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similar studies of DNA sequences in bacteria and virus combinations that ibit the phenomenon of lysogenesis ere a complete virus genome, inhibited some way, is replicated along with a terium for many successive generans until it is activated by a chemical or ultraviolet light, when multiple replition of the virus abruptly occurs, with is and death of the bacterium) have n carried out to measure degrees of nology or relatedness. This whole subject is of interest in relation to various hypotheses concerning cancer and other diseases, and it is possible that a clearcut distinction between host DNA and "parasite" DNA is, ultimately, not even philosophically tenable. We carry, in part, both the past and the future within us.

For a number of other interesting facets of the work in progress in the Department the reader should scan the reports by individuals as given in the balance of this report.

GEOPHYSICS

Part of the pleasure of any retiring Ditor must be the creative results of new ntures undertaken during his adminiscion. The efforts reported here of a all part of the staff of the Department d a large group of our South American leagues are but one of several such ntures undertaken in the past 20 years the life of the Department. No one of in the Geophysics Section feels that the rector's retirement is anything but a allenge to continue this venture. The portunity for the geophysical study of s complex and irregular planet on which live has never been more enticing and manding. It is with no little pleasure at we anticipate the continued interest, uition, and intellect of the retiring rector as a significant part of our conued efforts to plumb the many tantang (and often discouraging) studies of e processes that have shaped the earth. If a single focus of the efforts of the geoysics group can be made, it must be the uth American continent. From the citing delineation of the anomalously h conductivity under the altiplano of thern Peru and Bolivia, and the major orts to analyze the extensive earthake data in the Carnegie Lima Analysis nter, it is obvious that a major share of e geophysical work is directed southrd. Attempts to correlate by age deminations rock units in Uruguay and gentina with those in South Africa have far been unsuccessful. The confirmation of the hypothesis that the two continents were once joined must thus depend on relationships between rock units on the Brazilian shield. This shield is known to have a complex geological history and the lack of a clearcut answer in the southern part of the continent is something of a disappointment.

GEOMAGNETISM

Electrical Conductivity Anomaly Under the Andes

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Observational program. The cooperative programs begun in late 1962 with the Instituto Geofísico del Peru and in late 1964 with the Instituto Geofísico Boliviano to investigate conductivity anomalies in the earth's crust and mantle continued throughout the report year.

In Peru, Askania variographs were in operation at Casma, Huánuco, Cañete, Abancay, Camaná, Desaguadero, and Arequipa from late 1964 through July 1965. In September 1965 these variographs were moved to portable shelters in the Cuzco–Lake Titicaca region to provide more definitive data concerning the conductivity anomaly in that area. From October 1965 through May 1966

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records were obtained from the stations at Abancay, Limatambo, Cuzco, Urcos, Ocobamba, Marangani, and Santa Rosa.

In Bolivia, Askania variographs have been operating at Cochabamba and Sicasica since January 1965. The La Cour variometers, in permanent magnetic observatories in La Paz and Santa Cruz, began registration in January 1966.

Measurements and reductions of D, H, and Z have been made for several nighttime events (magnetic bays) selected from the records obtained during the several phases of the Peruvian observational program from 1963 to the first part of 1966 and from records obtained from March 1957 through 1958 during the IGY program for investigating the equatorial electrojet in Peru. Similar reductions were made for several nighttime bays registered in Bolivia since January 1965. The external (inducing) field for these selected nighttime bay events, which were recorded at many widely separated areas in Peru and Bolivia, is found to be quite uniform over these areas. As discussed later, this uniformity greatly facilitated the derivation of a preliminary coherent indication of the general crustal conductivity variation over a large region of the Andes.

Deductions from Daytime Magnetic Variations

It is well established that the H-amplitude of low-latitude daytime variations is greatly enhanced near the line of zero dip ("dip equator"). This "electrojet" effect results from the fact that all ionospheric current systems on the day-lit side of the earth are pinched together within a narrow latitude zone just above the dip equator. This effect applies to slow diurnal variations as well as to fast daytime fluctuations. Even though the "electrojet" is a part of some worldwide system, its transient field and the resulting induction within the earth may be considered separately from the large-scale system by continuing its field smoothly through the electrojet zone.

Forbush and Casaverde[1] and Ogbuchi and Onwumechilli[2] gave representative cross sections through the jet-field in Peru and Nigeria, respectively. They observed maximal enhanced H-amplitudes directly on the dip equator which drop off within about $\pm$ 10° dip to their "normal" levels outside the electrojet zone. The corresponding Z-amplitudes pass through zero on the dip equator and have extreme values near $\pm$ 5° dip. Thus the jet-field on the ground resembles that of an overhead current-band flowing in a west–east direction between $\pm$ 5° dip, plus an induced field of similar symmetry. The induced field should be slightly delayed because of the finite subterranean conductivities involved.

The Z/H ratio (positive in the south and negative in the north) is primarily determined by the ratio of induced to inducing jet-field, i.e., by the depth of the induced subterranean currents in relation to the half-width of the jet-field. Where their depth is comparatively small, for example, much less than 250 km, Z/H approaches zero because external and internal Z-variations cancel each other. Otherwise, the Z/H ratio might be close to unity near the Z-maxima (see Table 1). Hence, the Z-to-H relationship when studied on profiles perpendicular to the dip equator for daytime variations of different periods can reveal the change of conductivity with depth or the "normal" stratified conductivity distribution under the jet-field.

Horizontal discontinuities or internal "conductivity anomalies," on the other hand, are best detected with observations on isoclines (lines of equal dip) which are more or less parallel to the dip equator. We may expect similar daytime variations along isoclines, after correcting for longitude variations that depend on local time, provided that the flow of the induced jet-currents is not perturbed by local conductivity anomalies. This makes it possible to detect such anomalies with daytime variations. Elongated anomalies with a trend parallel to the dip equator

TABLE 1. Daily Range (S_Q + jet) and Amplitude (S_D + jet) for H and Z at Several Dip Latitudes

		Daily Range (S_Q + jet)*		Amplitude (S_D + jet)†	
Station	Dip-Latitude	H	Z	H	Z
FUquene	+18.3°	36 + 0γ	−21 − (3)γ	24 + 0γ	0 + (22)γ
HUC	+ 2.7	54 + 39	0 − 31	24 + 31	−13
CAS	+ 2.7	54 + 36	0 − 25	24 + 32	−21
ABA	− 0.2	53 + 85	5 + 3	24 + 84	−5
CAT	− 0.1	53 + 79	5 + 21	24 + 78	+14
DEA	− 2.5	52 + 56	9 + 59	24 + 48	+12 (phase)
CAM	− 2.6	52 + 42	9 + 55	24 + 32	+40
PIlar	−15.0	29 + 0	...	22 + 0	...

* 1965, March 15–20. † Short-period fluctuations, 1965, March 3, $11^h40^m - 12^h45^m$.

remain, of course, undetected and can only be found on cross profiles.

Further evidence for internal conductivity anomalies under the electrojet can come from a careful study of D-variations. Since the overhead current flow is usually east–west, D-variations are not found near zero dip. At places where they nevertheless occur, they are most likely "anomalous" and indicate that the internal jet-currents are here locally deflected from their normal east–west direction by zones of high or low mantle conductivity.

On the basis of these considerations the 1965 survey in Peru has been conducted with three pairs of stations, one station of each pair located on the Pacific coast and the other on the same isocline 200–300 km inland high in the Andes (Fig. 1). The central pair (CAT–ABA) occupied the dip equator, while the northern and southern pairs (CAS–HUC, CAM–DEA plus ARE) were on the ± 5° isoclines near the previously determined Z-maxima. Two more stations (COC–SIS) were added later in the program to extend the southern profile into Bolivia.

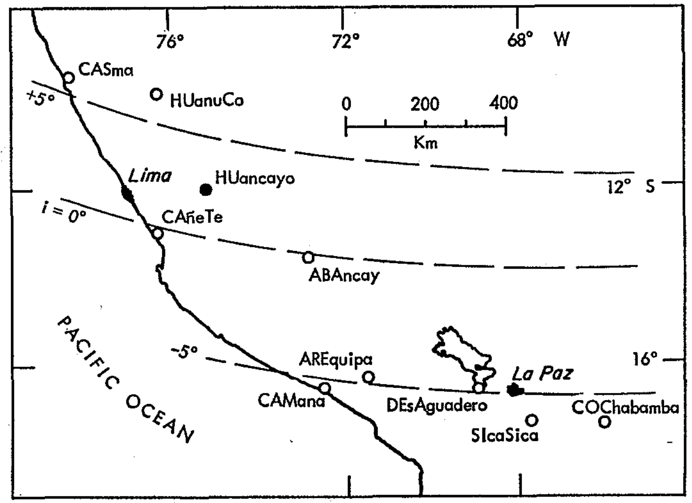


Fig. 1. Location of Peruvian and Bolivian magnetic field stations, December 1964–June 1965, in relation to lines of equal dip i.

Figure 2 displays the mean diurnal variations for a series of quiet days during the equinoxes. Comparing the daily ranges in H and Z at the coast and inland, we do not observe any striking differences between coastal and inland stations. Thus any definite "ocean-edge" effect is absent. The slightly reduced H-range at CAM in comparison to DEA can be explained by the somewhat greater dip latitude of CAM. The large, positive Z-range at CAT on the dip equator defies any simple explanation and seems to indicate that the center of the jet is here shifted northward. The dissymmetry of the Z-ranges north and south of the dip equator is the same at the coast and inland, diminishing thereby the likelihood that this dissymmetry is of internal origin.

The appearance of substantial D-variations near noon implies that overhead currents flow across the dip equator at that time from the northern into the southern S_Q-system (Fig. 3). Moreover, it is interesting to note that these D-variations are stronger in the south than in the north and that they occur earlier in the Andes than at the coast. This time-shift cannot be explained by the difference of approximately 15 minutes local time. It could mean that the induced jet is deflected northward under the Andes, following a channel of high mantle conductivity.

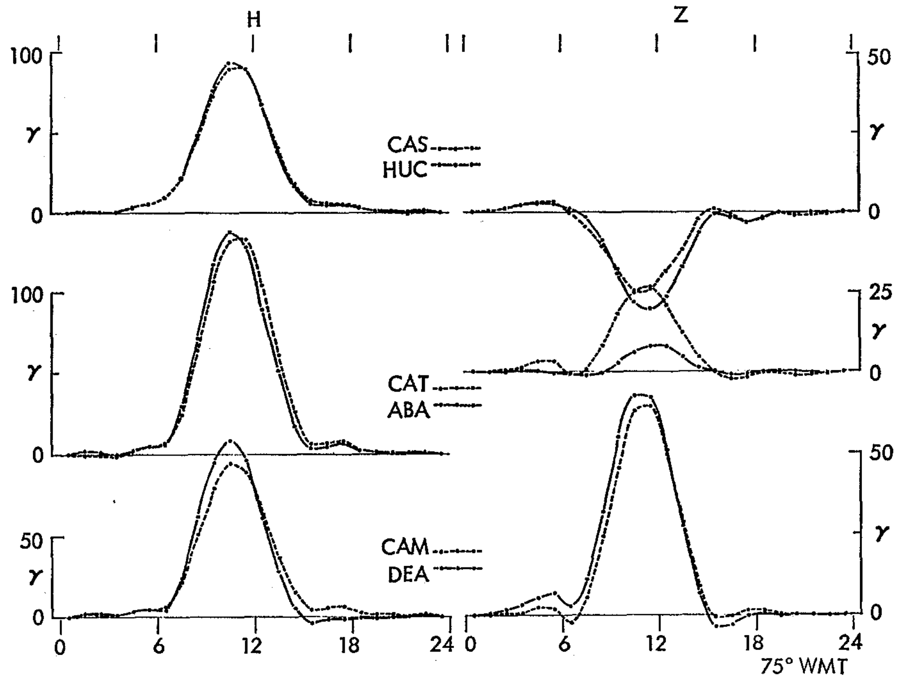


Fig. 2. Hourly means in H and Z, averaged over 6 quiet days (March 15–20, 1965), showing electrojet enhancement of daily H-range at zero dip (central curves) and corresponding Z-ranges of opposite sign and different magnitude north and south of dip equator (upper and lower curves). The transient jet field appears to be quite uniform along isoclines except for slightly reduced H- and Z-ranges at coastal stations (dashed curves) in comparison to Andean stations (solid curves). This discrepancy could be of internal origin, even though it is not explainable as "ocean-edge" effect upon the induced jet-field.

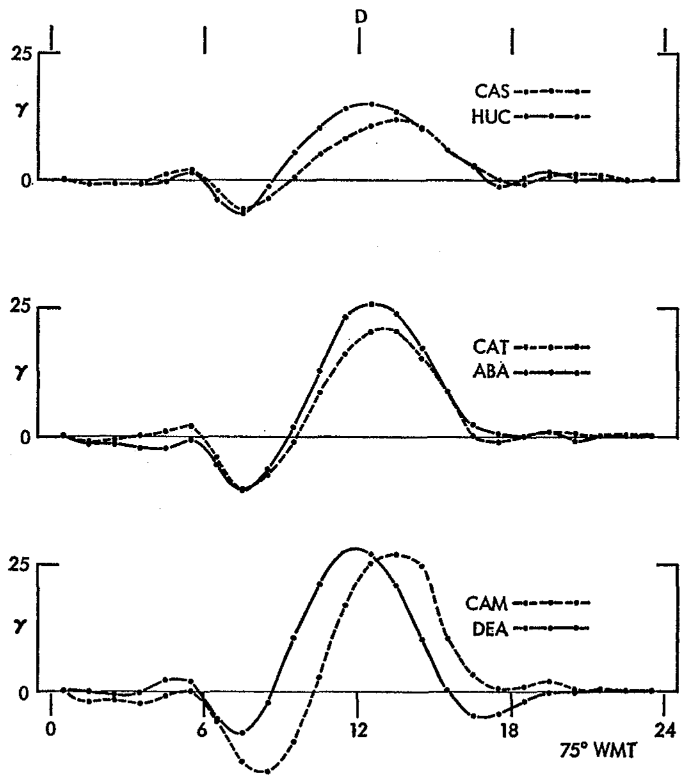


Fig. 3. Hourly means in D, averaged over the same 6 days as in Fig. 2, indicating flow of overhead urrents across dip equator near noon. The time delay of maximum noon departure at CAM relative DEA exceeds difference in local time and could imply that internal currents under DEA are deected to the north as a result of high mantle conductivities under the Andes.

As anticipated from the results of the 963 survey (*Year Book 63*, pp. 354–362), he behavior of fast daytime fluctuations more complex. Figure 4 shows a series f typical daytime oscillations of about 1-hour period, superimposed on the nooth diurnal trend near noon. Hightitude stations in Alaska were at the me time greatly disturbed by a polar orm of short duration. Thus these equarial fluctuations seem to be connected ith low-latitude return currents of the obal S_D-system that is intensified in e electrojet zone.

The H-amplitudes show the expected hancement at zero dip, but behave otherwise quite "normally" and are surprisingly small outside the electrojet zone at Fuquene and Pilar. In D we observe conspicuous fluctuations at the stations DEA, SIS and COC that are closely correlated to those in H. Such D-variations are characteristic for stations near the eastern slope of the Andes. They have been detected during the 1963 survey at Ccapana, Cuzco, Ayacucho, and Huancayo, even though they do not appear at HUC. They are almost certainly "anomalous," indicating as in the case of the diurnal variations that the large-scale induced subterranean jet-current is guided into a high-conductivity channel under the crest

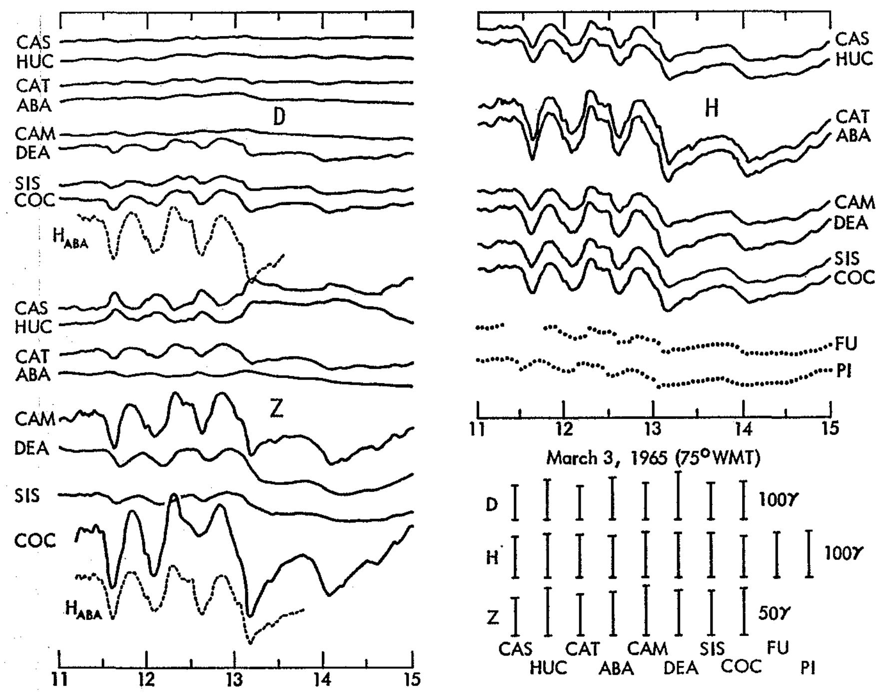


Fig. 4. Low-latitude daytime oscillations. Pronounced equatorial enhancement of H-amplitudes near zero dip. Anomalous D-variations and variable Z-amplitudes along southern isocline CAM–COC suggest that internal jet currents follow high-conductivity zone under the Andes. Anomalous D-variations are hardly visible at northern stations, where the internal currents flow at right angles to trend of this zone and remain undeflected.

of the Andes. More evidence for this interpretation will come from nighttime events.

The Z-variations are surprisingly small at the northern stations (Z/H negative) and also at some southern stations (Z/H positive). At these stations the external Z-field of fast jet-fluctuations is almost completely compensated by the opposing Z-field of near-surface induction currents. Notice the time lag of Z relative to H at DEA.

In contrast are the large Z-variations at CAM and COC indicating that both stations must be just north of an internal concentration of induction currents at shallow depth. At CAM the situation is highly complicated because of the nearby Pacific Ocean, and the enhanced Z-variations could be caused by an "ocean-edge" effect. COC, on the other hand, seems to be right on the edge of the high-conductivity channel under the Andes, which has been deduced already from the anomalous D-variations.

A detailed analysis of daytime events is under way. It requires a frequency analysis and cross-correlations between components and stations after the electrojet field has been separated from the smooth background field in low latitude. To effect this separation, which is essential for deriving the internal conductivity distribution, the time-varying surface field of the large-scale overhead and subterranean current systems is expressed in terms of pherical surface harmonics P_n^m (cos ϕ)· xp (im λ) as function of co-latitude ϕ and ongitude λ. In the case of diurnal S_Q-ariations, the longitude dependence long one parallel of latitude is equivalent o their local time dependence at one tation in that latitude, since the S_Q-ystem follows the sun around the earth. Considering the mth time-harmonic of the iurnal variations along a certain merid-an, the co-latitude dependence of the ield components H (northward), and Z downward) is described by the series

$$H(\theta) = \sum_{n=m}^{\infty} (E_n + I_n) \frac{\partial P_n^m}{\partial \theta}$$

$$Z(\theta) = \sum_{n=m}^{\infty} (nE_n - [n + 1]I_n)P_n^m \quad (1)$$

E_n and I_n are thereby periodic time func-ions with complex amplitudes, referring o the external and internal fields, re-pectively.

During the equinoxes when the S_Q-ortices in the northern and southern emispheres are of equal strength, H is ymmetric and Z antisymmetric to the quator. Thus the series in (1) contains hen only the terms P_{m+1}^m, P_{m+3}^m, . . ., nd for a first approximation we drop all erms except the first one.

It can be shown that the latitude de-endence of P_{m+1}^m is simply $\cos^{m-1}\phi \cdot \sin \phi$ with $\phi = (\pi/2) - \theta$, which when sub-tituted into (1) yields

$$I(\phi) = H(0) \cos^{m-1}\phi \; [\cos 2\phi - (m - 1) \sin^2 \phi]$$

$$(\phi) = C_m \cdot H(0) \cdot \cos^{m-1}\phi \sin 2\phi \quad (2)$$

vith $C_m = \dfrac{nE_n - (n+1)I_n}{2\,(E_n + I_n)}$

nd $n = m + 1$.

As it should be, $Z(\phi)$ is determined by he relative strength of the induced field nd disappears when $I_n = n/(n + 1) \cdot E_n$ perfectly conducting earth). Chapman's nalysis of the solar daily variations[3] gave for the second and third time-harmonics the ratios $I_3/E_3 = 0.43 + i \cdot 0.14$ and $I_4/E_4 = 0.38 + i \cdot 0.15$, yielding $C_2 = 0.42 - i \cdot 0.24$ and $C_3 = 0.72 - i \cdot 0.35$.

The relations in (2) are now applied to the daily ranges of H and Z, shown in Fig. 2. The daily range is thereby defined as the maximum hourly mean of H or Z near noon during quiet days minus the average of the hourly means for 0–1 and 23–24 hours 75° WMT. We observe that the Z-maximum occurs slightly delayed relative to the noon peak in H, which could reflect the expected phase shift between the inducing and induced jet-field. At present this time lag will be disregarded.

The resulting daily ranges are listed in columns 3 and 4 of Table 1, represented as the sum of "normal" low-latitude S_Q plus equatorial electrojet. The "normal" S_Q during these days has been derived from the daily ranges at the Colombian observatory at Fuquene (73.7°W, 5.5°N), 2000 km north of the dip equator. Assuming that the H-range is here unaffected by the jet, the equatorial S_Q-range $H(0)$ follows readily from (2), after inserting for ϕ the dip-latitude of Fuquene ($tg\ \phi = \frac{1}{2} \cdot tg$[dip]) minus 3°. This shift of the "effective S_Q-equator" to about 10°S seems to be the proper compromise between geographic and geomagnetic equator, according to Forbush, Casaverde,[1] and Onwumechilli.[4]

The relatively large Z-range at Fuquene requires us to adopt the latitude dependence of the third time-harmonic for the low-latitude S_Q-field when Chapman's ratio of internal to external parts is used. Setting $m = 3$ and $|C_3| = 0.81$ in (2) gives $H(0) = 54\gamma$ and $Z = -21\gamma$ for Fuquene, which agrees reasonably well with the observed range of -24γ. Consequently, from the total H-range of 138γ under the jet at Abancay, 53γ are attributed to the external (38γ) and internal (15γ) "normal" S_Q-system and the remaining 85γ to the external (70γ) and internal (15γ) jet-field as indicated later. The H-range of 108γ for the sum of these two external parts, derived from averages for March 15–20, 1965, agrees with the value of 105γ for the external noon H-peak obtained directly from rocket measurements on March 18, 1965 (communication from Dr. K. Burrows, NASA). Defining the ratio of external (jet + S_Q)-range to external S_Q-range as "equatorial enhancement," we obtain a nearly threefold enhancement for the 6 quiet days here considered, while the ratio of internal (induced) to external (inducing) H-range is 1/2.5 for the S_Q-system and 1/5 for the jet.

In the case of fast daytime fluctuations, we have to decide first to which global current system they might belong. Solar-flare effects, for instance, would be part of the S_Q-system, but such oscillations as shown in Fig. 4 are presumably connected with the S_D-system of polar storms. Their horizontal surface field should be quite uniform near the equator with practically no Z-variations above a "normal," i.e., horizontally stratified internal conductivity structure (see Equation 4).

Table 1 gives in columns 5 and 6 the mean H- and Z-amplitudes for the two central oscillations of Fig. 4 between 11^h40^m and 12^h45^m75° WMT, disregarding again any time lags between components or stations. Assuming that the H-amplitude at Fuquene is "jet-free" and also representative for the unintensified S_D-level under the equator, 24γ of the total H-amplitude at Abancay are considered to be "normal" S_D, of which two thirds (16γ) are external ($I/E = 0.5$). From the remaining 84γ we associate 59γ with the external and 25γ with the internal jet-field as shown below. Thus the equatorial enhancement of these fast fluctuations is nearly fivefold and the ratio of induced to inducing jet-field, 1/3.

The limited number of stations used in the survey does not permit us to conduct a formal separation of the internal and external jet-field, so a simplified procedure will be used to obtain some preliminary information about the deep conductivity distribution under the jet. Let us replace the external jet by a line current at the height ℓ above zero dip, observing that the ground field of a line current is quite similar to that of a band current of the width $2 \cdot b$ at height $\sqrt{\ell^2 - b^2}$. Since no phase-shift has been considered between components or stations, we substitute for the conductive layers of the earth a superconductor at the depth h^* and derive the induced surface field from an "image-jet" at the depth $L = 2h^* + \ell$, "in-phase" with the external jet. The components of the surface field then follow readily from the relations

$$H(x) = C \cdot \left\{\frac{\ell}{x^2 + \ell^2} + \frac{L}{x^2 + L^2}\right\}$$

$$Z(x) = Cx \cdot \left\{\frac{1}{x^2 + \ell^2} - \frac{1}{x^2 + L^2}\right\}$$

which when solved for h^* and ℓ give

$$\frac{2h^*}{x} = \frac{Z(x) \cdot H(0)}{N}$$

$$\frac{\ell L}{x^2} = \frac{Z^2 + H^2}{N}$$

$$N = H(x) \cdot [H(0) - H(x)] - Z^2(x) \quad (3)$$

(x = distance from the jet-center, negative northward). Plots of the expression on the right-hand side versus x^{-1} and x^{-2} for various stations should yield straight regression lines, the tangent of their slopes being equal to $2h^*$ and $\ell \cdot L$, respectively.

The daily electrojet range at the northern inland station HUC (x = 320 km), for instance, leads to the values h^* = 480 km and ℓ = 240 km (L = 1200 km), when the equatorial jet-range $H(0)$ = 85γ from Abancay is inserted into (3). This shows that the northern diurnal jet-field penetrates deep into the earth's mantle and produces induction currents around 500 km depth as in the case of the normal S_Q-system.

When we insert instead the amplitudes of the fast daytime fluctuations into (3) we obtain h^* = 120 km and ℓ = 180 km (L = 420 km), which implies that the bulk of the internal currents is now concentrated near 120 km depth because of the shorter period of the inducing field. The induced jet-field of such short-period daytime variations is quite strong at the surface and well suited for the investigation of the conductivity distribution in the upper mantle.

The varying height of the overhead line current might have significance for the study of the electrojet itself. After replacing the line current by an equivalent band current at a height of 100 km, in accordance with rocket observations,[5] the resulting bandwidth varies between 440 km during the slow diurnal S_Q-variations and 300 km during the fast daytime S_D-fluctuations. Together with the increased equatorial enhancement of fast variations, this suggests that the equatorial pinching effect is greater upon currents of the S_D-system than upon those of the S_Q-system. The products of bandwidth and equatorial enhancement are in both instances nearly equal, which implies that the integrated jet-current remains unaltered.

Corresponding values for h^* and ℓ from observations in southern Peru are not meaningful. We know that the induced Z-field during short-period events is here greatly affected by internal conductivity inhomogeneities and that the southern Z-range of the diurnal variations is greatly increased by a nonsymmetric current distribution in the jet.

Deductions from Magnetic Nighttime Events

The frequent and extensive daytime magnetic activity under the equator stands in contrast to the relative magnetic "quietness" during the night hours when the intensifying electrojet effect is absent. Only severe magnetic storms create sizable and continuous nighttime disturbances, but these are rare events and none were recorded during the 1965 survey.

More abundant are so-called bays, which are isolated effects of about two hours' duration, superimposed upon the otherwise smooth traces at night. In low latitudes they produce bay-shaped deflections in H of about 50γ and show a remarkable uniformity over many degrees in latitude (Fig. 5), while the accompanying deflections in D and Z are comparatively small above a horizontally stratified conductivity distribution. Thus bays are ideally suited to a search for internal conductivity anomalies in low latitudes, supplementing the study of short-period daytime oscillations in a very effective way.

A typical bay, recorded at nine survey stations, has been scaled every 3 minutes for 2 hours. The resulting traces in D, H, and Z are plotted in Fig. 5, together with corresponding readings from the three permanent observatories — Fuquene (5.5°N, 73.7°W), Huancayo (12.1°S, 75.3°W), and Pilar (31.7°S, 63.9°W).

The bay began at 23^h30^m March 3, 1965 (75°WMT) with a slight downward deflection in H from a smooth night level, followed by a sharp upward movement to a peak deflection of about 45γ within 15 minutes and a subsequent drop-off to a new night level 20γ above the "pre-bay" level. Notice that the maximum H-deflections increase from 40–45γ at coastal stations to 50–53γ at Andean stations (except for HUC). Otherwise the H-traces agree remarkably well over 37° in latitude without any indication of an equatorial enhancement.

During the peak of the bay, the D-traces at most stations are slightly deflected downward. Taking an eastward declination of a few degrees into account, we see that the horizontal disturbance vector is polarized almost exactly in the geographic north–south direction. This is true for low-latitude bays in general and merely reflects the fact that the center of the overhead bay-system, a high-latitude "polar elementary storm" on the nightside, is always more or less due north (or south) from the equator.

A more careful intercomparison of the D-traces reveals that their downward deflection is more pronounced near the coast than inland, where it can be absent or even reversed as in COC. We conclude

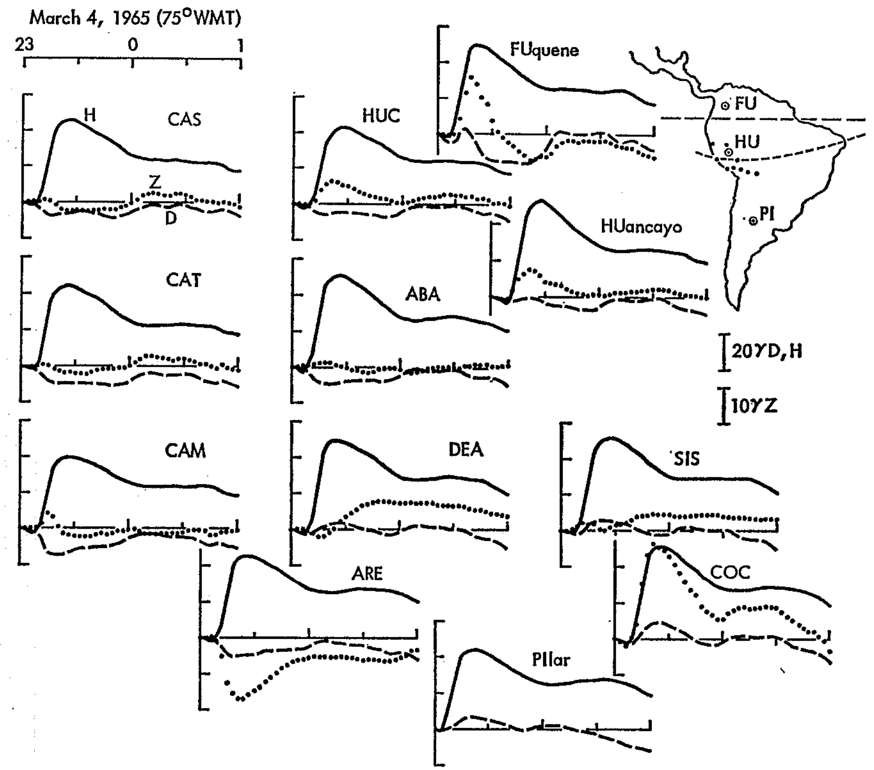


Fig. 5. Two-hour-long sections of nighttime records, containing a typical bay. Great uniformity of H-traces (solid) prevails over many degrees in latitude without indication for equatorial enhancement. H-amplitudes are slightly larger at Andean stations than near the coast. Z (dotted) reverses sign between coast and eastern slope of the Andes (CAS–HUC, CAT–HU, ARE–COC) with similar differences in D (dashed). These differences correspond to those during day events and indicate likewise a local concentration of bay induction currents under the Andes.

from the combined anomalous behavior in H and D that the Andean stations lie above concentration of deep bay-induction currents flowing under the Andes in a northwesterly direction, while the undisturbed flow is due west (Fig. 6). Another explanation would be that the coastal stations lie above a corresponding current dilution near the coast. Both interpretations are compatible with the observations, since the "normal" levels in H and D are uncertain. However, the anomalous behavior in Z favors the first and contradicts the second interpretation.

Before turning our attention to the Z-traces, let us first estimate which Z-amplitudes we could expect under "normal" conditions, i.e., above a layered deep-conductivity distribution. From the theory of electromagnetic induction in a layered medium it follows that

$$\frac{Z}{H} = k \cdot h^* \qquad (4)$$

where k is the wave number of the large-scale transient field distribution with $L = 2\pi/k$ as spatial wavelength;[f] h^* denotes the depth at which the main part

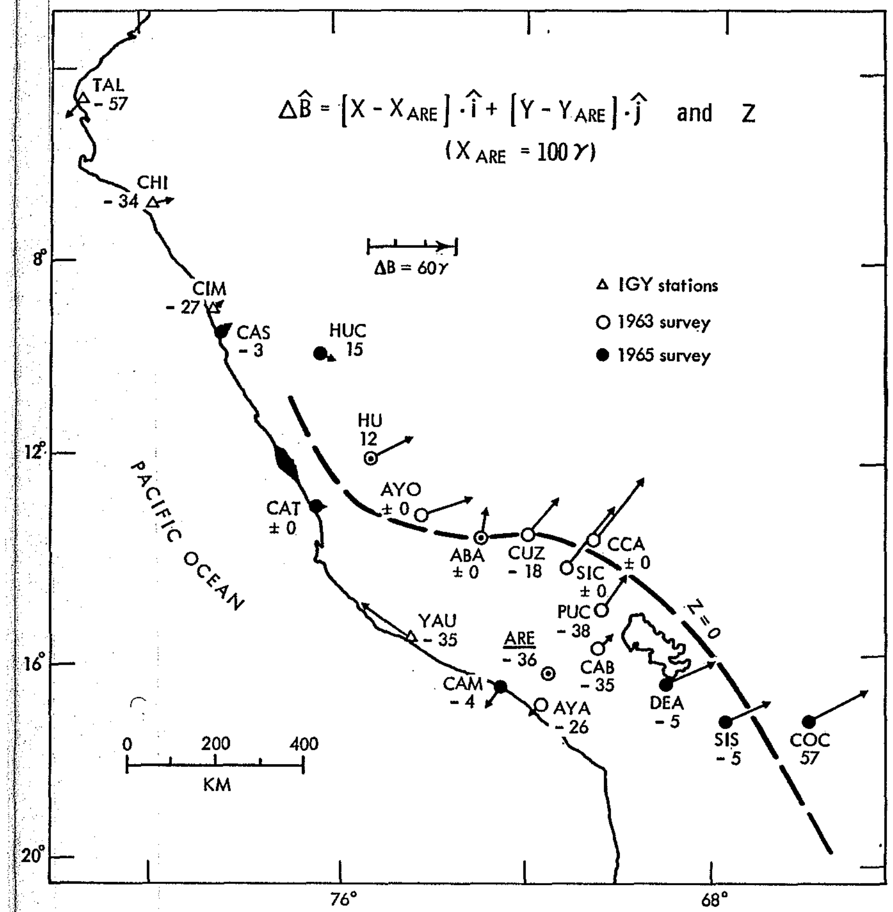


Fig. 6. Andean anomaly, deduced from two bays at each station and normalized with the transient X (north–south) component at Arequipa. The anomalous behavior of horizontal variations is represented by "perturbation vectors." Numbers refer to the Z-amplitude. A line of no Z-variations indicates trend of high conductivity and presumably "hot" zone under the Andes. The perturbation vectors are properly oriented at right angles to this zone and of maximum length near the eastern slope of the Andes. For a quantitative interpretation see Fig. 7. The divergent direction of the perturbation vector at YAU is probably due to some very local anomaly.

of the large-scale induced currents flows. The peaks in H and Z may be shifted relative to each other in space or time, depending on the nature of the source field.

Because of the great uniformity of H, we may choose a wavelength equal to the circumference of the earth. Setting $k = 0.00016\ \mathrm{km}^{-1}$ and using a reasonable estimate of 250 km for h^* gives $Z/H = 0.04$. Thus we may expect a Z-amplitude of 2γ during the March 3 event under normal conditions.

As seen from Fig. 5, the Z-amplitude exceeds this "normal" level at many survey stations and should be considered "anomalous." Furthermore the conspicuous differences between the Z-traces that are reproducible from event to event follow a distinct geographical pattern. This emphasizes their connection with horizontal discontinuities in the internal conductivity structure.

Most striking, of course, is the reversal in Z between ARE and COC, but we observe consistently positive Z-bays near the eastern slope of the Andes (FU, HUC, HU, COC) and negative Z-bays near the coast (CAS, CAT, CAM, ARE) with practically no Z-variations at ABA and SIS. This reversal of the Z/H ratio across the Andes agrees well with the postulated concentration of internal induction currents under the crest of the Andes, following a high-conductivity zone.

Let us comment briefly on the "reversed" coastal anomaly in Peru and the clearly visible phase shift between Z and H at DEA. At many places around the world the Z-amplitude of short-period variations is greatly intensified near the coast of large and deep oceans. This coastal Z-anomaly arises from an offshore concentration of near-surface induction currents, probably in the highly conductive seawater itself, plus their interaction with deep induction currents in the upper mantle (for a summary see Rikitake).[6]

We would expect positive anomalous Z-amplitudes along the Peruvian coast when H is positive. Naturally these anomalous Z-variations would be small in northern Peru, where the coastline is nearly parallel to the predominant north–south orientation of the horizontal disturbance vector; but in southern Peru the coastline forms a definite angle with the meridian, and a positive Z/H of about 0.5 should be observed at a station like CAM. In fact the Z/H ratio at CAM is negative, and similar observations have been made all along the Peruvian coast during the IGY program and the 1963 survey. It was concluded at that time (*Year Book 63*, p. 361) "that the absence of such a (coastal) anomaly in Peru implies that a highly conductive substratum comes close to the surface, thereby damping the oceanic induction currents and likewise reducing the coastal anomaly. Furthermore the negative Z-variations at the coast suggest that the depth of the subsurface induction currents increases toward the ocean." In the light of the new observations, the last statement should be modified by saying that the depth of the subsurface induction currents *decreases* from the coast inland without reference to their possible depth under the ocean.

A very close inspection of the traces at the coast, particularly at CAM, shows that a short, upward deflection in Z takes place at the beginning of the bay, as if Z were to follow H under the influence of the normal coastal effect. Thus for rapid fluctuations the anomalous behavior of Z near the coast seems to reflect the true ocean-edge effect, but for periods of 1 to 2 hours the "Andean anomaly" becomes predominant.

The upward deflection in Z at DEA is clearly delayed relative to the upward deflection in H. A similar time lag has been observed during daytime events. Since such a phase shift is characteristic for anomalous Z-variations caused by conductivity anomalies within the uppermost layers, we conclude that DEA lies near the southern edge of a highly conductive surface structure, probably a deep trough filled with unconsolidated sediments.

For a statistical study of bays we take into account the following theoretical aspects of internal induction problems. Let $F(P,t)$ be the transient magnetic disturbance vector during a bay defined by the deviations in D, H, and Z from their smoothed night levels at a low-latitude station P. We distinguish between its "normal" part, $\bar{F}(t)$, which is considered to be the same at all survey stations, and its "anomalous" part, $\Delta F(P,t)$, which accounts for differences between stations. More specifically, $\bar{F}(t)$ represents the large-scale bay field near zero dip which arises from the practically uniform flow of overhead currents and subterranean induction currents in a iormal," stratified conductivity strucre. The bulk of these internal currents)ws beneath continents deep within the antle, probably between 100 and 300 n. Local deviations from a stratified ructure lead to anomalies in the induced rface field $\Delta F(P,t)$, provided that they fect the flow of the internal currents. It can be shown that linear relations ist between the components of ΔF and that are invariant at one place throught events of different form and intensity. iese relations involve a matrix of nine efficients for each frequency component the transient variations, and each coicient may be complex to allow for iase shifts between anomalous and rmal variations. The objective of the ta analysis is to determine moduli and guments of the coefficients as a function frequency and location and to derive om the "normalized" anomaly the rturbed internal conductivity structure.

Let us first transform the observed D-d H-variations into true-north X- and ie-east Y-variations according to the clination of the permanent field at each e, since differences of the declination tween stations could obscure truly omalous horizontal variations. Acrdingly the components of the normal d anomalous disturbance vectors are noted $\bar{X}$, $\bar{Y}$, $\bar{Z}$ and $\Delta X = X - \bar{X}$, $\Delta Y = Y - \bar{Y}$, $\Delta Z = Z - \bar{Z}$, respectively. "Normal" bays in low latitudes are ll represented by their transient northrd component $\bar{X}(t)$ alone, and we have consider only three coefficients of the mplete matrix. Assuming that the time riations are periodic with exp (2π ift) time factor we define them by

$$\begin{aligned}\Delta X(P,t) &= h_x(P,f) \cdot \bar{X}(t)\\ \Delta Y(P,t) &= d_x(P,f) \cdot \bar{X}(t)\\ \Delta Z(P,t) &= z_x(P,f) \cdot \bar{X}(t)\end{aligned} \qquad (5)$$

reality, of course, nighttime events are nperiodic, and we have to deal with eir Fourier transforms to find the coicients as a function of frequency. This n be done by developing a sufficient mber of bays within limited intervals of the same length, T_0, into harmonics with $f_0 = T_0^{-1}$ as (arbitrary) fundamental frequency. The resulting cosine (index u) and sine-terms (index v) of the nth harmonic are then combined and averaged according to the scheme

$$\begin{aligned}S_{A,B}(nf_0) &= < A_uB_u + A_vB_v > + \\ &\quad i < A_uB_v - A_v B_u > \\ S_A(nf_0) &= < A_u^2 + A_v^2 >\end{aligned} \qquad (6)$$

($<>$ = average over all bays); S_{AB} when multiplied by f_0 represents the complex valued cross spectrum between the time series $A(t)$ and $B(t)$, while S_A is the power spectrum of $A(t)$. The coefficients follow then from the formulas for a "least-square-fit" as

$$h_x(P,f) = \frac{S_{\Delta X,\bar{X}}(P,f)}{S_{\bar{X}}(f)}$$

$$d_x(P,f) = \frac{S_{\Delta Y,\bar{X}}(P,f)}{S_{\bar{X}}(f)}$$

$$z_x(P,f) = \frac{S_{\Delta Z,\bar{X}}(P,f)}{S_{\bar{X}}(f)} \qquad (7)$$

To test the statistical significance of the coefficients derived in this way, the amount of "unrelated" noise in each component is expressed by "residuals," defined for ΔZ by

$$\epsilon_z(P,f) = \frac{<|\Delta Z - z_x \cdot \bar{X}|^2>}{<|\Delta Z|^2>}$$

$$= \sqrt{1 - \frac{(z_x \cdot S_{X,\Delta Z})}{S_{\Delta Z}}} \text{ real}$$

corresponding definitions apply to ϵ_x and ϵ_y. A numerical value of $\epsilon_z(P,f) = 0.2$, for instance, implies that 80% of the observed Z-variations at the station P can be linearly related to normal X-variations for the frequency f.

For a preliminary study we scaled the maximum deflections in D, H, and Z from smoothed night levels during a number of well-developed bays that were recorded at all survey stations. After transforming the D- and H-values into corresponding X- and Y-deflections, we tried to determine their "normal" parts $\bar{X}$ and $\bar{Y}$ during each event in such a manner that the resulting "anomalous" differences ΔX and ΔY at the various stations would fit into a general geographical pattern, consistent with the anomalous behavior of Z. This was achieved by regarding the deflections in X and Y at Arequipa, halfway between the high Andes and the coast, as "normal." Subsequent model calculations justified this choice (*cf.* Fig. 7).

Thus we assumed that $\Delta X = X - X_{\text{ARE}}$, $\Delta Y = Y - Y_{\text{ARE}}$, and $\Delta Z = Z$ are the components of the anomalous disturbance vector during the peak of the bay. The distinction of sine and cosine terms in (6) is unnecessary here, and we can write the equations (7) in the simplified form

$$h_x = \frac{\langle \Delta X \cdot X_{\text{ARE}} \rangle}{\langle X^2_{\text{ARE}} \rangle}$$

$$d_x = \frac{\langle \Delta Y \cdot X_{\text{ARE}} \rangle}{\langle X^2_{\text{ARE}} \rangle}$$

$$z_x = \frac{\langle Z \cdot X_{\text{ARE}} \rangle}{\langle X^2_{\text{ARE}} \rangle} \qquad (8)$$

All available records from Peruvian and Bolivian stations were examined for suitable bays and included in this pilot study. (Arequipa was not yet in operation during 1957–58, and the horizontal variations at Huancayo served as "normal" reference for IGY data, corrected for differences in X and Y between Huancayo and Arequipa.) The results are shown in Fig. 6. We see that a line of zero Z-variations follows the crest of the Andes, flanked by negative Z-amplitudes between the coast and the high Andes and positive Z-amplitudes toward the eastern lowlands. The anomalous behavior in X and Y is visually displayed by normalized "perturbation vectors,"* which give direction and relative strength of the anomalous horizontal variations

$$\Delta B = \Delta X \cdot \hat{\imath} + \Delta Y \cdot \hat{\jmath}$$

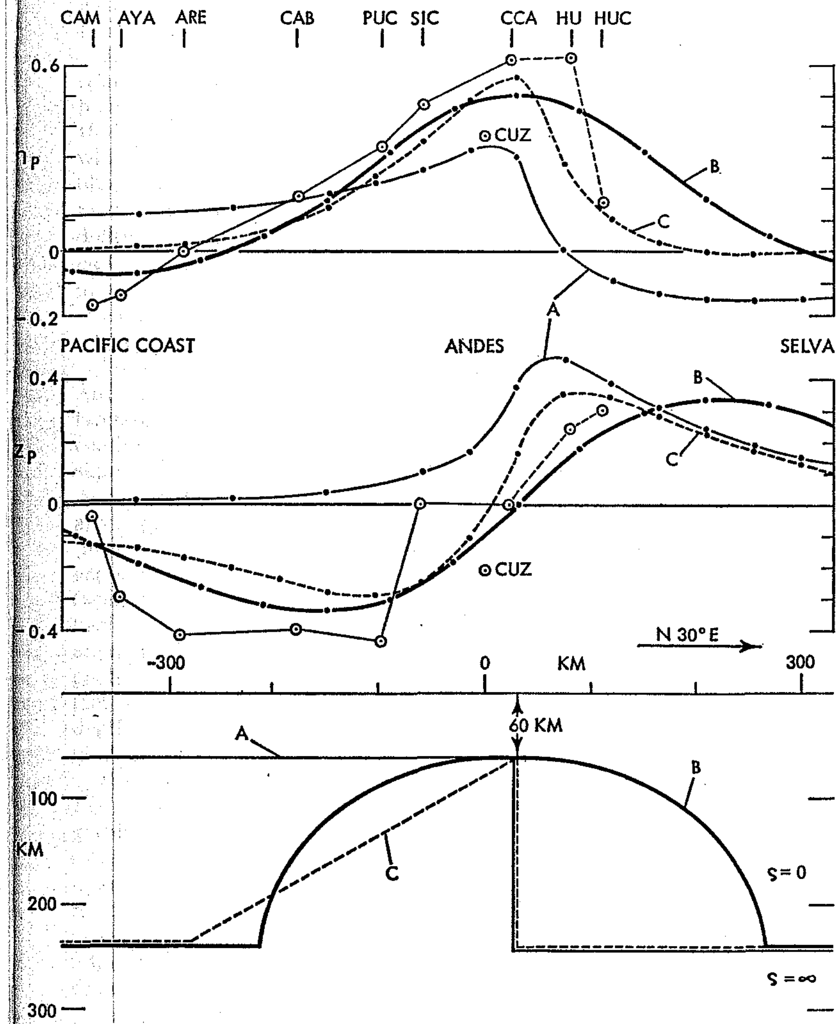
($\hat{\imath}, \hat{\jmath}$ = unit vectors toward true north and true east). These vectors, when rotated 90° anticlockwise, indicate intensity and direction of anomalous internal currents, which follow some subterranean high-conductivity structure and are superimposed on a uniform westward flow of unperturbed induction currents.

We infer from Fig. 6 that anomalous horizontal variations in the high Andes are oriented in a northeasterly direction and are perpendicular to the line $Z = 0$. This, together with the reversal in Z, confirms that an anomalous concentration of deep induction currents exists beneath the Andes in connection with unusually high internal conductivities. Some coastal stations have reversed perturbation vectors pointing seaward, but the meaning of this reversal is not yet clear.

Conclusions. What quantitative deductions can be made from these observations? Here we have to bear in mind that local anomalies, revealed by equatorial bays, indicate zones of unusually high or low internal conductivity but do not disclose their depth. This ambiguity arises from the fact that the overall change of conductivity with depth, which would yield the average depth distribution of the induced currents, remains uncertain. In principle, the change of conductivity could be inferred from the ratio of vertical to horizontal variations in regions free from local anomalies, but because of the great uniformity of the low-latitude bay field, "normal" Z-variations are minute (*cf.* Equation 4) and hardly recognized as such, near anomalous zones.

In contrast, the equatorial electrojet field, because of its limited spatial extent, is ideally suited to an investigation of the mean vertical conductivity gradient in the earth's mantle under the dip equator, provided that the distorting effect of local anomalies can be removed with the aid of nighttime observations. Thus a combined

*The perturbation vectors should not be confused with Parkinson's vectors,[6] which refer to the relationship of the Z-amplitude with the X- and Y-amplitude at one site. They point toward concentrations of internal currents but disappear at maximum concentration. It is difficult to determine them at equatorial stations where the transient horizontal disturbance vector is confined to one principal direction under normal conditions.



ig. 7. Calculated and observed cross sections through Andean anomaly in southern Peru. itours A, B, C in lower graph represent assumed interfaces between nonconducting and super- ductive matter in upper mantle and refer roughly to internal iso-conductivities of 0.1 $[\text{ohm}\cdot m]^{-1}$, ch in turn correspond to internal isotherms of 1500–1700°C. The upper curves show the horizontal) anomalous component of a horizontal transient surface field of unit strength, positive toward the t. The circles are empirical values, deduced from bays at the stations listed in the top row. Contour ndicates form and dimensions for the proposed rise of highly conductive and probably hot mantle terial under the Andes. The z_P curves represent the anomalous vertical component, normalized he same way.

study of day and night events is needed to arrive at definite conclusions about the anomalous conductivity structure under the Andes.

Additional information could come from earth-current observations as they have been carried out for many years at the Huancayo observatory. It is worthwhile to recall in this context Rooney's observation[7] that the transient electric field vector of the diurnal variations is deflected at Huancayo from its "normal" east–west orientation to a northwesterly direction, possibly under the influence of similarly deflected deep induction currents.

For a first-order interpretation of the Andean anomaly, let us assume that the large-scale induction currents of bays are confined to the surface of a substitute superconductor, 240 km deep east of the Andes. We exclude the possibility that any significant portion of the internal (in-phase) bay field comes from superficial earth currents, affected by geological surface structures such as sedimentary basins. To account then for the observed anomaly in Peru and Bolivia we have to postulate that the superconductive surface is bent upward to about a 60-km depth under the crest of the Andes with a gradual descent toward the Pacific coast.

This interpretation is illustrated in Fig. 7 by model calculations. The lowest graph presents the contours of three possible interfaces between a nonconducting upper region and a superconducting lower region in the earth's mantle. These interfaces are two-dimensional, extending to infinity in a direction normal to the shown vertical plane of projection.

Suppose a transient magnetic field representing the bay field in low latitudes exists in the upper region. Let P and Z be its horizontal and vertical field components in the projection plane. Their internal parts above the indicated contours are then locally perturbed, since internal induction currents perpendicular to the projection plane will be drawn together in elevations of the superconductive substratum. It can be shown that any transient field component normal to the projection plane remains unperturbed. This allows for the relation between anomalous and normal field components the simplified "two-dimensional" formulation (*cf.* Equation 5)

$$\Delta P = \Delta X \cdot \cos\alpha + \Delta Y \cdot \sin\alpha = h_P \cdot \bar{P}$$
$$\Delta Z = z_P \cdot \bar{P} \qquad (9)$$

(α = angle between true north and projection plane). Thus the anomalous field disappears when the normal horizontal variations $\bar{P}$ are zero, i.e., when the flow of unperturbed large-scale induction currents is parallel to the projection plane, or perpendicular to the trend of the anomaly.

This statement applies, however, only to source fields of great spatial uniformity, such as the equatorial bay field, and not to the electrojet field, for instance. Fortunately the Andean anomaly in southern Peru is nearly parallel to the east–west flow of large-scale bay induction currents, leading to a pronounced perturbation of bays. The situation is less favorable farther north, and there we have to depend mainly on anomalies in the electrojet.

The h_P- and z_P-profiles, shown in Fig. 7, have been derived from the distorted pattern of field lines above the contours, the ultimate field line being tangential to the interface of nonconducting and superconductive matter. This ensures that the transient field component normal to that interface is zero as required. The necessary calculations have been carried out with a transformal mapping method for the step-model A (*cf.* Fig. 12, Schmucker, 1963)[8] and with a numerical relaxation method for the triangular upheaval C (*cf.* Fig. 97, Rikitake).[6] The semielliptic uplift B has been treated according to the well-known formulas for flow lines around an impermeable two-dimensional body with an elliptical cross section.

For a comparison of calculated and observed anomalous field components we first recalculate the empirical coefficients h_x, d_x, and z_x from (8) with respect to $P = X \cdot \cos\alpha$ as "normal" horizontal variations. Using according to (5) and (9) the relations

$$h_P = (h_x \cos\alpha + d_x \sin\alpha)/\cos\alpha$$
$$z_P = z_x/\cos\alpha$$

h_P- and z_P-values have been derived for stations close to the line AYA–CCA (*cf.* Fig. 6), setting $\alpha = 30°$. They are shown as circles in Fig. 7. Corresponding values for the northern stations HU and HUC, which lie east of the line of zero Z-variations, are added for comparison after projecting these stations onto the AYA–CCA profile but using $\alpha = 60°$ according to the different trend of the Andean anomaly in the north.

We find the empirical h_P- and z_P-values in reasonable agreement with both the model curves B and C, each suggesting an upheaval of highly conductive matter under the Andes. Evidently a unilateral uplift near the eastern mountain front according to model A cannot explain the observed anomaly.

What finite internal conductivities are most likely to be involved in the Andean anomaly? Here we may contend that a substitute superconductor indicates roughly the depth of penetration for the large-scale bay field within the conductive layers of the earth. Thus the conductivity σ along superconductive contours as in Fig. 7 should be for a given period T such that the "skin-depth"

$$p = 15.2 \cdot \sqrt{T/\sigma}\ [\text{km}]$$

(T in hours, σ in $[\text{ohm} \cdot m]^{-1}$) is reasonably small, in particular, much smaller than the half-width of the anomaly.

Since T is about 1 hour for bays, a conductivity of 0.1 $[\text{ohm} \cdot m]^{-1}$, yielding p = 50 km, seems to be an appropriate estimate. Hence the contours B or C in Fig. 7 may be considered as "iso-conductivities" for this value.

From experiments on minerals commonly found in ultrabasic rocks, it is well known that their conductivity increases sharply with absolute temperature T around 1000°K according to $\exp(-A/T)$, where A is a constant. Thus internal conductivities are sensitive temperature indicators in the upper mantle and a value of 0.1 $[\text{ohm} \cdot m]^{-1}$ corresponds to roughly 1500°C, even though this estimate depends also on the assumed composition of the mantle material and the ambient pressure. As stated by Hamilton,[9] a tenfold increase in conductivity "can be produced by a 200°K increase in temperature (from 800 to 1000°K), a 10% increase in fayalite (of olivine), or a 40 kbar increase in pressure . . ." Hughes,[10] on the other hand, found that increasing temperature and pressure have opposing effects upon conductivity, which would give undulating internal "isotherms" a smoother appearance than undulating "isoconductivities."

Nevertheless an immense and deep-seated horizontal temperature difference seems to be well established between high mantle temperatures under the Andes—a mountain belt of intense tectonic and magmatic activity in recent times—and low mantle temperatures under the eastern lowlands, which are part of the ancient Brazilian shield, a region of long-lasting tectonic stability and magmatic inactivity. We cannot say why such a thermal imbalance should be there, but its existence has an important bearing upon theories dealing with the cause and history of mountain building.

A more complex picture of the Andean anomaly may evolve when additional observations are made. A detailed study with densely spaced stations is already under way between Abancay and Desaguadero. As is evident from Fig. 6, more stations are needed on the eastern slope of the Andes and in the adjacent lowlands of eastern Peru and northern Bolivia.

In 1967 we plan to operate a net of nine stations, following a pattern similar to that used in 1965, to allow again a concurrent study of day and night events. These stations will be installed in sets of three on isoclines north of zero dip, at zero dip, and south of zero dip. Each set will have one "sierra" station in the high Andes, one "montaña" station in the eastern foothills, and one "selva" station deep within the jungles of the Amazon and its tributaries. Even though excellent results have been obtained with the Askania variographs, some instrumental improvements will be necessary to ensure their reliable performance under tropical conditions at these inaccessible sites.

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The Absolute Geomagnetic Field of the Equatorial Ring Current

S. E. Forbush and L. Beach

Reliable absolute values U_0 for the horizontal magnetic component at the geomagnetic equator, due to the equatorial ring current (ERC), and their temporal variations provide valuable data for investigating several geophysical phenomena. Variations in U_0 resulting from the envelopment of the earth by solar plasma streams and their relation to changes in cosmic-ray intensity, often observed in the same streams (the so-called Forbush effect), provide information concerning the width of the streams, and the extent to which the streams may be deformed by the magnetosphere.

Wilcox[11] found that during each of two solar rotations four successive plasma streams swept past the earth. He showed that these streams emanated from four different longitude sectors on the sun. From one sector to the next the direction of the photospheric magnetic field, near the center of the sun's visible disk, was alternately toward and away from the sun. Near the earth, the direction (toward or away from the sun) of the magnetic field within each solar stream corresponded with that at the sun over the sector from which the stream emanated. The determination of values U_0 for the ERC field is under way for the same period to determine if these also indicate the passage of four successive streams during each of the same solar rotations.

Graphs of three-hourly values of U_0, over long periods, may be used to select magnetic storms during which the variations of U_0 are comparatively smooth and regular. The recovery of these storms may take a week or more. For these selected storms the values of U_0, together with corresponding values of vertical intensity Z, may be useful for determining induction within the earth for frequencies between about 2 and 0.2 cycles per day. If successful, this could improve knowledge concerning the variation of conductivity with depth. The success of this approach depends upon the extent to which the Z-variations are free, or can be made free, of contributions from non-ERC sources such as the S_D-current system.

The basis for the determination of U_0, discussed later, determines rather precisely the secular variation of the horizontal component H of the earth's permanent field at observatories outside the auroral zone. The results for a number of observatories indicate that the rate of secular change in H remains remarkably constant for intervals of several years, and then abruptly changes within a year or less to another constant value. The determination of such abrupt changes in H (and in Z) at a number of not too widely spaced observatories in Europe, will indicate the depth for the source of such changes.

Three-hourly values of U_0, derived for a few weak storms from midday values of H at 10 observatories at equally spaced