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23. *Variation of Concentrations of Radon and Some Other Constituents of Underground Waters in a Landslide Zone: Narao District, Nagano Prefecture.*

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Abstract

The concentrations of radon and some other constituents (Ca^{2+}, Mg^{2+}, SO_4^{2-}, Cl^-, HCO_3^-), in underground waters of the sliding zone and its surrounding area in Narao district, Nagano Prefecture, were observed over a period of more than one year. The radon concentration was found to be variable possibly owing to occasional exacerbation of the slide, while the other constituents did not show such a significant variation as to be correlated with the slide. The use of radon as an indicator in surveillance of a slide was suggested.

1. Introduction

A spontaneous landslide with a total area of about 16 ha started on October 6, 1976 in Narao (36.5°N, 138°E), Nagano Prefecture. The average velocity of the movement was about 40 cm per day in the beginning. The movement began to slow down to a few cm per day towards the end of 1976, and still continued at a rate of less than 1 cm per day in 1978. The geology of the field was described by SHIMA *et al.* (1977). They also gave a detailed account on the early stage of the slide and pointed out that the sliding surface existed within the weathered rock layer.

The landslide is generally thought to be closely related to a sudden change of underground water systems possibly involving chemical reactions at the sliding surface (YOKOZAWA, 1972). Chemical constituents of such waters may have some significance. Existing data from slide areas, however, are rather limited; further accumulation of data may be necessary for a better understanding on the possible bearing of chemical species in underground waters. This paper proceeds from previous findings (SATO *et al.*, 1976) and is concerned with a more detailed investigation of waters in the Narao district.

2. Analysis of water samples

Radon and certain chemical species, Ca^{2+}, Mg^{2+}, SO_4^{2-}, Cl^- and HCO_3^-, were investigated with the intention of finding possible differences in concentration between the waters from the sliding zone and from its surrounding area.

Sample waters were obtained from various points of the area as illustrated in Fig. 1. There were four springs outside the sliding zone. As the water outlets in the sliding zone were mostly broken down as the slide proceeded, the sources of water available throughout for sampling were very limited in this zone.

Chemical analyses were occasionally made at most sampling points. The results obtained for the concentrations of Ca^{2+}, Mg^{2+}, SO_4^{2-}, Cl^- and HCO_3^- are listed in Table 1. The values listed are those averaged

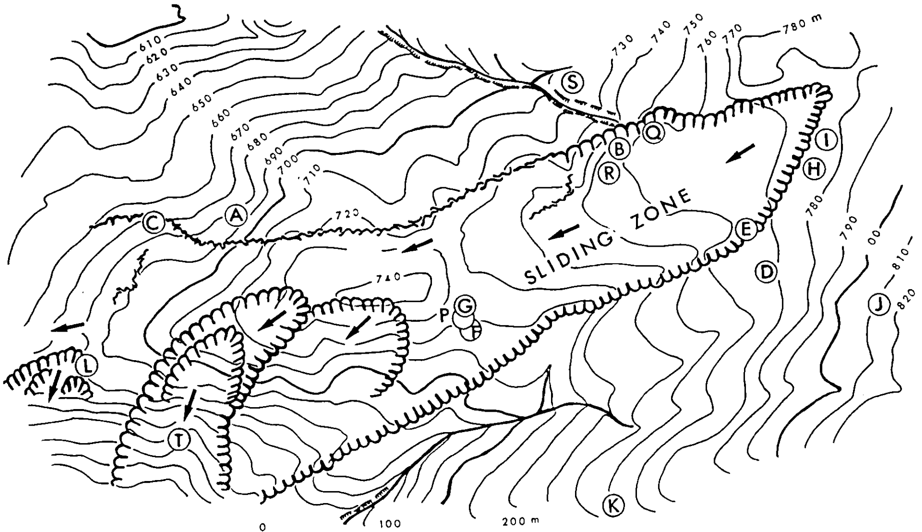

Fig. 1. Localities of sampling points within and outside the sliding zone.

Table 1. Analyses of underground waters from Narao district

Sampling points	4.3 alkalinity (me/*l*)	Ca^{2+} (mg/*l*)	Mg^{2+} (mg/*l*)	Hard-ness (mg/*l*)	Cl^- (mg/*l*)	SO_4^{2-} (mg/*l*)
Sliding zone						
B	0.81	23.9	7.9	92.2	13.6	34.9
E	1.32	19.5	6.2	74.1	3.1	24.5
F	1.20	28.7	17.4	143.0	27.3	61.2
G	1.33	28.9	18.5	148.0	28.6	63.1
H	1.44	23.3	10.0	99.2	10.9	28.7
I	1.40	22.1	4.9	75.4	2.1	19.4
L	2.01	36.8	27.0	203.0	58.0	42.2
P	1.11	30.0	17.0	145.0	29.2	64.5
Q	1.06	24.3	5.0	81.3	8.9	18.3
R	1.43	24.5	13.6	117.0	13.1	58.8
T	1.27	48.5	20.7	206.0	11.0	151.8
Surrounding						
D	0.30	3.2	1.4	13.9	0.8	7.8
J	0.33	2.9	1.6	13.8	0.5	5.8
K	0.41	12.2	3.3	44.1	2.0	65.9
S	—	8.8	2.7	33.0	7.4	37.9

for the period of 1 month after the beginning of the slide, as the concentrations showed no significant variation. Analytical method is given in the previous reports (SATO *et al.*, 1976; YOKOZAWA, 1972).

3. Concentrations of Ca^{2+}, Mg^{2+}, SO_4^{2-}, Cl^- and HCO_3^- in underground waters

The prime feature of the data in Table 1 may be a general trend of ionic concentrations in waters from the sliding zone to be several times higher than those from the surrounding area. KITANO *et al.* (1967) pointed out that high concentration of HCO_3^- and Ca^{2+} in natural water may be a good indicator of the weathering of rocks in a certain district and would be a precursor of the resultant phenomena such as the collapse of a hill. Their observation appears to be consistent with the trend obtained in the present investigation. However, the work by KITANO *et al.* is concerned with water systems from an extensive area. It may be premature to make further discussion by comparing the present observation with their data.

The data in Table 1 indicate that waters rich in Ca^{2+} are also rich in other components. For convenience, Ca^{2+} will be regarded as a representative of other constituents. Fig. 2 illustrates the distribution of Ca^{2+} concentration in the area. It is seen from Fig. 2 that the concentrations are relatively high in the waters from lower points of the slope, *i.e.* the lower reaches of underground water (SHIMA *et al.*,

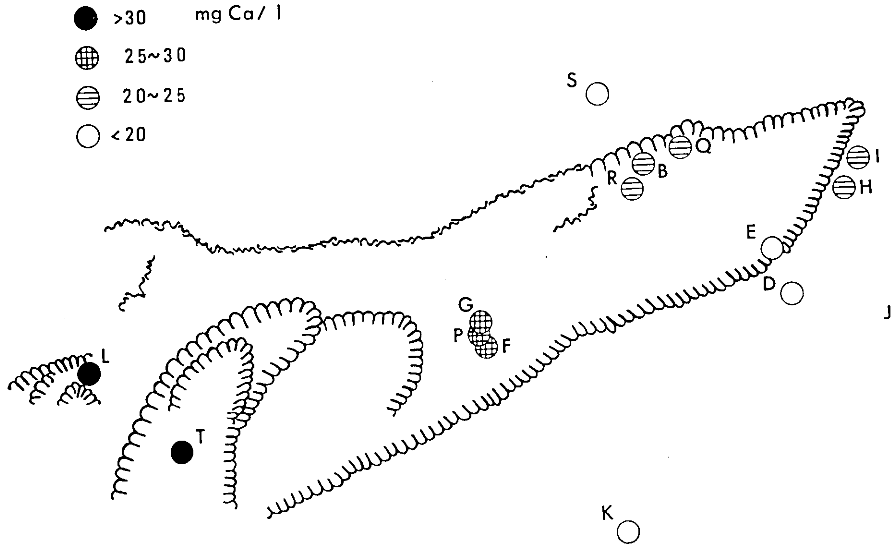

Fig. 2. Distribution of Ca^{2+} conentrations in underground waters. Concentrations are based on the averaged values for the period of the early stage of sliding.

1977).

4. Distribution of radon concentration in underground waters

Fig. 3 illustrates the distribution of Rn concentrations in waters for all of the outlets investigated. The Rn concentrations are indicated

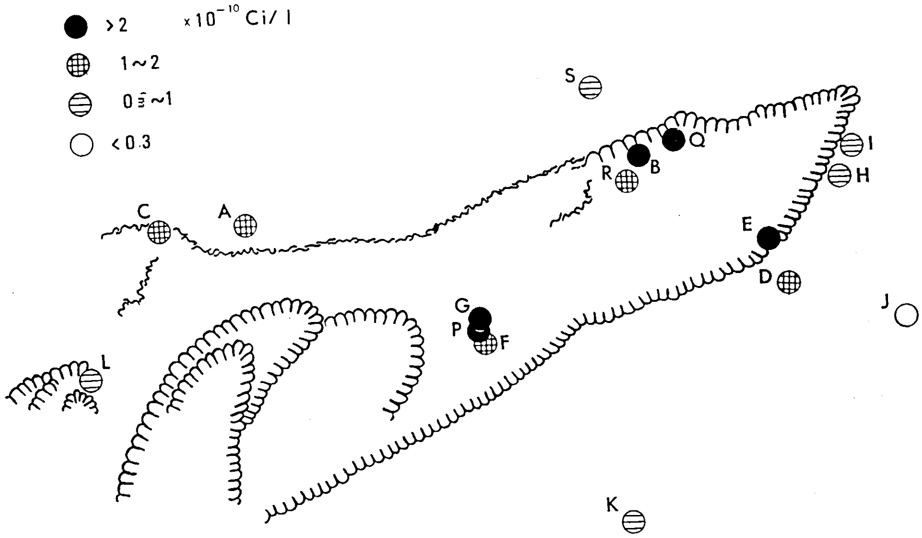

Fig. 3. Distribution of Rn concentrations in underground waters. Concentrations are based on the averaged values for the first two months of sliding.

by gradations which are based on the average values for the first two months. It is seen from Fig. 3 that the Rn concentrations in the waters from the outlets in the sliding zone are slightly but significantly higher than those from the surrounding area.

5. Variation of radon concentration in underground waters from the sliding zone

There was one pair of outlets, E and D, which were located close to each other: outlet E was located in the sliding zone and outlet D just outside (Fig. 1). Fig. 4 is a combined diagram of Rn and Ca^{2+} concentrations and the displacement of the slide plotted against time, which is based on observations of the first three months. An inspection of Fig. 4 reveals two characteristic features:

(1) There is a significant difference in the variation in Rn concentration between the two outlets, though there are small rises and falls in both the outlets. The Rn concentration in the water from the sliding zone (outlet E) was higher than that from the surrounding area (outlet D). A gradual decrease in the Rn concentration in outlet E followed the reduction of the moving speed, while the concentration in the water from outlet D showed no remarkable trend of variation.

(2) The behaviour of Ca^{2+} is quite different from that of Rn. The Ca^{2+} concentration in the water from outlet E did not show such a variation as was observed for the Rn concentration. It is essentially invariable at least for the period of the present observation.

It follows from the above observation that there is some cases where the movement of landslides is reflected in a change in Rn concentrations in underground waters flowing out of the sliding mass.

There was another set of outlets also close to each other. This set consisted of three outlets, F, G and P, which were all located in the middle of the sliding zone (Fig. 1). No significant difference in the Ca^{2+} concentration was observed among the waters from the three outlets (Fig. 5).

The variation of the Rn concentration in the water from outlet F shows a trend similar to that observed for the water from outlet E, possibly reflecting the movement of the slide. Unfortunately, outlet F broke down shortly after the observation started. Outlets G and F started to release waters before the collapse of outlet F. Their Rn concentrations were clearly different from that of outlet F, whereas the Ca^{2+} concentrations of these three outlets were very similar to one another. As outlet P was a shunt of outlet G, no difference between their Rn and Ca^{2+} concentration was expected. The difference in Rn concentration between F and the other two (G and P) indicates that

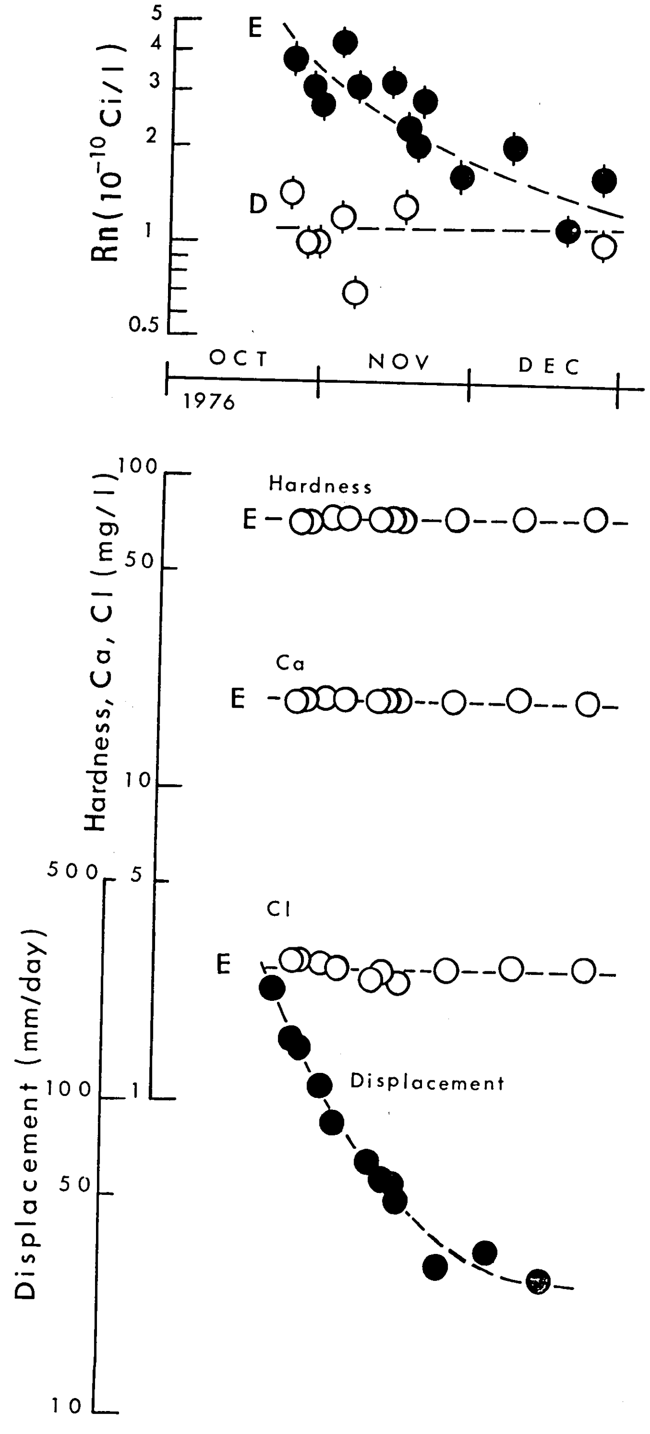

Fig. 4. A combined diagram of concentrations for Rn, Ca^{2+}, Cl^- and hardness in the water from D and E points, together with the rate of displacement of the slide in the period from October to December, 1976.

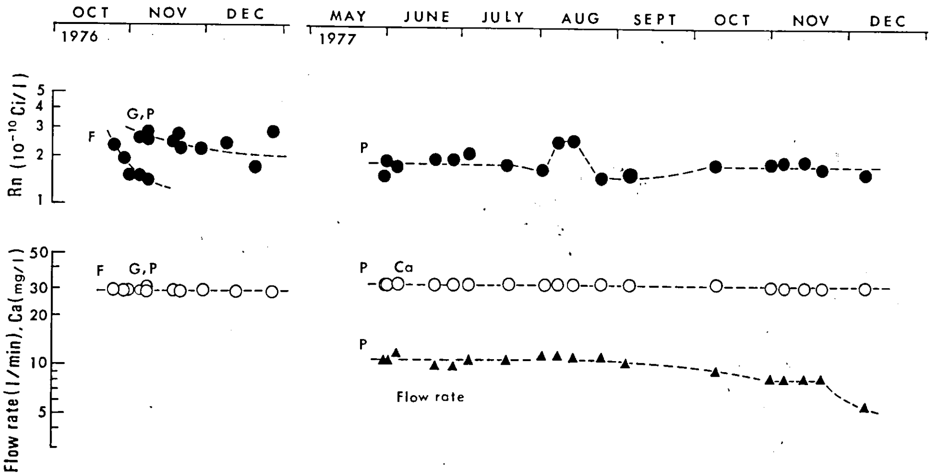

Fig. 5. A combined diagram of concentrations for Rn and Ca^{2+} in the water from the three points (P, G, and F) located in the middle of the sliding zone. Flow rate of P point is also shown.

there may be some cases where two adjoining outlets release waters quite different in Rn concentration. This warns that furture use of adjoining outlets which are conventionally selected may not always be acceptable.

Observation was continuously carried out on the water from outlet P for a period of more than one year with an interuption of four months in winter. A slight decrease in its Rn concentration was observed in the early stage of the slide in 1976, when a remarkable decrease was observed in outlet F. In the early summer of 1977, when the slide nearly ceased, the Rn concentration for outlet P remained almost unchanged. A striking rise in the Rn concentration for outlet P occurred suddenly in August, 1977. Immediately after this observation, wide cracks were found to have developed in the upper part of the sliding zone along its boundary, indicating a sudden increase of the movement. The increase of the movement was not recorded on the monitoring measure set in the lower part of the sliding zone.

6. Radon concentrations in waters from the surrounding area

There were two outlets, J and K, in the area surrounding the slide: outlet J was located on the upper point at the back of the sliding zone and outlet K was located on a slope across a small valley.

The results obtained from the two outlets are shown in Figs. 6 and 7. A general trend of gradual decrease in Rn concentration was

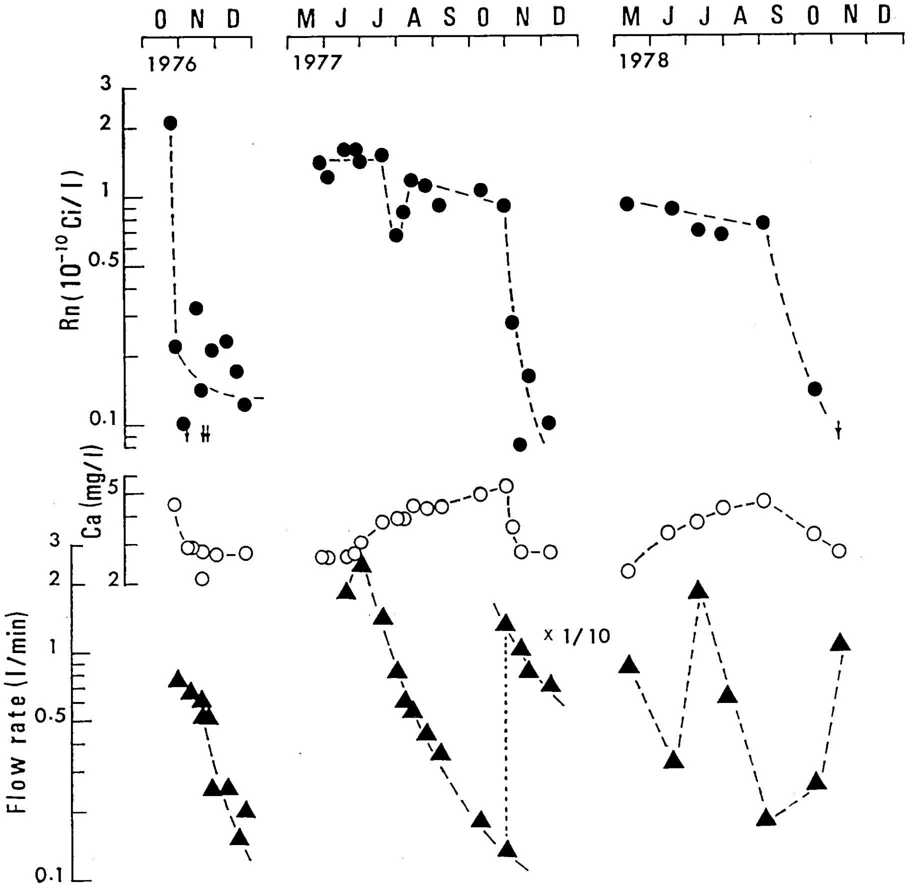

Fig. 6. A combined diagram of concentrations for Rn and Ca^{2+} in the water from J point located in the surrounding area. The variation of the flow rate is also shown.

observed for both of the outlets through 1977 and 1978.

Abrupt falls of one order of magnitude in the Rn concentration were observed in the water from outlet J in the early winter of both 1976 and 1977. A simultaneous decrease in Ca^{2+} concentration was observed for the J point. In the early summer of 1977 and 1978 the Rn concentration was found to have recovered. This variation pattern appears to be characteristic of point J, possibly being related to some seasonal change. No such variation was observed in the water from outlet K.

In August, 1977, the Rn concentration in outlet J was observed to have suddenly fallen for a short period. A comparison of Fig. 6 with Fig. 5 indicates that this fall was coincident with the sudden rise of the Rn concentration in the water from outlet P. It appears that the change in Rn concentration in outlet J, though located in the surround-

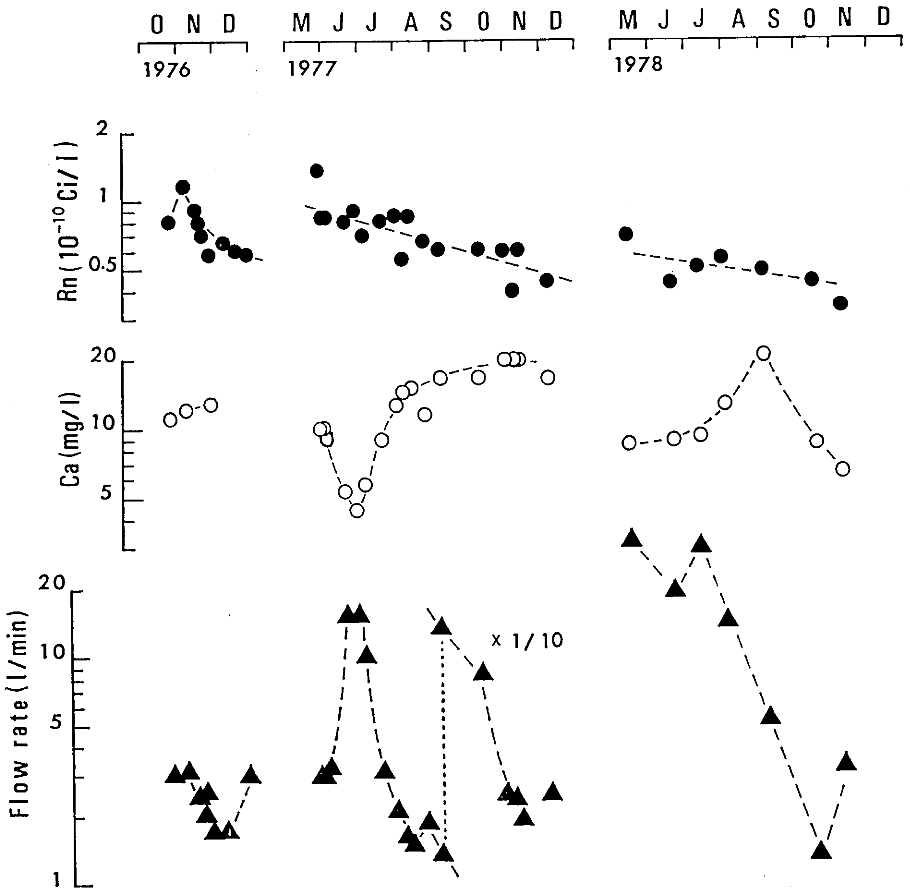

Fig. 7. A combined diagram of concentrations for Rn and Ca^{2+} in the water from K point located in the surrounding area. The variation of the flow rate is also shown.

ing area, may possibly be reflecting the movement of the landslide.

7. Variation of calcium concentration

The flow rate of water from outlets J and K was observed to vary widely as shown in Figs. 6 and 7. The concentration of Ca^{2+} in the water from point K seemed to be correlated closely with the flow rate; as the flow rate goes higher, the concentration tends to drop. As is shown in Fig. 7, the Rn concentration in the K point does not appear to have any relation with the flow rate, at least in the period of the present observation. Also in the J point a gradual increase in Ca^{2+} concentration is understood to be correlated with the decrease of the flow rate, though the correlation is not so conspicuous. This observation suggests differing origins of Rn and Ca^{2+} in underground waters of this area.

8. Summary

(1) There are two patterns of variation in Rn concentration: one is closely correlated with the movement of the sliding mass (as was observed at point E) and the other is some seasonal change which goes together with Ca^{2+} concentration (as was observed at point J). The Rn source for the waters from the sliding zone may be different from that for the ordinary underground waters.

(2) The underground water systems in the slide area are complicated in that there is sometimes a significant difference in the Rn concentration between waters from outlets located close to one another.

(3) The Rn concentration in underground waters is a useful indicator of the development of a landslide, if suitable water outlets or wells are available throughout for observation. Waters from the surrounding area may provide helpful information.

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23. 地辷り地帯の地下水中のラドン濃度およびいくつかの化学成分の濃度変化: 長野県奈良尾地区の場合

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1976年10月に始まった長野県奈良尾地区の大規模な地辷り地帯の地下水について，発生直後より1ケ年以上にわたって，ラドンおよびいくつかの化学成分 (Ca^{2+}, Mg^{2+}, SO_4^{2-}, Cl^-, HCO_3^-) の濃度の観測を行い，次のような観測結果を得た.

（1） 地辷り地帯内からの湧水中のラドン濃度は，周囲の地域からの湧水にくらべ高く，地辷りの進行の激しさに密接に関連し変化するが，他の化学成分の濃度には，このような際立った変化は見られない.

（2） 湧水中のラドン濃度は，隣接したものの間でも異なる場合がある.

（3） 地辷り地帯内外の湧水中のラドン濃度は，地辷りの動きをよく反映するようなので，地辷りを監視する場合には役立つものと考えられる.