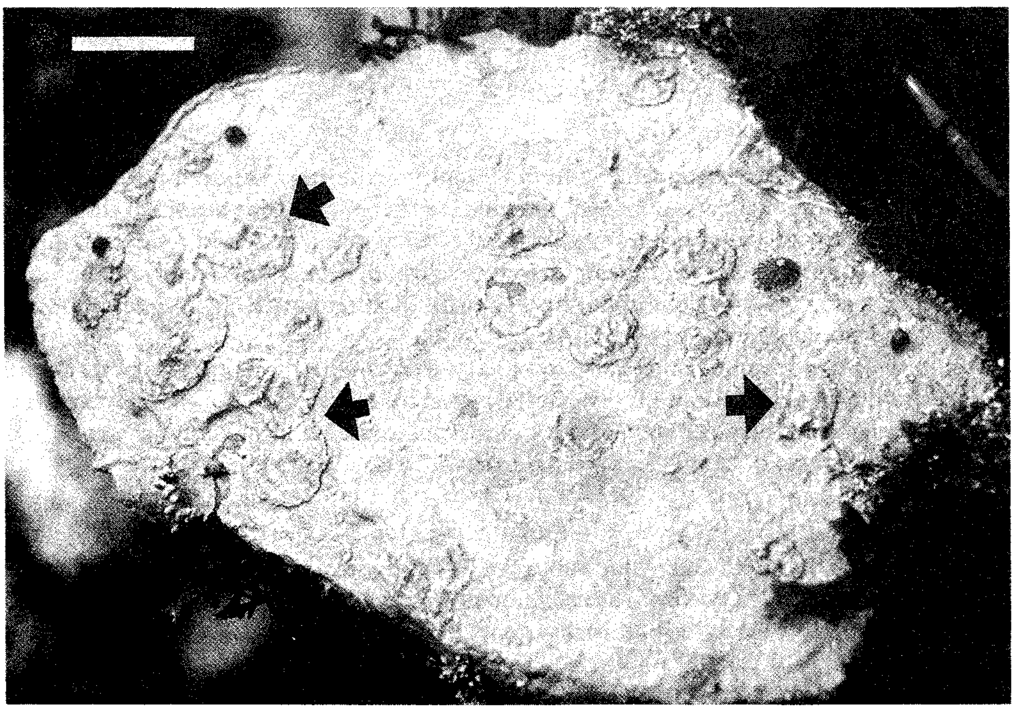


FIG. 12.
Pink encrusting algae. *Lithophyllum incrustans* colonies, some arrowed, growing over other species. From Edyvean and Ford (1986). Bar = 5 cm.

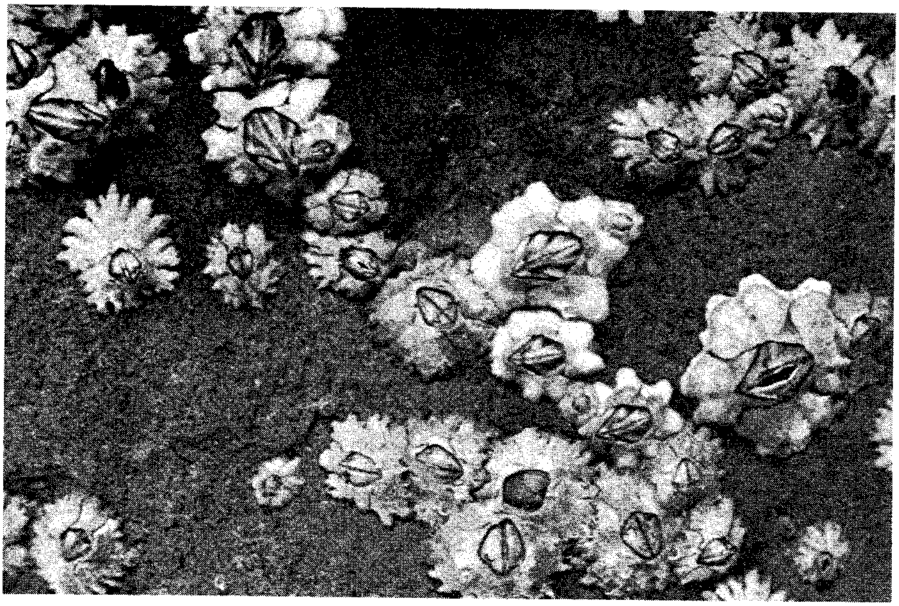


FIG. 13.
Barnacles. *Elminius modestus*—larger four-plated individuals; *Chthamalus montagui*—six-plated and with a crenate edge. (photo J. H. Crothers).

modestus, Semibalanus balanoides, Chthamalus stellatus and *C. montagui* (see Rainbow, 1984). The mussel, *Mytilus edulis* (Fig. 14) may be regarded as an encrusting organism from this point of view. The holdfasts of the larger algae may protect the rock surface until they are detached when some of the surface may be removed. Encrusting lichens can also be included, especially *Verrucaria mucosa* on the middle shore.

The effects of encrusting organisms are difficult to specify as their presence on an upstanding area of rock may indicate either that they have protected it from erosion or simply that they have colonised it after it was formed.

FIELD STUDIES

The first stage of field study involves visual identification of zones; the second stage involves the quantification of the abundance of organisms.

Colour zones

Most biological zones have different colours which can be used to identify them. Classically, proceeding down the shore, they are:

1. *An upper orange zone* dominated by the lichens *Xanthoria parietina,* or *Caloplaca marina* and *C. thallinocla.*

2. *A black zone* dominated by one or more black species of the lichen genus *Verrucaria. V. maura* is the tar spot lichen and indeed appears similar to spots of tar on the rock (take care to discriminate between the lichen and actual spots of tar!).

3. *A brown seaweed zone* dominated by species of *Fucus* and/or of *Pelvetia* and *Ascophyllum.*

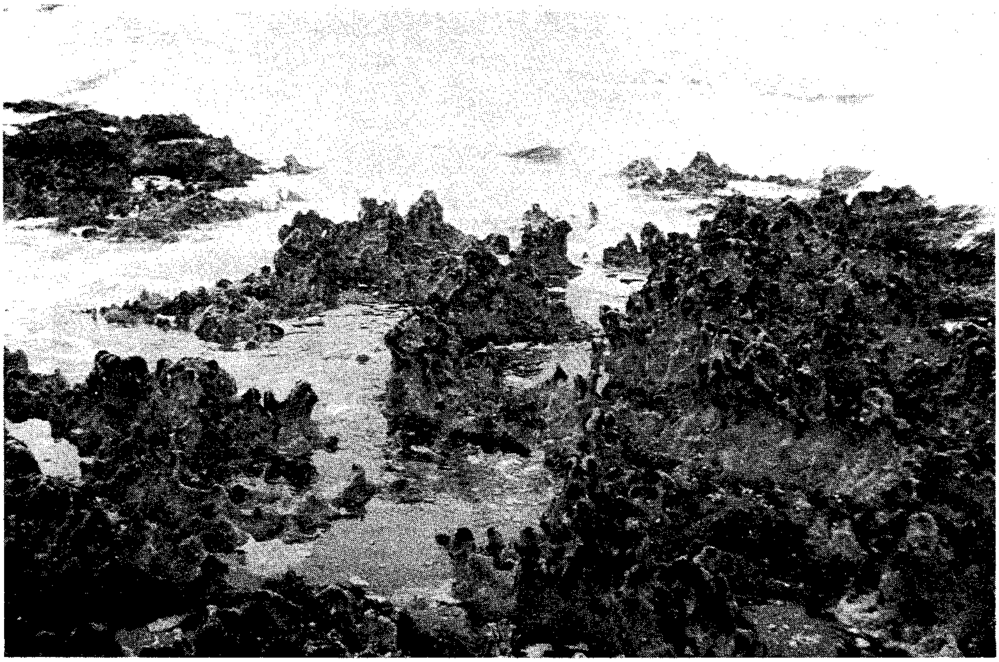


FIG. 14.
Mussels, *Mytilus edulis*, on pinnacles, Co. Clare, Eire.

4. *A light coloured barnacle zone* dominated by *Semibalanus balanoides, Elminius modestus* or species of *Chthamalus*.

5. *A lower shore zone, red or brown* dominated by red algae and/or the oar weeds, *Laminaria* spp.

These zones, and any others, should be identified and any coincidences with morphological types noted. Morphological description will be assessed below, but first, more detailed biological abundance scales will be discussed. It should be remembered, however, that the boundaries of the zones may be diffuse, especially in areas of large tidal range, and difficult to distinguish on the rock, even though they are clearly visible from a distance.

Biological abundance scales

Some indication of the abundance of organisms is necessary when recording the distribution of plants and animals on the rocky shore. Different methods may be required for plant covers and scattered individuals but the ACFOR scale is commonly used. This is an acronym for:

A = Abundant
C = Common
F = Frequent
O = Occasional
R = Rare

A sixth grade is required, N = None, for when the organism is absent.

The application of this scale is shown in Table 1.

Table 1. *The ACFOR Scale used during this survey*

% Cover (e.g. algae, lichens)		*Large individuals* (e.g. limpets)			*Small individuals* (e.g. barnacles)		
A	>30%	A	>10	$0.1\ m^{-2}$	A	>100	$0.01\ m^{-2}$
C	11–30%	C	5–10	$0.1\ m^{-2}$	C	11–100	$0.01\ m^{-2}$
F	6–10%	F	3–4	$0.1\ m^{-2}$	F	1–10	$0.01\ m^{-2}$
O	2–5%	O	2	$0.1\ m^{-2}$	O	6–25	$0.25\ m^{-2}$
R	1% or less	R	1	$0.1\ m^{-2}$	R	1–5	$0.25\ m^{-2}$

A more elaborate scale, used for biological surveys is given by Chalmers and Parker (1986) Table 7 p. 25 and by Baker and Crothers (1987).
Quadrat sizes. $0.25\ m^2$ is a square of side 50 cm: $0.1\ m^2$ is a square of side about 31.7 cm: and $0.01\ m^2$ is a square of side 10 cm.

Morphological Description

Processes and questions

The aim of morphological description is to observe forms and to infer how they have developed by erosion processes. In turn, inferences can be made about how they provide advantages and disadvantages as habitats for plants and animals. Primarily, observations focus upon the dissection of the rock material.

Dissection occurs by erosion along weaknesses, especially along joints, in areas of less well cemented rocks and areas more prone to chemical weathering. Low-lying areas dissected out between upstanding areas are more retentive of moisture and thus can provide "good" habitats for plants and animals at low tide when desiccation stress occurs on the more open, upstanding sites.

This is more important on exposed shores as such low-lying areas may provide the few sites which plants and animals can colonise. In sheltered sites, dissected areas are less crucial as much wider areas may provide suitable habitats (though here upstanding sites may provide areas for colonisation by barnacles and lichens if the surrounding area is densely covered with seaweeds).

However, if dissection originates because of focused wave action or abrasion by sand, the joints and crevices provide rigorous habitats, unsuited for plant and animal life as compared to surrounding areas. On the other hand, where dissection is produced by only episodic action, or by non-violent action, then crevices provide shelter for plants and animals. Thus, opened joints and crevices may be either areas of rigorous habitat or of greater shelter. The questions which arise are thus:

How dissected is the intertidal zone?

How was the dissection produced?

Does any dissection provide shelter for plants and animals?

Quantitative data can be collected with these questions in mind, and some relevant techniques are described below. However, measurement is no substitute for observation and, while observations will be made during measurement, it is important first to explore briefly the intertidal zone to look at and to think about the inter-relationships between morphology and the distribution of plants and animals.

Several detailed questions arise during observation:

1. Are there any particular organisms associated with pools and absent elsewhere? (Fig. 15).

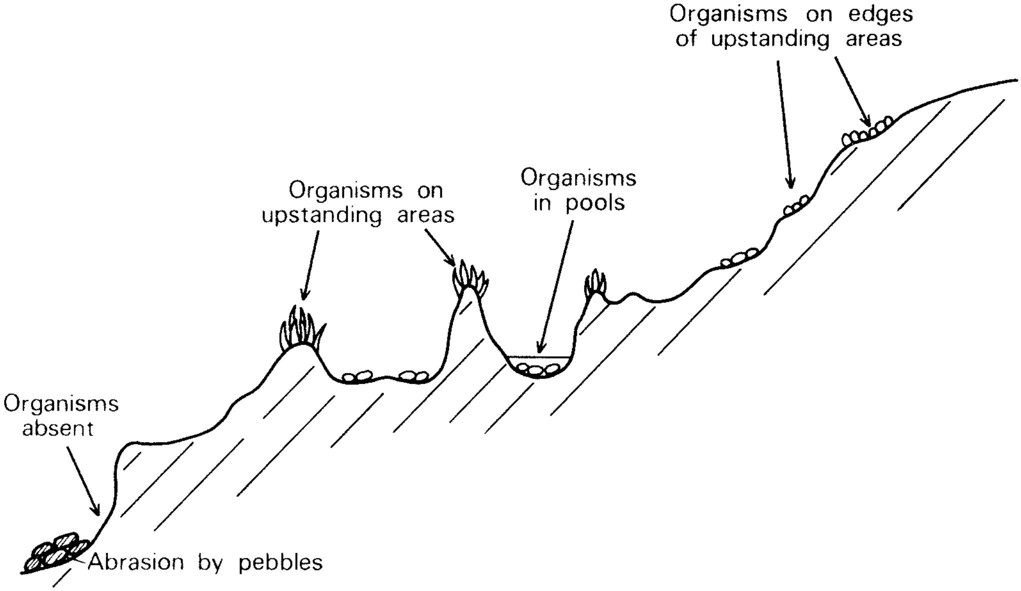


FIG. 15.
The influence of geomorphology on the distribution of organisms.

2. Are there any organisms only found on upstanding areas or on edges?

3. Are there any organisms confined to sheltered crevices? (Fig. 16).

4. Are there areas bare of organisms, and if so, is this in relation to the abrasive action of sand or cobbles? (Fig. 17).

5. If there are areas with no algae present but neither any sand nor cobbles, is there a population of limpets or other animals present which could be grazing on the algae and removing them? If not is there any other factor you can think of? If so, are there any grazing marks visible on the surface? (Fig. 9). Often, in these situations, the only palatable algae present are those growing on the backs of limpets, where they are safe from grazing by other limpets (Fig. 18); and those inaccessible in crevices or amongst *Corallina*.

6. Are any joints and crevices more populated than the surrounding area? (i.e., can it be argued that the forms are providing shelter?); or, are they kept swept clean by wave action and or sand abrasion?

7. Are there any other clues to the nature of the erosion process, such as salt crystals (suggesting that salt may be crystallising in pores, prising the rock material apart and leading to honeycombing)?

8. Are there erosive stones present in potholes and runnels?

Once these questions have been asked and the answers considered, it will be appropriate to proceed to the measurement of landforms, and the distribution of plants and animals.

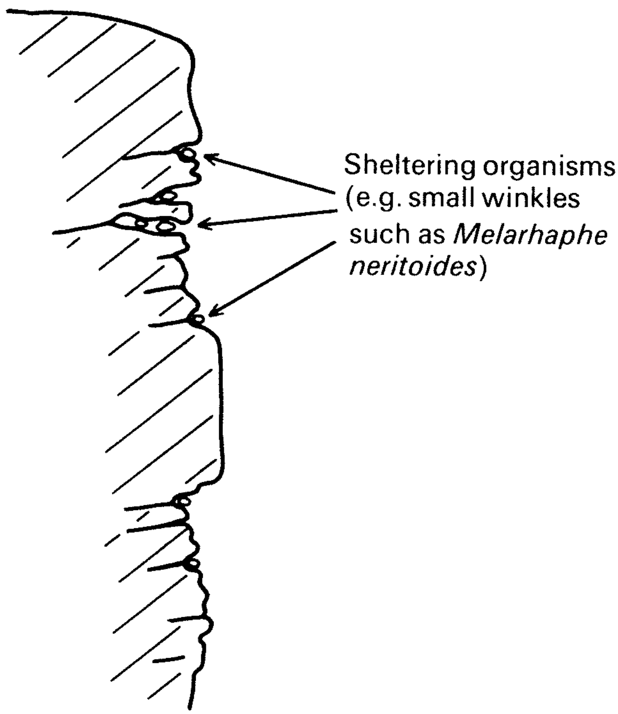


FIG. 16.
Organisms and shelter.

Measurement

The subjective observations discussed above are an important first step but, in order to test the validity of any impressions gained, it is necessary to obtain more precise data on the relationships between morphology and the distribution of organisms. In some cases, a formal hypothesis may be stated concerning the relationships between morphology and distribution in the light of some assumed or inferred process that is thought to be operating (e.g. limpets are absent where abrasion by sand is present). The hypothesis may be tested by a sampling programme, with statistical analyses. Any departures from the hypothesised relationship can then be discussed and/or the relationship can be qualified and quantified (e.g. limpets only occur 300 mm above sand on a vertical rock face; or, only small limpets are found, indicating recent colonisation and, probably, the removal of older limpets during storms, and so on).

In other cases, associations may be noted. Often, however, on transects, sample quadrats are taken every few metres and this procedure may miss out some of the detail. Thus, before commencing field work it will be necessary to decide whether a *general* transect is to be taken, where the overall relationships will be illustrated, or whether *special purpose* sampling is to be undertaken in order to test or illustrate a specific relationship. Often, it is best to first carry out a general purpose transect and a special purpose survey second, in the light of the data obtained, focussing on particular organisms and/or morphologies.

Exposure to wave action

On rocky sea shores, wave action is the dominant process affecting both erosion and the environment for plant and animal growth. Wave action is difficult to measure directly

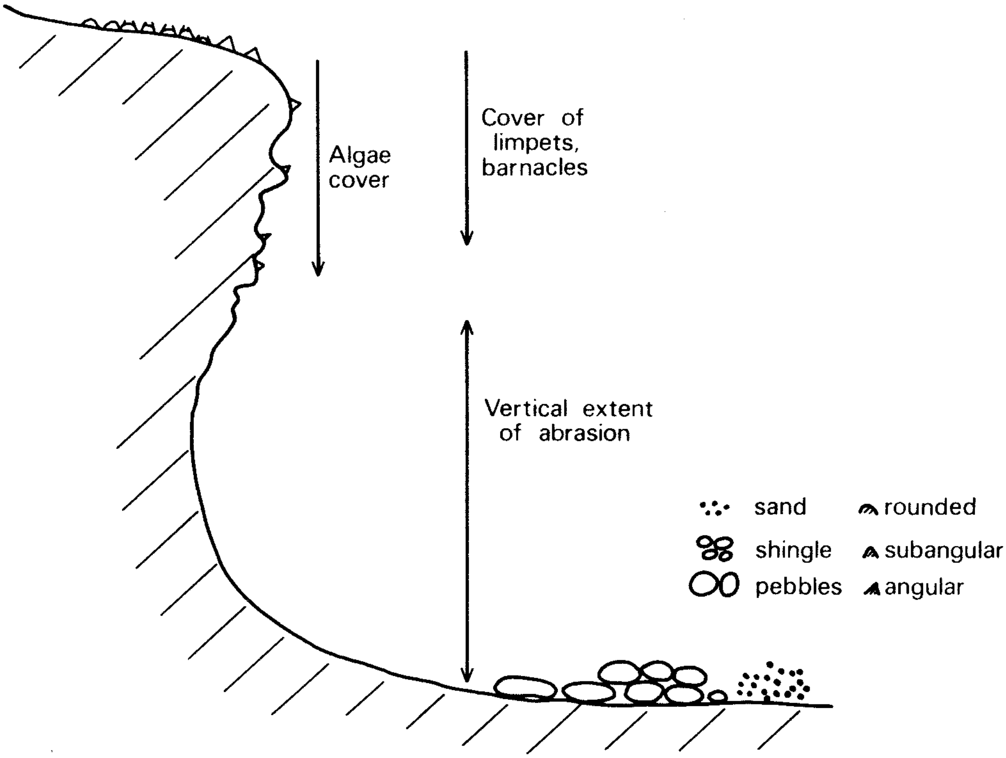


FIG. 17.
Abrasion.

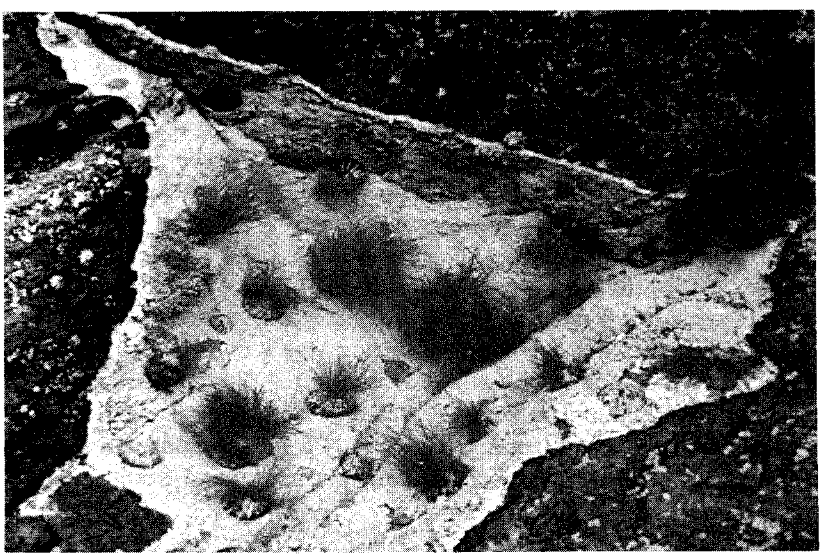


FIG. 18.
Algae on backs of limpets.

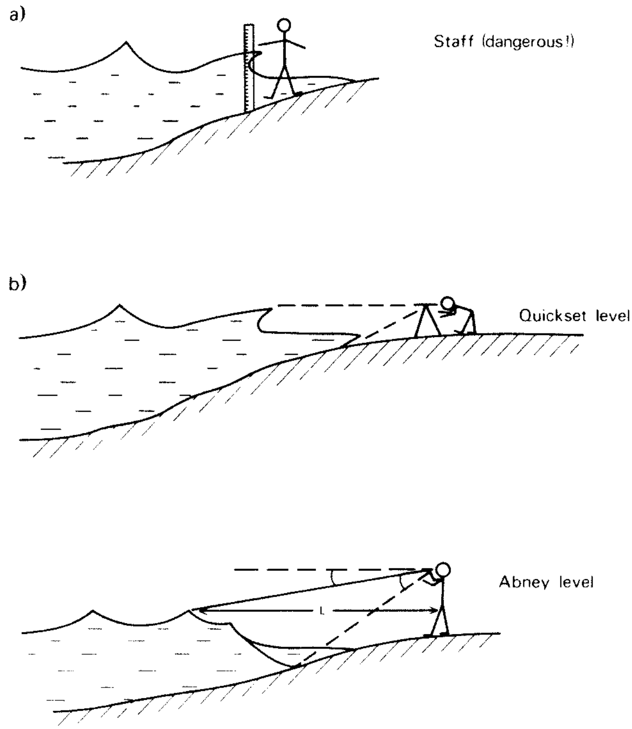


FIG. 19.
Techniques for surveying the height of waves.

unless sophisticated and expensive apparatus is available to measure the pressure of breaking waves. Measurement of wave heights may be an indicator of the energy expended on the shore, but it is a hazardous operation when measured with a wave staff, (Fig. 19*a*) involving partial (or complete!) immersion during measurement. This procedure should only be undertaken in calm weather, with the observer roped securely to the shore and with assistance available. Even then, it is not a generally recommended procedure because of the danger of being swept away by the undertow and it should never be attempted unless the waves are below 300 mm in height. As the significant wave heights (i.e. those controlling the environment) are very much bigger than this—perhaps 2 m or more—there appears to be little practical value from data obtained in this way. The surveying of wave height from the shore is less hazardous (Fig. 19*b*, *c*). However, because of the inaccuracies (not to mention the dangers) involved in direct measurement, it is better to derive an indirect index of exposure to wave action, as discussed by Thomas (1986), Ballantine (1961) and Baker & Crothers (1987).

Such a measure can be gained by the use of a compass to derive the angle of exposure (Fig. 20). This has the advantage of indicating long-term exposure. Any direct measurement of wave height can only give an indication of conditions at the time of measurement and, as most intertidal organisms live for many years, a long-term index is a much more valid indication of conditions. As Fig. 20 suggests, the observer stands on the shore and takes compass bearings to the intersections of the land with the horizon on either side (when facing out to sea). A straight shore will have an exposure angle of approximately 180° (Fig. 20*a*) and a headland may approach 360° (Fig. 20*b*); whereas a sheltered bay will

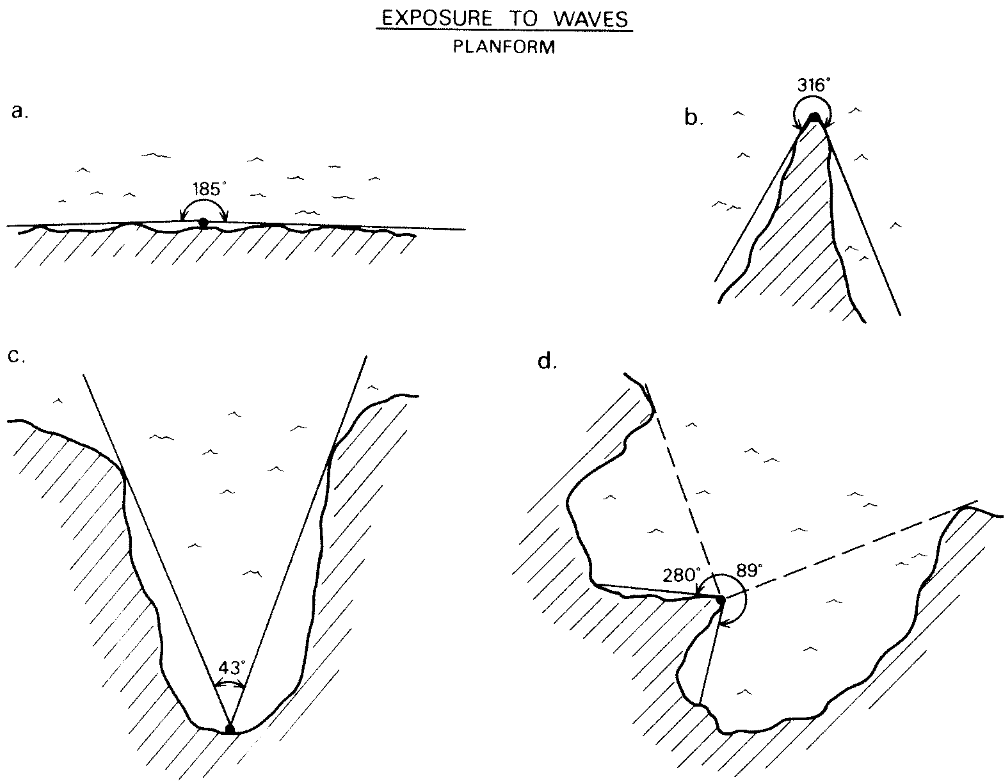


FIG. 20.
Exposure.

have a much lower angle (Fig. 20*c*). Both local angle and regional angle may be involved (Fig. 20*d*). Thus, an index of relative exposure to wave action may be gained and compared for contrasting shores where different organisms may dominate. For example, the egg wrack, *Ascophyllum nodosum*, is usually found on the more sheltered shores in Britain. Exposure angles may be measured to establish the conditions under which it is present (or absent) and its relative abundance compared with exposure.

In addition, some knowledge of *fetch* is vital. The frequency of wind direction, especially of winds in excess of force 6, may be determined using information from local meteorological stations. The length of open water in particular directions and the depth of water offshore may be assessed from charts; the former indicates the fetch and the latter indicates how waves might build up as they steepen in shallow water.

Structural orientation

The effects of wave action can be considerably modified by the orientation of geological structures. If the structures (joints or vertical beds) are parallel to the shore, they will afford shelter for organisms living on the landward side of upstanding blocks; alternatively, structures perpendicular to the shore will allow wave action to penetrate further up the intertidal zone. Thus, angles of structural orientation approaching 0° to the shore suggest a high degree of protection (Fig. 21). Take a compass bearing along the shore line

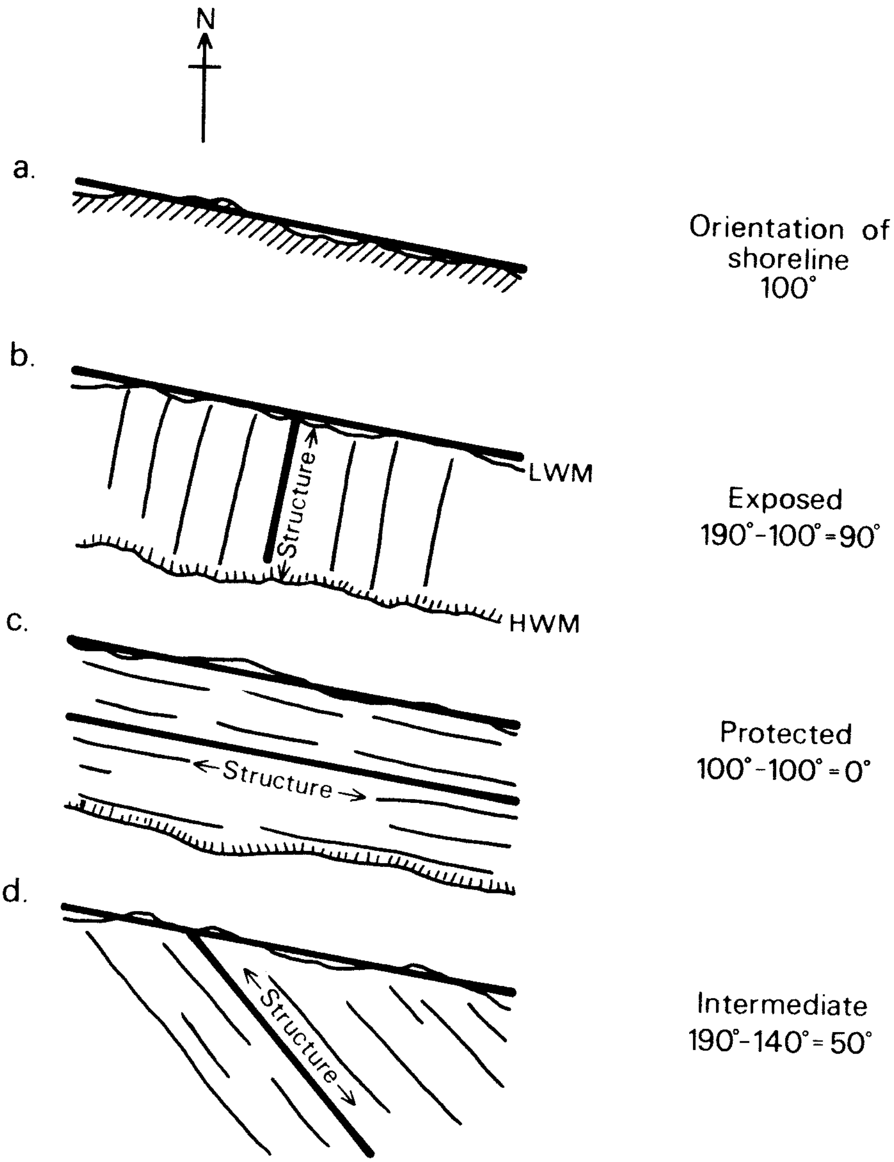


FIG. 21.
Structural orientation.

and a second bearing along the structures. In the case of Fig. 21*a* the shore line is at 100°; Fig. 21*b*, *c* and *d* illustrate some possible situations of structural orientation. Subtract the smaller figure from the larger. The smaller the result, the greater the protection afforded from wave action perpendicular to the shore. Fig. 21*b* shows maximum exposure to wave action along the structures, while Fig. 21*c* shows maximum protection and Fig. 21*d* an intermediate situation. Wave direction may not be perpendicular to the shore, so examine the configuration, especially in relation to wave refraction, the direction of the flood tidal current, dominant winds and fetch—and then modify your assessment accordingly.

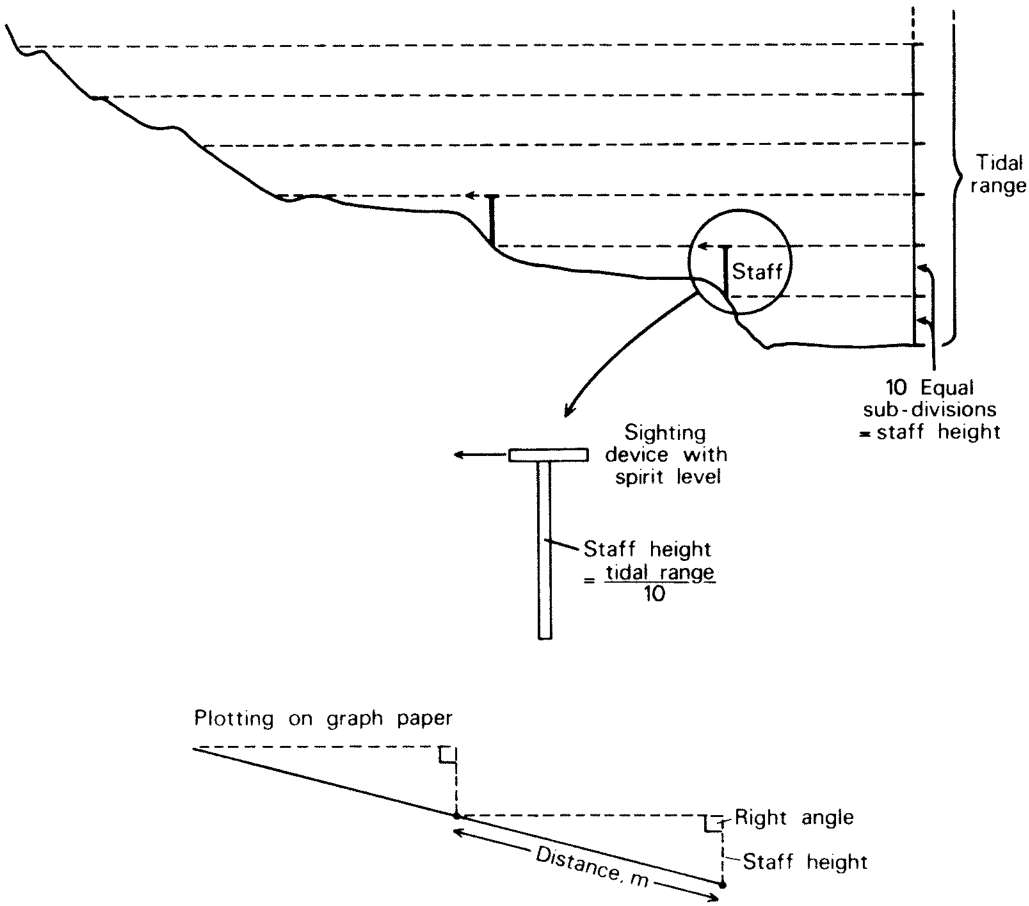


FIG. 22.
The surveying technique used for transect.

Morphological transects

Transects can be laid out upslope perpendicular to the shore line. They may be surveyed from one prominent feature to another, noting the angle and the length between points. Alternatively, levels may be taken at fixed height intervals. It is advisable to make the height intervals a convenient subdivision of the tidal range (Fig. 22). The transect can be plotted on graph paper, as shown. The cross staff height is fixed to give a reasonable number of points (say 10) within the tidal range and, as the staff is provided with a spirit level, a horizontal sighting may be made to another point at a fixed height up the shore. It is easiest, though no means obligatory, to work upshore.

Readings can be taken to indicate vertical dissection by noting the vertical distance to the surface from a tape or string stretched tightly from point to point at regular intervals, say 1 m (Fig. 23). This is, however, difficult in high winds. An alternative method is to note the dissection alongside a quadrat to give an indication of small scale relief (see below). The height data can be treated to give a mean height:

$$\bar{h} = \frac{\Sigma h}{n}$$

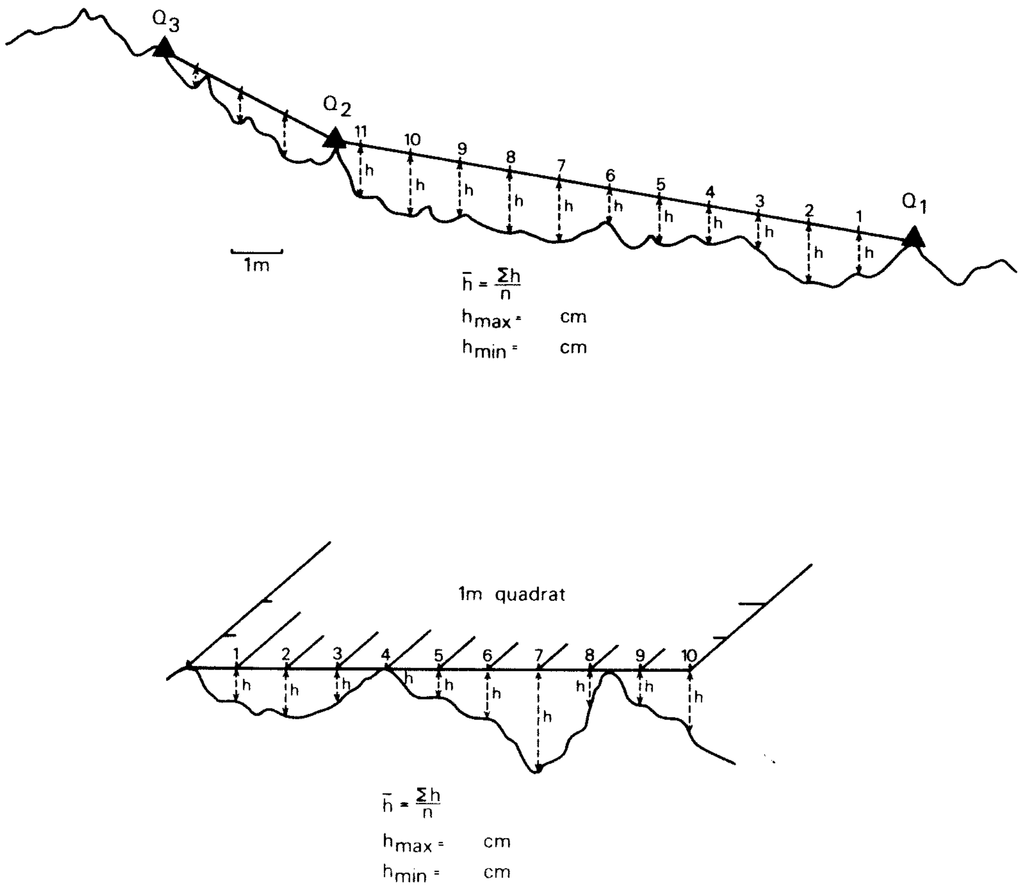


FIG. 23.
Measurements of dissection, h.

where:

$\bar{h}$ = mean height
Σh = total heights for study section
n = number of observations.

The maximum and minimum should be noted. A histogram of height distributions can also be plotted. By these indices, sites may be compared with each other, either up the shore or from transect to transect.

Simple annotated drawings are made from such transects, noting form in three dimensions, supported by measurements. Organism distribution patterns can also be plotted on the drawing to illustrate the conspicuous relationships (Fig. 24).

Individual morphological features can be described and measured, as suggested in Figs. 26–30. Potholes are defined as having depth, D, greater than width, W (Fig. 25); whereas for pools, the reverse is true. Runnels, vertical faces and wave cut notches are shown. For upstanding blocks (Fig. 26), height, H, is recorded, again with the mean of several readings or a representative reading. The backing and facing angles can be measured and correlations with organisms can be noted in relation to the protection afforded. In the example, *Ascophyllum nodosum* is seen on the backing side and *Fucus serratus* on the facing side.

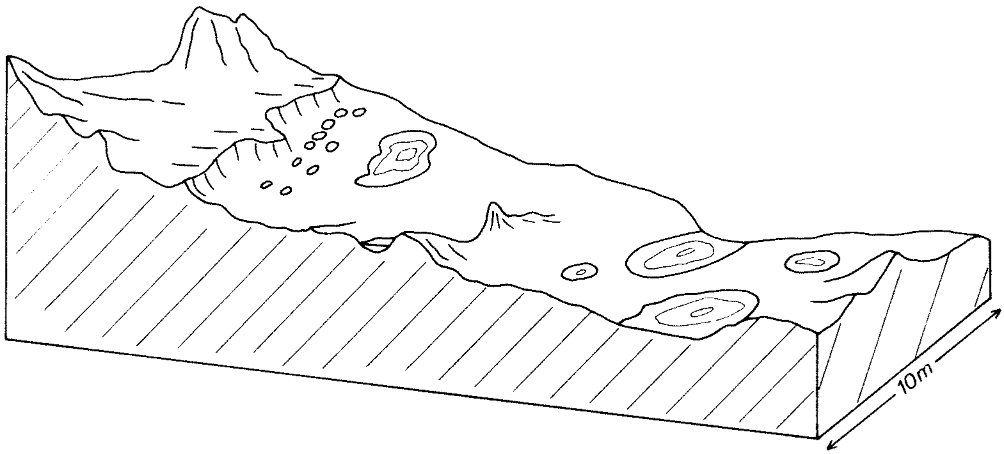


FIG. 24.
Block diagram of an intertidal section. Positions of organisms can also be drawn on the diagram.

In planform, the use of large quadrats can facilitate the quantification of depressions. Fig 27 shows a 1 m^2 quadrat laid over several pools. Simple indices can be used to describe the relief:-

Density of pools, pits and potholes, D_p:

$$D_p = \frac{n}{A}$$

where

D_p = density of pools or pits
n = number of pools
A = area sampled

In the worked example (Fig. 27) there are 8 pools in the 1 m^2 quadrat. A greater density would give a higher figure.

Index of area of pools or pits, IA_p:

$$IA_p = \frac{A_p}{A} \times 100$$

where:

A_p = area of pools (each square = 100 cm^2).

Mean area of pools or pits, $\overline{A}_p$:

$$\overline{A}_p = \frac{A_p}{n}$$

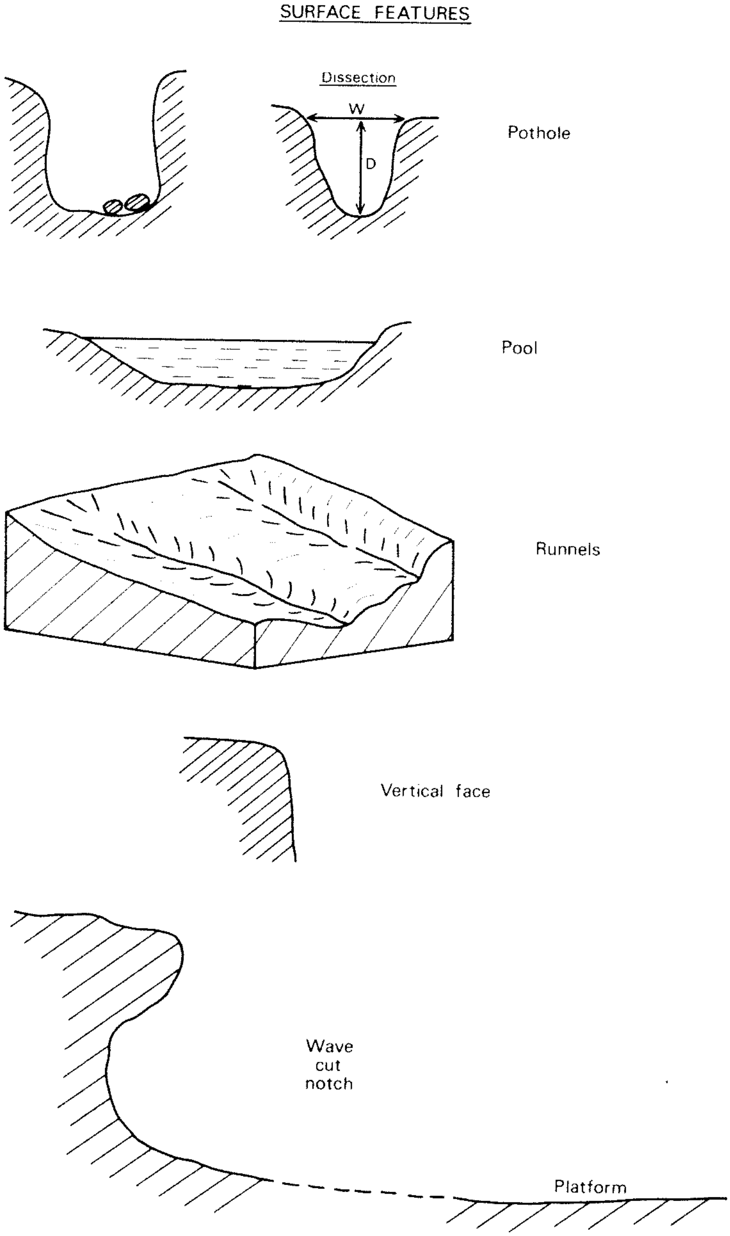


FIG. 25.
Features—depressions.

Index of pitting, I_p:

$$I_p = \frac{A}{A_p}$$

The lower the number, the larger the area occupied by pits.

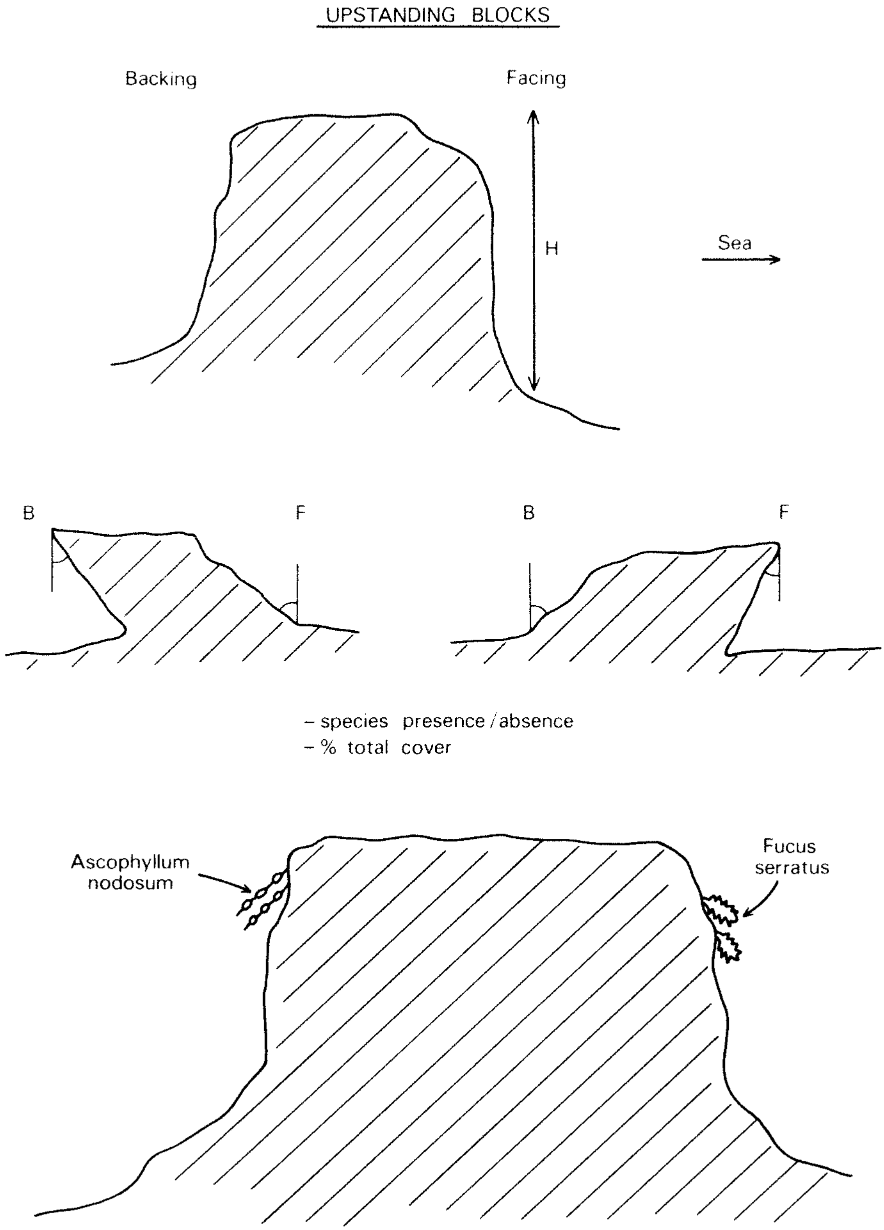
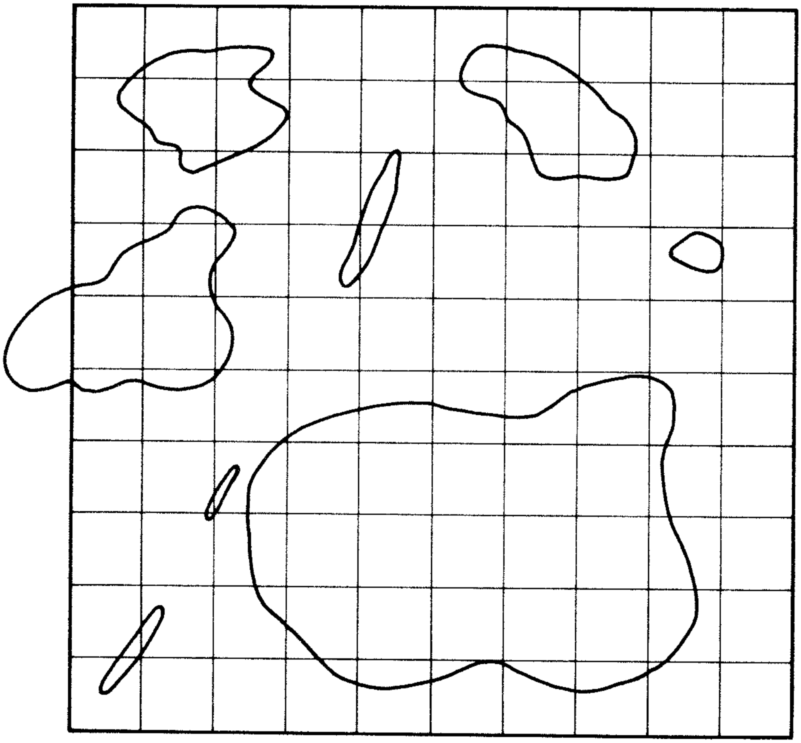


FIG. 26.
Features—upstanding areas.

Index of complexity of pits, IC_p:

$$IC_p = \frac{IA_p}{n}$$

The lower the number, the more complex and pitted the surface; the complexity being proportional to the number of pits but inversely proportional to their area.



$$Dp = \frac{n}{A} = \frac{8}{10{,}000} = 0{\cdot}0008$$

$$IAp = 37\% \left(\frac{37{\cdot}100}{10{,}000}\right) 0{\cdot}100 \quad \text{(approx. 37 squares covered)}$$

$$\bar{A}p = \frac{IAp}{n} = \frac{3700}{8} = 462{\cdot}5\,cm^2$$

$$IP = \frac{A}{Ap} = \frac{10{,}000}{37} = 0{\cdot}27$$

$$ICp = \frac{IAp}{n} = \frac{37}{8} = 4{\cdot}63$$

FIG. 27.
Area of pools.

Clearly, these measurements are dependent upon the accuracy of the estimation of the area of pools. This is not easy; care has to be taken and the smaller the grid squares in the quadrat, the more accurate and easier the estimation becomes. Such indices are of little use as individual measurements but become valuable as indices for comparing situations between sites, either down the shore or between locations. Correlations between percentage cover and abundance of organisms are then possible.

Micromorphology

Within quadrats or along transects, morphological types can be identified. This process is somewhat subjective, but the diagram in Fig. 28 is intended to assist with identification,

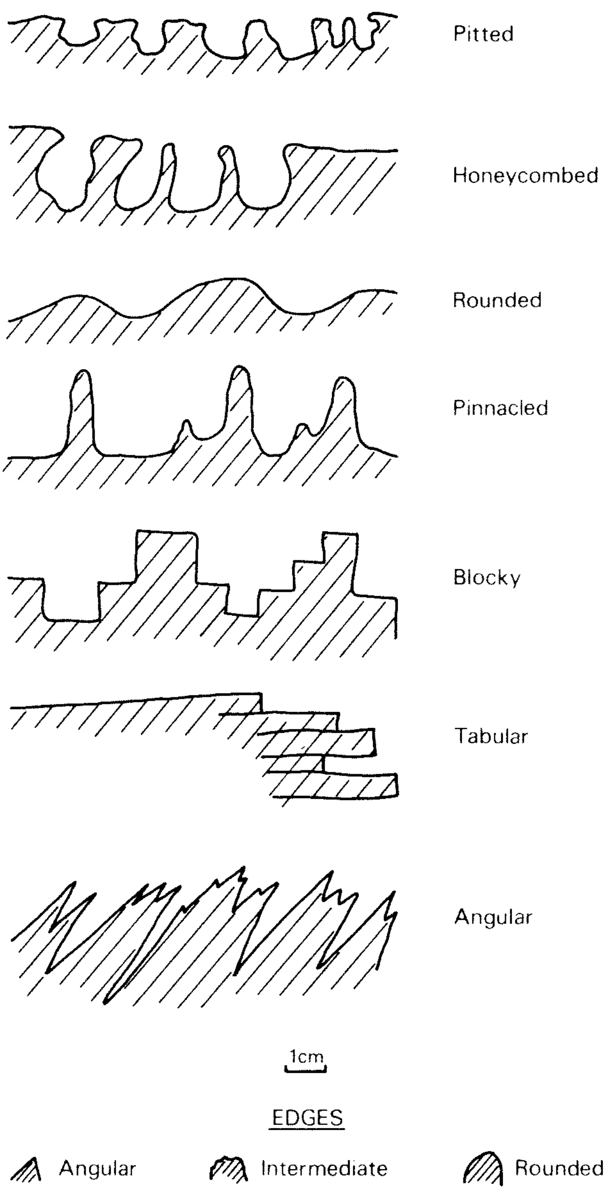


FIG. 28.
Micromorphology.

although intermediate types might be recognised. *Pitted* surfaces are occupied by small (<10 mm width) circular or near-circular holes in a generally rough surface. Some indication of size (with widths, depths and ranges of these) is useful. The holes in *honeycombed* surfaces tend to be larger (>10 mm width), and excavated in an otherwise smooth surface. Other terms are illustrated.

It is desirable to use a standard notation, so that one site can be compared with another, even when they have been described by different people. However, since all assessments

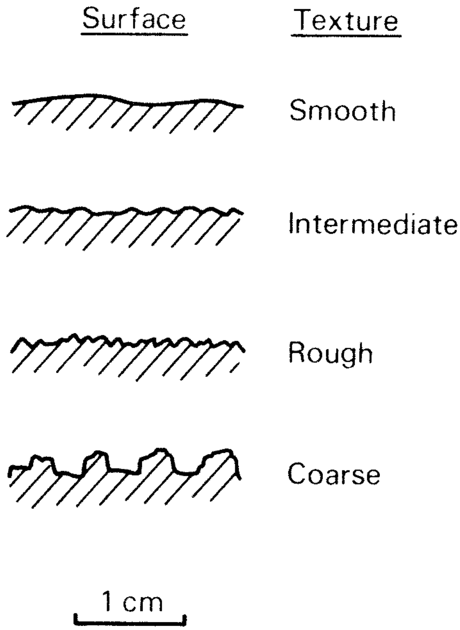


FIG. 29.
Surface texture. The surface may also be hard, firm or friable.

are subjective, a field sketch and notes on sizes are extremely useful for later comparison and discussion.

A measure of surface roughness can be gained from the "roughness ratio" of Wright (1981). Here, a tape is laid closely onto the rock from one point to another (over about 1 m), following all the indentations (T_r), (m); the measurement is then repeated with the tape stretched tight (T_t), (m). The roughness ratio, R (m), is then:

$$R = \frac{T_r}{T_t}$$

R = 1 for, a smooth surface and numbers increase with increasing roughness.

Surface textures are shown in Fig. 29 and these are often best described by feel (blindfolding can be useful as it seems to increase the tactile sensitivity). *Smooth* surfaces have no roughness about them; *intermediate* feel like fine sandpaper and *rough* ones are like rough sandpaper. A *coarse* surface is one in which individual grains wider than 1–2 mm can be detected. In addition, the surface may be *hard, firm* or *friable* (loose and crumbly). These descriptions may assist in assessments of erodability; the looser the surface, the more erodable it is. A summary chart for recording morphology is given below.

In all cases, the questions which should be asked are:

1. What is the morphology like?
2. Why is it like it is?
   a) in relation to geological structures?
   b) in relation to physical and chemical erosion?
   c) have any organisms had an influence on it?
3. How does morphology influence the organisms?

So far, the focus has been on the first question. The second question involves thinking about the geological structure and how it interacts with the erosional agencies—which may, of course, involve the actions of organisms. Often it is not possible, in the short time available for study, to come up with conclusive answers but it should be possible, by observation and thought, to give a list of likely erosional agencies and their relative importance. In particular, the smoothing action of sand abrasion and the grazing trails of molluscs can be readily identified. Rougher surfaces are produced by salt weathering and chemical action. Note any different colours in the rocks, particularly rust coloured iron staining—this may give clues about differences in cementation and hardness. Look for fractures and scrape the surface with a finger nail and then a penknife to assess its hardness. In these ways, observations can be made which will assist in assessments of the erosional agencies and their effects.

Summary, Study Guidelines and Recording Observations

The purpose of the integrated study of geomorphology and ecology on rocky shores is to understand how plants and animals influence the production of landforms—together with chemical and physical erosion agencies—and how, in turn, landforms influence the distribution of plants and animals. In many ways, it is a mutual, two-way relationship with the form influencing the biota at the same time as the biota influence the form. Such a mutual circle of relationships can be difficult to study as it is not always clear where to start—where to break into the circle. However, there are two main independent factors which control the overall relationships—lithology and exposure to wave action. These factors, therefore, form the start of the study. They, and others, will be summarised in turn, with the recording forms in Tables 2 to 4.

Site, exposure and lithology (Table 2)

Exposure angles are recorded in the field, together with the overall slope of the rock surface. The key lithological factors are mineralogy, hardness, planes of weakness (joints, bedding planes, cleavage) and orientation of structures relative to the orientation of the shore. Once all these have been recorded, transect study can be made. Once the site description has been completed, inspect the shore for zonation (see p. 251). Decide whether the study is to be of:

1. Quadrats representative of each zone.

2. Transect with observations: (a) at regular "horizontal" intervals (say 1 m) but irregular verticals, or (b) regular vertical intervals (say 10% of tidal range) but irregular horizontals (Fig. 22).

3. As 2 (a) or (b) but with quadrats at each observation interval.

For each quadrat, record using Table 3 and for Transects use Table 4.

Data Plotting, Analyses and Examples

Using the distance and angle data collected in the field, the transect can be drawn up back in the laboratory, at an appropriate scale on graph paper using a protractor and ruler. Detail can be added on morphology and correlations with organisms. Below, some

Table 2. *Site characteristics*

Site name: __________

Overall Slope of shore: __________
Aspect of shore: __________
Exposure angle to horizons: __________
Orientation angle of shore: __________

Rock type: __________

Orientation angle of major structures: __________
Major structure angle relative to shore angle: __________

Structure in detail:

Planes of weakness present:	Spacing	Orientation (1)	Orientation (2)
BEDDING PLANES			
JOINTS			
CLEAVAGE			

(1) With respect to the vertical (clinometer angle).
(2) With respect to the horizontal (compass angle).

Rock hardness (tick one):
HARD: Surface cannot be scratched with penknife: __________
INTERMEDIATE: Surface can be scratched with penknife but not with finger nail: __________
SOFT: Surface can be scratched with finger nail: __________
CRUMBLY: Surface crumbles when rubbed with finger: __________

examples of observations are given. These are not comprehensive in terms of procedures or sites but merely indicate some of the potentials for study.

A. **Penmon** Carboniferous Limestone coast, Anglesey, N. Wales

This is an east facing coast, sheltered partly by a small offshore island but influenced by strong tidal currents from the Menai Straits. The boring sponge, *Cliona*, is widely distributed in the bases of pools and also in moist depressions (where it is probably no longer active although the excavations remain. Downcutting of other areas has probably led to the drainage of pools). Algal and other microscopic perforations are evident in the mid-intertidal while on the upper intertidal, abrasive gravel and cobbles have worn a smooth surface. Many pinnacles and potholes are evident, resulting from differential erosion down joints which has left the intervening joint blocks upstanding. This process has been exaggerated by the further deepening of pools, often by bioerosion, notably by *Cliona*. Borings by *Cliona* and *Hiatella* are noticeable in stones and rock fragments thrown up from the lower intertidal by storms. Some of these now appear on parts of the upper intertidal beach. A shore transect is shown in Fig. 30, indicating the presence of organisms and morphological features. Continuous lines have been used to indicate organism cover and pecked lines, for sporadic distributions. This represents a quick way of field recording, without detailed quadrat work. The focus is on the relationships between organisms and

Table 3. *Quadrat recording*

(a) MORPHOLOGY Zone: ______________

Surface (tick as appropriate):

Smooth	______	Hard	______
Intermediate	______	Firm	______
Rough	______	Friable	______
Pitted	______	Honeycombed	______
Salt crystals	______		

Edges:

Sharp	______	Intermediate	______
Rounded	______		

Joints:

widths: ______________________________ mm

depths: ______________________________ mm

surface texture of joint faces:

smooth______ intermediate______ rough______ pitted______

Loose material:

SIZE:		SHAPE: Angular	Intermediate	Rounded
Sand (1–2 mm)	______	______	______	______
Shingle (2–10 mm)	______	______	______	______
Pebbles (10–50 mm)	______	______	______	______
Cobbles (> 50 mm)	______	______	______	______

Vertical faces:

Height: ______mm. Shape: straight______ notched______

Surface texture of vertical faces:

smooth______ intermediate______ rough______ pitted______

Dissection:

Dissection heights:

*h values:______________________________

____

Calculations:

Sum of heights, Σh: ______

Number of observations, n: ______

Mean height, $h = \Sigma h/n =$ ______

Pools, pits and potholes:

*Area of quadrat, A: ______ mm^2

*Number of pools, pits or potholes in quadrat, n: ______

Calculation:

Density of pools, pits or potholes, $D_p = n/A =$ ______

*Area of pools, pits or potholes, A_p: ______

Table 3. (*Continued*)

Calculated indices:
Index of area of pools, pits or potholes, $IA_p = A_p/A$: ____________
Mean area of pools, pits or potholes, $\bar{A}_p = A_p/n$: ____________
Index of pitting, $IP = A/A_p$: ____________
(The lower the number, the higher the area occupied by pits).
Index of complexity of pits, $IC_p = IA_p/n$: ____________
(The lower the number, the more complex and pitted the surface).
Roughness Ratio (m): $*T_r$______; $*T_t$______, T_r/T_t = ______.
*Field Measurements (the rest can be completed in the laboratory)

(b) BIOLOGY

Surface type, (tick as appropriate):
Pools with standing water: ____________
Depressions without standing water: ____________
Crevices, Joints: ____________
Upstanding areas: ____________
Intermediate areas (not upstanding or depressions) ____________
Vertical face: (a) facing sea ____________ (b) backing ____________
Other (specify) ____________

ABUNDANCE OF ORGANISMS:

Eroders:	A	C	F	O	R*
Boring algae					
Lichens (specify)					
Boring sponges					
Boring molluscs					
Limpets					
Other grazers (specify)					
Protectors:					
Pink encrusting algae					
Barnacles					
Mussels					
*Others*** (specify)					

*ACFOR: See Table 1. **e.g. lichens, fucoids, red algae, coralline algae, kelp.

Table 4. *Transect recording*

Observation Point:	1	2	3	4	5	6	7	8	9	10	11	12
Angle (up +, or down −)												
Distance												
(a) MORPHOLOGY *Surface:*												
Smooth												
Hard												
Intermediate												
Firm												
Rough												
Friable												
Pitted												
Honeycombed												
Salt crystals												
Edges:												
Sharp												
Intermediate												
Rounded												
Joints:												
Width												
Depth												
Surface texture of joint faces:												
Smooth												
Intermediate												
Rough												
Pitted												
Vertical faces:												
Height: (mm)												
Shape:												
Straight												
Notched												
Surface texture of vertical faces:												
Smooth												
Intermediate												
Rough												
Pitted												
Dissection:												
Dissection heights, h:												
Sum of heights, Σh:												
Number of observations, n:												
Mean height, $\bar{h} = \Sigma h/n$												

Table 4. (*Continued*)

Observation Point:	1	2	3	4	5	6	7	8	9	10	11	12
Loose material:												
Sand (1–2 mm)												
Angular												
Intermediate												
Rounded												
Shingle (2–10 mm)												
Angular												
Intermediate												
Rounded												
Pebbles (10–50 mm)												
Angular												
Intermediate												
Rounded												
Cobbles (> 50 mm)												
Angular												
Intermediate												
Rounded												
Surface type:												
Pools with standing water:												
Depressions without standing water												
Crevices, Joints:												
Upstanding areas:												
Intermediate areas (not upstanding or depressed):												
Vertical face: facing sea												
backing												
Other (specify)												

ABUNDANCE OF ORGANISMS: (Use the abundance scale e.g. Table 1).

Observation Point:	1	2	3	4	5	6	7	8	9	10	11	12
Eroders:												
Boring algae												
Lichens (specify)												
Boring sponges												
Boring molluscs												
Limpets												
Other grazers (specify)												
Protectors:												
Pink encrusting algae												
Barnacles												
Mussels												
*Others*** (specify)												

**e.g. Lichens, fucoid algae, coralline algae, kelp etc.

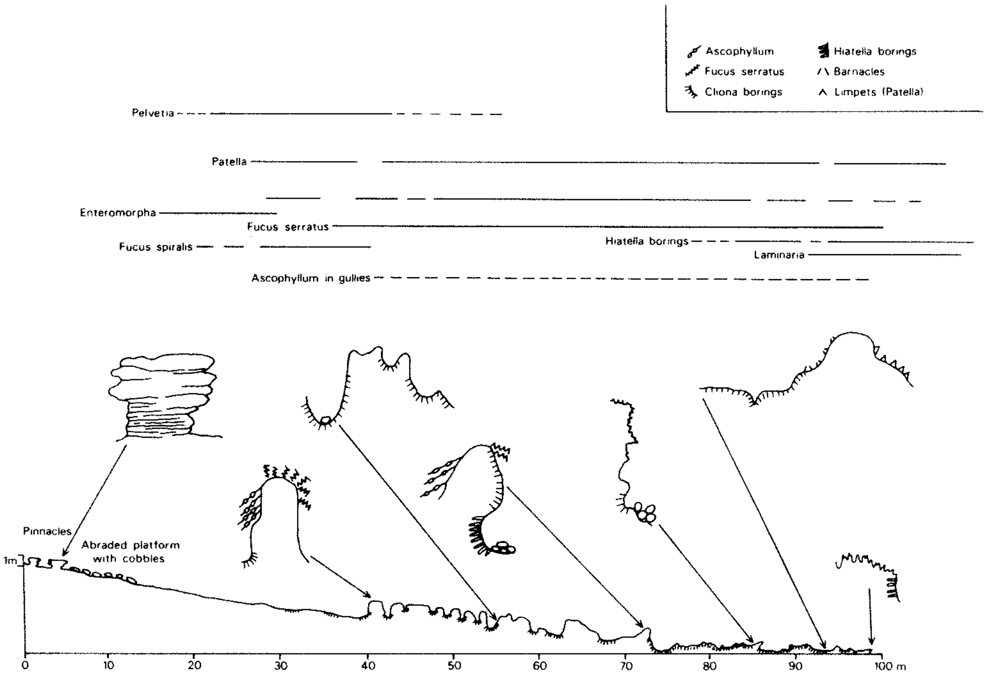


FIG. 30.
Coastal section at Penmon, Anglesey, N. Wales.

morphology and small field sketches have been drawn on to exemplify some of the relationships.

Attention can be drawn to several features. On the upper shore, note the pedestals, with undercutting by the action of cobbles. This is followed by an abrasion platform where few organisms can survive. As the effects of cobbles decrease downshore, old *Cliona* borings appear until a higher bedding plane is intercepted. The joints have been eroded and the upstanding blocks provide shelter for the egg wrack, *Ascophyllum nodosum,* on the shoreward side, with serrated wrack, *Fucus serratus*, on the exposed seaward side. Below the Channel Wrack (*Pelvetia*) zone, *Cliona* is restricted to the bases of depressions but lower down the shore, where it is moist for longer periods of time, *Cliona* becomes more extensive in the more eroded, subdued relief. Locally, cobbles are important in potholes. *A. nodosum* occurs in gullies and limpets and barnacles occur on upstanding areas. On the lower shore and in pools, *Hiatella* borings are evident, together with the notches they have created by weakening the rock. In this particular case, the sketches have been used as the most important part of the recording, with clear examples of bioerosion in depressions, pits, potholes, pools and undercut notches. The upstanding areas then have an effect on shelter, affecting the distribution of seaweeds and animals.

B. **Prawle Point,** S. Devon

This transect is shown in Fig. 31. Here the rock is chlorite mica schist and the shore is east facing (near site 9, PS, in McCarter & Thomas, 1980). This study is more detailed, with ACFOR recordings and dissection heights, h, noted on the scale drawing. Honeycombing is noted on the upper shore towards the lower part of the lichen zone. Both

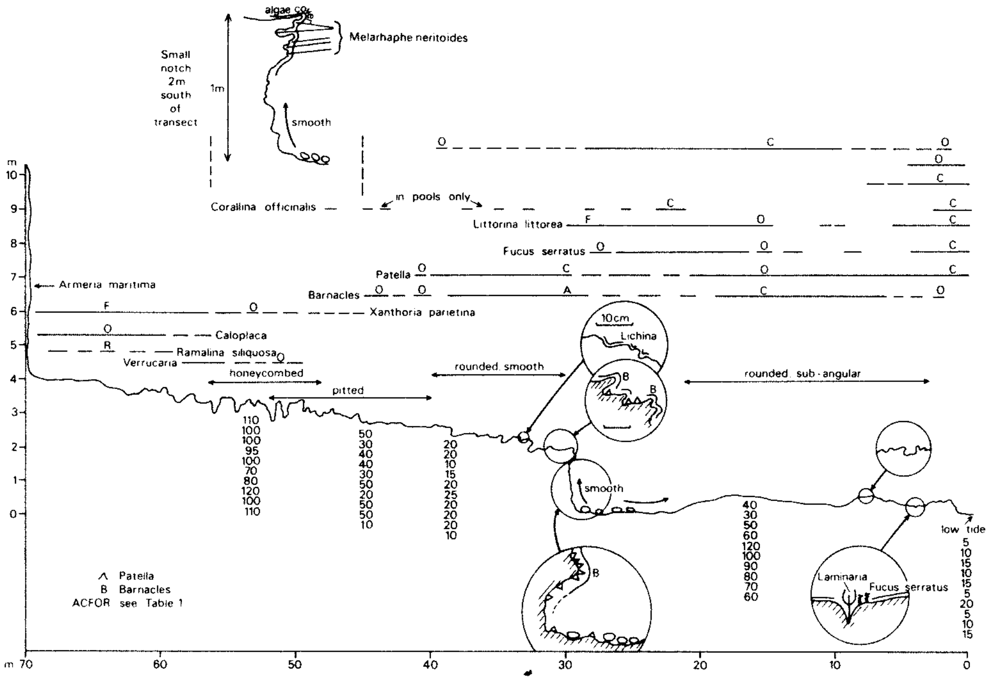


FIG. 31.
Coastal section on the west coast of County Clare, Eire.

chemical weathering and salt weathering occur (Mottershead, 1982). A lower pitted zone gives way to a more subdued zone as wave action becomes important downshore, with smoothing by cobbles where present.

The apparent decrease in dissection downshore can be tested by the study of h values, these change as shown: (mm)

	Upper shore			Lower shore	
Σh	980	370	180	700	110
n	*10*	*10*	*10*	*10*	*10*
Σh/n	*98*	*37*	*18*	*70*	*11*

The sample shows that the upper shore is, indeed, more dissected than the lower, but that there is no smooth progression in the data. Instead the middle/lower shore section shows a high level of dissection, with smooth-sided opened joints present to the side of the transect produced by cobble erosion in the joints. Dissection is thus the most marked both in the zone of chemical and salt weathering above and, also in that of cobble erosion below. Elsewhere, relief is more subdued, with less evidence of differential erosive forces.

Biological erosion is limited to grazing, associated with smoother surface textures. Coarser textures are found in the upper weathered zone. Relief then exerts an influence on organisms.

Corallina officinalis is found only in pools where cobbles are absent. Larger algae are in joints, again where cobbles are absent. Where cobbles are present, smooth surfaces with few or no organisms are found.

Crevice dwellers, such as *Melarhaphe neritoides* are found in the upper-mid shore, as is the tufted black lichen of the genus *Lichina*.

In this situation, biological erosion is not a dominant process, apart from grazing, but the morphology has a considerable influence on organism distribution.

C. **Co. Clare,** W. Coast of Ireland

The transect is on a west-facing coast, exposed to the Atlantic, on Carboniferous Limestone where horizontal bedding planes form benches (Trudgill, 1987; Trudgill & Crabtree, 1987; Trudgill *et al.*, 1987).

The upper lichen zone gives way to an abraded zone, with few organisms. There then follows a rough 'scoriaceous' zone, dominated by the action of boring algae. Dissection then increases, with pools excavated by the boring sea urchin *Paracentrotus lividus* and undercut notches with *Cliona* and *Hiatella*.

On this shore, biological erosion is a dominant process, leading to dissection, pool formation and notch formation.

D. **Manorbier Bay,** Pembrokeshire, S. Wales

Here, sandstone outcrops parallel to the coast on an exposed Atlantic facing (SW) site. The geological structures provide exposed seaward facing sites and sheltered landward facing sites.

The exposure angle to the horizon is 150°, the major structure angle to the shore, 0° and the slope angle around 15°. Bedding planes are near vertical (80–90°), with a spacing of 50 mm–1 m.

Summary notes on observations are that in the lichen zone, the surface is hard, rough and pitted. Joint spacing, 20–200 mm, depths 50–100 mm; texture intermediate.

Dissection values (h): 0, 20, 50, 100, 150, 100, 80, 520, 100, 150 mm; $\Sigma = 1170$, $n = 10$, $\Sigma h/n = 117$.

D_p values range from 15 to 5.

Honeycombing is present. Small calcite inclusions in the sandstone show pitted weathering patterns.

Moving down the shore, observation shows that morphology is important for organism distribution. Barnacles, *Chthamalus montagui*, are present in crevices in the mid-intertidal, but barnacle cover (*Semibalanus balanoides*) becomes more widespread lower down the shore. *Porphyra* weed grows on rounded exposed surfaces. A general sketch section is shown in Fig. 32.

This shore is excellent for the study of how geological structure influences organism distribution. Bioerosion by lichens and algae is only evident on calcite inclusions in the rock, but elsewhere, the vertical structures, orientated parallel to the shore, afford a great variety of microhabitats in an otherwise exposed situation.

E. **Blue Anchor Bay,** Bristol Channel, Somerset

Again, structures are orientated parallel to the shore, but in a far less exposed situation. The influence of morphology, with shelter behind upstanding ridges, is thus seen to a lesser extent than at D above. The Bristol Channel is heavily silt-laden and muds exist between rock ridges, with brown algae confined to the stable rock substrate. *Fucus serratus* occurs behind ridges, but also to a lesser extent on their tops. Summary sketches of observations are presented in Fig. 33.

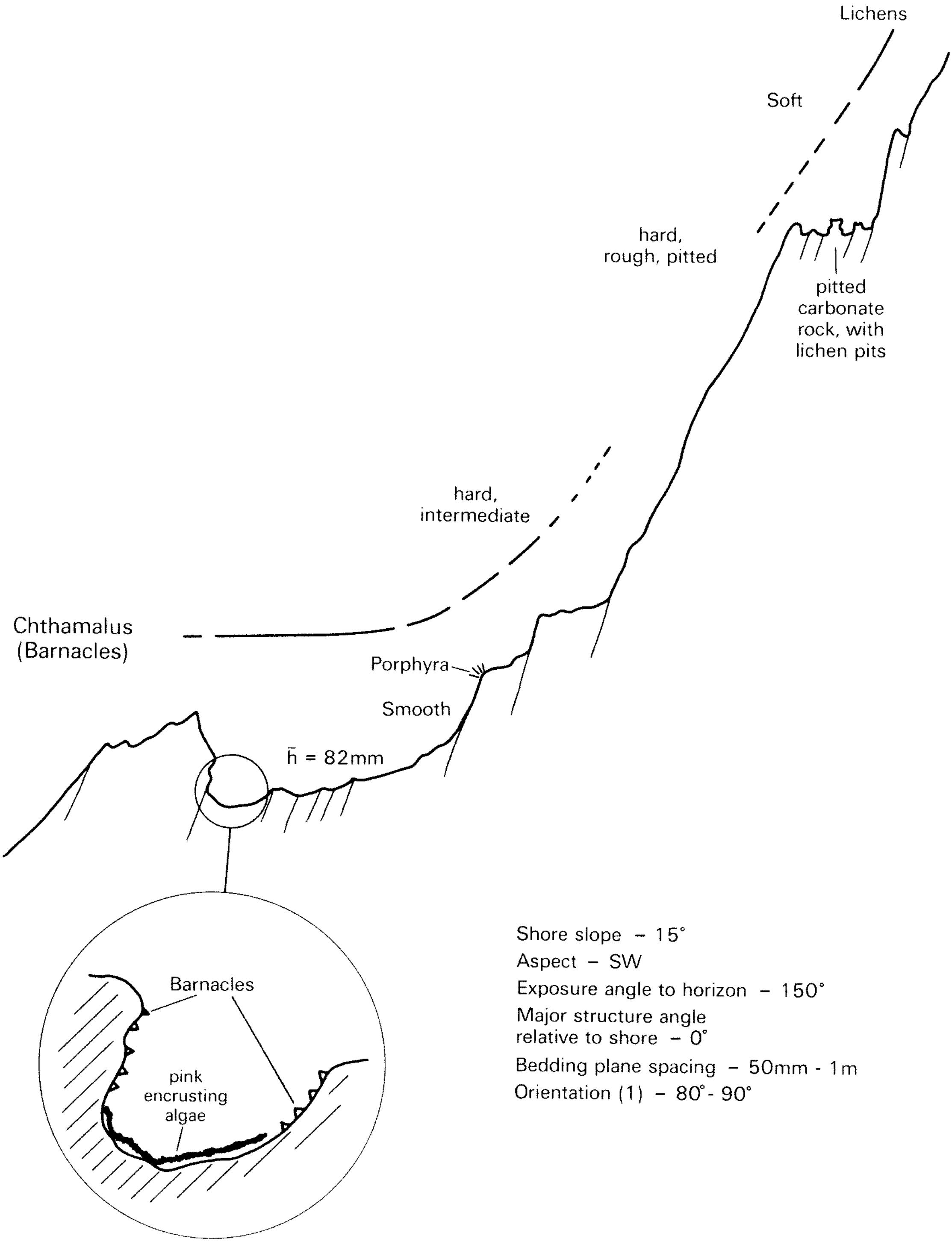


FIG. 32.
Sketch section, Manorbier Bay, S. Wales.

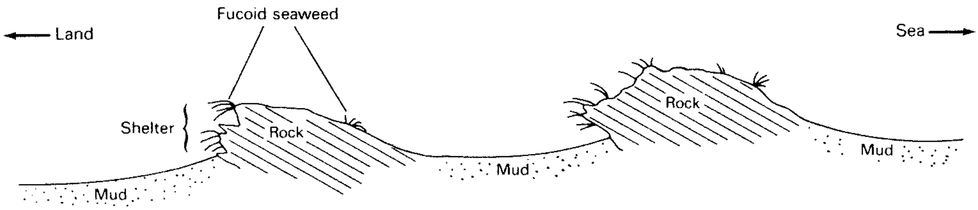


FIG. 33.
Field Sketches, Blue Anchor Bay, Somerset.

FURTHER STUDY

Further reading can be found in the following: rocky shore transects in S. Devon: McCarter & Thomas (1980); Habitat survey: Holme & Nichols (1980); Biokarst: Viles (1984); Measurement of exposure Thomas (1986) and morphometric analyses: Trudgill, (1979).

ACKNOWLEDGEMENTS

To present and former Staff of Slapton Ley Field Centre, especially Nigel Coles and Tim Mitcham who, with unwitting sixth formers, have contributed to discussion and trial evaluations; Staff at the Leonard Wills Field Centre, Nettlecombe and Philip Rainbow for assistance with field work; Tony Thomas for initial discussion and John Crothers for careful editing.

REFERENCES

BAKER, J. M. and CROTHERS, J. H. (1987). *Intertidal Rock.* In: Baker, J. M. & Wolff, W. J. (Eds.). *Biological Surveys of Estuaries and Coasts.* Estuarine and Brackish-Water Sciences Association Handbook. C.U.P.

BALLANTINE, W. J. (1961). A biologically-defined exposure scale for the comparative description of rocky shores. *Field Studies,* **1**(3), 1–19.

CHALMERS, N. and PARKER, P. (1986). The OU Project Guide. *Occasional Publication of Field Studies Council,* No. 9.

CARR, N. G. and WHITTON, B. A. (1973). *The biology of cyanobacteria.* Biological Monographs. Blackwell.

COBB, W. R. (1969). Penetration of calcium carbonate substrates by the boring sponge, *Cliona. American Zoologist,* **9,** 783–790.

DROUET, F. and DALY, W. A. (1956). Revision of the coccoid Myxophyceae. *Butler University Botanical Studies,* **10,** 1–218.

EDYVEAN, R. G. J. and FORD, H. (1986). Population structure of *Lithophyllum incrustans* (Philippi). (Corallinales Rhodophyta) from south west Wales. *Field Studies,* **6,** 397–405.

HOLME, N. A. and NICHOLS, D. (1980). Habitat survey cards for the shores of the British Isles. *Occasional Publication of the Field Studies Council,* No. 2.

HUNTER, W. R. (1949). The structure and behaviour of *Hiatella gallicana* (Lamarck) and *H. arctica* (L.), with special reference to the boring habit. *Proceedings of the Royal Society of Edinburgh,* B63, III, 271–289.

JONES, R. I. (1965). Aspects of the biological weathering of limestone pavements. *Proceedings of the Geologists' Association,* **76,** 421–434.

MCCARTER, N. H. and THOMAS, A. D. (1980). Patterns of animals and plant distribution on rocky shores of the South Hams. *Field Studies,* **5,** 229–258.

MOTTERSHEAD, D. N. (1982). Coastal spray weathering of bedrock in the supratidal zone at East Prawle, South Devon. *Field Studies,* **5,** 663–684.

NEUMANN, A. C. (1966). Observations on coastal erosion in Bermuda and measurements of the boring rate of the sponge *Cliona lampa. Limnology and Oceanography,* **II,** 92–108.

OTTER, G. W. (1932). Rock-boring echinoids. *Biological Reviews,* **7,** 89–107.

RAINBOW, P. S. (1984). An introduction to the biology of British littoral barnacles. *Field Studies,* **6,** 1–51.

SCHNEIDER, J. (1976). Biological and inorganic factors in the destruction of limestone coasts. *Contributions to Sedimentology,* **6,** 1–112.

THOMAS, M. L. H. (1986). A physically derived exposure index for marine shorelines. *Ophelia,* **25**(1), 1–13.

TRUDGILL, S. T. (1976). The marine erosion of limestones on Aldabra Atoll, Indian Ocean. *Zeitschrift für Geomorphologie,* Suppleband, **26,** 201–210.

TRUDGILL, S. T. (1979). Surface lowering and landform evolution on Aldabra. *Philosophical Transactions of The Royal Society,* **B, 286,** 35–45.

TRUDGILL, S. T. (1983). *Weathering and Erosion.* Butterworth (Heinneman).

TRUDGILL, S. T. (1985). *Limestone Geomorphology.* Longman.

TRUDGILL, S. T. (1987). Bioerosion of intertidal limestone, Co. Clare, Eire-3: Zonation, process and form. *Marine Geology,* **74,** 111–121.

TRUDGILL, S. T. and CRABTREE, R. W. (1987). Bioerosion of intertidal limestone, Co. Clare, Eire-2: *Hiatella arctica. Marine Geology,* **74,** 99–109.

TRUDGILL, S. T., SMART, P. L., FRIEDERICH, H. and CRABTREE, R. W. (1987). Bioerosion of intertidal limestone, Co. Clare, Eire-1: *Paracentrotus lividus. Marine Geology,* **74,** 85–98.

VILES, H. A. (1984). Biokarst: review and prospect. *Progress in Physical Geography,* **8,** 523–542.