Title
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Authors
Hoversten, G.N.
Lee, K.H.
Morrison, H.F.

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Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA, BERKELEY

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G.N. Hoversten, K.H. Lee, and H.F. Morrison

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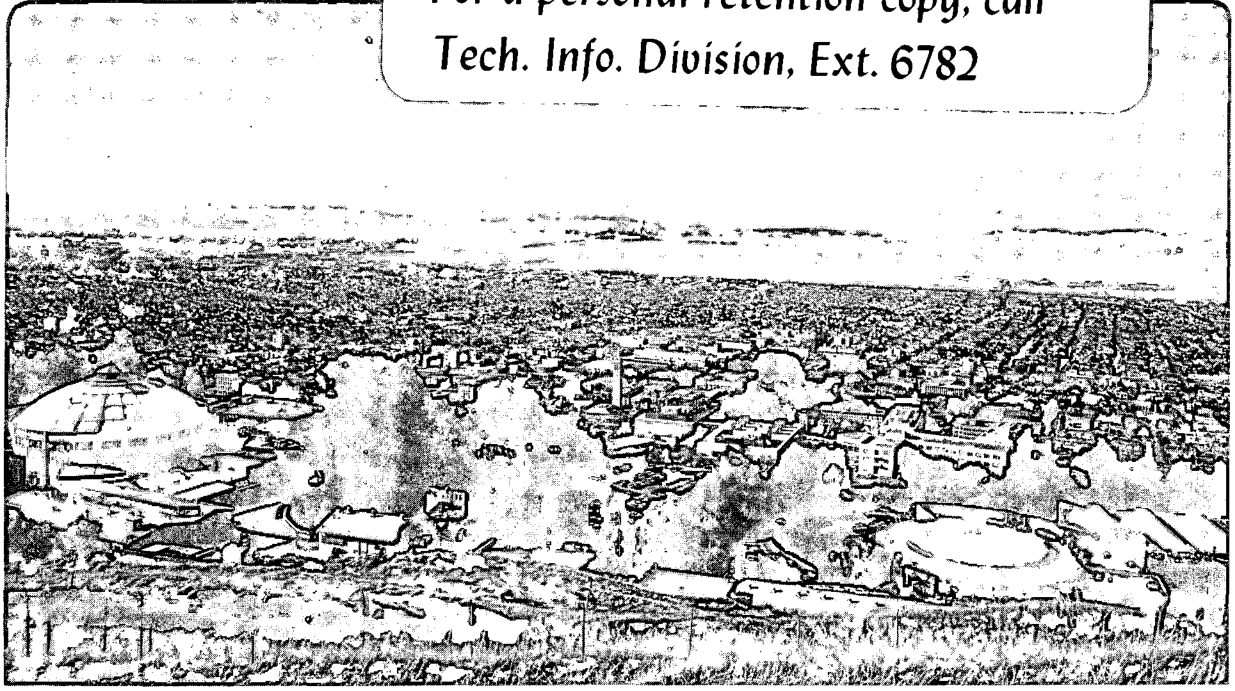

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ELECTROMAGNETIC PROFILING OF CONDUCTIVE OVERBURDEN

by

G. M. Hoversten
K. H. Lee
H. F. Morrison

Earth Sciences Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

and

Engineering Geoscience
University of California
Berkeley, California 94720

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Examination of vertical and radial magnetic fields from a horizontal-loop electromagnetic system over a layered model with a conductive surface layer shows an anomalous response at frequencies just below those where the field behavior asymptotically approaches the plane wave response. In particular, a pronounced trough, or minimum, develops in the phase response of the vertical component (loop-loop system). An example of this is shown in Figure 1. The vertical field, H_z, and its phase, ϕ_z, for a transmitter-receiver separation ($R = T_x - R_x$) of 300 m, a loop radius of 56.4 m, and a unit dipole moment are shown as a function of frequency for a uniform half-space of $\sigma_1 = 1$ S/m (curve D) and for the case of a conductive overburden layer of thickness 50 m and $\sigma_1 = 1$ S/m overlying a half-space of $\sigma_2 = 0.02$ S/m (curve A). The frequency-domain solution follows the development of Morrison et al. (1969).

If the surface-layer conductivity is greater than the basement conductivity, then for a given transmitter-receiver separation the value of the phase at the minimum, ϕ^{min}, and the frequency at which it occurs, f^{min}, constitute a unique point on a plot of ϕ^{min} versus f^{min} for various thicknesses, h_1, and conductivities, σ_1, of the overburden layer. Figure 2 shows such a plot for a transmitter-receiver separation of 250 m, a loop radius of 1 m, and a basement of infinite resistivity ($\sigma_2 = 0$). This plot is effectively independent of the resistivity of the basement as long as it is at least 100 times that of the overburden. For any arbitrary sounding, only ϕ^{min} and f^{min} are needed to determine uniquely the conductivity and thickness of the surface layer. With modern equipment, a phase accuracy of ±1° and a frequency accuracy of a few percent would clearly locate a point in σ, h space quite well.

To test the efficiency of this approach to overburden profiling in a realistic situation, we have applied it over a two-dimensional model in which there is an abrupt change in overburden thickness (Figure 3) and over a model in which both the thickness and the conductivity of the overburden change abruptly (Figure 4). These results were obtained using the finite-element program recently developed by Lee (1978). Figure 3 presents the model along with ϕ_z at five frequencies for five transmitter-receiver separations taken in a profile across the region of abrupt change. The five values of ϕ_z^{min} are plotted on Figure 2 and marked "Profile 1." As can be seen, the (ϕ_z^{min}, f^{min}) points make a smooth transition from $h_1 = 50$ m to $h_1 = 75$ m while staying very close to the line $\sigma_1 = 1$ S/m. Considering that for profile position 1 the receiver is only 50 m from the discontinuity and for position 5 the transmitter is only 50 m from the discontinuity, this system gives remarkable resolution.

Figure 4 is the same as Figure 3 with the exception that both the conductivity and thickness of the surface conductor change abruptly. The phase minima for this model are plotted on Figure 2 and marked "Profile 2." The conductivity and thickness were changed so that their product, $\sigma_1 \cdot h_1$, would remain constant. This was done for comparison with results that might be obtained from a least-squares inversion of data from such a model. For such cases, unless a data point happens to fall right at the phase minimum, the statistics of the generalized inverse would indicate that only the product $\sigma_1 \cdot h_1$ could be accurately resolved, whereas the ϕ_z minimum seems to show no such ambiguity. The phase minima of Profile 2 make a smooth transition from $\sigma_1 = 1$, $h_1 = 50$ to $\sigma_1 = 0.666$, $h_1 = 75$ and determine both parameters very accurately at 50 m on either side of the contact. Profile 2 also serves to illustrate the fact that models of constant $\sigma \cdot h$ produce vertical lines on plots of ϕ_z^{min} versus f^{min}. Figure 2 also shows that as h approaches R, the separation between lines of constant h decreases, prompting the suggestion that R be $\geqslant 2h$ for an accurate estimate of h.

It is worth noting two sources of error in the profile points plotted on Figure 2. The first is due to estimating ϕ_z^{min} with only five data points, as shown in Figures 3 and 4. (The restriction to five data points was done merely to minimize the high cost of running the two-dimensional models.). The second is the numerical error of the modeling program, which amounts to ±1 degree of phase.

In conclusion, a microprocessor-controlled profiling system which would search for a minimum in ϕ_z and then either calculate ϕ_z^{min} or compare stored ϕ_z^{min} values with the measured values could be used to provide fast and accurate surveys of conductive overburden. The system would be capable of determining σ_1, h_1 and the location of discontinuties in σ_1 and h_1. For greater accuracy in determining the locations of discontinuities, the transmitter-receiver separation could be shortened at the expense of penetration depth.

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Figure Captions

Fig. 1 Vertical field amplitude and phase for models A and D; transmitter-receiver separation 300 m.

Fig. 2. Plot of ϕ_z^{min} versus f^{min} for surface conductive layers.

Fig. 3. ϕ_z trough at five profile positions spanning discontinuity in surface layer thickness.

Fig. 4. ϕ_z trough at five profile positions spanning discontinuity in surface layer conductivity and thickness.

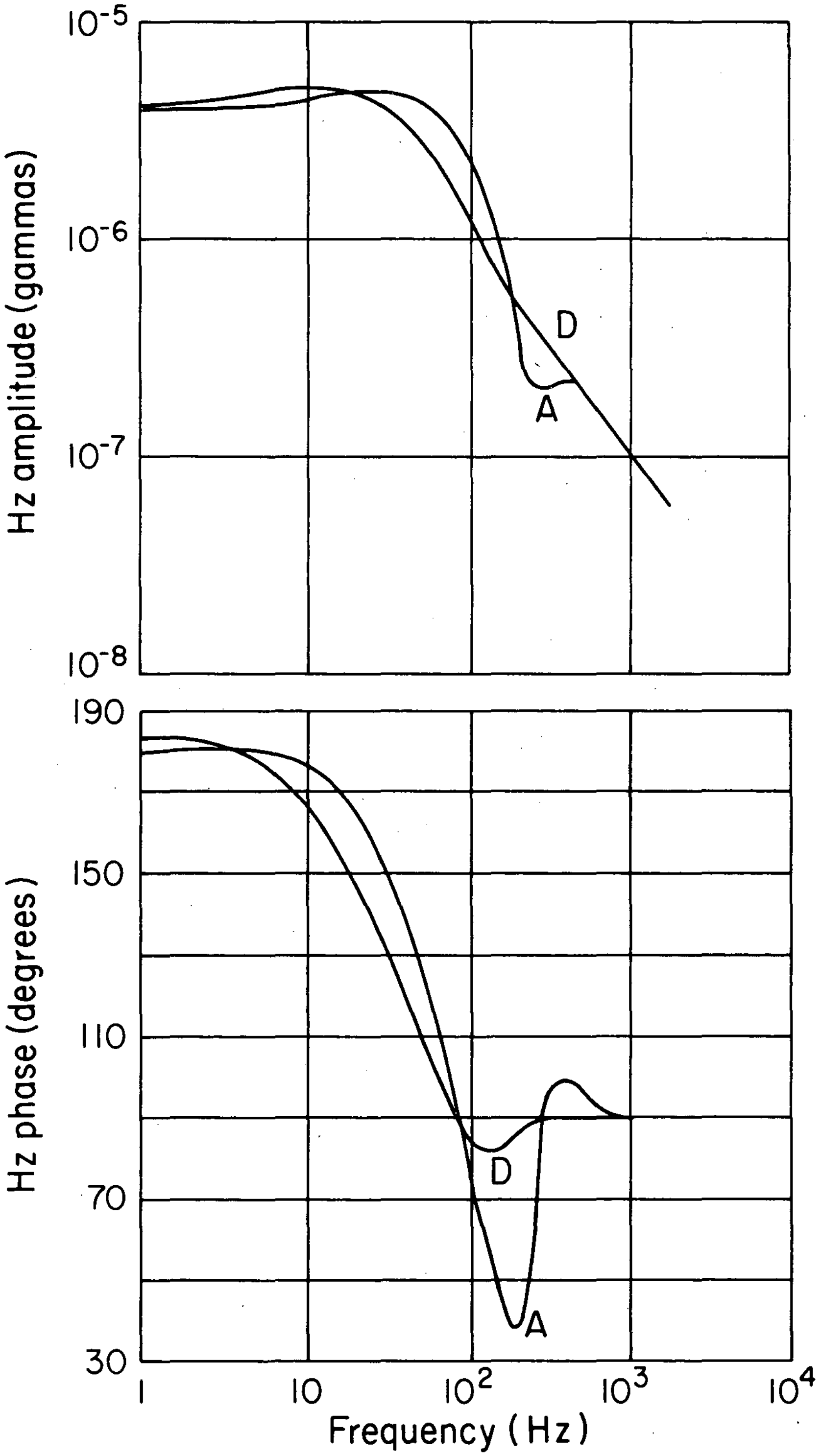

Fig. 1

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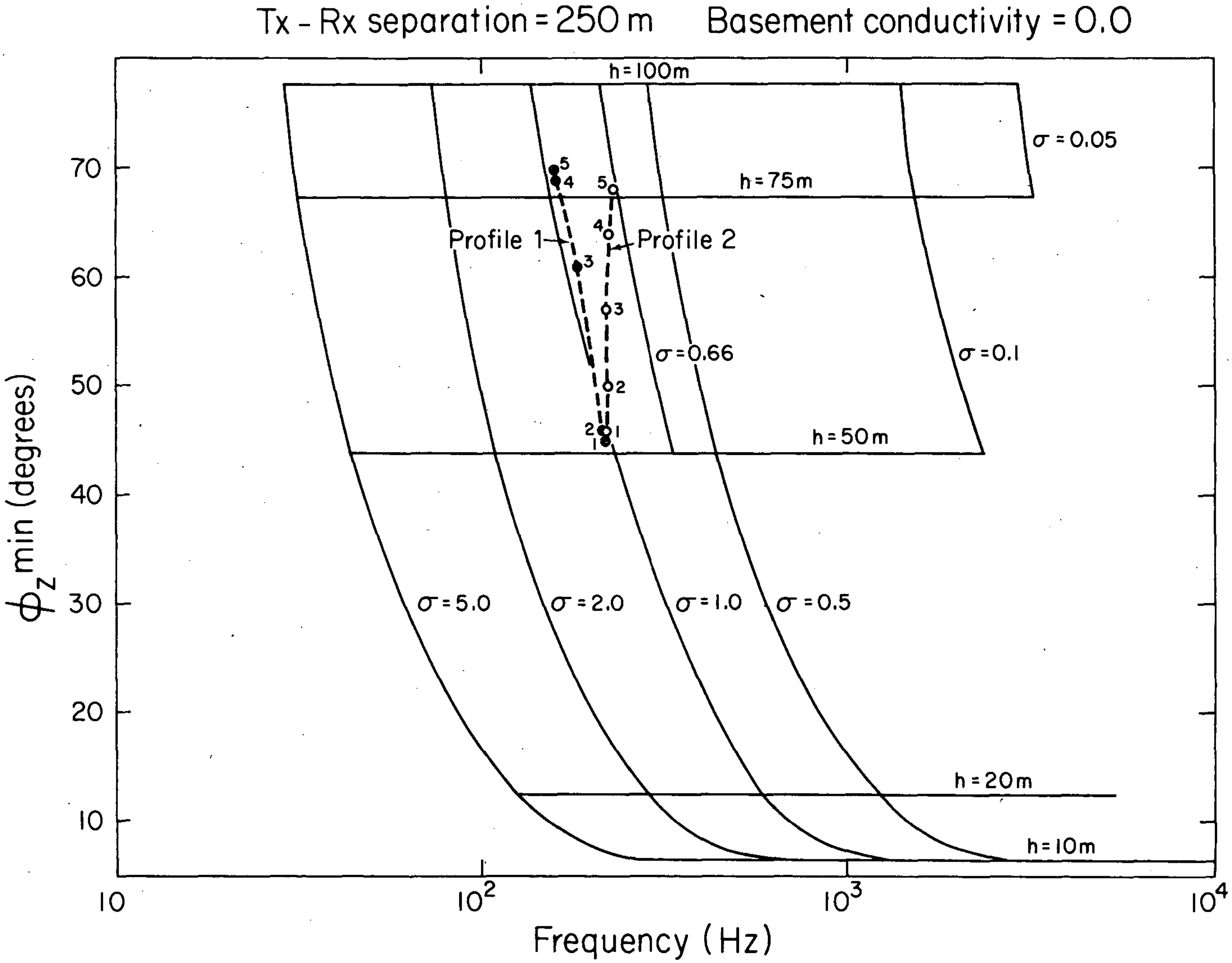

Fig. 2

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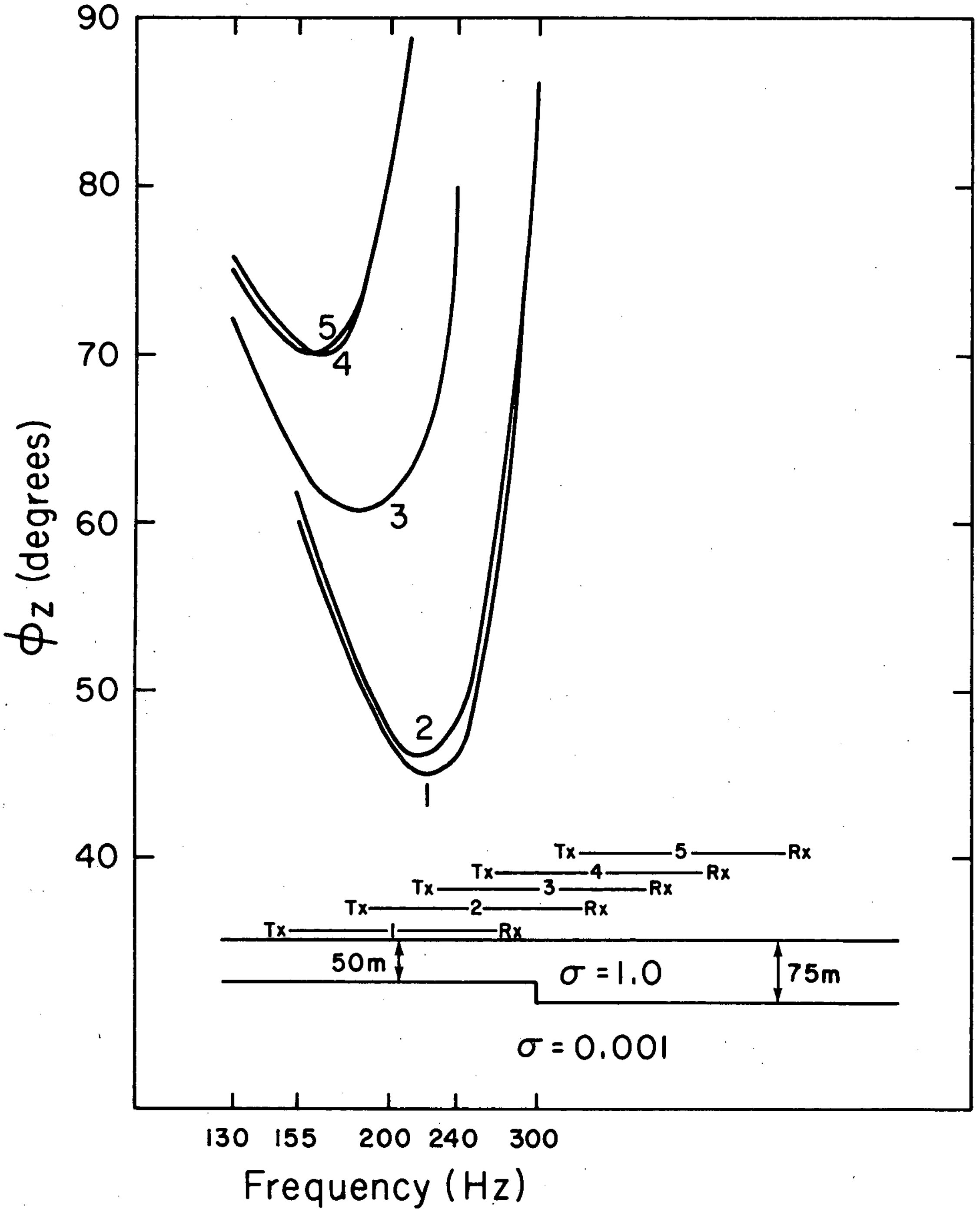

Fig. 3

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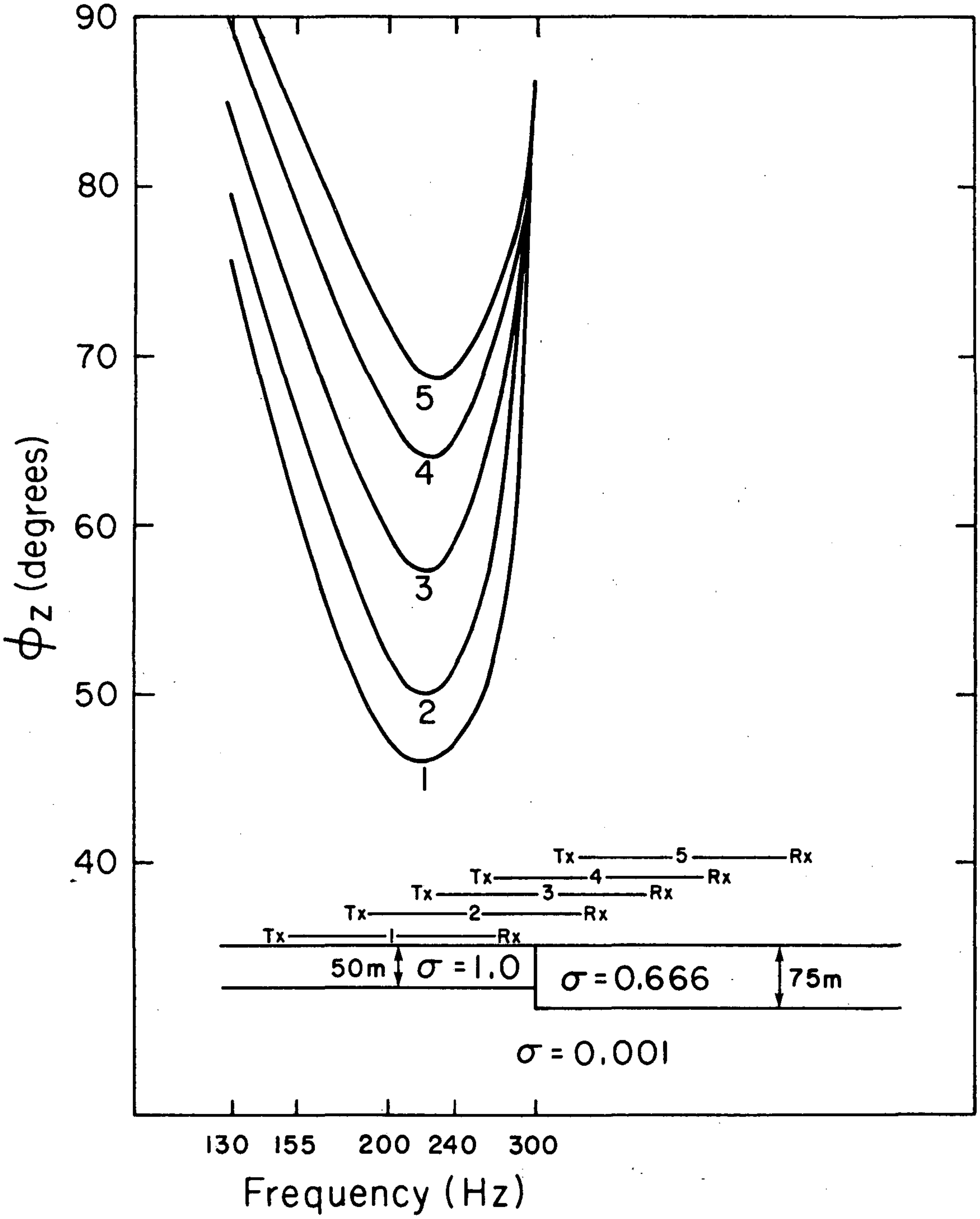

Fig. 4

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