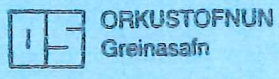
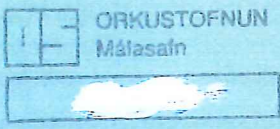


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GAMMA RAY ACTIVITY IN ICELANDIC ROCKS

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ABSTRACT

The correlation between both the natural gamma ray intensity and the concentration of the radiogenic elements U, Th, and K is found to follow the degree of differentiation of rocks in the IRDP-hole. As the pile penetrated by the hole is considered to be typical, and as similar results have been obtained in numerous other holes in Iceland, these results are considered to be typical for Icelandic rocks. The heat generated by radioactive decay in rocks in Eastern Iceland is found to be negligible compared with the regional heat flow.

INTRODUCTION

Radioactive isotopes with half life of the order of 10^9 - 10^{11} years and emitting gamma radiation are ^{238}U , ^{235}U , ^{232}Th , ^{176}Lu and ^{40}K . Due to the low concentration of lutetium in rocks and the relatively low energy of the gamma ray in the decay of ^{176}Lu , the main radiogenic elements in rocks are U, Th and K.

In igneous rocks, the concentration of U, Th and K depends on the differentiation of the rocks in such a way that U, Th, and K tend to be enriched in the more acid phases of magmatic differentiation. Iceland is built up predominantly of igneous rocks, and definite answer should therefore be obtainable on whether the gamma ray activity as well as the concentration of U, Th and K follows the degree of differentiation of the rocks. Until now hardly any measurements have been made on the natural radioactivity of Icelandic rocks, and reported determinations on uranium and thorium concentration of Icelandic rocks are very few (Heier et al. 1966, Sun and Bor - Ming Jahn 1975).

In 1978 a continuously cored 1919 m deep borehole was drilled in Eastern Iceland (IRDP - 1979). The core recovery was 99.7% and extensive chemical analysis have been carried out on samples of the core. After drilling extensive geophysical logs were run in the hole (Stefánsson 1979). The present paper describes the comparison of the concentration of the radiogenic elements U, Th and K in the core with the continuously registered gamma ray log. It is found that the radioactivity follows closely the degree of differentiation of the rocks. As this pattern is of a general nature and because similar results have been found in numerous other wells in Iceland it is concluded that the results obtained in this single borehole are typical for the occurrence of natural radioactivity in Icelandic rocks.

2. APPARATUS AND METHODS

The intensity of natural radioactivity of rocks determined in the laboratory is hampered by the low level counting in obtaining a proper determination of the background radiation. Determination of the natural gamma ray activity in a borehole has the advantage that the background can be neglected, and the probe is entirely surrounded by the material which is to be investigated.

The gamma ray tool used in this study is a conventional gamma ray tool used in oil industry. It consists of a GM-tube, and is calibrated in API (American Petroleum Institute) gamma ray units. By definition 200 API gamma units are equal to the radiation emitted by a special radioactive concrete situated at the University of Texas, containing about 4% K, 24 ppm Th, and 12 ppm U. More detailed description of the apparatus has been given elsewhere (Stefánsson 1979).

All the major elements analysed in the core have been determined by X-ray fluorescence analysis using a Philips (Model 1450) automatic and computerised spectrometer. For the concentration calculations, the "Alphas" computer program of Philips were applied.

U and Th have been determined by instrumental neutron activation analysis (INAA). Two reactor irradiations in a thermal neutron flux of $8 \cdot 10^{13}$ $n \cdot cm^{-2} \cdot s^{-1}$ with subsequent analysis were carried out. Description of the analysis method is given elsewhere (Puchelt 1977).

3. CHEMISTRY OF RADIOGENIC ELEMENTS AND RADIOACTIVITY

The continuous registration of the gamma ray intensity is shown in Fig. 1. There is also shown the depths where determinations of U, Th and K concentrations of the core were made. Table I shows the results of the chemical analysis used in this paper, as well as the gamma ray intensity at these particular depths in the hole. Comparison between the radiogenic elements and the measured gamma ray intensity is shown in Fig. 2. The correlation is good.

It therefore seems natural to assume that a linear combination of the concentration of the radiogenic elements should fit the measured gamma ray intensity.

$$[\gamma] = a_0 + a_1 [U] + a_2 [Th] + a_3 [K]$$

However, it is found that there is no unique solution to this equation. This is due to the fact that U, Th, and K are not independent variables in this context.

The correlation between the three radiogenic elements should give a measure on how well these three elements follow each other in the differentiation process. Fig. 3 shows the correlation between the elements U, Th and K. The correlation is found to be good.

In order to select a chemical variable to link with the gamma ray intensity, the concentration of SiO_2 was chosen. Fig. 4 shows the correlation between SiO_2 and the gamma ray intensity, and the relation between the radiogenic elements and the SiO_2 is shown in Fig. 5. A simple relation between the gamma ray intensity and the silica content of the rock is found to be:

$$[\gamma] = 3.65 [SiO_2] - 144$$

where

$[\gamma]$ are in API units

$[SiO_2]$ are in per cent.

The gamma radioactivity is found to depend on the degree of differentiation of the rocks.

4. HEAT PRODUCTION

Radioactive decay is a heat source within the rocks. The heat generated can be described (Ryback 1976, Ormaasen and Raade 1977)

$$A \text{ (HGU)} = 0.62 \cdot U \text{ (ppm)} + 17 \text{ Th (ppm)} + 0.19 \text{ K}_2\text{O (\%)}$$

where

$$1 \text{ HGU} = 10^{-13} \text{ cal} \cdot \text{cm}^{-3} \cdot \text{s}^{-1}$$

Heat generation calculated from this equation is compared with the SiO_2 content of the rock in Fig. 6. In this case also a good correlation is found between the heat generation and the differentiation of the rocks. The heat generation of 1 HGU contributes 10^{-2} HFU per km of the crust, where $1 \text{ HFU} = 10^{-6} \text{ cal} \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$. The near surface temperature gradient is appr. $80^\circ\text{C}/\text{km}$ (IRDP 1979), and the heat flow is assumed to be 3 HFU (Pálmason and Saemundsson 1979). A uniform distribution of radiogenic element within a 30 km thick crust would not contribute more than ten per cent to the observed heat flow at surface.

TABLE I
Selected chemical components of the IRDP core and corresponding
heat generation and gamma ray intensity.

UNIT	DEPTH m	SiO ₂ %	MgO %	K ₂ O %	Th ppm	U ppm	HGU 10 ⁻³ cal cm ⁻³ s ⁻¹	gamma int. API gamma units
4.1	35.2	49.6	6.34	0.26	0.93	0.36	0.43	33.6
6.2	44.98	48.0	5.21	0.34	2.0	0.71	0.84	35.5
10.1	79.8	48.6	4.99	0.61	0.50	0.67	0.67	32.6
33.2	201.7	51.7	4.61	1.04	1.8	0.93	1.08	49.0
44.1	269.8	49.7	5.04	0.61	1.7	0.52	0.73	34.6
51.2	307.1	50.0	4.41	0.16	1.4	0.43	0.53	28.8
64.1	384.2	47.7	5.37	0.22	<0.7	0.43	0.43	26.9
91.2	535.9			1.23	2.2	0.65	1.01	38.4
127.2	749.6	51.5	3.86	1.55	2.5	1.3	1.53	60.5
172.1	1016.0	53.7	4.19	1.29	2.3	0.92	1.21	52.8
178.4	1044.2	50.7	4.16	0.81	2.0	0.75	0.96	38.4
185.5	1091.1	58.9	2.83	1.85	4.2	1.5	2.01	72.0
197.1	1154.1	58.2	2.35	3.57	4.5	1.7	2.50	76.4
200.9	1171.0	45.5	7.91	0.14	0.91	<0.3	0.37	29.8
210.2	1228.9	58.0	2.91	0.98	4.4	1.8	1.24	71.0
220.7	1297.5	57.9	2.54	1.84	4.5	1.4	1.98	78.7
259.1	1521.1	48.8	6.89	0.34	0.77	<0.3	0.38	25.0
264.1	1546.8	49.4	6.68	0.10	0.73	<0.25	0.30	19.2
287.2	1690.2	48.1	5.69	0.61	1.0	0.42	0.61	30.7
290.3	1700.7	48.9	7.74	0.33	<0.7	0.28	0.36	25.9
296.1	1736.1	50.6	4.50	1.74	1.9	0.76	1.12	37.4
314.1	1838.8	50.1	5.60	0.40	0.72	0.43	0.34	34.6

5. CONCLUSIONS

The correlation between the gamma ray intensity and the concentration of the radiogenic elements U, Th and K in the rocks of the IRDP drill core is found to be good.

The gamma ray intensity and the concentration of U, Th and K follows the degree of differentiation of rocks.

The heat generated in the rocks by radioactive decay is found to be small compared with the regional heat flow of Eastern Iceland.

ACKNOWLEDGEMENT

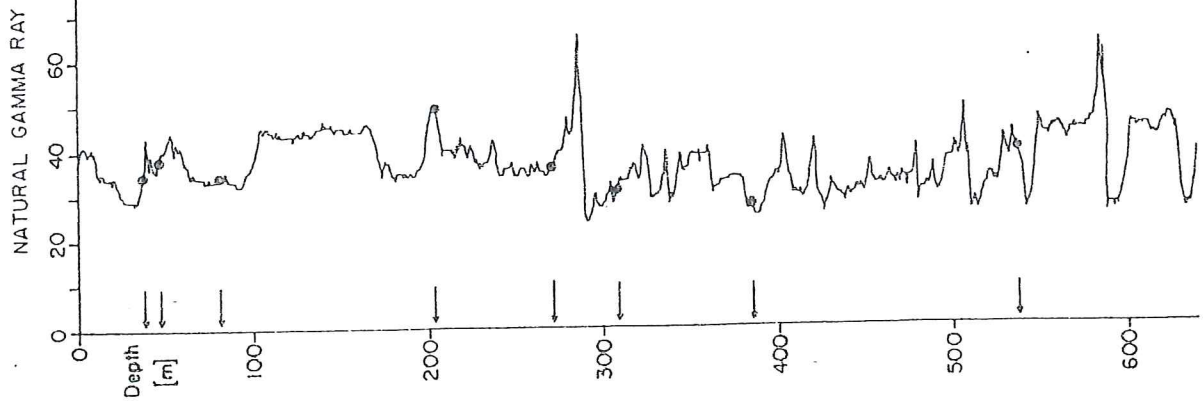
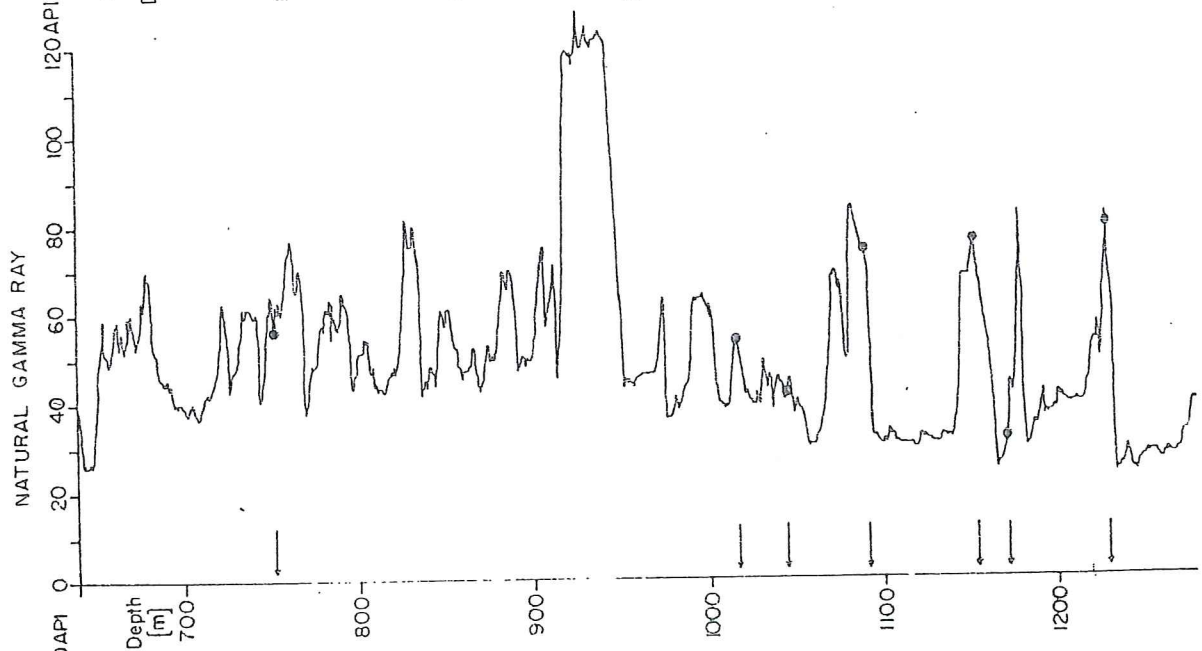
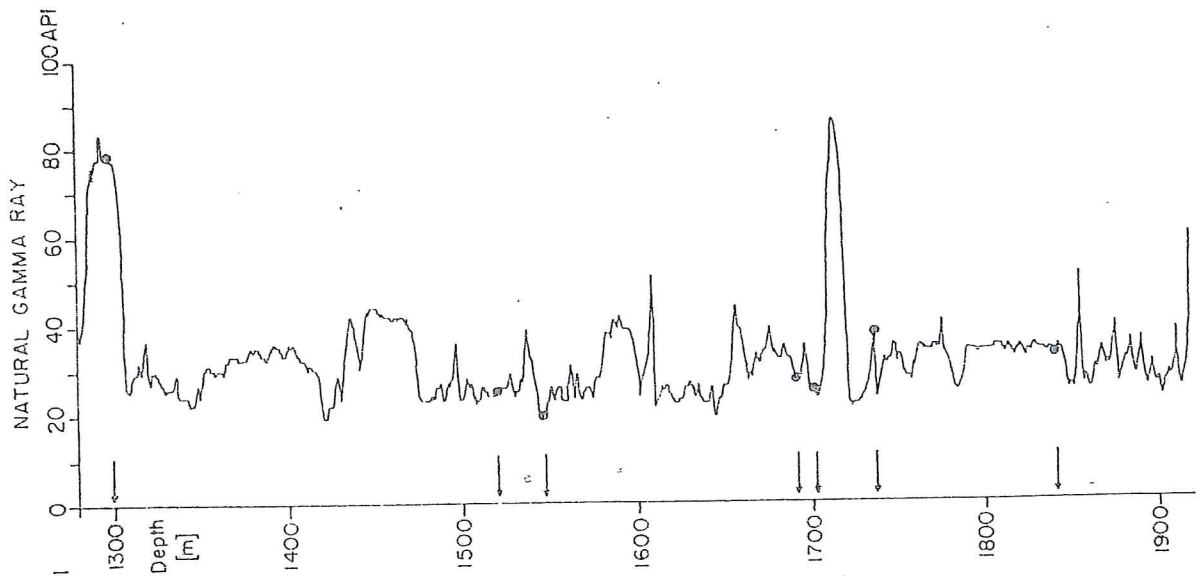
We thank Geirfinnur Jónsson for his valuable assistance in working out the correlation calculation. Thanks are also due to Dr. Ingvar Birgir Fridleifsson, Ásgrímur Guðmundsson and Dr. Hjalti Franzson which have read the manuscript and suggested several improvements.

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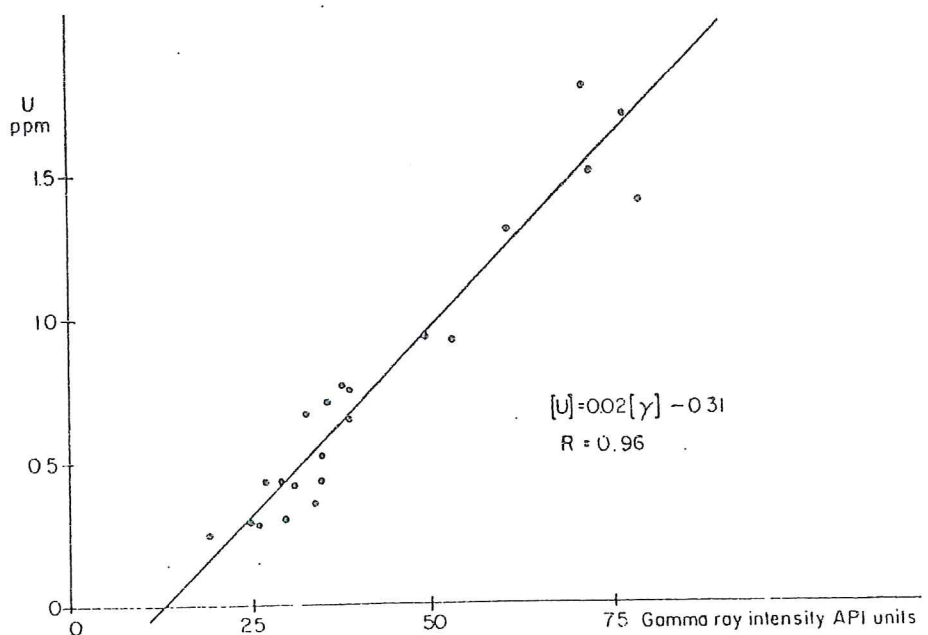
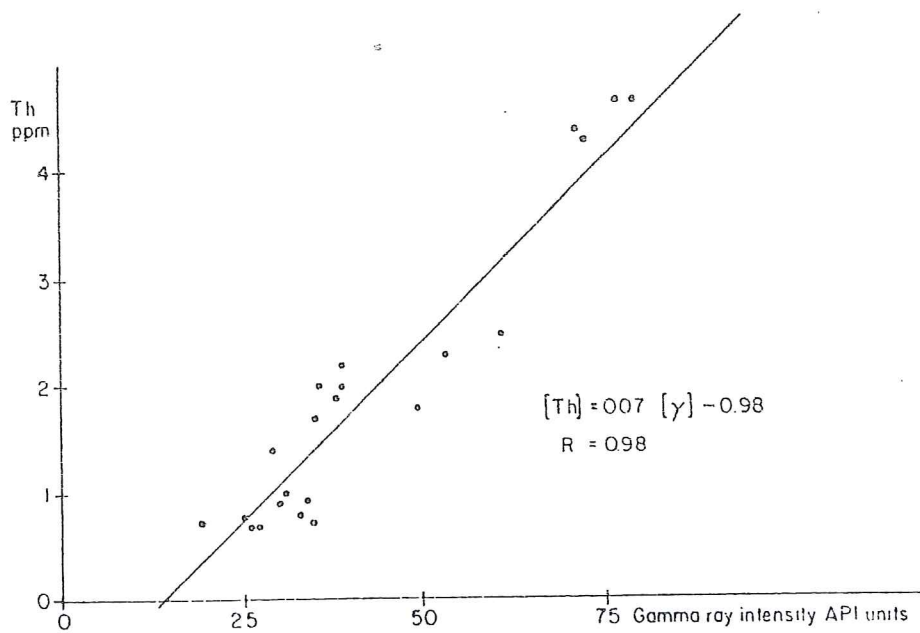
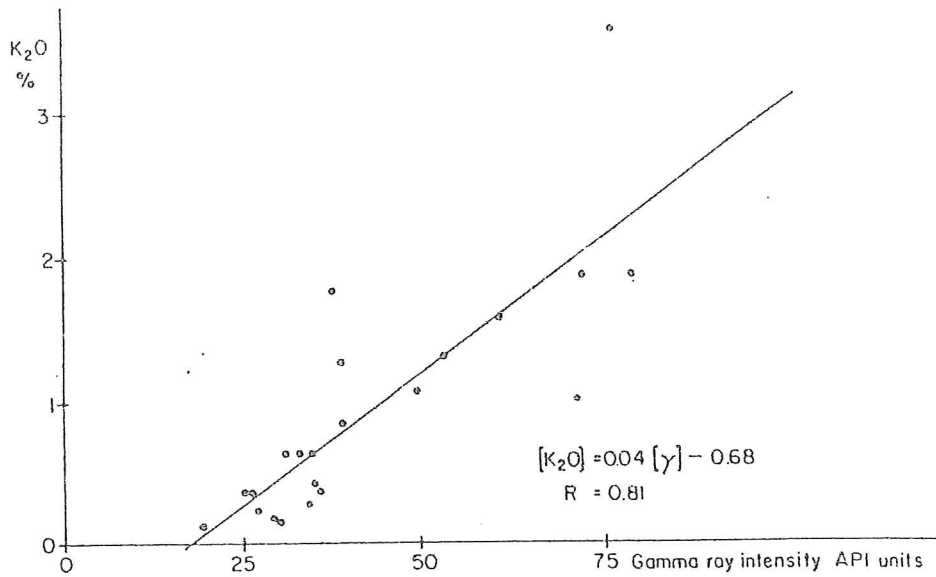
FIGURE CAPTIONS

- Fig. 1. The continuously registered gamma ray intensity in American Petroleum Institute (API) gamma units as function of depth in the IRDP-hole. The depth locations in the core for the analysis of U, Th, and K are marked with arrows and the corresponding gamma ray intensity is marked with dots on the gamma ray intensity profile.
- Fig. 2. The correlation between the gamma ray intensity in API gamma units with the concentration of U, Th, and K_2O of the rocks. R denotes the correlation coefficient.
- Fig. 3. The correlation between the concentration of U, Th, and K_2O . R denotes the correlation coefficient.
- Fig. 4. The correlation between the gamma ray intensity in API gamma units with the concentration of SiO_2 . R denotes the correlation coefficient.
- Fig. 5. The correlation between the SiO_2 concentration and the U, Th, and K_2O concentration of the rocks. R denotes the correlation coefficient.
- Fig. 6. The heat generation in $HGU = 10^{-13} \text{ cal} \cdot \text{cm}^{-3} \cdot \text{s}^{-1}$ caused by radioactive decay in rocks correlated to the concentration of SiO_2 . R denotes the correlation coefficient.



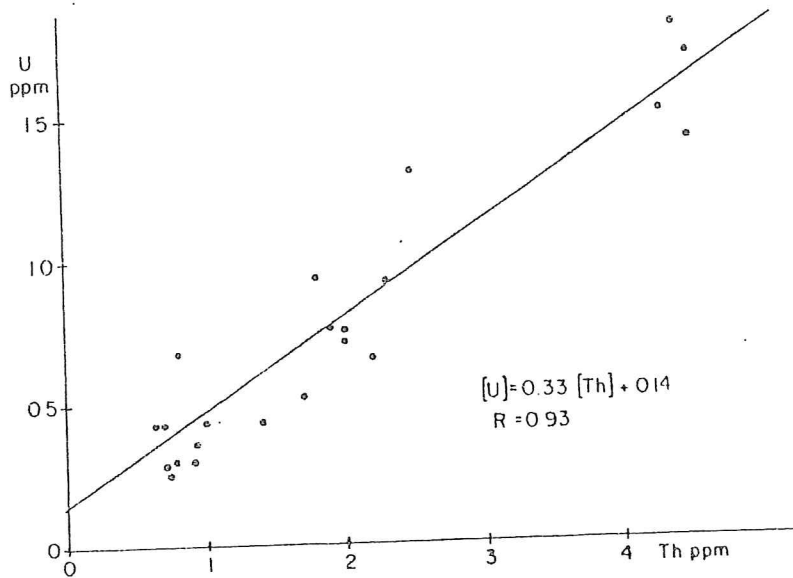
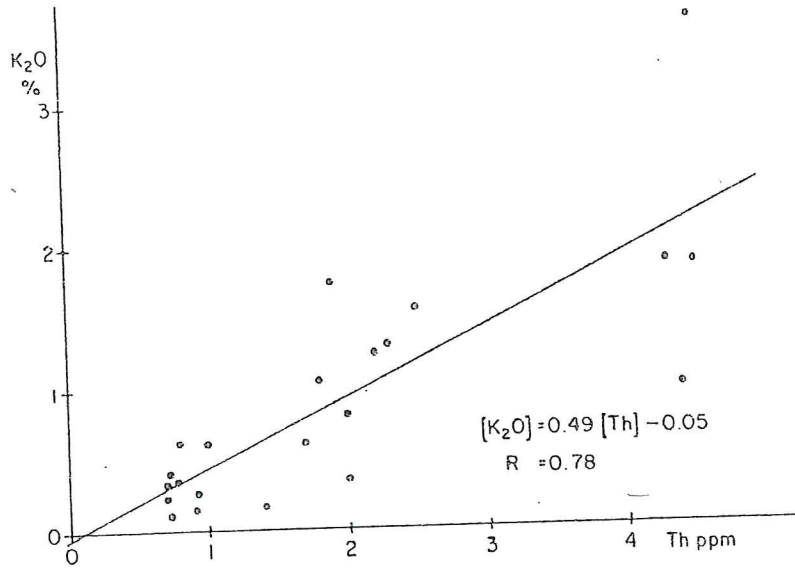
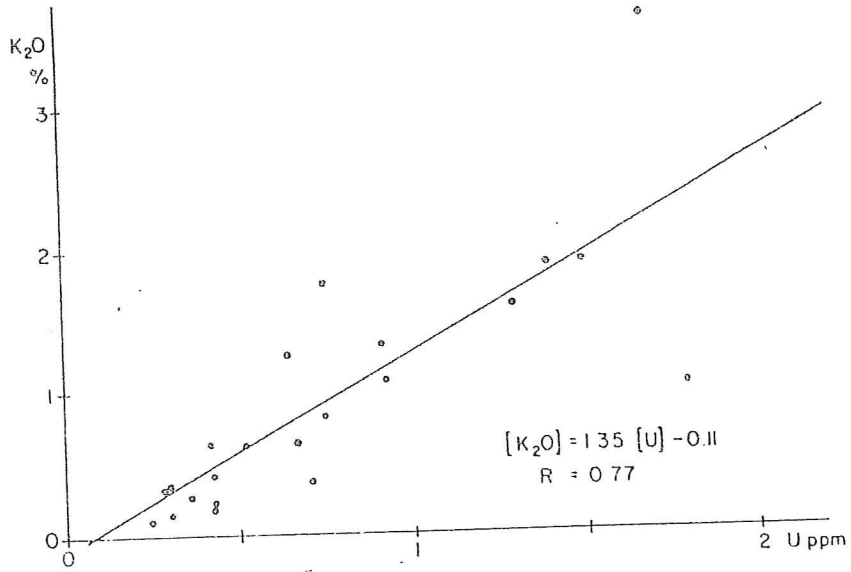
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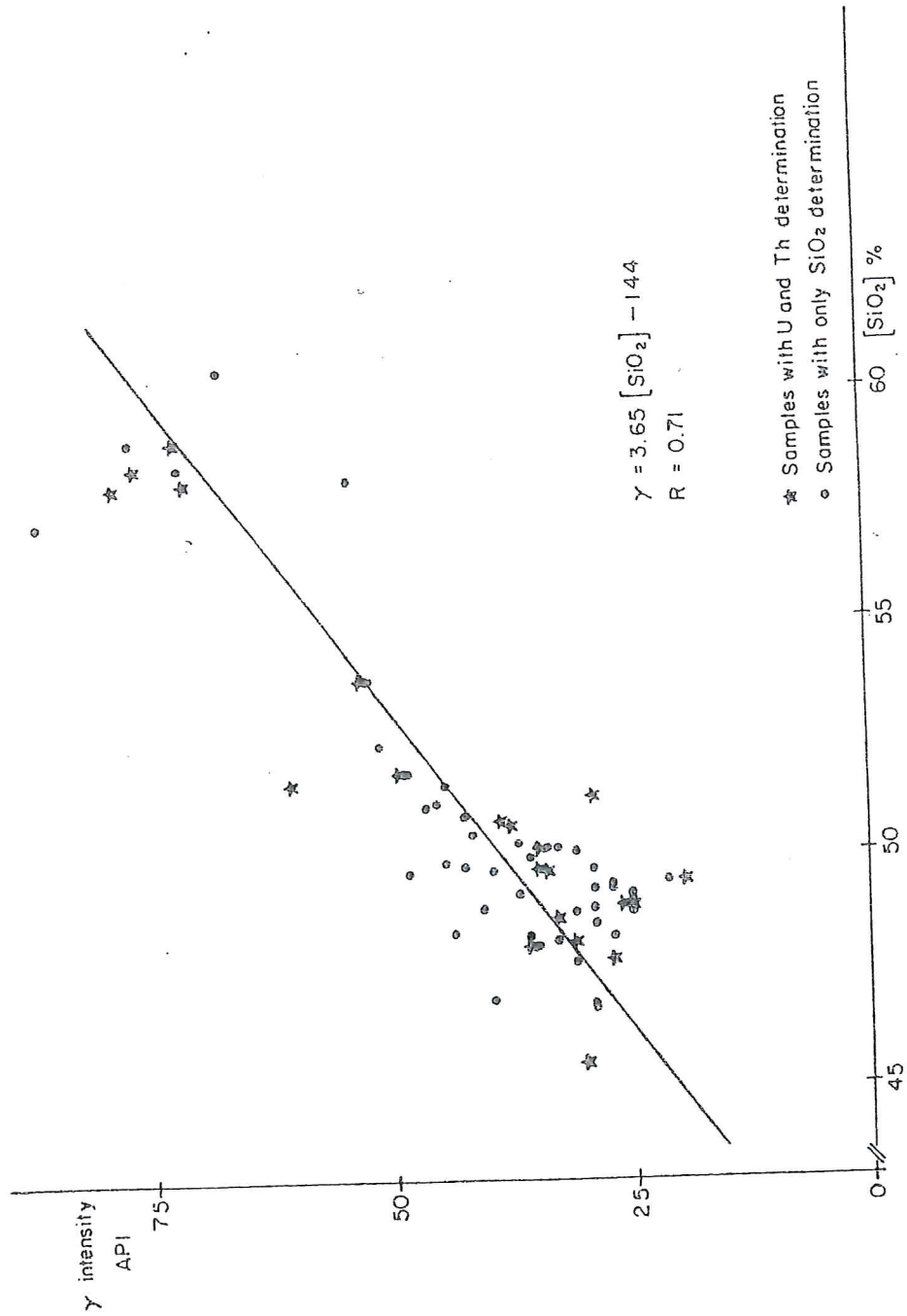


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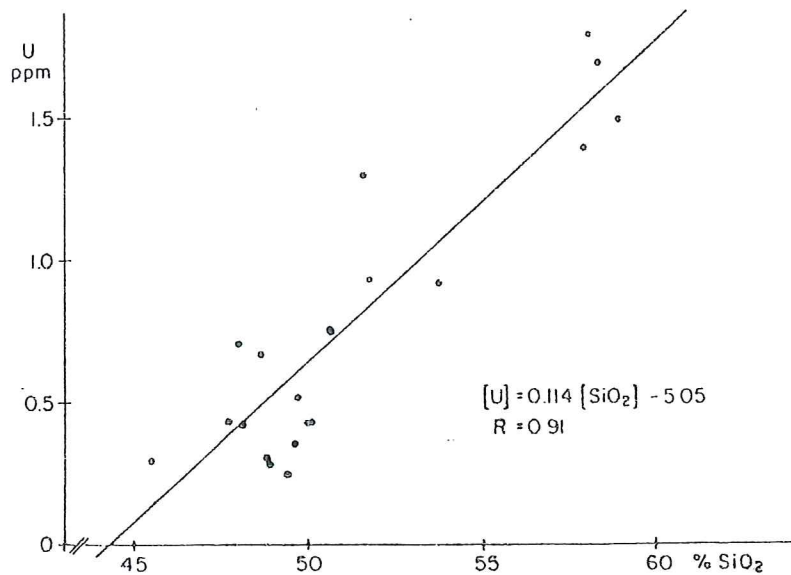
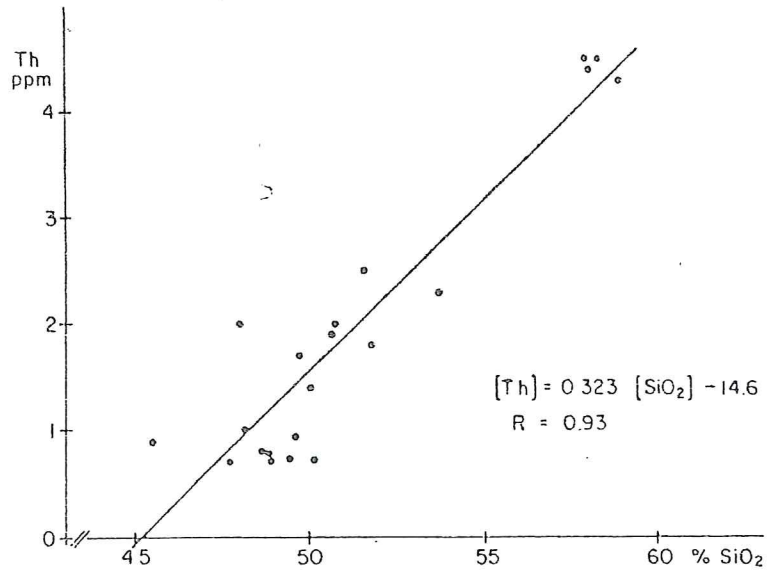
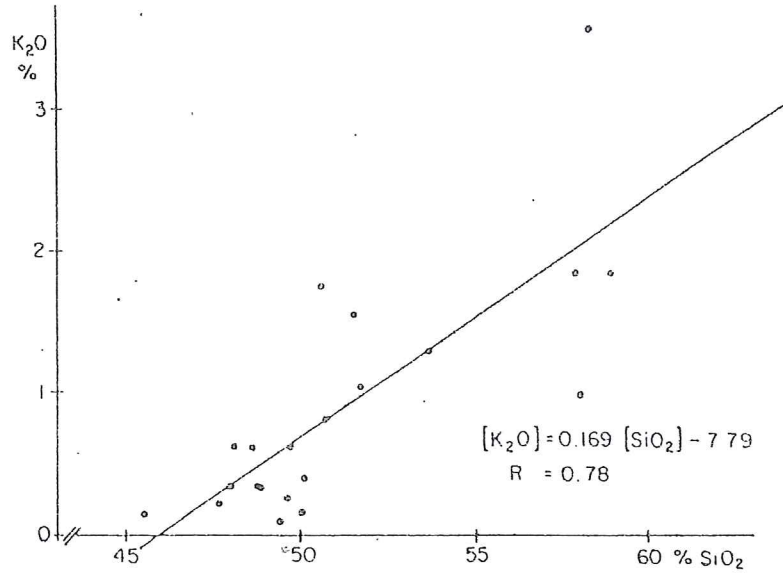


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Relation between heat generation unit and SiO₂ content

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