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Imperfection of stratigraphic record

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Stratigraphic sections are the only records of past sedimentation history. However, they are incomplete. Besides unconformities, there are innumerable smaller gaps in otherwise conformable sections. Every bed and lamina surfaces are such gaps and more often than not, they bear no evidence of erosion. Between erosion and deposition, some gaps owe their origin merely to non-deposition. If sediment input on a depositional surface is equal to sediment output therefrom, neither erosion nor accretion of sediment would take place. Only the delicate features like preferred termination of burrows, rootlets, cementation, and/or borings can help detection of such subtle omission surfaces. Furthermore, stratigraphy is biased toward episodic deposits at the expense of day-to-day sedimentation. Consequently, the time recorded in stratigraphy represents only a minuscule part of the time lapsed in building it up. Hence one should be cautious in the application of many fundamental principles of sedimentology that assume continuity of sedimentary records.

Keywords: Stratigraphic record, Omission, Event bias, Sedimentation rate, Minuscule representation, Non-uniformitarian

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INTRODUCTION

Sedimentary strata preserved in rock records with time are always the key elements for geohistory reconstruction (Smith *et al*., 2015). Whatever the primary physical, chemical and biological signatures they retain that would be the only clue for sedimentologist to carry out their investigation of the past depositional condition. While arranged chronologically the revelations would enable them to reconstruct the evolution of the depositional basin through time and space, in the direction of sediment accretion. Interpretation thereof depends largely on the concept of Uniformitarianism. Here lies the danger of this approach, an uncritical acceptance of the geological axiom, "Present is the key to the past". For example, Walther's Law, one of the most celebrated principles of sedimentology, is based on the perception of continuity of sedimentation. However, sedimentologists and stratigraphers find the issue in adopting continuous sedimentation in over a wide range of time (Miall, 2015; Nichols, 2017). This gap in lithostratigraphy has also been corroborated by biostratigraphers (Saraswati, 2019). The reason is that sedimentary record is by nature fragmentary (Barrel, 1917) and it is biased in favour of event deposits. Preservation potential is higher for storm deposits than for fair-weather deposits in lakes and shallow seas. High rate of sedimentation and consequent rapid burial favour preserving more storm deposits than the fair-weather product deposited over far longer time intervals. A storm removes a considerable number of fair-weather beds because of its high energy. Similarly, turbidites of considerable thickness in deep seas record only a minuscule time interval with respect to that needed for deposition of the associated pelagics. Even the fair-weather sedimentation is not continuous. In a meandering river sediment accretes on point bars, but at the same time sediment is removed from the cut banks; deposition and erosion operate hand in hand. A complete stratigraphic record is thus an exception rather than a rule. With unconformities on one side and the lamina and bed surfaces on the other, it attributes that sedimentation hiatuses vary from seconds to millions of years. The incompleteness of stratigraphic record is thus readily acceptable but hard to quantify (Barrell, 1917; Reineck, 1960; Singh, 1969; Schumm, 1977, Sadler, 1981). Thus, the geological time recorded in stratigraphic sections is generally shorter than the time lost. Large-scale angular unconformities and disconformities are readily recognized, but not diastems. The hiatuses can be short-lived and can befool sedimentologists. Our intention in this paper is, however, to focus on those hiatuses that often evade and prevent us to reconstruct geological history in satisfactory detail. The paper aims to create awareness about gaps in global stratigraphy. Our main targets are not the unconformities recognizable in snaps, but the gaps that demand deeper insights and greater sophistication in approach for their recognition. We focus upon gaps in the scale of years, hours, minutes, and even a fraction of seconds. Even in the best-cited examples of exceptional preservation, formations still display bedding and lamina planes depicting the gaps in the record.

CONTINUOUS RECORD AND UNIFORMITARIANISM

Even today, there remain lingering legacies of the old-fashioned uniformitarianism and an instinctive abhorrence for short-lived events still persists. We tend to favour subconsciously continuity over discontinuity, gradual over spasmodic and average over extremes. Cyclicity, a special form of uniformity (uniform change with uniform deviation from norm and uniform repetition rates), is often claimed in order to explain sequences of alternating lithologies. That is for equilibrium in place of disequilibrium and steady state in place of erratic arrangement. This paradigm imposes more order on nature than what exists.

The idea that geological processes, although very slow are also steady at least in part, and many other key concepts in sedimentary geology are based on this concept of continuity in the sedimentary record. The stratigraphic classification and correlation, Walther's law, cyclic sedimentation, and facies models, all are based on the perception of 'present is the key to the past'. We tend to adjudge ancient sedimentary records on the human time scale. In refutation to that, the catastrophic view of the early 19th century saw a history of the earth as punctuated by brief but violent upheavals separated by long periods of tranquility, i.e. ordinary day-to-day processes. Ager (1993) imparted a more important role to large-scale catastrophic events than to non-events in building up sedimentary successions. Nichols (2017) pointed out that the search for replication of modern environments in the rock record is often hazardous, if not impossible in some cases. Even within the relatively young Phanerozoic sequences, the 'present is the key to the past' principle is hard to extrapolate. The Pleistocene global glacial record, for example, hardly has any equivalent in the present world, neither at high altitudes nor in the poles (Hughes *et al*., 2020). The prevalent idea that the major meandering river systems developed during the Phanerozoic also needs significant modification (Nichols, 2017). The stability of river banks, which is one of the major reasons for meandering of rivers, has generally been correlated to the advent of land plants that appeared during the Silurian (Schumm, 1968) or perhaps middle Cambrian-early Ordovician (Morrris *et al.*, 2018). However, at the early stage of land plant evolution, the angiosperms had a simple rootlet system offering only limited resistance to erosion (Schumm, 1968; Nichols, 2017). In contrast, grasses that appeared only during the mid-Cenozoic, have a very effective rootlet network, enhancing the sediment binding capacity (Fig. 1; Nichols, 2017; Fox *et al*., 2018), although diversification in grass has been reported from late Cretaceous (Prasad *et al*., 2005, 2011). Hence the meandering pattern of rivers became preponderant in the post-mid-Cenozoic (Hooke, 2007). The Phanerozoic world had witnessed several cycles of icehouse and greenhouse states (Royer *et al*., 2004) and in consequence, the sea level fluctuated over tens of meters (Fig.1; Craig *et al*., 2015). Evidence

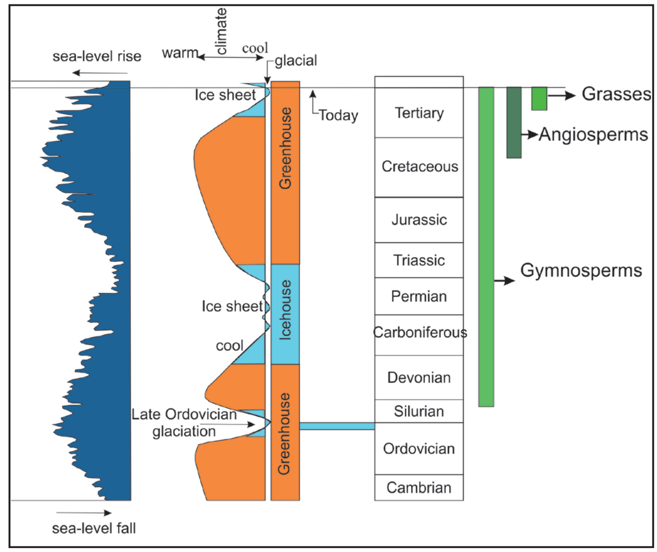

Fig. 1. Secular variation in vegetation types in the background of major climatic variations and fluctuations of sea level during Phanerozoic (modified after Craig *et al*., 2015 and Nichols, 2017).

from the Quaternary stratigraphy suggests that sea-level changed relatively rapid with high magnitude and frequency (Costas *et al*., 2016). It certainly affected marine and related depositional environments. Climatic fluctuations affect continental depositional settings, especially the lake basins (Nichols, 2017). Understandably, weathering rate changed drastically in response to climatic change. As a corollary, the mode of preservation of stratigraphic records also underwent rapid changes and the pattern of sequence evolution altered significantly. Extrapolation of knowledge gathered from the modern world or from ancient non-glacial periods would thus be of limited use for interpreting the Holocene stratigraphic record. The unsteadiness within the geomorphic processes, fluctuations in the rates of weathering, erosion, transport and accommodation space creation are bound to generate numerous discontinuity surfaces of different orders and styles within the sedimentary successions formed during the glacial periods (Sadler, 1981; Mellet *et al*., 2013; Bechstädt *et al*., 2018). The slowness of geological processes observed in the present world is hardly relevant in explaining glacial sequences. Neither the rise of a mountain, nor its removal by erosion is visible in a lifetime, yet the 4.6-billion-year-old earth has undergone such aberrations of geological processes many times. So, a sedimentologist cannot afford anymore to remain saddled with baggage that hinders their progress.

VARIATION OF SEDIMENTATION RATE

In recent years we have learned that many geological processes are more rapid than once believed (Nichols, 2017). The Atlantic Ocean widens at a rate of 1 to 10 cm per year (Harmon *et al*., 2020). The rise of sea level at the end of the last glacial period locally pushed the coast inwards approximately 10-15m (Lambeck *et al*., 2014). Every year Mississippi delta adds approximately 550 million metric tons of sediment into the Gulf of Mexico (Turner, 2017, Russell *et al*., 2021) and if left undisturbed, the equatorial ocean is likely to be filled up with sediment in a few hundred million years. If these rates are typical, do we need all of the time available to account for the events recorded by the rocks? The answer is clearly negative. Studies of modern depositional environments taught us that the rates of deposition are different for varied environments. Measured rates are known to vary from 3 mm/1000 years for deep-sea red clay to several meters per year locally in major deltas (Reineck and Singh, 1973). Shallow water carbonates in the Bahamas have a rate of 0.323 mm/ year over the past 6000 years while during the Kimmeridgian and Berriasian time it was at the rate of 0.07 to 0.6 mm per year (Strasser and Samankassaou, 2010). Aggradation rates of an alluvial fan in semiarid environments are generally in the range of 7.7 to 10.1 mm/ka (Poulos and Pierce, 2017). The average accumulation rate of sediments in California offshore fans for the total duration of five stratigraphic intervals identified from 6.9 ka to the present is 1.3 km^3/kyr and the total mass of 3.7 metric ton per year compares well with the estimated sediment flux of the Santa Clara River over historical times (3.2 metric ton per year) (Allen, 2017). The accumulation rate of the Santa Ana River which feeds the Newport deep marine offshore fan of California is 200-280 mm/kyr in the latest Pleistocene-Holocene (Allen, 2017). We may apply these rates to the deposits left behind by the equivalents of the past with due allowance for such matters as overburden compaction and time. The results of such estimates are intriguing for we find that rock record invariably requires only a small fraction of the available time even if we take into account all possible breaks in the sequence. This might be expected but the universality and especially the magnitude of the shortfall are startling.

It is true that ancient sediments represent less time than actual. The accumulation rate obtained by dividing the thickness of a deposit by the length of the time interval it occupies ought to be smaller than deposition rate in the equivalent modern environment (Sadler, 1981; Schumer and Jerolmack, 2009; Restreppo *et al*., 2020). This, indeed, turns out to be the case and fraction of time not represented by the deposits is very large. Furthermore, the vast amount of data gathered by Sadler (1981) shows that the accumulation rate (thickness/ available time) is inversely proportional to the length of the interval over which they are estimated. It is obvious that the aforementioned data set, despite its intrinsic value, provides only net sedimentation rates, averaged over a variable range of time. It is like missing the trees for the forest. Gaps in knowledge are bound to exist; the actual sedimentation rate must have been higher than estimated. The perception of uniformity in stratigraphic record is thus a utopia, valid neither in space nor in time.

Spatial variability in the net rate of sedimentation is, indeed, startling. 30 ammonite zones in just 0.3048-meter Jurassic sediments in Sicily are represented by 457.2 meters of a single zone in Oregon (Imlay, 1981; Dietze *et al*., 2021). Again, in the late Carboniferous coal measures of Lancashire, a 9.14-meter fossil tree has been found still standing in the living position (Broadhurst and Magraw, 1959). It clearly illustrates that sedimentation was so rapid that the tree was buried before it had time enough to decompose. It is easy to demonstrate that in coal measures very rapid sedimentation alternated with very slow sedimentation and that the former was responsible for the bulk of, at least a major part of the coal reserve. In the thin coastal marine member intervening between the two terrestrial members, Lower and Upper, of the Cretaceous Bhuj Formation, Kutch trace fossils serve as an efficient guide to distinguish between records of slow and rapid deposition as well as continuous and discontinuous deposition (Fig. 2). Biota is always far more sensitive than inanimate objects in this regard and trace fossils cannot be reworked before their cementation. The trace fossils thus illustrate how rapidly the sedimentation rate fluctuated in the same paleogeography and within a short period (Fig. 2). The resolution of this scale is, however, difficult to achieve in a regional study.

GAPS IN RECORDS

Before the initiation of the Deep-Sea Drilling Project (DSDP, Yeats and Haq, 1981), it was widely believed that the sedimentary record in the deep ocean, at least, would be complete without gaps. It turned out to be far from true. In South Atlantic, for example, barely half of the history of the last 125 Myr is recorded in the sediments (Luo *et al*., 2018). It is no better for the other oceans, where besides non-deposition major gaps have been created by erosion and corrosion under influence of deep-ocean currents. Understandably, incompleteness is far more common in perpetually and universally agitated shallow marine and continental environments. Even in a low-energy micro-tidal zone on the Eastern coast of India large-scale coastal scours were present (Fig. 3.1; Sarkar *et al*., 1991). They were up to 18 cm deep and 2 m wide and frequent in occurrence (Fig. 3.1). It is understandable that despite low-energy depositional condition they must have removed a significant amount of sediment from the stratigraphic record. Flattened crests of ripples and dunes in tidal flats (Figs. 3.2, 3.3) because of current reversals indicate the loss of some already settled sediment from the stratigraphic record.

From a 500 m-thick fluvial sequence spanning over 7.5 Myr, Sadler (1981) showed that with a reasonable annual deposition rate, in the flood plain of a perennial river, this sediment thickness could be achieved in only 5000 yrs. The observed sequence would thus be 0.075% complete. On the other hand, in case of flash deposition, estimated on an hourly basis, the section completeness would perhaps be 1 in 10 million (Chen *et al*., 2018; Pujalte *et al*., 2022).

Laterally extensive the rhizoconcretion carpet on top of

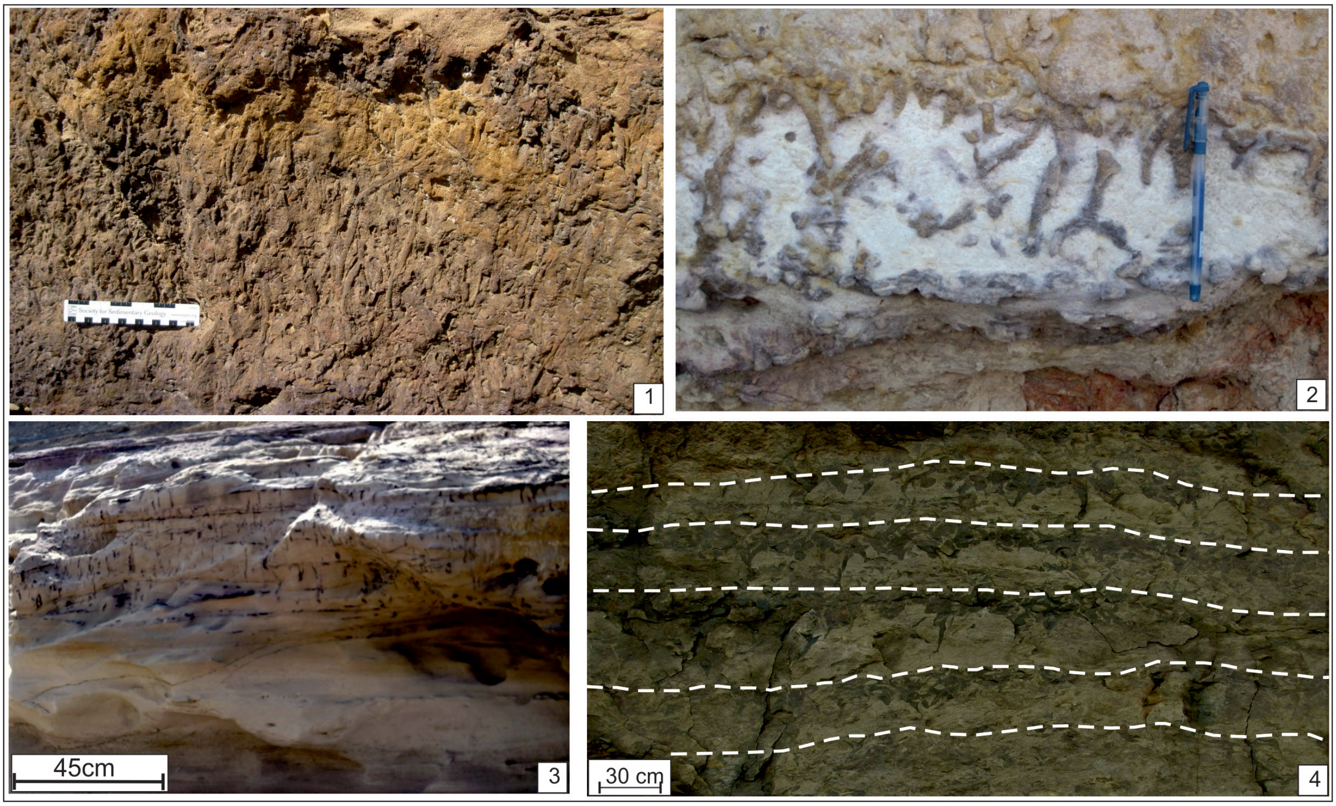

Fig. 2. Qualitative estimation of sedimentation rate from the presence of trace fossils presents within the Bhuj Formation, Kutch. Slow and continuous sedimentation (1), slow but discontinuous sedimentation (pen length= 15 cm) (2), and rapid continuous sedimentation in the lower part while rapid discontinuous sedimentation in the upper part (3). Preferred concentration of mud-filled burrows defines pause planes (bedding) (dotted lines) in an apparently continuous record of sedimentation, the Bhuban Formation, Surma Group (4).

the Marine Member and at the base of the Upper Terrestrial Member of the Early Cretaceous Bhuj Formation, Kutch represents a considerable time gap (Figs. 4.1, 4.2; Koner *et al*., 2021). On top of a marine highstand systems tract and under a fluvial succession the carpet represents a quickly shifting river on a graded profile. The river continually scoured vegetated surface where it moved in and allowed vegetal growth wherefrom it moved out. However, the river was not allowed to erode the substratum to any significant depth and mere reworking of the rhizoconcretions was within its reach. Neither erosion nor deposition prevailed. Evidently, the lack of accommodation space did not allow fluvial sediment to accrete and thus compelled the river to migrate swiftly while gradually reclaiming landfilling the marine basin; a diachronous unconformity surface was thus created (Fig. 4; Mandal *et al*., 2016).

CONSEQUENCES

The consequence of inferred severe incompleteness of stratigraphic record and its relation to time scale deserves serious attention because they distort the history of sedimentation and interpretation of its driving mechanisms in many ways. Consider, for instance, the problem of defining the real boundary between two stratigraphic units. The probability of preservation of such a boundary is much greater for units of long duration than the brief ones. The chance of finding the boundary between two strata of 5 Myr duration in an interval of 25 Myr is much greater than that of locating the boundary between two beds each spanning 1 Myr. Conversely, a short-lived marker, such as a volcanic ash bed, traced over a wide region cannot be accepted as a stratigraphic boundary of any order unless a drastic change in paleogeography of deposition is associated with it.

Any cliff face of the Rewa Range in central India displays a huge, perfectly conformable section of the Rewa Sandstone (Fig. 5). Hundreds of meters of sandstone and minor shale appear as a continuum in stratigraphy. But is it really so, then what do all those bedding planes stand for? Are not they mini-unconformities? If we really had continuous sedimentation then there would surely be no bedding planes at all! Far ahead of others, Barrel (1917) inferred that breaks represented by bedding planes are diastems with a time value of years to decades that must characterize practically all stratigraphic successions (Fig. 6).

Many gaps in the record can be easily illustrated, especially those on the longer time scale, for example,

Fig.3. Meso-scale coastal scour (1), flat crested ripples (2) and dunes (3) are present in Chandipur intertidal flat, on the eastern coast of India.

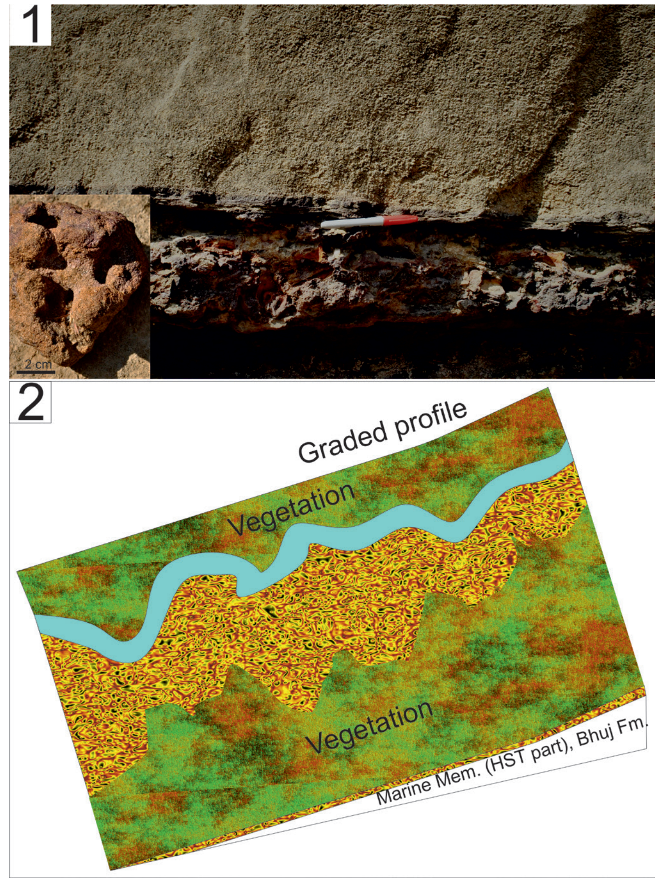

Fig.4. Rhizoconcretion carpet underneath the Upper Terrestrial Member, the Bhuj Formation, Kutch (pen length= 15 cm). The inset at the left bottom is an individual concretion (1). On top of the marine highstand systems tract (HST), the river profile is graded. The graded profile with a slight increase of gradient upslope allowed little erosion and deposition. The river without having the scope for either aggradation or degradation, moved only laterally, uprooting the trees and creating the thin blanket of rhizoconcretions (2).

the splendid unconformity between the Gondwanas and the Precambrian in the Indian Peninsula (Fig. 7). Yet the conclusion is inescapable that most breaks are not at all apparent and remain concealed. Non-deposition, no doubt, produces surfaces, but these are extremely subtle unless corroded or mineralized to form hardgrounds. The amalgamated storm beds with bioturbation on top of each bed within the Bhuban Formation of the Surma Group, Mizoram represent omission surfaces (Fig. 2.4). On its upper part, the Early Cretaceous Ukra Member in Bhuj, top of every shoaling-up parasequence is well demarcated by dark reddish ferruginous coloration, possibly because of lichen growth during events of near-cessation of sedimentation (Fig. 8; Sarkar and Koner, 2020).

Numerous such gaps can be observed even in a meter scale trench section from a modern backshore depositional environment (Fig. 9.1). The mm-scale beds deposited within inferred beach deposits of the Upper Rewa Sandstone (Fig. 9.2) of the Vindhyan Supergroup (Bose and Chakraborty, 1994) may be the ancient equivalent of the so-called continuous sedimentation. Campbell (1967) in the same vein suspects that the time represented by bedding surfaces far exceeds that heralded by the beds themselves. In fact, it is virtually impossible to demonstrate that a given sequence is free from stratigraphic breaks, although many of us confidently speak of continuous stratigraphic records (Figs. 6, 9.2). The very fact that rocks are stratified indicates that there must have been pauses in sedimentation, if not actual erosion (Figs. 5, 6, 9).

If we are to locate anything approaching a continuous stratigraphic record, we naturally look for the available section of maximum thickness of a particular unit. Even then it has been calculated, taking the systems as a whole, that the maximum rate of sedimentation would have been approx 30.48 cm per thousand years (Chorley *et al.*, 2019). We have a paradox here too for continuous sedimentation is also the thinnest sedimentation unit, laminae/bed. Obviously, in such apparently continuous developments, there must be few, if any, erosional breaks, but there must be immense non-depositional phases. The successive storm deposits with bioturbation on top of each bed also signify the non-depositional phases of sedimentation (Fig. 2.4). Even in the apparently continuous enormously thick flysch sequences, contact of each sandstone layer with the subjacent sandstone layer is invariably marked by basal erosion.

Fig. 5. A tall and perfectly conformable sandstone bed succession of the Rewa Sandstone, Vindhyan Supergroup appears to be a product of continuous sedimentation. Close scrutiny, however, would reveal numerous intervening (sedimentation) pause planes of, at least, two different orders.

It will be an idle dream if we think that anything like a complete succession for any part of the stratigraphic column exists in any one place. There is perhaps no type section, which can possibly pretend to be representative of a whole unit of the stratigraphic column. Not surprisingly, *North American Stratigraphic Codes* notes "Unfortunately few available sequences are sufficiently complete to define stages and units of higher rank and those upper and lower limits of a stratotype need to be in the same section or region". Accommodating the variable degree of imperfection from place to place, NASC (North American Stratigraphic Commission) emphasizes lower rather than upper boundaries in defining a stratotype. There can be no further arguments about gaps or overlaps. Through efforts of many generations of stratigraphers, we have now compounded a fairly complete geologic column subdivided into system, series, and stages and set them into the framework of radiometric dates.

As far as the stratigraphic record is concerned, it seems sedimentation and breaks are inextricably mixed up. The correlation charts published by GSA (Geological Society of America) and GSL (Geological Society of London) clearly illustrate that nowhere the stratigraphic record is complete, everywhere there are gaps and there are perhaps many more gaps, yet to be deciphered, particularly those because of non-deposition. In any Aeolian interdraa section one finds numerous heavily iron-coated surfaces with little evidence of erosion at their base. They elicit non-deposition over months or years. In the example cited here from the top of the Bhuj Formation prompts us to conclude that the time lost was greater than the time recorded (Koner *et al*., 2021). Non-deposition without erosion in an aeolian environment can take place because of sand input equaling the output or sand supply dwindling on diversion of wind or wetting of the source. Ager (1980) and Sadler (1981) thus, view stratigraphic records from an opposite angle, and maybe they are nearer to the truth. They hold that it is a long record of gap intervened by occasional sedimentation (Fig. 6; Barrel 1917). So the stratigraphic record is comparable to a net, which has lots of holes tied together with string. Or, it may be matched with notes and intervals of music, where intervals are as important as the notes themselves, so bedding planes are as important as the beds.

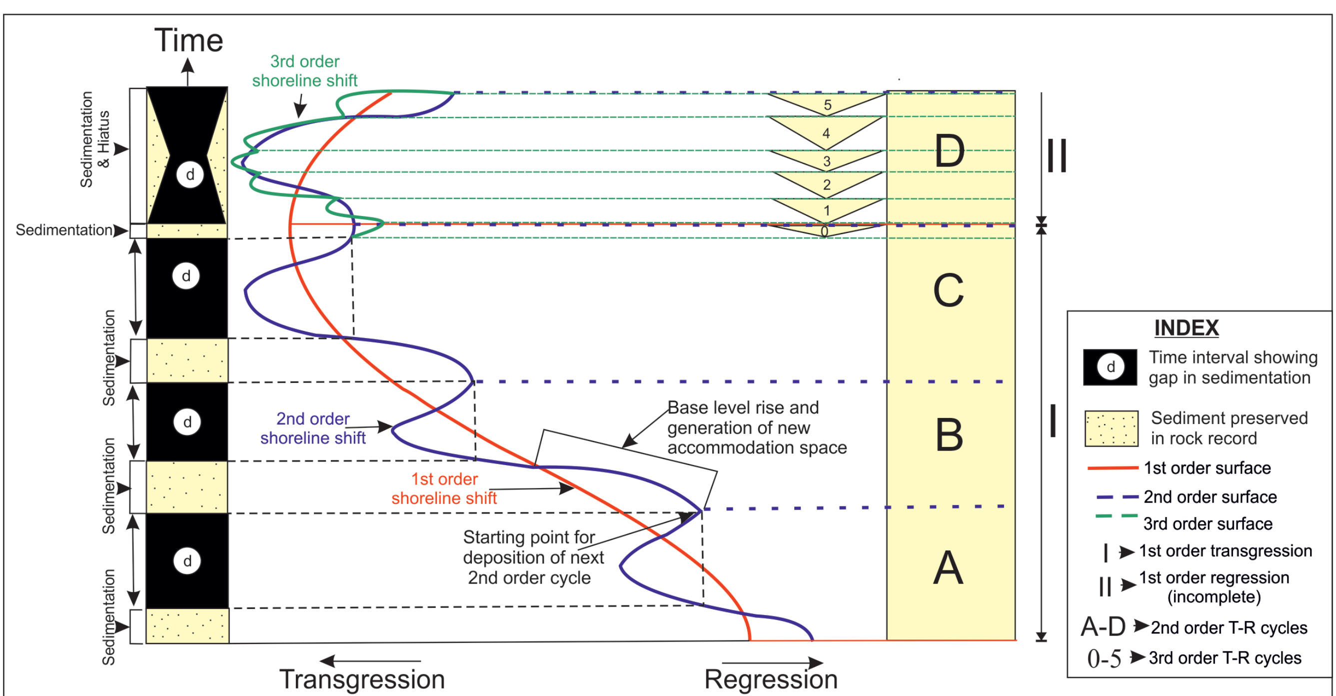

Fig. 6. Conceptual distribution of sedimentation and hiatus in stratigraphy, temporally or spatially apart, concerning the three orders of sea level changes (modified after Barrel, 1917 and Catuneanu, 2006).

Fig. 7. Unconformable contact between Precambrian basement and Gondwana rocks, Peninsular India (Manendragarh, central India; hammer length= 45 cm).

EPISODIC SEDIMENTATION

So, the lesson from the stratigraphic record is that it is spasmodic and ridiculously incomplete, with short periods of sedimentation separated by vastly longer gaps than anything that is preserved (Dott, 1983). To paraphrase Ager (1980) the stratigraphic record is something like the life of a soldier that consists of long periods of boredom and short periods of terrors. There is no dearth of such rare and brief moments of terror in nature. Such moments include earthquakes, volcanic eruptions, storms, floods, and landslides that make headline, in news. Devastating meteorite impacts are rarer and may not appear over generations. We should also add submarine slides, gravity flows and turbidity currents in the underwater world. While talking about significance of rare events, one must never forget the significance of old truism that given time, the rare event becomes a probability and given enough time, it becomes a certainty. Gretener (1967) examined the question probability of rare events and his graph shows that if there is 60% chance of one event in a year, then there is an 85 % of that event once in 2 years and as virtual certainty (98%) of one such event with a 4 years span. By adjusting the graph, it appears that, for a rarer event with a one-in-a-million chance of occurring once in a year, there is, nonetheless, near certainty of five such events in 10 Myrs.

Although large magnitude rare events obviously do much work, what is the net long-term preservation potential of their results? Perhaps more mundane day-to-day normal processes obliterate the records of rare events, especially above the base level of erosion. Most fluvial deposits form at or above base level, would have a low probability of preservation over geological time unless there is subsidence or rise of base level to protect them from erosion (Catuneanu, 2006). As evidenced from records of ancient fluvial sediments, such preservation has indeed occurred. Deposits formed below the base level, especially deep-water bodies, no doubt, have a relatively high preservation potential (Catuneanu, 2006). But

Fig. 8. Parasequences (average thickness- 1.2 m) with their tops encrusted with dark red ferruginous cement (Yellow arrows).

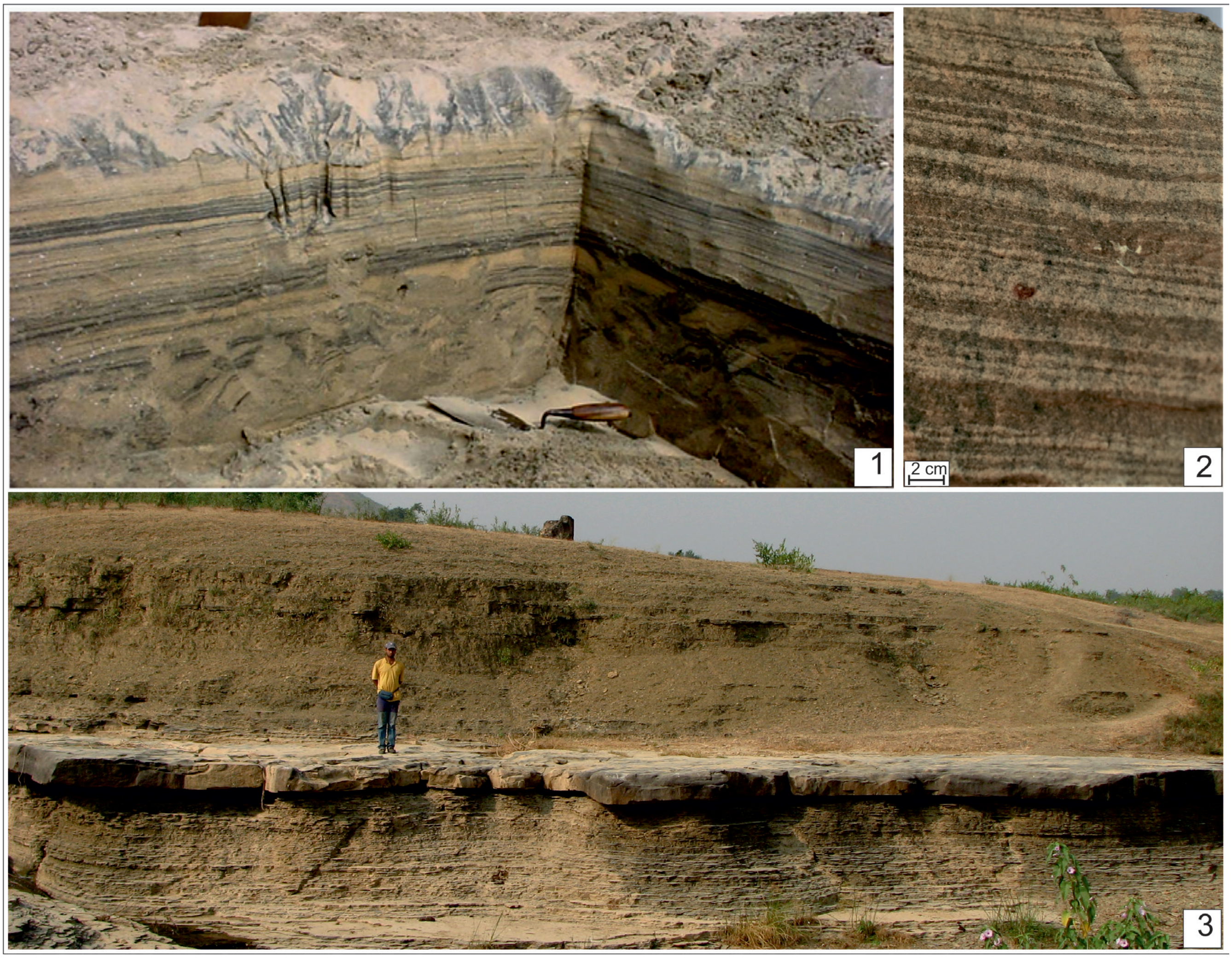

Fig. 9. Numerous mm-scale bed surfaces represent gaps in sedimentation from a modern trench section in Chandipur, east coast of India (1). Bed surfaces from an inferred beach deposits from the lower part of the upper Rewa sandstone, Vindhyan Supergroup (2). Relatively coarse-grained sandstone emplaced by episodic event within fine-grained sediments, the Sirbu Shale, Vindhyan Supergroup (3).

here again, tectonic uplift or fall of sea level could endanger their preservation (as could be subduction). Any sedimentary deposit, even if preserved may suffer biogenic and / or diagenetic modification as to obscure it beyond recognition. In short, what ultimately enter into stratigraphic record is not necessarily obvious.

Significance of abnormal, high magnitude rare processes, lies in their deviation from average or steady-state conditions and also that unlike day-to-day processes, recurrence interval or rare events ranges between decades to few million years. Let us consider positive deviations of greater-than-normal magnitude episodes e.g. as storms; negative deviations of lesser-than-normal deviation must be recognized as episodes (Fig. 9.3; Table – 1). Negative deviations typically result in surfaces of non-deposition, such as mineralized hardgrounds (Strasser, 2016). Alternating bioturbated and non-bioturbated zones also attest to important episodic deviations and provide insight into relative process rates (Fig. 2.4). A potential complexity creeps in where a single surface or deposit may record both a positive and a negative deviation. For example, high intensity scouring may be followed by a long period of non-deposition accompanied by hardground mineralization – thus a positive deviation was followed by a negative one. All of these considerations emphasize the fundamental difference between instantaneous deposition rate, which is commonly reported for modern processes and net accumulation rate which is generally deduced for ancient deposits (Fig. 10).

Table 1. Recurrence intervals of event deposits concerning those of day-to-day products (modified after Dott, 1983)

	(+) Deviations	(-) Deviations
Process	Storms, Volcanism, Tsunamis Asteroid Impact	Non-deposition, Annihilation of organisms
Products	Erosion Surfaces, Abnormal coarser sediment, Abnormal volume of sediment, Chaotic Texture	Hardground surfaces, Condensed sections, Skeletal concentration, Shell hash, Gaps in the evolutionary record

Episodic sedimentation and its bearing on stratigraphic record are perhaps best illustrated in turbidite sequences comprised of graded sandstones alternating with pelagic mud (Shanmugam, 2021). By any reasonable estimate, a turbidite sandstone as compared to pelagic mud (3 mm/1000 yr) must be regarded as geologically instantaneous, having been deposited by a relatively large-magnitude but relatively rare event. Simple calculation as in Table-2 dramatizes the great contrast in rates and volumes of sediment produced and bring into sharp focus the fact that well over half of the thickness of most turbidite sequences represents miniscule time. Similar result is obtained from other sequences dominated by event phenomena and there is perhaps no environment, which is entirely free from major perturbations.

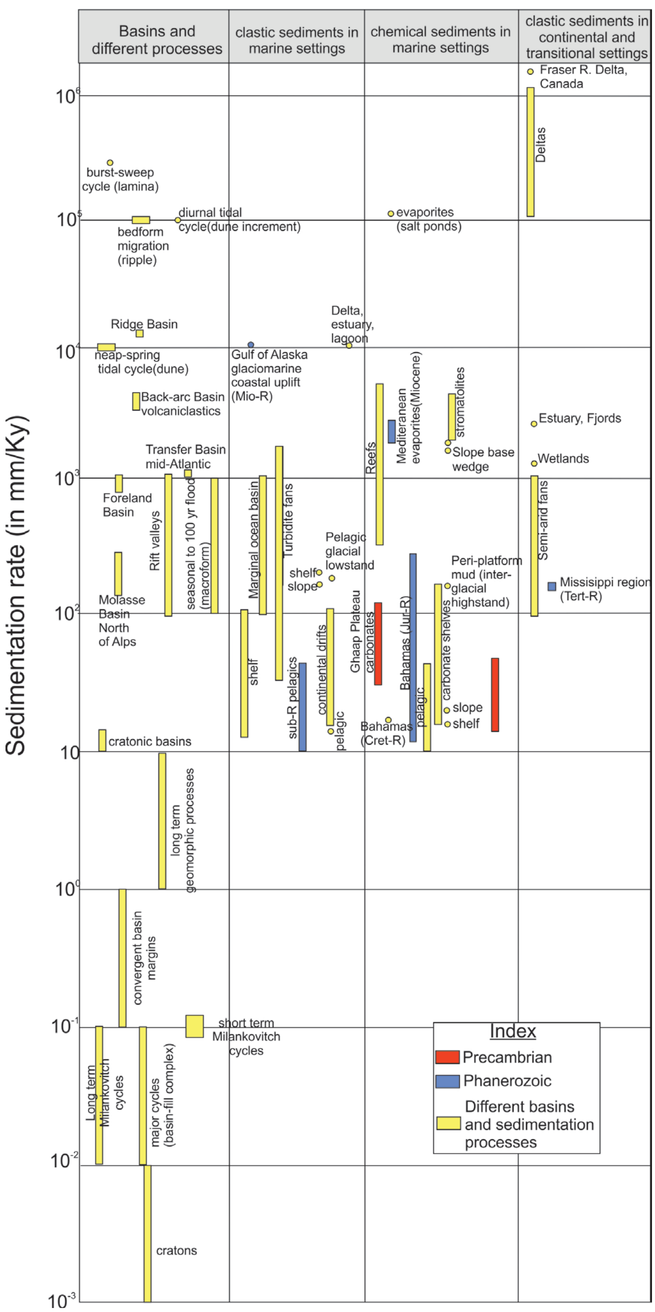

Fig. 10. Sedimentation rate for a wide range of basins and process of deposition in different setting (modified after Eriksson *et al*., 2004 and Miall, 2015).

Table 2. Turbidity current frequency and accumulation concerning pelagic mud deposition (modified after Dott, 1983)

Given	A sequence with 100 couplets, each composed of turbidites averaging 10 cm thick and normal pelagic mud 5 cm thick (total = 1500 cm)
Assumed	1. Average pelagic mud deposition 5 cm / 1000 yr 2. Turbidites are geologically instantaneous
It follows that	1. Total time for deposition of 100 couplets of 500 cm mud- 5 cm /1000 yr = 100,000 yr 2. Average frequency of turbidity current 100,000 yr / 100 turbidites = 1000 yr intervals between events
Conclusions	1. 2/3 of the sequence was deposited by instantaneous events that occurred only once per millennium. 2. In 10 my : 10,000 events could deposit 1500 m of strata

CONCLUSIONS

The stratigraphic record is, therefore, not only incomplete but also biased towards major perturbations. Those may be catastrophic, but rare in our life span. Nonetheless, they are common in geological time scale and, dominate the preserved rock record. Many leading scientists believe that sedimentary rock record is chronicles of episodic events. That means meager availability of the record of normal times, far longer in duration. That makes the task of a sedimentologist to unveil the general character of a depositional environment of antiquity difficult. He must remain alert, not to miss brief occasional glimpses. Even where a post-depositional modification has been overprinted upon episodic deposits, as by burrowing organisms, nonetheless, a volume of sediment has been added to the record even if it's greatly obscured. It is a challenge to us to read through the overprint. A researcher thus should approach a stratigraphic record with an expectation to find more gaps than the whole. A sedimentologist must enhance the sensitivity to locate every narrow window available to look at the records of non-event periods and thereby enable to picture the depositional environment in its totality. Even then, the event deposits and gaps in sedimentation let us perceive the total spectrum of variability in depositional mechanism, sediment sources, and diagenesis that took place within the same palaeogeography of deposition.

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