A LUNAR SIGNATURE IN THE GEOMAGNETIC Ap-INDEX*

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Abstract. A study has been performed in an effort to detect a lunar signature in geomagnetic data. Ap-indices available for the period 1932–1972 have been used for this purpose. The data have been divided into some 500 lunar months which were superimposed in synchronism with the phase of the Moon. At or shortly after full Moon a peak appears which exceeds the average value by about 3 standard deviations. Possible explanations for the generation of geomagnetic disturbances by the Moon are given.

A great number of studies have been carried out in the past to decide whether or not a relationship exists between geomagnetic disturbances observed at the surface of the Earth and the phase of the Moon. A critical review by Schneider (1967) of the previous work done in this field led to the conclusion that the statistical volume of data was still too small to bring the noise level down low enough for a lunar signature to become detectable in the geomagnetic activity.

The dynamics of the Earth's magnetosphere are almost entirely controlled by its interaction with the solar wind. The dependence between the degree of solar and geomagnetic activity is therefore very pronounced, as is to be expected. By nature of its size, the Moon's direct interaction with the magnetosphere cannot be expected to have a major influence on magnetospheric processes. Figure 1 shows the relative geometry of the Earth's magnetosphere and the orbit of the Moon. The Moon spends about 90% of its orbital period in interplanetary space. It enters the magnetotail of the Earth for a few days every month around full Moon.

There are several ways in which the Moon may impress its signature on geomagnetic data. When the Moon is outside but close to the magnetosphere, its wake may interact with the magnetopause, thereby causing disturbances within the magnetosphere. Inside the magnetosphere, in particular at times of low lunar ecliptic latitudes, the Moon will encounter the magnetospheric plasma sheet, a region of fairly hot plasma which has been observed out to distances of 60 Earth radii in the magnetotail (Nishida and Lyon, 1972; Rich *et al.*, 1973).

The Moon's major influence on the terrestrial environment is due to gravity forces which cause the well known diurnal tidal effects in the ionized upper atmosphere and these, in turn, produce currents in the lower ionosphere. These currents are reflected in magnetometer recordings on the ground (Gupta, 1974). Lunar tidal effects are best analysed by studying the daily variations in the geomagnetic recordings. On the other hand lunar interactions with the more distant magnetosphere are expected to show up

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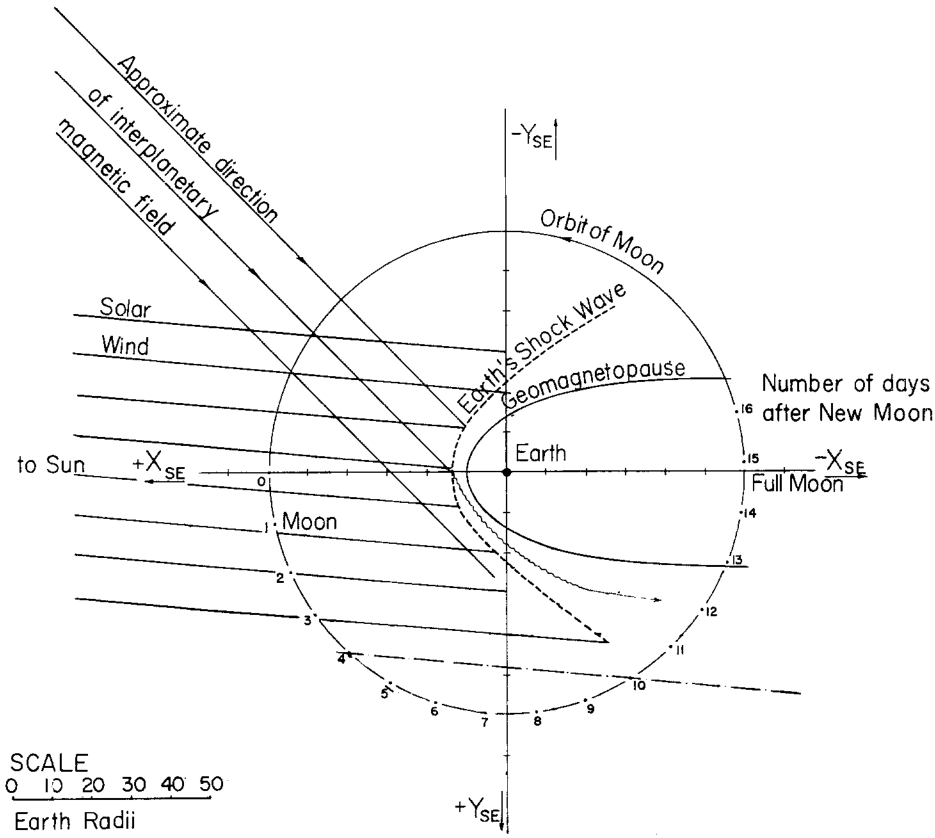

Fig. 1. Relative geometry of the lunar orbit and the Earth's magnetosphere (from Schneider, 1967).

more clearly when magnetic parameters are studied as a function of the phase of the Moon.

To detect lunar magnetosphere interactions an attempt has been made in the present study to establish a relationship between the magnetic Ap-index (Rostoker, 1972) and the transition of the Moon through the magnetosphere which occurs once per lunar month around the time of full Moon. The Ap-index describes on an approximately linear scale the general state of planetary geomagnetic activity. It contains contributions from at least two major sources – the auroral electrojet and the ring current. Daily Ap-values from 1932 until 1972 compiled by Lenhart (1968) were used in the analysis. These data cover about 4 solar cycles – namely, cycles 17, 18, 19 and 20 – which had varying degrees of solar activity.

The interval from 1932 to 1972 has been subdivided into lunar months with the day of full Moon at the mid-point of these months. Ap-indices of corresponding days in various lunar months have been summed. This superposition which is in phase with the lunar motion around the Earth results in epochal histograms. It is expected that solar influences – although predominant in intensity and often repeated with the solar rotation period of 27 days which is close to that of the lunar period – will average out in such diagrams if a sufficiently large number of lunar cycles is used. This follows from the fact that solar events occur at random during a lunar month and no fixed phase relationship to the lunar phase exists.

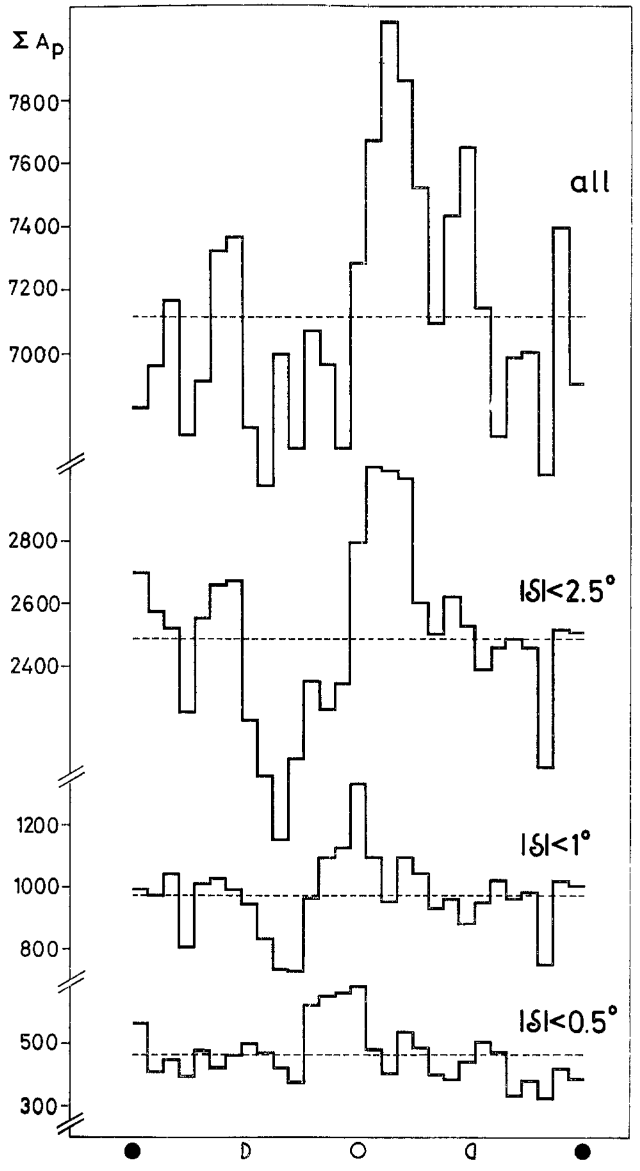

Fig. 2. Histograms of geomagnetic Ap-index covering lunar months from 1932 until 1972 for different lunar ecliptic latitudes.

It has been argued in the past (Michel *et al.*, 1964) that an index on a logarithmic scale, such as Kp, may be more appropriate to detect a weak lunar signal within the dominating solar events. However, as Rostoker (1972) points out, the summation of Kp indices, which is in fact what is performed in their analysis, should be treated with caution since the addition of such quasi-logarithmic qualities can provide misleading results. It is for this reason that Ap rather than Kp has been selected in the present study.

Figure 2 shows epochal histograms for different ranges of lunar ecliptic latitudes. The upper plot includes all lunar months from 1932 until 1972; the second only those where the lunar ecliptic latitude was less than 2.5°, etc. Plotted along the vertical axis is the sum of the applicable Ap-indices. Full Moon always occurs in the middle of the diagrams. The dashed lines give the average level for each histogram.

A peak well above the remaining statistical variations appears in all cases near full Moon, that is at the time when the Moon sweeps through the magnetosphere. For low lunar ecliptic latitudes the peak occurs at or shortly before the day of full Moon; when higher latitudes are included the peak seems to shift to a few days after full Moon. In all cases the peak exceeds the average level by 2-3 standard deviations.

It appears that the lunar signature in the various histograms is most pronounced for low lunar ecliptic latitudes. However, the relatively short time that the Moon spends at low ecliptic latitudes limits the number of months which can be used to study this effect. In fact, the clear appearance of a peak for low latitudes is most remarkable, given the few months which have been superimposed. The peak near full Moon is most pronounced in the histogram covering lunar ecliptic latitudes less than 2.5° as this seems to be the best compromise between poor statistics and low ecliptic latitude.

Although a prominent peak near full Moon exists in the histogram covering the last four decades, the peak is less evident when the data are split up in individual histograms for the last four solar cycles. This is shown in Figure 3 which like all subsequent diagrams contains data for ecliptic latitudes less than 2.5°. Considering each histogram individually it would be difficult to claim a clear relationship between geomagnetic activity and the lunar age. The period of 11 years is obviously too short to average out the effect of a very strong geomagnetic storm which occurs independent of the position of the Moon and is triggered by a strong eruption on the Sun.

One very striking feature which has been discovered during the course of this study is the apparent lack of a lunar signature in a histogram which covers positive lunar ecliptic latitudes only, and a very prominent peak in a histogram for negative latitudes. This is shown in Figure 4. The lower part of this figure is a superposition of all lunar months with positive lunar ecliptic latitude, that is of all months when the Moon sweeps through the northern part of the magnetosphere. The upper part of the figure shows a histogram for lunar encounters of the southern half of the magnetosphere. This effect is clearly seen even when the data have been split up into different solar cycles. In Figure 5 the result is shown for positive latitudes only. Clearly none of the four diagrams suggests any relationship between geomagnetic activity and the age of the Moon.

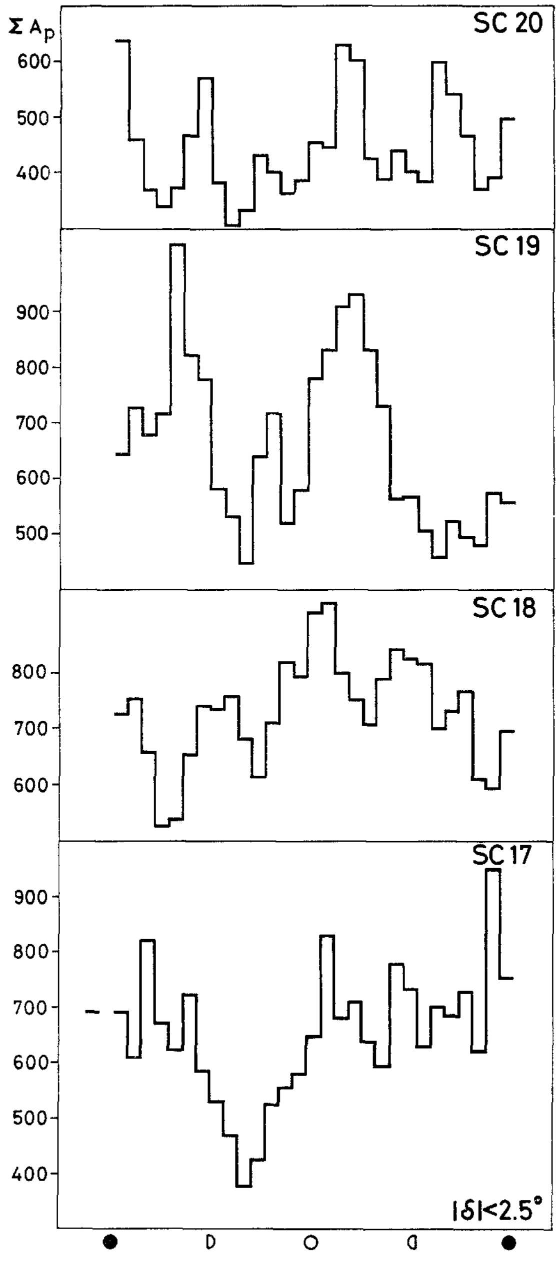

Fig. 3. Histograms of geomagnetic Ap-index for lunar ecliptic latitudes less than 2.5° for different solar cycles (time interval 1932–1972).

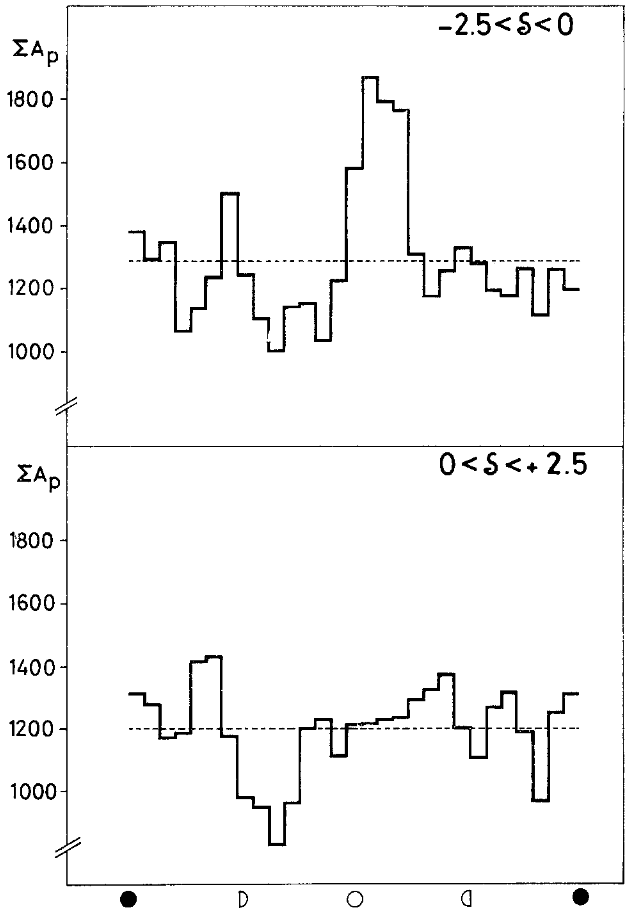

Fig. 4. Histograms of geomagnetic Ap-index for lunar ecliptic latitudes $-2.5° < \delta < 0$ (southern) and $0 < \delta < 2.5°$ (northern latitudes)

In contrast the same histograms for negative ecliptic latitudes are shown in Figure 6. Practically all histograms show a peak around full Moon. The content of Figures 4, 5 and 6 clearly suggests that a signature of the Moon in geomagnetic data appears primarily for negative lunar ecliptic latitudes, that is for transitions of the Moon through the southern half of the geomagnetic tail.

For the interpretation of the results presented so far, the reader is referred back to Figure 2. A shift of the lunar peak from just before full Moon to just after occurs if larger ecliptic latitudes are considered. The peak for $\delta < 0.5°$ occurs when the Moon is in the very centre of the geomagnetic tail. This location deviates from the Earth–Sun line because of the aberration of the solar wind arrival from this line (see Figure 1). This geometry suggests that the peak at low ecliptic latitudes may be caused by the lunar encounter of the plasma sheet in the magnetotail.

In this region the Moon can act as a sink for energetic electrons and as a source for cold photoelectrons. The mechanism invoked at the illuminated front surface of the Moon is the following. The photocurrent released from the lunar surface is much larger than the plasma current impinging on it (Feuerbacher *et al.*, 1972). Moderate positive charging of the lunar surface prevents most photoelectrons from escaping and a quasistationary layer of photoelectrons is formed. Every high energy plasma electron which impinges and is absorbed at the surface, effects the release of a low energy photoelectron from the stationary layer. By balancing the inward plasma current and the outward photocurrent and using characteristic energies, a high energy electron population of low density is transferred into a low energy electron population of high density. It has been noted by Brice (1970), for example, that cold electron injection into a hot

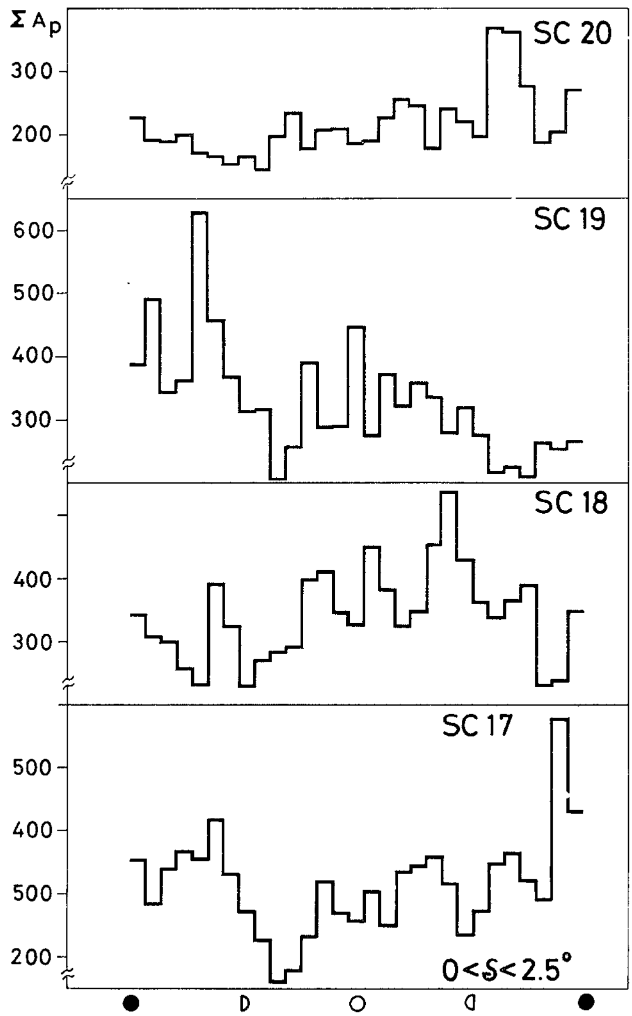

Fig. 5. Lower histogram of Figure 4 ($0 < \delta < 2.5°$) split up into different solar cycles.

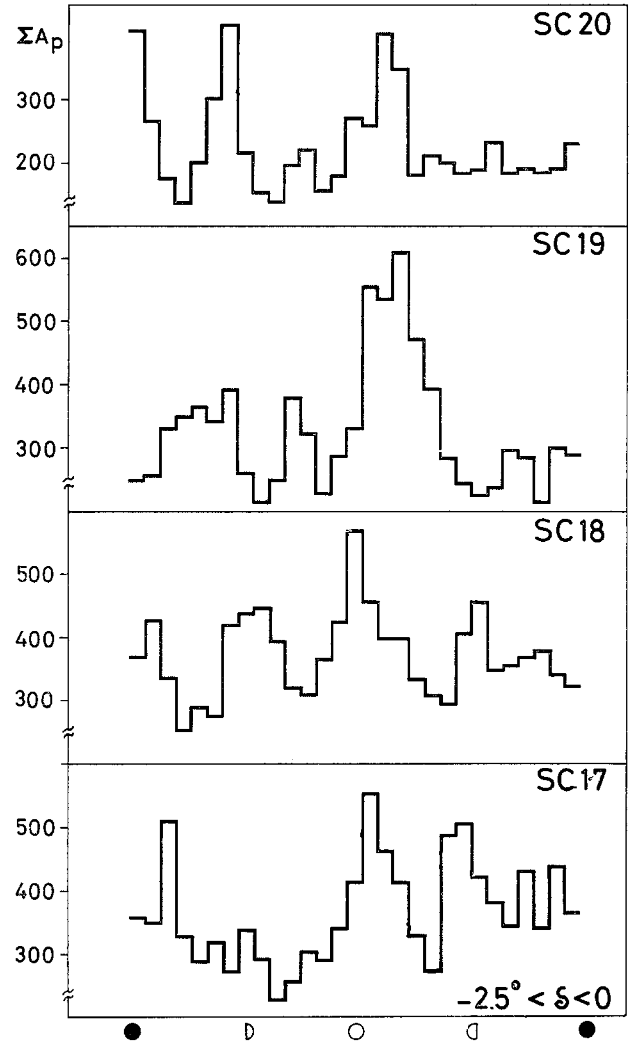

Fig. 6. Upper histogram of Figure 4 ($-2.5° < \delta < 0$) split up into different solar cycles.

plasma will lead to instabilities and may on a magnetospheric scale be used to seed substorms.

The second process which impresses a lunar signature on geomagnetic data must be sought for a few days after full Moon, at the time when the Moon traverses the dawn magnetopause. A shift of the maximum in the lunar histograms a few days away from full Moon was already noted in a previous study by Guez (1966). Remarkably enough, no such enhancement is observed during lunar encounter of the dusk magnetopause. On the contrary, it appears that a decrease in geomagnetic activity can be associated with that phase of the Moon.

An asymmetry in terms of disturbance between the dawn and dusk magnetopause has been reported by Howe and Siscoe (1972) on the basis of their Explorer 35 plasma measurements. It appears in general that the dawn side of the magnetopause somehow interacts more strongly with the solar wind than the dusk side. It seems, however, difficult to decide whether enhanced reconnection or diffusive or viscous interaction is taking place. The results of the present study suggest that the Moon amplifies any such process. If the ecliptic north–south asymmetry in the lunar signature is accepted as a valid and not just an incidental feature, we may have a clue to the interaction process at the dawn side of the magnetopause.

A comparison of the results of previous work, which was mainly based on Kp-indices, with the results of the present study, which is based on Ap-indices, leads to the following conclusions:

(1) Epochal histograms using Ap-indices over the period 1932–1972 show a peak around full Moon. This peak has a statistical significance of 2–3 standard deviations and becomes even more pronounced if the ecliptic latitude of the Moon is narrowed down.

(2) Studies based on Kp-indices over similar periods – although carried out frequently and in great depth – did not establish a lunar influence on geomagnetic activity (see the review paper by Schneider (1967) which summarized all previous work).

(3) In this situation the suitability of a logarithmic or linear index must be considered and it must be realised that

(a) a logarithmic compressed index is more suitable if larger spikes in the noise must be damped out.

(b) a linear scale is more appropriate if small differences in strong signals are to be brought out more clearly.

(4) The appearance of a lunar signature in the histograms based on Ap seems to favour the latter hypothesis and leads to the final statement:

(5) When inside or close to the magnetotail, the Moon may act as a catalyst or weak amplifier of geomagnetic disturbances which originate from the Sun.

Acknowledgement

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