Introduction to Paleontology: Uncovering Animal Life Forms

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SUMMARY

Paleontology, derived from the Greek words palaios (ancient), ontos (creature), and logos (study), is the scientific investigation of ancient life through the analysis of fossils, the preserved remains of organisms that lived at least 10,000 years ago. The field has evolved significantly since its inception in the late 18th century, with Georges Cuvier often credited as its founder. Paleontology encompasses various sub-disciplines, including paleozoology, paleobotany, and micropaleontology, each focused on different types of fossils. The formation of fossils is a complex process involving both biostratinomy, which addresses the post-mortem processes affecting remains before burial, and diagenesis, which pertains to the changes occurring after burial. Therefore, in this chapter, we discuss the processes of fossil formation, the significance of the Siwalik Group in paleontology, and the methods used to reconstruct ancient ecosystems and climates, including stable isotope analysis and paleopathological studies.

INTRODUCTION

The word paleontology is a combination of three Greek words, palaios (παλαιός) meaning old or ancient, ontos (ὄν) meaning being or creature, and logos (λόγος) meaning study. This term has been used since 1822, primarily used by Henri Marie Ducrotay de Blanville, although some sources claim that William Buckland first used this term. Whoever first used this, from the term, it can be deduced that paleontology is the study of ancient creatures. The typical definition of paleontology is "the study of fossils" and fossils are "the remains of ancient life forms" with a minimum settling of 10000 years (Cowen, 2000). Georges Cuvier (1769-1832), is often called the founder of paleontology. Paleontology plays a crucial role in advancing our understanding about the properties, classification, relationships, descent, conditions of existence, and distribution of ancient life on earth, as well as theories of organic and cosmogonic evolution (Dany et al., 2018). The discipline has a long history, starting in the late 18th century, and has seen significant growth and development in the 21st century, with the publication of major manuals and recently increasing the number of researchers uncovering new practices and proxies to interpret these ancient life forms (Dany et al., 2018). Geology is regarded as the mother of paleontology. Three branches of paleontology are widely accepted based on the nature of fossils under study and these are Paleozoology (study of animal fossils), Paleobotany (study of plant fossils), and Micropaleontology (study of microscopic organisms). Paleozoology is further divided into Vertebrate Paleozoology (Vertebrate Paleontology) and Invertebrate Paleozoology (Vertebrate Paleontology) based on the category of studied organisms. In this chapter, we are introducing paleontology as a branch of zoology (Paleozoology) while focusing on the Siwalik's, fossil bearing sediments in the Indian subcontinent, and its relationship with the past ecosystem.

HOW FOSSIL DEPOSITED AND FORMED?

It is necessary and tempting to understand how animals are deposited and turned into fossils which have been formed. Fossils are formed through a combination of geological processes and conditions working on prehistoric life for at least 10,000 years (Hortola, 2016), however, time frame for fossilization is still debatable. Preservation in the fossil record is a rare event that requires organisms with hard anatomical parts, such as mineralized skeletons or resistant organic materials, and burial within sediments (Brett & Thomka, 2013). Extraordinary preservation of fossils, including articulated skeletons and soft parts, often requires rapid burial in low oxygen sediments and early mineralization (Rich & Zambito, 2022).

The study of fossil preservation, known as taphonomy, involves understanding the processes that affect potential fossils from death to burial, including decay, disarticulation, abrasion, and chemical corrosion (Ivarsson et al., 2010). Taphonomy is divided into biostratinomy and diagenesis. Biostratinomy focuses on processes that affect potential fossils from death to final burial, including decay, disarticulation, bioerosion, and transport. Diagenesis, processes that shape the organic remains after burial, viz. compaction and mineralization. The preservation of fossils can be influenced by taphonomic processes, mineral composition,

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and the energy of the depositional environment. Different depositional environments, such as marine shelves or deep-sea environments, can favor exceptional preservation of fossils (Crampton, 1907). Fossils can be deposited in various ways. Moving water can carry sediment and drop it when it slows down, leading to the formation of deltas and layers of varying thickness and constitution. Storm activity can result in the deposition of conglomerate and sandstone, with lithic clasts and fossils picked up from nearby river mouths or estuaries (Steven & Holland, 1995). The stratigraphic distribution of fossils can be influenced by sampling effects, facies control, and stratigraphic cyclicity, leading to patterns of occurrence within para-sequences and gaps between them (Banks, 1970). Preservation of fossils is more likely occurred in areas prone to very active sediment accumulation, such as shallow offshore, storm-affected, and marine environments, as well as deep sea, deep lakes, and river point bars (Brett & Thomka, 2013). Overall, the preservation of fossils is influenced by the characteristics of the organisms, the sedimentary environment, and the taphonomic processes that occur after death and burial. Fossiliferous materials are technically accessible to paleontologists and contribute to the science of paleontology. The paleontological deposits can also include sub-fossilized and non-fossiliferous skeletons and strata that provide data on ecological and ethological conditions (Esperante et al., 2015).

SIWALIK GROUP AND ITS DIVISIONS

Himalayas is the youngest mountain range of the world that is divided, based on the average elevations, into three series, the Greater Himalayas, the Lesser Himalayas and the Outer Himalayas (Burrard & Hayden, 1907; Wadia, 1944). In the Indian subcontinent (Pakistan and India), Bhutan and Nepal, the fossiliferous deposits are present at the foothills of outer Himalayas known as the Siwalik Group or Siwalik (Barry et al., 2013; Flynn et al., 2023).We find four spelling variants in the literature for the Siwalik that are; Sewaliks (Cautley, 1836), Sivalik (Ghosh, 2016), Shivalik (Kumar & Sankhyan, 2021), Siwalik (Kaur et al., 2019) and Siwalik (Cautley, 1839), however, Siwalik are most commonly and widely accepted used spellings for the Tertiary deposits. The Siwalik range, also referred to as the Shivalik or Churia Hills, derives its name from the Shivalik Hills, symbolizing a significant mountain chain situated at the base of the Himalayas. This range spans roughly 2,400 kilometers (around 1,500 miles), stretching from the Indus River in the west to the vicinity of the Brahmaputra River in the east, covering the northern territories of the Indian subcontinent. The name 'Shivalik' is rooted in the phrase meaning 'tresses of Shiva,' underscoring its cultural relevance. The Siwalik are particularly noted for their abundant vertebrate fossil records from the late Neogene epoch (Barry et al., 2013; Nanda et al., 2018; Flynn et al., 2023). From a geological perspective, the Siwalik are part of the Tertiary deposits in the Outer Himalayan region, with an age range from about 18 million to 600,000 years ago (Barry et al., 2013; Nanda et al., 2018; Abbas et al., 2021; Flynn et al., 2023). The rock formations in this range are primarily composed of mudstone, siltstone, sandstone, and conglomerate, which are the compacted sediments eroded from the Himalayas located to the north (Pilbeam et al., 1977). The Siwalik range has traditionally been categorized into three major divisions: Upper, Middle, and Lower Siwalik, each defined by distinct lithological characteristics and fossil assemblages (Pilgrim, 1913; Nanda, 2002). These divisions are further broken down into various formations, including the Kamlial and Chinji formations within the Lower Siwalik, the Nagri and Dhok Pathan formations in the Middle Siwalik, and the Tatrot, Pinjor, and Boulder Conglomerate formations within the Upper Siwalik. Nevertheless, some experts suggest that the Soan Formation is the primary component of the Upper Siwalik (Pilgrim, 1913; Pilbeam et al., 1977; Barry et al., 2002; Flynn et al., 2013).

RELATIONSHIP OF SIWALIK WITH PALEONTOLOGY

The Siwalik has abundant fossiliferous deposits and fossils are being excavated since the 18th century, the Siwalik have a significant relationship with paleontology. Studies in the Siwalik have focused on various aspects of paleontology, including taxonomy, paleopedology, paleoenvironment, and palaeoclimatology (Pilgrim, 1913; Quade & Cerling, 1995; Retallack, 1995; Khan et al., 2010, 2012, 2013; Khan 2013, 2014; Abbas et al., 2018a, b, 2019, 2021; Rafeh et al., 2020; Nelson, 2007; Badgley et al., 2008; Waseem et al., 2019, 2021; Ameen et al., 2022; Flynn et al., 2023; Hameed et al., 2023). It is an important source to trace out the evolutionary history of mammals of the Indian subcontinent and adjacent areas as well as their ecological conditions and changes in climate throughout the Miocene to present, migratory events and routes of migration, endemism, speciation and extinction, and certain other aspects related to Siwalik fauna (Flynn et al., 1995, 2016, 2023). It is evident from the paleontological work done so far that various vertebrate (also invertebrates) and especially mammals thrived and were present during the Miocene to Pleistocene and these taxa include almost all the today's living orders like Artiodactyl, Perissodactyl, Carnivora, Proboscidea, Rodentia, etc., with enormous diversity (Khan et al., 2010, 2012, 2013, 2023; Khan, 2013; Abbas et al., 2018a, b, 2019, 2021; Rafeh et al., 2020; Croitor et al., 2021, 2022; Ríos et al., 2022; Sánchez et al., 2022).

The Siwalik Hills also provide insights into the paleoenvironment during the Miocene to Pleistocene with evidence of a floodplain rich in continental and freshwater fauna (Nair, 2005; Nelson, 2007; Badgley et al., 2008; Ameen et al., 2022). Additionally, the Siwalik fossils have contributed to the understanding of paleodietary and paleoclimatic conditions, such as the analysis of stable isotopes and enamel hypoplasia in hipparionine horses (Nelson, 2007; Waseem et al., 2019, 2021; Ameen et al., 2022). Overall, the Siwalik Hills have played a crucial role in expanding our knowledge of the Mio-Pleistocene transitional fauna and the paleoenvironment of the region.

MAJOR ANIMAL TAXA INCLUDING BOTH VERTEBRATES AND INVERTEBRATES

The fossil record, which provides evidence of ancient life on Earth, comprises various sources. These include trace fossils of the Ediacaran biota from just before the Cambrian period (Narbonne, 2005), the Burgess Shale fauna (Briggs et al., 1995), and body fossils from the Siwalik Group fauna, among others. In recent years, additional significant discoveries have expanded our knowledge of Earth's life history. The fossil record reveals that both invertebrates and vertebrates are represented in these ancient remains.

Major animal taxa of fossilized invertebrates

The taxonomy of invertebrates commonly found as fossils is a complex and continually developing area, integrating both traditional and modern palaeozoological terms. The primary invertebrate groups preserved in the fossil record span a wide range, from protists to arthropods. Most invertebrate fossils are from groups such as protists, mollusks, arthropods, and echinoderms."

Throughout the world, hundreds and thousands of invertebrate species have been reported since the beginning of 18th century and list is growing. It is matter of the fact most of those species are extinct i.e., these do not have any living member at this time. Like the other regions of the world, Siwalik also hold the record of various invertebrate taxa that include mollusks (bivalves and gastropods), and arthropods (ostracods) (Saeed, 2002; Bhandari et al., 2014; Nath, 2013; Sharma et al., 2015; Poudyal et al., 2022). Other than Siwalik, a number of invertebrate taxa are known from the Pakistan that include mollusks (oysters, mussels and other bivalves, ammonites, belemnites, nautilides, gastropods, etc.) echinoderms (starfish, croinoides, etc.) arthropods (trilobites) and a variety of foraminifers, and cnidarians (Malkani, 2019).

Major animal taxa of fossilized vertebrates

Vertebrate fossils are known from the Cambrian and represent animals that immensely diverse in forms, sizes and shapes. The history of vertebrate record is a subject of many works with a long bibliographic history (Romer, 1966; Carroll, 1997; Benton, 1990, 1997), and progressive of appearance of each linage is well-known in many outlines. During the 19th century and onwards, a progressive work was done on these broad outlines, and the sequence includes the armoire ostracoderms and placoderms of the Devonian, Carboniferous amphibians, Permian mammal-like reptiles, Mesozoic dinosaurs, ichthyosaurs, plesiosaurs, pterosaurs, and birds, Tertiary mammals, and Plio-Pleistocene hominids. All the major vertebrate taxa are known from the Siwalik that include a variety of fishes, amphibians (only few), reptiles (predominately crocodiles and snakes), birds (only few), and mammals (abundant and varied). As the majority of fossils from the Siwalik include mammalian fossils, so, most notable works on the Siwalik taxa include the taxonomy of mammalian taxa as discussed above.

PALEOECOLOGY AND PALEOCLIMATE, AND APPROACHES TO THEIR RECONSTRUCTION

In paleoecology, the fossil taxa and their relationship with environment is studied while paleoclimatology is the assessment of the prehistoric climatic condition taken on the scale of the entire history of planet earth. There are various approaches to determine the palaeoecological interactions and palaeoclimatological interpretations like stable isotope analysis, mesowear and microwear analysis, and palaeopathology (Fortelius & Solounias, 2000; Ameen et al., 2022; Böhmer & Rössner, 2018; Waseem et al., 2021; Nawaz et al., 2022). Study of the past climate provides a clue to understand the possible impacts of global change (Uhl et al., 2006). Hence, study of the past climates is a tool for the understanding of changes that may occur in modern and future climatic conditions. For the paleoclimatic reconstructions, both the qualitative and quantitative assumptions and assessments are used that also include the use of computer-based process simulations. However, before the availability of instrumental records, such reconstructions were solely dependent upon a variety of proxy methods to collect information from the tree rings, boreholes, glaciers, skeletons of tropical coral reefs, shells and fossils. Whatever approach is applied to reconstruct the paleoclimate, it is necessary to understand the relationship between the source of evidence and climate (Shuman, 2007).Paleoclimatologists usually consider past geological epochs on the basis of long term atmospheric conditions, whether a specific time period was warmer, colder, dry, semidry, humid or semi-humid compared to the present climate and due to the availability of the of limited seasonal emphases in many climate proxies, determination of potential changes in the annual cycles is often not possible (Jones et al.,2003).

STABLE ISOTOPE APPROACH TO TRACK PALEOENVIRONMENT

One of the best applied approaches for the exploration of paleodiet and paleoecology of past life is stable isotope analysis (SIA). The foundation was mainly laid during the 1990s when it was established that atmospheric and lithogenic carbon, evaporation/residence time affects the relative inputs of soil zone, water isotopic composition, and information on water temperature. These parameters are recorded in the stable isotopic data from modern European stream and lake shore carbonates (Andrews et al., 1997). The results of stable isotope analysis are shown in the familiar delta (δ) notation in parts per mil (‰) using V-PDB (Vienna Pee Dee Belemnite) or VSMOW (Vienna Standard Mean Ocean Water) standards, used to reconstruct the past diets ($\delta 13C_{diets}$) and paleoenvironmental meteoric water ($\delta 18O_{mw}$), respectively (Quade et al., 1992, 1995; Cerling et al., 1997, 2015; White et al., 2009; Sanyal et al., 2005, 2010; Uno et al., 2011; Waseem et al., 2020, 2021a, b). The most abundant fossil faunas, in particular those of bovids, are widely used tools for obtaining data about paleoenvironmental conditions (Spencer, 1997; Vrba, 2000). For the determination of paleoenvironmental conditions, carbon, oxygen and nitrogen isotopes are used in such studies, however, carbon and oxygen isotopes are used widely and frequently to determine the paleoenvironmental conditions.

As mentioned above, carbon isotopes can provide various types of information regarding vegetation cover, resource partitioning and habitat use, dietary strategies, and especially the paleo-vegetation (Kohn, 2002; Cerling, 2004).As far as the vertebrates are concerned, stable carbon isotope ratios

(13C/12C) in fossil tooth enamel holds extremely valuable information about the paleoenvironmental trends and this method is useful for indirectly inferring the habitat preferences in savanna ecosystems as it provides the relative proportions of grass and browse consumed. When tooth enamel is used for carbon isotope analysis, proportions of C3 and C4 plants and presence or absence of C4 grasses in the diets of fossil animals using biological apatite that primarily consists ofδ13C. The carbon isotope analysis also provides answers to some important questions (Cerling et al., 1997; Passey et al., 2005) like, when C4 grasses emerged? When these became major components in biomass during the Late Miocene? or when C4 and C3 grasses proportion was changed as a result of shift in rainfall seasonality?

The oxygen isotope (δ18O/δ16O) compositions from bioapatite's of terrestrial mammals have been used to infer air temperature, climate, relative humidity or aridity of the past environments as well as mobility, drinking behavior, and birth seasonality of specific mammal taxa (Levin et al., 2006). As the carbon isotope analysis, the oxygen isotope analysis also focuses on the bioapatite where its composition in mammalian fossils is determined by body water because body water controls the oxygen isotope compositions from different oxygen input sources and oxygen output fluxes (Luz & Kolodny, 1985). As the oxygen isotope composition in water can vary greatly from time to time and from area to area because of the variations in local surface water are prone to air temperature and as well as to the amount of local precipitation and evapotranspiration (Fricke & O'Neil, 1996), hence, proportions of δ18O/δ16Oin the skeletal remains of fossil mammals can directly provide clue to paleoclimatic conditions based on the oxygen isotope composition (Tütken & Vennemann, 2009).

Recently, Nelson (2007), and Waseem et al., (2021a, b) have applied the above-mentioned techniques for the determination of paleoenvironmental conditions in the Miocene (Middle to Late Miocene) deposits of the Siwalik. Nelson (2007) reconstructed the habitat change surrounding the extinction of Sivapithecus during the Late Miocene while Waseem et al., (2021a, b) determined the paleoenvironment of mammalian fauna during the Middle Miocene.

PALEOPATHOLOGY

Palaeopathology is the study of diseases and injuries in the primitive animal taxa through the examination of their fossils, skeletal remains, mummified tissues, and by the analysis of coprolites. A detailed demarcation of Paleopathology was provided by (Ortner, 2003), including the study of disease, both human and nonhuman, in antiquity using a variety of different sources including human mummified and skeletal remains, ancient documents, illustrations from early books, painting and sculpture from the past, and analysis of coprolites." The term "palaeopathology" was coined by R.W. Schufeldt in 1892.

The prime focus of the paleopathological studies is the study of skeletal material or preserved bodies in any form either in fossilized form or in mummified. The mummified bodies can be natural e.g., mummy of Anatosaurus (dry form) and mummy of baby mammoth (frozen form) or can be artificial e.g., mummified ancient Egyptian pharoes (Lynnerup, 2007). However, focus is shifting towards the dental palaeopathology with the passage of time because dentition holds the record of individual age, feeding strategy and animal's diet and these features can provide the information about the ecology, physiology and life history of extinct organism being studied (Böhmer & Rössner, 2018). The use of palaeoradiology analysis of ancient remains now involves the computed tomography (CT)scan imaging and this technique has an advantage on the traditionally used X-ray imaging, delivering a higher resolution, bigger range of cross-sectional views as well as having a digital 3D reconstruction (Chhem & Brothwell, 2008). A recent example of non-invasive use of radiological scan is the study of Böhmer and Rössner (2018) on two mandibles of extinct rhinoceros Prosantorhinusgermanicus from the Miocene through X-ray tomography. The study material revealed that one specimen documents decreased dental wear of deciduous cheek teeth, mandibular bone resorption as well as abnormal cemental deposition and other specimen revealed an abnormal reduction in thickness of enamel in the deciduous cheek tooth.

CONCLUSION

Taken together, paleontology is a vital scientific discipline that uncovers the history of life on Earth through the study of fossils. The formation of fossils, influenced by various geological and taphonomic processes, offers a window into the past, preserving crucial details about ancient organisms and their environments. The Siwalik Group, with its rich fossil deposits, has played a pivotal role in advancing our knowledge of the evolutionary and ecological history of the Indian subcontinent. Through techniques like stable isotope analysis and paleopathological studies, paleontology continues to shed light on the intricate relationships between ancient life forms and their environments, offering valuable insights into the Earth's history.

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