TECTONIC CONTROLS ON SEDIMENTATION IN ROCKS FROM THE JURASSIC SERIES (YORKSHIRE, ENGLAND)

DAVID J. TYLER, PhD, MSc, BSc.
c/o P.O. Box 22, Rugby, Warwickshire, CV22 7SY, England.

ABSTRACT

One of the classic areas of British geology is reexamined using perspectives provided by the tectonically-controlled rock cycle and the Biblical record of the Flood. Field evidences are described which are highly suggestive of inter-related catastrophic processes and short time intervals. The conventional lengthy geologic timescales claimed for these rocks are challenged. The observations have a bearing on discussions relating to the position of the Flood/post-Flood boundary.

KEYWORDS

Sedimentology, Catastrophism, Diluvialism, Ecological successions, Jurassic Series, Crustal blocks, Tectonic controls, Flood/post-Flood boundary.

1. INTRODUCTION

The Jurassic rocks of England have been studied in great detail for nearly 200 years. More recently, research has intensified. Many of the workable reservoirs of oil and gas discovered in the North Sea during the past two decades lie in Middle Jurassic sandstones. The Yorkshire Coast provides exposures of all the main sequences and includes many classic localities of world renown. In general, field geologists have approached these strata from the perspective of uniformitarianism. They have attributed the sediments to a variety of depositional environments (shallow seas, estuaries, rivers and lakes) over a period of 62 million years.

An alternative conceptual model for interpreting geological phenomena has been proposed by Tyler [27], based on catastrophic rather than uniformitarian processes of erosion and deposition. Conventionally, catastrophic episodes are understood as isolated short periods of intense activity separated by long periods of quiescence. However, the tectonically controlled rock cycle provides a framework for interpreting an integrated series of related catastrophic processes - with consequent shrinking of overall timescales. The Yorkshire Coast Jurassic Series in north-east England has been reexamined from the perspective of this catastrophic conceptual model. Numerous features may be identified which have been associated with tectonic control of geologic processes [27]: abrupt transitions between sediments of different character, fault-bounded sedimentary basins, lateral persistence of both thin and thick beds, evidence of transitory occupation of environments, and characteristic features of rapid sedimentation. The field evidences can be integrated within an interpretative framework of rapidly-moving tectonic blocks to both create sedimentary basins and to control sedimentation within the basins.

This paper takes a selective view of field evidences - focusing attention on several key localities which illustrate the principles of the reinterpretation. The diversity of rock types are evidence for a geological history involving an orderly sequence of events. Certain formations can be related to modern depositional environments - but with important differences which are the subject of discussion here. It is of interest that the first serious systematic field guide to these rocks, by Young in 1822 [28], sought to interpret the observations so as to be consistent with the Biblical history of the global Flood in the days of Noah. This framework is still relevant to interpreting the British Jurassic sequences, but the conclusion of this paper is that the rocks are better interpreted as the result of post-Flood catastrophism extending over several decades.

The evidences reported here are well-known and well-documented. Field guides to the area are by Hemingway *et al.* [12], Young [30], Brumhead [8] and Rawson and Wright [22]. A technical appraisal has been published by the Yorkshire Geological Society [23], and the relevant British Geological Survey overview of the region is by Kent *et al.* [16]. An overview of the solid geology is in Figure 1. The main formations in the area are listed in Figure 2. Most of the observations reported in this paper are familiar to the writer. However, unless observations are indicated to be a personal observation [pers.obs.], reference to relevant follow-up literature is provided.

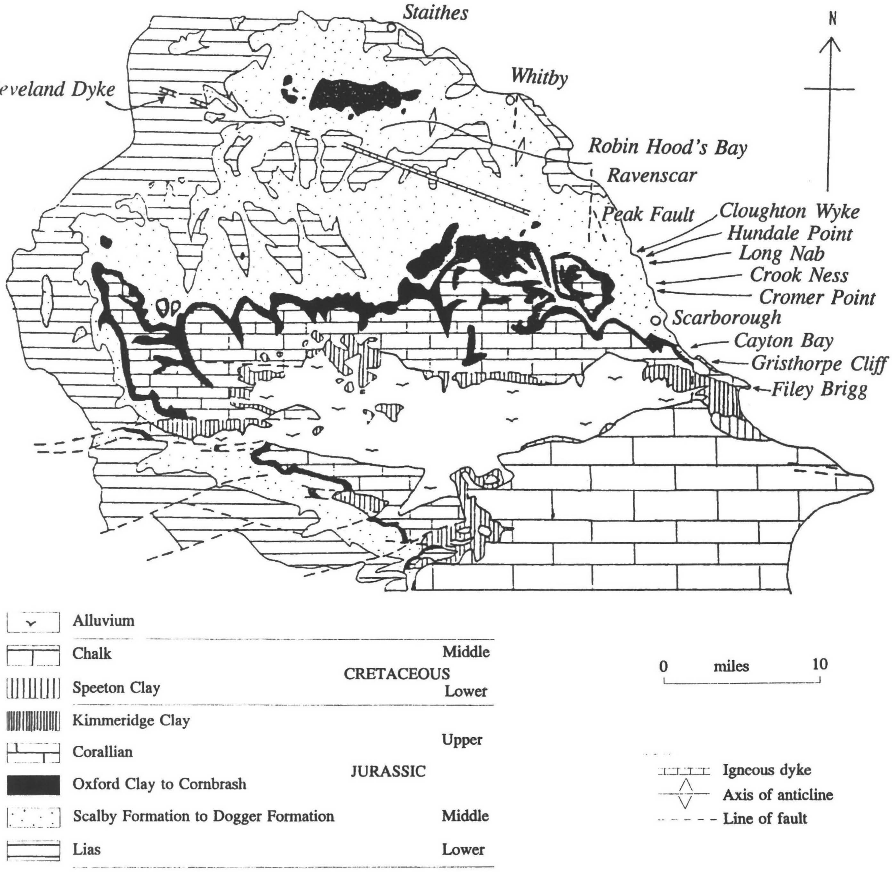


Figure 1: Solid geology of the Yorkshire Coast region
(after Brumhead [8]).

2. STRUCTURAL SETTING

The rocks under consideration in this study belong to the Jurassic Series and were deposited in a structure known as the Cleveland Basin (Figure 3). Details about the boundaries of this Basin are limited, because of the nature of the outcrop, but there are certainly fault zones to the south, where the Market Weighton Block can be recognised, and to the west, where the Basin meets the Askrigg Block. To the east is an extension of the Basin into the North Sea, known as the Sole Pit Trough. To the north are outcrops of sediments which underlie the Jurassic.

Although originally deposited in a basin, the lithified sediments have been affected by Tertiary earth movements and now form a broad antiform called the Cleveland Dome. Numerous smaller scale anticlines and synclines occur within the strata, and this has led to the same rocks being exposed repeatedly along the coast.

UPPER JURASSIC		Upper Calcareous Grit Formation	
		Coralline Oolite Formation	
		Lower Calcareous Grit Formation	
		Oxford Clay Formation	
		Kellaways Beds Formation	
		Cornbrash Formation	
MIDDLE JURASSIC		Scalby Formation	
		Scarborough Formation	
		Cloughton Formation	Gristhorpe Member Lebberston Member Sycarham Member Blowgill Member
		Eller Beck Formation	
		Saltwick Formation	
		Dogger Formation	
LOWER JURASSIC	Upper Lias	Blea Wyke Sandstone Formation	Yellow Sandstone Member Grey Sandstone Member
		Whitby Mudstone Formation	Fox Cliff Siltstone Member Peak Mudstone Member Alum Shale Member Jet Rock Member Grey Shale Member
	Middle Lias	Cleveland Ironstone Formation	
		Staithes Sandstone Formation	
	Lower Lias	Redcar Mudstone Formation	Ironstone/pyritous shales Siliceous shales Calcareous shales

Figure 2. Stratigraphic sequence exposed along the Yorkshire Coast.

The Market Weighton Block is concealed, but can be inferred from the pattern of sedimentary rocks around it. Kendall [13] and Kendall and Wroot [14] considered it an anticline, but subsequent studies did not confirm the existence of folded strata. Beds wedge out as they approach the structure, and it is more likely that they terminate in faults. Consequently, the structure is now regarded as an unfolded block that has affected sedimentation by its vertical movements [15]. Gravity anomalies show a significant low above this block, suggesting granite intrusion at depth [7,15,16].

The Askrigg Block, to the west, has been studied in much more detail. This rigid pre-Carboniferous structure has had a major effect on patterns of deposition in its immediate vicinity. The Dent Fault marks the western boundary and the Craven Fault system the southern boundary. To the north are the Teesdale and Lunedale Faults which separate the Askrigg Block from another well-documented massif, the Alston Block. Both structures are concealed but borings have been made in order to investigate their composition. The results show that both Blocks contain Caledonian granites. To the east of the Askrigg Block lies the Cleveland Basin with a faulted boundary.

For many years, the Askrigg and Alston Blocks have been recognised as actively controlling patterns of Carboniferous sedimentation by their vertical movements [16]. This paper makes the hypothesis that their influence continued into the Mesozoic and argues, furthermore, that deposition in the Cleveland Basin bears the marks of tectonic control.

Intra-basinal tectonic activity during deposition has, until recently, thought to be negligible. Those few faults that are present were widely regarded as having formed in the Tertiary. However, seismic data from within a 30 km offshore zone has led to the discovery of the Peak Trough [18], a 5 km wide graben that was active during the Jurassic. This implies that all the major faults in the Basin were capable of influencing sedimentation.

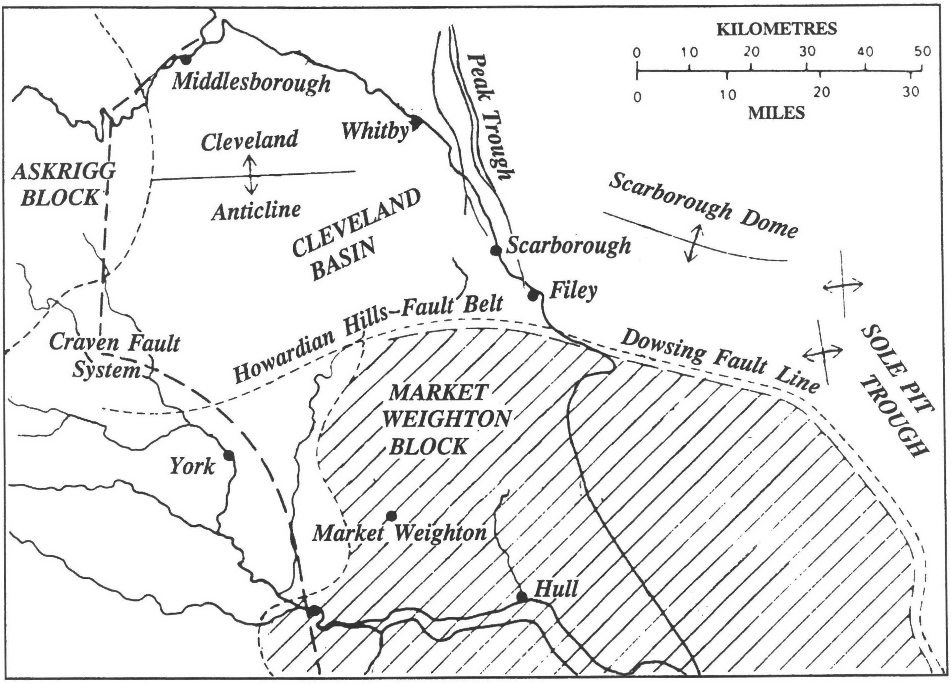


Figure 3: Major structural features associated with the Cleveland Basin (after Kent *et. al.* [16] and Rawson & Wright [22]).

3. LOWER JURASSIC - THE LIASSIC

The Lower Liassic rocks at the base of the exposed sequence were once marine muds, but are now compressed to form dark shales. These may be examined in Robin Hood's Bay. There is no evidence of an authentic sea bed. Bivalves, for example, are not in life positions. Whereas the shells of *Pinna*, a suspension feeder, are found in life with their posterior projecting from the sediment, in the rocks, their half shells lie loose on their sides. They are often aligned [pers.obs]. Various accumulations of body fossils are observed on some bedding planes: where these contain distinctive zone fossils, they are often marked in the field guide maps. These evidences indicate that the muds and the fossils within them were reworked by currents, and that the environment was quite active. This conflicts with the conventional interpretation of a distal sea floor environment with the slow deposition of fine-grained sediments. Some have argued that the fine layering observed in the Liassic mudstones represents a broad rhythmic control of sedimentation [16]. However, it is now clear that such fine laminations may be produced by rapid, continuous processes [4,5].

North of Robin Hood's Bay are exposures of Middle Liassic sandstones and ironstones. Here, the sediments are coarser and the fauna more varied [16]. Trace fossils are common [pers.obs.]. Again, there is no evidence of an authentic sea bed. The main constraint on time is the presence of fossil traces, where organisms were able to feed and burrow during temporary lulls in sedimentation. Many of the layers in these rocks show graded bedding [pers.obs] signifying that the layers were deposited as discrete units and rapidly.

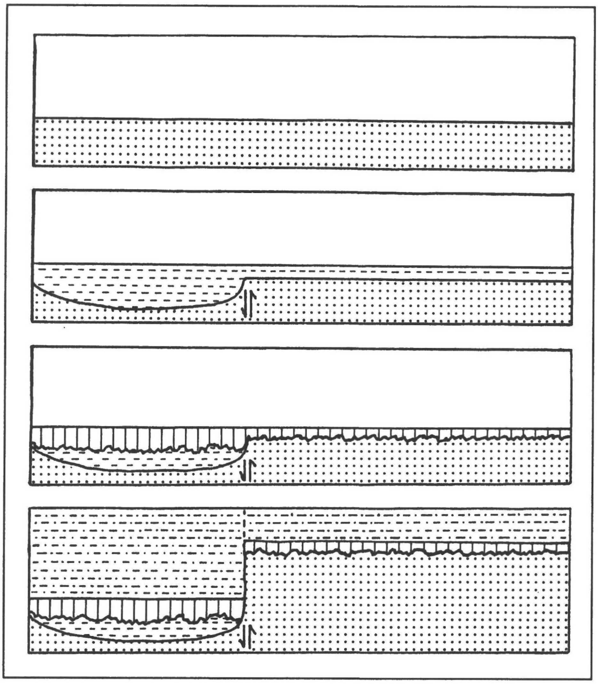
Further north still are the Upper Liassic shales. However, these are better seen at Ravenscar, Staithes and in Whitby East Cliff. As well as trace fossils, bivalves, belemnites and ammonites, these rocks have yielded spectacular saurians [3]. If it had taken thousands of years for these large marine creatures to be slowly covered by muds, they would have disintegrated and their remains, if any, would have been scattered: modern taphonomic studies suggest that sedimentation rates must be rapid to avoid the remains of dead organisms being recycled. Corroborating evidences of rapid sedimentation are numerous: accumulations of ammonites on certain bedding planes, a belemnite cutting through several centimetres of shale instead of lying flat on the surface (pers.obs.); cone-in-cone structures in one calcareous bed [pers.obs.]. (This is a phenomenon with various interpretations, but generally attributed to compression. Here, the proposal is that it is associated with rapid loading from the accumulating cover of mud).

The Peak Fault is oriented north-south and cuts the coastal cliff at Ravenscar. The Lias/Dogger junction is displaced vertically by 106 metres. In most of the area, the youngest strata of the Lower Jurassic are the Alum Shales, and these are succeeded across a marked unconformity by the Dogger Formation. At Ravenscar, however, west of the Peak Fault, the Dogger rests on the Alum Shales. East of the fault, the Dogger is separated from the Alum Shales by about 60 metres of Upper Liassic shales and sands. The Dogger itself is a different thickness on each side of the fault.

The explanation of syn-sedimentary faulting (*i.e.* deposition contemporaneous with faulting) was first suggested in 1874, and this was widely accepted by subsequent researchers [23,30]. However, it does not explain all the facts, and other scenarios have been sought [23]. Further work has established that similar Upper Liassic strata exist in small pockets in several other parts of the Cleveland Basin: namely, in the Roxby Basin, the Ralph Cross Basin and the Crosscliff Basin. It has been suggested that a combination of transcurrent and normal faulting at a much later date (during the Tertiary) could bring strata from one of these basins adjacent to strata outside it. Lateral displacements of about 8 km have been considered. This view was championed by Hemingway [12,23] and was widely accepted.

Brumhead [8] was not entirely happy with this second interpretation and suggested several arguments against it: no transcurrent faulting has been detected on any of the other faults in the Cleveland Basin; the fault breccia visible in the Peak Fault is not as severe as might be expected for transverse movements of this magnitude; and numerous points of speculation are still required for the explanation to be coherent. These arguments warrant the verdict that "no completely satisfactory analysis has been made" [8]. In addition, facies and thickness changes across the fault suggest syn-depositional movement, although these have not been easy to regonise until the structure of the Peak Fault became clear [18].

In the light of recent research, the explanation of syn-sedimentary faulting should be regarded as correct. The several small basins containing Upper Liassic sediments are referred to as "structural basins" in the literature. These must represent syn-sedimentary deformation leading to the deposition of muds and sands which, according to the section now exposed at Ravenscar, reached a thickness of at least 60 metres. The syn-sedimentary deformation may have been accompanied by syn-sedimentary faulting - as was the case with the Ravenscar deposits, which are associated with the Peak Trough. The development of local disparities in the thicknesses and character of beds on either side of the Peak Fault is by no means an intractable problem - as Figure 4 illustrates. The scenario presented does not require large transcurrent fault movements.



1. Deposition of the Alum Shale.

2. Localised deformation and the deposition of the Blea Wyke Formation. Early stages in the development of the Peak Trough.

3. Erosion and deposition of the Dogger Formation, which develops a different thickness on either side of the active fault zone.

4. Sedimentation continues alongside active faulting during development of the Peak Trough.

Figure 4: Proposed development of the Peak Fault

In brief, there are evidences for both syn-sedimentary and syn-sedimentary faulting deformation during the Upper Liassic. These field evidences, when understood in the context of the tectonically controlled rock cycle are associated with short timescales.

4. MIDDLE JURASSIC - THE 'DELTAIC' SERIES

The base of the Middle Jurassic is marked by the Dogger Formation: a remarkably continuous and distinctive sideritic sandstone with marine fossils. Within the basin it varies in thickness from 5m to less than 1m [16]. The lateral persistence of this thin transgressive bed does not find a ready explanation in terms of modern analogues.

Overlying the Dogger are the finer grained sediments of the Saltwick Formation as seen in Whitby East Cliff, and coarser grained sandstones which may be examined in Whitby Town and at Ravenscar. The 'Khyber Pass' mega-channels in Whitby provide a striking contrast to the well-bedded facies at East Cliff and Ravenscar [8]. The sediments are not marine: they lack marine fossils, and they contain a variety of plant remains such as *Equisetites* and also the fresh water mollusc *Unio* [16]. Modern analogues have some value here in interpreting the sedimentary structures. The mega-channels represent river bed deposits - a high energy environment which has no requirement for long periods of time. At the same stratigraphic level are finer grained sediments deposited in horizontal beds. These rocks have at least two evidences suggesting a sub-aerial environment: shrinkage cracks and several horizons of plant root development. These are interpreted here as overbank deposits, as is the case in the field guides [16,17,22]. The shrinkage cracks are considered to be mudcracks because of the association with root horizons. Whereas uniformitarian analogues for deposition require long periods of time, the evidences in the rocks do not suggest a need for anything more than a few years.

Within the overlying Cloughton Formation is the well-known Lebberston Member, or Millepore Bed. The popular name derives from the presence of a branching bryozoan in the unit, and this organism is an indicator of marine affinities. The Millepore Bed may be examined NNE of Cloughton Wyke [16,17]. It rests unconformably on shales and has 3 sub-units, none of which show any signs of in-situ accumulation [pers.obs.]. The material appears to be transported debris. Shells are generally fragmented, and the character of the bed suggests a violent and rapid deposition rather than a marine transgression lasting for an extended period. The observations are fully consistent with a tectonic control of sedimentation and relatively short timescales.

Still within the Cloughton Formation, the overlying sandstones show signs of being typical fluvio-deltaic sediments. The most interesting features of the Cloughton Formation are at least six horizons of in-situ root development [pers.obs.]. The roots have been assigned to the plant *Equisetites*, and form carbonaceous films through the sands and muds below the surface. A clear illustration is in reference 22, page 53. The lowest root bed is formed mainly in clayey muds, and measures about 2m thick [pers.obs.]. Other beds are thinner, and the roots generally pass through sands. Unlike modern horsetails, these plants did not have spreading underground rhizomes. However, other features are similar: the hollow stem, the sections of stem joined by nodes, and the tendency to have part of the stem below ground. The roots have a uniform character, suggesting that each bed is a mono-specific horizon. *Equisetites* appears to have been a pioneer species, and a single growing season would have been sufficient time to form each root bed, but time was insufficient for other species to become established. The 2m thick lowermost bed may be interpreted in the following way. Plants began to grow in an area accumulating muddy sediments. To avoid burial, the plants continued to grow upwards. The buried stems now form part of the fossilised root bed. In all six root beds observed, growth of the plants was terminated by water action - high energy currents brought in new sediment either to cover the plants or to erode the soil surface and deposit more sandy beds.

The possibility that these root beds were allochthonous was seriously considered. In the geologic record, there are many examples of polystrate plant remains which do not testify to *in situ* growth [10]. The empirical investigations of Coffin [9] are of some interest here. He has considered the way modern day *Equisetum* stems in water tend to be oriented in the upright position for many days before becoming waterlogged. However, the experiments relate to stems which were not attached to basal rhizomes, and whilst they are relevant to polystrate *Calamites* elsewhere in the Middle Jurassic sequence, they do not bear directly on the Cloughton Formation rootbeds. Coffin did argue that the surrounding palaeoecology and sediments should be examined carefully before coming to a conclusion on allochthonous or autochthonous modes of formation. This is the methodology adopted here. The downward development of roots is uniformly consistent, even with coarser sand sediments, and even when the sands show distinct signs of high energy deposition. In places the roots are seen to cross breaks in sedimentation in the beds. The roots can be traced up to stems, which may be infilled by the incoming sediment: an evidence which supports the need for an explanation which does not consider stems and roots separately. The roots permeate the rock units: they are not associated with cracks nor are they a surface phenomenon. Several beds of sand separate the units containing the root beds, an observation which argues both for the biological origin of these structures and for short timescales. The autochthonous growth interpretation was considered the only defensible option.

A further exposure of these rocks occurs further south below Gristhorpe Cliff, known as the "Gristhorpe plant bed". The rocks here contain fossilised plant parts rather than roots. The leaves of numerous plants (including Bennettitales, Ginkgoales, conifers and ferns [16]) are well preserved in mudstone. In ironstone nodules, the plant parts retain their three-dimensional form. Lack of decay may be attributed to the speed of deposition in a lacustrine environment rather than to the preservative effects of anoxic sediments.

The marine Scarborough Formation is exposed at Hundale Point (the type locality) and at Gristhorpe Cliff. Gowland and Riding have made a recent detailed analysis of the sedimentological and palaeontological data [11]. Above the root beds at Cloughton Wyke is a 1 m unit of sandstone showing soft-sediment slumping. This is associated with movement on the Peak Fault, the line of which was only a few hundred metres to the east [18,22]. This unit is thought to lie close to the base of the Scarborough Formation [11]. The rock sequence suggests submersion of the underlying non-marine deltaic sands (the upper part of the Cloughton Formation), a deepening-upward sequence of siliclastic and carbonate deposits, followed by shallowing due to a prograding sandy shore. The fossils are typically fragmented and poorly preserved, although some densely-bioturbated horizons are present. This marine transgression can be analysed into distinct phases, each having a recognisable character. The marine sediments were not swept into place as one unit, but successively. The changing character of the sediments, the fossil assemblages, the bioturbation traces and the presence of distinct boundaries between beds indicate that a depositional history over a significant period of time is necessary to explain these observations. However, none of the evidences require long timescales. If the rates of sedimentation were tectonically controlled, as is proposed here, timescales of the order of a year are adequate.

Inland, towards the top of the Scarborough Formation, *Gyrochorte* burrows are found: the *Gyrochorte* organism is thought to be "an opportunistic animal ideally suited to exploiting highly mobile substrates" [21]. The argument that the formation of these facies require high energy, shallow water, tidal beach conditions appears to be valid. If there was a tectonic control on sedimentation, there is no reason to doubt that, as well as being high energy, the strata must have accumulated rapidly.

At Hundale Point there is a major unconformity at the top of the Scarborough Formation. The spectacular cross-beds of the Moor Grit Member of the Scalby Formation outcrop here and, because the rocks are well-cemented, they form the headland. The regional picture reveals that coarse mature sands were carried into the basin by powerful rivers [16]. The current flow indicators show them to have been very disturbed [pers.obs.], suggesting high energy turbulence. Again, all this activity is suggested to be under tectonic control and relatively rapid. The Moor Grit passes up into massive quartz sandstones, well sorted by water action. These are succeeded by the famous Meander Belt deposits: the Long Nab Member of the Scalby Formation.

The Meander Belt may be examined at Crook Ness, Long Nab and Gristhorpe Cliff. In addition to the fossil meandering channels and the overbank deposits, fossil oxbow lake structures are seen at Cromer Point and Gristhorpe Cliff [16,19]. The floodplain has good examples of shrinkage cracks. These are interpreted as mudcracks because of their association with dinosaur footprints here [8,16]. Obviously, such features on bare surfaces require time: to shape the surface and to preserve the markings. However, a constraint on timescales is set by the general lack of vegetative growth over the floodplain [pers.obs.]. Other evidences of rapid sedimentation are seen. The abandoned channel at Cromer Point has been infilled by flaser-bedded sediment with rising ripples [pers.obs.] suggesting gentle but continuous sedimentation. Adjacent to Cromer Point are some point bar sediments which also show a rising ripple texture. The Cromer Plant Bed consists of coalified bed-load plant debris: some of it enclosed in sandstone, other debris wedged between cross-beds.

Livera and Leeder have reviewed sedimentological studies of these rocks [17]. They suggest that the different depositional regimes (wave-tide-fluvial) can be compared to the present day delta of the River Niger. Although there are undoubtedly elements of similarity, the modern analogue fails to account for the numerous evidences of rapid processes. The implications of these evidences in the Scalby Formation are apparent to geologists working within conventional timescales, and this has created an unresolved tension. Thus Livera and Leeder comment: "Problems arise concerning the time taken for deposition of the formation since at least 10 ammonite zones must be represented between the topmost Scarborough Formation and the overlying Cornbrash" [17]. The argument can be extended, because contacts between the Cloughton, Scarborough and Scalby Formation are all sharp and lack any evidence of significant erosion (making it difficult to introduce time gaps to the interpretation) [11].

Alexander [2] has suggested that there must be some tectonic control on the deposition of the Scalby Formation. This approach shares common ground with the views presented in this paper. However, the writer finds no evidence for long periods of time in order to form the strata with its enclosed fauna and flora. Nevertheless, it is necessary to propose a depositional history of these deposits which involves a sequence of events over a significant period of time. Modern day catastrophists have shown that particular features of the rock record can be reinterpreted in a non-uniformitarian way. For example, Oard has reviewed data related to the formation of shrinkage cracks [20] and it is clear that syneresis cracks are possible. Oard argues that it is vital for investigators to look for several corroborating lines of evidence before concluding that shrinkage cracks require a subaerial environment for formation. The evidences presented above show that for these Middle Jurassic rocks, there is a coherent picture of shallow water, non-marine deposition, with periods of subaerial exposure for plants to grow, mudcracks to form and for gentle sedimentation to occur. Whether dinosaurs walked on land or in shallow water is not an issue here: the fact that their footprints are preserved shows that preservation processes happened soon after they were formed [24]. The evidence for time is significant, but a few decades is not an unreasonable estimate.

5. UPPER JURASSIC

High Red Cliff on the southern side of Cayton Bay comprises much of the Upper Jurassic sequence. The sediments are marine, with contrasting lithologies.

Abrupt changes in the depositional environment must be postulated to explain the contrast between sandy clay (Kellaways Beds), grey uniform clay (Oxford Clay) and sandy oolitic carbonates (Corallian Beds) [16]. Such changes are more readily understood where sedimentation is tectonically controlled and rapid than where it is linked to modern analogues. A convolute bed in the Corallian is understood [18] to be induced by an earthquake shock associated with the Peak Trough.

The Corallian is best studied at Filey Brigg. This locality has some of the finest *Thalassinoides* burrows to be seen anywhere [16]. These burrows occur in both the Hambleton Oolite and the Middle Calcareous Grit. Interpreted in the light of modern analogues, these sediments represent different environments (an oolitic, sandy limestine, a limey sandstone and a sandy limestone), yet the burrowing, filter-feeding organisms were present in all three types of sediment. Moreover, the fact that these strata are intensely bioturbated by only one type of organism points to an unbalanced ecosystem. The appearance of large numbers of one species, together with colonisation of both oolite and calcareous grit sediments, suggests an abnormal and temporary situation.

6. DISCUSSION

Subsequent to the laying down of the Jurassic sediments, a notable series of events occurred. Igneous activity to the west of Scotland about 300 miles away, and particularly activity centred on the Island of Mull, led to the development of tension cracks across Scotland and Northern England [16]. The Cleveland Dyke was a major intrusion of magma across Northern England, with outcrops occurring only a few kilometres from the exposures mentioned above. Their presence is evidence that tectonic disturbances of the Earth's crust are able to affect regions far distant from their source. Vertical movements of the Cleveland Basin have produced many depositional changes, and the prime candidates for initiating these changes are the neighbouring Askrigg and Market Weighton blocks.

Any discussion of the timescales for producing these field evidences must first address questions about interpretative frameworks. The starting point chosen in this case is the pioneering work of Young [28,29]. Young was one of a number of 19th Century clerics who made themselves experts in geological science. Young differed from most, in that he adhered to short timescales of earth history and argued for the dominant role of the Genesis Flood in forming the fossiliferous strata. After a detailed description of the Yorkshire Coast field evidences, Young presented his readers with an interpretative framework, using the following arguments to prove that "the different members of our strata have been all deposited nearly about the same period".

1. All strata are affected by the same deformation and faulting processes. Wherever we look, faults pass through successive strata and are not cut off. Thus, evidence of time intervals cannot be inferred from a study of deformation.
2. There is evidence that all strata were semi-consolidated at the time of deformation. That is, rocks which are now significantly different in hardness are folded and faulted to the same extent. Consequently, if all the rocks were then semi-consolidated, it may be inferred that they did not differ markedly in age.
3. There is little evidence for long intervals of time between successive strata. Within a sequence, different beds are sometimes observed to grade into each other. Where there are distinct lines of separation, the levelness of the bedding planes is an indicator that erosive processes were minimal before the deposition of the upper beds.

Young's arguments were not accepted by his peers, primarily because of the overriding influence of Charles Lyell and the interpretative framework of uniformitarianism. Young fought a losing battle. Many years later, Kendall and Wroot [14] referred to Young in passing as "primitive". However, the three arguments for rapid deposition cannot be dismissed so easily - they are not infantile speculation but logical argument based on a close acquaintance with field evidences. Admittedly, all the points need qualifying: there is evidence for syn-sedimentary deformation, and possibly faulting; rocks experiencing creep under pressure do behave differently from rocks at the surface; there are indications of time (root horizons, sedimentary structures and trace fossils which suggest periods of non-deposition). However, none of these qualifications require us to reject Young's basic thesis that these beds were laid down over relatively short time periods.

Most contemporary geologists regard the British Jurassic as a time of placid deposition. The recent interest in neo-catastrophism has raised a few questions about timescales of deposition. Ager [1] draws attention to unusually large regional variations in thickness of a biostratigraphic zone, and also the presence of boulder beds in the Upper Jurassic in Sutherland, Scotland. However, apart from the recognition of storm deposits, few have acknowledged any role for catastrophic processes, and even fewer have moved any distance from the uniformitarian framework adopted by earlier geologists.

Berthault [6] has argued that a radical rethink is necessary on the meaning of terms like "stratum" and "layer". He has suggested that stratification can result from continuous sedimentation processes, and that this revolutionises stratigraphy. Whilst this argument has been used to promote diluvialist interpretations of the rock record, it must be tested in the field. The evidences reviewed in this paper have not been interpreted as resulting from continuous sedimentation. Footprints, bioturbated horizons, root beds, and sedimentary structures like meander beds, channels and overbank deposits, require a coherent interpretative framework: the model proposed by Berthault does not provide it.

Scheven [25] has argued a case for the Noahic Flood being the primary cause of the Palaeozoic Series of rocks. The Mesozoic and Cenozoic Series represent post-Flood catastrophism and are associated with faunal and floral mega-successions. The British Jurassic provides an instructive test case for the proposed model. The review of field evidences presented here has suggested that the Yorkshire Jurassic may be described satisfactorily as post-Flood deposits associated with transitory epi-continental seas. Contemporaneous tectonic activity resulted in the raising and lowering of crustal blocks, with consequent rapid shift of water and sediment into subsiding basins and the occurrence of syn-sedimentary deformation. Within this model, the continually changing environments had profound effects on their living inhabitants: ecological successions were characterised by rapid replacement of faunas and unbalanced ecosystems. Whilst these observations are related to a specific area, the rest of the Jurassic, and indeed the whole Mesozoic, shows a similar picture, as Scheven has indicated in a 1993 review paper [26].

Science is widely accepted to operate within large-scale interpretative frameworks, sometimes referred to as paradigms. The uniformitarian paradigm leads inevitably to a rock cycle based on present-day processes and to timescales lasting millions of years. The Diluvialist paradigm utilises a rock cycle based on catastrophic processes and timescales are consequently short [27]. Scientific work can be undertaken within both these paradigms: this paper has adopted the Diluvialist paradigm and explored the development of Jurassic Series strata deposited in the Cleveland Basin. The regional picture gives confidence that the general approach is viable and that further detailed work on specific strata will yield fruitful results. A key issue for science concerns the testing of hypotheses against data. This paper is concerned with the hypothesis that the Jurassic Series of rocks represents post-Flood depositional processes and it is concluded that, in the Cleveland Basin, the hypothesis is capable of integrating successfully numerous field evidences.

A necessary implication of the analysis presented here is that there are qualitative differences between Palaeozoic rocks (Flood deposits) and post-Palaeozoic rocks (post-Flood deposits). Differences should be apparent in studies of trace fossils (activity and escape traces vs dwelling traces); evidences of plant growth (allochthonous vs autochthonous); shrinkage cracks (subsediment syneresis cracks vs subaerial mudcracks); monospecific horizons (water sorting vs unbalanced ecosystems). Major differences should be apparent in the sedimentary basins and the smaller scale structures associated with deposition. It is the writer's judgment that such differences do exist, but documenting them is outside the scope of this paper.

7. CONCLUSIONS

(a) Different paradigms of geological interpretation exist which permit radically different interpretations to be placed on the same basic evidence. It is the work of science to test the interpretations rigorously against the data and to explore the effectiveness of different hypotheses in explaining the observations.
(b) The tectonically controlled rock cycle provides valuable assistance during field research: identifying significant and interrelated phenomena and pointing to appropriate mechanisms.
(c) The Cleveland Basin of Yorkshire provides an example of a classic area of geology with a complex geological history. Whereas all research since Young [28,29] has adhered to the uniformitarian paradigm, there are many evidences that favour an alternative interpretation based on catastrophism.
(d) The specific hypothesis that the field evidences can be explained satisfactorily by a Diluvialist model, where the Jurassic Series represents post-Flood sediments, has been explored. The results suggest that the hypothesis is viable and worthy of elaboration.
(e) This paper provides an input to discussions among Diluvialists of the positioning of the Flood/post-Flood boundary. A pre-Jurassic boundary is to be preferred.

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