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ELECTROMAGNETIC PROFILING OF CONDUCTIVE OVERBURDEN

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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 $\pm 1^\circ$ 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 $(\phi_z^{\min}, f^{\min})$ 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 $\geq 2h$ 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 discontinuities 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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- Lee, K. H., 1978, Electromagnetic scattering by a two-dimensional inhomogeneity due to an oscillating magnetic dipole (Ph.D. dissertation): Berkeley, University of California.
- Morrison, H. F., Phillips, R. J., and O'Brian, D. P., 1969, Quantitative interpretation of transient electromagnetic fields over a layered half space: Geophysical Prospecting, v. 17, p. 82.

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.

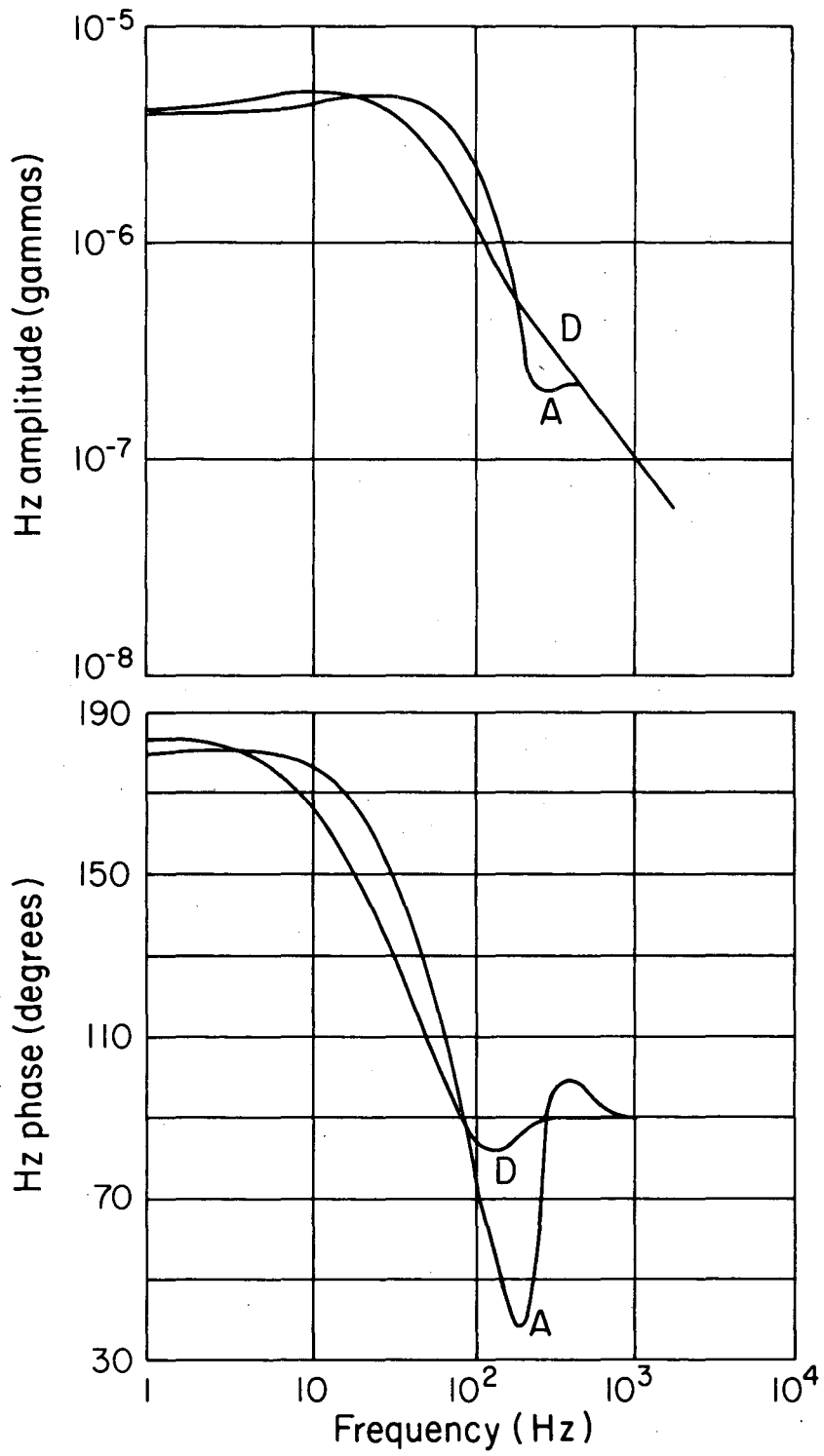


Fig. 1

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Tx - Rx separation = 250 m Basement conductivity = 0.0

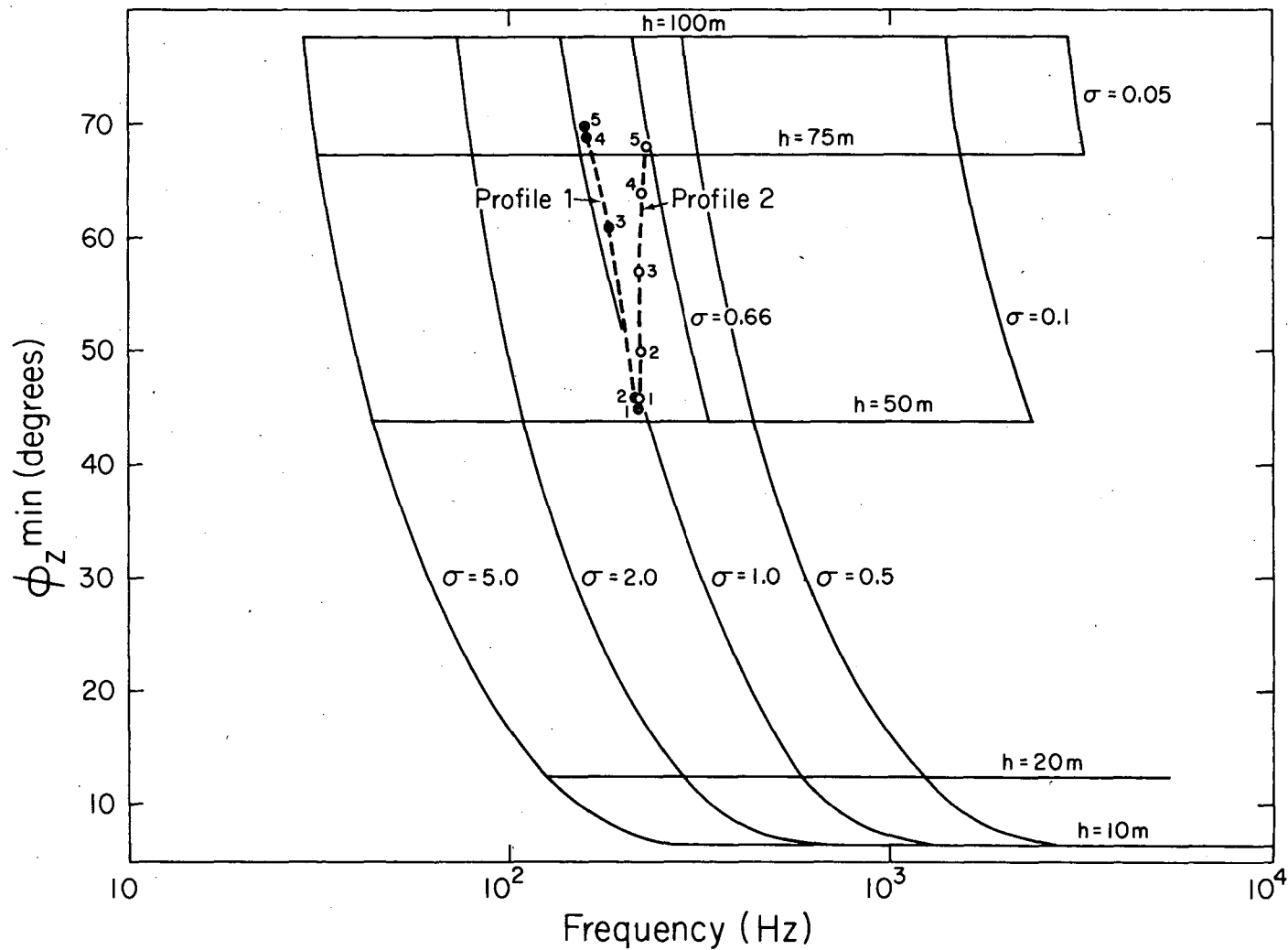


Fig. 2

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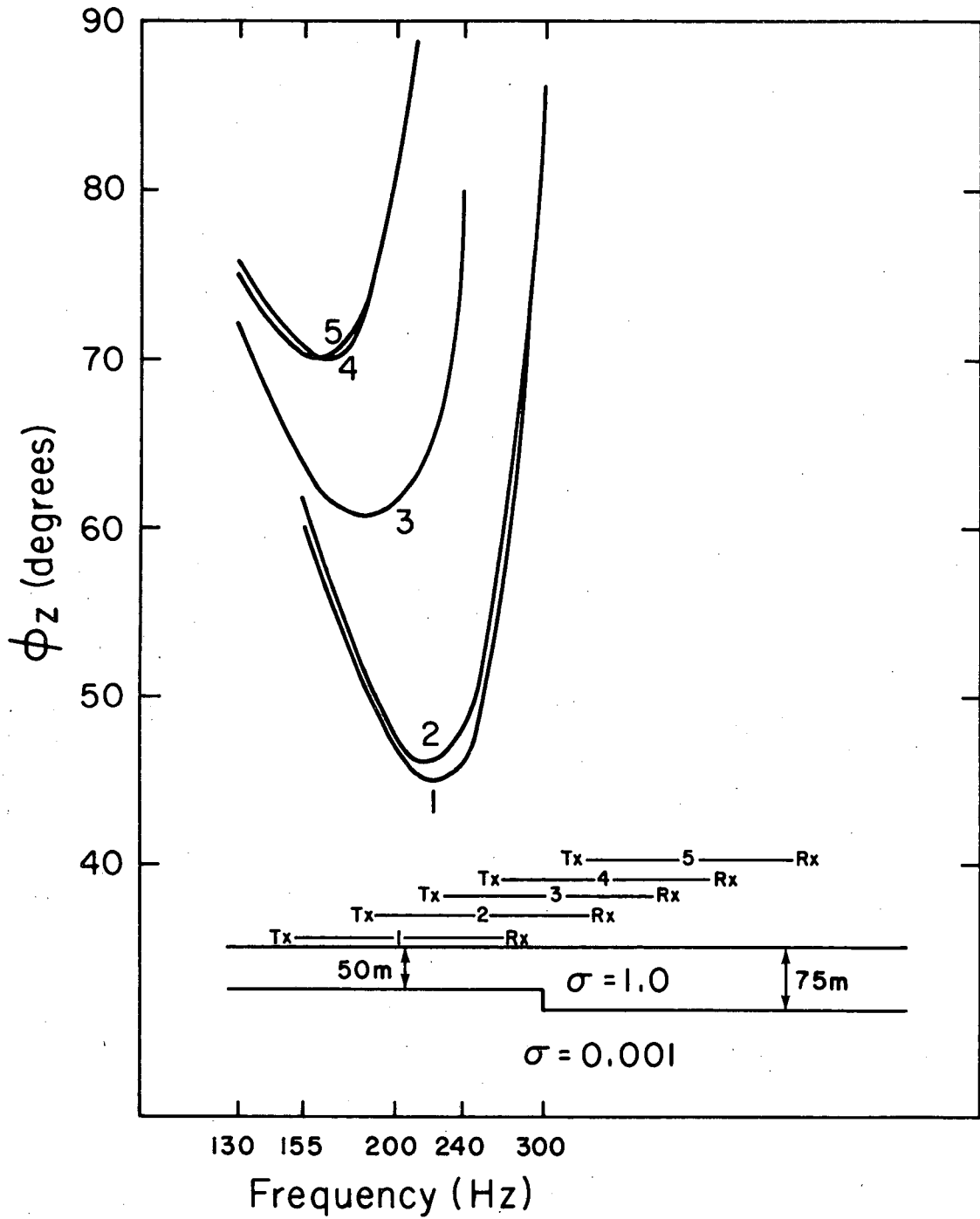


Fig. 3

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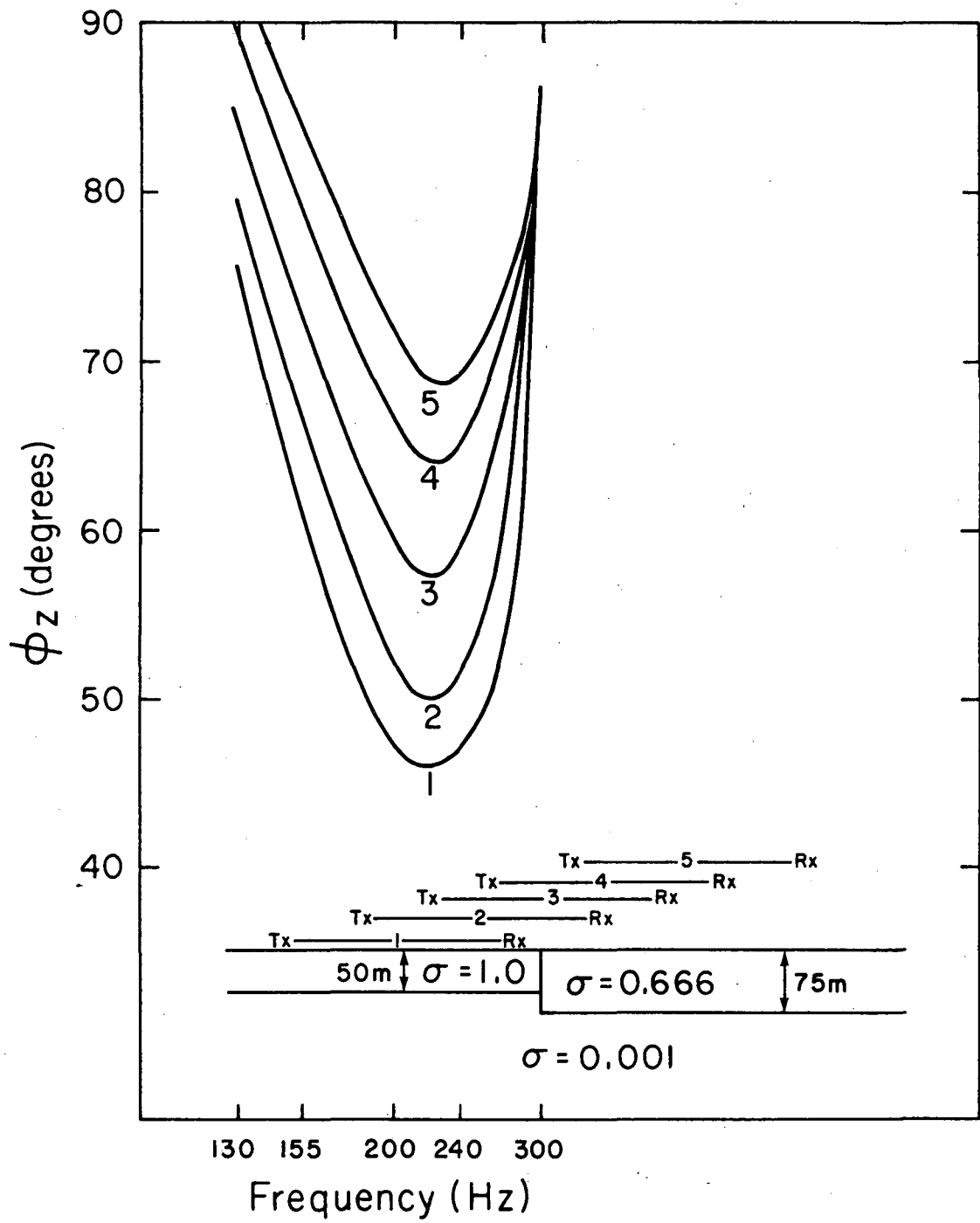


Fig. 4

XBL 811-2574

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