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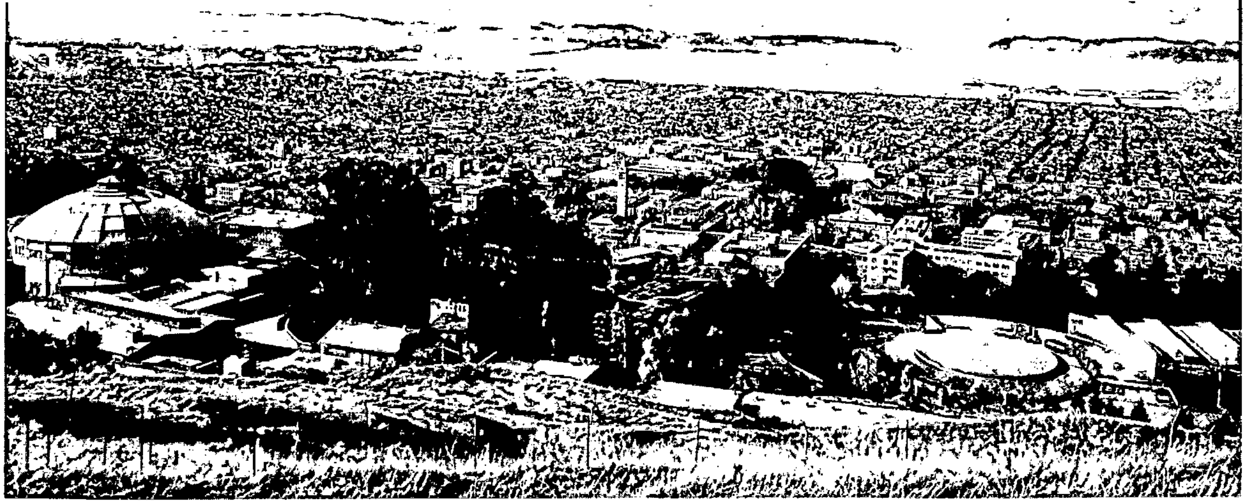

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RADIOGEOLOGICAL ASSESSMENT OF CANDIDATE SITES FOR NUCLEAR WASTE REPOSITORIES, EXEMPLIFIED BY STUDIES OF THE STRIPA PLUTON, SWEDEN

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ABSTRACT

Investigation of candidate sites for nuclear waste isolation will require an assessment of their radiogeologic settings. Studies at the Stripa research facility in granitic rock of central Sweden incorporated the distribution and abundance of naturally occurring radioelements in rocks encompassing the underground experiments and in the accompanying fracture-controlled groundwater system. These studies showed that besides defining the natural radioactivity baseline upon which the effects of radioactive waste will be superimposed, radioelement distributions can be used to determine the apparent age of the groundwater and its flow paths. In crystalline rocks, where the groundwater systems are confined to the joints and fractures, the uranium daughter element, radon-222 in the water serves as a natural tracer to locate fractures along which significant flow is occurring and to measure the flow rates. The heat production from radioactive decay of uranium-238, thorium-232, and potassium-40 in the rock, combined with measurements of regional and local geothermal heat flow, permit calculation of the apparent size of the rock mass that will encompass the repository. This method is especially useful in terranes such as at Stripa where the contacts between plutons and older rocks are concealed.

INTRODUCTION

To properly characterize candidate sites for radioactive waste isolation, it will be necessary to obtain a good understanding of their radiogeologic settings. The distribution and abundance of the naturally-occurring radioelements, ^{238}U, ^{232}Th, their daughters and ^{40}K in the rock mass encompassing the repository and in neighboring rocks, comprise the baseline upon which the effects of the radioactive waste are superimposed. The distribution of these radioelements is also a good indicator of the geochemical homogeneity of the rock mass. At the Stripa experimental facility in an inactive iron mine in central Sweden (1), radiogeologic studies included gamma spectrometric surveys on the surface and underground of the U, Th and K contents of the quartz monzonite pluton encompassing the experiments, high-grade metamorphic rocks surrounding the pluton, and neighboring larger granitic plutons (2). A geological cross section through the experimental workings comprises Figure 1.

DISTRIBUTION OF RADIOELEMENTS

The abundance of the radioelements, K, U and Th, was measured, both on the surface and underground by a portable gamma-ray spectrometer to obtain a preliminary indication of the geochemical homogeneity of the Stripa pluton and to calculate its radiogenic heat production. Gamma readings were made at both surface and underground locations with the detector held in contact with the rock. A hand specimen for subsequent laboratory analyses was collected at each sample location. The field gamma spectral measurements were calibrated by laboratory analyses of hand specimens and drill cores, permitting calculations of radioelement concentrations from field counting rates.

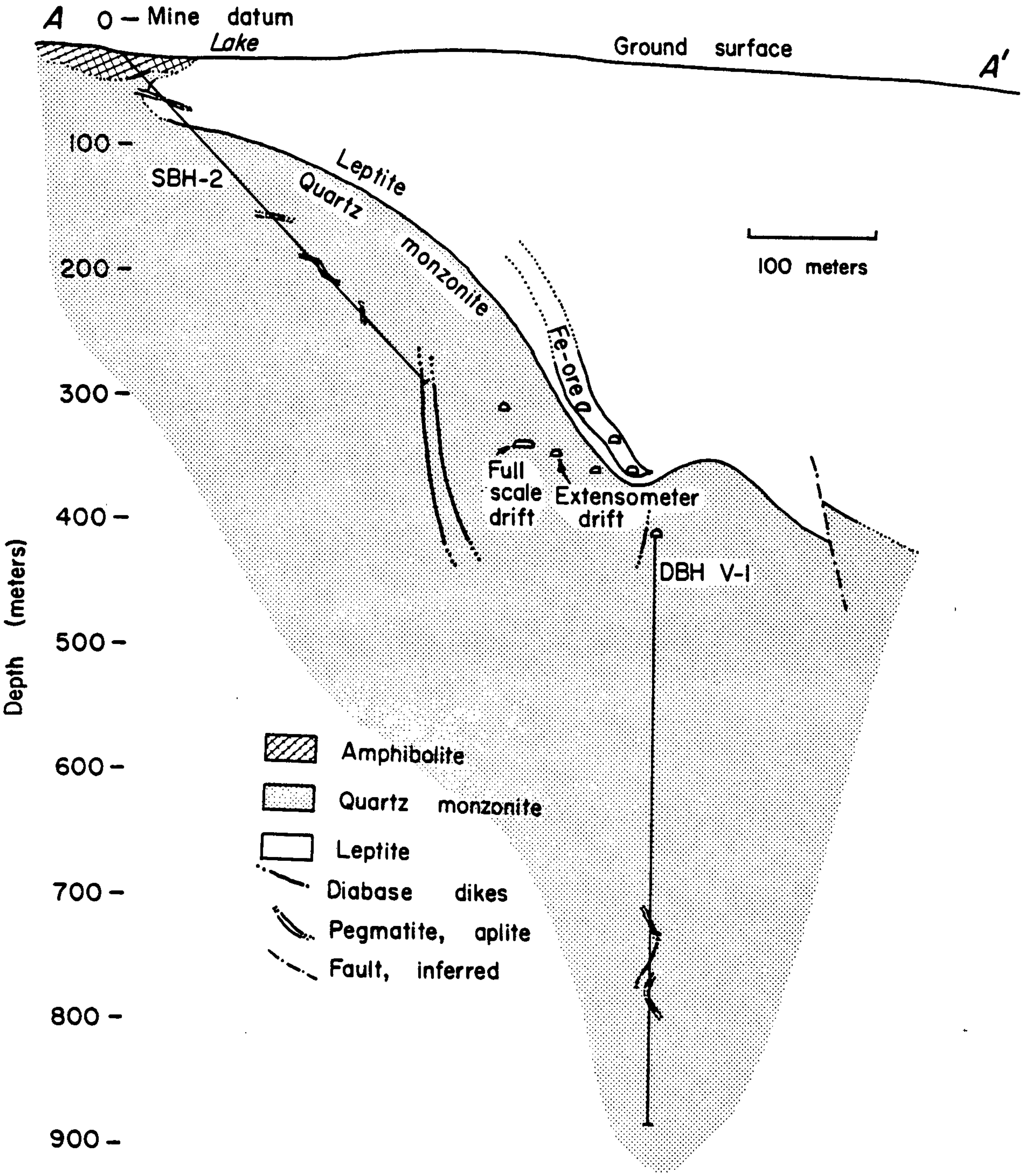

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Figure 1. Vertical cross section through experimental workings showing inclined and vertical boreholes.

The Stripa quartz monzonite is unique in its radioelement content, both in the abundance of radioelements and their ratios, (summarized on Table 1). The relatively high uranium and thorium contents of the quartz monzonite contrast with those of the other plutons measured in the region. Inspection of Figure 2, the triangular diagram relating the corrected abundance of U, Th, and K measured by field gamma spectrometry, shows that there are distinct fields for the Stripa pluton, compared with the neighboring leptite (metamorphosed volcanic rock) and other granitic rocks in the region. The Th/U ratio of the Stripa quartz monzonite is considerably lower (1.2 in surface and 0.8 in subsurface exposures) than in most other granitic rocks measured in the region (2.6) and in granitic rocks in general (2 to 4).

Table 1. Mean and Standard Deviation of Radioelement Contents by Field γ Measurements

Rock Type	No. of meas.	U, σ (ppm)	Th, σ (ppm)	K, σ (%)	Th/U
Stripa Qtz. Monz.					
Surface	9	26.9, 5.5	33.0, 5.7	4.6, 0.7	1.1, 0.1
Underground	34	37.4, 6.2	29.2, 3.8	3.9, 0.3	0.8, 0.1
Leptite					
Surface	5	3.3, 0.7	11.9, 2.9	3.1, 0.6	3.6, 0.4
Underground	9	5.4, 3.1	17.9, 1.4	2.8, 0.5	3.9, 1.2
Regional Granitic Rocks	7	17.6, 15.4	26.6, 6.6	5.2, 1.5	2.4, 1.2
Regional Metamorphic Rocks	5	6.1, 1.5	14.6, 8.7	2.5, 1.1	2.6, 1.9

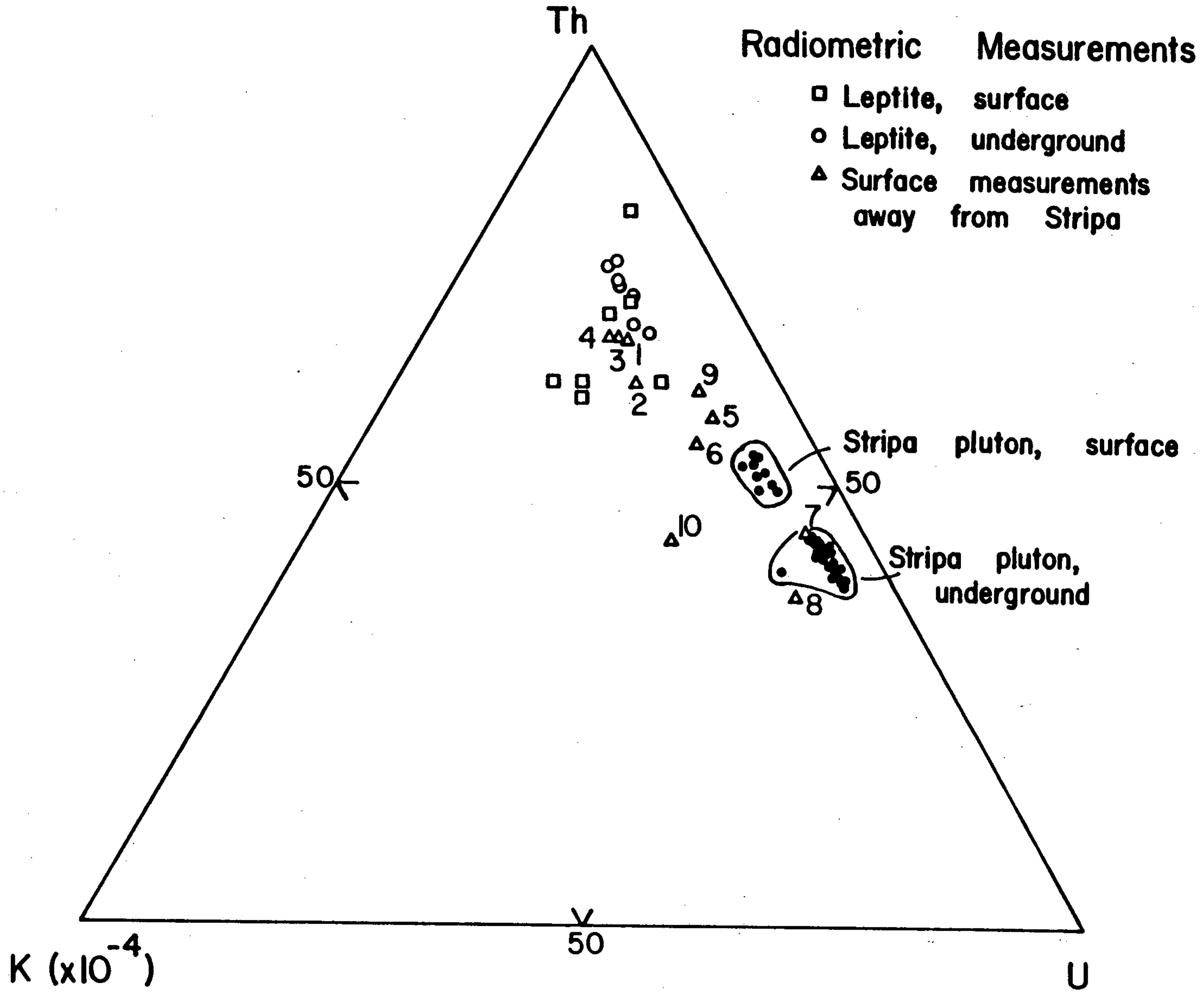

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Figure 2. Relative abundances of radioelements.

Inspection of Figure 2 and the plot of Th and U versus depth in the quartz monzonite (Figure 3), indicates that uranium is depleted in surface exposures of quartz monzonite and leptite at Stripa relative to its abundances in the same rock units underground. The depletion of uranium in weathered exposures of crystalline rock with respect to its abundance in relatively unweathered exposures of the same rock is well documented in the literature. A possible explanation for the depletion at Stripa is that the sites of U within the rock, primarily associated with chloritic zones and most likely a uranium-thorium oxide mineral, favor the removal of U from surface exposures by slightly acidic near-surface ground water (Fritz and others (4) indicate that the pH of water from three wells in the quartz monzonite is 5.15, 6.6, and 7.60). There is a gradational increase in U and Th with depth below the 410 m level shown by the laboratory gamma-spectrometric analyses of cores from the vertical borehole DBH V-1 (Figure 3). This apparent increase in radioelements with depth might result from deeper portions of the borehole having penetrated a zone of the pluton where late-stage fluids containing oxyphile elements concentrated. The variation could also be influenced by the varying proximity of the borehole to a diabase dike (or dikes) as indicated on the vertical cross section, Figure 1. The diabase has considerably lower radioelement contents than the quartz monzonite.

RADIOELEMENTS IN FRACTURES AND GROUNDWATER

Fission track radiography disclosed the distribution of ^{235}U within the rock and indicated that at Stripa uranium is primarily associated with high-radioactivity (up to 25% U) opaque minerals, and is also disseminated in

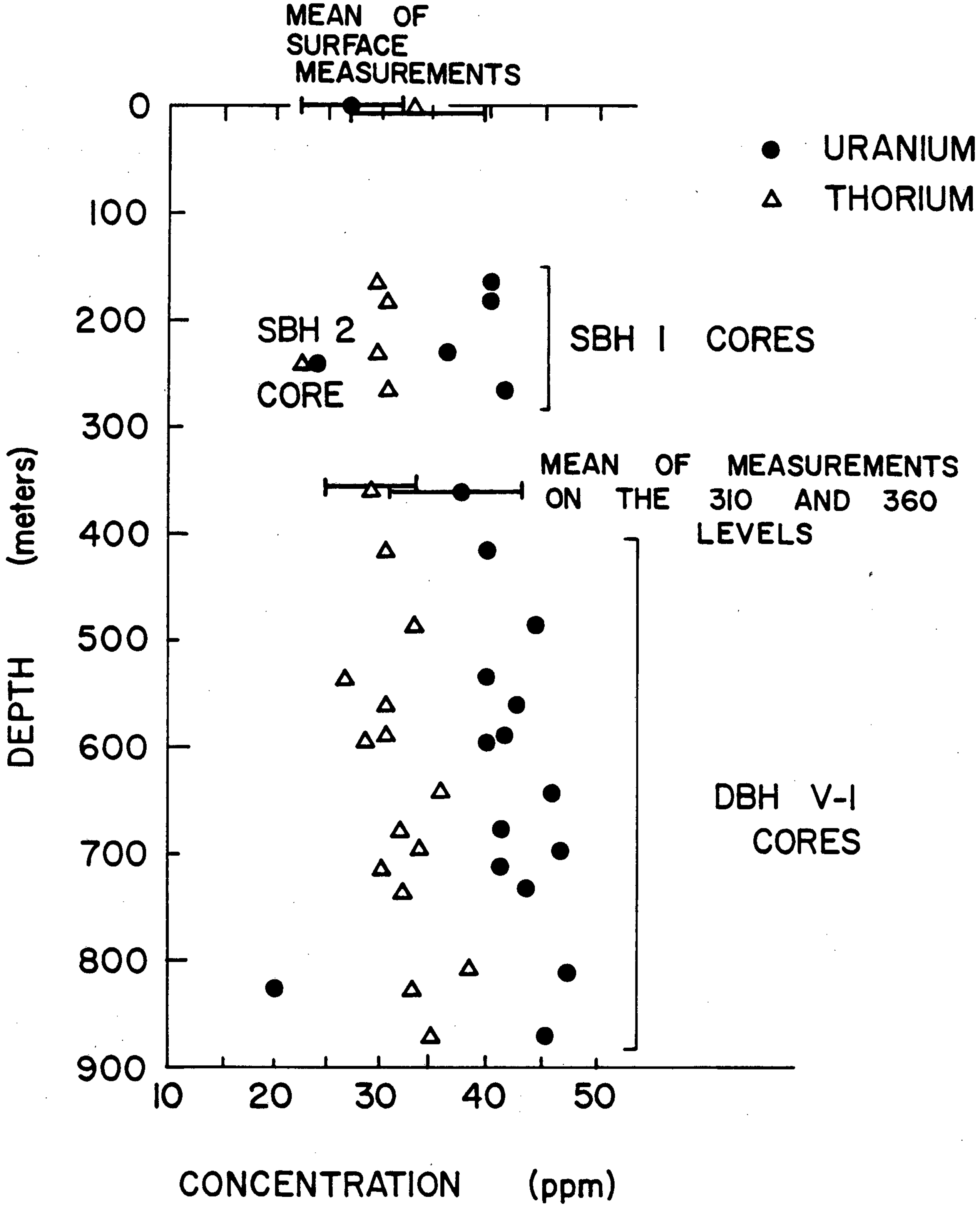

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Figure 3. Variation of U and Th with depth in the Stripa pluton.

chlorite, the predominant fracture-filling mineral in the quartz monzonite. This uranium-mineral association suggests that a significant component of the uranium has been mobile and is in contrast to the association in most plutonic rocks where U is generally locked in to accessory minerals such as sphene, zircon, monazite and apatite. The association of U in fractures is shown on Fig. 4.

The strong association of uranium with chloritic fracture-filling material suggests that it is the principal source of ^{222}Rn observed by Nelson et al. (3) in water of some of the Stripa boreholes. In hydrologically saturated crystalline rock masses, where the groundwater systems are confined to the joints and fractures, the presence of the uranium daughter ^{222}Rn in the water serves as a natural tracer to locate fractures along which significant flow is occurring and to measure their flow rates. At Stripa, gamma-ray logging of boreholes drilled from the subsurface, together with laboratory analyses of samples of the borehole water, indicated that ^{222}Rn is the principal radioactive constituent of the groundwater that fills the fractures (3). Radon activity concentrations in water from some fractures reaches one microcurie per liter. The total measured activity increases where such water enters a borehole from an intersected fracture. Because of this natural radon tracer, the gamma-ray log serves as a flow profile, and zones where water enters or leaves the hole are located by increases or decreases in total gamma activity. Therefore, it is important that the natural radioactivity of groundwater at candidate repository sites should be determined, and monitored to detect changes in response to changing hydrologic conditions.

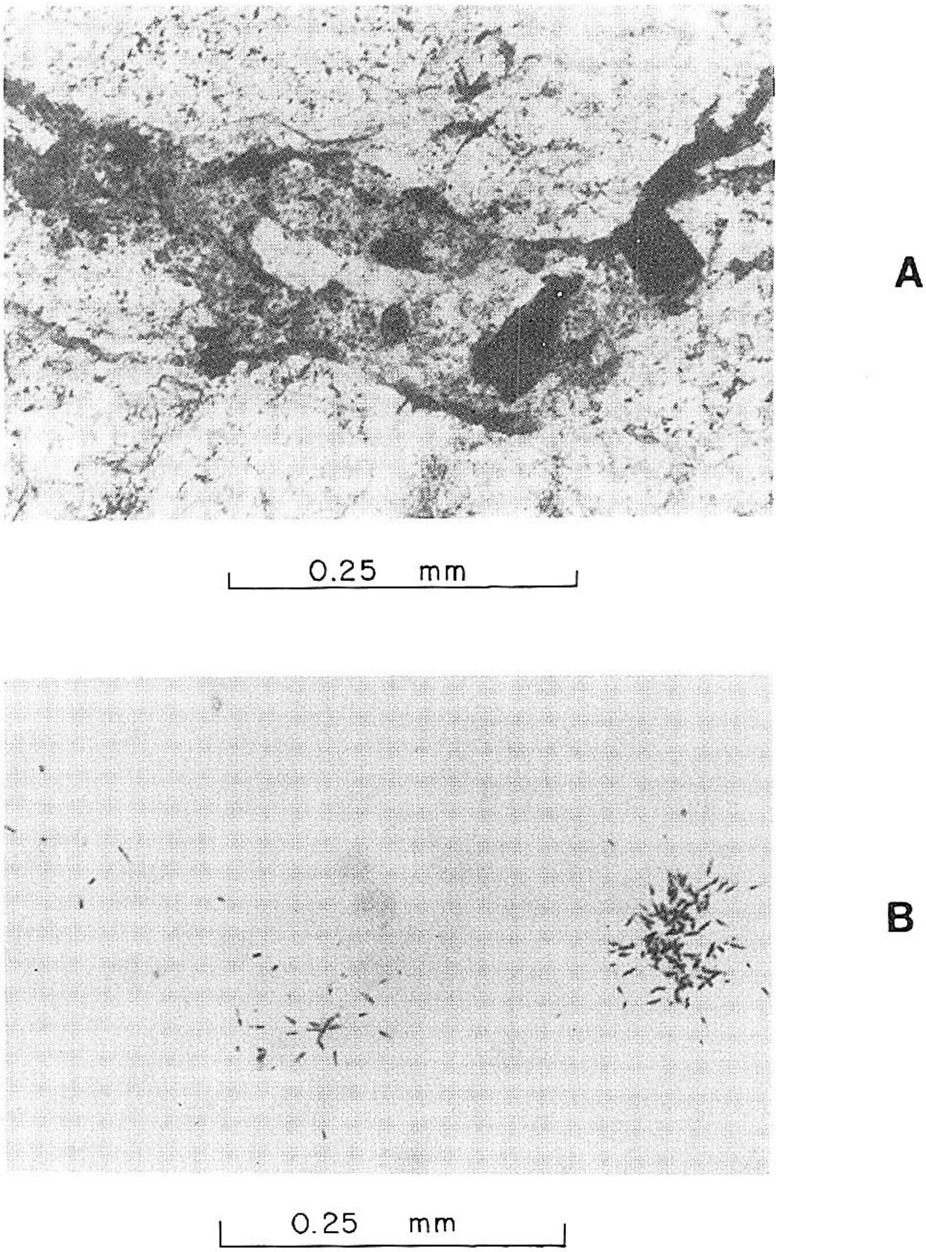

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Figure 4. Fission tracks (B) from U in euhedral opaque grain (20-30% U), and along fine chlorite-filled fractures (0.5 - 1% U) in fractured quartz monzonite.

The concentrations and distributions of uranium, thorium and their daughters in the accompanying groundwater system also form an important baseline, and when combined with rock radioelement concentrations, permit determination of the apparent age of the groundwater. At Stripa, water ages in the range 5×10^4 to 2×10^5 y were based on the ^{4}He content of the deep water and U and Th contents of the rock and fracture filling material (4), (2). These ages are in accord with ^{14}C dating, which indicated that water discharging in the deeper portions of the mine and in a deep borehole drilled below the 410 m level was recharged prior to 20,000 years ago.

RADIOGENIC HEAT PRODUCTION

Besides defining the natural radioactivity baseline, radioactive decay of the U, Th, and K in the rock yields the radiogenic heat production which, combined with measurement of the regional and local heat flow, permit calculation of the apparent size of the rock mass encompassing the repository. This method was especially useful at Stripa where the margins of the pluton were concealed by glacial debris. The radiogenic heat production of the quartz monzonite averages $11.9\mu\ \text{Wm}^{-3}$, considerably higher than that of the neighboring leptite and other plutons in the region. The conductive heat flow, the product of the rock's thermal conductivity ($3.6\ \text{Wm}^{-1}\,°\text{C}^{-1}$) and the geothermal gradient, corrected for glacial-climatic effects (20.5°C/km) is $73.8\ \text{m Wm}^{-2}$.

Roy and others (5) developed the concept of the linear relationship between conductive heat flow and radiogenic heat production. They proposed that the observed heat flow,

$$Q = q^* + DA_o, \tag{1}$$

where q is the heat flow from below the upper portion of the earth's crust within which most of the radioelements are concentrated, D is the effective thickness of the radioactive layer, and A_o is the radiogenic heat production.

From heat flow and heat production measurements in central Sweden, Landström and others (6), applying equation (1), estimated that D is 15.6 km and $q^* \simeq 25 mW\ m^{-2}$. Accepting these as the basic conditions for central Sweden, we then estimated the effective thickness of the Stripa quartz monzonite, assuming a two-layered case, by a modification of the above equation:

$$Q \simeq q^* + D_1A_1 + D_2A_2, \qquad (2)$$

where D_1 and D_2 are the respective thicknesses (in km) of the quartz monzonite below 570 m depth and of rock of an underlying layer, and A_1 and A_2 their respective radiogenic heat productions. Solving equation (2) using radiogenic heat productions of the quartz monzonite and metamorphic rocks (11.9 and $2.8\mu\ Wm^{-3}$ respectively) and a corrected heat flow of $73.8\ mWm^{-2}$, a q^* of $25\ mWm^{-2}$, and a 15.6 km thick radioactive layer, results in $D_1 = 0{,}75$ km, $D_2 = 6.1$ km; this configuration suggests a total thickness of 1.3 km of Stripa quartz monzonite.

Alternatively, a layered intrusive configuration was considered: quartz monzonite overlying rock with heat production of the other granitic rocks in the Stripa region ($6.8\ \mu Wm^{-3}$). If we assume that the effective thickness of the quartz monzonite is at least 1 km (drilling indicates that it extends to at least 900 m depth), application of equation (2) yields an effective thickness of the underlying granitic rock of 5.4 km. These alternative two-layer models are illustrated in Figure 5.

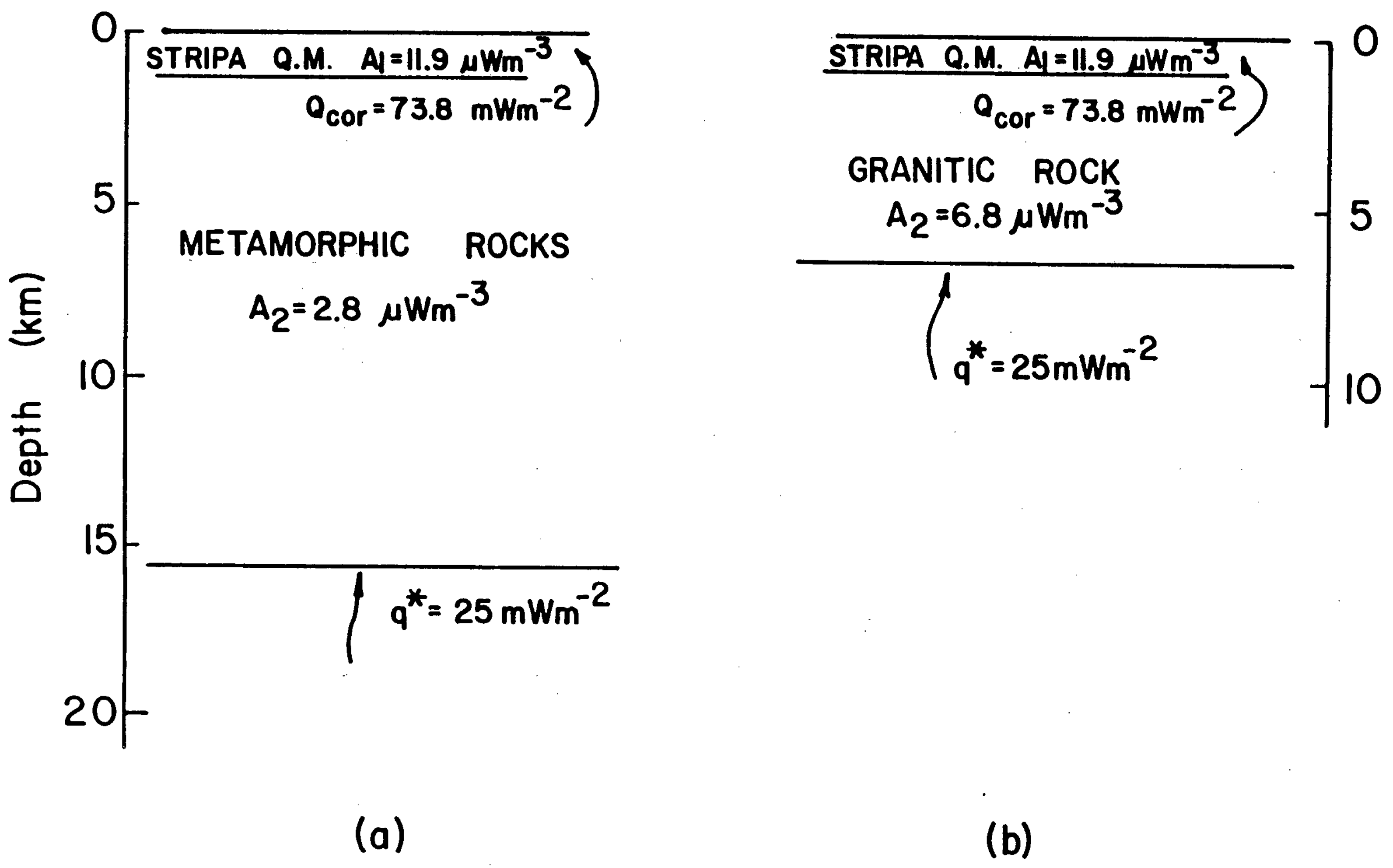

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Figure 5. Layered models of possible configurations of the Stripa pluton.

Thus, though the Stripa quartz monzonite contains high abundance of radioelements, it has little effect on the regional heat flow. If it occurs in a layered plutonic setting, the Stripa pluton is not more than ~1.5 km thick; otherwise it may comprise a stock or dike that is relatively small compared to the large granitic plutons in the region.

CONCLUSION

In conclusion, radiogeological assessment of candidate repository sites is necessary to characterize the distribution and abundance of naturally occurring radioelements in the rock. This information not only provides the radiological baseline upon which the waste will be superimposed but also helps to determine the age and flow rate of ground water, the loci of radioelements in the rock matrix and fracture-filling material, and permits an estimate of the size of the rock body encompassing the respository.

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REFERENCES

1. Witherspoon, P. A., N. G. W. Cook, and J. E. Gale, 1981. Geologic storage of radioactive waste: Field studies in Sweden. Science, vol. 211, Feb. 27.

2. Wollenberg, H. A., S. Flexser, and L. Andersson,1981. Petrology and radiogeology of the Stripa pluton. Lawrence Berkeley Laboratory, Berkeley, California 94720, LBL-11654.

3. Nelson, P. H., R. Rachiele, and A. Smith, 1981. The effect of radon transport in groundwater upon gamma-ray borehole logs. Lawrence Berkeley Laboratory, Berkeley, California 94720, LBL-11180.

4. Fritz, P., J. F. Barker, and J. E. Gale, 1979. Geochemistry and isotope hydrology of groundwaters in the Stripa granite, results and preliminary interpretation. Lawrence Berkeley Laboratory, Berkeley, California, LBL-8285.

5. Roy, R. F., D. D. Blackwell, and F. Birch, F., 1968. Heat generation of plutonic rocks and continental heat-flow provinces. Earth Planet. Sci. Lett., v. 5, no 1, pp. 1-12.

6. Landström, O., Sv. Å. Larsson, G. Lind, and D. Malmqvist, 1979. Varmflöde i berg. Chalmers Tekniska Högskola Geologiska Instituionen Publ B 137.