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Geological journey through the Himalaya - Early research and discoveries

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ABSTRACT

A number of contributions to the understanding of geology of Himalaya prior to the 20th C. are described. These include observations made by the Chinese about marine fossils found in high mountains; records from 1720s of the Jesuit Priest, Ippolito Desideri, along the course of the Yarlung-Tsangpo-Brahmaputra River; the work of Cautley and Falconer on vertebrate fossils from Miocene of the Siwaliks; and the first geological traverse of the mountain chain. This latter was undertaken by Lieutenant Richard Strachey in 1848 and his detailed cross sections were published in 1851. It is this transect that represents the 'journey' described in this paper where Strachey's observations on the geology of the Himalaya are given. The work of some other notable geologists in the second half of the 19th C is recorded. This leads to a discussion of isostasy and theories about the structure of this and other mountain chains, including the geosynclinal theory that prevailed up until the end of the 19th C.

Keywords: Himalaya, geological journey, research, discoveries

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INTRODUCTION

Early history of geological research in the Himalaya with some important contributions to the subject prior to the 20th Century (C.) are discussed. Whilst not a comprehensive account of the subject, some key moments in the evolution of geological ideas are captured. Gansser (1964), Searle (2013) and Edmundson (2019) have useful information of the subject, especially covering the 19th C. The field of Himalayan geology emerged as an independent and systematic branch of science in the 1850s, and the latter half of the 19th century has been referred to as the "Golden Age" of this discipline, as noted by Gansser (1991). In an important work, Sorkhabi (1997) documented the chronology of significant events in the development of Himalayan geology.

The 'Asiatic Researches' and 'Journal of the Asiatic Society of Bengal' were important periodicals for the study of the Himalayan geology in the 19th century. The 'Asiatic Researches' was first published in 1788 by the Asiatic Society of Bengal. The 'Journal of the Asiatic Society of Bengal' began publication in 1832 and was a continuation of 'Gleanings in Science', a journal launched by J. D. Herbert in 1829. Both of these journals provided a platform for early geologists to publish their findings and observations on the geology of India and the Himalaya. Despite the challenging conditions of working in the rugged terrain of the Himalaya, ground-breaking discoveries of pioneering geologists were reported in these journals.

Chinese science

As Joseph Needham established in his mighty work, 'Science and Civilization in China' which ran to very many volumes (e.g. Needham, 1974), China was responsible for numerous scientific discoveries before similar 'discoveries' were made in the West. However, the geographical scope of these researches did not appear to extend to the Himalaya. Nevertheless, observations were made that had relevance to the subject. For instance, Chu Hsi (1130–1200) was a leading Chinese scholar, thinker, and teacher of the revival of philosophical Confucianism or 'neo-Confucianism'. He wrote that the '*stone animals'* found at the top of mountains had once been at the bottom of the sea (Zhang and Faul, 1988).

Hsi's work was not an isolated flash of insight – he was one of a long series of Chinese writers considering the origin of fossils and mountains (Needham et al., 1970). This is relevant considering the presence of Ordovician fossils high on Everest and fossils found elsewhere high in the Himalayan mountain chain. It is notable that these Chinese reports predate other recorded claims of being the first to recognize that fossils high in the mountains had their origin in the sea, for instance by Leonardo da Vinci (1452–1519) and Charles Darwin who, whilst on the Voyage of the Beagle (1830–1836), found marine fossils high in the Andes mountains.

Jesuit Journeys

Jesuit missionaries travelled extensively in the Himalaya in the 17th and 18th Centuries. Few of these missionaries left reliable records of their travels but the Jesuit Priest, Ippolito Desideri (1684–1733), was an exception (Pamplun, 2010). He is considered to be one of the first great experts on the culture and religion of Tibet. Whilst he did not make much reference to the rocks he travelled across, Desideri did make valuable observations about the Yarlung-Tsangpo-Brahmaputra River (which he called the Tsangpo) that predated by two hundred years the generally accepted 'discovery' and mapping of the surprising course that this river takes (Fig. 1).

To understand the context we must look at the map of the

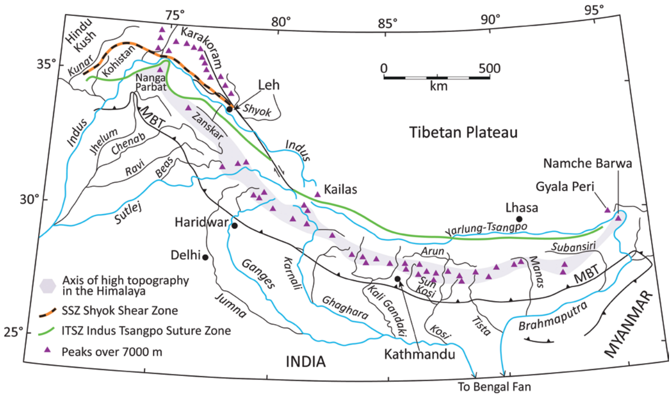

Fig. 1: The circuitous course of the Yarlung-Tsangpo-Brahmaputra River (blue colour) together with the three other holy rivers with their source in the Mount Kailas region. MBT; Main Boundary Thrust (modified after Searle, 2013).

region Desideri would have had at his disposal. This was a map by Herman Moll (c. 1654–1732). Moll, born in what is now Germany (or the Netherlands, no one seems to be sure), was the most renowned cartographer of early 18th C. Britain (Reinhartz, 1977). His large double-sheet atlas, *The World Described*, first published in 1709 and expanded during Moll's lifetime and even after his death, was the most important folio atlas of its day.

Moll's map of the Himalayan region is remarkably accurate in many respects (the Indus River and its tributaries are generally accurately displayed) whilst in others he repeats what were most probably common misconceptions (drainage into the Caspian Sea is exaggerated at the expense of drainage into the Arabian Sea). When it comes to the course of the Yarlung Tsangpo River, however, Moll shows it draining from the east westwards into Lake Manasrovar. In his account of his travels in Kashmir, Ladakh, Tibet and Nepal (1715–1721) Desideri recognized this as an error and wrote "… the principal [river] runs the length of … Tibet through its middle from *west to east*…flowing through the entire province of lower Kongpo …. the river turns southeast and after passing through the lands of the Lhopas *descends into Rangamati* [Chittagong], a province of the Mogul empire beyond the Ganges, into which it merges …"

Desideri's principal river is clearly the Yarlung-Tsangpo and he would appear to have understood that it connected with the Brahmaputra (not fully understood until 1913, Edmundson, 2019) and drained into the Indian Ocean. As Petech, the Italian authority on Tibet, observed "Desideri had a clear and exact idea of the course of the great river" (Petech, 1988). This was a remarkable contribution to our understanding of the Himalaya.

Desideri named the narrow gorge through which his Tsangpo River flowed southwards, the 'Gorge of the Tsangpo'. This is now known as the Yarlung Tsangpo Grand Canyon which has a reasonable claim to be the largest canyon in the world. Desideri also described the natural environment of the region, including the high peaks and deep valleys of the Himalaya, and the diverse flora and fauna he encountered in the mountains and on the Tibetan Plateau.

GEOLOGICAL RESEARCHES IN THE 19TH C. - PHYSIOGRAPHY

The Himalaya has captivated scientists and explorers due to the region's unique geological features but it was not until 1816 that this mountain range was thought to be the highest in the world, rising higher than the Andes, the previous claimant. It was Robert Colebrook, the Surveyor-General of Bengal, who made this observation (Colebrook, 1816).

The alignment of the rivers was a fascination for many researchers, Hodgson (1874, original 1849) noting how many of the streams flowed perpendicularly to the strike of the range, merging to form large rivers debouching into the plains. This resulted in a physiography, he argued, of spurs and transverse river gorges. Hodgson reflected on the history of these mountain rivers with their deep gorges, a subject that has recently been summarized by Valdiya and Sanwal (2017) as follows. The four major rivers of the Himalaya – Indus, Sutlej, Karnali/Ghaghara (Ganges tributary) and Brahmaputra - have flowed through deep gorges and canyons for many million years, cutting their way south across the Himalayan mountain barriers that rose in their paths. These rivers have maintained their original courses, progressively cutting deeper channels as the mountains gradually rose up. This resulted in the development of rivers with rapids and knick-points and characteristic deep gorges and canyons, with practically vertical to convex valley walls.

The canal builders

A century after Desideri wrote about the Himalaya, the East India Company canal builders Lieutenant Probey Cautley and Dr. Hugh Falconer were discovering fossils in the Siwaliks that were to make them famous. This was in the 1830s when canal building was of critical importance to the development of infrastructure prior to the age of steam railways. Their work involved the construction of the Ganga Canal which was to divert the Ganga water into the Doab ('two water') area, between the Yamuna and the Ganga rivers. It is no accident that canal builders had an eye for fossils. In their work on canals, just as with William Smith (canal builder and author of the first geological map of England, Smith, 1816), engineers defined the strata they encountered in canal building according to their fossils.

Cautley and Falconer were working in the Saharanpur area (north of Delhi, see Fig. 2) from where they could get to the Siwalik Hills easily in their spare time. What they found was a 'complete zoo of extinct animals that lived and died as the foothills [of the Himalaya] were forming' (Edmundson, 2019). Vertebrates discovered near Haridwar, included prehistoric elephant, rhinoceros, sabre-tooth tiger, pig, giant tortoise and antelope (Edmundson, 2019; Clark-Lowes, 2022). What Cautley and Falconer had established in addition was that these provided evidence of warm humid conditions suitable for a diverse mammalian fauna. The context was that this first range of mountains of the Himalaya, the most southerly range, the Siwaliks, were composed of Cenozoic fluvial deposits. Dr. Falconer went on to befriend Charles Lyell and support Charles Darwin on the subject of mammalian evolution (Falconer, 1868). Many British geologists, including Sir Roderick I. Murchison (1792–1871), were fascinated by the Siwalik fossils, and Murchison himself acquired a collection of these fossils for the British Museum.

Richard Strachey's cross section

It was the work of Sir Richard Strachey (1817–1908) and his traverse of the mountain chain in 1848 that first brought an understanding of the geology of the mountains 'behind' the Siwaliks (Strachey, 1851a,b). This was the main range of the Himalaya and its geological composition was something of a mystery. Nepal was closed to foreigners and hence the route chosen for the traverse was through Almora in the Kumaun region, from southwest of Saharanpur and on to the north to a position east of Mount Kailas (Fig. 2). The traverse took him from the Siwalik Hills, on a line perpendicular to the regional strike, over a 5,000 m high pass east of Nanda Devi (7,816 m) and on into Tibet.

Like Cautley, Richard Strachey was at the time of his traverse a Lieutenant with the East India Company (he was with the Bombay Engineers) working on the Ganges Canal and, also like Cautley, he had to take leave to undertake his geological research. He was only 31 years old when he made his traverse, an expedition that lasted a few months. His results which were published in the proceedings of the Quarterly Journal of the Geological Society (Strachey, 1851a) included impressive cross section drawings, the main one of which is reproduced as Figure 3. On entering Tibet, which was closed to foreigners at the time, he assumed disguise as a Buddhist pilgrim and visited Mount Kailas. Strachey correlated Tibetan marine formations with those in Great Britain described by Murchison in 'The Silurian System' (1839). His fossil collections were later to play a key role in defining the Tethys Ocean from which the Tethyan Himalayan Series was derived and named.

Tectono-stratigraphic units of the Himalaya

Strachey's transect established the first understanding of the major divisions of the mountain chain. Although the prior work by Herbert (1842), in his study of the geology of the Sutlej and Kali valleys of the Himalaya, had already divided the Himalayan rocks into primary (central gneiss and schist) and secondary (sandstone), his work was 'local' and did not encompass the full range of the mountain belt.

Strachey documented the geology of the Himalaya Mountains and Tibet as follows. He found the mountains to comprise a complex and varied landscape shaped by millions of years of tectonic activity. He described the region as a "geological museum" with rocks and formations from a wide range of geological periods. In his geological observations he recognised the different tectono-stratigraphic units of the Himalaya, and divided them into three major tectonic units based on their stratigraphic and structural characteristics. These units, arranged in a southwest-northeast transect, are as follows:

- 'Metamorphic strata without fossils' - these correspond broadly to the Lesser Himalayan Series,
- 'Crystalline Schists' - these correspond broadly to the Greater Himalayan Series and
- 'Azoic (un-fossiliferous) Slates' through to 'Paleozoic' and Secondary strata (corresponding to the Tethyan Himalayan Series) and finally the Tertiary Strata in the 'Plain of Tibet'.

The general configuration and northerly dip of the rocks Strachey described, going from metamorphic and crystalline rocks at the southern end of the section to un-fossiliferous slates and a fossiliferous Palaeozoic, Secondary (Mesozoic) and Tertiary section to the north are clearly illustrated in his cross section.

The fossiliferous section can be seen to be consistent with the law of superposition as popularised by William Smith in his publications and in his famous 1815 geological map of

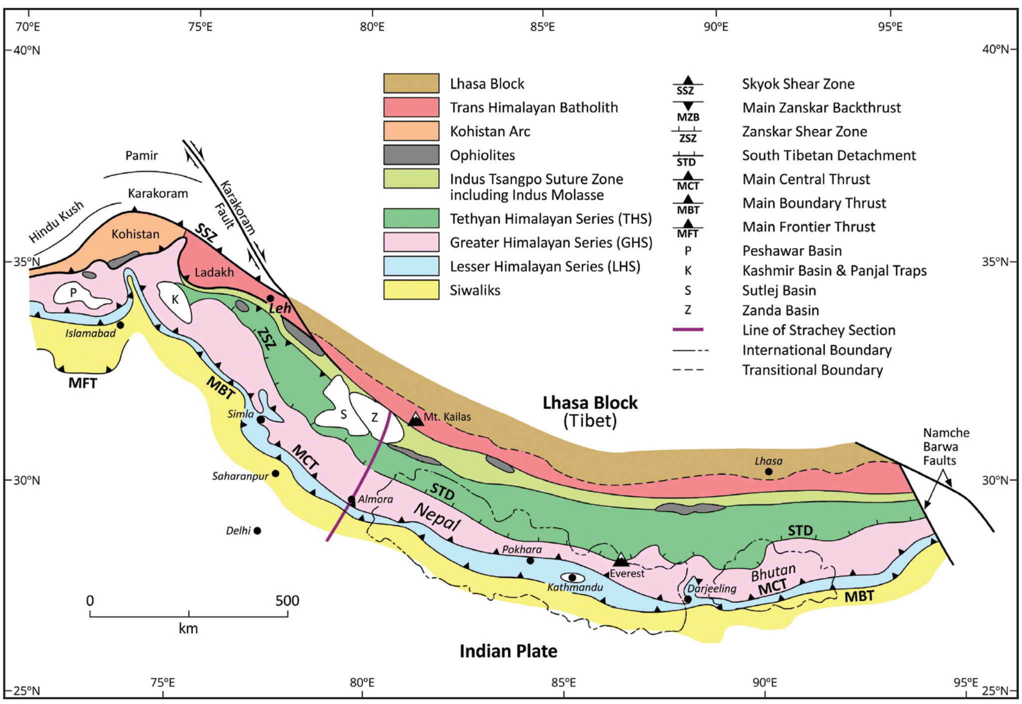

Fig. 2. Geological sketch map of the Himalaya showing the location of the Strachey section (modified after Dèzes, 1999; Searle and Treloar, 2019; Clark-Lowes, 2022).

England, Wales and parts of Scotland (Smith, 1816), works with which Strachey would no doubt have been familiar. The younger rocks to the north clearly lie above the older rocks to the south. Strachey particularly recognised the equivalents of Silurian limestones from Wales and, from England, Triassic Muschelkalk limestones, Jurassic Oolitic limestone and Jurassic ammonite-rich shales. He appears to have been well connected in geological circles in being able to request fossil identifications from, among others, the famous Edward Forbes, Professor of Natural History at the University of Edinburgh. He noted that many of the fossils identified and the oolitic limestones were clearly evidence of marine sedimentation. He considered their presence at an elevation of 10,000 ft (c. 3,000 m) to be good evidence of the uplift of the mountain chain from sea level. Strachey's work was widely acknowledged and was used by Greenough to provide detail to the Himalayan part of his magnificent 1855 geological map of Greater India, the first of its kind.

Vertebrate fossils of the Zanda Basin

As shown in Strachey's cross section (Fig. 3), at the northern end of his transect, as he entered Tibet and met the course of the Sutlej River, he encountered a more-or-less horizontally bedded succession of Tertiary deposits. This succession he recognised as lying unconformably on the 'Secondary' (or Mesozoic) strata. Strachey made an impressive collection from this locality but the exact provenance of the specimens is uncertain. His collection included many vertebrate fossils such as bones from 'Hippotherium' (an extinct genus of horse). Wang et al. (2013) and Wang et al. (2020) summarised our present knowledge of these deposits and their fossils in what is now defined as the Zanda Basin. This basin is composed of Neogene terrestrial sandstones. Strachey's collection included bones of other horses and, additionally, bones from a bovine ruminant and a rhinoceros. Lying at an elevation of 4,500–5,000 m these Neogene strata provided evidence of considerable uplift of low altitude sediments to their present elevation. The timing of this uplift of the Tibetan Plateau is the subject of much debate (Shackleton and Chengfa, 1988; Searle, 2013), although clearly the uplift occurred well within the Neogene.

At the Niti pass, Strachey documented Neogene strata at an even greater elevation. Here the rocks are at 5,000 m and above. He also recorded a detached portion of this 'sediment stratum' located some kilometres below the pass on the south. He attributed the separation of this portion to the result of dislocations related to the 'uplift of these enormous mountains' (Wang et al., 2020).

Prior to Strachey, the first mention of vertebrate fossils was by Reverend William Buckland. He described bones of horses and deer found at an elevation of 4,900 m, which were acquired from Chinese Tartars (Edmonds and Douglas, 1976).

Characteristics of the metamorphic strata and crystalline schists

The structural features within the metamorphic strata and crystalline schists were of great interest to Strachey. Whilst noticing that the foliation of these rocks was, like the sedimentary strata, mainly dipping to the north, he observed two examples where the dip switched to the south creating synclines that are illustrated on his cross section at Naini-tal and at Bagesar. Noting the complexity of the structures within these rocks he wrote, by way of interpretation, of 'upheaving forces from below' and of 'violent lateral thrust' (Strachey, 1851a). He understood the significance of faulting and wrote of 'a series of great faults along the southern edge of the mountains' (to the north of the Siwaliks) and, in places, of 'absolute rupture and dislocation of an immense mass of strata' resulting in significant localised reorientation of the dip/foliation of the rocks.

The igneous rocks of the mountains were broadly divided by Strachey into granites and greenstones. Some of the granites he found high in the 'Crystalline Schists' were characterised by the presence of schorls (black tourmalines) and were found to be contiguous with the foliation of the surrounding schists and gneisses, some of these metamorphic rocks containing the metamorphic index mineral kyanite. These granites would appear to have the characteristics of typical mid-crustal-melt leucogranites. Many of the great peaks of the region were described as being composed, similarly, of schistose rocks with granite veins.

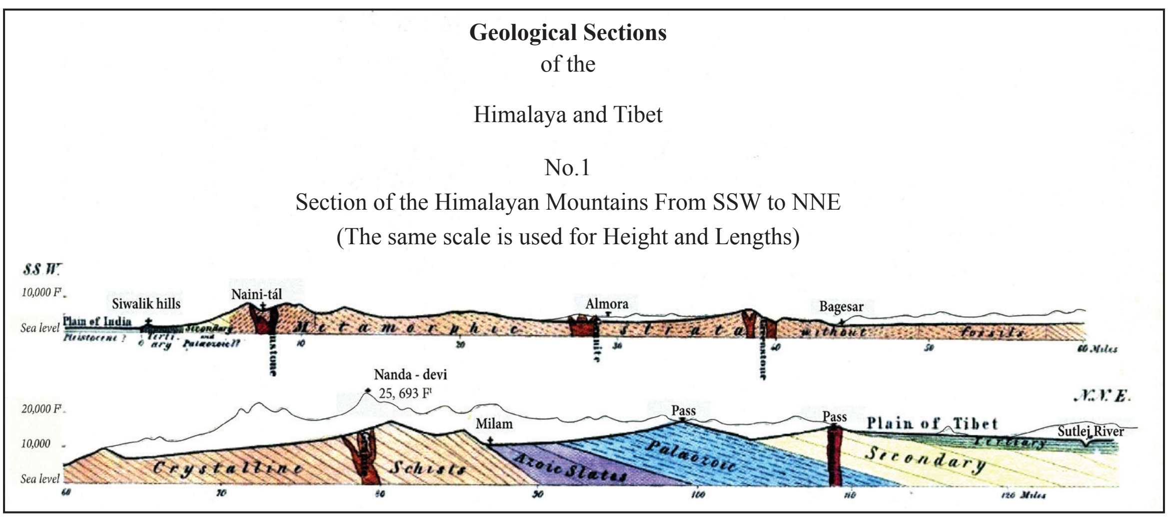

Fig. 3: Cross section through the Kumaon Himalaya and northwards. Richard Strachey published this geological cross section following his 1848 reconnaissance across the mountain range in the Quarterly Journal of the Geological Society. The traverse took him from the Siwalik Hills, over a high pass east of Nanda Devi (7,816 m) and on to Tibet. For location of section see Fig. 2 (Strachey, 1851; partly redrawn from Edmundson, 2019).

Strachey had been promoted to Captain by the time his 1851 papers were published. Following his time in the army he went on to pursue a remarkable career as geologist, meteorologist, railway company chairman and Indian administrator, by which time he had been knighted. He had a remarkable family with thirteen children, ten of whom survived to adulthood, one of whom was Lytton Strachey, the writer and critic, and another was Pippa Strachey, a well-known suffragette.

Whatever the cause, it was apparent to Strachey from the structures within the mountain chain that major 'upheaving' forces were at work and that 'vast dislocations accompanied the elevation of the mountains'. But still, an overarching explanation for the structure of the mountain chain eluded him.

James Hall's geosynclines

Mountains were thought by some to be caused by cooling and shrinkage of the earth causing 'wrinkling at the surface' and by others to be the result of an expanding earth and consequent differentiation of stable and unstable crust. But in 1859, James Hall (1811–1898), a New York state palaeontologist, put forward a new theory for mountains. His theory was that of Geosynclines (his term) where mountain-building was the result of 'landslides' that filled huge nearshore 'chasms' with massive accumulations of sediment, later to become sandstone, limestone and shale (Dott, 2005).

As the sediments within the 'chasms' were buried deeper into the Earth's crust, with time they sank down into hot basement and melted. Eventually everything expanded because of the heat and rose high on the surface of the earth to form mountains. This thermal expansion theory was accepted for the best part of a century and was the prevailing orthodoxy for the rest of the 19^{th} C. While the geosynclinal theory provided a foundation for understanding mountain building and the processes that shape the Earth's surface, it had limitations in explaining the formation of the Himalayan mountain range. The theory wasn't a very satisfactory theory for the Himalaya since it begged the question as to how a chasm could have formed between India and Asia containing sedimentary rocks with marine fossils. It was the surveyors engaged with the Great Trigonometrical Survey that made the next major contribution to the debate on the structure of the mountain chain.

The Great Trigonometrical Survey

The Great Trigonometrical Survey of India (GTSI), to map out 'British India', was undertaken initially by the East India Company and then by the Geological Survey of India, at one stage under the leadership of Colonel Everest.

Surveying work was being undertaken by two methods, triangulation and using the position of the stars. Measurements taken just south of the Himalayan Mountain Range, at Saharanpur, while using a sextant and a plum bob (to level the instrument) turned out to be inconsistent with measurements from triangulation. It was recognized that this might be because an extra gravitational force was being exerted laterally by the large mass of the mountain range and this was affecting the plum bob. But applying corrections related to the mass of the mountain chain failed to provide a convincing match with the data. The gravitational pull of the mountains turned out to be less than would be expected.

It was Professor George Airy in the mid-19^{th} century, the Astronomer Royal in London, who realised that this anomaly could be explained if the mountains had deep roots of relatively light continental material beneath them. And in developing this idea he established the basis for the so called 'Airy model of isostasy', one aspect of which was that the visible mass of a mountain chain would be balanced at depth by a sizable root. This theory was confirmed in the 21^{st} century by modern geophysical techniques that were able to directly observe the deep roots of mountain chains using seismic imaging techniques, confirming the validity of the Airy model of isostasy (Nield, 2007).

Research workers, mapping and discoveries in the second half of the 19^{th} C.

In 1854, Alexander Cunningham (1814–1893) was looking beyond the section described by Strachey and beyond the main Himalayan ranges, northwards onto the Tibetan plateau. He introduced the term "trans-Himalaya" (Fig. 2) for this region and gave a good description from his studies based in Ladakh (Cunningham, 1854). Within the main Himalayan ranges, H.B. Medlicott, Director of the Geological Survey of India (GSI) from 1885 to 1887, coined the term "Main Boundary Fault" for one of the major thrust faults of the range (Fig. 2), and independently worked out the structure of the Sub-Himalayan region between the Ravi and Ganga rivers (Medlicott, 1864). A number of different Himalayan regions were mapped during the second half of the 19th Century, many of them published by the Geological Survey of India (e.g. Spiti and the Salt Ranges). The Kashmir and Chamba region was mapped by Lydekker and published in 1883 and the Austrian geologist, Carl Griesbach (Director GSI, 1894–1903), produced a detailed report on the Central Himalaya in 1891. In Northeast Himalaya a major memoir from was produced by Mallet (also GSI) in 1875 on the Darjeeling area, a work that serves as the foundation of geological knowledge of the region. Thomas Oldham (first Superintendent GSI 1851–1876) extended his work on the stratigraphy of India and the Himalaya (Oldham, 1887) and was responsible for launching the widely-known publications 'Palaeontologia Indica' and 'Memoirs and Records of the Geological Survey of India'.

CONCLUSIONS

This account of a number of important contributions to the early history of geological research in the Himalaya covers the period up to the end of the 19^{th} C. The researches described were characterised by detailed observations resulting from committed hard work often in difficult circumstances. It was also the case, one suspects that rising to the challenge and the adrenaline of adventure played a part in some of this work.

The Chinese were the first to discuss the significance of marine fossils (their 'stone animals') at high elevations in the mountains and to ponder how they got there. Later, among the Jesuits to visit the Himalaya was the Priest Ippolito Desideri. In the 1720s he made important observations about the flow direction of the Yarlung-Tsangpo River and its connection to the Brahmaputra River, during the course of his very extensive travels.

In the 19^{th} C. those working for the East India Company and the Great Trigonometrical Survey made major contributions. In the Siwaliks, Probey Cautley and Hugh Falconer found fossil vertebrates including prehistoric elephant, rhinoceros, and many others, providing evidence of warm humid conditions suitable for a diverse mammalian fauna in the Miocene. In the major ranges of the Himalaya and northwards, Richard Strachey provided a description of the metamorphic, igneous and sedimentary rocks of the mountains, having undertaken and published the first geological traverse of the Himalaya. At the northern end of his traverse, in the Zanda Basin, he found vertebrate fossils, including horse bones, at high elevations, providing evidence of considerable uplift. His observations on the structures of the mountains and conjectures on their causes were perceptive but it was James Hall in the United States who came up with the thermal expansion geosynclinal theory of mountain building.

Although widely accepted at the time, the geosynclinal theory was less helpful to understanding the Himalaya than the concept of isostacy that resulted from detailed work by the surveyors of the Great Trigonometrical Survey. Anomalies in their measurements led them to look at questions of the gravitational pull of the mountains. It was George Airy who realised that the anomalous readings could be explained if the Mountains had a deep root of relatively light continental material. This is now understood to result from crustal thickening consequent upon the collision of the Indian Plate with the Asian Plate, the crust being thickened by the stacking of thrust sheets (Parsons et al., 2016; Clark-Lowes, 2022). This caused uplift of the mountains bringing to high elevations the marine fossils that so intrigued the Chinese a thousand years before, these fossils now understood to be from the margins of the closed Tethyan Ocean.

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