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Nicholas Stephens

# Geomorphology in the service of man

University College of Swansea

UNIVERSITY COLLEGE OF SWANSEA

# GEOMORPHOLOGY IN THE SERVICE OF MAN

**Inaugural Lecture**

*Delivered at the College on 11 December 1979*

*by*

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# GEOMORPHOLOGY IN THE SERVICE OF MAN

Geomorphologists are concerned with the study of landforms, especially their morphology or shape, and their genesis. This involves the study of landscape modification by a variety of complex and inter-linked processes, and the identification of the relevant processes operating across many different climatic zones, and with a frequency varying from a few minutes to perhaps several thousand years. We are still unsure of fundamental aspects of the character and the manner and speed at which many geomorphic processes operate and we may well not yet have recognised all processes at work. But perhaps in the examples which follow, I can demonstrate some of the fields of study, and the methods of operation of some geomorphologists (Embleton and Thornes, 1979).

Geomorphologists are aware of the enormous changes resulting from the continuing interference by man with the environment, often on a catastrophic scale, as the study of erosion and deposition over 50000 years in the Mediterranean Lands illustrates (Fig. 1). The alternations of erosion and deposition probably resulted from different degrees of activity by man, although we must view these against a background of the climatic variations that have occurred. Certain periods of the past were clearly favoured climatically in North-West Europe, and elsewhere (West, 1968), and the beginning of land clearance for agriculture on an extensive scale, which started in the Neolithic was well advanced by Medieval times, with consequent rapid increases in alluviation of sediments in the bottom lands of the major river valleys (Vita-Finzi, 1969, 1973). But there is still controversy concerning the exact role of variation of climate, as against man's activities, and particularly there is controversy concerning the causes which led to the crossing of certain 'thresholds', and thence to instability of the land surface. Undoubtedly, some land surfaces are more susceptible to instability than others, but we are still a long way from achieving quantitative analysis that will enable us to distinguish 'stable' from 'unstable' areas, and it may well be that rather subtle and relatively minor changes of sea-level, of climate, or of land management, can set in train rather rapid, and indeed, even catastrophic effects (Thomas, 1956). Short-term and long-term interference with natural systems is likely only to increase in intensity in the future, and I feel sure that the work in progress today will provide some most interesting comparisons with the findings of R. L. Sherlock, who, in his little book—'Man as a Geological Agent' (1922), and republished in 1931 as 'Man's Influence on the Earth', provides an appraisal which is still well worth reading. Human impact on a variety of physical processes must, of course, be measured against the immense time that natural processes, both endogenic and exogenic, have been operating on planet Earth. But few will deny that man's activities have been highly significant, and are of increasing magnitude. Fortunately, there is now International concern for man-environment relationships, and geomorphologists wish to play their part in developing Global Programmes of investigation, using sattelite imagery, field investigations, and process modelling to aid the more precise measurement and prediction of the effects of human activity, as well as to improve upon our interpretation of landforms. The examples I propose to use are drawn from fields of study in which I have been interested, but it is of course possible only to present a very few of them to you this evening. Let us begin first with the palaeo-environments of the Quaternary, that period of earth history representing some 2 to 3 million years of the immediate past, when advances and retreats of ice-sheets and valley glaciers, in high latitudes and at high altitude, brought about enormous environmental changes. These are fields in which Mr Fielding, Miss Piggott, Dr Rouse and Dr Shakesby of our department staff are working.

## Quaternary events in the Tropics

The alternation of glacial and interglacial periods is well documented, and as a result of the work of many earth scientists we now know that there were between fifteen and twenty major cold and temperate periods in the last 2 M. years or so, and that the old 4 or 5 episodes of the glacial and interglacial Alpine sequence of Penck and Brückner should be abandoned (Bowen, 1978). Analysis of ocean core sediments suggests that no interglacial may have lasted longer than about 12000 years—a sober thought because we are already 10000 years



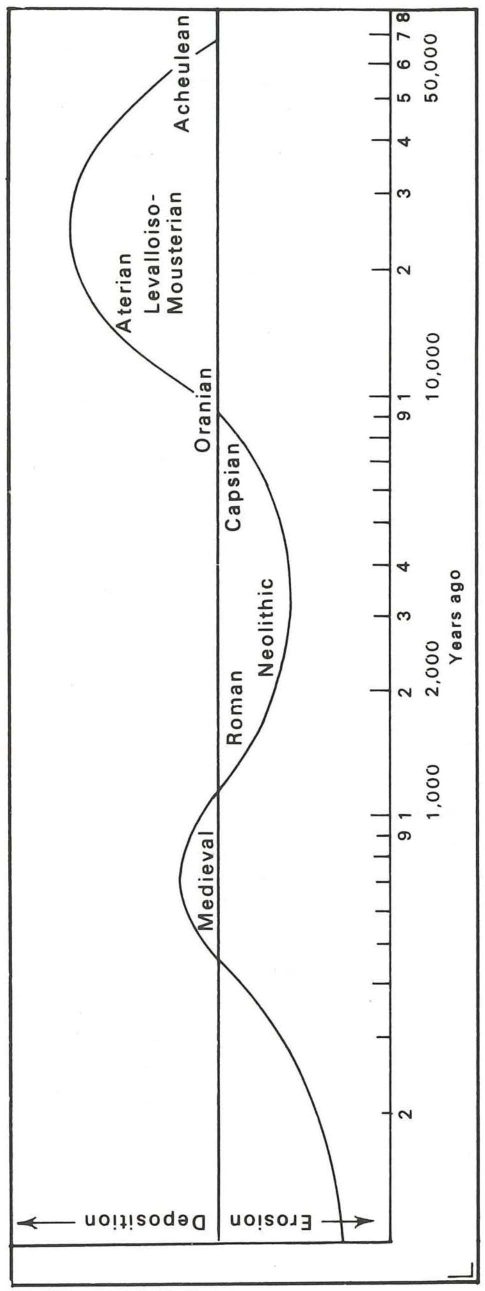


Fig. 1.
Generalised phases of soil erosion and alluviation of sediments in the bottom lands of Mediterranean valleys over 50000 years: redrawn from C. Vita-Finzi, 1969.

advanced into the present post-glacial period. But it is likely that long periods of cooling are actually necessary to initiate the preparation for an ice age proper, perhaps between 20000 and 50000 years, so hopefully in the Northern Hemisphere there is a little more time to prepare! (Imbrie and Imbrie, 1979).

In Inter-Tropical areas, climatic changes during the Pleistocene period brought about major latitudinal shifts of humid and arid zones. The pluvial or humid phases recorded in areas where serious dessication is now normal have sometimes been related to phases of glaciation in higher latitudes. But it is also known that the most recent pluvial phases, indicated by extensive lake deposits, were not necessarily synchronous between different continents (Goudie, 1977). The varying age of lake deposits in Africa and North America is indicated in Figure 2.

The evidence collected by Grove *et al* (1975), relating for example to the age of high, intermediate and low lake levels in Africa, is not easy to interpret (Fig. 3.Al-A4 and Fig. 4C; Goudie, 1977). But whatever the causes of the climatic fluctuations believed to have been responsible for these changes, it is necessary to determine where such effects have occurred, where they may happen in the future, and to quantify the effects on the ground.

The former existence of extensive lakes is also known in Australia and North America, within the experience of Palaeolithic Man, and is of great importance.

In the Basin and Range Province of western U.S.A., the enormous extent of the Pleistocene lakes compared with those of today can be appreciated (Thornbury, 1956). The high levels of Lake Bonneville can be directly correlated with the expansion of valley glaciers in the Wasatch Mountains at Little Cotton Creek (Morrison, 1965). Lake Lahontan also had systems of high shorelines, some cut across fresh fault-line scarps, and the highest marked by the upper limit of tufa. But such direct correlations between high lake levels and the presence of valley glaciers where none exist today cannot be demonstrated elsewhere, and thus we have a wide range of age for these former lake systems between different continents. It is against these enormous environmental changes that we need to compare the changing levels of lakes, such as Pyramid



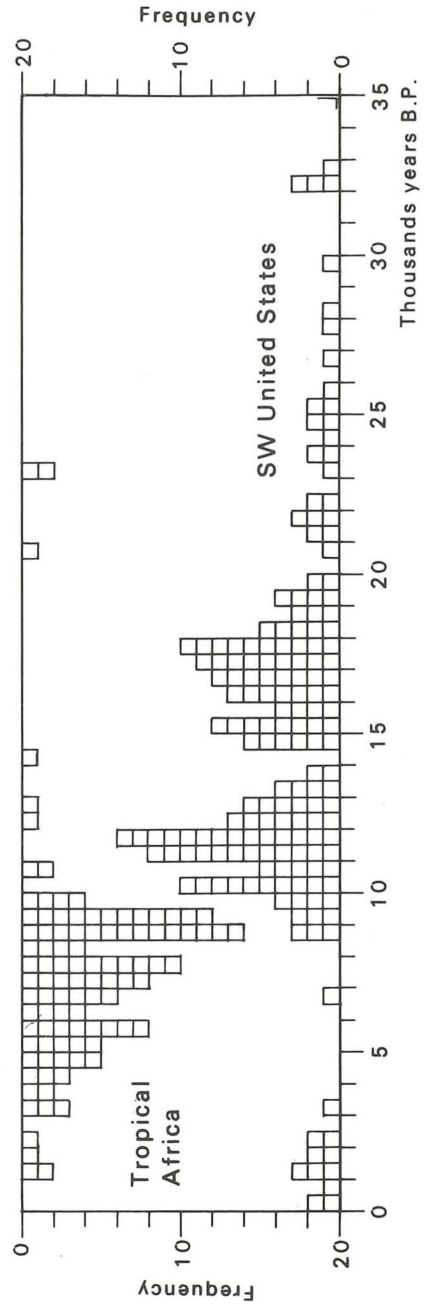


Fig. 2.
The non-synchronous nature of high lake levels during various pluvial periods in eastern and north-eastern parts of Tropical Africa and south-western parts of the United States, and including the Basin and Range Province: redrawn and simplified from A. T. Grove *et al* 1975 & A. S. Goudie, 1977.

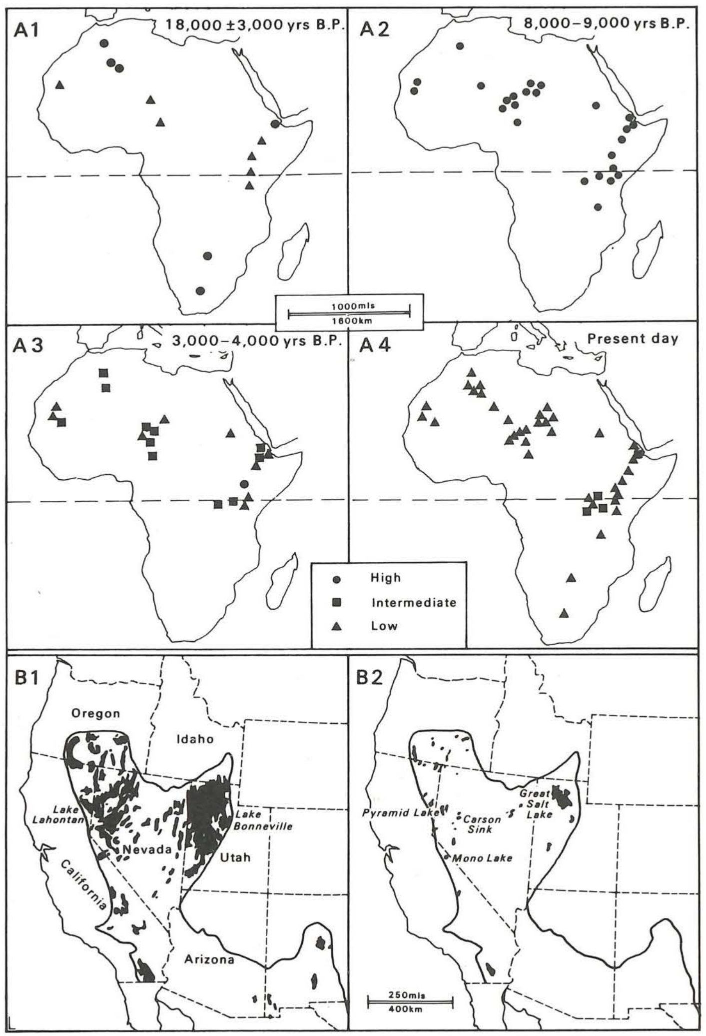


Fig. 3.
A1—A4.
Fluctuations of lake levels in Africa for selected periods during the last 20000 years, illustrating the complexity of the problem of studying pluvial periods: high, intermediate and low lake levels are indicated by symbols: redrawn from F. A. Street and A. T. Grove, 1976 and A. S. Goudie, 1977.
B1-B2.
Contrasts in the extent of Late-Pleistocene and present lakes in the Basin and Range Province of Western United States: redrawn from W. D. Thornbury, 1956.



Lake, Nevada, where the highest shoreline is indicated by the top of enormous tufa domes, and shorelines which extend up to 20 m. above present lake level, but which date only from about 1860. The hand of man is impressed strongly on this range country, where water abstraction has been accelerating in the last 100 years.

The tracing of the former extent of great sand dune systems in Africa, to areas where today rain forest is the predominant natural vegetation, is of importance to mankind (Fig. 4A). Similar fossil dune systems are known in India and Australia, and require investigation and careful mapping, alongside the evaluation of the climatic conditions pertaining at the time of their formation (Goudie, 1979). The extent of the present spread of arid conditions, or 'desertification', is also our concern, and is a research topic in the Department of Geography. Mr Davies, Dr Bridges and others are investigating aspects of 'desertification' in parts of the Sudan, as part of a joint research programme with the University of Khartoum. The collective story of earth scientists is, in general, a gloomy one in Africa (Fig. 4B; Dregne, 1977, Hare, 1977). Increasing dryness marked by the expansion of sand dune belts, for example in the Sahel, and the fall of the levels of large lakes (Fig. 3A4), is well known. It may be that by the end of the century we shall witness an intensification of aridity in some areas, and increasing cold, wetness and lower values of evaporation in other parts of the mid-and low-latitudes.

Consequently geomorphologists must play their part in making an inventory of the state and form of the earth's surface during the cold and warmer periods of the past, and in the present post-glacial period. Only when we have collected a large body of data about the palaeo-morphology of the past and about the present landforms and processes, and attempted to relate them to climatic events, shall we be able to approach a real understanding of pace of landscape change, both before and after substantial numbers of people occupied the earth's surface, and in the future.

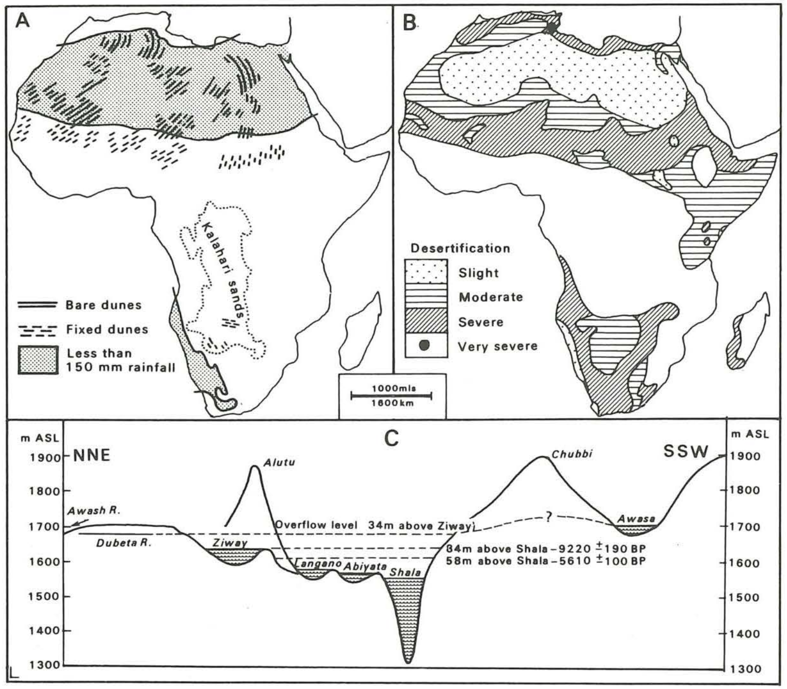


Fig. 4.
Environmental conditions in Africa.
A. The present extent of blown sand is confined mainly to areas receiving less than 150 m.m. of mean annual precipitation. Whereas old dune systems (Fixed dunes and Kalahari Sands) extend into humid areas and indicate that arid conditions have at times affected large areas: redrawn from A. T. Grove, 1976 and A. S. Goudie, 1977.
B. The current state of desertification: four grades of land deterioration measured by the present extent of damaged pastures, eroded soils, salt encrustations in irrigated fields, dune encroachment on farmland and settlements and the expansion of the desert. Loss of topsoil and reduction of vegetation or crop yields by more than 50 per cent, or salinity levels preventing sustained crop production, marks the passage from moderate to severe desertification, from which recovery is likely to be slow and very costly. The large area of slight desertification indicates the North African climatic deserts, in which man can do little to worsen matters: redrawn from H. E. Drenge, 1977.
C. Pluvial lakes in Ethiopia: the past and present extent of lake systems in the Galla basin is shown, with radio carbon dating indicating that maximum levels were reached and maintained for long periods between 12000 and 7000 years ago: redrawn from A. T. Grove *et al* and A. S. Goudie, 1977.



## Ice sheets and glaciers

Some 15 M. km² of ice still remains on the earth's surface, although during the maximum expansion of ice sheets and glaciers during the Pleistocene period this figure increased to about 45 M. km². Two limits of glaciation are shown in Figure 5, (Maximum extent of Glaciation and extent of the Last Glaciation). The significance of the study of the former extent of ice in relation to human activities has made considerable progress. For example, careful calculation of the rate of isostatic recovery of the Baltic area from the maximum depression suffered under the ice of the Last Glaciation indicates that part of the area still has about 200 m. of recovery to take place, if the present rate of 10 cms of uplift per century is maintained. The progressive shallowing of the Northern Baltic sea is already far advanced, some harbours can no longer operate, and if the process goes to completion, then the effect of drying out a large land-locked sea area must have some climatic effect (Goudie, 1977; West, 1968).

Variations in the volume and length of glaciers are known from many areas, including Alaska, Canadian Rockies, Greenland, the Alps and the Himalayas. In the Mt. Blanc massif fluctuations of glacier margins have been plotted against time, with peaks of advances occurring in 1830-50 and 1930-50 and retreats in 1880-1920, but the pattern is irregular between glaciers. Rates of advance and retreat have reached 15 m. per day at times, but what is important is the determination of the stability of the regime (Grove, 1966). If melting is steady, then summer discharges of meltwater are unlikely to increase catastrophically, but if melting is irregular, then very serious flooding can occur down valley of the glacier snout (Fig. 6B).

It is also perhaps worth recording that some of the greatest changes in glacier length occurred during the so-called 'Little Ice Age', between about 1550 and 1830 (Fig. 6A; Grove, 1972). Alongside glacier advances there was considerable mass movement and flooding, and in some areas, such as Scotland, a real loss of agricultural production because of the climatic deterioration, and such conditions could return.

There were also other effects, for in the Southern Alps of New Zealand meltwater from Pleistocene glaciers and

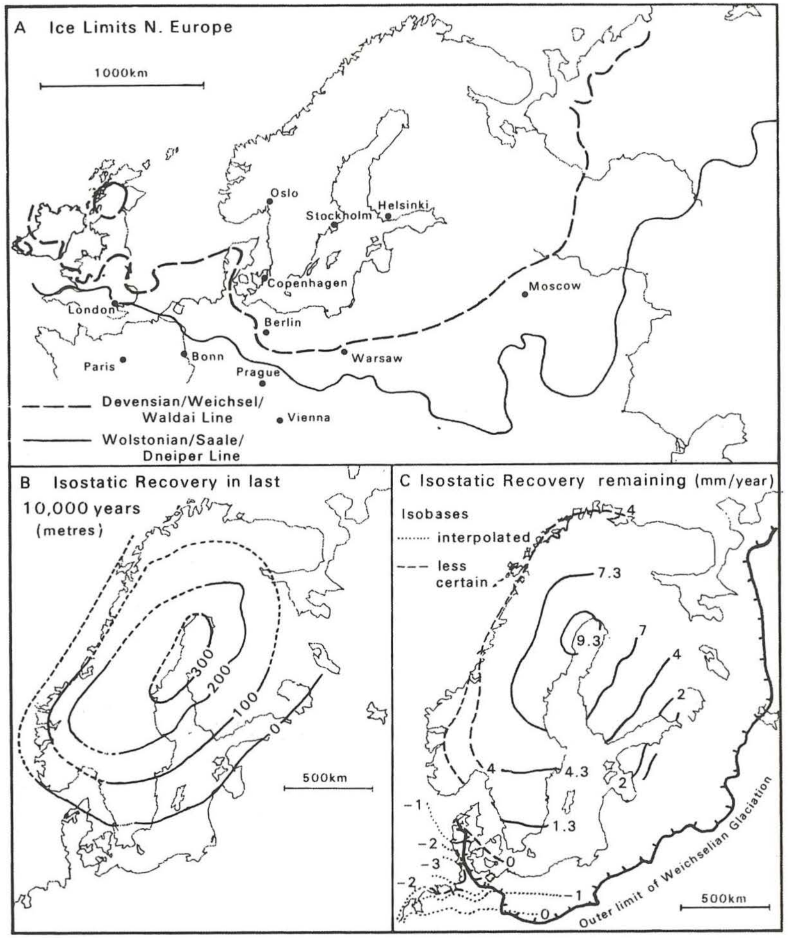


Fig. 5.
A. The greatest known extent of ice sheets at the maximum of the Pleistocene glaciations in Northern Europe—solid line. The extent of the Last Glaciation ice sheets in Northern Europe: redrawn from R. G. West, 1968—dashed line.
B. The amount of isostatic recovery of the Baltic lands in the last 10000 years: redrawn from A. S. Goudie, 1977 and R. G. West, 1968.
C. The present rate of isostatic recovery over the Baltic lands: redrawn from R. G. West, 1968.



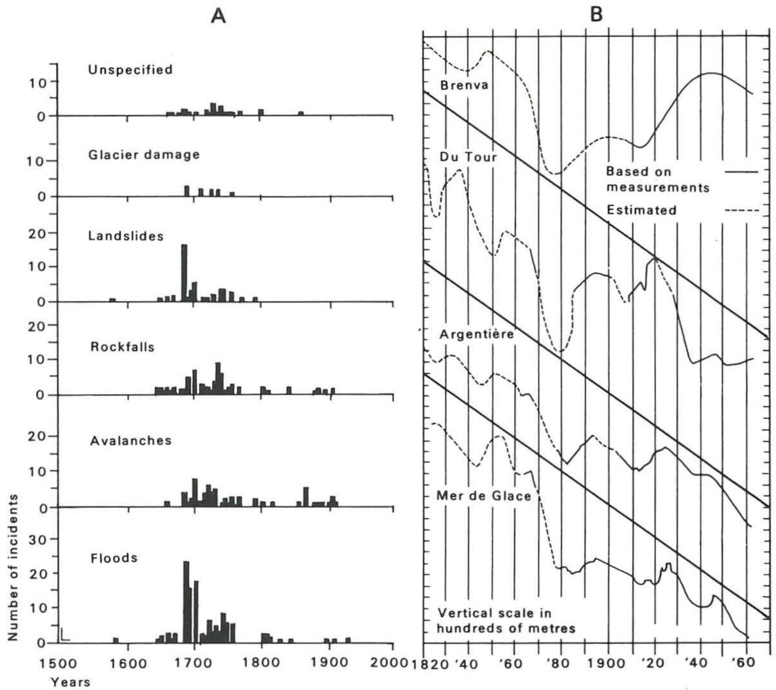


Fig. 6.
A. The incidence of glacier advances, landslides, rockfalls avalanches and floods during the Little Ice Age, with the peak of activity between 1650 and 1750, in the Jostedalsbre region of western Norway: redrawn from J. M. Grove, 1972 and A. S. Goudie, 1977.
B. The fluctuation of glacier margins in the Mont Blanc Massif between 1820 and 1963: redrawn from J. M. Grove, 1966 and A. S. Goudie, 1977.

snowfields produced enormous volumes of water which carried massive quantities of gravels far beyond the confines of the mountains as aggradational alluvial fan surfaces, which helped to build the Canterbury Plains (Soons, 1968) (Fig. 7). The present heavily braided channels of rivers, such as the Waimakariri, flowing across the Plains have dissected and re-distributed much of this enormous load of Pleistocene sediments, often with catastrophic flooding of this valuable farming area (for example, Rayner & Soons, 1965). Thus, careful mapping of the behaviour of mountain snowfields, and of glaciers, is of vital importance to the understanding

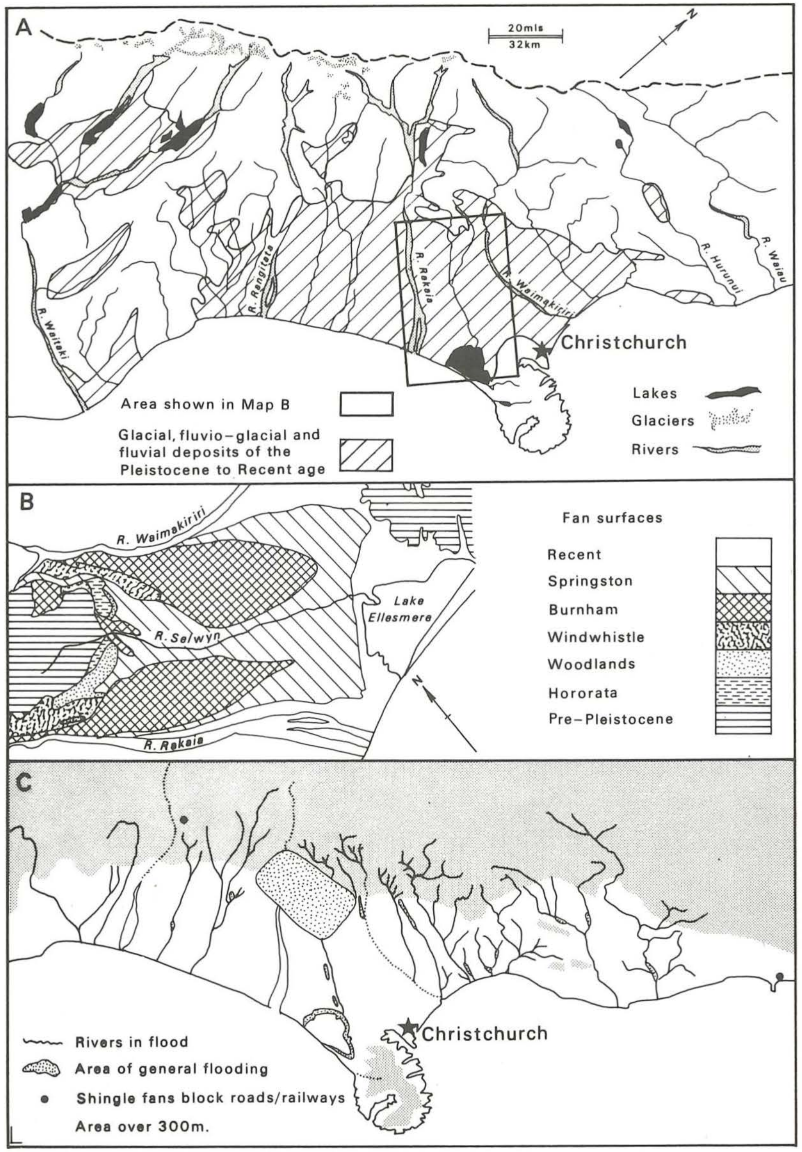


Fig. 7.
New Zealand: Pleistocene and recent events in South Island.
A. The extent of glacial, fluvio-glacial and fluvial deposits on the flanks of the South Island Mountains and on the Canterbury Plains between the Rivers Waitaki and Waiau: present day glaciers are also indicated.
B. Aggradation of gravels during cold phases of the Pleistocene contributed to the building of successive fans, which now form much of the Canterbury Plains.
C. River flooding, 12-17th July, 1963, in the Canterbury Plains.
Maps based upon and redrawn from illustrations in J. N. Rayner and J. M. Soons, 1965 and J. M. Soons, 1968.



and prediction of the changing hydrology of rivers dependent upon these sources for water. The flood control and channel stabilisation constructions along the Waimakariri and Waiau require constant attention, and have been over-topped by flood waters on several occasions in this century.

The control, or rather the prediction, of discharge of snow-fed or glacier-fed rivers is also of vital importance for irrigation in such areas as the Great Valley of California and in the Syr Darya Basin of Turkestan, for hydro-electric engineering works on the Colombia River in N.W. U.S.A. and in the Alps.

## Changing sea-levels

The effects of the withdrawal of ocean water (eustatic factor) during the building of the last great ice sheets, 25000 to 18000 years ago, and the subsequent melting of the ice sheets and return of water to the world's oceans, by about 5000 years ago, resulting in the post-glacial Flandrian marine transgression, is reasonably well documented. A fall and recovery of sea level by about 130 m. was involved, quite apart from changes of land level where ice loading and unloading of sections of the earth's crust (isostatic factor) was involved. Loading and unloading of the continental shelves by the addition and withdrawal of huge volumes of ocean water was also an important factor in controlling sealevel against our coasts (Fig. 8; Mörner, 1976). There are a number of graphs of this type for the post-glacial rise of sealevel against stable areas where no isostatic effect was involved. But because there is a close relationship between sea level and the volume of ice remaining in the world's ice sheets, geomorphologists and others are studying carefully the behaviour, and the mass balance and stability of the remaining large ice masses, especially that of the Antarctic Continent.

Total melting of the Antarctic and Greenland ice caps would raise world sea level by about 66 m., although as yet we are unsure if there was ever total melting, even during the most temperate of the past Interglacial periods. There is of course a necessity to relate such studies to climatic fluctuations and to the deep ocean core records of the type ob-

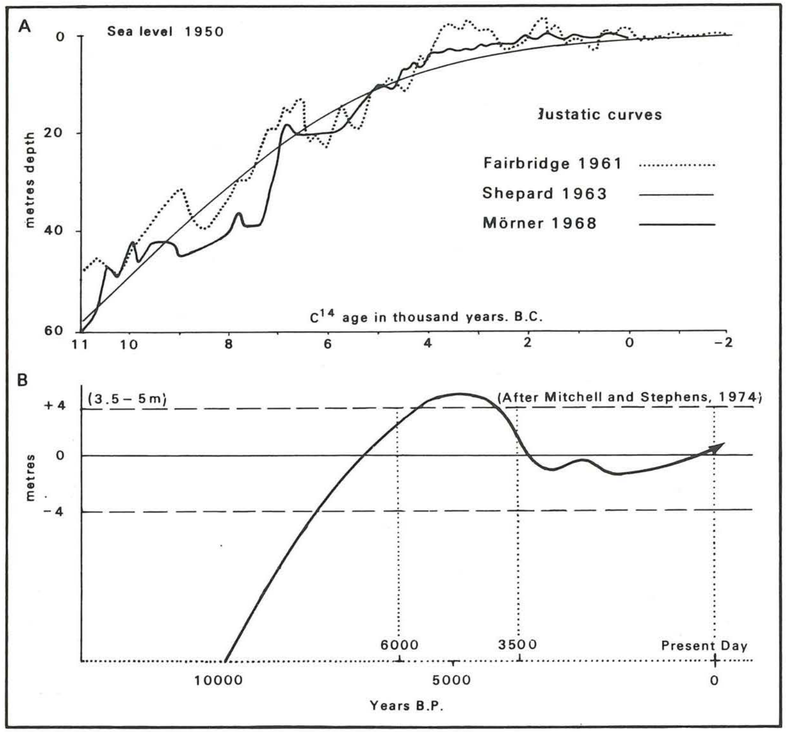


Fig. 8.
Sea level fluctuations during the last 11000 years.
A. Holocene eustatic sea level curves based upon the published data of Fairbridge, Shepard and Mörner, and indicating the recovery of sea level from the low level attained during the Late-Pleistocene: based upon N. A. Mörner, 1969, and redrawn from A. S. Goudie, 1977.
B. Possible Holocene sea level fluctuations recorded in various parts of the world, but based upon evidence obtained for the eastern coastlands of Ireland: redrawn from G. F. Mitchell and N. Stephens, 1974.

tained by Shackleton (1975) and others. This may enable us to determine more accurately the short-term behavioural patterns of the ice masses.

But fluctuations of sea level may not have ceased, and in some areas this may involve more than a few millimetres a year. For example, some studies within the Irish Sea suggest that there was a relative rise of sealevel—a marine transgression—to +4 m. some 5000 years ago, (Mitchell and



Stephens, 1974), although this is denied by others (Kidson, 1977). In some areas it is difficult to correlate the elevated position of the marine deposits with very late isostatic recovery, although for the moment the matter is still problematical and different viewpoints are held by different workers. But if transgressions to this sort of level can happen, without invoking the isostatic factor to explain them, then we must investigate carefully. It has been suggested that instability within a portion of the Antarctic ice cap might lead to break up of a large section of the ice mass, an increased rate of melting, and thence a short, sharp rise of sea level, within 50 years. This is believed by some to have occurred during the Last Interglacial, carrying sea level at least to +7 m. If it happened, the consequences are clearly serious for all coastal habitation sites (Tooley, 1971). Consequently, in 1974, there began an International Programme to study changes of sealevel during the last 15000 years. The I.G.C.P. programme has close links with similar projects examining climatic change, vertical coastal movements and the history of the world's major ice-sheets and glaciers. They are all of vital importance to many millions of people.

The position of the high tide mark, and perhaps even more significant, the upper extent of storm wave activity, sets a limit to permanent human occupancy. Certain coasts are especially vulnerable, for example, the nearly flat delta lands at the head of the Bay of Bengal, especially as hurricane frequency appears to be increasing. In the Netherlands millions of people live several metres below the marine limit, and are protected only by sophisticated, well-designed, and extremely expensive sea defences. Even here disaster can strike suddenly, as it did in 1953, when a major Storm Surge in the North Sea raised sealevel. Storm waves over-topped the defences, and much land drainage was backed-up to flood further areas in Eastern England as well as the Netherlands.

Essex suffered severely in 1897 from sea flooding, and again in 1928, 1953 and 1976. Canvey Island was inundated in 1953 (Fig. 9). After the 1953 floods, sea walls were rebuilt, coastal dune barriers re-established and the Thames Embankment walls raised, the latter by an average of 50 cms. in 1971, but the threat remains. It is a complex equation which has to be considered. The London area, as part of South East

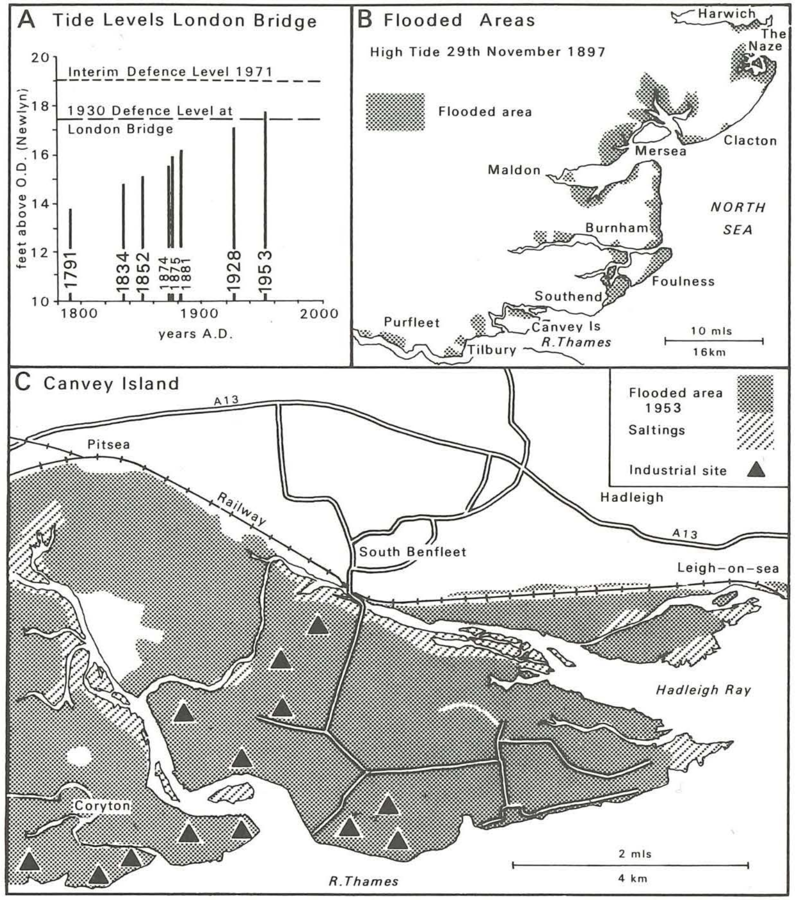


Fig. 9.
Tidal records and marine flooding in Essex and the Thames estuary.
A. Changing tide levels at London Bridge between 1791 and 1953: redrawn from A. S. Goudie, 1977.
B. Marine flooding in Essex in 1897.
C. Marine flooding of Canvey Island and adjacent areas in 1953.
B. and C. are based upon maps published by J. A. Steers, 1953 and 1978, and T. S. Dymond, 1899.



England, is sinking at between 11 and 40 cms. per century, the amount depending upon the authority consulted, and along the river frontage, parts of Roman London are several metres below Trinity High Water Mark (Steers, 1946). But World Sea Level is currently rising by about 10 cms. per century, thus giving higher tides. Tide records suggest an increase of 1.22 m. between 1791 and 1963 (Fig. 9). The net effect in round figures is a rise of water level against the flood walls of the Thames of between 20 and 60 cms. in the last 100 years, and more when meteorological conditions are favourable to the backing-up of water in the estuary. London is also sinking as a result of water extraction from the Chalk, leading to hydro-compaction of the London Clay and Chalk, although Sherlock provides us with the interesting figure that the city in 1913 was rising at a rate of 30 cms per 100 years on its own debris, although this can hardly be a factor of importance along the immediate river frontage (Devoy, 1977); (Rossiter, 1972).

Geologists, engineers and geomorphologists have now convinced the authorities that there is a real risk of serious flooding in London. Meteorologists and climatologists have added support to this opinion, and the result is the construction of the unique flood barrier across the Thames at Woolwich. The London Times recorded the slow progress of the building of this £426 M. barrier on its front page on Monday, 19th November 1979, and an article appeared in the Sunday Times Colour Supplement on 9th December 1979, with the comments that another Storm Surge in the North Sea might breach the presently inadequate defences. If it did, then the shaded area on the map (Fig. 10) may predict the areal extent of that flooding at street level.

Many other parts of the coastline are also at risk, for example, the Wash, Somerset Levels, and parts of north-west England where sea defences have been breached on numerous occasions (Tooley, 1971). It just does not make sense to allow the continued migration of domestic housing and industrial plant, (e.g. on Canvey Island) to low-lying coastal sites below the +10 m. contour, nor to allow the unrestricted removal of protective beach-forming sediments, of which in many areas there is only a finite amount. Major sea floods have occurred on British coasts in 1928, 1953, 1976 and 1978, and if we ac-

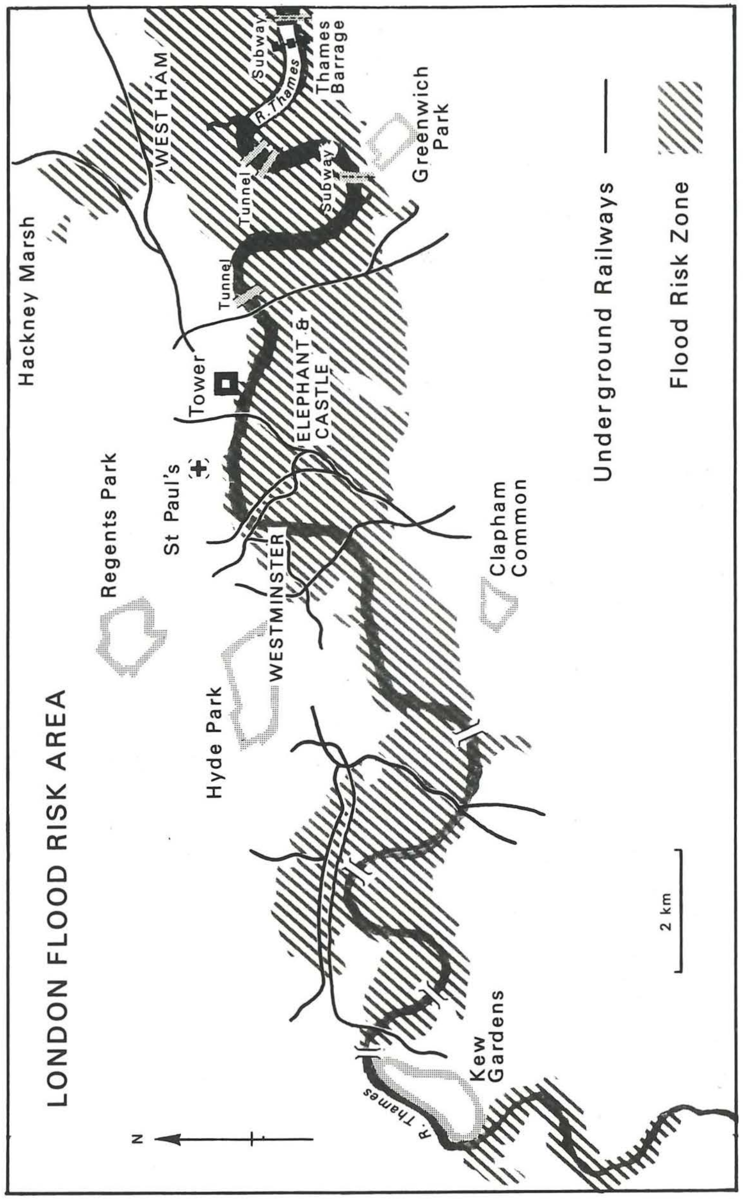


Fig. 10.
London Flood Risk Area.
The shaded area indicates the zone adjacent to the River Thames which is liable to flooding at street level should there be a storm surge from the North Sea of the magnitude of the 1953 surge. The position of the Thames Flood Barrier now under construction at Woolwich is indicated: redrawn from London Flood Control Centre Information Brochure.



cept the warnings provided by such crude data as we have, then we may expect a major coastal innundation in south-east England before 2000 A.D. Although Dr Perry of our department informs me that his analysis of the climatological data indicates that the statistical probability of such a storm surge is 1 in 1000 years, which would flood at least 116 km² of the lower Thames Valley, and directly affect the lives of 1.25 million people, we cannot ignore other evidence which implies a different return period for serious marine flooding.

Thus geomorphologists have a clear duty to engage in interdisciplinary studies of sea-level change, of the processes operating on different rock types, and to assess long-term changes on low coasts. At the International Geographical Union in Tokyo, in 1980, reports are to be presented by geomorphologists dealing with historical changes on the world's sandy shorelines, on marsh shorelines, including mangrove coasts, the effects of artificial structures on shoreline features, and on the instability problems of coastal dune systems. At a time of increasing pressure by mankind on the coastal zones we require knowledge of the processes involved and their spacial and temporal distribution.

## Mass Movement

Soil mechanics methods have been allied to morphological and geomorphological mapping in the study of slopes, and in terrain analysis, particularly in the context of planning for building and highway construction. Geomorphologists have become increasingly attracted by field and laboratory methods which can be used to determine the degree of stability of slopes, and the factors which are involved in the movement of landslides, mudflows and rockfalls. The behaviour of over-consolidated glacial tills, as well as other clays, in the presence of varying water content, will depend upon the extent to which the shear stresses operating are greater or lesser than the strength of the material forming the slope. Where stress levels exceed the strength of the material and where water content is high, then flowing and landsliding may occur: when stress levels are less than the strength of the material there will be some form of creep. Speeds of movement of slope forming materials thus vary considerably (Brunsden, 1979). Where such movements threaten highways or settlements, for example, the catastrophic movements of 'quick clays' in Canada (St. Vianney, Quebec), in Norway and Sweden (Göta Valley), then the engineer, geologist and geomorphologist have joined forces to carry out investigations (Hutchinson and Bhandari, 1971; Hutchinson, *et al,* 1974). In the Göta Valley of S.W. Sweden, 31 houses were destroyed in 1950 and 67 in 1977 by clay-flows of this type, and there are many other examples. Investigations of slope instability as a result of landsliding requires good laboratory and technical facilities to back up field investigations, and a number of geography departments, including our own in Swansea, have the capability for such work. Dr Rouse of our department is conducting studies of slope instability in various parts of South Wales.

There is a wide variety of types of mass movement, and on all slopes gravity, geology, topography and climate are important factors in determining their geographical distribution and their characteristics. Mudflows and debris flows are well known, and sometimes provide spectacular geomorphological phenomena.

In Northern Ireland various mass movement phenomena, including a series of mudflows at Minnis North were studied for several years (1968-1974) and their movements monitored by well-tried surveying techniques (Fig. 11, Prior, *et al*, 1970; 1972). A variety of other equipment included automatic rain gauges, water level recorders measuring both ground water and adapted to measure peg movement on the mud flows, as well as precise electrical piezometers to supplement normal pipe piezometers measuring pore-water pressure at depth in the mud. Very rapid rates of movement were recorded on slope angles varying from 9-35° in mudflows consisting of a mixture of weathered Liassic shale and glacial till (Prior, *et al,* 1972; Hutchinson, *et al,* 1974, Fig. 12A and B). Undrained loading on the more gently inclined parts of the coastal slope resulted in high pore water pressures and hence a lower shear strength of the material.

Between 27th October and 4th November 1971, nine successive days were spent monitoring the piezometers and mud movements (Fig. 13). The diagram indicates the conditions



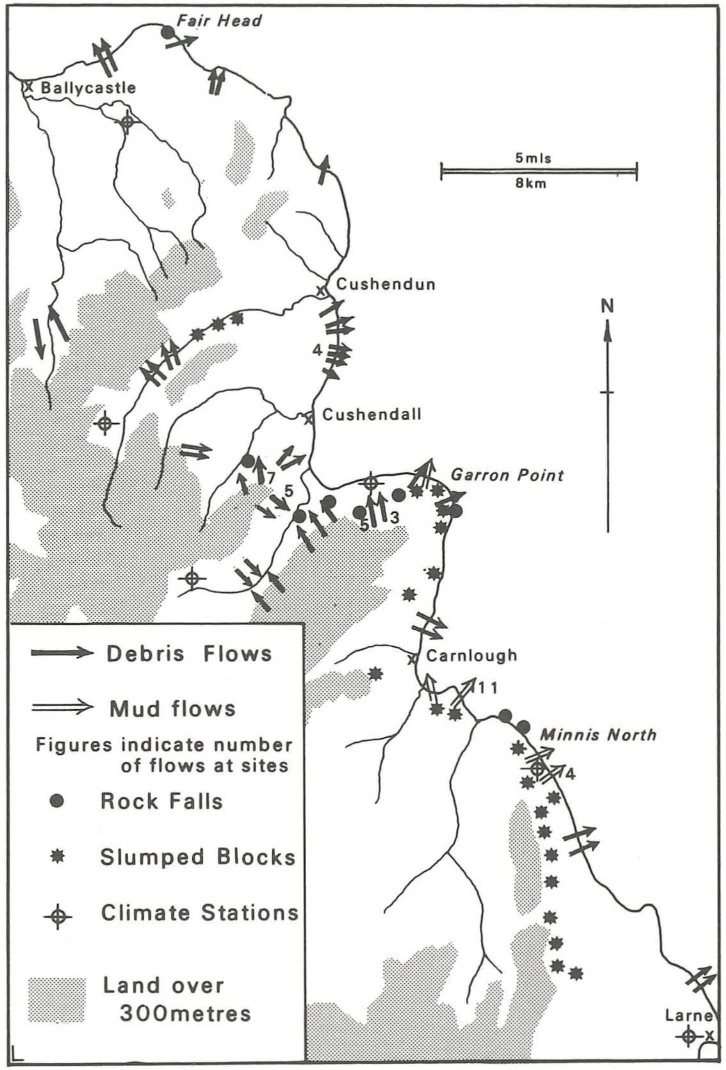


Fig. 11.
Mass movement sites in Co. Antrim, Northern Ireland. The Slumped Blocks are now stable but are believed to have been active during the late-glacial period (c. 14000-10000 years B.P.), and the Rock Falls, Debris Flows and Mudflows are processes currently active: based upon publications by D. B. Prior, N. Stephens and D. R. Archer, 1968: D. B. Prior, N. Stephens and G. R. Douglas 1970; 1971.

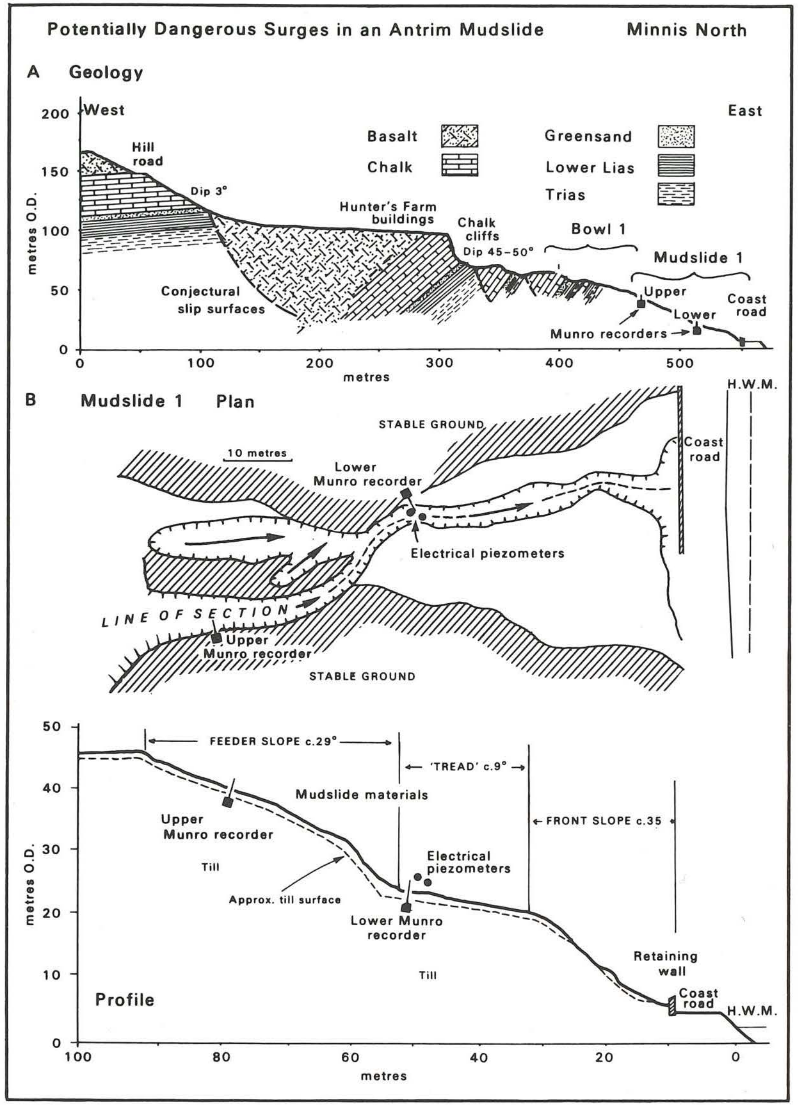


Fig. 12
Minnis North, Co. Antrim, Northern Ireland.
A. Generalised section of the geology and topography of the Slumped Blocks and Mudflows: the mudflows are located on the lower parts of the ancient (late-glacial) slumped blocks which form prominent morphological features on the margins of the basalt plateau in north-east Ireland.
B. Plan and longitudinal profile of Mudflow 1, at Minnis North: the stepped nature of the coastal slope allows 'feeder flows' to build-up 'accumulation flows' on the more gently sloping 'treads': the Munro Recorders monitored the movement of pegs in the surface of the mudflows while the Electrical Piezometers recorded changing pore-water pressure in the mud moving in channels down the coastal slope to spill on the Antrim Coast Road.
A. and B. are redrawn from J. N. Hutchinson, D. B. Prior and N. Stephens, 1974.



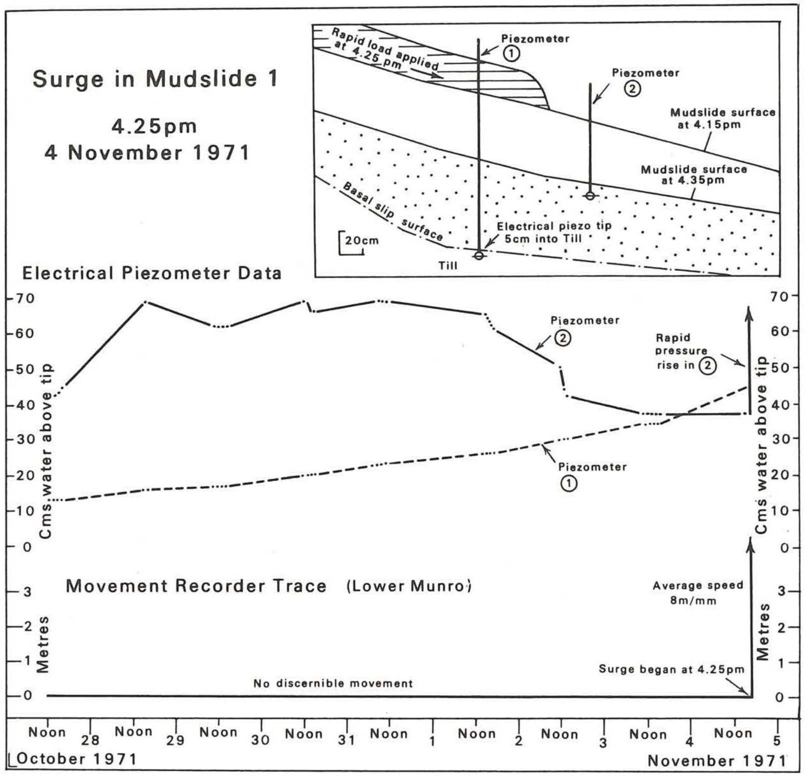


Fig. 13.
Minnis North, Co. Antrim, Northern Ireland. Piezometer and movement measurements in Mudflow 1, 28th October to 4th November, 1971: these recordings of pore-water pressure and peg movement took place on the prominent 'tread' in the slope indicated in figure 12B, and indicate a typical sequence of the sudden increase in water pressure and subsequent failure and flow-surge of the mud following sudden loading of the 'tread' at 4.25 p.m. on 4th November.
Redrawn from J. N. Hutchinson, D. B. Prior and N. Stephens, 1974.

with two electrical piezometers in position, and the geometry of the mudslide known from successive measurements. The final major surge of the mud was caused by sudden loading of about 0.3 metres of mud onto the pre-existing surface—this new mud derived from one of the feeder flows upslope. Heavy rain was falling as this happened and there had been 1·8 mm. of rain in the previous 24 hours. The loading took place at 4.15 to 4.25 p.m. Then at 4.25 p.m. movement of surface water over the mud ceased, the sound of running water stopped, birds stopped chirping, and for a few seconds there was almost complete silence. Suddenly, the mass of mud surged away, and all movement ceased in the channel at 4.30; by 4.35 p.m. 200 m$^3$ of mud was spread out across the road. At this time too resurveying of the new surface of the mud took place and is indicated in the diagram. Unfortunately the Peekel micro-strain recorder could not monitor the last sharp rise in pore-water pressure, the needle going off scale. But it was clear that there was a very rapid rise in pressure; little mud volcanoes were observed on the mud surface on other similar, but less catastrophic occasions. Speeds of movement of approximately 8 m. per minute have been observed and examples of Recorder traces of pegs in the mud flows are given in Figure 14. In places along this coast artificial cuts because of road widening have undoubtedly stimulated such movements by over-steepening slopes and increasing the stress being applied to sections of the slope. Stability analysis indicated that all the slopes involved were steeper than that of the limiting slope for sliding under a range of water pressure conditions. Many surges have occurred as indicated in Figure 15, and a number have reached the coast road (October 1971-November 1972).

For the most part, the mud moved in natural channels cut by successive flows in the coastal slope, and much of the mud reached the coast road. Thus natural accumulation of mud on the more gentle parts of the slope, or behind ramparts of turf, dried mud or slipped masses from adjacent slopes, can lead to the loading necessary to start movement. The danger of a combination of a long profile with steep feeder flows, a flatter tread, and a steep frontal slope, or multiples of this arrangement, is quite clear.



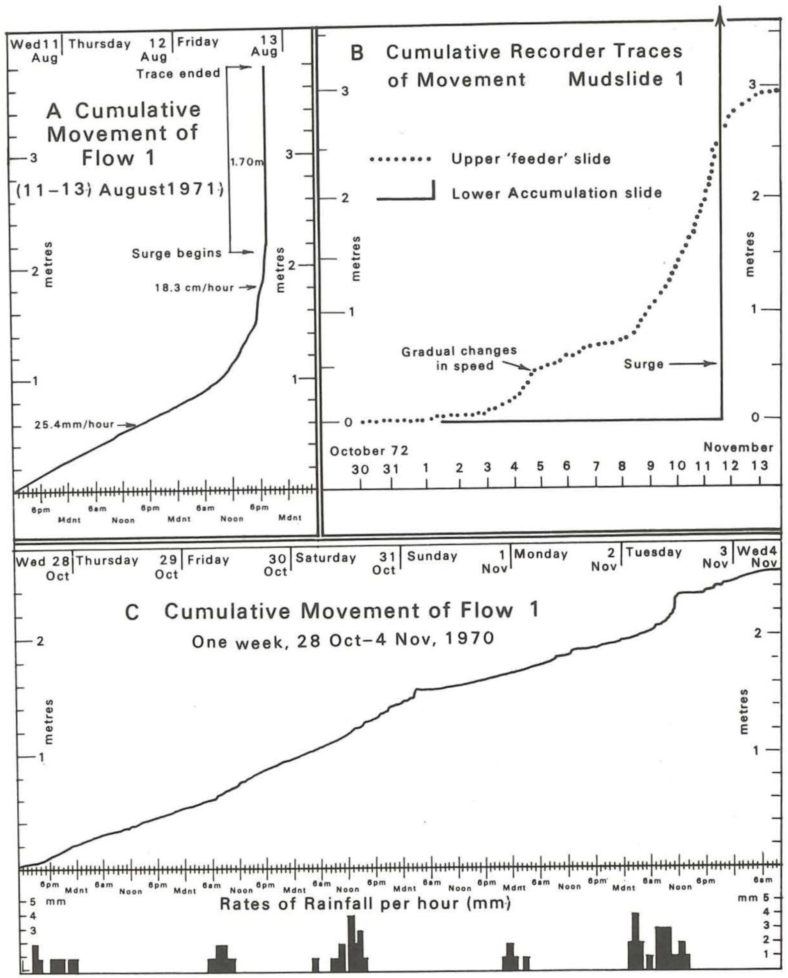


Fig. 14.
Minnis North, Co. Antrim, Northern Ireland.
A, B & C. Representative examples of the Munro Recorder traces of pegs in Mudflow 1, both in the more steeply sloping feeder flows and the accumulation flows on the prominent 'tread' in the slope indicated in figure 12B. The relationship of increased flow rate to rainfall can be observed in C., 28th October to 4th November 1970, although the flow-rate depends upon other factors such as precipitation in the previous period, as well as the clay and water content of the mud.
Redrawn from D. B. Prior and N. Stephens, 1971; J. N. Hutchinson, D. B. Prior and N. Stephens, 1974.

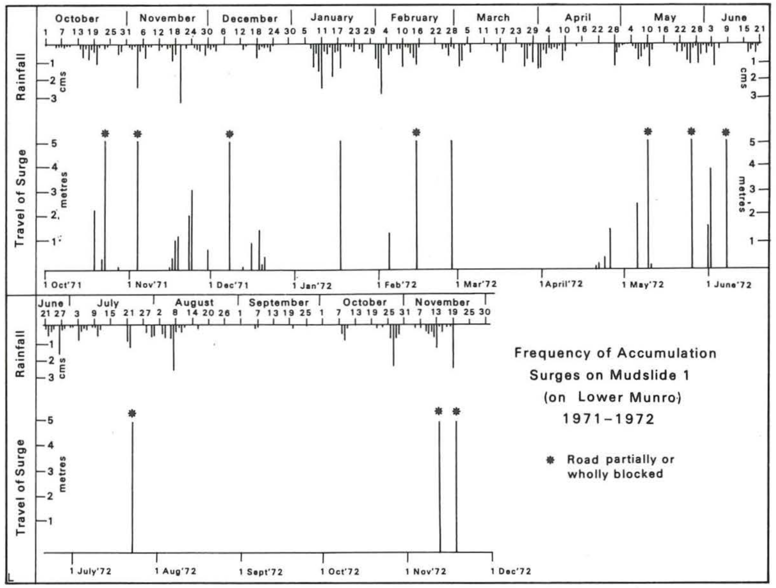


Fig. 15.
Minnis North, Co. Antrim, Northern Ireland.
Automatically monitored data for 1971-72 on Mudflow 1 (Accumulation flow) indicates that 36 rapid accumulation slides of various size occurred and of these 10 were large enough to block the coast road either partially or completely. Rainfall data is provided and indicates that there is only a partial relationship between precipitation amount and movement of the mud. Redrawn from J. N. Hutchinson, D. B. Prior and N. Stephens, 1974.

## Fluvial geomorphology and hydrology

Factors affecting the natural storage of groundwater and the movement of water and sediments through drainage basins are of vital importance to the farmer, forester and engineer. There is considerable geographical variation in river discharges, and of suspended sediment movement, which is largely related to climatic factors, but Man's activities must also be considered.

In Wyoming, logging activities have resulted in the doubling of the sediment yield in the streams, and in Chile, erosion gullies 6-15 m. deep followed upon clear felling of mature forest. In the humid Tropics even more serious con-



sequences have followed forest clearance for agriculture, with gullying and landslides causing severe problems. In the U.S.A. Leopold has shown that although reservoirs can act as sediments traps and may minimise the flood peaks passing downstream, for about 60 km. below the Denison Dam on the Red River over 43 M $m^3$ of sediment has been removed in a comparatively short time after dam construction. Erosion of the river bed and channel banks has been severe because of the increased energy possessed by water lacking its usual component of sediments.

In parts of the U.S.A. such as the American Middle West and Piedmont, where a half to one third of the land area has been broken for cultivation, the sediment yields in the streams have increased by a factor of 6; where two-thirds of the land is cultivated the factor is 35. Valuable farming land is thus placed at risk, especially along the bottom lands or flood plains of many of the major valley systems. Short-term and long-term modifications of the volume of river flows, and the transfer of sediment by various processes, have all been affected by changes in land use (Stoddart, 1971). It has therefore come to be realised that the drainage basin is a vital unit in the study of the various systems, climatic, geological and geomorphological, which combine to bring about new landforms over very large areas. Processes working in a drainage basin vary in space and time, and in intensity, and thus present serious problems of measurement; and consideration must be given to the number of monitoring stations needed to obtain data which can be applied with confidence to the whole basin and the number of years of measurement necessary to allow the data to be used to predict long-term trends of stream discharge and sediment transport (Gregory and Walling, 1973). The recurrence interval or return period of floods is predictable by plotting a consecutive number of annual maximum discharges recorded for as long a period of years as possible. Unfortunately, it is impossible to know, in spite of careful field work and statistical analysis, whether or not the 100 year flood level will occur in consecutive years; or indeed, if the 50 year, 100 year or even the 500 year flood might not occur in successive years. Because of the insatiable demands for land, settlements and industrial sites have been extended onto hazard sites and except on the coasts, none is perhaps in a more dangerous situation than on river floodplains. Local authorities, Government Agencies, Planners, Architects and the Insurance World are now aware of the problem, but it has taken a long time to push the message home. While the Maximum Probable Flood, where the worst meteorological/hydrological conditions combine, is extremely rare, as in the case of Lynmouth in August 1952, and for which there is no real protection, the same is not true for lesser flood conditions. A great deal has been achieved to initiate flood warnings for farmers, householders and industrialists, based upon sound instrumentation of drainage basins. Knowledge of the spacial and temporal distribution of peak rainfall over a catchment, combined with known discharge conditions on a variety of rock types and soils, and with groundwater data available, can enable the behaviour of a river over time to be predicted accurately. Even in ungauged catchments, which present special problems, regional flood frequency methods can be combined with data from adjacent areas and local knowledge to provide estimates of possible flood conditions. Geomorphologists are currently engaged in studying a range of parameters on over 100 small catchments in the British Isles. For example, studies of bedload, streamflow, the role of different types of forest litter on overland flow and infiltration, the effect of different types of vegetation, especially trees, on intercepting precipitation, the ways in which water moves by throughflow below the surface and yet above the general water table, and whether or not systems of natural pipes exist below the surface to aid such movement, are all being examined. The effect of burning surface vegetation has also been studied. Loss of canopy and forest litter, and where burning fuses soil particles, more rapid overland flow may occur. This can lead in turn to more sharply 'peaked' discharge curves. Burning has also had the effect of so weakening the vegetation cover that rill incision from the surface can breach underground natural pipe systems, leading to gully formation and considerable landscape instability. In Tasmania, near Hobart, a fire disaster occurred on 7th February 1967, which devastated a large area of forest and scrub land, and thus allowed a potentially unstable situation to develop (Fig. 16); such fires are of relatively common occurrence in parts of Australia, U.S.A. and the



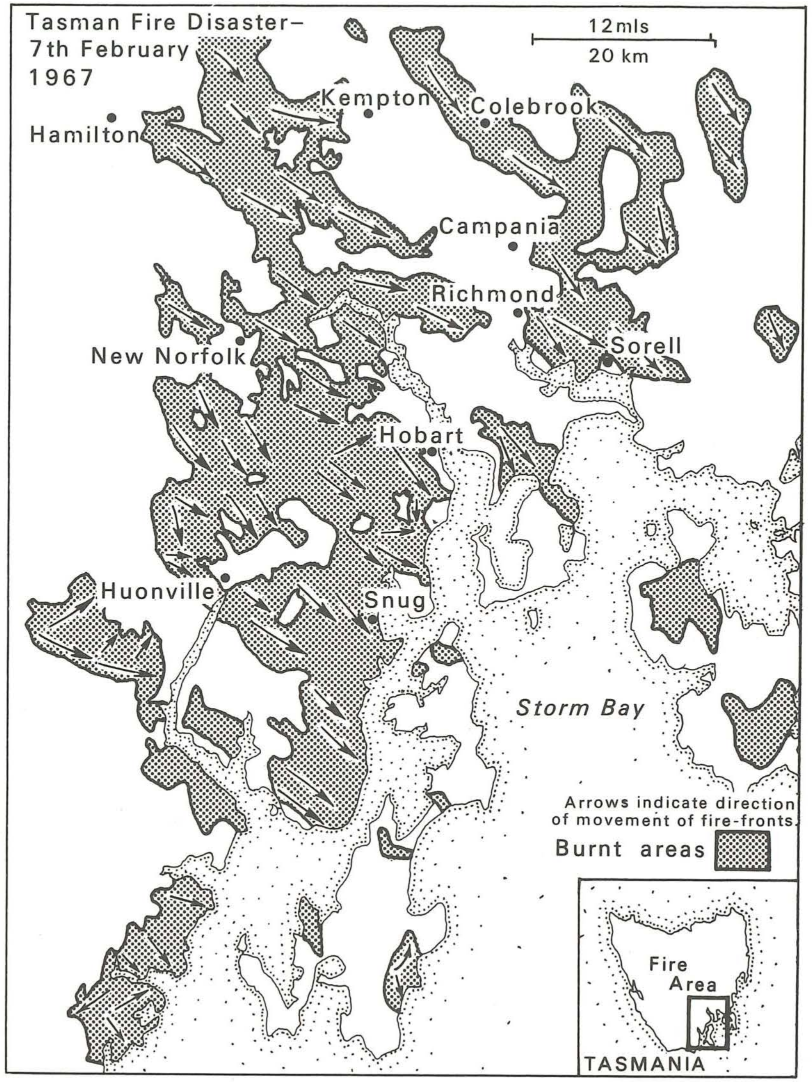


Fig. 16.
Tasmania.
The Tasmanian Fire Disaster on 7th February 1967 devasted a large area of forest in the vicinity of Hobart and caused considerable loss of canopy and surface litter.
Redrawn from Tasmanian Year Book, 1968.

Mediterranean Lands. At Bel Air in California, convectional rain after forest fires resulted in the mass transport of mud and charcoal to bury whole streets.

Another type of investigation has studied the direct effect of building activity (Walling and Gregory, 1970), and of the presence of urban and industrial areas on the suspended and solute loads carried by rivers. Gregory and Walling pioneered much of this work in Britain, and their research shows that suspended loads may increase by factors of between 2 and 10, and occasionally by 100 times the norm, and solutes by a factor of 10 times the norm, on streams below areas undergoing building activity. It has been estimated that in newly expanding towns (e.g. Milton Keynes), or in expanding suburban areas, for each additional 100 persons becoming resident, an extra 1000 tonnes of sediment/year may be added to the total load—first carried by the new storm drains and later perhaps by the river into which they discharge. Further, the magnitude of the maximum annual flood recorded downstream of a substantial new riverside urban area may increase by a factor of 4 or 5. Because it is calculated that 12% of the area of England is now 'urbanised' or 'built-up', the seriousness of this problem of large areas of impermeable concrete and brick, and of rapid discharge by storm drains, is at once evident. An example can be given of the sampling of suspended and solute sediments carried out on the River Don in Aberdeen (Coelho, 1979). Two sampling stations were established, one in a rural situation upstream of the urban area and airport (Parkhill), and the other downstream of the city and a section of river where a number of paper mills and a creamery are sited (Seaton, (Fig. 17A). In the autumn and winter sudden and substantial storm flows occur, as the hydrograph indicates (Fig. 17B). With heavy snowfall there can be a marked lag between precipitation and runoff, particularly if severe ground and air frosts occur—as they do in north-east Scotland—and thus delay rates of melting. For example, after snowfall on 14/15th January 1977, there was a delay until 22nd January for the peak river discharge to take place, the intervening period being marked by zero temperatures.

There was considerable daily variation in the amounts of suspended sediment recorded in the graph for the Seaton



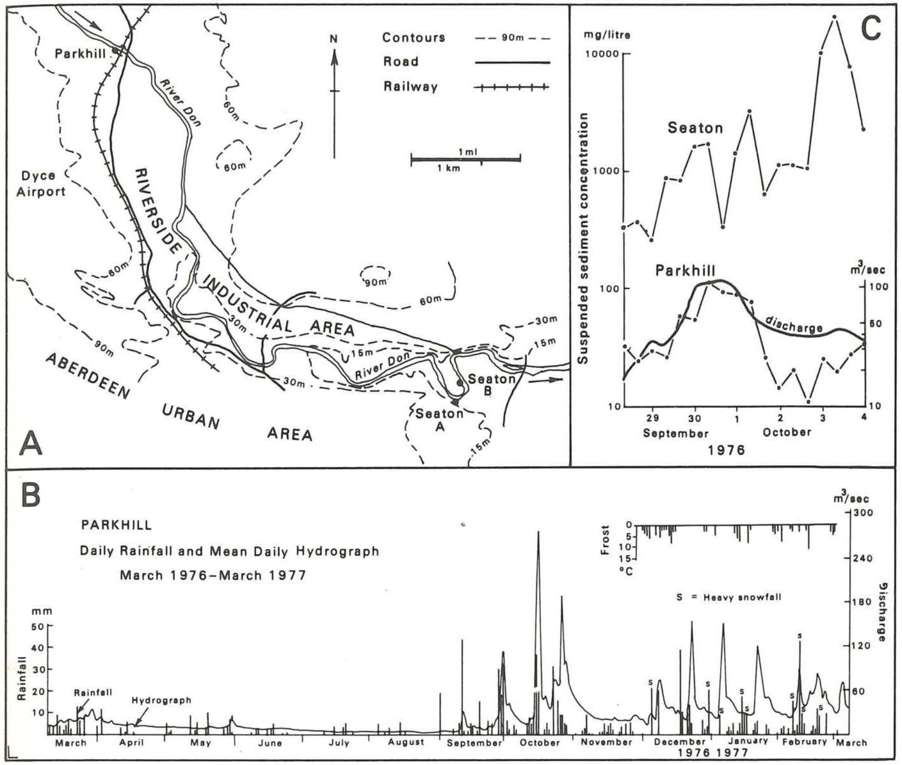


Fig. 17.
River Don, Aberdeen.
A. Parkhill is the rural sampling station situated upstream of the Aberdeen urban area and the Riverside Industrial area. Seaton A and B are the urban sampling stations close by one another in Seaton Park.
B. The hydrograph for Parkhill, March 1976 to March 1977, indicates that in the autumn and winter considerable flood flows occurred, although sometimes there was a lag between precipitation and runoff, especially when severe ground and air frosts occurred.
C. The graphs indicate the variation in suspended sediment concentration at Parkhill and Seaton. The considerable increase in sediment concentration at Seaton, with falling river discharge, indicates the importance of the urban/industrial area in providing additional sedimentary material. Based upon the investigations carried out by Celeste Coelho, 1976-78.

(Urban) site, and three distinct periods (A, B, C) have been indicated in Figure 18. There were also occasions in 1976 and 1977 (e.g. 29th September-4th October 1976) when the suspended sediment concentration actually increased at Seaton, even though river discharge and sediment concentration decreased at the upstream rural station of Parkhill (Fig. 17C). The abundance of celulosic fibres, together with the inorganic material recorded at Seaton, identified a man-made problem. Undoubtedly, the paper mills contributed a considerable amount of waste material to the river, although some of the fibrous waste may be 'old' and derived from the river bed where it had accumulated over a long period of time.

In winter the increase in the sand-sized sediments at Seaton, and the sharp rise in the sodium level of the solute load, probably indicated the influence of runoff from roofs, gardens and especially the airport extension works and roads carrying a heavy load of sand and salt for de-icing purposes. Solute loads were usually diluted by high river discharges, but subject to considerable daily and seasonal variation.

Thus we can see that the 'urban effect' can be important, both for sediment movement and water quality studies. Analysis of the River Don data, begun as a Ph.D. project, will continue as Dr Celeste Coelho publishes details of her results. This type of work is also required urgently in the Tropics, where Dr Walsh of our department has been working in Sarawak and in the West Indies. Sediment loss as a result of hurricanes and agricultural malpractices can affect the quantity of food production, reservoir life and water quality, and as can be seen in Figure 19, data of the type collected for the River Don to be used to calculate erosion rates for catchments of various size.

## Conclusion

One of the geomorphologist's chief problems is acceptance that local conditions will always allow catastrophic events of the type I have described to take place at various scales. We are faced with the problem that the landforms we study may owe their form to a variety of combinations of processes acting



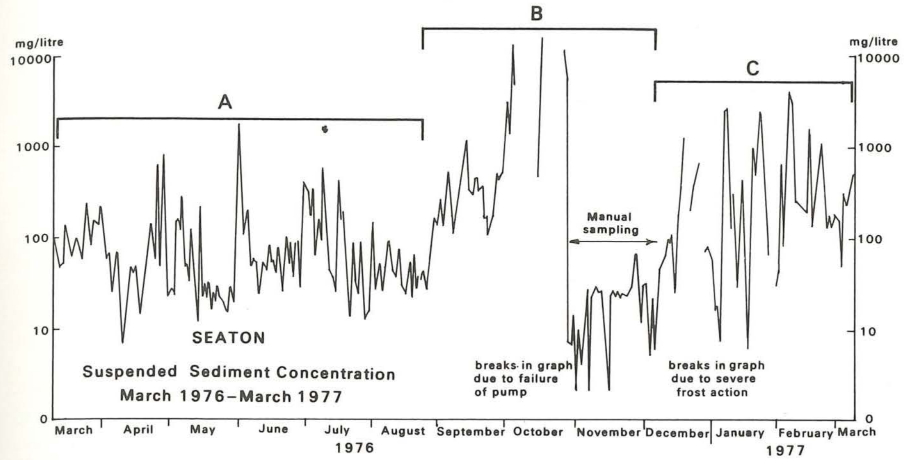


Fig. 18.
River Don, Aberdeen.
Suspended sediment concentration variations are shown, and three distinct phases are indicated for the urban sampling station at Seaton.
A. March-August, 1976: generally high concentrations of suspended sediment were recorded, but variation is apparent and a maximum of 2000 mg./litre was recorded during the passage of a floodpeak between 29th May and 4th June.
B. September-November 1976: very high concentrations of suspended sediment were recorded and closely related to flood conditions; between 14-18th October concentrations of 15000 mg./litre were detected before the equipment was finally submerged by a peak discharge of nearly 400 $m^3$/sec at Seaton (300 $m^3$/sec at Parkhill—Figure 17). The suspended sediment concentration increased on the rising limb of the flood hydrograph, as shown in figure 17C for an early flood. But at Seaton, both discharge (100 $m^3$/sec higher than at Parkhill) and sediment concentration was higher because of the urban/industrial area and the airport contributing to extra runoff and excess of sediment from roofs, gardens and particularly roads and airport runways.
C. December 1976-March 1977: the concentration of suspended sediment remained high but variable, and maximum concentrations did not always coincide with peak flood discharge.
Based upon the investigations carried out by Celeste Coelho, 1976-78.

over both short and long periods. We must, therefore, be prepared to examine a wide range of geomorphic systems across a series of climatic thresholds if we are to gain data which will really help in planning the optimum use of the planet's land surface, and this is particularly true of the Tropics, where the bulk of the World's population live. Sometimes we must delve back into the past to study systems which operated before the hand of men made such an impression on the earth's surface, and increasingly we must be prepared to supplement short-term (Ph.D. type studies) by long-term studies of vulnerable areas and particular problems. We must also be able to organise at short notice a small geomorphological 'task force' to examine a local catastrophic event (e.g. land-sliding, river flooding), and to undertake a range of applied problems on a contractual basis. Only then I feel shall we begin to work towards an understanding of the long-term effects of a series of changing systems.

There is thus a need to have a balanced, but flexible programme of both basic and applied geomorphological research. But I hope we shall remain closely associated with the other branches of geography, sources from which we have learnt a great deal, particularly so far as analytical techniques are concerned; in turn, we hope our work will be useful in various ways, including man-environment studies. I hope, too, that we shall continue to maintain close links with colleagues in the natural sciences, and bring about a re-activation of our traditional links with geology in particular. I recognise that this will need a conscious effort on our part, to improve our techniques, and to show a willingness to take part in inter-disciplinary investigations.

To do all this requires a well-housed, well-organised base, with laboratories, equipment, transport and the technical back-up of the type accepted or regarded as normal in most of the Pure and Natural Sciences. We are extremely fortunate in the University College of Swansea, in being well provided for in a number of these requirements, although not in all. We shall seek to improve our facilities in the years to come.

My final message this evening is that in spite of present difficulties which all universities and departments face, this geomorphologist looks to the future with enthusiasm, in the



belief that we shall find many new things to interest us and stimulate us, that we can provide a Service to Man, and that Geomorphology will continue to be alive and well in Swansea.

| Period considered 8th March 1976-7th March 1977 | Suspended Sediment Load (metric tonnes/year) | Catchment Area ($Km^2$) | Erosion Rate (metric tonnes/year/$Km^2$ | Rate of Surface Lowering (cms/$Km^2$/1000 years) |
|---|---|---|---|---|
| Parkhill (rural station) | 26149 | 1273 | 20.54 | 8.2 |
| Seaton (urban station) (= rural & Urban) | 406362 | 1299 | 318.82 | |
| Urban area *only* | 380213 | 26 | 146.58 | |
| | Solute Load (Mg, Ca, Na, K) | | | |
| Parkhill | 30520 | 1273 | 24 | 9.6 |
| Seaton | 34929 | 1299 | 27 | |
| Urban area *only* | 4409 | 26 | 169 | |
| | Total Dissolved Solids | | | |
| Parkhill | 166820 | 1273 | 131(117) | |
| Seaton | 183749 | 1279 | 141(128) | |

Fig. 19.
River Don Catchment.
Suspended and solute loads are considered for the 12 month period 8th March 1976-7th March 1977, and the following formula used to permit calculation of the rate of erosion:-

$$\text{Erosion Rate} = \frac{\text{Concentration (mg./Litre) x Discharge (m}^3\text{/sec)}}{\text{Drainage Area (Km}^2\text{)}}$$

The calculation requires a knowledge of the total volume of water removed per unit area over a given period, and the quantity of material (suspended and/or solute) being carried per unit volume of water during that period. The crude figures for Total Dissolved Solids at Parkhill and Seaton require adjustment, and reduction by the amount of the input from precipitation, and the corrected figures are given in brackets. The input of solutes from farming practices, from the application of de-icing salt to roads and airport runways, and from the chemical action of suspended sediments could not be quantified.
Based upon the investigations carried out by Celeste Coelho, 1976-78.

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