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A Study of the Criteria Necessary for Determining the Morphological Development and the Young Geological History of the Coastal Zone of Ghana, West Africa

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Introduction and abstract.

The authors have studied the landforms and accompanying superficial deposits of the coastal zone of Ghana (formerly Gold Coast) for a number of year, and have in particular collected data on raised shore-lines. A preliminary 'note' on these shore-lines has already been published (Anderson and Brückner 1957) while a more complete and partly modified account was presented, simultaneously with this paper, at the INQUA Congress held in Spain during September 1957 (Anderson and Brückner, manuscript). These studies of the raised shore-lines involved an analysis of the whole morphological development of the coastal belt. Such an analysis can only be satisfactory if the criteria involved are fully understood, and it became apparent to the authors early on in their investigation that although many of the criteria had been studied in similar or different contexts and their application was familiar to most geologists, there were others that had received scant attention, or were not entirely understood or had not been applied to such an analysis. This paper is thus the outcome of a systematic study of these criteria and the authors hope that it will be of assistance to others working on coastal morphology both within and beyond Ghana's boundaries. No apology is made for including already familiar facts and methods of geological reasoning or deduction as these are necessary for a complete presentation and understanding of this thesis.

This study is mainly concerned with the separation of features of marine origin from those of terrestrial origin; the problems brought about by the reshaping of surfaces under changing conditions and by reworking, as well as those resulting from the mechanical wear and chemical weathering not only of rock fragments and pebbles but also of prehistoric implements; and finally with the establishment of the sequence of events in the area and their dating.

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(1) This paper was prepared while both its authors were members of the University College of Ghana.

I. The chief features of denudation and deposition occurring in the coastal zone of Ghana.

1) *Features of marine origin.*

The two chief *erosional forms* created by the sea when encroaching upon a coast are a 'wave-cut platform' gently inclined towards the sea and a 'coastal cliff' parallel with the shore marking the landward boundary of the platform and of direct sea action. When these two forms are fully developed they meet at the base of the cliff in a notch that lies at, or slightly below, mean sea level, i.e. at an approximately constant height, the 'cliff base'. Near-shore portions of the platform as well as the cliff can show considerable minor irregularity of form that depends in part on the varying resistance of the material to the attack of the waves, and in part on the duration and intensity of this attack. It follows that the cliff base of a shore-line may also be somewhat irregular in height but in general it varies little from mean sea level.

In the coastal zone of Ghana cliff-accompanied wave-cut platforms, usually showing a good deal of minor irregularity, can be observed at many places, both at existing sea level and at raised levels.

Marine *deposits,* sensu stricto, are by definition confined to the area covered by the sea, i.e. they only occur seaward from the coastal cliff, or the shore-line in general, and they may cover all or part of the wave-cut platform and the deeper parts of the sea floor.

In Ghana only remnants of littoral, or beach, deposits have been found on the wave-cut platforms mentioned above. These deposits generally consist of more or less clearly bedded beach sands that are frequently underlain by a basal, bouldery to pebbly, bed. The pebbles included in the latter are characterized by a high degree of rounding of all grades larger than sand size. A special kind of boulder bed occurs where the sea has eroded massive rocks that have previously undergone spheroidal weathering (see fig. 1). The freed boulders, which have usually suffered but little subsequent wear, have been mistaken at several places for the material of storm beaches (O. Davies 1956); storms sufficiently strong to give rise to storm beaches do not occur at present along the coast of Ghana. Beach deposits have locally prevented the sea from developing a cliff line, particularly at the mouths of streams and rivers where beach bars have resulted in the formation of lagoons.

Coastal dunes, although not strictly marine deposits, are related to sea action, and they sometimes parallel the Ghana beaches a short distance inland (rarely more than a few dozens of metres). Generally the dune sands grade laterally into the true beach sands and both normally contain a fairly high proportion of calcareous fragments from marine mollusc shells.

2) *Features of terrestrial origin.*

In the coastal belt of Ghana the three chief *erosional forms* due to terrestrial agents are stream and river valleys, pediplains with their associated pediments, and scarps.

Stream and river action is clearly seen in the large number of valleys with a more or less open V-profile that are cut into planed surfaces of terrestrial or marine origin. The down-cutting is a conspicuous feature of the western part of the coastal belt (west of Saltpond) and becomes less well marked towards the east.

Paralleling the rivers are the pediplaned surfaces which are very even, and where fully preserved they rise with a gentle gradient from the central lines of the valleys towards the watersheds, steepening slightly as they approach the latter. These pediplains thus have concave profiles (see fig. 2). The oldest portions of the pediplains, i.e. those parts that border the rivers, have, however, often been lost due to subsequent valley rejuvenation. It must be stressed that pediplaned surfaces are normally linked to the drainage pattern of an area and that only those that

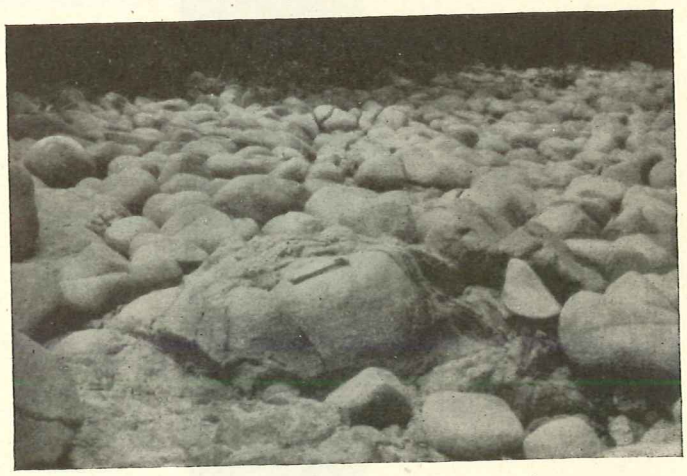

FIG. 1

lie along the coast between stream mouths slope towards the sea. The separation of such seaward-sloping pediplains from raised wave-cut platforms may be difficult or arbitrary.

Where completely developed the pediplain surfaces of adjacent drainage areas meet to form inconspicuous watersheds. Where this end stage has not been reached, however, scarps or steps of varying height and steepness separate the pediplains from higher (older) pediplain levels and occasionally completely surround and isolate hills that are then termed 'inselbergs'. The scarp bases associated with pediplains increase in height with lateral distance from the valley centre with which they are associated. This variation in height in a direction approximately parallel with the coast-line is an important feature since it enables a scarp base of terrestrial development to be distinguished from a cliff base of marine origin which latter maintains a nearly constant height along the coast. The widespread development of pediplain and scarp forms at several levels in Ghana indicates that the semi-arid to arid conditions necessary for their formation operated in this country during several periods. Pediplanation features are particularly well developed in the eastern part of the coastal belt which is at present drier than the

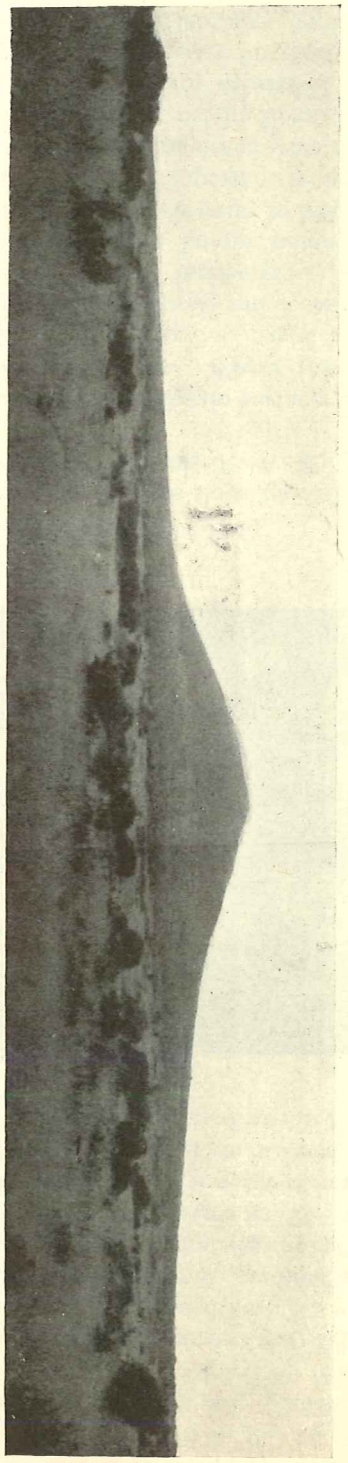

Fig. 2

western part. Pediplains are, however, also present in the latter area and inselbergs can be found throughout the coastal zone.

The terrestrial *deposits* of Ghana have previously been described by Brückner (1955,1956,1957) who showed that in the coastal belt of Ghana the three most important lithological types of deposit present are as follows:

(i) The stone-layer type of deposit. This results from physical breakdown of bed rock under semi-arid to arid conditions, with the smaller particles originating during the process being removed by rainwash or wind while the coarser resistant bodies are condensed to form a layer of usually angular stones (' desert pavement '). Most of these ' stones ' are vein quartz fragments, and ferruginous ' rubble ' derived from lateritic crusts (see below). The development of this lithological type is contemporaneous with periods of pediplanation.

(ii) The ' loamy-sand ' type of deposit. Represented by a sandy to loamy or clayey soil sediment (2) that accumulates on the land surface mainly as the result of the activity of soil-transporting animals (termites, ants, earth worms, etc.) and of gentle creep wherever the vegetation was, or is, thick enough to prevent the immediate removal of the sand and clay particles by rainwash. The presence of this type of deposit is therefore an indication of semi-humid to humid climatic conditions and the existence of a plant cover thick enough to prevent soil erosion at a pace faster than the growth of the soil sediment.

(iii) The ferruginous-hardpan-and-crust type of deposit. This results from a gradual concentration of iron oxides that starts a few feet below the top of superficial deposits, and later continues at the surface when the subsurface hardpan has been stripped of its overburden by rainwash and become a surface crust. The origin of this lithological type is linked with periods of gradual desiccation.

The gravels deposited by streams or rivers although only of local occurrence must also be mentioned here, and in Ghana these can generally be distinguished from marine gravels by a clearly inferior degree of rounding of the pebbles, especially in the smaller grades (below about 2 centimetres diameter). These fluviatile gravels are usually fossil and therefore rarely preserved in an undisturbed state. They grade laterally into the stone layer type, i.e. they were formed simultaneously under a comparatively dry climate.

Locally there are also black lagoonal or swamp deposits that are linked laterally with the ' loamy-sand ' type of deposit.

A zone of chemically altered strongly rotten bed rock nearly always underlies the ' true ' terrestrial deposits listed above. Its origin is certainly terrestrial and

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(2) The grain size distribution in this type of formation is variable as it depends on a variety of factors, in particular on the availability of quartz particles in the subsurface. In general, medium and coarse grains of sand are present, but on some kinds of bed rock the surficial soil sediment may be altogether devoid of sand. In such cases the term ' loamy sand ' should be considered as the name of a particular kind of formation rather than as a strict granulometric description.

linked to humid climate. This zone represents the chief source of the material forming the ' loamy sand ' and the ferruginous-crust deposits.

It has been shown by Brückner (1955,1957) that the chief lithological types of the young terrestrial deposits of Ghana have developed during climatic cycles comprising three stages (dry-wet-desiccation), and three of these cycles have been distinguished.

II. Reshaping of landforms and deposits with changing conditions.

1) *Influence of the advance of the sea.*

Whenever the sea encroaches upon a coastal zone a fresh wave-cut platform and cliff line will develop as described earlier. Where the coastal stretch consists of raised marine platforms, the latter will gradually be destroyed and give way to the new platform and cliff. This development can be observed at many places on the Ghana coast where remnants of three raised shore-lines exist very near to the present-day shore. Where, however, the sea encroaches directly on a coast of terrestrial forms and deposits, first the mantle of superficial deposits will be eaten into, then the zone of rotten rock, and finally the fresh country rock. These three stages can also be observed at various places along the Ghana coast.

During an advance of the sea the material eroded from the shore is transported, worn, and finally incorporated in the marine sediments forming at the same time. The coarse bodies become part of the basal boulder and pebble bed, finer-grained material is added to the beach sands, and the finest matter joins the off-shore sediments. The wear of eroded material within the surf zone is so strong that only very resistant rocks and minerals stand any chance of continuing as fragments of any size within the littoral zone. Ferruginous particles derived from seemingly resistant lateritic hardpans or crusts are destroyed fairly rapidly (mechanically and chemically), and only very compact particles of this kind can normally be found embedded in the developing littoral sediments.

The fairly rapid rounding of resistant rocks and minerals within the surf zone usually makes it difficult or impossible to distinguish between pebbles derived from former, now raised, marine deposits and others added by erosion of terrestrial stone layers or of fresh rock. At some places on the Ghana coast it is nevertheless possible to state that a great many of the pebbles rolling about on the present beach are derived from raised shorelines since the process of their reworking can be observed directly.

2) *Influence of climatic change.*

It has already been stated that climatic cycles, each with a dry, a humid, and a desiccating stage, have determined the nature of the young terrestrial formations of Ghana. Therefore the changes in forms and deposits brought about by these successive climatic changes need to be considered here.

When the climate changes from dry to wet, physical disintegration becomes negligible, while chemical rock-rotting becomes important and a 'loamy-sand' layer accumulates at the very surface burying the stone layer formed in the preceding dry phase. Under such a regime, general lowering of the land relief is only possible by (a) slow subsurface transport of clay or silt particles from the mantle rock to the stream and river courses by percolating groundwater, a process of little significance, or by (b) soil animals carrying sand and clay particles from the deeper mantle rock layers up to the surface to be removed by rainwash. Under a forest cover erosion of the soil is also insignificant wherever the land relief lacks steeper slopes and, therefore, the landforms of forest areas of low relief are particularly stable during wet climatic periods. Throughout the valley systems, however, the greater rainfall of a wet period increases the eroding power of the streams and rivers which consequently begin to incise their beds. This leads to an overall 'climatic rejuvenation' which is, of course, ultimately controlled by the base level of erosion. Subsequently a lateral widening of the valleys or opening of their V-profiles during the humid phases can be assumed.

During the stages of desiccation the relief forms are probably highly stable due to the overall development of the ferruginous crusts. Increasing dryness, however, initiates a rather rapid landscape change. First any incidental residuals of the superficial 'loamy sand' layer are removed by rainwash, then the ferruginous crust begins to crumble physically, and with it any old stone layer material that it has cemented is reworked while resistant stones from the underlying rotten and fresh bed rock are being added because of the new advance of physical destruction. Pediplanation begins along the stream and river courses and gradually progresses outwards, while at the same time it resumes its advance on any older pediment or pediplain surfaces with continuous loss of the higher ground in its path. In the latter case the share of successive dry periods is morphologically indistinguishable and only the remnants, in situ or reworked, of the deposits formed during the intervening humid and desiccating phases are then evidence that interruptions occurred.

3) *Influence of change of base level of erosion.*

In a coastal belt variation of the base level of erosion is just as important as climatic change in bringing about alteration in the form of the landscape.

Lowering of base level gives rise to rejuvenation of any existing stream and river valleys and to the formation of new ones. As in the case of climatic rejuvenation, these incised valleys can secondarily serve as the starting levels for pedimentation during any simultaneous or subsequent semi-arid to arid phases, thus creating new pediplain steps. Lowering of base level furthermore forces the sea to abandon its shore-line, and the now raised platform and cliff can be subjected to the attack of terrestrial agents, i.e. in Ghana to pediplanation or to chemical weathering and accumulation of humid-climate loamy sands, or to ferruginous encrustation.

Raising of base level, on the other hand, leads to the drowning of the near-sea

valley tracts followed by silting-up with lagoonal, fluviatile, and rainwash deposits, while new shore-lines are developing farther inland than the old ones.

The presence of several raised shore-lines and of deeply buried river channels in the coastal zone of Ghana means that changes of base level must be given careful consideration in any attempt to establish the morphological history of this region, particularly as regards their interaction with climatic changes.

III. Reworking, wear and weathering of 'stones' in the coastal belt of Ghana.

The presence or absence of certain 'stones' in the marine and terrestrial deposits of the coastal zone of Ghana, and their state of preservation and surface textures are features of particular importance for assisting in the determination of the morphological, climatic and human history of the country. 'Stones' in this context are meant to be fragments (angular, subangular), or pebbles (rounded, subrounded), of various rock types and of vein quartz, as well as prehistoric stone implements made from these materials. Well-rounded quartz pebbles may be considered as evidence for the marine origin of the planed surface on which they occur; worn stone-tools in a gravel may be interpreted as older than, or contemporaneous with, the including deposit; wind-polished stones may be taken as an indication of a dry climate prevailing during the formation of the layer that contains them; etc. However, in the course of their morphological studies in Ghana the writers have found that such interpretations as these need to be drawn with very great care as the pediplains, desert pavements and raised shore-lines occur at several levels and are of different ages so that resistant 'stones' may have been reworked once or several times during their lifetime. Thus a rounded pebble found on a planed surface may have originated during the formation of the surface, or it may have been reworked in situ, or it may have arrived on the surface at some date subsequent to its formation, etc.

1) *Reworking.*

In Ghana evidence has been found of a number of semi-arid to arid periods of which the last four are most probably Quaternary in age. During all these periods pediplains and desert pavements were formed, but the majority of the landforms and deposits of this kind that have been preserved developed during the last two or three, probably young Quaternary, drier periods. In the coastal belt these young landforms and deposits have arisen at the expense not only of older terrestrial forms and deposits but also of raised marine platforms and their accompanying marine sediments. The stone layers therefore include primarily 'stones' that have been reworked from older terrestrial and marine deposits. Consequently a bed composed mainly of marine or fluviatile pebbles cannot by reason of its composition alone be declared with certainty a marine or fluviatile

formation, nor is the rock surface beneath it necessarily a wave-cut platform or a river bed. Where the majority of the stones are angular (or subangular) and the minority rounded then the latter have undoubtedly been reworked and the only conclusion that can be drawn from their presence is that a marine or fluviatile invasion (or invasions) occurred in the past either at the place in question, or somewhere in the neighbourhood, as some lateral transport nearly always accompanies reworking.

In the coastal belt of Ghana it is particularly difficult to point to the source of the pebbles in the young stone layers as there are not only Quaternary marine and fluviatile deposits present along the coast but also pebble-bearing formations of Tertiary, Mesozoic and Paleozoic age. An added complication is that in the past the outcrops of some of these formations must have been more widespread than they are today.

The reworking of *stone age implements* found in the Quaternary mantle horizons of Ghana must also be considered here. Those that occur in stone layers may be contemporaneous with them, i.e. dropped by fossil man while the stone layers were forming or just after they had formed, but they could equally well have been reworked once or several times without being involved in much transportation or wear. Implements within stone layers fossilized by ferruginous cementation obviously stand less chance of reworking. However, to the writers' knowledge no implement has yet been found in undisturbed remmants of either the older or the younger ferruginous crust of Ghana. The only implements that may be regarded as unquestionably in situ are those embedded in the 'loamy sand' layers. To-date, however, such unreworked implements have been recovered from the 'Upper loamy sand' alone (Quasi-Magosian and younger cultures). All finds representing older cultures have so far been made in stone layers and they are then not necessarily in situ and may well have been reworked once or several times [3].

Reworking of stones by the sea is less frequently recognizable than on pediplains because the rapid wear in the littoral zone gives a similar rounded shape to all the coarse bodies that enter this environment. When rolled implements occur in littoral pebble beds the possibility must be considered of their having been reworked from terrestrial deposits considerably older than the beach itself.

Reworking by human activity is another point that needs to be touched upon here. Fossil man seems to have carried stones and pebbles about over considerable areas and the present-day population does the same thing, e.g. for constructing the foundations of their mud houses. The presence of isolated large pebbles (larger than about 5 centimetres in diameter), unaccompanied by smaller pebbles (with diameters between 5 centimetres and sand size), is therefore by no means conclusive evidence for a marine invasion, or of river activity, at the point concerned.

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[3] Most information on the occurrence and dating of stone artefacts in Ghana's coastal belt has been gained by the authors from discussions and excursions with Dr. O. Davies.

2) *Wear.*

Many 'stones' in the young terrestrial and marine deposits of Ghana (the bulk of which have been derived from quartz veins) show signs of mechanical wear. The kinds of wear that need to be considered here have resulted from movement of 'stones' in the surf along the sea shore, from rolling in rivers or streams, or on pediplains, or from wind blast. The higher degree of rounding of small pebbles characteristic of wear in the littoral zone, and the inferior degree of rounding of small stones found in the fluviatile deposits of Ghana have already been mentioned. On the pediplains mechanical transport and wear of stones is of little importance and seems only to lead to subangular shapes. Wind wear affects the re-entrant areas as well as the salient portions of the stone surfaces and gives them a shiny, polished aspect.

3) *Weathering.*

During the humid periods that alternated with the dry ones in Quaternary times chemical weathering was very active in Ghana. The upper portion of the country rock became rotten, varying of course in depth and degree of decomposition according to the resistance offered by the bed rock to chemical attack. In the same way rock fragments included in the stone layers or 'loamy sands' covering the country rock rotted where they contained minerals susceptible to chemical weathering. Only rocky outcrops and stones lying on the very surface resist this rapid rotting as they are never exposed to the continuous chemical attack of ground water. If, therefore, unweathered pebbles or fragments of rock types liable to chemical decomposition are found on an ancient pediplain or marine platform, they must have been dropped there recently and cannot be remnants of ancient deposits buried under a soil cover for a long time as it would have been quite impossible for them to have survived one or several periods of humid-climate weathering without having completely rotted away. One area in which the writers encountered this problem was near Cape Three Points, the southernmost point of Ghana, where fresh pebbles, rarely less than 5 centimetres in diameter, derived from readily weathering basic volcanic rocks occur on the so-called late-Tertiary peneplain. As they are fresh, it is quite impossible to interpret them as remnants of an ancient beach and as evidence for the wave-cut origin of the underlying 'peneplain'; they must have reached their present position recently and in all probability they were carried up from the present shore by native farmers who used them as grinding stones or as weights on traps, or perhaps by their children as playthings. These pebbles must therefore be classed as stones reworked by man's activity (see above).

Among the processes of chemical weathering the *solution of quartz* requires special consideration since quartz 'stones' occur so abundantly in the mantle rock of Ghana. Quartz is known to be highly stable in the acid environment, but moderately soluble where alkaline conditions prevail, which is the case in the soils of semi-arid to arid regions. Quartz fragments attacked by alkaline solutions have their surface etched, and when the process continues for some time all their angular portions become rounded. The effect of solution in these latter cases can

therefore be mistaken for that of mechanical wear. Solution, like wind wear, affects both the re-entrant and salient portions of the surfaces attacked, but while they are given a polished aspect by wind wear, they are usually roughened by solution, particularly the surfaces of coarsely crystalline quartz aggregates. Wherever quartz solution occurs it affects, of course, all quartz fragments present alike, the unworn angular ones as well as those rounded previously by mechanical wear; careful examination is, therefore, necessary to assess the relative shares of chemical and mechanical action in any particular case.

Solution 'wear' of quartz fragments has been given attention in Ghana but recently. Its occurrence had to be suspected when evidence accumulated that this country witnessed several dry periods in the recent past during which alkaline conditions must have prevailed in its mantle. Etched quartz fragments have now been found at a large number of places and not only in the drier regions where alkaline conditions are still in existence today, but also in the humid forest areas where acid reaction can be found at present in the mantle to reach from the surface to considerable depths.

Solution 'wear' has, of course, also affected many stone age implements made of quartz or quartzite, and where all wear of implements has been interpreted as mechanical (O. Davies 1952, 1956), some cases will almost certainly need to be reconsidered and the conclusions drawn from their wear revised.

IV. Sequence of events, their dating and correlation.

In this last section it is necessary to discuss briefly how the geological data obtained from any one place in the coastal zone of Ghana may be correlated with similar data from other localities, and how the sequence of geological events in the region, i.e. its young geological and morphological history, may be established. In addition the dating of individual geological events within the sequence is considered and also how long-distance correlation may be effected between the events in Ghana and those determined for other parts of the world.

1) *Local or short-distance correlation.*

Wherever continuity of landforms or deposits is broken either by their non-development, or because of their subsequent destruction, short-distance correlation has to be made. This is done by assuming that the landforms or deposits on either side of such breaks correspond to one another when their individual features are identical or at least very similar. Thus with landforms a contemporaneous origin may be ascribed to remnants of wave-cut platforms that lead up to cliff bases of equal height; pediplains of adjacent drainage areas that start from the coast at the same elevation were formed simultaneously; neighbouring valley systems exhibiting the same degree of rejuvenation must have been rejuvenated at the same time, and so on. In the same way deposits of like lithology and/or

fossil content occupying a similar physical setting were formed at the same time. A great deal of correlation of the type illustrated by these examples was necessary to establish the young geological history of the coastal belt of Ghana. Many of these short-distance correlations are based on abundant evidence and are therefore not likely to be disputed, but there are others that are based on scanty evidence and these are questionable and may ultimately be rejected.

2) *Sequence of events and their relative ages.*

In order to establish the sequence of geological events in a region it is necessary to determine their relative ages. By the relative age of an event is meant whether it is younger, older, or contemporaneous with some other event with which it is being compared. A few examples will show the nature of these age relationships.

A pediplain that grades laterally into a wave-cut platform has developed contemporaneously with it; two lithologically different deposits that grade laterally into each other have the same age; a pediplain and the stone pavement covering it have developed simultaneously; a littoral deposit occurring regularly on the wave-cut platform of a particular shore-line is of the same age as the shore-line. A shore-line is younger than any of the landforms or deposits upon which it has encroached; a pediplain is younger than the landforms destroyed by its advance; a stream valley is younger than the surfaces into which it is incised; concretions are younger than their host formation; etc. These and a great many more age relationships have been established in the coastal belt of Ghana and by placing them in their correct age sequence a fairly complete picture of the young geological history of the region has emerged. It must be stressed that the evidence for some of these relationships is much greater than for others and that within the entire sequence some re-arrangements may need to be made in future as new evidence is discovered for the relative ages of particular events.

The determination of the relative ages of fossiliferous deposits can be confirmed in most cases by a study of the contained fossils but unfortunately in the coastal zone of Ghana only a few of the deposits contain animal or plant fossils and so far the species that have been identified are still known as living forms. These fossils cannot therefore be used as age indicators. Better results have been obtained from a study of the stone implements left by stone age man. Thus in Ghana, O. Davies (1952,1956) has been able to identify artefacts belonging to cultures from the Chellean to the Neolithic. These artefacts are of particular value for dating the terrestrial deposits within which they occur and from which all other fossils have disappeared in one way or another. The use of archaeological material for the dating of deposits or the landforms on which they lie is, however, restricted, as many of the artefacts, particularly of the older cultures, have been reworked or suffered solution (see the preceding sections). The absolute age of only one deposit of the coastal belt of Ghana has so far been determined. This was done by means of a C^{14} dating of fossil wood (4).

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(4) Specimen collected by Dr. O. Davies, C^{14} determination made by Prof. H. de Vries.

3) *Long-distance correlation.*

Unlike local correlation of landforms and deposits long-distance correlation of the young geological history of particular areas cannot be based on morphological, lithological or structural similarities. Thus to correlate the geological record of the coastal zone of Ghana with the records from other parts of the world comparisons have to be made of their palaeontological (including archaeological) data, their palaeoclimatic data and their sequence of sea level changes. Palaeontological correlation needs no comment since it is the established geological method. Comparison of palaeoclimatic data is based on the assumption that general trends of climatic development have been the same across large regions or belts of the earth. Our present knowledge of Quaternary climates and their changes is, however, far from complete, and even the palaeoclimatic interpretation of some of the evidence from type areas is still subject to doubt and discussion. Further, the palaeoclimatic record of particular areas is likely to be incomplete. Palaeoclimatic long-distance correlation must, therefore, still be considered as highly tentative. A comparison of the sea level changes in different areas is based on the assumption that world-wide fluctuations of ocean level during the Quaternary are related to the advance or withdrawal of the world's glaciers and ice sheets (glacial and interglacial periods with minor fluctuations) so that in theory every raised or drowned shore-line not related to local earth movements corresponds to a particular period of the glacial record. As with palaeoclimatic correlation, correlations based on changes in sea level must be speculative or tentative since the glacial record is still imperfectly known, and in addition along a coast of limited length like that of Ghana it is possible that certain shore-lines are now very poorly preserved and consequently unrecognizable, or absent altogether. The likelihood of a long-distance correlation being correct is, of course, greatly increased when the results obtained independently from these three types of comparison are in agreement with one another.

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ZUSAMMENFASSUNG

In dieser Arbeit werden systematisch die Kriterien besprochen, die in der Küstenzone Ghanas erlauben, die Entstehungsweise der Landformen und der sie begleitenden Verwitterungsbildungen und Sedimente zu erkennen und ihre Altersbestimmung und Parallelisierung vorzunehmen. Dies geschieht in der Hoffnung, zukünftige Studien von Küstengegenden in West-Afrika und anderswo zu erleichtern.

Im *ersten Kapitel* werden die Erscheinungen mariner und terrestrischer Entstehung voneinander unterschieden.

Marine Erosion führt zu Steilküsten mit vorgelagerten Brandungsplatten, die sich entlang einer horizontalen, häufig durch Brandungshohlkehlen charakterisierten Linie ungefähr auf mittlerem Meeresniveau treffen. Solche Formen kommen in Ghana nicht nur entlang der jetzigen Küstenlinie vor, sondern existieren auch in mehreren höheren Niveaus.

Marine Sedimentation ist vertreten in Strandsanden, hie und da auch Strandschottern, die dem Fuss der rezenten Steilküsten entlang sowie in Form von Nehrungen an den Mündungen von Tälern vorkommen. Ueberreste solcher Sedimente finden sich auch an zweien der gehobenen Küstenlinien. Ein Streifen von Stranddünen begleitet vielfach die strikt-marine rezente Strandzone.

Auf *terrestrische Erosion* lassen sich in Ghana die folgenden Formen zurückführen:

a) Bach- und Flusstäler mit V-förmigem Querschnitt, in relativ junger Zeit unter feuchten klimatischen Verhältnissen eingeschnitten;

b) Pediplanierte Flächen auf mehreren Niveaus, stets den Fluss-Systemen zugeordnet und in relativ trockenen Klimaperioden entstanden;

c) Stufenhänge zwischen den verschiedenen pediplanierten Flächen, im Initialstadium mit wiederholter Talvertiefung während feuchter Klima-Abschnitte zusammenhängend. Durch Ausdehnung der Pedimente sind manche dieser Stufenhänge soweit zurückgedrängt, dass sie nur noch isolierte Hügel, sog. Inselberge, umgeben.

Terrestrische Sedimentation is in Ghana hauptsächlich in den folgenden drei Ablagerungstypen vertreten:

a) « Steinschichten », im wesentlichen aus Bruchstücken von Quarzadern und lateritischem Eisenstein bestehend, unter semi-aridem bis aridem Klima entstanden (Wüstenpflaster);

b) « Lehmige Sande », über den Steinschichten gebildete « Bodensedimente » von sandigem bis tonigem Charakter, im wesentlichen durch die Tätigkeit von Termiten und anderen Bodenbewohnern in feuchten Klimaperioden aufgebaut;

c) « Eisenstein-Krusten », zunächst als Konkretions-Horizonte in den Böden angelegt und nach erosiver Freilegung an der Oberfläche weiter konzentriert, in Perioden allmählicher Austrocknung entstanden.

Hie und da treten auch Fluss-Schotter auf, die sich von den Strandschottern durch viel geringeren Abrollungsgrad der kleineren Gerölle unterscheiden. Schliesslich sind noch schwarze Lagunen-Sedimente zu erwähnen, die seitlich mit den « lehmigen Sanden » verknüpft sind.

Im Liegenden all dieser terrestrischen Sedimente findet sich gewöhnlich eine Zone, in welcher der Felsuntergrund in situ chemisch weitgehend verwittert ist; diese Zone ist die Haupt-Materialquelle für die im Hangenden auftretenden Bodensedimente.

Im *zweiten Kapitel* werden die Umgestaltungen behandelt, die Landformen und Sedimente des Küstenzone Ghanas erlitten haben, wenn sich die einen oder anderen Verhältnisse änderten.

Zuerst wird der Einfluss der *fortschreitenden Küstenerosion besprochen*, die ein Zurückweichen der Küstenlinie und sukzessive Zerstörung aller küstennahen Erosionsformen und Sedimente früherer (mariner oder terrestrischer) Entstehung mit sich bringt.

Dann wird der Einfluss von *Klima-Aenderungen* erwähnt: Während der feuchten Klimaperioden wurden Bach- und Flussläufe in ganzer Länge vertieft und allmählich etwas ausgeweitet, doch wurden die zwischen den Wasserläufen liegenden Flächen wegen des ausgezeichneten Schutzes der dichten Vegetation wenig bis gar nicht verändert. Während der Klimaperioden allmählicher Austrocknung wurden alle Landformen stabilisiert durch die Eisenstein-Verkrustung der Oberflächen. Während der trockenen Perioden aber führte Pediplanierung rasche Umformung herbei.

Schliesslich wird der Einfluss von *Aenderungen in der Höhe der Erosionsbasis* diskutiert. Absenkung führt bekanntlich zu sog. gehobenen Küstenlinien und zu schluchtartigem Einschneiden der fliessenden Gewässer im Küstenstreifen. Hebung der Erosionsbasis ertränkt zuerst die Unterläufe der Täler, worauf gewöhnlich Füllung mit Sediment folgt.

Im *dritten Kapitel* werden die Einflüsse von Aufarbeitung, Abnützung und Verwitterung auf Verbreitung, Formen und Aussehen isolierter « Steine » behandelt, worunter Bruchstücke von verschiedenen Gesteinsarten und Quarzadern sowie prähistorische Steinwerkzeuge aus diesen Materialien verstanden sind.

Terrestrische Aufarbeitung von Quarzbruchstücken, -geröllen und -werkzeugen fand während jeder der trockenen Klimaperioden statt, wenn physikalische Verwitterung neue Steinschichten auf neuen Pedimenten erzeugte.

Marine Aufarbeitung war die Folge jedes erneuten Meeresvordringens.

Aufarbeitung durch menschliche Tätigkeit, d.h. Transport von Steinen über kürzere oder längere Distanzen, liess sich ebenfalls nachweisen.

Mechanische « Stein »-Abnützung in der Küstenzone Ghanas liess sich auf vier verschiedene Ursachen zurückführen:

a) Durch Wellenwirkung am Meeresstrande, wobei grössere und kleinere Steine gleichartig hohe Abollung erfahren;

b) Durch Bach- oder Flusstransport, wobei die kleineren Steine nur schlecht gerundet werden;

c) Durch gelegentliche Regenfluten auf den Pedimenten, wobei nur Kantenrundung zustande kommt;

d) Durch Windwirkung, die zur sog. Windpolitur vorspringender sowohl als einspringender Partien der Stein-Oberflächen führt.

Chemische Verwitterung hat während der feuchten Klimaperioden die in Bodenhorizonten eingebetteten isolierten Bruchstücke beinahe sämtlicher Gesteinsarten, gleich dem anstehenden Fels darunter, sozusagen vollständig zersetzt wegen der kontinuierlichen Anwesenheit von Grundwasser. Nur Aderquarz, vereinzelte kompakte Quarzite und in geringerem Grade auch kompakter Eisenstein verhalten sich in dieser Situation resistent. An der Oberfläche aber, wo Regenwasser rasch abläuft und verdunstet, werden Bruchstücke und Aufschlüsse der meisten Gesteinsarten chemisch nur geringfügig angegriffen. In alkalisch reagierendem Grundwasser ist auch Quarz (Ader-Bruchstücke, Gerölle, Steinzeit-Werkzeuge) relativ gut löslich, wird geätzt, aufgerauht, und allmählich so gerundet, dass mechanische Abrollung vorgetäuscht wird; die Lösungsvorgänge erfassen aber nicht nur die vorspringenden Kanten, sondern auch die einspringenden Partien der « Steine ».

Im *vierten Kapitel* wird gezeigt, wie die Abfolge und das Alter der jungen geologischen Ereignisse der untersuchten Region bestimmt, und wie Parallelisierungen über kurze und weite Distanzen vorgenommen werden können.

Parallelisierung über kurze Distanzen beruht auf der Gleichheit oder Aehnlichkeit geologischer Eigenschaften beiderseits trennender Lücken.

Die *Abfolge der geologischen Ereignisse* ergibt sich durch Studium der gegenseitigen Beziehungen der mannigfaltigen Landformen und Sedimente. Zur *Bestimmung des relativen Alters* der Sedimente haben sich bis jetzt nur archaeologische Funde von Nutzen erwiesen; ihr Wert ist aber durch die zahlreichen Möglichkeiten von Aufarbeitung eingeschränkt. *Absolute Altersbestimmungen* sind nur in seltenen Fällen durch C^{14}-Analysen fossilen Holzes aus Lagunensedimenten möglich.

Parallelisierungen über weite Distanzen, weit über den geographischen Rahmen dieser Studie hinaus, können auf Grund archaeologischer Funde und klimatischer Veränderungen versucht werden, aber auch mittels der Beziehungen der verschiedenen Landformen und Sedimente mit weltweiten eustatischen Meeresspiegelschwankungen. Da aber das Beobachtungsmaterial für alle drei genannten Parallelisierungs-Möglichkeiten noch recht unvollständig ist, muss der spekulative Charakter der bis jetzt gemachten Parallelisierungs-Versuche betont werden.