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MEMORANDUM

TO: H. P. Ross

FROM: W. R. Sill

SUBJECT: Self-potential Studies in East Puna, Hawaii by C. J. Zablocki

In the above paper Zablocki proposes a convective model for the self-potential anomalies as in Figure 1 (his Figure 4). In a recent report (Sill, 1982) I investigated the modeling of self-potential effects due to convection. Figure 2 shows the results for two models. In both models the maximum temperature (200°C) is the same as are the velocity fields. The maximum temperature and velocity are at $X = 0$, $Z = \beta^{-1}$ as indicated in the figure. The flow field is upward in the plume ($-a \leq x \leq a$) and the return flow takes place in the exterior region. As the figure shows, the self-potential reaches a maximum near the center of the plume and it is larger in the case where the cross coupling parameter (L) is zero exterior to the plume. The normalized potential (ϕn) in the model is related to the true potential (ϕ) by

$$\phi' = \phi_n L' Vo' \Delta x'/\sigma'. \qquad (1)$$

where L' = true velocity cross coupling parameter

V_o' = true convective velocity (maximum)

$\Delta x'$ = true length scale

σ' = true conductivity.

The velocity cross coupling parameter L is related to the better known streaming potential coefficient (C) by

$$L = \sigma C/k. \tag{2}$$

where k = permeability.

In order to scale the model results to any geological setting we have to estimate the true parameters in equation (1). The length scale ($\Delta x'$) can be estimated by noting that the anomaly width at the one-half amplitude points is around 3 to 4 model units. The one-half amplitude widths in Zablocki's report are in the range from 500 m to 600 m so the length scale is around 150 m to 200 m. The depth to the maximum temperature (200°C) and the maximum velocity in the plume is then around 300 m to 400 m. The estimates of the other parameters is simplified by making use of an approximate relation between the maximum temperature change Tm and the maximum velocity (V_0)

$$V_0 \cong \gamma \alpha g \, Tm \, k_0 \eta_0 / \eta(Tm). \tag{3}$$

where α = rate of change of water density with temperature

g = acceleration of gravity

k_0 = permeability at room temperature

η_0, Tm = Viscosity of water at room temperature, Tm

γ = shape factor for type of convection.

The shape factor γ varies from 1/2 for nearly equidimensional flows (horizontal length = vertical length) to values greater than 1 for flows with vertical length > horizontal length.

Making use of equations (3) and (2) in equation (1) and noting that parameters for the model are specified at room temperature, we get

$$\phi' = \gamma\phi_n \; C \; \alpha \; g \; Tm \; \Delta x' \eta_0/\eta(Tm). \qquad (4)$$

In equation (4) the parameters $\Delta x'$, Tm, γ have already been specified ϕ_n, α, g and $\eta_0/\eta(Tm)$ are known so the only free parameter is the streaming potential C. Typical values of C for rocks full in the range from 5 to 25 mv/atm (1 mv/atm = 10^{-8} MKS). Taking as a best case, model 2 (ϕ_n = .4) with C = 25 mv/atm we get an estimate for the self-potential (ϕ') of about 200 mv. Since the observed anomaly (Figure 1) is about 400 mv we fall short by a factor of two. The anomaly could be explained with C = 50 mv/atm but values this large are not typical of rocks. For model 1 the required streaming potential is around 100 mv/atm. One might be tempted to scale up Tm in equation (4) but the model results are not linear in temperature and the Tm used in equation (4) must be the same as that used in the calculation of ϕ_n. The results of this investigation indicate that the model suggested by Zablocki is in the gray area of plausibility. The required streaming potentials are very large compared to the typical values for rocks but then the model fit to the real situation is poorly known. A reduction in the required streaming potential could result from an increase in temperature but more likely from an increase in the shape factor γ. The latter should increase some if the flow has a thin plume with a large vertical scale. Estimating γ or the true V_0 would involve the solution of the appropriate convection problem. In a "full up" solution of the convection problem the calculated velocity field can be used to model the self-potential by the technique presented in Sill (1982).

References

Sill, W. R., 1982, Self-potential effects due to hydrothermal convection (velocity cross coupling), Dept. of Geology and Geophysics, University of Utah, DOE Report DOE/ID/12079-68.

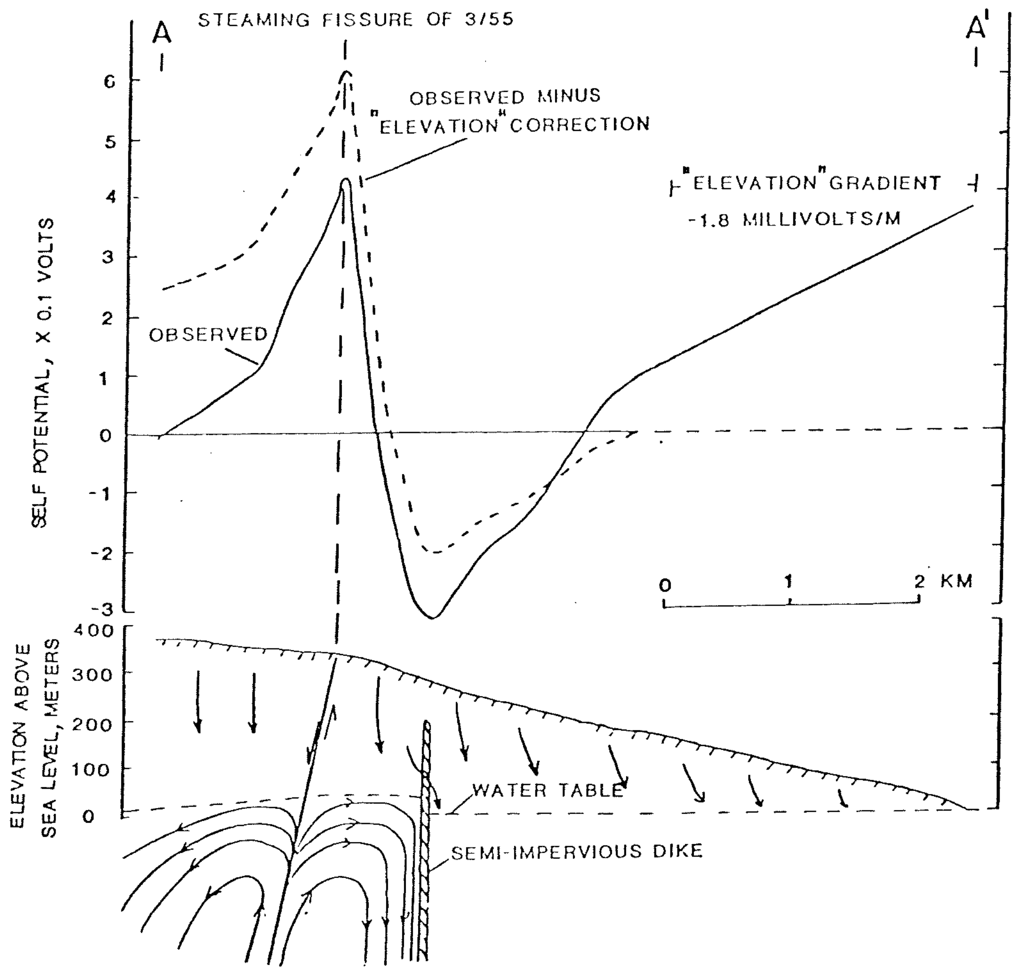

Figure ~~4~~ 1 Self-potential profile (solid) along traverse A-A' (Fig. 2) and modified profile (dashed) after removal of an "elevation" gradient. The cross section shown below the profile is a conceptual model of the hydrology and substructure that may account for the potential distribution as discussed in the text. Arrowed-lines below water table are idealized streamlines of fluid (liquid and vapor) flow, and above water table, are downward migration of meteoric water.

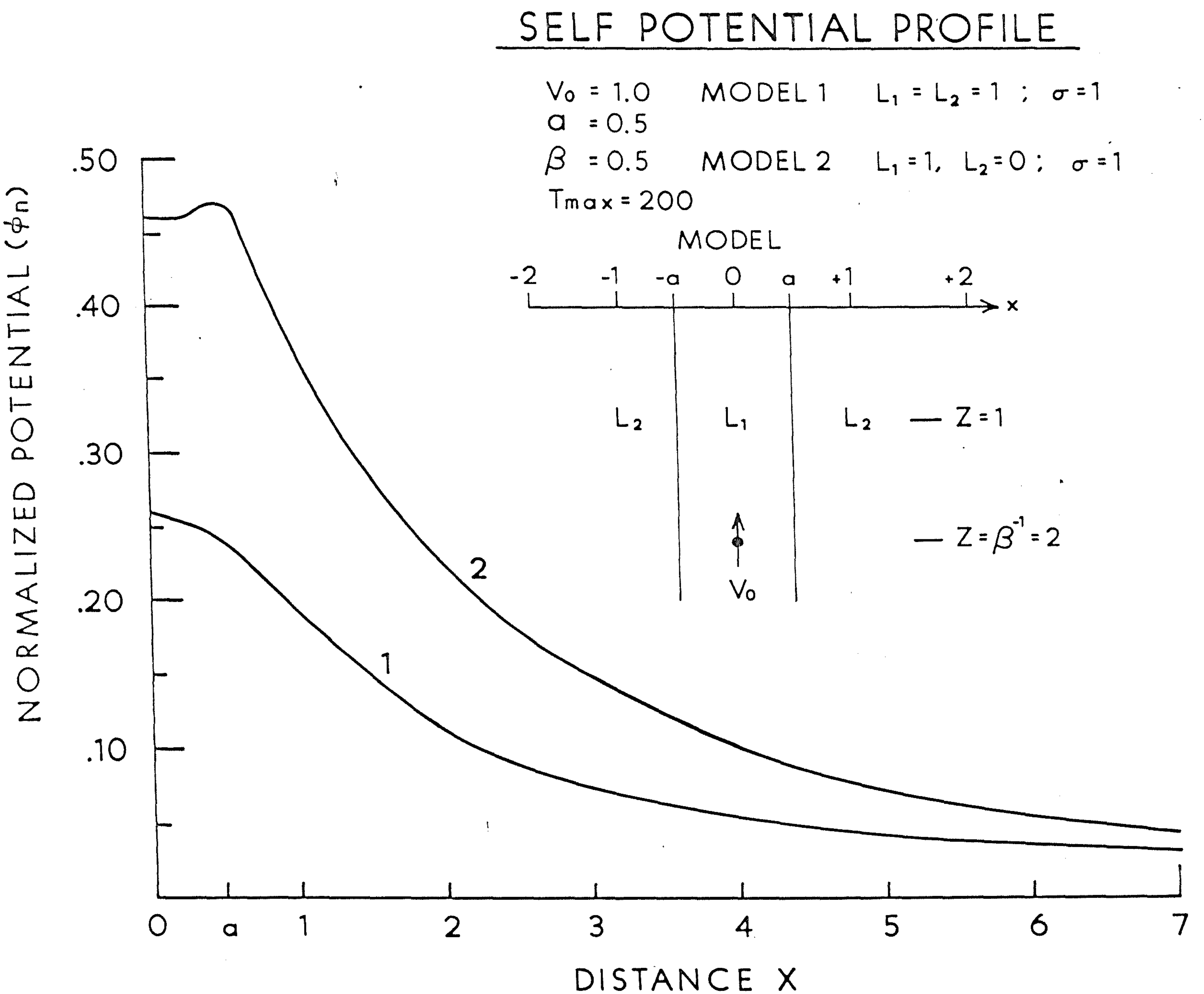
SELF POTENTIAL PROFILE
V₀ = 1.0
a = 0.5
β = 0.5
Tmax = 200
MODEL 1 L₁ = L₂ = 1 ; σ = 1
MODEL 2 L₁ = 1, L₂ = 0 ; σ = 1
MODEL
-2
-1
-a
0
a
+1
+2
x
L₂
L₁
L₂
Z = 1
Z = β⁻¹ = 2
V₀
NORMALIZED POTENTIAL (φn)
.50
.40
.30
.20
.10
2
1
0
a
1
2
3
4
5
6
7
DISTANCE X

FIGURE 2