

Index Fossils

Evidences from Plant Sources

Dipanjana Ghosh

Index fossils are commonly found, widely distributed fossils that are limited in time span. They are used for the determination of the age of organic rocks and other fossil assemblages and also help to establish relationships between rock units. Index fossils of plant origin are very rare. In this article, I describe many of their important features, uses, and some of their limitations.

The word 'fossil' literally means anything dug out of the earth. Fossils are actually vestiges of plants or animals preserved in strata of earth that give evidences of their presence in the geologic past [1]. In a strict sense, fossils include not only the remains of organisms or their parts but also any thing connected with an organism proving its existence (trace fossil). Thus, a chemical which could not exist without an organism or a prehistoric trail mark of a worm or footprints of an animal (ichnofacies) on a stone is also a fossil. Under favourable circumstances, such as mineral rich medium, acidity and anaerobic condition in the environment, the natural disorganisation of plant or animal remains can be prevented and the persisting remains ultimately become fossilized.

All types of fossilized remains are abundant in sedimentary rock. Sedimentary rock occurs in the form of layers or beds. Individual beds differ considerably from each other by their structure, texture, colour, etc. (*Figure 1*). Under normal conditions sedimentary rocks are laid down one over the other in ascending order; thus maintaining superposition of rocks. The oldest sedimentary rock lies at the bottom and the youngest lies at the top. Sedimentary rocks constitute nearly 75% of the earth's surface.



Dipanjana Ghosh teaches Botany in a Higher Secondary School in the Birbhum district of West Bengal. Apart from teaching he is associated with programmes like popularization of science in the district, science communication among local people, and popular science writing. He also delivers talks on science topics on All Indian Radio, Kolkata Centre on a regular basis.

Keywords

Index fossil, guide fossil, correlation, age determination, *Dicroidium*, *Glossopteris*.





Figure 1. *A sedimentary rock section showing super position of rock forming strata. During lithification, by the enormous pressures of the newly deposited sediments, various sedimentary materials like silts or mud, sands, pebbles and boulders produce strata from siltstones and shales to sandstones and conglomerates depending on the size and range of the sedimentary particles. Sandwiched by these rock forming strata, plant or animal remains become fossilized.*

Index fossil – A General Notion

In 1796, William Smith, a British civil engineer, first noted that rock were characterised by unique sets of fossil taxa. By noting the presence of fossils, it became possible to correlate rock units of varying lithologies across vast distance and to establish time horizons in lithologically uniform diachronous rock units. Certain floral and faunal remains are often found to be restricted to a particular geologic horizon. Such fossils are known as ‘index fossils’ or ‘guide fossils’. Thus, index fossil is an abundant and easily identifiable fossil with a wide geographic distribution and a short geologic range. The term geologic range refers to the total length of geologic time that an organism was, or has been, present on earth. If the taxa concerned were shortlived (in geological terms, lasting a few hundred thousand years) then surely the sediments in question were deposited within that narrow time period. The shorter the lifespan of a taxon, the more precisely it can correlate different sediments, and so rapidly evolving types of fossils are particularly valuable. Hence, the best index fossil, useful in biostratigraphy, should be common, abundant and diagnosable, geographically widespread, with restricted geologic time range, easily preservable, of short species duration and found in multiple environment.

Index fossils are used by geologists and palaeontologists as significant aids to determine the correlation and age of rock sequences [2]. Geologists use both large fossils or ‘macrofossils’ and microscopic fossils or ‘microfossils’ as indices to define and identify geologic periods. Macrofossils have the advantage of being easy to see in the field, but they are rare. Microfossils are very commonly used by oil prospectors and other industries interested in mineral resources when accurate knowledge of the age of the rocks being looked at is needed.

Index Fossils as Useful Tools

Despite the stability and antiquity of rocks, the earth’s crust is under continuous change due to various tectonic and biogenic activities. As a result, primary structures of sedimentary beds



may be transformed (*Figure 2*). An upper bed may go down below an older one or the whole sequence may be reversed. Such kind of diastrophism (any sort of change in the initial sedimentary structure) sometimes creates problem in determining the proper order of superposition of rock strata as well as to correlate between two rock units of a single area or even between two continents. Stratigraphic correlations can be made by some physical or biological methods. Rock strata of different sections in wide apart areas can be correlated with their palaeomagnetic data. Also lithologic similarity between rock units may be ascertained by using one or two marker beds.

The floral and faunal remains in rocks are often found to be a very useful tool for the correlation of local sections. Thus the problem can easily be solved if there is a common fossil representative in both of the rock units. Evidences from index fossils had enabled Alfred Lothar Wegener to establish his Continental Drift hypothesis in 1912. According to this concept all the present continents have originated from a single megalandmass or supercontinent named 'Pangaea', by breaking into smaller pieces that slowly drifted away from each other, nearly 200 million years ago. In fact Wegener found fossils of tropical plants like ferns and cycads in the Arctic island of Spitsbergen. Also the fossil remains and the rock structure found along the coastline of South America, Africa and India were remarkably similar despite being widely separated by the Atlantic and the Indian Ocean [3]. Thus identical fossil remains across the continents supported the existence of Pangaea.

Similarly, determination of the age of fossil rock is essential to understand the evolution of life (see *Box 1*). Using the stratigraphic principles of Nicholas Steno (1668) and the uniformitarian principle of James Hutton (1795), geologists of the early 19th century established the relative ages of rock units. In 1905, Ernest Rutherford and Bertram Borden Boltwood employed the principle of radioactive decay to measure the age of rocks.

Rocks are made up of many individual crystals, each comprising

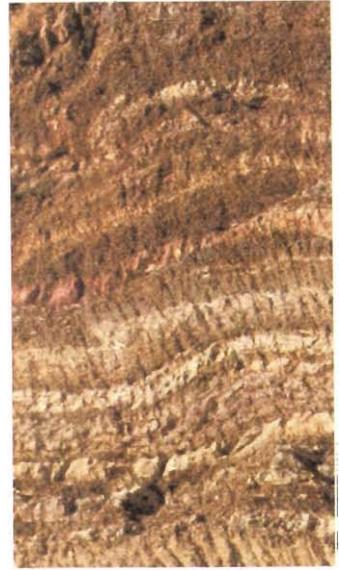


Figure 2 At the time of formation, all sedimentary beds remain horizontal to the earth's surface. However, subsequent geotectonic or biogenic activities, cause appreciable changes in the original sequence of the superimposed sedimentary beds in the form of faults, tilting, folding, overturning, etc. as shown in this picture.



Box. 1 The Geological Column and Time Scale

| Beginning age (million years) | Duration (million years) | Era | Period | Epoch | Characteristic organisms and some major geological events. | | | |
|-------------------------------|--------------------------|------------------|--------------------------------------|------------------|---|--|--|--|
| | | | | | Plant association | Associated animal | Climatic inference | |
| | 5000 – 10000 years | Ceno- zoic | Quater- nary | Holo- cene | | | Retreat of continental ice sheets | |
| | 2.5 | | | Pleisto- cene | Redistribution of floras | Woolly mammoth and giant bison; Appearance of modern man. | Successive glaciation, some elevation of continents and drainage of major synclines | |
| (2.5) | 4.5 | | Tertiary | Plio- cene | Spread of grasslands, caused local restriction of extinction of some species | Camels, horses, cats | Elevation of Andes, climatic changes in temperate latitude. | |
| (7) | 19 | | | Mio- cene | Restriction of broad leafed evergreen forest to lower latitude and establishment of present day forest associations | Rise and rapid evolution of grazing mammals and ape-like creatures | Continental uplift, rise of Alps, Himalayas, climatic cooling. | |
| (26) | 12 | | | Oligo- cene | Widespread occurrence of relic taxa like Metasequoia | Saber toothed cats, true cats, dogs, rodents and great rhinoceroses | Mild temperate climate | |
| (38) | 16 | | | Eo- cene | Distinctive forest in northern and southern latitudes; many genera of angiosperms became extinct with appearance of new types | First horses, all modern mammals. | Subtropical climate with heavy rainfall | |
| (54) | 11 | | | Palaeo- cene | Primitive angiosperm families like Magnoliaceae, Lauraceae, Juglandaceae | First lemurs, some modern groups of birds | Trend from temperate climate to mild subtropical climate; seasonal variation | |
| (65) | 76 | | | Meso- zoic | Creta- ceous | Upper | Angiosperms rise to dominance in Upper Cretaceous. First trace of angiosperm pollen, leaves and flowers in Lower Cretaceous monocots and dicots present. | Modern group of insects; First pouched and placental mammals; Extinction of giant reptiles |
| (141) | 54 | | Lower | | | Highly similar plant communities composed of ginkgos, conifers, ferns, cycads, cycadeoids and some pteridosperms | Dinosaurs abundant, rise of higher insects and birds. | Uniform, mild climates from North to South Poles. |
| (195) | 30 | | Triassic | | Upper | Rise of cycadophytes, ginkgoales; | First mammals, rise of dinosaurs. | Arid to semiarid savanna – type climate |
| (225) | 55 | Middle | | | Diversification of conifers and ferns; | | | |
| (280) | 45 | Lower | | | Declines of glossopterids; Extinction of arborescent lycopoids and sphenopsids | Diversification of reptiles | Cooler and drier climates with extensive glaciation in Southern hemisphere | |
| (325) | 20 | Carboniferous | Pennsylvanian | | Upper | Origin of conifers, formation of great swamp forest comprising mosses, lycopods, sphenopsids, ferns, seed ferns | Origin of reptiles, diversification of amphibians, insects abundant | Uniformly warm, humid climate |
| (345) | 50 | | | | Lower | Primitive ferns, seed ferns, arborescent lycopods, calamites | Insects evolved wings, spread of amphibians, sharks, bony fishes | Warm, equable climate |
| (395) | 40 | Palaeo- zoic | Devonian | | Upper | Diversification of vascular plants, establishment of heterospory and seed habit, liverworts and fungi | Origin of amphibian, diversification of fishes | Heavy rainfall and aridity, extensive inundation of continents to form seas. |
| (435) | 65 | | | Middle | First vascular land plant in mid Silurian | First air breathing animals, scorpions and millipeds, brachiopods, corals | Mild climate, lowlying continents with epicontinental flooding. | |
| (500) | 70 | | Silurian | Upper | Abundance of green and red algae | First vertebrate, graptolites, nautiloides, cystoides | Warm, mild climate, epicontinental seas | |
| (570) | 4130 | | | Lower | Cyanophytes, green and red algae | Abundance of marine invertebrates, first trilobites and foraminifers | Warm and equable | |
| (4700) | | Pre- cambrian | Protero- zoic Archaeo- zoic | | Bacteria-first living cell, cyanobacteria, red algae and possibly green algae | Questionable invertebrate fossils | Warm climate | |



several different chemical elements like iron, magnesium, silicon, etc. Although most elements are stable, atoms of some elements are unstable in their natural state as they undergo radioactive decay. Radiometric dating is the process of determining the age of rocks from the decay of such radioactive elements. (See *Box 2*.) There are several techniques of radioactive dating, each using a different radioactive element or a different way of measuring them. Radiocarbon dating can be done on organic sediments, fossils, carbonate deposits and other samples of biological origin by measuring the amount of C_{14} isotope they contain. Again Potassium–Argon dating is a viable technique for dating older rock samples as much as 4 billion years old. However, a good index fossil provides simple ways to calculate the relative age of rock beds as well as helps in dating other fossils found in the same sedimentary layer, particularly during field study or spot identification.

Plant Fossils as Guide

In reality, animal remains get predominance over plant remains as the former are more numerous. The basic material of plant cell wall is cellulose. Some other complex biochemicals such as lignin, suberin, cutin, etc., are also present in cells and tissues of different plant organs like wood, cork and leaves. But, these materials are not always able to resist the decay of dead tissues even in favourable environment of fossilization. So getting perfectly preserved plant fossil is very difficult as plants lack the so-called hard tissues.

Pollen grains of higher plants are probably the most resistant parts as they are encased within a unique substance, sporopollenin. Sporopollenin is responsible for the prevalence of fossil pollen grains in many types of rock sediments over any other fossilized plant remains, i.e., mega fossils. Unfortunately, other than such microfossils as pollen and spores, which can be widely distributed and are abundant, most plant remains are not good index fossils. Even though they may have a wide geographical distribution and are preserved in a variety of sedimentary rocks,



Box 2. How Dating of Fossil Sample is Done

The correct age determination of fossils is necessary. In other respect, it was very difficult to understand their antiquity and importance in establishing earth's history except to say that one fossil was older or younger in respect of others. However, this problem has been solved by applying the 'radiometric dating'. Radioactive isotopes of certain elements in nature decay at a constant rate irrespective of any environmental factors. Through emission of alpha and beta particles, the element transforms to an atom of different element. All naturally occurring heavy elements from Polonium (Po-84) to Uranium (U-92) are radioactive. There are nine elements of low atomic number which are also radioactive, out of which Carbon (C_{14}) and Potassium (K_{40}) are important for radiometric dating. By using this property of elements, the age of rock associated with fossils is determined accurately although there is a percentage of error. Another way to express the rate of decay is in terms of 'half-life'. Half-life is the time required for decay of a given amount of radioactive element to half of its initial value, e.g., the half-life of Uranium-238 is 4.47 billion years, as it takes this much time to convert half of its atoms into the decay product, which is Lead-206.

There are different methods of radiometric dating, out of which three are needed to be mentioned. One is Uranium (U) - Lead (Pb) system. Radioactive U_{238} after emission of 8 alpha particles, 6 beta particles and energy, ultimately produces Pb_{206} . The half-life of this system is 4.5 billion years. By using this technique we can determine the age of any igneous rock but not any fossil as igneous rocks do not contain fossils. However, this method finds its use in geology, geophysics, and other branches of science. The age of the sedimentary rock containing fossils is determined by the Potassium (K) - Argon (Ar) system. K_{40} after capturing an electron produce 88 per cent calcium (Ca_{40}) and 12 per cent Ar_{40} , an inert gas. Measurement of the conversion of potassium to argon may lead to accurate dating of sedimentary rock. The half-life of this system is 1.25 billion years.

Dating of organic sedimentary body of recent origin (not more than 60,000 years old) is made by radiocarbon dating technique. This method was developed by Willard F Libby in 1950s. Radiocarbon dating is based on a simple natural phenomenon. In the upper atmosphere nitrogen (N_{14}) atoms are converted into an unstable isotope of carbon, the C_{14} , by cosmic radiation. This C_{14} becomes incorporated and assimilated in the green plants during photosynthesis. Ultimately this C_{14} passes to the animals after ingesting the plants through food chain. The process of ingesting C_{14} continues as long as the plant or animal remains alive. After the death of the individual plant or animal, these accumulated C_{14} change to N_{14} by beta decay. The rate of decay in terms of the half-life of C_{14} is 5730 years. The gas counting method (carbon dioxide generated due to fossil burning) and the liquid scintillation counting are two important methods of radiocarbon dating. Radiocarbon dating can also be done on prehistoric samples of wood, charcoal, bones, peat, carbonate sediments such as tufa, caliche, marl, etc., and dissolved carbon dioxide and carbonate present in oceans, lakes and ground-water sources.

they may have long geologic ranges of millions of years [4]. Perhaps these are the main causes of inadequacy of good index fossils of plants than their animal counterparts (See Box 3).



Box 3. Animal Index Fossils

In contrast to plants, animal fossils always dominate the chart as a majority of them usually fit those demands, that a good index fossil should exhibit. Among animal index fossils, invertebrates deserve special mention. A large number of marine invertebrate fossils that provide index fossils are generally grouped under the following heads:

- a) Ammonites – group of fossil molluscs possessing exogastrically coiled shell; *Perisphinctes tiziani* is a Jurassic and *Trophites subbullatus* is a Triassic index fossil.
- b) Gastropods – another groups of molluscs have asymmetrical bodies with usually dextral, spirally twisted shell; *Nerinea trinodosa* is a Jurassic index fossil.
- c) Pelecypods – a mollusc enclosed with bivalved shell and ventrally located tongue-shaped foot; *Venericardia planicosta* is a Tertiary index fossil.
- d) Brachiopods – bilaterally symmetrical coelomate animal with bivalved shell; *Billingsella corrugata* is a Cambrian and *Dictyoclostus americanus* is a Carboniferous (Pennsylvanian) fossil brachiopod.
- e) Crinoid – a marine invertebrate, usually possessing a cup-shaped body and five or more feathery tentacles; *Cactocrinus multibrachiatus* of Carboniferous (Mississippian) is a good example of index fossil.
- f) Trilobites – extinct marine arthropods with more or less oval body divided into three lobes by two longitudinal furrows; *Paradoxides pinus* and *Bathyrurus extans* are index fossils of Cambrian and Ordovician periods, respectively.

Some other groups of invertebrate animals like corals (*Cystiphyllum niagarensis* of Silurian), conodonts (*Palmatolepus unicornis* of Devonian), graptolites (*Tetragraptus fructicosus* of Ordovician), fusulinids (*Parafusulina bosei* of Permian), etc., are the best-known fossils that have been widely used for this. Terrestrial fossils, such as the teeth of mammals, have also been used as index fossils.

However, there are at least a few index fossils of plant origin in the Indian Gondwana system which are significant. The most prevalent one in this respect is *Dicroidium* (Figure 3). This shrub-like seed fern (about 4m high) of the family Corystospermaceae is a typical member of the Triassic [5] tropical forest of the southern hemisphere. This form leaf genus is found abundantly along with some other organ genera of the same group, viz., *Rhexoxylon* (stem), *Pteruchus* (pollen grain) and *Umkomasia* (ovule) from the Triassic deposits of South Africa, Australia, South America (Argentina), India and Antarctica.

Dicroidium has about 20 reported species, although a large number of species are yet to be identified. Different species vary

Figure 3. A portion of *Dicroidium* frond – an index fossil of the Triassic period. This specimen has been collected from the South Rewa Gondwana basin (Parsora Formation), Madhya Pradesh.





Figure 4. *Glossopteris* leaf; with more than hundred and fifty reported species, this form-genus is the most abundant among the mega-fossil bearing groups of Indian Lower Gondwana sedimentary rocks. This specimen has been collected from Kalipahari (Barakar Formation), West Bengal.

mainly in the frond (leaf of seed fern) shape. The venation is clearly marked with a midvein and secondary veins which are simple or bifurcate near the margins [6].

Another very well known index fossil of the Gondwana system is *Glossopteris* (Figure 4). The reconstructed *Glossopteris* tree of the family Glossopteridaceae has a tall trunk (about 8m high) with leaves arranged in close spirals or apparently in whorls in the extremities of branches. This form leaf genus is found abundantly along with 6 other leaf genera, *Vertebraria* (root), *Araucarioxylon* (trunk) and about 40 fertile organs of the same group, from the Permo-Carboniferous rocks with few remains in the Early Triassic deposits. *Glossopteris* has about 160 species. Leaf morphology varies considerably among the species. However, in general, leaves are simple, mostly tongue-shaped and petiolate. The reticulate venation pattern differs from species to species [7].

Biostratigraphic deduction (See Box 4) is not always made only by using index fossil genera – a few characteristic events of plant evolution sometimes help. For instance, if we get net veined angiospermous leaf in any stratum, then we can assume that the stratum cannot be older than the Lower Cretaceous. On the other hand, if a radiospermic pteridospermous seed is found, then the common deduction is that the stratum can not be younger than Carboniferous.

Box 4. Biostratigraphy and Biozones

The branch of stratigraphy dealing with the fossil evidences in rock samples, is called biostratigraphy. Biostratigraphy attempts to establish units of strata that have distinctive fossils or fossil assemblages and to correctly order the fossil assemblages. This implies that the rock strata are of the same approximate relative age and thus were deposited at about the same time.

In sedimentary systems, fossiliferous zones are called biozones. The most common biozones are range zones (for an individual fossil type), concurrent range zones (the zone of overlap of two or more fossil types) and assemblage zones (fossil types commonly occur together). Fossil types are referred to as taxon. The most accurate biozones use the species level taxon.

Epilogue

It should be clear that there are no perfect index fossils possessing all the features as stated earlier in this article. Even good ones are subjected to some constraints. One of the fundamental requirements of an index fossil is its wide geographical distribution. However, any living organism requires a particular set of environmental factors which cannot exist everywhere during a particular time [2]. Therefore, modern stratigraphers prefer the assemblage of three or more fossils rather than a single index fossil to deduce the age of a rock-formation.

Suggested Reading

- [1] D Ghosh, Plant Fossils: Storyteller of the Primeval Earth, *Geography And You*, Vol. 4, No. 1-2, pp. 22-24, 2004.
- [2] D Ghosh, The Buried Past, *Indian Science Cruiser*, Vol.14, No.1, pp. 11-18, 2000.
- [3] A J Saigeetha and R K Banyal, Alfred Wegener—From Continental Drift to Plate Tectonics, *Resonance*, Vol. 10, No.6 pp. 43-59, 2005.
- [4] W N Stewart and G W Rothwell, *Palaeobotany and the Evolution of Plants*, Cambridge University Press, 1993.
- [5] G J Retallack, Reconstructing Triassic Vegetation of Eastern Australia: A New Approach for the Biostratigraphy of Gondwanaland, *Alcheringa*, Vol.1, pp. 247-278, 1977.
- [6] J M Anderson and H M Anderson, *Paleoflora of Southern Africa—Molteno Formation (Triassic)*, Vol. I, A A Balkema, Rotterdam, The Netherlands, 1983.
- [7] D Ghosh, Glossopterids : Suzerains of Geologically Past Indian Forests, *Resonance*, Vol. 5, No. 3, pp. 60-65, 2000.

Address for Correspondence

Dipanjana Ghosh
Biological Science
Department
Kirnahar Shib Chandra
High School
Kirnahar, Birbhum 731302,
West Bengal, India.
Email :
keyurghosh777@hotmail.com



It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is the most adaptable to change.

Charles Darwin quote

