Figure 4. Photomicrograph of transverse section of a dinosaur bone at Dirang showing development of dense secondary haversian system throughout the compacta. Bar scale = 0.3 mm.

Figure 5. Photomicrograph (closer view) of secondary haversian system of a dinosaur bone at Dirang. Transverse section of cylindrical secondary haversian canals are seen as irregular rings, where concentric growth rings (lamellae) grow towards inner spaces; rings of later generations overlap those of earlier ones. Bar scale = 0.3 mm.

more complete skeletal remains of the animal, is being continued in and around Dirang for getting a more complete picture about the creature and identification of the genera and species.

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Disturbance time variation of geomagnetic vertical field in the Indian equatorial electrojet

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The disturbance time variations of the vertical component \( (Z) \) of the geomagnetic field at stations in the Indian chain, following a sudden commencement storm show a spectacularly large decrease at only the electrojet stations, Thiruvananthapuram, Etaiyaparam, Kodaikanal and Annamalainagar. This decrease is not synchronous in time with the decrease of the horizontal \( (H) \) field. The peak depression of the \( Z \) field occurs about three hours before the time of peak decrease of \( H \), i.e. during the middle of the main phase of the storm, when the ring current is developing at the fastest rate. This first clear description of \( \text{Dst}(Z) \) at Indian electrojet stations is further confirmation of the sub-surface conducting channel in Palk Strait, where currents are induced by the ionospheric source current, producing large decrease of \( Z \) field at ground level. Similar analysis of \( \text{Dst}(Z) \) at different equatorial stations around the world is recommended to understand the abnormal features of Indian equatorial electrojet.

Moos\(^1\) was the first to make an extensive study of the magnetic disturbance effects on the horizontal geomagnetic field \( (H) \) using the data from Colaba, India. After

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removing the normal daily variation and arranging over a number of storms, the magnetic storm was found to start with a sudden increase of $H$ field lasting a couple of hours, followed by a decrease continuing for a couple of hours and later by a slow recovery to normal conditions in a day or two. These different stages of the magnetic storm are now called as initial, main and recovery phases, while the whole phenomenon is called disturbance time (Dst) variation. Sugiuira and Chapman made an extensive analysis of the disturbance variations of the geomagnetic field at a number of a observatories around the world. They had divided the stations into groups of varying latitude belts and hence any regional anomalies in the phenomenon were not identified. They had concluded that the equatorial electrojet does not experience any effect different from those at other low and middle latitude stations. The Dst(Z) was found to be much less than the Dst(H) for all latitudes, except for the low-latitude edge of the auroral zone. Rastogi of SSC(Indian stations has shown the daily variation study of the ampli tude of sudden storm commencement Dst(field) at Kodaikanal and Alibag during large magnetic storms. A definite effect of abnormal electrical conductivity on the amplitude of peak depression of the corresponding SSC(fields) at low latitudes has been shown. An extensive study of the amplitude of sudden storm commencement (SSC) at Indian stations has shown the daily variation of SSC(Z) at Thiruvananthapuram to be very similar to the corresponding SSC(H), with a midday peak of comparable magnitude. It was also shown that the large ratio of $\Delta Z/\Delta H$ during SSC, exceeding the value of 1.0, occurs only at the electrojet region of the Indian longitude sector and not anywhere else in the world. It was felt desirable to examine the disturbance time variations of the Z field at the Indian stations, a totally neglected aspect of geomagnetic storm phenomenon. The present paper is the result of such a study.

Since 1975, a unique network of geomagnetic observatories is operative in India, confined to a narrow longitude zone, but extending from the latitude of the centre of the electrojet current belt to that of the focus of the sq current system. In 1980 there was a very important addition of the observatory at Etaiyapuram and now we have four observatories regularly operating within the equatorial electrojet belt in India. The coordinates of these observatories, for the year 1980 are given in the Table 1.

The first storm selected was the one which started at 0957 h 75°E on 19 December 1980. Figure 1a shows the variations of Dst(H) index, storm-time variations of $H$ and $Z$ fields at all stations in the Indian chain on 18, 19 and 20 December 1980. No data were available from Annamalainagar. The storm had a weak initial phase after the SSC and a large drop of Dst(H) index had started after 1830 h on 19 December 1980 which reached the minimum value of –240 nT at 2230 h on 20 December 1980. The Dst variations of the $H$ field at all stations followed remarkably well the variations of the Dst(H) index, both in amplitude and time correspondence. The storm-time variations of the $Z$ field at TRD showed a sharp decrease after 1730 h, but reached a minimum value of –150 nT at 2030 h, about three hours earlier than the time of minimum $\Delta H$. Further, the magnitude of $\Delta Z (= –157$ nT) is unexpectedly large, being about half of the $\Delta H$. The observations north of TRD, i.e. KOD and ETT recorded a decreasing $\Delta Z$. It is to be noted that the time of minimum $\Delta Z$ was about three hours earlier to that of $\Delta H$.

The second magnetic storm chosen had started at 2335 h 75°E on 11 September 1986. Figure 1b shows Dst variations of $H$ and $Z$ fields at all stations. The sudden decrease of the Dst(H) index indicated the start of the main phase at 0630 h. The Dst index reached a minimum value of –170 nT at 1130 h on 12 September 1986. This storm had been studied earlier and it was shown that the daytime storm was associated with a significant ionospheric westward current in time coincidence with the variation of the ring current itself. It is again seen that Dst(Z) at all equatorial stations TRD, ETT, KOD and ANN showed a decreasing value with the start of the main phase, but the minimum value of $\Delta Z (= –81$ nT) was recorded at 0830 h, about three hours before the time of minimum Dst(H) index. On this occasion, a small decrease of $\Delta Z$ at the same time as at equatorial stations was associated even at Hyderabad and Alibag. The main phase of the storm on 19 December 1980 had occurred in the early part of the night when the electrojet currents are weak, but the storm of 12 September 1986 had its main phase when the electrojet currents are strongest.

The third storm chosen was with SSC at 0056 h on 10 May 1992. The variations of Dst(H) index and the storm-time variations of $H$ and $Z$ fields at all stations are shown in Figure 1c. The ring current in this case seems to have started immediately after the SSC (0056 h) and reached its minimum value of –392 nT at 1930 h. The storm-time variation of $H$ field at any sta-

<table>
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<th>Geog. long. °E</th>
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Figure 1. Storm-time variations of the horizontal ($H$) and vertical ($Z$) fields at geomagnetic observatories in the Indian Chain during the magnetic storm starting at (a) 0957 h 75°E on 19 December 1980; (b) 2335 h 75°E on 11 September 1986; and (c) 0056 h 75°E on 10 May 1992.
tion followed the expected variation similar to that of Dst(H) index. The Dst(Z) variations showed a large decrease of \(-149\) nT at 1530 h. The decrease of Z was fairly small at ANN and absents at stations north of ANN. Looking at the temporal variations of Dst(H) index and Dst(Z) at equatorial stations, it can be concluded that the maximum decrease of \(\Delta Z\) occurs near the middle of the main phase, when the ring current is increasing at the fastest rate.

Even the earliest observations of the geomagnetic fields at Thiruvananthapuram during the IGY had indicated a large range of the solar daily-range of the Z field\(^7\). The model calculations of vertical field by Yacob\(^8\) and later by Thakur and Rao\(^9\) showed that the \(S(q)\) range of Z field is abnormally larger than the theoretical value. Srivastava and Sankar Narayan\(^10\) interpreted the anomaly in terms of ocean effects and the electrical conductivity anomalies in the upper mantle at a depth of 200–800 km. Nityananda et al.\(^11\) postulated the presence of a conductor in the upper mantle or lower crust between India and Sri Lanka. Rastogi\(^6\) suggested an additional effect due to the concentration of the induced currents over the extended latitude zones towards the conducting graben in the Palk Strait between India and Sri Lanka. Rastogi\(^12\) has shown that the induction effects in the Z field at electrojet stations in India during solar flares are related to the sharpness of the initial temporal development of the sfe in the \(H\) field. Thus the induction is larger and extends to a larger latitude from Thiruvananthapuram northward when the source current develops faster. It is confirmed here too that the induction effects in the Z field during the geomagnetic storms are larger and extend to larger latitudes when the ring current develops faster during the main phase.

This is an account of the disturbance storm-time variations of the vertical component of the geomagnetic field in the Indian electrojet region and needs to be critically studied in relation to other magnetospheric field in the Indian electrojet region and needs to be critically studied in relation to other magnetospheric variations of the vertical component of the geomagnetic field. Thus the induction is larger and extends to a larger latitude from Thiruvananthapuram northward when the source current develops faster. It is confirmed here too that the induction effects in the Z field during the geomagnetic storms are larger and extend to larger latitudes when the ring current develops faster during the main phase.

Major lineaments and gravity-magnetic trends in Saurashtra, India

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The lineament map of Saurashtra prepared from false colour, thematic maps indicates four major structural trends. The NE-SW trend reflects the Precambrian Aravalli trend which is dominant in the SE part of Saurashtra and largely represents the basic dykes and plugs exposed in this sector. The ENE-WSW to E-W trend represents the Precambrian trend of Narmada–Son lineament in southern Saurashtra, volcanic pipes of late Cretaceous in central Saurashtra and Gulf of Kutch and Kutch rift basin of Jurassic times, north of Saurashtra. The NW-SE trend parallel to the west coast of Saurashtra is possibly related to coastal tectonics which evolved during late Jurassic due to the break-up of Africa from India. The N-S to NNE-SSW trends prevalent in the eastern and the central parts of Saurashtra are parallel to the Cambay rift basin which evolved during late Cretaceous, due to interaction of the Reunion plume with the Indian lithosphere. It is significant to note that N-S trends occur in pairs, indicating fracture zones. The Bouguer anomaly map also reflects similar structural trends in different parts of Saurashtra, where individual trends are predominant compared to the others. Some of the N-S structural trends coincide with gravity gradients or linear gravity anomalies, indicating fracture zones/faults which may be important for groundwater exploration. Besides, the Bouguer anomaly map has also delineated six circular gravity ‘highs’ of 40–60 mGal over the volcanic plugs/stocks. The large wavelength gravity ‘low’ over the Jasdon


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