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MEMORANDUM

April 13, 1981

TO: Mr. Allan Jelacic

FROM: D. L. Nielson and H. P. Ross

SUBJECT: Hot Dry Rock Project, Conway Granite, New Hampshire

The Earth Science Laboratory, UURI, was asked to estimate the average thermal gradient within the White Mountains batholith, and to indicate a "best case" (most optimistic) and a "realistic" case for minimum depths to the 250^{0}C isotherm. Christian Smith and Duncan Foley of our staff have reviewed the data generated by DOE funded studies in the area, the articles sent in the data package, additional articles from our library, reviewed modeling of the geophysical data, and contacted people familiar with the geology of the area.

REVIEW OF EXISTING DATA

The two main data sets relevant to this brief review of the geothermal potential of the Conway granite are by Osberg et al (1978) and by Hoag and Stewart (1977). We concur with the data compilation, modeling and interpretation of Osberg et al (1978), and feel that they have done an exemplary study. Smith has verified some of the one-dimensional modeling, but Osberg et al's (1978) finite element two-dimensional model is more appropriate.

An important geologic conclusion of Osberg et al (1978), and Hoag and Stewart (1977) is that the Conway Granite is not a single uniform body but consists of several different phases; the composition varies considerably both laterally and vertically, as in the Redstone drill hole. This variation indicates that the radiogenic heat production is different for different units. All units have relatively high thermal conductivities ($k \geq 0.0058$ cal/cm^{0}C sec). The thermal conductivity is not likely to decrease with depth.

The gravity model of Osberg et al (1978) which estimates a maximum thickness of 4-6 km for the White Mountain batholith, is reasonable, and fits well with proposed emplacement mechanisms for the Conway Granite, and the depth profiles of other granite bodies.

GEOPHYSICAL EVALUATION

Thermal Gradient. We have calculated a thermal gradient of approximately $32^{o}C/km$ based on the measured bottom hole temperature of $33.6^{o}C$ in the Redstone drill hole (Hoag and Stewart, 1977) and an estimated mean annual temperature of $4.4^{o}C$. The integrated gravity-heat flow model of Osberg et al (1978) indicates a thermal gradient of 26^{o} - $28^{o}C$ for depths of 0 to 6 km. Both of these values are consistent with one-dimensional modeling by Smith, and may represent a logical range of thermal gradient values. A simple straight line extrapolation of the $33.6^{o}C/km$ gradient (oversimplified and generally unreliable) yields an estimated depth of 7.8 km to the $250^{o}C$ isotherm. This is approximately 3000 meters deeper than the LASL hole at Fenton Hill.

Several temperature versus depth profiles were computed by Smith using equations for normal heat flow (one-dimensional model) developed by Costain et al (1977) and Osberg at al (1978). Heat flow, heat generation and thermal conductivity values for New Hampshire lithologies and the Conway Granite in particular were taken from Birch et al (1968) and Osberg et al (1978). These computations indicate that low thermal conductivity could be more important than radiogenic heat generation to the development of high temperatures at depth (noted earlier by Constain et al and Osberg et al) and in general support the more complete studies of Osberg et al (1978) and their conclusions as stated on pages 89, 91, and 92 and shown in Fig. 1. It is exceedingly unlikely that $250^{o}C$ temperatures exist at depths less than 7.0 km. In view of the probable lower limit of $k=0.0058$ for thermal conductivity of the Conway Granite, an exceptionally high heat flow approximately double that observed would be necessary to support $250^{o}C$ at depths shallower than 5 km.

Best Case. The most optimistic possible case has been defined by Hoag and Stewart (1977). They postulate a maximum thickness of 7.2 km for the red (most radiogenic) phase of the Conway granite, with $A=25$ HGU, with which they would generate a maximum heat flow of 2.7 HFU. They predict a temperature of $T=260^{o}C$ at 6 km.

Critique. Hoag and Stewart pose a "what if" case. The maximum thickness of the batholith is probably 4-6 km (Osberg et al, 1978); only a portion of this is the Conway granite; a mean value for the radiogenic phase is about 17.5 HGU; and the highest observed heat flow is 2.2. HFU. We are unable to verify the temperature calculation of $260^{o}C$ at 6 km since their math is not given. A linear projection of the $dt/dz = 32^{o}C/km$ from the Redstone hole and one-dimensional model calculations assuming $k=0.0058$ and $q_{o}=2.7$ suggest $T=200^{o}C$ at 6 km, $T=250^{o}C$ at 7.8 km.

Realistic (but possible) Best Case. This case is described in detail by Osberg et al (1978). Their finite element model for a Conway Granite body of limited lateral extent incorporates a likely maximum thickness of the batholith of 5.25 km and is matched to observed Conway area heat flow of 2.1 HFU. They use a heat generation of A=17.5 HGU, thermal conductivity of k=.0058, both favorable and realistic physical property parameters. Their computational results, shown as Plate 10 of their report, indicate the following temperatures and depths: T=170°C at 6 km, T=220°C at 8 km, T=250°C at 9.5 km. Our Fig. 1 summarizes their model and results.

SUMMARY

The linear relationship between heat flow and radiogenic heat generation is now well known, as a result of the work of Birch, Roy and Decker, and of the ongoing work on the Atlantic Coastal Plain by Costain, Glover, and Sinha at VPI. Since the thermal conductivity of the Conway Granite is reasonably well fixed by the average 27% quartz content and observations at 0.0058 (lower limit for the best case), and heat flow observations (though limited in number) seem to reach a maximum of 2.0 - 2.2, one is led to the conclusion that the bulk heat generation (i.e. volume integral of heat generation distribution) has been overestimated. Our results confirm that the presence of a thermal resource in a conductive environment requires either a thick blanket of insulating sediments (the Atlantic Coastal Plain model of VPI and SU) or a secondary source of heat (LASL HDR site at Fenton Hill). The Conway Granite has neither of these characteristics, and therefore does not make an attractive thermal target.

Our evaluation, as expressed above, forces the following recommendations:

1) Select an alternate site for the proposed hot dry rock power generation experiment, where an insulating cover or secondary heat sources are present (Atlantic Coastal Plain, Fenton Hill, or Roosevelt Hot Springs (Getty Oil Co. hole 52-21, 250°C at 3 km.)
2) Obtain additional heat flow, thermal gradient, and thermal conductivity data on the Conway Granite area with perhaps five additional holes to depths of 300m and thermal conductivity measurements on these holes and on the Redstone drill core. These data would allow more detailed thermal modeling. If substantially higher heat flow is not determined, abandon the project.

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DLN;HPR:jr

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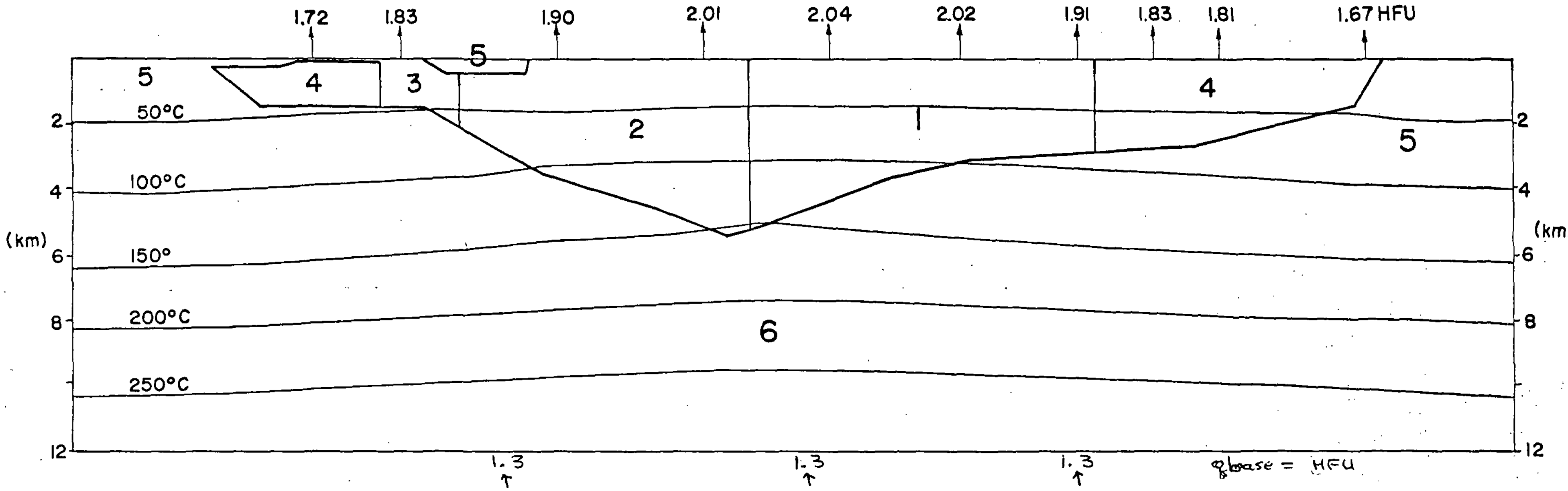

material number	rock type	k (cal/cm sec C)	A (HGU)
1	Conway Granite	.0058	17.5
2	Mt. Osceola Granite	.0058	15.3
3	Albany Quartz Syenite	.0058	13.6
4	New Hampshire Magma Series Granite	.0058	9.7
5	Littleton Formation	.0071	5.5
6	crustal rock	.0055	2.0

Figure 1 - REALISTIC MODEL AND THERMAL GRADIENT DISTRIBUTION. (Combined from Plate 10 and Figure 22 of: Osberg, P. H., Wetteraurer, R., Rivers, M., Bothner, W. A., and Creasy, J. W., 1978)