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Geomagnetic Disturbances

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With knowledge gained by satellite and space probe measurements substantial progress has been made in the understanding of geomagnetic disturbances. Much of the advancement in this field in the past three years probably results from our recognition of the importance of the magnetosphere in the interpretation of geomagnetic disturbances. In earlier years, energy sources of geomagnetic disturbances supplied by the Sun were thought to have their influences on the geomagnetic field almost directly without intermediate interactions in the magnetosphere.

The magnetic measurements made with instruments aboard Pioneer 1 [*Sonnett et al.*, 1960], Pioneer 5 [*Coleman et al.*, 1960], Explorer 10 [*Heppner et al.*, 1963], and Explorer 12 [*Cahill and Amazeen*, 1963] indicate that steady solar wind causes the Earth's magnetic field to be confined in a cavity carved in the streaming solar plasma. At the subsolar point the interface between the magnetosphere and the solar plasma is situated at a geocentric distance of about 10 Earth radii. Within this interface the magnetic field is relatively quiet. In the region of thickness approximately 20,000 km outside the interface the magnetic field is irregular. Beyond this disturbed region the magnetic field is weak and less irregular.

According to the observations made by Explorer 10, the magnetospheric boundary on the dark side of the Earth appears to extend to 20 Earth radii or to even greater distances [*Heppner et al.*, 1963].

The plasma measurement made with Mariner 2 by *Neugebauer and Snyder* [1962] established the existence of a steady flow of plasma from the Sun.

Coleman et al. [1960] observed an interplanetary magnetic storm by Pioneer 5 and related it to a magnetic storm observed on the Earth's surface.

Kellogg [1962] examined possible consequences of supersonic solar wind around the Earth and interpreted the outer boundary of the disturbed region outside the quiet magnetosphere as a shock front.

Dessler [1961, 1962] discussed the stable features of the cavity surface and suggested that the geomagnetic K_p index may represent a measure of the time rate of change of the combination of plasma and magnetic pressure on the magnetosphere rather than the solar wind strength itself.

The shape of the magnetospheric boundary has been the subject of intensive theoretical study by a number of workers including *Beard* [1960, 1962*a*, 1962*b*], *Hurley* [1961], *Midgley and Davis* [1962], *Slutz* [1962], *Spreiter and Briggs* [1962*a*, 1962*b*], and *Mead* [1962]. But the idealizations and approximations made in these studies probably limit their application to the equatorial to moderate latitudes. The shape of the magnetospheric boundary in high latitudes and over the poles remains unexplored both experimentally and theoretically.

The sudden commencement of a magnetic storm can be interpreted as the effect of the impact of a solar plasma stream upon the magnetosphere. *Dessler, Francis, and Parker* [1960] interpreted the relatively slow buildup of sudden commencements, as indicated by their rise time of several minutes, to be caused by the cumulative effect of hydromagnetic waves generated by the abrupt solar plasma impact arriving with varying transit times from different positions on the magnetospheric boundary to a point on the Earth's surface.

Wilson and Sugiura [1961] made an extensive morphological study of the sudden commencement of magnetic storms and presented a model for the sudden commencement. According to their model, the solar plasma impact on the magnetosphere generates compressional hy-

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dromagnetic waves which propagate to the Earth in low latitudes; while traveling through the outer regions of the magnetosphere the compressional hydromagnetic waves generate transverse hydromagnetic waves that propagate along the lines of magnetic force to the polar regions in the northern and southern hemispheres.

On the basis of the distribution of oppositely polarized sudden commencements *Wilson* [1962] determined the streaming direction of the storm producing solar plasma.

Akasofu and Chapman [1960] reviewed the studies made on the sudden commencement of magnetic storms and suggested that part of the sudden commencement field variations originates in the polar regions.

Matsushita [1960] analyzed the sudden commencement of magnetic storms observed during the IGY using data from the U.S. magnetic stations. *Matsushita* [1962] investigated sudden commencements, sudden impulses, and storm durations.

Vestine and Kern [1962] attributed the preliminary reverse impulse of the storm sudden commencement to the effect of electric currents driven in the ionosphere by a charge distribution in the polar regions; they discussed how such a charge distribution may be produced by distortions of the magnetosphere by a solar stream.

From investigations of a ring current that would produce the decrease of the magnetic field during the main phase of a magnetic storm, *Akasofu* [1960*a*] analyzed two large magnetic storms that occurred during the IGY.

Akasofu and Chapman [1961] proposed a model radiation belt responsible for the ring current; in their view protons of energies of the order of a few hundred kev are intermittently captured between 5 and 8 Earth radii during a magnetic storm, forming a transient belt. *Akasofu, Cain, and Chapman* [1961] computed the magnetic field decrease due to the proposed ring current.

Beard [1962*b*] and *Akasofu* [1962] discussed self-consistent calculations of the ring current.

Dessler, Hanson, and Parker [1961] suggested that hydromagnetic waves generated by the impact of solar plasma on the geomagnetic field may form shock waves in the magnetosphere which may heat the ambient protons to produce a diamagnetic ring current.

The observations by satellites and space probes have so far been limited to high-energy particles, and direct observational verification of the ring current has not yet been made.

Akasofu and Chapman [1963] examined the development of the main phase of magnetic storms by studying individual storms and showed that there are different types of magnetic storms. More studies of individual storms are needed to supplement studies of the average morphology of magnetic storms, as made by *Sugiura and Chapman* [1960].

Akasofu [1960*b*] studied large-scale auroral motions and polar magnetic disturbances, referring to the magnetic and auroral events of September 23, 1957.

Akasofu and Chapman [1962] discussed the ring current and the aurora on the basis of their neutral line discharge theory.

Kern [1961] discussed the distortion of the geomagnetic field by a solar stream and suggested that this distortion may produce auroral electrojets.

Investigation of geomagnetic micropulsations has greatly expanded during the period covered by this report. Workers at Lockheed Aircraft Corporation, National Bureau of Standards, University of Alaska, University of Texas, Air Force Cambridge Research Laboratories, U.S. Army Signal Research and Development Laboratory, California Institute of Technology, Lamont Geological Observatory, and others have contributed to progress in this field.

Campbell and his collaborators studied micropulsation activity in Alaska in relation to other disturbance phenomena [*Campbell and Leinbach*, 1961; *Campbell and Rees*, 1961; *Campbell*, 1962].

Tepley [1961] and *Tepley and Wentworth* [1962] observed hydromagnetic emissions, and *Wentworth and Tepley* [1962] discussed a possible mechanism for hydromagnetic emissions by electron bunches.

Sugiura [1961] presented examples of low-frequency transverse hydromagnetic waves generated in the magnetosphere and transmitted to the auroral zones along the lines of magnetic force.

Phenomena observed simultaneously at magnetically conjugate areas have attracted much attention in the past few years. Using the records from Macquarie Island and the Alaskan

IGY stations, *Wescott* [1961] showed that in magnetically conjugate areas magnetic variations are remarkably similar. *Mather and Wescott* [1962] investigated Earth current records from a New Zealand–Alaska conjugate pair and found that major disturbances occur simultaneously.

Magnetic observations at a pair of conjugate areas have also been conducted by the National Bureau of Standards; their stations were in Eights, Antarctica, and in Quebec, Canada. Campbell and his collaborators made simultaneous observations of micropulsations at College and Macquarie Island. Other experiments are now being conducted.

In conclusion, the research activities in geomagnetic disturbances have considerably expanded in scope during the past three years, and many fruitful studies have been made with good results.

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