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A STUDY FOR THE BEHAVIOR OF GROUNDWATER FLOW ALONG THE OPEN FISSURES WITH HIGH DIP ANGLES

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1. INTRODUCTION

The Yashio dam which is the upper dam of the Shiobara Power Plant has a thin ridge at the right bank of its reservoir.

The smallest thickness of the thin ridge is about 100 m at the elevation of HWL (EL.1,048m) of the reservoir. We have been worried about potential leakage through the thin ridge to the opposite mountain stream because of its thickness and the intrusive nature of the rock (porphyrite) with dense columnar joints (Fig. 1, Fig. 2).

With this context, we had conducted the curtain grouting from the tunnel which we installed at the ridge of the right bank of the reservoir. The tunnel is about 2.8km long. A curtain grouting whose measurements are 200m to 400m in length and at 1.5 to 12.0m intervals from one grout hole to another (Fig. 3).

Fig. 1
Plan of the Shibara Power Plant

Some degree of leakage reduction can be achieved utilizing this curtain grouting, but further reduction was necessary. We estimated that most of the leakage flowed below the bottom of the grout curtain, therefore, we did some boring and tested the permeability of the bed rock 150m below the grout curtain. Further, we also conducted a tracer investigation to probe the path that the leak was travelling. We used NaCl and activable tracers on this investigation.

Via this investigation, we found that the permeability didn't decrease corresponding to the depth, and that the highly permeable zone (10 to 100 Lu or more) exists at a deeper area (Fig. 4, Fig. 9). In addition, we found that groundwater flowed from the reservoir to the opposite mountain stream which was confirmed by the a activable tracer investigation. On the other hand, we discovered the drainage holes at the bottom of the reservoir. Through this investigation, we found that the drainage holes like craters existed on the layer of the bentonite which we placed on the whole of bottom of the reservoir for this investigation.

According to this result, we conducted the grouting at the area (Ichinosawa: one of the streams in the reservoir) where craters were distributed. Though, the grouting was conducted at about 30m intervals, we were able to significantly reduce the leakage (Fig. 5). For further reduction of the leakage we anticipated a clogging up the permeable zone with fine particles in the water of the reservoir.

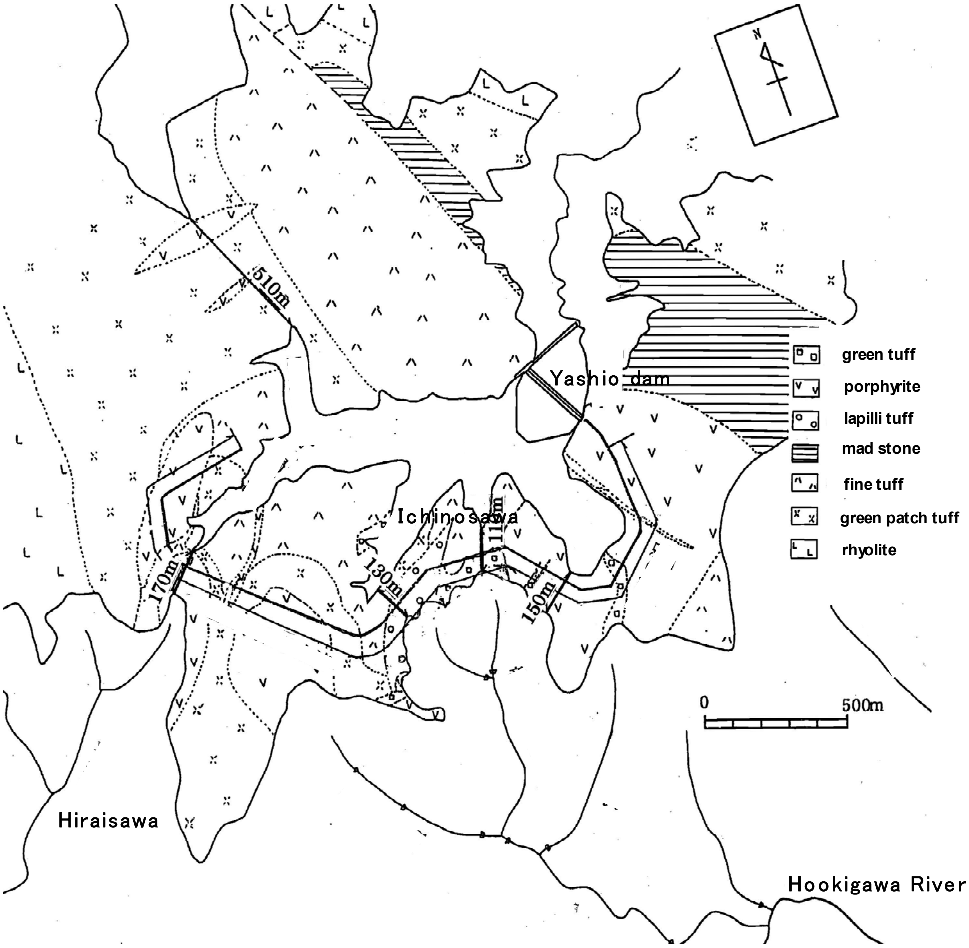


Fig. 2
Plan of the slice of the around of the Yasio dam reservoir at EL.1,048m(HWL)

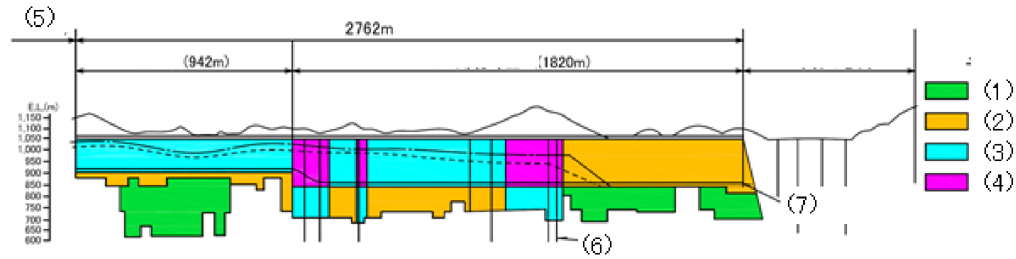


Fig.3
Grout curtain from the grout tunnel in the ridge at the right bank of the reservoir

But the decrease of leakage was still insufficient, so we conducted additional investigations, and are now conducting the grouting based on the results of the investigations. In this paper, we describe the study of the behavior of groundwater flow and the cause of the high permeable zone based on data acquired from the investigations and grouting.

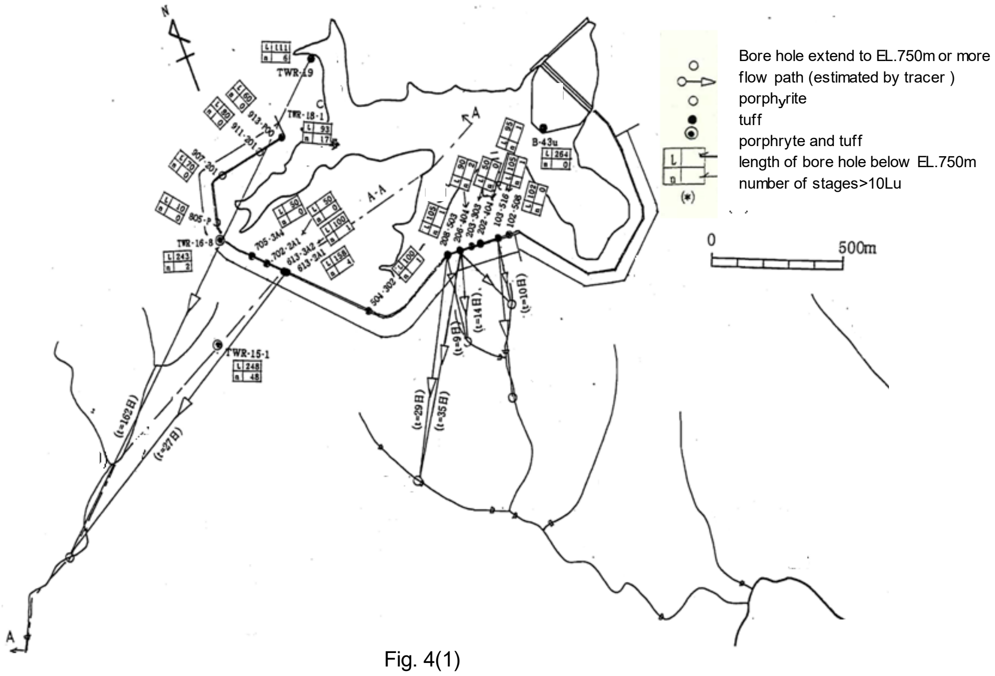


Fig. 4(1)
Results of tracer investigation

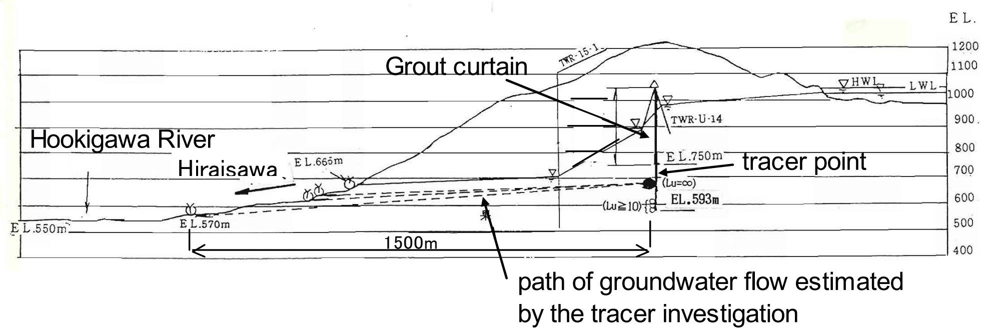


Fig. 4(2)
Result of the the investigation of bellow the curtain grouting

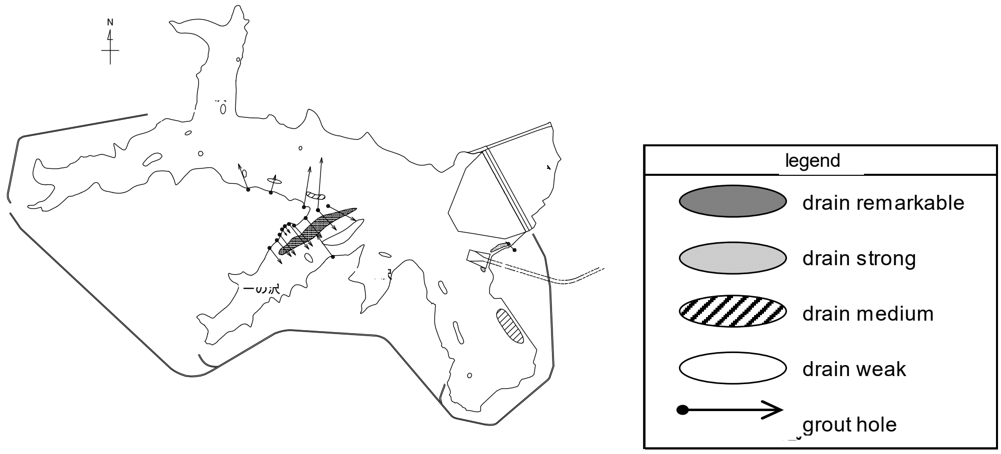


Fig. 5
Result of the investigation at the bottom of reservoir

2. RESULTS OF THE INVESTIGATION AT THE BOTTOM OF THE RESERVOIR IN THE ICHINOSAWA AREA

2.1. PERMEABILITY

We investigated the geological features and others by boring holes at the bottom of the reservoir in the Ichinosawa area where a large number of craters were distributed. We set the boring holes below the craters where water flow was strong. These craters were the mouths of the path of leakage and led to the Hiraisawa which had the largest increase of flow quantity in the opposite mountain streams. We confirmed it by investigation using activable tracers. The activable tracer is the high precise tracer, used in the fields of medical treatment or agriculture. The boring hole was 275m in length. We confirmed that tuff was distributed in the boring core. The site was comprised mainly of tuff. The high permeable (10Lu or more) zone was found continuously in deep areas. And we found that the extreme high permeable zone (more than100Lu) existed intermittently (Fig. 6).

2.2. OPEN FISSURES

2.2.1. Strike and dip of the open fissures

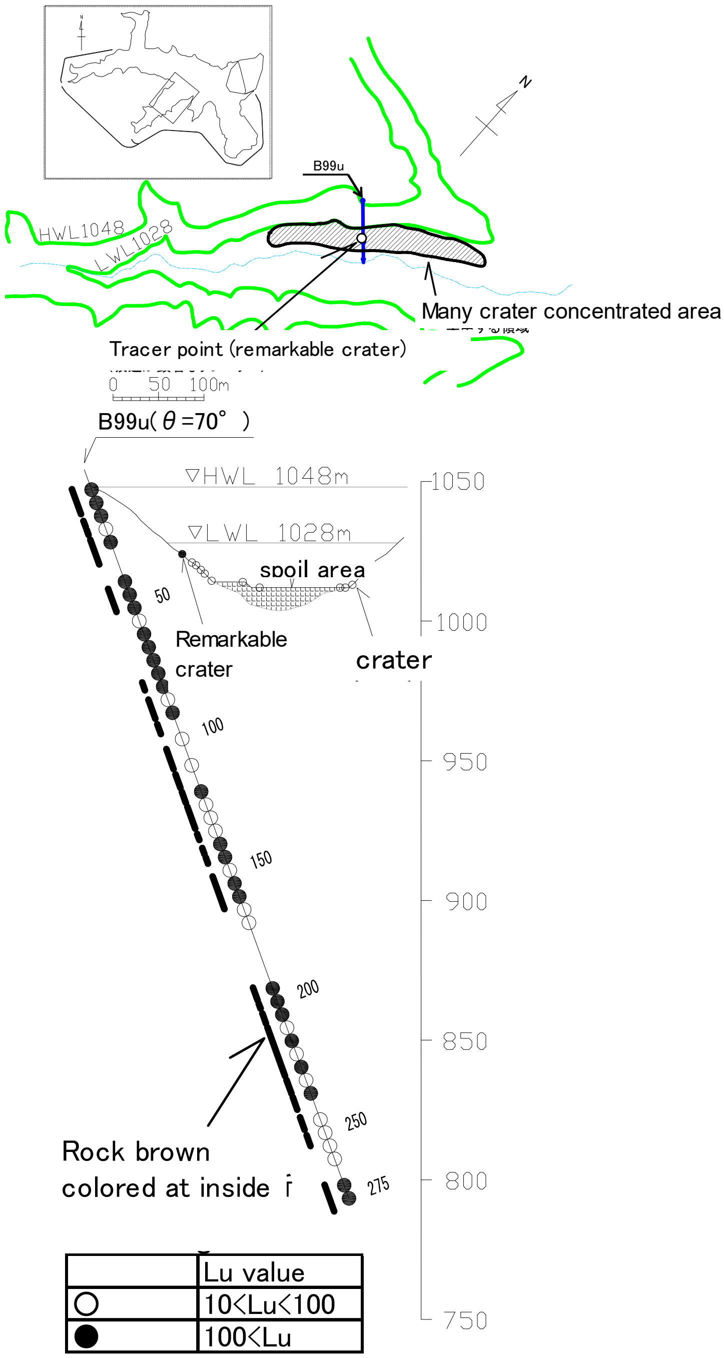
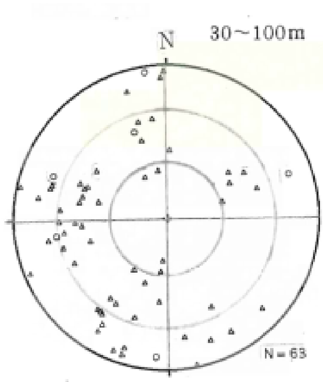


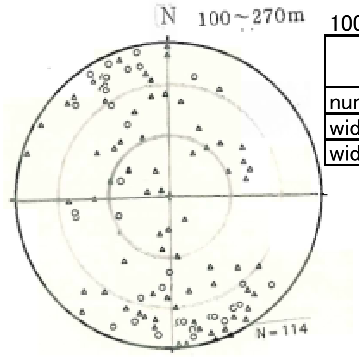
Fig. 6
Distribution of permeability of boring hole at the Ichinosawa area

We investigated the features of the open fissures by BHTV (Bore Hole Tele Viewer) in the boring hole. We divided the data of strikes and dips of the open fissures into four groups which were classified by their width (more or less than 1 mm) and their depth from ground level (more or less than 100 m). The maximum width of the open fissures was 8 mm. We found that the open fissures with a width of more than 1mm mainly had an N-S strike and mainly had a dip of more than 60 degrees. This N-S direction was equal to the direction to Hiraisawa (Fig. 7).



30 to 100 m from ground level

	open fissures	
	dip angle<60	dip angle>60
number	33	30
width(ave.)	0.3mm	0.6mm
width(max.)	2.0mm	1.0mm



100 to 200 m, 230 to 270 m from ground level

	open fissures	
	dip angle<60	dip angle>60
number	47	67
width(ave.)	0.5mm	1.0mm
width(max.)	2.0mm	8.0mm

△ width less than 1mm
○ width not less than 1mm

Fig.7
The strikes and dips of the open fissures at the Ichinosawa area
(The projected figure on the southern hemisphere)

2.2.2. Features of open fissures

We described the features of rock by observing the boring core below. The rock distributed less than 30 m depth from the ground surface was weathered and brown colored in appearance. The rock which was distributed more than 30m in depth has a brown colored in appearance at the most of the parts where open fissures existed. Especially, at all of the open fissures with more than 1 mm width appeared brown color along the fissures and at the inside of the rock. We concluded that the brown color of rock was caused by hot water with high pressure. We came up with this estimate based on the state of gradation and observation of the foil of the rock utilizing a polarizing microscope. We verified that the brown color lightened gradually, as there was inside of the rock and identified a brown colored area developed along the micro cracks. We also identified that some alterations caused by hot water was existed at the edge of the chlorite and that there was a little bit of calcite existing (Photo. 1).

The pieces of boring cores of each side of the open fissure were met well and we couldn't see the streak, so we concluded that the open fissures were made by tensile stress (Photo. 2).

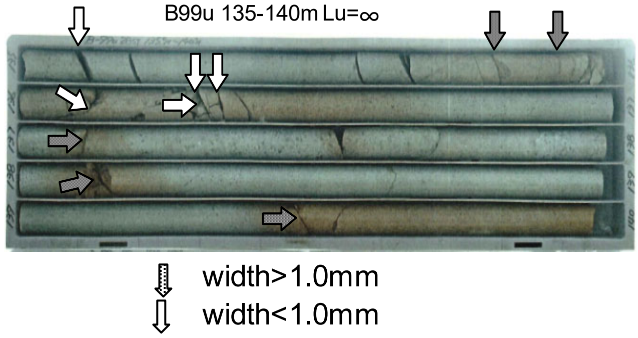


Photo.1
Boring core at the Ichinosawa area

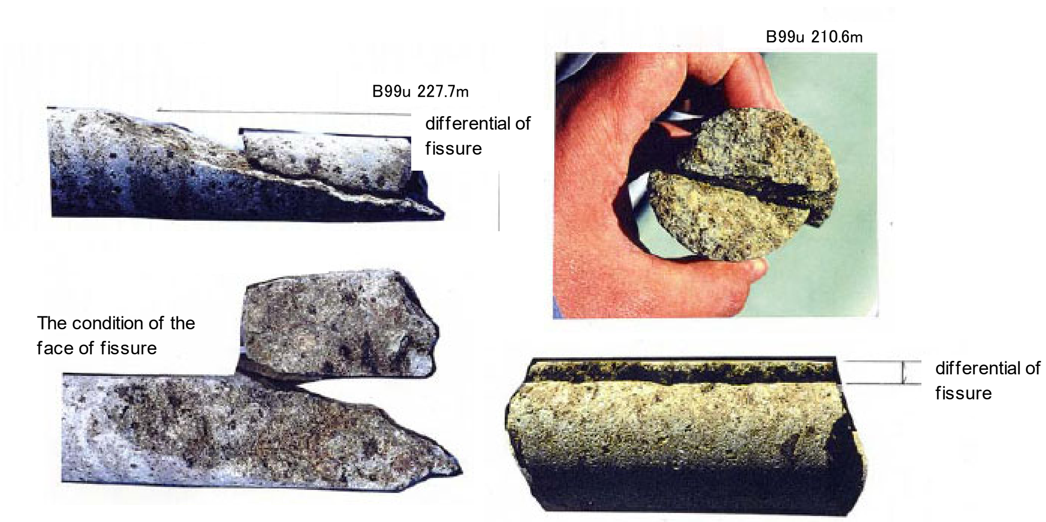


Photo.2
The pieces of boring cores of each side of the open fissure

2.3. THE INVESTIGATION OF GROUND WATER FLOW AT THE ZONE BETWEEN THE CRATER AND THE BOREHOLE BY TRACER

We investigated by putting the NaCl as the tracer into the crater to measure the velocity of fluid between the crater and points of the borehole which had a high level permeability exceeding 100 Lu. The crater we put the NaCl into was identified connecting to the opposite mountain stream by the investigation using activable tracers.

We evaluated the fluid velocity by measuring the conductivity of ground water at the eight points with high permeability in the borehole. The velocity was calculated utilizing the distance from the crater to the observing point in the borehole and the time when we identified an increase in conductivity. We identified that the tracer reached all the observing points. The tracer traveled the fastest moving vertically than any other direction with a maximum velocity of about 4 cm/sec. We estimated that the ground water that flowed along the network consisted of fissures, because more than one peak value of conductivity was observed. We estimated that ground water at the Ichinosawa area mainly flowed along the open fissures with high dip angles and that the network consisted of open fissures. And they were found in deeper areas in the bed rock (Fig.8).

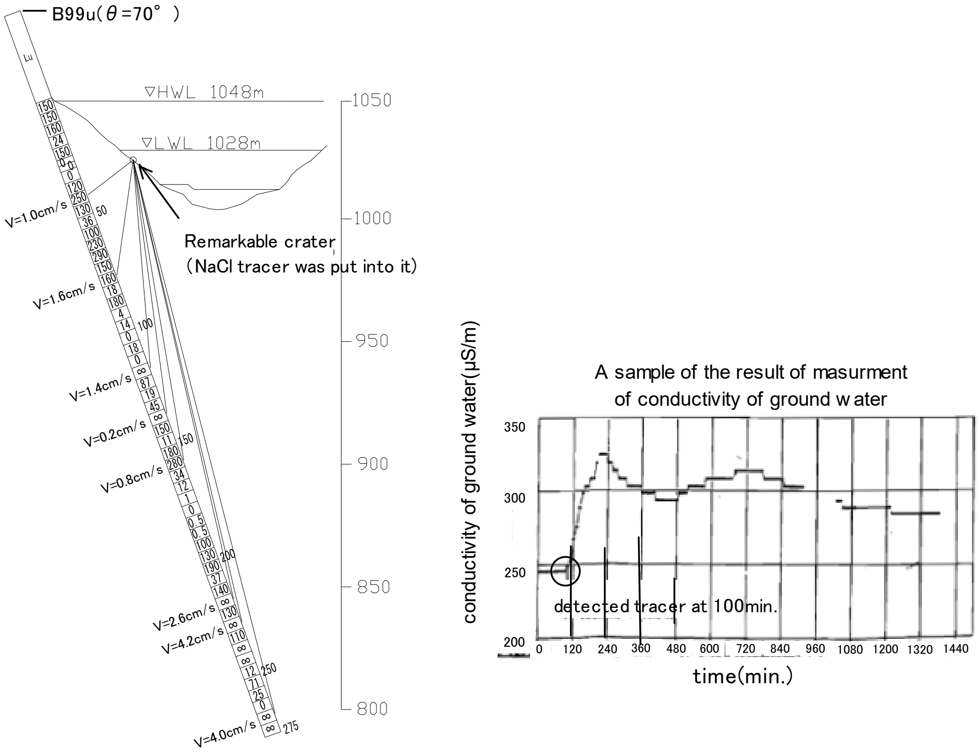


Fig.8
Results of the investigation of velocity of ground water flow by NaCl tracer

3. GEOLOGICAL FEATURES BELOW THE GROUT CURTAIN AREA

As mentioned above, the boring cores at the part where we put the activable tracer appeared with brownish color and had a high permeability of 10 to 100 Lu (Fig. 9, Photo.3). Incidentally, this activable tracer was detected in the running water at the opposite mountain stream. And we investigated the features of the open fissures by BHTV at the part of the bore holes where we put the activable tracer into. All of the dips of the open fissures in the bore holes whose width were 1 to 4 mm were more than 60 degrees.

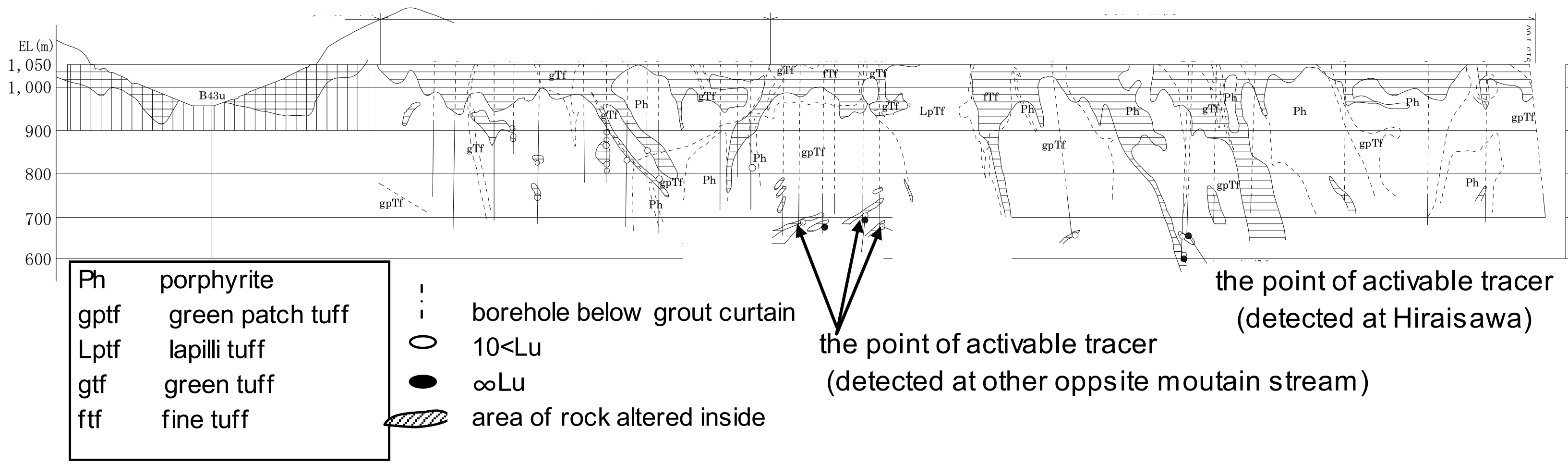


Fig.9
Geological features below the grout curtain area

Their features were similar to the ones of the Ichinosawa area. We estimated that the one of causes of the paths of leakage to the deeper areas in the bed rock was alternation by the hot water. We estimated that the network of open fissures with high dip angles was formed by hot water with high pressure and tensile stress caused by unloading due to reason unverifiable at this time.

Photo.3
A sample of boring core below the grout curtain

4. THE CAUSE OF UNLOADING AT THE RIGHT BANK OF RESERVOIR

We studied the processes of topography formation in the large regions and the causes of unloading at the right bank of the reservoir. We can see that the reservoir of the Yashio dam is at the outer rim of a volcanic crater which is in the north direction of the Takahara volcano on the topographical map at a scale of 1:200,000 (Fig. 10). We found the sediments of the pyroclastic flow at a part of the ridges of the right bank of the reservoir and the ridges around the caldera. We estimated that the area was comprised of level ground, but after the eruption of the Takahara volcano, the caldera was formed. After that, ejecta piled up on the north side of the Takahara volcano and the deposits piled up on former Lake Shiobara due to multiple eruptions of the Takahara volcano. The water level of former Lake Shiobara rose with the deposits, and water seeped over the edge of the Eastern part of the caldera. After that, the Hookigawa River formed and the caldera wall and both banks of Hookigawa River were rapidly flooded. We estimated that the process of formation of topography around the Yashio reservoir caused the unloading of the right bank of the reservoir (Fig. 11).It was estimated that the caldera was formed about 300,000 to 500,000 years ago based on age measurements of ejecta (by K-Ar method 1)). Further it was estimated that Hookigawa River was formed about 20,000 years ago by the analyzing of the volcanic ash of the Deposits in former Lake Shibara 2).

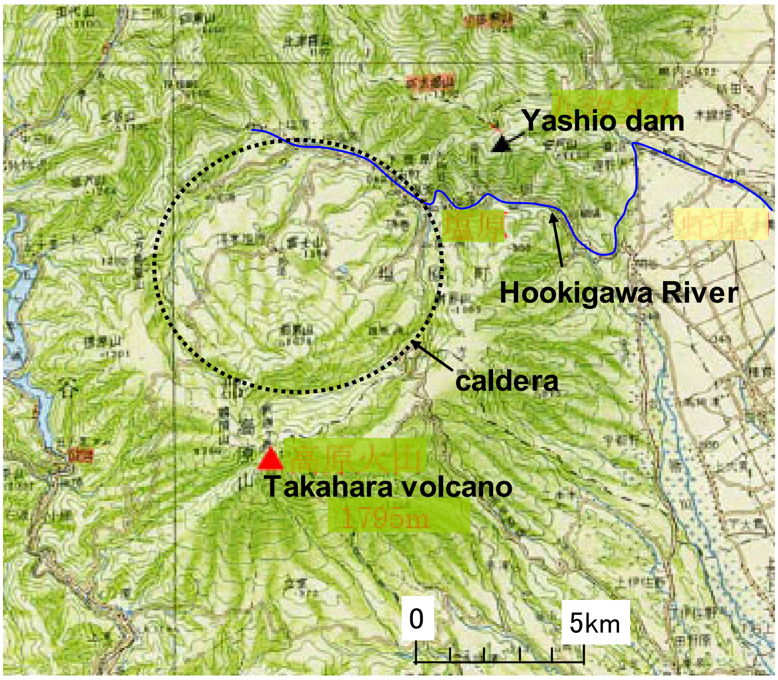


Fig.10
The Takahara volcano and the somma

5. CONCLUSION

We found that the leakage from the Yashio dam reservoir which flowed along the network consisted of the open fissures with high dip angles which were found in deeper areas via the investigation by the BHTV or the tracer. Based on the boring core investigation and studies of the processes of topography formation, we estimated that the cause of the leakage was as follows.

(a) First, a network of the fissures was created by hot water from deep underground.
(b) Second, a major creep occurred at the edge of the caldera created by a volcano near the dam site and that the creep developed by encroaching. The widths of the fissures were extended by the creep and the network of the fissures was formed deep underground.

At present, we are conducting the grouting at the bedrock of the bottom of the reservoir filled with water. We adopted this method, because we considered that it would be impossible to make a grout curtain at more than 500 m in depth, and we expected that the groundwater flow (velocity of fluid was about 4 cm/sec) brought the grout material a long distance and the leakage of grout material to the surface of the reservoir decreased. We will report about this in the near future.

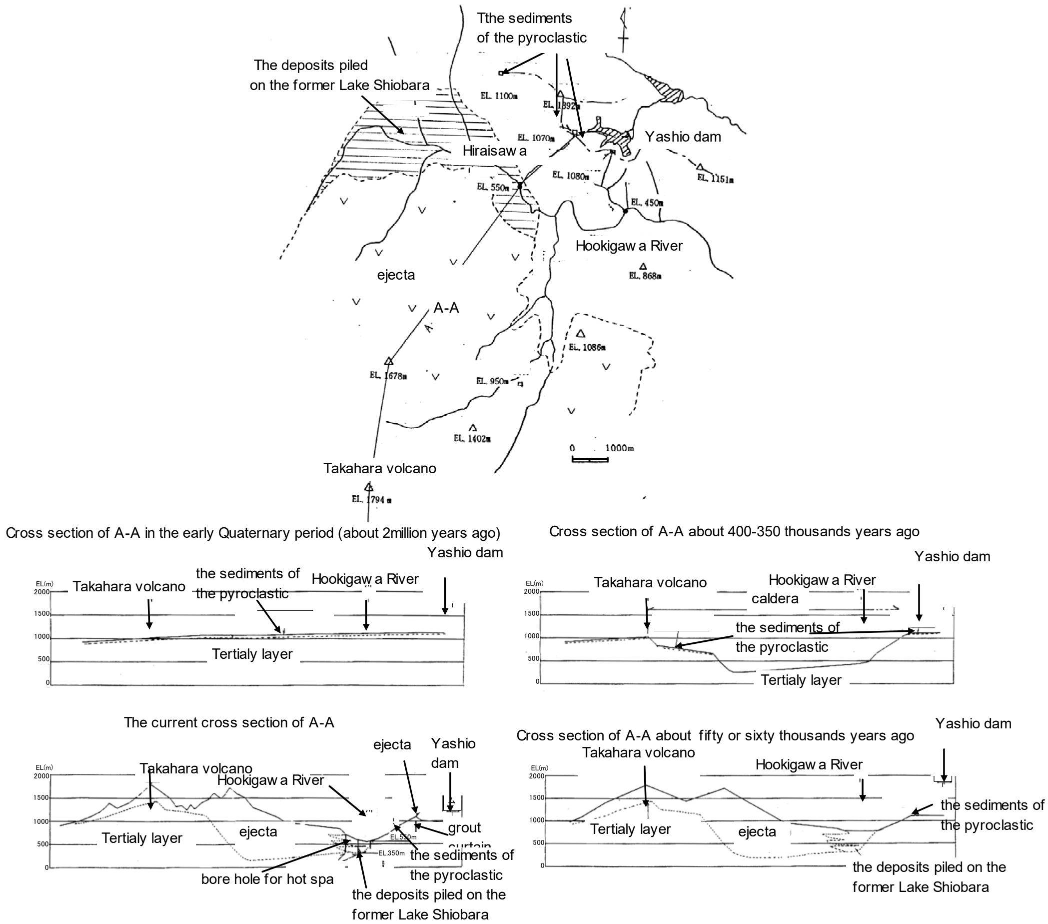


Fig.11
History of the topography formation in the large regions around the reservoir

6. REFERENCES

[1] TORU ONOE. Palaeoenvironmental Analysis based on the Pleistocene Shiobara Flora in the Shiobara Volcanic Basin, central Japan, *Geological Survey of Japan, Reports, 269*, 1989

[2] TADAHIRO HAYAKAWA. Development and displacement of fluval terraces across Sekiya Fault, in upperstream of Houki River, Tochigi Prefecture, *The Research Group for Active Faults of Japan, Reports No.1,* 1985 (in Japanese)

SUMMARY

The Yashio dam has had significant leakage from the right bank of the reservoir to the opposite mountain stream. To reduce the leakage, we conducted the curtain grouting from the tunnel which we installed at the ridge of the right bank of the reservoir. However through this grouting, we were unable to reduce the leakage satisfactorily.

Therefore we conducted many measurements, investigations and studies at the area below the grout curtain and the bottom of reservoir. We found that the cause of leakage was open fissures in the bed rock with high dip angles and that the fissures were located more than 500m in depth from the maximum water level. In addition, we studied the processes of topography formation in large regions. As a result, we estimated that the cause of the open fissures was the location of the reservoir which was at the edge of the caldera caused by a volcanic eruption near the dam site. That is to say, the fissures were created by a combination of hot water with high pressure from emanating deep underground and the width of the fissures were extended by the creep which first appeared at the edge of caldera and was developed by encroaching.

In accordance with these studies, we are conducting the grouting at the bedrock of the bottom of the reservoir filled with water in order to more efficiently decrease the leakage.

KEY WORDS

leakage from the reservoir, open fissures with high dip angles, groundwater flow, activable tracer