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Report

Car-borne Survey for a Black Shale Area and Influence of Snowfall on Absorbed Dose Rate in Air of a Coastal Area

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A car-borne survey of absorbed dose rate in air (referred to as “dose rate”) was conducted on Oshika Peninsula, Miyagi Prefecture located in the northeastern part of Japan in the early spring; measurements were made using a 2-in.×2-in. NaI(Tl) scintillation counter. The influence of snowfall on the dose rate was evaluated, and the relationship between the distribution of the dose rate and surface geology was also discussed. The dose rates were seen to increase due to snowfall, although the radon concentration which would be related to its progeny concentration was reported to be relatively low in winter to spring. This might be because of the continental air masses containing high concentrations of radon and its progeny which come from the Asian continent to Japan in winter. The dose rates were found to be high in the middle and eastern parts of the peninsula and low in the southern and northwestern parts. The results indicate the correspondence between the distributions of dose rates and surface geology at the high dose rate areas.

Key words: car-borne survey, dose rate, geological feature, snowfall

1. Introduction

Humans are exposed to natural radiation emitted from rocks, soils and building materials which contain natural radionuclides such as uranium and thorium. The contribution of terrestrial radiation to the world mean annual effective dose for the public is not small, and accounts for approximately 20% of the mean value[1)]. Thus, it is important to investigate the absorbed dose rate in air (hereinafter, this is called “dose rate”) causing external exposure. A national survey for ambient natural radiation was conducted in Japan from 1967 to 1977 by the National Institute of Radiological Sciences and the representative dose rates in each area were investigated[2)]. However, Abe[2)] did not consider corrections for measurement geometry as the survey was focused on investigating representative dose rates from the viewpoint of public health. Therefore, the results were the actual dose rates which the public were exposed to, and the measurement geometry effect on them should be reduced to establish the relationship between geological features and dose

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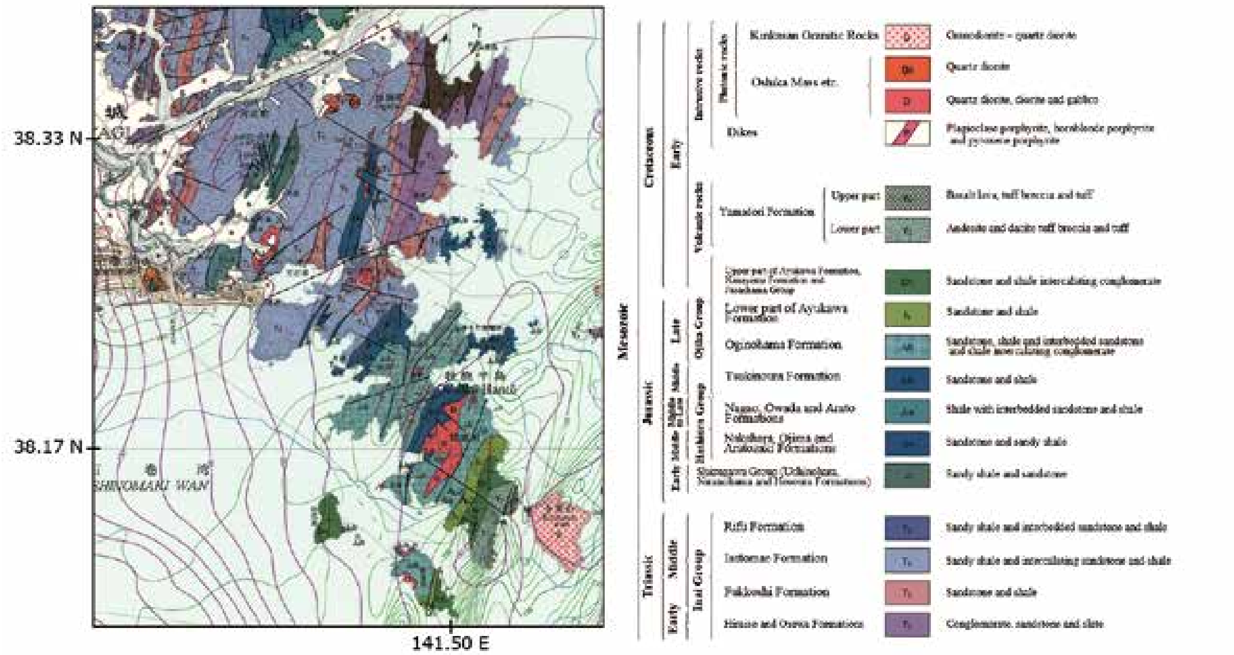

Fig. 1. Geological map of Oshika Peninsula. This figure is after Takizawa *et al.*[11] CC BY-ND. It was modified by the authors of the present paper with permission from the Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology.

rates more precisely.

Many researchers have reported that several factors would affect the dose rates such as geological features, measurement geometry, atmospheric radon progeny concentrations and local meteorology (e.g., rainfall, snow accumulation)[3-6]. Among geological features, it is well-known that uranium concentrations in acidic rocks such as granite and rhyolite are higher than in other types of rocks, thus the dose rates attributed to igneous rocks are high[3]. It has been reported that the intensity of gamma-rays and uranium concentration in slate were also relatively higher than in other rocks[7, 8]. In the northeastern part of Japan, there is an area on Oshika Peninsula of Miyagi Prefecture where slate and black shale are widely exposed as the ground surface. The outdoor radon concentrations in this area have also been reported to be high compared with the national average value of 6.1 Bq/m[3, 9, 10]. However, there are few publications which describe detailed survey results for the dose rate of an area with slate and black shale. This paper obtained detailed car-borne survey results for the Oshika Peninsula, a slate and black shale area. In addition, the influence of snowfall on the dose rate was also discussed.

2. Materials and Methods

2.1 Geology of the study area

The geological setting of Oshika Peninsula is mainly comprised of mid Triassic to upper Jurassic sedimentary rocks (e.g., slate, black shale, sandstone) and lower Cretaceous volcaniclastic rocks with lower Cretaceous intrusive rocks (Fig. 1)[11]. These geological bodies are distributed from the northeast to the southwest, and their distribution is constrained by faults and folds. The peninsula study area can be divided into three parts according to the geological setting: the northern part (base), central part, and southern part (tip). In the base mid Triassic sandy shale partly accompanied by slate (the Isatomae formation) is mainly exposed. In the central part, the main surface rock types are the upper Jurassic sandstone and shale (the Tsukinoura formation and Oginohama formation). In these formations, quartz diorite and gabbro were partly intruded in the early Cretaceous period. In the southern edge, upper Jurassic sandstone and shale (the Ayukawa formation) and the lower Cretaceous volcaniclastic rocks of andesite and dacite tuff breccia (the Yamadori formation) are exposed.

2.2 Car-borne survey

A car-borne survey was carried out on Oshika Peninsula using a 2-in.×2-in. NaI(Tl) scintillation counter (S-1857, Ohyo Koken Kogyo Co. Ltd., Japan) from March 24 to 26, 2010 . The survey route covered almost all of the area in the peninsula as shown in Figure 2. Count rates were measured for 1 min with a time interval of 1 min between the measurements along the route. The count rates were corrected by considering measurement geometry and shielding by the car body, and the corrected count

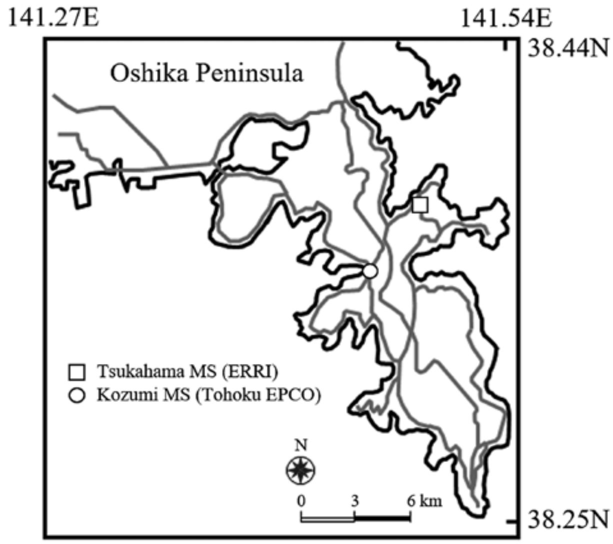

Fig. 2. Route of the car-borne survey on Oshika Peninsula.

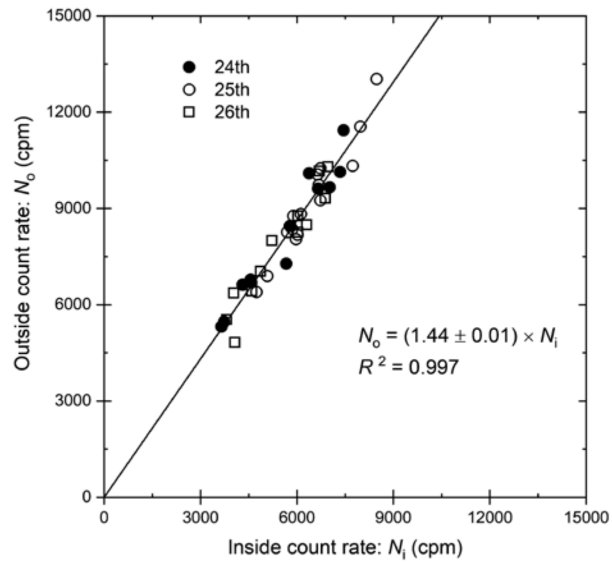

Fig. 3. Relationship between the daily count rates inside and outside the car.

rates were then converted to the dose rates by the calibration using a 3-in.×3-in. NaI(Tl) spectrometer[12]. For the correction of measurement geometry, the count rates measured at roads along cliffs were corrected by an interpolation using data obtained before and after passing by each cliff area. In order to accurately estimate the dose rate for all measurements, the speed of the car was kept in the range of 20-40 km/h during the survey[13]. The count rates inside and outside the car on the road were also measured for 1 min to make a correction for shielding by the car body. In addition, the shielding effect of the pavement had to be corrected by measuring on an unpaved surface at ~2-3 m from the road to consider the relationship between the geological features and the dose rates. As well, the count rates were also measured every day during the survey because of the possibility of a snowfall which might cause an increase or decrease in the dose rate[5, 14]; in fact, there was a snowfall on March 25. The effect of snowfall was also evaluated using data of the measurements at fixed points and compared to the data obtained by the car-borne survey and the environmental monitoring conducted by the Environmental Radioactivity Research Institute of Miyagi (ERRI) and Tohoku Electric Power Co., Inc. (Tohoku EPCO) at the Kozumi and Tsukahama Monitoring Stations (MSs), respectively.

3. Results and Discussion

3.1 Shielding by car body and pavement

Figure 3 shows the relationship between the daily count rates inside and outside the car. A good linearity was found between them by fitting ($R^2 = 0.997$) and no significant effect on the fitting slope from the snowfall was observed. The conversion factor from the inside to the outside count rates was estimated to be 1.44 ± 0.01, which was in a good agreement with previous reports[12, 15-17].

The relationship between the count rates on the pavement and those measured on the unpaved surface is shown in Figure 4. The count rate increases by the snowfall on the pavement and unpaved surface were estimated to be 2180 ± 456 and 1989 ± 472 cpm, respectively. No significant difference was observed between them by the paired-samples t-test ($p = 0.38$). It should be noted that one data for each surface type was excluded for the calculation and analysis after the Smirnoff-Grubbs' test at the 95% significance level. Hirouchi *et al.*[18] reported that infiltration and surface runoff characteristics of radionuclides in rain contributed to the dose rate increases, and those increases differed by surface type. However, the present results indicated that there was no significant difference in the magnitude of the count rate increase caused by the snowfall on the different types of surface. Also, the ratio of count rates measured on the pavement to those measured on the unpaved surface during fine weather and the snowfall were estimated to be 1.23 ± 0.29 and 1.09 ± 0.15, respectively. There was no statistically significant difference between the ratios by paired-samples t-test ($p = 0.64$). Thus, all data were used for the fitting to correct the effect of the pavement, and the conversion factor from the count rates on the pavement to those measured on the unpaved surface was estimated to be 1.70 ± 0.19. Shielding power of the pavement should

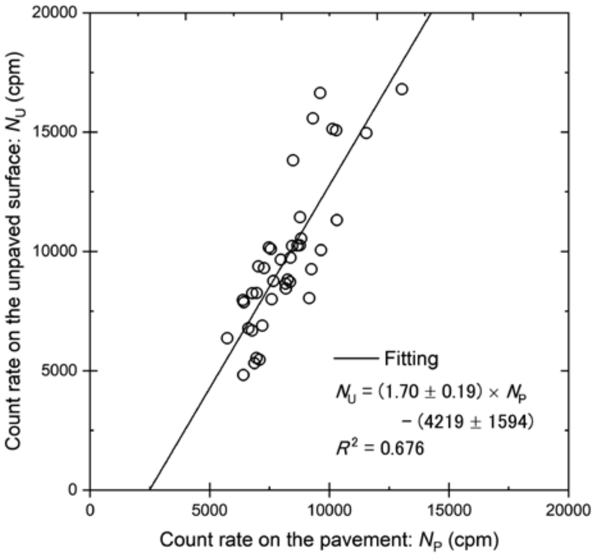

Fig. 4. Relationship between the daily count rates on the pavement and unpaved surface.

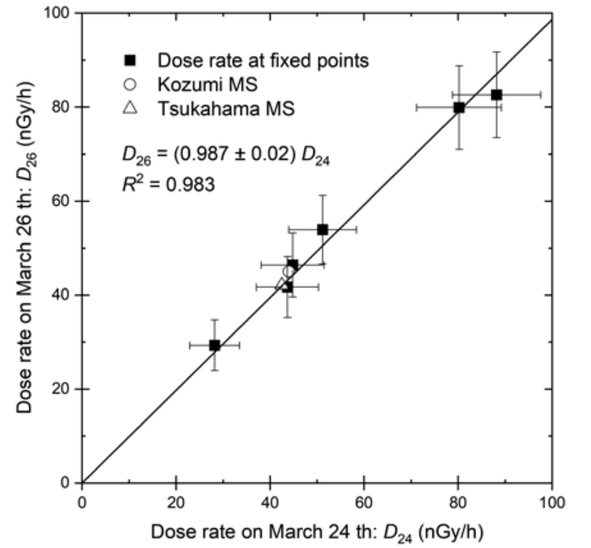

Fig. 5. Relationship between the dose rates measured on March 24 and 26. The data from environmental monitoring by the ERRI and Tohoku EPCO at Kozumi and Tsukahama MSs were in good agreement with the results in the present study.

significantly affect the conversion factor from the count rate on the pavement to that obtained on the unpaved surface although some papers reported that it would be negligible[12, 15-17]. The difference in the effect might be attributed to the pavement thickness as reported by Minato[19]. In the present case, the pavement might be thicker than in other reports.

3.2 *Influence of snowfall on dose rate*

The dose rates measured on March 26 were not much different from those measured on March 24 as shown in Figure 5. Therefore, for the analysis of the influence of snowfall on the dose rate, the data measured on March 26 were used as measured during fine weather. It is well-known that shielding due to accumulated snow might decrease the dose rate[20]. However, no significant shielding effect of snow was observed in the present study, which might be due to the small snowfall amount. Figure 6 shows the relationship between the dose rates during fine weather and during snowfall. The dose rate increased due to the snowfall; however, some papers have reported that rainfall and snowfall in areas adjacent to the Pacific Ocean had hardly any effect on the dose rate[12, 21]. According to Fujinami[22], the increase of dose rate due to rainfall was mainly caused by a scavenging mechanism within the cloud (rainout) not from that below the cloud (washout). In addition, Omori *et al.*[9] reported radon concentrations on Oshika Peninsula were not high in winter and spring, indicating that the radon progeny concentrations would also be expected to be low. Thus, the dose rate increases seen in the present study might be attributed to the season in which the data were obtained.

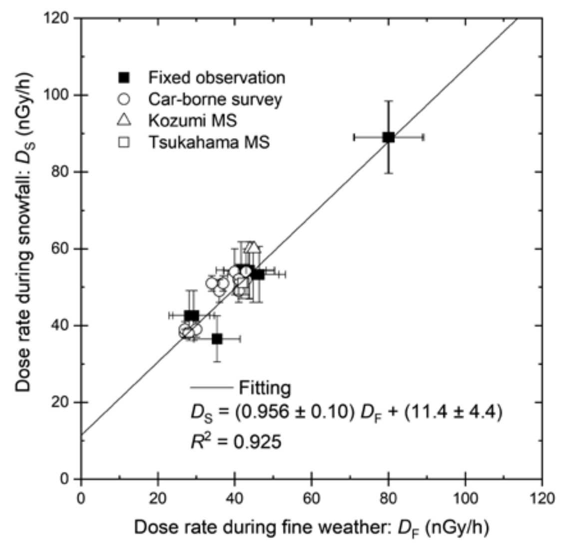

Fig. 6. Relationship between the dose rates during fine weather and snowfall.

In winter, a seasonal north-west wind occasionally dominates over the Japan Sea[23]. Continental air masses which contain relatively high concentrations of radon and its progeny come from the Asian continent to Japan in winter whereas air masses which have a low radon concentration come from the Pacific Ocean in summer due to the ocean's high atmospheric pressure[24, 25]. Ishikawa *et al.*[26] have reported that ^{210}Pb concentration at Onagawa town and Oshika town was high in winter and the amount of deposition of ^{210}Pb by fallout was high in spring. In addition, Hosoda *et al.*[13] reported that the dose

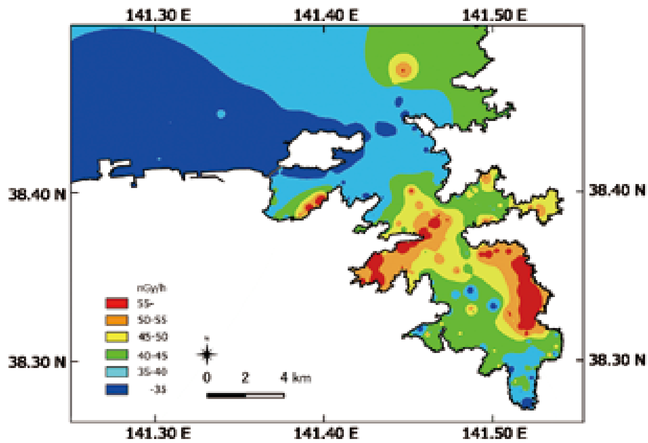

Fig. 7. Dose rate map for Oshika Peninsula.

rates were not significantly changed in summer. Thus, the seasonal factor could be related to the increase of the dose rates.

3.3 Relationship between distributions of dose rate and surface geology

The dose rate map constructed using the results obtained in this study by converting the count rate to the dose rate on the unpaved surface is shown in Figure 7. The data measured on March 25 were used after eliminating the effect of the snowfall by the equation shown in Figure 6. The dose rates for the middle and eastern parts of the peninsula were higher than the southern and northwestern parts which were relatively low. The ^{226}Ra, ^{232}Th and ^{40}K concentrations in a black shale sample, which was obtained from the high dose rate area in the eastern part, were evaluated to be 89.0 ± 0.8, 124.2 ± 1.4 and 1436 ± 7.9 Bq/kg dry, respectively, by measurement using a high purity Ge detector. Shale and slate cover most of the Oshika Peninsula; however, the present study found the only limited areas had high dose rates. By comparison between the dose rate map (Fig. 7) and geological map (Fig. 1), the surface rock types of the high dose rate areas on Oshika Peninsula were found to be sandstone and shale of the Oginohama formation and the Tsukinoura formation[11], which indicates the correspondence between the distributions of dose rates and surface geology.

4. Conclusion

In this study, the car-borne survey for absorbed dose rate in air was conducted on Oshika Peninsula where shale and black slate are widely exposed as the ground surface, and the relationship between the geological features and the dose rate was considered. Additionally, the influence of snowfall on the dose rate was also evaluated. The results indicated that there was no significant difference in the magnitude of the count rate increase measured caused by the snowfall on the different types of surface. The dose rates were increased by snowfall and it might be due to the winter continental air masses that contain high radon and radon progeny concentrations. It was found that the dose rates at the middle and eastern parts of the peninsula were high and those of the southern and northwestern parts were relatively low. The results indicated that the correspondence between the distributions of dose rates and surface geology at the high dose rate areas.

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Conflict of Interest Disclosure

The authors declare that they have no conflict of interest.

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