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Geomagnetic field precursors associated with earthquakes

B. R. ARORA and B. P. SINGH

Indian Institute of Geomagnetism, Colaba, Bombay

ABSTRACT. An association between local geomagnetic field changes and earthquakes has been often reported since the later part of 19th century. Such possible 'seismomagnetic' effects are interpreted to be due to the stress-induced changes in the magnetization of rocks composing the earth's crust. Observational trials to establish such association have suggested a strong correlation of the tectonic activity, such as earthquake occurrence or volcanism, with local anomalous areas where the secular change of geomagnetic field is larger than the normal one. Also the temporal fluctuation in the secular variation of the geomagnetic field corresponds to the maximum of seismic activity in the vicinity of observatory. In addition to this, the study of long-term behaviour of induction vector of short period fluctuations suggests a sort of cyclic variation, the extremes of which appear to occur prior to large earthquakes. The changes in the transfer functions of such events tend to coincide with the occurrence of moderate and large earthquakes. The preliminary results of an analysis of geomagnetic data from Alibag indicate that seismomagnetic effects of earthquakes in the Koyna region can be identified in the magnetic records of Alibag which may provide a means of predicting earthquakes from Koyna region.

Immediately after the recognition that the rocks containing magnetic grains under the effect of mechanical stress produce changes in magnetization and hence changes in the magnetic field, attempts were made to explain the then already reported geomagnetic field perturbations which were believed to be related in some way with earthquake occurrence on the basis that the accumulating mechanical stress in the earth's crust might locally distort the geomagnetic field at the corresponding sites in the earth's crust. In general, two types of changes in the geomagnetic field can be expected, the one taking place concurrently with earthquake occurrence and may be attributed to the sudden release of mechanical stress in the neighbourhood of the focus of earthquake. Other type, in theory, is the local distortion of the geomagnetic field in the earthquake focal areas caused by the mechanical stress in the earth's crust, which is accumulated until a breakup of the earthquake. This effect, if it can be identified, would be a precursor of the earthquake. Theoretical calculations show that such effects would produce surface anomalies only of a few gammas (1 gamma $= 1\gamma = 10^{-5}$ gauss) much smaller in magnitude than the geomagnetic field fluctuations of ionospheric and magnetospheric origin. Probably for this reason, very few reliable results have ever been obtained for the theoretically expected geomagnetic changes associated with, earthquake occurrence, though observational trials to find some correlation between earthquake occurrences and local geomagnetic secular variations have been repeatedly reported from China, Japan, U.S.A. and U.S.S.R.

2. In one such recent attempt, Tazima and his co-workers in Japan, based on some accurate repeat measurements of field at 100 stations in the time interval of 1967-1973, constructed the averaged isoporic charts for the epoch of 1970. They found that there are a number of local anomalous regions of very small areal extent over which secular change is larger than the normal as determined from the overall isoporic charts. Judging from the local nature of such changes, Tazima *et al.* (1976) felt that geomagnetic secular change over some areas in Japan is getting affected by a change in the magnetization within the earth's crust. It also appeared that local anomalies of secular change are closely correlated with earthquakes occurring in the nearby area and having a magnitude of 6 or greater. Trend of secular change at a few stations was found to be markedly different from that at the neighbouring stations. Fig. 1 gives some typical examples of this type. The vertical component, Z, at the station Morioka has been decreasing along with that at other neighbouring stations until 1969. However, after that year, a large increase in Z began to take place at Morioka, while the decrease in Z continued at other stations at almost the same rate. The increase at Morioka relative to the surrounding stations has exceeded 30γ or so by 1975. The Morioka station is located in a pasture about 7 km distant from the top of Mt. Iwate, an active volcano.

Another anomaly worth noticing is that of Shimod station where Z component shows an anomalous decreasing tendency while an increase or atleast no change can be observed at all the

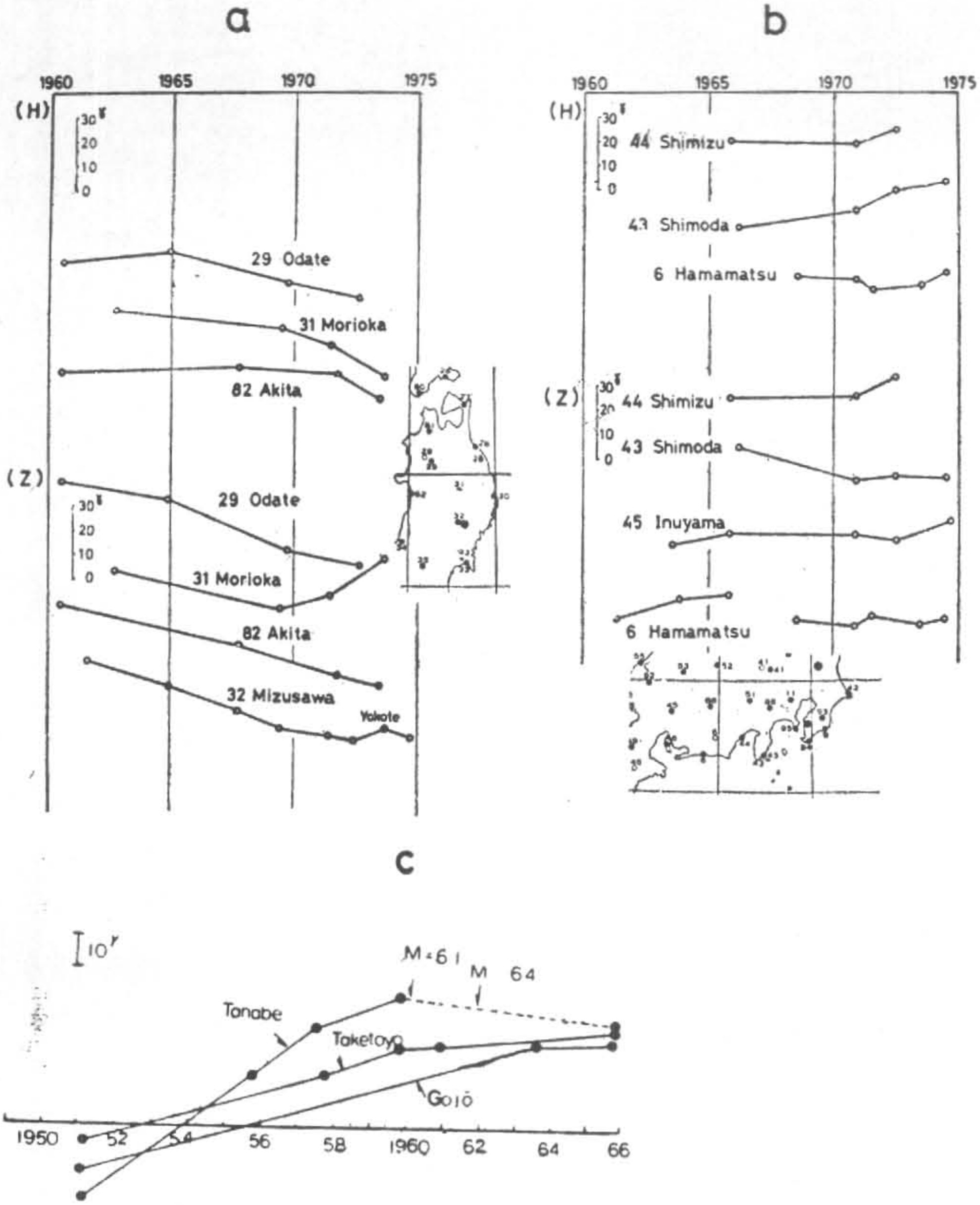

Fig. 1. Anomalous secular change in the vertical compo-nent, Z, of the geomagnetic field at (a) Morioka and (b) Shimoda in relation to neighbouring stations (*After* Tazima *et al.* 1976). Lower diagram (c) shows large secular change in horizontal component at Tanabe. Occurrences of two earthquakes in the vicinity of Tanabe are indicated in the figure along with their magnitudes (Tazima 1968).

neighbouring stations. In May 1974, an earthquake of magnitude 6.9 occurred off the Izu peninsula. Shimod station is located in the aftershock area, only a few kilometres away from the epicentre.

The lower graph in the Fig. 1 gives anomalously large secular variation in H at Tanabe on Kii peninsula of central Japan. It is apparent that the change in the horizontal intensity at Tanabe is anomalous compared to that at neighbouring stations, which are several tens of kilometres distant from Tanabe. It is interesting to note that the anomalous change seemed to vanish after the earthquakes of magnitude 6.1 and 6.4 that occurred near Tanabe in 1960 and 1961. An anomalously large rate of secular variation in the horizontal intensity observed at Tanabe in the 1950's might be a precursory change in the geomagnetic field.

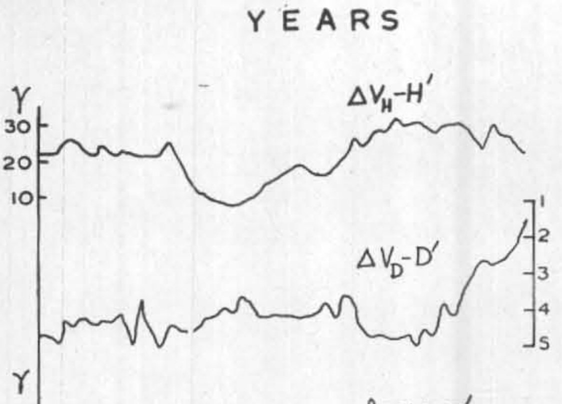

Fig. 2. The anomalous behaviour of the secular change in the three geomagnetic elements in relation to seismic activity at Tbilisi (*After* Nodia *et al.* 1968).

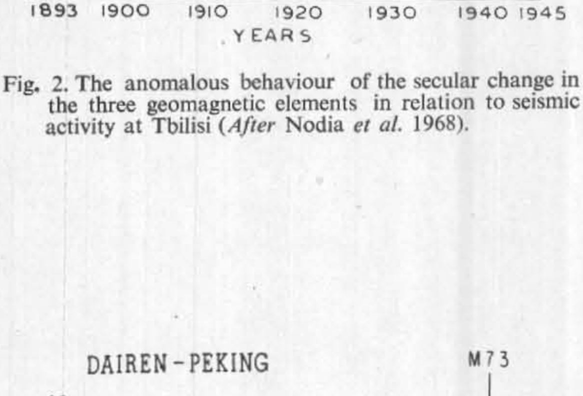

Fig. 3. The difference between monthly averages of the magnetic field measured at Dairen and Peking; *G F, H* and *Z* are total, horizontal and vertical fields, respectively. Dairen is 460 km from Peking and 235 km from the epicentre of the Haicheng earthquake (*After* Raleigh *et al.* 1977)

Fig. 2 gives another example of the anomalous behaviour of the secular change in relation to seismic activity at Tbilisi in U.S.S.R. Top three curves give the fluctuations of secular variation in the three geomagnetic elements *H, D* and *Z* obtained after eliminating the effects of regular secular variation as well as the changes determined by solar activity. Fluctuations so obtained can be associated with factors in peripheral parts of the earth's crust. Fourth curve in the figure gives the annual numbers of earthquakes in the vicinity of Tbilisi observatory. Vertical lines represent years with destructive earthquakes in the Caucasus. A comparison of the magnetic data with the seismic curve and the years of destructive earthquakes shows that among the magnetic data, *Z* curve correlates best with the seismic data. This is quite natural if we consider the closer relationship between the variations of the vertical component and local geology. A detailed comparison of the *Z* fluctuation curve with the seismic data shows that the maximum on the seismic curve approximately corresponds to the maxima or minima on the magnetic curve.

3. Fig. 3 probably gives the sole example where a geomagnetic field change was used in predicting earthquake in China. Here the differences between the monthly averages of magnetic field measured at Dairn and Peking were computed for the three geomagnetic elements *H, Z* and *F*. The two stations are separated by about 460 km. As a consequence large portion of variation associated with ionospheric and magnetospheric sources are eliminated. These difference curves revealed about 15-20γ change between October 1973 to May 1974. The changes in *H* and *Z* are of opposite sign. Based on this 20γ change in the vertical component it was predicted at the State Seismological Bureau Conference held in June 1974 that an earthquake of magnitude 5-6 might occur in the northern Pohai region within the next 1-2 years. The Haicheng earthquake of magnitude 7.3 occurred on 4 February 1975 about 8 months after the prediction.

In addition to the above measurements, magnetic field measurements were made at each of 19 stations in north China during the month of September 1974 and again in February-March 1975 after the Haicheng earthquake. The magnetic field values, two at all stations, relative to Peking were computed and finally from the differences between the February-March 1975 and September 1974 values, an anomaly map was drawn (shown in Fig. 4) and two anomalous regions were outlined, where the changes in excess of $\sim 6.5\gamma$ had occurred. The eastern anomaly is presumably related to the Haicheng earthquake.

4. According to American scientists this may be a peizomagnetic effect related to the co-seismic stress drop. However, Chinese expressed doubt as to whether an earthquake related stress drop would produce an appreciable peizomagnetic

effect change over so large an area. The western anomaly includes the site of Tangshan earthquake of magnitude 7.8 of 28 July 1976. In view of the proximity of Tangshan to reference station, Peking (150 km), it might be expected that Peking would be within the anomalous zone of earthquake of magnitude 7.8, and so it is not clear whether or not this anomaly constitutes a genuine earthquake precursor for Tangshan earthquake. But certainly it was identified prior to the earthquake. Wyss (1975) also observed a temporary decrease in the horizontal component before the Sitka as well as the Yakutat earthquake. The decrease was noted to be about 20 γ and it started 7.5 years before the earthquake.

5. With these observed facts in mind, we have tried to examine whether there was any geomagnetic field change prior to or accompanying Koyna earthquake of 11 December 1967. For this purpose the monthly mean values of H and Z at two observatories namely Alibag and Hyderabad are freed from the regular secular variation. Regular secular variation was estimated by fitting a second degree curve to the night time monthly values. From these secular free monthly values, regular seasonal variations were removed by the application of suitable digital filter and then the differences between Alibag and Hyderabad values were computed. These are shown in Fig. 5. The figure shows that in the case of H, the difference between ALB and HYD values which were continuously decreasing, started increasing about 3-4 months before the earthquake. At the same time, in Z the trends are reversed, *i.e.*, field which was increasing started decreasing about 5-6 months before the occurrence of the earthquake. The important feature of this curve is that signature of changes are opposite to that observed before the Haicheng earthquake of China, but nevertheless changes in H and Z difference curves are opposite, as observed for Chinese earthquake.

6. Much effort has also been put in detecting precursory or spontaneous seismomagnetic effects from the daily or still shorter period averaged field values. Since such values are seriously affected by transient geomagnetic variation, the most common technique to isolate seismomagnetic effect involves finding differences between the simultaneously made measurements at pairs of stations separated by less than few tens of kilometres. Johnston *et al.* (1976) have carried out many magnetic array studies along the San Andreas fault in California. In one of the surveys during which seven station magnetometer array was continuously operating, a significant increase of 2γ was observed about a month before the largest earthquake that occurred in this region during the period of survey, *i.e.*, January 1974 to September 1975, *i.e.*, the earthquake of magnitude 5.6 near Hollister. Coe (1971) from China reported that difference in the vertical intensity between Peking and Hongshan near Hsingtai sometimes decreased by 2γ four to five days before an earthquake of magnitude three or larger near Hongshan. The decrease appears to recover two days prior to the earthquake.

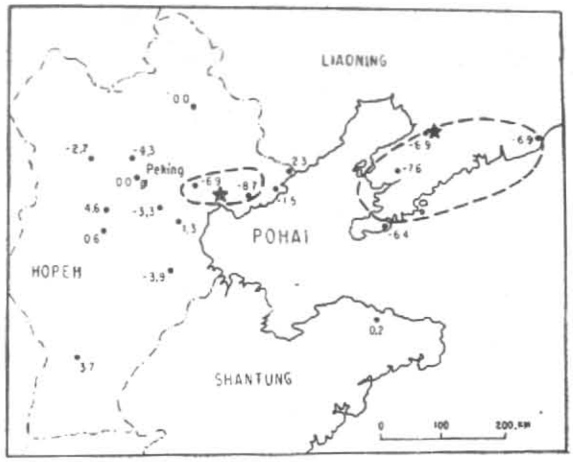

Fig. 4. Change in the monthly averages of the vertical component of the magnetic field measured in relation to Peking between September 1974 and February-March 1975. The changes are measured in gammas The epicentres of the Tangshan and Haicheng earthquakes are indicated by stars (*After* Raleigh *et al.* 1977)

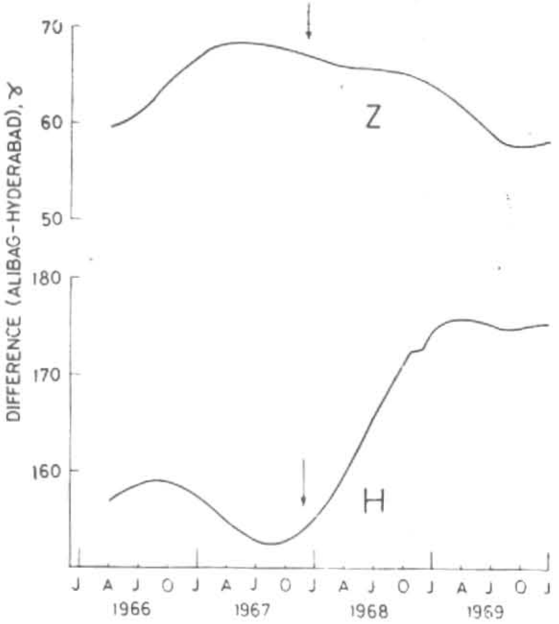

Fig. 5. The difference between monthly averages (corrected for regular secular and seasonal variations) of the magnetic field at Alibag and Hyderabad for the horizontal and vertical intensities, H and Z respectively.

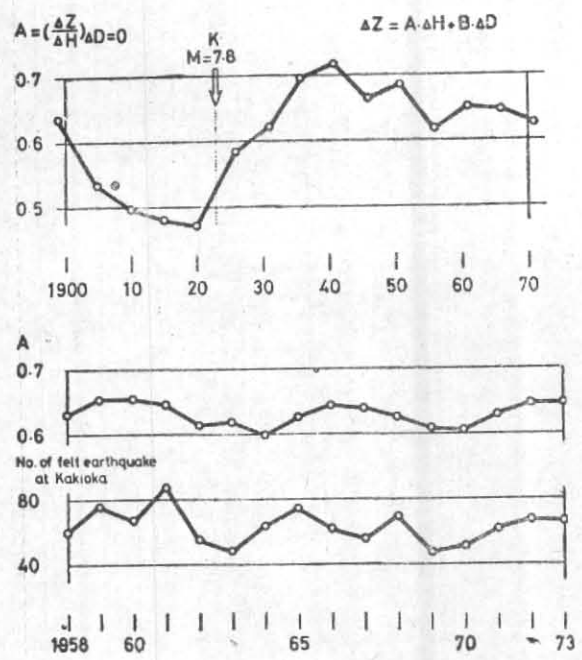

Fig. 6. Time changes of *A*-value at Tokyo (1897-1912 and Kakioka (1913-1973) : (*After* Yanagihara and Nagano 1976)

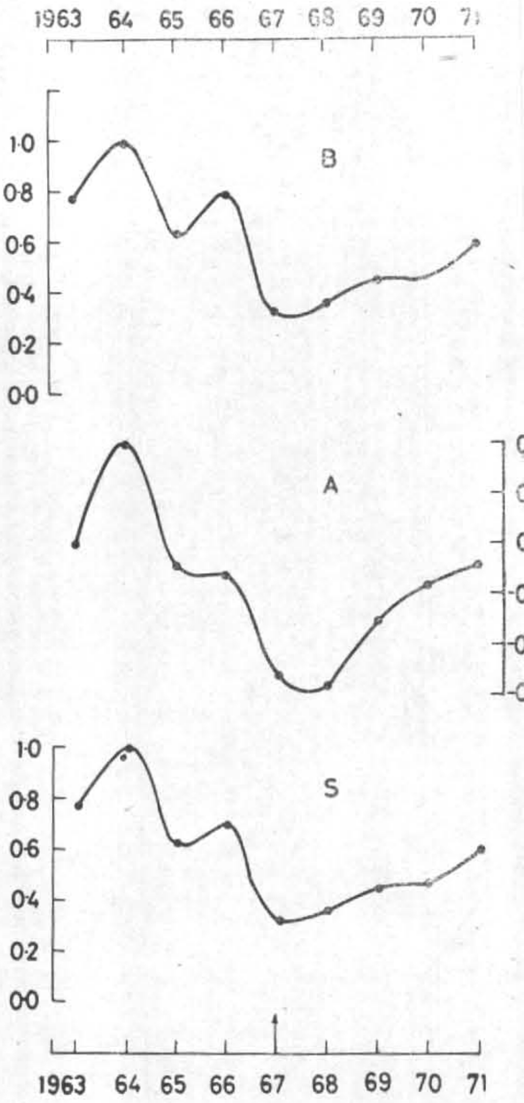

Fig. 7. Temporal changes in the transfer functions *A* and *B* as well as changes in the magnitude of the induction vector, *S*, for magnetic bays at Alibag during the period 1963 to 1971.

7. In addition to this earthquake associated changes of main magnetic field of internal origin, efforts have been also made to see the behaviour of other transient variations of external origin, because the varying field of this external sources gives rise to induced currents within the earth and both contribute to the geomagnetic field as observed at the earth's surface. The contributions from induced internal currents are quite significant for short period fluctuations. Since these currents flow mostly in crust or upper mantle where lateral contrasts in conductivity do exist, the anomalies in short period variations are widely used in the study of conductivity distributions. The Z component of the field variations is the most sensitive indicator of conductivity anomaly and using this property two indices have been adopted for earthquake prediction. Some authors calculate the variation with time of the $\triangle Z/\triangle H$ ratio and others use the length of the induction vector or its variant, the transfer functions *A* and *B*. The difference in the two approaches is more a matter of detail rather than physical. Yanagihara (1972) observed that the $\triangle Z/\triangle H$ ratio for magnetic bays at Kakioka took a minimum value three years before the great 1923 Kanto earthquake of magnitude 7.9 (Fig. 6a). The observatory was approximately located at a distance of 150 km from the affected area. The ratio recovered subsequently to its initial value. Later, Yanagihara and Nagano (1976) computed the annual values of transfer function *A* during the period 1958-1973 and found a cyclic change which appears to have some resemblance with the trend of the occurrence frequency of earthquakes felt at Kakioka. At Tashkent also a similar change has been observed. Miyakoshi (1975) found the induction vector for SSC's and SI's to increase in magnitude from 0.30 to 0.45 about two years prior to the 1966 Tashkent earthquake of magnitude 5.5. Here again the vector recovered to its original length after the earthquake. More quantitative measurements in terms of variations in apparent resistivity preceding earthquakes have been observed by Barsukov (1972) in the Garm region, U.S.S.R. and by Mazella and Morrison (1974) in the San Andreas Fault region, U.S.A. Honkura (1976) mentions that changes in resistivity measured by telluric methods cannot be used to predict deep earthquakes. However, the changes in magnetic field might be useful for the latter.

8. The changes noted above in the features of transient magnetic variations can be explained in terms of dilatancy models according to which a change in the electrical conductivity in the focal regions of forthcoming earthquakes occurs as a result of water diffusion into newly created cracks in the dilatant region (Rikitake 1976). Laboratory experiments on rock specimens saturated with water indicate a decrease in the resistivity by a factor of several to ten over a stress range near the rupture. Such a large conductivity will definitely modify the transfer function of short period geomagnetic variations. The transfer functions A and B are defined through the equation :

$$\triangle \mathcal{Z} = A \triangle H + B \triangle D \qquad (1)$$

where $\triangle H$, $\triangle D$ and $\triangle \mathcal{Z}$ are variations in the H, D and $\mathcal{Z}$ component of the earth's magnetic field. These transfer functions are good signatures of perturbations in internal current systems and thus it should be possible to detect changes in dilatancy through variations with time of A and B. Rikitake (1976) on theoretical considerations has shown that magnetic observations of micropulsations, SSC's, SI's and other short period variations can be used to predict the time of occurrence of earthquakes.

In this work we have tried to further test the above hypothesis with the Indian magnetic data. We have used geomagnetic bays data of Alibag, a station close to the Koyna region. The variations $\triangle H$, $\triangle D$ and $\triangle \mathcal{Z}$ were scaled directly from magnetograms for geomagnetic bays. In writing equation (1) it has been tactily assumed that whole of $\triangle \mathcal{Z}$ is of internal origin. No doubt this is a good approximation for the latitude of Alibag, still it will be more accurate to use records of more than ten events and then estimate A and B from the method of least squares. One would not expect the effect of external currents to be same for all the events and hence their contribution, if any, would be washed on taking the average over large number of events. The transfer functions A and B and the induction vector :

$$S = \sqrt{(A)^2 + (B)^2}$$

were calculated for each year for the period 1963-1971. The results are shown in Fig. 7. The coefficients A and B and as such S as well have been steadily decreasing until 1967 and after that their values started increasing again. The minimum in 1967 coincided with the year of the Koyna earthquake. Whether the undulation seen in 1965 is a precursor to earthquake is not clear. It will need further analysis. Probably similar anlaysis using data of a station sufficiently far from the earthquake area may indicate whether the undulation around 1965 is related to the earthquake of 1967 or not.

9. Our results, both the decrease in H and the variations in A and B, have clearly established that geomagnetic records of Alibag can be used as precursors to earthquake prediction for the Koyna area. However, at this stage it cannot be said definitely whether the changes noted here are due to pizeomagnetic effect or due to water diffusion into newly created cracks in the dilatant region. The directional anomaly as manifested through the variations in A and B could also be connected to anisotropy of the pizeomagnetic effect. It has been observed that the application of a stress to a rock does give rise to magnetic directional changes. The Koyna area seems to be a good area to understand many of the processes of geodynamics.

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