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THE LUNAR PERIOD, THE SOLAR PERIOD AND K_p

by

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Thesis Director's signature:

A handwritten signature in dark ink, which appears to read "A. J. Dessler", is written over a horizontal line.

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I. Introduction

Throughout recorded history, men have sought relations between astronomical objects and events on the Earth. Many of the proposed relations are commonly discredited today, such as those of astrology, whereas others, like the tides, are very definitely present. In 1963, another such influence was proposed by Bigg [1963a].

In that paper, Bigg proposed that the frequency of magnetic storms was somewhat greater during the first and third quarters of the moon and significantly smaller at new moon. This study was based on several hundred magnetic storms recorded at Greenwich over the period 1874-1954. In a sequel to that paper, Bigg [1963b] proposed that Venus, Mercury, and Mars also have an influence on geomagnetic storms, and that the lunar sidereal period might be more significant than the lunar synodic period in the frequency of magnetic storms.

These two papers by Bigg were followed by two by J. Bartels [1963a, 1963b], who challenged Bigg's hypothesis. Bartels calculated the frequency with which ΣK_p * exceeded 30 during each phase of the

* K_p is an index of planetary geomagnetic activity calculated for every 3-hour interval throughout the day. It is a weighted average of the 3-hour K values for a large number of magnetic observatories. These K values are obtained by scaling the largest variation observed in any component of the magnetic field at a given station during the 3 hours under question. The scale used is different for each station and is a strong function of latitude. The K values range from 0 (very little variation) to 9 (extreme variation); the K_p values cover the same range, but with the added resolution of a + or a - (i.e. 0, 0+, 1-, 1) equally spaced between two integers. K_p data is available for every year since 1932. The sum of the 8 K_p values for a given day is frequently used and is written ΣK_p .

ABSTRACT

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In this paper, the apparent variation of geomagnetic activity with the phase of the Moon is analysed for statistical significance. An autocorrelation of K_p reveals strong peaks at 27 days, 54 days, and so on for about five solar "period" altogether. Because of this, the probable error of points calculated by the method of superimposed epochs for periods near 27 days is $1\frac{1}{2}$ to 2 times larger than would otherwise be expected. Thus, when the analysis allows for these solar peaks, the apparent variation of geomagnetic activity with lunar phase is well within the limits of chance. In addition, there are no autocorrelation peaks at the lunar period or any of its simple harmonics.

However, due to the various recurrence tendencies in geomagnetic activity, no simple statistical analysis can be expected to give very accurate results. Therefore, the K_p data is then analysed by the method of superimposed epochs for several hundred psuedo-lunar periods between 24 and 31 days. By several different measures of "uniqueness", there is the expected broad peak around 27 days, with a tail several days long, and, by all these tests, the lunar period is typical of periods about the same distance from the solar period. In fact, the "uniqueness" of the lunar period is shown to be within one deviation of the average "uniqueness" of the periods around it. One may then conclude that, in the light of these considerations, the available data do not indicate any lunar influence on geomagnetic activity.

moon, a method used by Bigg. He then executed a similar analysis of fictitious months with random starting dates. Bartels found that the variations of the real and random data were of similar magnitude, and therefore concluded that the lunar variation was random. He also subdivided the data and analysed each of the subdivisions. He found that the curves for each division were uncorrelated, implying that the hypothesized lunar effect was spurious.

These papers were followed in 1964 by a report by Bell and Defouw [1964] that the index of geomagnetic activity K_p showed a non-random decrease before full moon and an increase after. These authors did a superposed epoch analysis* of thirty years of K_p daily sums and of five-day running means of these sums. They also showed that the frequency of disturbed days ($\sum K_p \geq 25$) was less than average before full moon and greater after, whereas the frequency of quiet days reversed this pattern. Further, they showed that all values of $\sum K_p$ before full moon had systematically different frequencies from those after full moon, indicating that the difference in the averages was not the result of a few isolated high values of $\sum K_p$. Bell and Defouw also analysed K_p with respect to two types of divisions: a "random" division into lunar months depending on whether the tens digit of the Julian date of full moon was even or odd, and a division into months from various parts of the 11-year solar cycle. Neither of these divisions seemed to affect the variation,

* Superposed epoch analysis is a method of isolating periodic tendencies. In this method, points are averaged together which are in the same part of the cycle being examined. Thus, if we were to do a superposed epoch analysis of $\sum K_p$ at 25 days, we would average the points at 0, 25, 50 etc. days, and similarly those at 1, 26, 51 etc. days.

which those authors took to mean that the effect was not random, and that it was not appreciably affected by the solar cycle. Bell and Defouw found a dip near new moon, smaller than the variations at full moon, which led them to conclude that the variation observed by Bigg was spurious.

Later in 1964, two papers were published [Michel et al, 1964; and Davidson and Martyn, 1964] both of which concluded that the observed variation was within the limits of statistical error. The first of these groups did a superposed epoch analysis of thirty years of 3-hour K_p data for the lunar period and several arbitrary psuedo-lunar periods. Since all the psuedo-lunar periods showed similar degrees of variation to that of the moon, the researchers concluded that the lunar variation was random.

The second of these groups analysed the frequency of great magnetic storms occuring since 1774 with respect to lunar phase, and compared this distribution to that of a like number of random numbers between one and thirty. Since the variations in the frequency of the random numbers was much greater than that of the magnetic storms, it was concluded that the variation in the frequency of the storms was entirely random. Bigg [1964] replied that none of these tests of significance was powerful enough to exclude the possibility of a lunar influence on geomagnetic activity.

In the same issue of the Journal of Geophysical Research, Stolov and Cameron [1964] published a superposed epoch analysis of the percent deviation of the 3-hourly K_p 's from the average K_p

for that lunar month. They compared the excursion length and area* of this result to those of some randomized data. Using the frequency with which excursions of a given length or area occurred in the random data as a criterion, they then calculated the probability that the lunar curve might occur by chance. Both the excursion length and excursion area estimates of the probability for chance occurrence of the lunar curve were quite low, so Stolov and Cameron concluded that the lunar effect around full moon was real. Dividing the data between "disturbed" and "undisturbed" months, they found that the effect was apparently not present during disturbed times.

Stolov [1965] followed his original paper recently with another which analysed the data with respect to several divisions, the most important of which was a division by whether the moon was at a large or small distance from the ecliptic at full moon. He found the greatest variation when the moon was near or on the ecliptic, virtually no variation when the moon was far from the ecliptic, and intermediate variation when the moon was a moderate distance from the ecliptic. He further found that the distance of the moon from the earth at full moon did not seem to alter the effect.

A few months before the second of Stolov's papers was published, D. F. Martyn [1965] published a paper which, among other things, attacked the possibility of any significant lunar influence on geomagnetic activity. Martyn here analysed several statistical

* The excursion length and area are tests of significance which can be applied to any superposed epoch curve. The excursion length of a curve is the maximum length of any excursion to either side of the average of the curve. The excursion area is the maximum area of any excursion.

effects which would tend to make random variations seem real, and showed ways to eliminate them. One of these methods was the comparison of the variation for psuedo-periods to that for the actual period.

Bell and Defouw [1966] recently followed their first paper with another in which they analysed the data with respect to several divisions. This work was quite similar to Stolov's second paper, although somewhat more elaborate.

All this controversy is essentially based on the question of how large the random variation of K_p at the lunar period should be. Since the variance at the lunar period is only two to three times the probable error as calculated by the simple methods used so far, obviously a probable error only a little larger than currently indicated would remove the possibility of a statistically significant lunar variation.

One factor, largely disregarded in the literature, which is capable of enhancing the probable error is the similarity of the solar and lunar periods. Bigg [1963] and Bell and Defouw [1964], who felt there was a lunar effect, noted this similarity in periods but passed over it with only a superficial analysis, while others (Martyn [1965] and Michel et al [1964]) who feel the lunar variation to be spurious, mention the similarity without analyzing its effect in this specific case. It is the purpose of this paper to show, both by statistical methods and by analysis of psuedo-lunar periods, that this proximity of the lunar and solar periods is indeed

sufficient to account for the apparent dependence of K_p on the phase of the moon, and that any true lunar effect would be masked by solar noise.

It is well known that solar plasma strongly affects the earth's magnetic field: the K_p index is a measure of its effect. A quick glance through the musical diagrams of the last 30 years of K_p data reveals a strong eleven-year cycle, in phase with the solar cycle. Similarly, a cursory examination of these diagrams shows a strong 27-day recurrence tendency. In fact, this tendency is so strong that K_p diagrams are conventionally arranged in 27-day rows.

Since the solar rotation period is not well-defined, there is no precise "solar period" at which one might make a superposed epoch analysis of K_p . However, it is possible to autocorrelate* the K_p data and to measure the neight of the 27-day, 54-day, and other

*

The autocorrelation function of a time sequence of data points, as used here, is the correlation of pairs of points separated by a given lag, as a function of the lag. Thus if we have a set a_i containing N equally spaced points, their autocorrelation at lag ℓ is

$$\rho(\ell) = \frac{\sum_{i=1}^{N-\ell} (a_i - \bar{a}_0)(a_{i+\ell} - \bar{a}_\ell)}{\sqrt{\left\{ \sum_{i=1}^{N-\ell} (a_i - \bar{a}_0)^2 \right\} \left\{ \sum_{i=1}^{N-\ell} (a_{i+\ell} - \bar{a}_\ell)^2 \right\}}}$$

where

$$\bar{a}_\ell = \frac{\sum_{i=1}^{N-\ell} a_{i+\ell}}{N-\ell}$$

is the average of the points under consideration. The autocorrelation is a measure of periodic tendencies in the data even when these tendencies are not locked to a definite period but are spread over a range of frequencies.

peaks. This was done both for the 3-hour K_p 's and for the daily ΣK_p 's. The autocorrelation of the 3-hour K_p 's is plotted in Figure 1. It should be noted that the peaks tail off into noise at about 6 periods, and that the lunar period is well within the first solar peak.

It would seem likely that the proximity of the solar synodic rotation period to the lunar month should have some effect on what is seen at the latter. An autocorrelation of K_p shows strong peaks at 27, 54, and 81 days, and so on for several solar synodic periods, as shown in Figure 1. Therefore, since K_p tends to stay high or low for several days at a time, these first few solar peaks will correspond to almost the same point on a lunar period superposed epoch analysis. This means that successive points added together at some part of the month will not be independent, and the error in their sum will therefore be increased.

II. The Solar Effect at the Lunar Period

It would be quite remarkable if a superposed epoch average at the lunar period, or any other, showed no variation whatsoever. However, the question of whether such a variation is due to the moon or is random is difficult to resolve. If the observed variation is of the order of the expected random variation, then any lunar effect would be hopelessly buried in the random fluctuations, and further analysis would be pointless. Thus the crucial problem becomes testing the "significance" of the observed curve, or evaluating the expected random variation.

Three methods have been used to calculate an expected variation:

- (1) Simple statistical calculations [Bell and Defouw 1964, 1966],
- (2) Comparison with random or "randomized" data [Stolov and Cameron, 1964, Stolov, 1965; Davidson and Martyn, 1964], and,
- (3) Comparison with psuedo-lunar periods. [Michel et al, 1964; and Bartels 1963a, 1963b].

It is interesting to note that Bell and Defouw and Stolov and Cameron, whose analyses disregarded or destroyed any solar auto-correlation, have both come out in favor of a lunar effect, whereas Michel et al, whose analysis did not destroy the solar influence, believe the variation to be random. The method of comparison with psuedo-lunar periods is fully explained by its name, but it

would be appropriate to give an exact account of the other two methods.

Bell and Defouw worked with two different curves, the superposed epoch averages of ΣK_p and five-day running averages of this curve. On the first curve they assumed that the variance of the averages for a random curve, σ_1^2 , would be the variance of a single K_p point divided by the number of points averaged together:

$$\sigma_1^2 = \frac{\sigma^2}{N}$$

where σ^2 is the variance of the K_p daily sums, and N is the number of points averaged together. This is equivalent to assuming that there is no correlation (other than that caused by the moon) between the values of ΣK_p separated by 29.53 days. As can be seen in Figure 1, the point at 29.53 days falls well within the first solar peak. Similarly, Bell and Defouw's test of significance for the five-day running means of K_p was based on a standard error, σ_5^2 , of

$$\sigma_5^2 = \frac{\sigma^2}{nN} \left[1 + 2\rho_1 \left(\frac{4}{5}\right) + 2\rho_2 \left(\frac{3}{5}\right) \right]$$

where ρ_1 and ρ_2 are the one and two-day autocorrelations, respectively. As will be shown below, this is equivalent to assuming that the only non-zero values of the correlation are for lags of one and two days, whereas the full formula includes terms from the entire first solar auto-correlation peak and part of the second.

Stolov and Cameron's work also effectively ignored the solar effect, since their method of randomizing the data leads to curves whose random variation is not enhanced by the 27-day solar autocorrelation. These authors obtained 120 randomized curves by circularly shifting the 30 days centered on each full moon by a number of 3-hour intervals equal to $2 \times \langle \text{random analysis number} \rangle \times \langle \text{month number} \rangle$. Although for short shifts this is similar to the method of pseudo-lunar periods, as the shifts get longer it significantly mixes periods much longer than the lunar period with those much shorter. Also, the body of these randomized intervals correspond to pseudo-lunar periods distant from the three days or so to each side of the solar rotation "period" in which the solar effect is most significant. Thus the solar effect is submerged because the few curves where it is active are outnumbered by those in which it is nonexistent. These researchers, like Bell and Defouw, have analysed the data in such a manner as to disregard the solar enhancement of variation at the lunar period.

III. The Magnitude of the Solar Effect at 29.53 days

It is not particularly difficult to obtain numerical values for the solar enhancement of variance around the lunar period. From statistical theory, the expected variance of the sum of several quantities σ_{Σ}^2 is simply the sum of the entries in the covariance matrix between the quantities:

$$\sigma_{\Sigma}^2 = \sum_i \sum_j \sigma_{ij}$$

where σ_{ij} is the covariance between variable i and variable j .

$$\sigma_{ij} = \sum_{k=1}^M (a_i(k) - \langle a_i \rangle) (a_j(k) - \langle a_j \rangle)$$

Since $\sigma_{ij} = \sigma_{ji}$, and since the individual variances of the quantities are the same, all of them being the variance of a single K_p point, we have

$$\sigma_{\Sigma}^2 = N [1 + 2 \sum_{i < j} \rho_{ij}] \sigma^2$$

where σ^2 is the expected variance of the sums, N is the total number of points, and ρ_{ij} is the correlation between variables i and j ,

$$\rho_{ij} = \sigma_{ij} / \sqrt{\sigma_{ii} \sigma_{jj}}$$

Now for a time series of quantities, the correlation coefficients ρ_{ij} are just the autocorrelation coefficients for a lag equal to the time difference between the two points. A simple count of the number of times each coefficient appears gives

$$\sigma_n^2(\tau) = \frac{\sigma^2}{Nn} \left[1 + 2 \sum_{i=1}^n \frac{n-i}{n} \rho(i) + 2 \sum_{j=1}^m \left(\frac{N-j}{N} \right) (\rho(j\tau) + \sum_{i=1}^n \frac{n-i}{n} (\rho(j\tau + i) + \rho(j\tau - i))) \right]$$

where $\sigma_n^2(\tau)$ is the variance of the n-day average of the superposed epoch averages at the period τ . It is assumed that for lags greater than $m\tau$ (about 120 days for this situation), the autocorrelation is zero. This formula is identical to that quoted by Bell and Defouw if we let $m = 0$ and assume that $\rho(3)$ and $\rho(4)$ are zero.

Because of the strong 11-year cycle in solar activity, our last assumption is not strictly true for K_p : the large amount of power at 11 years leads to a long, low cycle in the autocorrelation. However, since the principal contributions to the sum above are from the first two or three solar peaks, rather than carry out the autocorrelation to large lags, a reasonable base value was simply subtracted from the coefficients. To make our analysis compatible with that of Bell and Defouw, the autocorrelation used in this latter analysis was of ΣK_p rather than of the 3-hour values, and the base value used was .07.

Table I gives σ_5 as calculated by Bell and Defouw and as calculated in this paper for $m = 0, 1, 2$, and 3 .

<u>Source</u>	<u>σ_5</u>	<u>σ_5/σ</u>	Maximum deviation at the
			<u>lunar period: $(18.6/\sigma_5)$</u>
Bell and Defouw	6.4	.64	2.9
$m = 0$	6.7	.68	2.7
$m = 1$	8.7	.88	2.1
$m = 2$	9.3	.94	1.97
$m = 3$	9.3	.94	1.96

TABLE I.

σ_5 as calculated to various degrees of accuracy.

As can readily be seen, the last value is quite a bit larger than that calculated by Bell and Defouw. Since the averages are for five days, there are at least $29.5/5 = 6$ independent points in the superposed epoch analysis. Actually there are more, since it is possible to select the best of 30 points, none of which is entirely dependent on the values of adjacent points. However, the probability that at least one of only six independent points will be at least 1.96 deviations from the mean is .26, which indicates a quite large probability that the apparent lunar effect is random. If we use the third highest point rather than the highest, to counteract the fact that there are 30 points to choose from rather than 6, the distance becomes only 1.35 standard deviations, and the probability becomes .68.

A similar analysis may be conducted on K_p or ΣK_p rather than on the five-day running sums of ΣK_p , with similar results. Although the enhancement of the variance is not as large in these two cases, we are not dividing by $n = 5$, so that the probability remains about the same.

It has thus been shown that a rigorous statistical analysis of K_p at the lunar period yields a rather high probability that the lunar averages could be reproduced by chance. It is therefore likely that there is no statistically significant lunar influence on K_p .

Because of the complexity of geophysical data in general and K_p in particular, and because of the large number of unknown correlations and effects, a relatively simple statistical analysis like that described above cannot be expected to yield very accurate results. For this reason, it is extremely useful to compare the "significance" of the lunar curve to those of non-lunar comparison data. However, the selection of such data must be done with care: one must not eliminate or introduce any effect which could alter the significance. (Except, of course, the lunar effect we are attempting to isolate.)

One such effect which, as shown above, one must be careful not to exclude from the comparison data is the effect of the 27-day solar autocorrelation. As noted above, this effect was destroyed in the only other major work which used the comparison technique, that of Stolov and Cameron.

Perhaps the most foolproof method of obtaining comparison data is from the analysis of psuedo-lunar periods. By analyzing K_p at periods near that of the moon, but far enough that the hypothetical phase-locked lunar effect will be eliminated, one can obtain comparison curves that embody all the apparent non-lunar effects without including any lunar effect. One problem does arise in this analysis, however. To fairly judge the lunar curve, one must obtain a large enough set of comparison curves to constitute a good statistical sample. These curves, however, must be taken far enough apart that they are not strongly correlated. Because the hypothesized enhancing effect depends on how far a given period is from the solar period, it is not strictly possible to obtain a set of comparison periods with a uniform solar effect.

To circumvent this, a large enough sample of psuedo-lunar periods was taken to "map out" the entire region around the solar and lunar periods, from 21 to 37 days. Averages were then taken of the "significances" of small subsets of periods, and the points one standard deviation of the subset above and below the average were plotted. Figure 2 shows such plots for the three significance criteria noted in the caption and described below. The position of the point for the lunar period is marked by an X on each graph, and the two jagged lines are the one deviation limits.

Several different measures of significance were used in these studies. Each of these measures was based on some analysis of the superposed epoch curves. The first such measure, (a) in the

diagram, was the variance of the set of points of the superposed epoch curve. Strongly oscillating curves should exhibit a larger variance and therefore would be significant. The disadvantage with this method is that it gives equal weight to curves which are just "noisy" and those which exhibit a large and regular variation at some part of the cycle.

To circumvent this difficulty, each curve was Fourier analysed for the first few harmonics, and the magnitude of each harmonic was calculated and plotted. This is equivalent to a partial power spectrum analysis, so that (b), which plots the magnitude of the first harmonic, is, in effect, a plot of the square root of the power at each period. In addition, the total magnitude through each harmonic was calculated, and (c) is a plot of the square root of the total power in the first through third harmonics at the periods shown.

As can be seen from the figure, by each of these measures of significance there is the expected broad peak around 27 days. In addition, by each of these measures the lunar period has a significance near or below the significance of the nearby periods, and seems to fit quite well into the tail of the solar peak. This indicates quite strongly that there is no statistically significant lunar effect on K_p .

To make this work more compatible with that of other researchers, I have also calculated the excursion lengths and areas of the set of superposed epoch curves. The excursion length and

area of each curve were compared to the excursion length and area of the lunar curve. Figure 3 is a plot of the fraction of periods in each half-day interval which had a criterion value greater than that of the moon. As can be seen, an appreciable fraction of the periods near the lunar period have greater excursion lengths and areas. The reader should also note that the periods near 27 days tend to be more significant than those well away from 27 days, and the lunar period is well within this peak of significant curves.

This research was completed by a formal power spectrum analysis* of the 33 years of K_p data. The spectrum was made of the K_p daily sums rather than of the 3-hour K_p points to conserve computer time. Figure 4 is a plot of the power in harmonics 350 to 500, or about 24 to 33 days. The X again marks the lunar point. As before, the lunar point shows less power than do the nearby points.

To show that the lunar curve is indeed indistinguishable from those of nearby periods, six periods, one of which is the lunar period, are plotted in Figure 5, arranged in random order. Before reading the caption, the reader should perhaps examine

* Power spectrum analysis is a method of finding periodic tendencies in data. It consists of calculating the sum of the squares of the Fourier harmonics at the period in question. The method usually used is to calculate the autocorrelation of the data, where the autocorrelation function is defined somewhat differently than that here, and then to calculate the cosine component of this function.

the figure and select the period that appears most significant. Tests that indicate the lunar period is significant would show that some of the non-lunar periods must be much more so.

IV. Discussion

It has now been shown that by two widely different methods of analysis there is no statistically significant correlation between the period of the moon and K_p , but that any analysis which disregards the strong solar effect will indicate that the lunar curve is significant. It is the autocorrelation of K_p at 27 days which enhances the variation at and near the lunar period so that it is larger than one would expect from a simpler analysis. It is this correlation that the proponents of a lunar effect have universally disregarded in their analyses. Bell and Defouw [1964] and Bigg [1963a] realized that such an effect was possible or even probable, but decided it was insignificant after only a cursory analysis, whereas Stolov and Cameron [1964] did not even mention the possibility of such an effect.

It might be argued that subsequent analyses have shown stronger effects, say, when the moon is near the ecliptic, but all this shows is that on a random division of random data, one part of the data will have more of any arbitrary characteristic than the others. Thus if one tossed ten coins ten times, there is better than an 80% chance that there would be 7 or more heads on at least one throw, but this does not mean that this throw is particular, or that the data has structure.

Similarly, if one should attempt to prove the significance of the lunar effect by using one of these subsets of the data, it should be borne in mind that if the subset being used as evidence

was drawn from n possible subsets, the probability that the effect seen in the subset would occur by chance must be one n th what it would take to prove the whole set significant. Also, in counting the number of possible subsets from which the one used was drawn, all the subsets from types of data division inspected but not used must also be counted.

It might be argued that the theories of the effect predict that it would be the subset chosen which should show the greatest effect, and therefore this subset need only show the significance required of the whole set of data. However, all the theories were derived ex post facto: it would have been just as possible to postulate a theory if the data had turned out opposite to what it did, just as it would be possible to make a theory which justified the fact that the seven heads occurred on the third toss. Thus, if the maximum apparent lunar effect on K_p had occurred when the moon was at a maximum distance from the ecliptic, it could be postulated that the moon affected K_p by interfering with the solar wind near the geomagnetic tail. In addition, none of the theories predicts the nature of the observed curve, only that the effect should be "around" full moon.

Similarly, the continuity in the size of the effect from large ecliptic distances to small, which is predicted by the present speculations, is easily accounted for by the fact that one of the major causes of the "effect" is the large correlation of points separated by about one month. The division of data used

in the current theories virtually divides the data into three sets of pairs of months, so that the 27-day autocorrelation would insure good continuity. This is similar to the "random" division of data by Bell and Defouw by whether the tens digit of the Julian date of the full moon was even or odd. They said that the similarity of the two curves indicated that the effect was real. However, since the lunar period is very near 30 days, this amounted to putting alternate months in the two groups, so that the full effect of the solar autocorrelation was brought into play to make the curves similar. It is somewhat unfortunate that they happened to pick a random data division that did this. In addition, the selection of the largest variations of the sum curve for inspection in the divided data curves tends to enhance the correlation within the sets of divided data curves.

In conclusion, it has been shown that when the techniques used take account of all the factors, particularly the strong 27-day solar autocorrelation, both a statistical analysis and a comparison with similar data yield no statistically significant correlation between the phase of the moon and the index of geomagnetic activity K_p . Since the solar effect at 29.53 days should be as large as the observed lunar curve, any true lunar effect would be undetectable in the solar noise.

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FIGURE CAPTIONS

- Figure 1. First 200 days of the autocorrelation of K_p for 1932-1964. It should be noted that there are no peaks corresponding to the lunar period, but that the solar peak is still appreciable around 29.5 days.
- Figure 2. Significance as a function of period by several tests. The points for individual periods were collected into groups about 0.2 days wide. For each group the points one deviation of that group above and below the average were plotted. The jagged lines mark these two limits. On each graph, the X marks the lunar point. The tests of significance used were:
- (a) variance of the superposed epoch averages;
 - (b) magnitude of the first harmonic;
 - (c) square root of the sum of the squares of the magnitudes of the first three harmonics.
- By all these tests, the significance at 29.53 days is typical of nearby periods.
- Figure 3. Histograms of the fraction of periods in each 1/2-day interval whose maximum excursion length or area equalled or exceeded that of the moon. This fraction is large near 29 days, and even larger at the center of the solar peak.

Figure 4. The power in ΣK_p , harmonics 360 to 500 (about 24 to 33 days). The X marks the lunar power. As can be seen, the power at 29.53 days is typical of the power level of nearby harmonics.

Figure 5. Superposed epoch averages of the 3-hour K_p 's for 1932-1964, at several periods:
(a) 29.623, (b) 28.899, (c) 27.432, (d) 29.53058 (lunar), (e) 27.411, (f) 27.777.

These curves all exhibit larger variations than the lunar curve, as well as greater excursion lengths and areas and increased smoothness. If the lunar curve is significant then these others must be much more so.

FIGURE 1

FIGURE 2

FIGURE 3

P54329

FIGURE 4

FIGURE 5

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