Geology and Geological Structure of Tsuruga Power Station Site

The D-1 Shatter Zone

Interim Report(No.2)

The Japan Atomic Power Company

March 15, 2013

Contents

1. Introduction

Evaluation of the shatter zones in the site of Tsuruga Power Station(Tsuruga PS) has been discussed during the seismic back-check by the former Nuclear and Industrial Safety Agency(NISA) and the former Nuclear Safety Commission(NSC).

In the discussion of the seismic back-check, based on the opinions expressed by the former NISA during a field survey on the shatter zones in the site of Tsuruga PS conducted on April 24, 2012 and the instructions issued by the former NSC, we decided to implement a further geological survey in order to collect additional data.

Basic principles for the additional survey are indicated below and the survey work has been achieved after obtaining a survey plan approval from the former NISA at the occasion of the hearing about the earthquake and tsunami on May 14, 2012.

- Evaluation of activities of the shatter zones in and after the Late Pleistocene should be based on the evaluation by the overlying strata analysis method.
- If evaluation based on the overlying strata analysis method would be difficult, evaluations should be carried out in a comprehensive manner, based on the results of various geological surveys and numerical analyses.

The Nuclear Regulation Authority(NRA) was established on September 19, 2012, under which "Experts Meeting of the Survey(EMS) on Shatter Zones in the Site of Tsuruga Power Station" was formed (approved by the NRA on November 14, 2012). Then, a preparatory meeting was held on November 27, 2012, which was followed by a field survey conducted on December 1-2, 2012, the first EMS on December 10, 2012, the second EMS on January 28, 2013 and the third EMS and peer-reviewing on March 8, 2013.

In the last EMS, the report titled "Evaluation of Shatter Zones in the Site of Tsuruga Power Station of the Japan Atomic Power Company(JAPC: temporarily Draft) on March 8, 2013 (Tsuruga・peer 1-2)" (draft of EMS report) was submitted. The draft of EMS report refers to the evaluation of the D-1 shatter zone with saying "the shatter zones in the site of Tsuruga PS can be judged that it is highly likely to be an active fault which should be taken into account in the seismic design, based on the data obtained so far." Also, it adds, "if there would be new knowledge and findings in the future, this may be reviewed, if required."

The conclusion of the draft of EMS report was based on the major reasons described as the followings:

1. JAPC does not clarify the reasons for identifying the G fault as the D-1 shatter zone.

2. The shear of the K fault reaches bedrock and facing strata/um and thus it cannot be denied activities in and after the Late Pleistocene. This means that the K fault must be taken into account in the seismic design. [Data-1 to 4]
3. JAPC just clarified that activities of the D-1 shatter zone were older than about 7,300 years ago. [Data-5]
4. It is highly possible that the K fault is connected to the D-1 shatter zone because they have the same configuration (strikes and dips) and are closely located. [Data-6]

Judging in a comprehensive manner from the above, the EMS members tentatively have reached to a conclusion that the D-1 shatter zone is highly likely an active fault that should be taken into account in the seismic design and it can be moved with the Urasoko fault, which located at an extremely close range, and then the integrity of the safety related facilities of Tsuruga PS, just above the crash zone, would be affected.

On the other hand, JAPC has evaluated that the D-1 shatter zone would not be an active fault which should be taken into account in the seismic design based on the following understandings. The scientific bases for these understandings are written in the section 3.

① The D-1 shatter zone consisting of “cataclasite” and “fault gouge” runs almost in a North-South direction with a high-angle westerly dip. It has a good continuity.

② Through observation of thin section samples collected from the D-1 outcrop, drilling cores of ②-1 and B14-2 of the D-1 shatter zone, the all displacement senses of the last slip show a “normal fault” and a “right-lateral slip” sense.

③ Through observation of thin section samples and the observation result of the trench, the senses of displacement of the last slip of the G fault show a “normal fault” and a “right-lateral slip” sense.

④ Meanwhile, based on the displacement direction of the strata, the K fault shows a “reverse fault” sense. Also, through observation of slickenlines of the last slip, it is confirmed that the K fault consists mainly of “reverse fault” components.

⑤ Whereas both the G fault and the K fault could be seen as an extension of the D-1 shatter zone, it is judged that the D-1 shatter zone, which has a “normal fault” sense, would not continue to the K fault, but would connect to the G fault due to the same displacement sense.

⑥ Through observation of the strata at northern pit in the D-1 trench, it is confirmed that the G fault at least has not displaced or deformed layer①, which is located lower than layer⑤, which strata contains the Mihama tephra of 120,000 years ago.

⑦ Through observation of the strata at northern wall surface of the D-1 trench, it is clarified at least, that the K fault has not displaced or deformed the lower part of layer ⑤, which strata contains the Mihama tephra of about 120,000 years ago.

⑧ It is also observed that in the northern part of the western pit, the K fault changes the directions from N-S to NNW-SSE with bending. The shatter zone with N-S direction strick does not displace and deform layer ③ that covered the K fault in the south part from the bend.

⑨ In order to confirm whether the K fault extends to the south or not, the drilling core of B14-2, which is crossing between the Unit 2 reactor building and the K fault, has been investigated. As a result, the K fault could not extend to the south at least beyond the drilling of B14-2, since no observation of a "reverse fault" has been found in the drilling data.

⑩ Based on the above, the D-1 shatter zone continues not to the K fault but to the G fault and the D-1 shatter zone, including the G fault, cannot be an active fault that should be taken into account in the seismic design. In addition, the K fault is not an active fault that should be taken into account in the seismic design neither.

This report has been updated to the last interim report of JAPC dated Feb 5, 2013 by adding the current survey results obtained until the end of February 2013.

Major differences of views between the draft of EMS report and this report are shown in the [Data-7].

2. Geology and geological structure of the site

2.1 Contents of survey

In order to grasp the geological conditions and structure of the site, the following survey, analysis and other efforts were undertaken: [Data-8 to13]

- Bibliographic survey
- Tectonic landform survey
- Surficial geology survey
- Drilling survey
- Trench survey, pit survey
- Test tunnel survey
- Dating
- Observation of microstructures in fault shatter zone(*1) (*2)

*1) Kenichi Kano, Akihiro Murata, 1998, Structural Geology, Asakura-shoten.

*2) Takashi Nakajima, Hideo Takagi, Kazuhiko Ishii, Toru Takeshita, 2004, Field Geology 7 “Alteration/Deformation”, Kyoritsu Shuppan

The last slip of fault crash zone for the microstructure observation is determined from the structures cutting a whole shatter zone, considering the degree of linearity and softening of fault gouge. The way to prepare the thin section samples, which EMS pointed out not to be appropriate, would be taken into account for further observations and it will be confirmed that the current evaluation is valid.

2.2 Survey results

2.2.1 Geography of the site

The site consists mainly of a mountainous area. The well-dissected older fan surface is found mainly along the Wakasa Bay and the west of Urasoko Bay. The low terrace surface is found in a very small scale along the Wakasa Bay. The lowest terrace surface is found in the east coast of Urasoko Bay. The younger fan surface is found in a small scale in the downstream of a valley excavating mountains. The present river bed and talus are found in valley excavating mountains and the mountain slopes. The alluvial plane surface extends around the lowland around Urasoko Bay. The coastal plain surface consisting of beaches and beach ridges extends around. [Data-14]

The result of bibliographic survey suggests that there has been no document mentioning the existence of an active fault in the site, except the Urasoko fault. [Data-15]

Through aerial photo interpretation and others, as the existence of Urasoko fault is indicated by the documents, it is learned that there is a geography with a potential existence of tectonic landform in a direction of Northwest-Southeast (lineament), which runs through a boundary between the mountains and the lowlands that extend from Cape Tateishi to the west of Inogaike, consisting of steep cliffs, saddles, straight valleys and bending of valleys. On the other hand, the tectonic landform corresponding to shatter zones is not recognized.

2.2.2 Geology of the site

The geology of the site consists of Kojaku granite, dolerite that penetrates into Kojaku granite, and the overlying quaternary deposits. Kojaku granite is judged to be formed in the times between the late Cretaceous and the Paleogene, since the values range from some 66.6-64.2 Ma measured by potassium-argon dating. Dolerite is judged to have penetrated into during the Neogene Period (Miocene), since the values stand at around 21.1 Ma measured by potassium-argon dating. Adjacent to the lineament, the high-angle northeasterly dip fault (Urasoko fault) can be seen. The shatter zones with hydro-thermal alteration are found in Kojaku granite and dolerite.

Kojaku granite consists of biotite granite, granite porphyry and aplite. [Data-16, 17]

Analysis of a fault gouge by x-ray diffraction has found that the fault gouges in Kojaku granite on the Units 1 and 2 side as well as on the Units 3 and 4 side contain quartz, potassium feldspar, plagioclase, muscovite, kaolinite and smectite. Measured values of clay mineral by potassium-argon dating (the time of rock or mineral changing in quality as a result of coming into contact with hot water) resulted in about 54.6-61.4 Ma. The fault gouge in the Urasoko fault contains quartz, potassium feldspar, plagioclase, muscovite, kaolinite and smectite. Measured value of clay mineral by potassium-argon dating method (the time of rock or mineral changing in quality as a result of coming into contact with hot water) resulted in about 50.3 Ma. The fault gouge in dolerite contains high volume of smectite, medium volume of calcite and laumontite. Measured value of clay mineral by potassium-argon dating method (the time of rock or mineral changing in quality as a result of coming into contact with hot water) resulted in about 18.9 Ma. [Data-18]

2.2.3 Geological structure of the site

Many shatter zones are found in the site. The shatter zones found around the location of Units 1 and 2 run in the directions between N-S and NE-SW. Many of them are westerly dip. Some run in the direction of NW-SE with a northeastern or southwestern dip. Among them, the shatter zones running in the direction between N-S and NE-SW show good continuity. [Data-19 to 25]

The shatter zones found around the location of Units 3 and 4 run in the directions between N-S and NE-SW. Many of them are easterly dip. In dolerite adjacent to the Units 3 and 4, the shatter zones running in the direction of ENE-WSW are found, which have displaced the shatter zones running in the direction between N-S and NE-SW. [Data-26 to 29]

Among these shatter zones, those running in the directions between N-S and NE-SW are predominant. Also, the joints run in the directions between N-S and NE-SW, NNW-SSE and E-W. Among them, those running in the directions between N-S and NE-SW are predominant. As for dip, many of those adjacent to the Units 1 and 2 are high-angle westerly dips, while many of those adjacent to the Units 3 and 4 are high-angle easterly dips. [Data-30]

Regarding the Urasoko fault, to which the literature refers, drilling survey and trench survey have been conducted to understand the activity of the fault. Also, in order to know the location of fault extension in the southern area of the site, electrical exploration method and seismic reflection method were used.

As a result of survey, the Urasoko fault is judged as a highly straight line-type fault with an uplifting in the northeastern side between Kojaku granite and quaternary deposits. Urasoko fault has been active since Late Pleistocene and the latest event was at least after 4,000 years ago. [Data-31, 32]

Evaluation of the continuity of the shatter zones recognized by drilling survey, outcrop survey and trench survey has been undertaken in the following way: [Data-33]

① The identified shatter zones should be extended, following their strikes and dips.

- For strike and dip, values measured by a borehole television, surficial geology survey and test pit survey should be used.
- If there is no rational ground to bend it, it should be extended linearly in principle.

② If "a shatter zone that has similar strike and dip exists" and "a shatter zone whose strike and dip are unknown exists" in the extended location, it should be evaluated as being continuous.

- It should be deemed as being continuous on the assumption that a strike and dip change locally (changes in strike and dip are estimated within a range of ± 20°).
- In the case of the characteristics (whether a fault gouge exists or not, linearity, etc.) of shatter zones being different, if strike and dip are similar, it should be deemed as an extension and being continuous.
- If in the extended location "the existence of a shatter zone is unknown," it should be extended directly.

③ In cases that in the extended location "the shatter zone is not identified," and "a shatter zone with a different strike and dip exists," it should not be extended further.

④ In case that in the extended location "the corresponding shatter zone is not identified and a different shatter zone is judged to cross," it should be deemed that the shatter zones are consolidated.

3. Evaluation of the D-1 shatter zone

3.1 Contents of survey

The following surveys have mainly been carried out in order to clarify the continuity and activity the D-1 shatter zone:

- Drilling survey
- Outcrop survey
- Trench survey, pit survey

- Dating (Tephra analysis, Pollen analysis etc.)
- Observation of microstructures in fault shatter zone

Some of these surveys are still under investigation. Based on the results obtained so far, the D-1 shatter zone has been evaluated. Here, all the evaluations has been carried out by appropriate combinations of several survey methods such as drilling survey, trench survey and so on, depending on conditions of the D-1 shatter zones.

3.2 Survey results

3.2.1 Drilling survey

The D-1 shatter zone was identified at the drilling core of B6-5, B6-1 and B14-2 in the north of Unit 2 reactor building, and at the drilling core of 14, ②-1 and 2 in the south of Unit 2 reactor building. All of them consist of cataclasite and fault gouge. In general, they run in the direction of N-S and are high-angle westerly dip. [Data-34 to 36]

At the drilling core of ②-1, the direction of the shatter zone was not measured by a borehole television. At the drilling core of B14-2 and ②-1, observation of thin sections from fault gouge to know the displacement sense of the last slip reveals that it is a normal fault and has a sense of right-lateral slip. [Data-37 to 40]

In order to confirm whether the K fault extends to the south or not, the drilling core of B14-2 hole has been investigated whether a “reverse fault” sense as similar to the K fault exists or not, because the drilling B14-2 is crossing between the Unit 2 reactor building and the K fault,

In the data from the drilling core of B14-2, three parts of shatter zones have been found with fault gouge. The thin section sample observations have been carried out in order to confirm the displacement sense, where the one, the D-1 crash zone, has been cut along vertical and horizontal directions, and the other two parts have been cut along fault slickenline direction. As a result it is confirmed that all the last slip of displacement sense of the shatter zones has a normal fault sense.

Based on the above, it is judged that the K fault could not extend to the south, at least to the south beyond the drilling of B14-2. [Data-41 to 45]

3.2.2 Survey on the D-1 outcrop

Regarding the geological strata of the D-1 outcrop, the sedimentary layers are classified into layers A to C from upper to lower, based on the facies, and the basement rocks are classified into D to H based on the type of rocks and the degree of weathering. [Data-46]

Layer A is surface soil consisting of humic sand with gravels. Layer B is talus deposit with a high content of gravels. Layer C is talus deposit consisting of silty sand with gravels. D is relatively hard granite porphyry. E is softened granite porphyry, due to the hydro-thermal alteration or weathering, though a degree of shattering is low. F is cataclasite changed from aplite. G is softened aplite, due to hydro-thermal alteration or weathering, though a degree of shattering is low. H is basement rock, where the original rock texture is more ambiguous due to high degree of weathering.

As a result of tephra analysis, it is learned that layer A contains Aira-Tanzawa (AT) (about 27,000 years ago), while layer C contains both Aira-Tanzawa (AT) (about 27,000 years ago) and Kikai-Akahoya (K-Ah) (about 7,300 years ago). [Data-47]

The D-1 shatter zone consists with aplitic cataclasite and fault gouge, and runs in a direction of NNE-SSW with a high-angle westerly dip. Detailed observation reveals that the texture of gouge of the shatter zone is unclear, due to weathering in the upper part of rock mass. [Data-48]

Observation of the D-1 outcrop to know the displacement sense in cataclasite reveals that it is a reverse fault with a right-lateral slip sense. [Data-49, 50]

The thin section sample observation of block samples collected from the D-1 outcrop reveals that the displacement sense of the last slip is normal fault with right-lateral slip sense. [Data-51 to 53]

The results of observation of the D-1 outcrop and tephra analysis reveal that the shatter zone has not displaced or deformed layer C, which is the layer deposited after Kikai-Akahoya (K-Ah) (some 7,300 years ago).

3.2.3 Survey on the D-1 trench

The locations and numbers of trench survey should be determined based on the investigation objectives. The D-1 trench survey is aimed to make it clear if the D-1 shatter zone could move simultaneously with the Urasoko activities, and thus the trench survey has been carried out basically in the location close to the Urasoko fault. To determine the locations and numbers of trench, the restrictions of space and/or interferences to existing facilities were also taken account.

Regarding the geological strata of the D-1 trench, the sedimentary layers overlying granite porphyry are classified into layers ① to ⑨ from lower to upper. [Data-54 to 57]

Layer① consists of very tight, poorly sorted sand gravels. Layer② consists of block-shaped, tight sandy silt and silty sand, and also contains lots of decayed gravels. Layer③ consists mainly of sand gravels, to which lens-like or layer-like silt layers and sand layers are inserted. This layer contacts with unconformity surface denuding lower layer. Layer④ is a belt-like oxidized portion on the top of layer③. Layer⑤ consists mainly of silty sand gravels and contains non-continuous alternate layers of silty sand gravels and silt. This layer can be segmentalized into the upper and the lower parts depending on the differences of sedimentary structures. The lower part shows the layer thickness has been decreased along the west direction of the north wall, but the thickness has been increased along the east direction. And this increase becomes strong as close to the Urasoko fault, since the basement line tends to be lower as close to the Urasoko fault. The upper part shows rather horizontal line and a constant thickness. The lower part erodes the lower layer greatly and it contacts with the layer in the unconformity surface. Layer⑥ consists of humic sandy silt and silty sand, and also contains lots of wood chips. Layer⑦ consists of sandy silt with gravels and silty sand with gravels. Layer⑧ consists of sand gravels with silty sand, and partly has stratified structures. Layer⑨ consists of sandy silt with gravels. From layer① to the upper part of layer⑨ are cut off by Urasoko fault.

The result of tephra analysis reveals that the upper part of the layer⑤ contains the Kikai-Tozurahara (K-Tz) tephra horizon.

A tephra consisting of hornblende was detected from the lower part of layer⑤. The tephra can be correlated to Mihama-tephra from the comparison of refractive index and ingredient components. According to Yasuno (1991) (*3), Mihama-tephra is located in the lower part of middle terrace marine deposit, which is under Sanbe-Kisuki (SK) tephra (about 110,000 – 115,000 years ago [Atlas of tephra in and around Japan (*4)]).

Based on the above, it is judged that the lower part of layer⑤ is equivalent to marine oxygen-isotope stage 5e.

In the tephra analysis of multiple measurement line, the tephra consisting of hornblende has an lower occurrence limit in the almost same horizon, there is no reverse of depositional age including other tephras, and the lower occurrence limit is located above the unconformity between layer③. Therefore the lower part of layer⑤ is judged to be a horizon of Mihama-tephra. [Data-58 to 59]

*3) Yasuno. T, 1991, Discovery of Molluscan Fossils and a Tephra Layer from the Late Pleistocene Kiyama Formation in West of Fukui Prefecture, Central Japan, Bull. Fukui Mus. Nat. Hist., No.38: 9-14

*4) Machida. H, Arai. F, 2003, Atlas of Tephra in and around Japan, Univ. Tokyo Press, Tokyo.

(1) About the G fault

The G fault is recognized at the northern pit of the D-1 trench, which is located on the line extended from the D-1 shatter zone. The G fault consists of granite porphyry cataclasite and yellow brown fault gouge and has strike in a direction of N-S and high-angle westerly dip. [Data-60, 61]

From the thin section observation of a block sample at the south of the northern pit, the displacement sense of fault gouge of the last slip has normal fault and right-lateral slip sense. [Data-62 to 64]

The G fault, which is recognized at the northern pit of the D-1 trench, has not displaced or deformed layer①, which is located under layer⑤ (a layer including Mihama-tephra about 120,000 years ago). At the southern pit, a shatter zone also has not displaced and deformed layer①. [Data-65, 66]

(2) About the K fault

The K fault is recognized in the deposit at northern wall surface of the D-1 trench. Due to the displacement of the strata, the K fault has reverse-fault sense.

At the northern wall surface of the D-1 trench, the northern part of the K fault is recognized in layer③, which is located under layer⑤ (a layer including Mihama-tephra about 120,000 years ago). The northern part of the K fault has a strike in a direction of N-S and westerly dip. The northern part of the K fault terminates in layer③ and is covered by the upper part of layer③. Southern part of the K fault changes its strike direction to NNW-SSE around western pit. The southern part of the K fault has westerly dip and terminate in layer③. [Data-67]

At L-cut pit, the K fault is recognized between decayed granite porphyry and layer②. Strike and dip is a direction of N-S and high-angle westerly dip consisting of fracture segment of gray fault gouge with hydrothermal alteration. There is no linear fault gouge in the shatter zone. From the geologic observation, the K fault is a reverse fault with right-lateral slip and the relative elevation of the basement rock is about 1.8m. [Data-68, 69]

From the observation of block sample, the K fault (N-S strike part) found at L-cut pit is judged to mainly have reverse fault components, because the slickenline direction of the last slip is 80 degrees R. [Data-70]

At the northern widening part of western pit in the D-1 trench, the K fault that has displaced layer③ curves in the pit and changes its strike direction from N-S to NNW-SSE. The shatter zone with N-S direction strike does not displace and deform layer③ that covered the K fault in the south part from the bend. [Data-71 to 74]

3.3 Evaluation of continuity and activity of the D-1 shatter zone

3.3.1 Continuity of the D-1 shatter zone

The continuity of shatter zone has been evaluated based on the concept of evaluating continuity described in "2.2.3 Geological structure of the site."

The data used for the evaluation of continuity are as follows:

- North of Unit 2 reactor building: The D-1 trench: Northern pit, Western pit, L-cut pit
  Survey drilling: B14-2, B6-1, B6-5
- Unit 2 reactor building: Survey of test pits: Pit A, Pit B, Pit C, shear test pit
- South of Unit 2 reactor building: Survey drilling: 14, ②-1, No. 2, the D-1 outcrop

The shatter zones recognized as the D-1 shatter zone run almost in a direction of N-S with high-angle westerly dip, and have excellent continuity. All consist of cataclasite and fault gouge with a sharply-defined brown colors.

The D-1 shatter zone and the G fault have the sense of normal fault from the observations of displacement sense, and the K fault changes the direction from N-S to NNW-SSE within the western pit of the D-1 trench, the K fault has the sense of a reverse fault and the K fault does not extend to the south at least beyond of the drilling B14-2. According to these facts, the K fault would be different from the D-1 shatter zone and that the G fault and the D-1 shatter zone compose of a series of shatter zones. [Data-75]

3.3.2 Activity of the D-1 shatter zone

In the outcrop of the D-1, the D-1 shatter zone has not displaced or deformed layer C, which was deposited after Kikai-Akahoya (K-Ah) (about 7,300 years ago). Also, at the northern pit of the D-1 trench, the G fault has not displaced or deformed layer①, which is located lower than layer⑤, which contains Mihama-tephra which is at least 120,000 years ago.

The K fault has not displaced or deformed at least the lower part of layer⑤, that contains Mihama-tephra which is at least 120,000 years ago, in the north wall of the D-1 trench.

Therefore, the D-1 shatter zone including the G fault was not active at least in and after the Late Pleistocene. In addition, the K fault was not active at least in and after the Late Pleistocene.

3.4 Evaluation of simultaneous activities of the D-1 shatter zone and the Urasoko fault

The simultaneous activities of the D-1 shatter zone and the Urasoko fault have been investigated based on their respective history of activity and from a dynamical point of view.

3.4.1 Investigation on history of activity

The most recent activity of the Urasoko fault took place no earlier than about 4,000 years ago and the mean recurrence is 5,000 years ± 2,000 years(Source: the National Institute of Advanced Industrial Science and Technology, et al. 2012[(*5)]), while the D-1 shatter zone has not been active at least for the past 120,000 years. This has led to the assumption that the Urasoko fault had moved over 10 to a couple dozen of times for the past 120,000 years. But, during this period, the D-1 shatter zone has never moved. Also, as no view has been expressed about the change of regional stress field since the Late Pleistocene, it is judged that the Urasoko fault and the D-1 shatter zone will not move simultaneously in the future.

*5) Survey on active faults in coastal zones; Yanagase and Sekigahara fault zones; Urasoko-Yanagase fault belt; Report of Results; May 2012; the National Institute of Advanced Industrial Science and Technology & Tokai University; p33.

Concerning with activity of Urasoko fault, JAPC currently performs additional survey on geography and geology from the view point of simultaneous activity of some active faults around the site of Tsuruga PS.

3.4.2 Study from dynamical point of view

In the evaluation of fault displacement caused by earthquake, “Regulatory Guide for Reviewing Seismic Design of Nuclear Power Reactor Facilities” (December 20, 2010, approved by the NSC) mentions the necessity of evaluating displacement and deformation due to the fault displacement, by numerical analysis, developed on the ground where buildings and other structures are located.

Based on this Guide, the numerical analysis has been carried out in order to clarify whether displacement may occur or not in the nearby shatter zones including the D-1 shatter zone, due to the activity of the Urasoko fault.

By numerical analysis, the bearing capacity of the grounds, containing the D-1 shatter zone in association with the activity of the Urasoko fault, has been evaluated. As for the stability evaluation of shatter zones, the local safety factors that was estimated by FEM analysis have been employed. [Data-76, 77]

In numerical analysis, first we performed analysis of the ground deformation based on the "elasticity theory of dislocation" with assuming that the ground is semi-infinite elastic medium, and then performed "basic study" and "study taking uncertainty into account," thus drawing up conditions for computation that would produce the severest results in evaluation of bearing capacity of the foundation ground of the Unit 2 reactor building. Then, based on such conditions, we performed analysis, using a Finite Element Method (FEM) model which is an in-depth model of the ground.

3.4.2.1 Elasticity theory of dislocation

(1) Objective

Based on the elasticity theory of dislocation, we studied vertical displacement (inclination) and horizontal deformation (horizontal shearing strain) to be caused by the activity of the Urasoko fault at the location where the Unit 2 reactor building stands.

As for the analytical conditions, the procedure of the Tsunami Evaluation Method (Tsunami Evaluation Subcommittee, Nuclear Civil Engineering Committee, Japan Society of Civil Engineers, 2002(*6)) is employed as a reference.

*6) "Tsunami Evaluation Method for Nuclear Power Plants," 2002, Tsunami Evaluation Subcommittee, Nuclear Civil Engineering Committee, Japan Society of Civil Engineers

In the analyses, the uncertainties of several parameters such as length of fault, angle of dip, width of fault, and so on have been taken into account.

(2) Inclineation of ground where Unit 2 reactor building stands

The case of p-axis = 90° that represents the maximum dip in the primary analyses, has been carried out with uncertainties. As a result, a dip becomes maximum, when the length of fault, i.e., the position of northern end of fault, is set near the reactor building. [Data-78]

(3) Deformation of ground where Unit 2 reactor building stands

The case of p-axis = 115° that represents the maximum horizontal shear strain in the primary analyses, has been carried out with uncertainties. As a result, a horizontal shear strain becomes maximum, when the length of fault, i.e., the position of northern end of fault, is set near the reactor building. [Data-79]

3.4.2.2 FEM analyses

By using the severest conditions, which are drawn up from the evaluation of bearing capacity of the foundation ground of the Unit 2 reactor building, a Finite Element Method (FEM) analysis has been examined based on the “elasticity theory of dislocation,”. In production of the FEM model, non-homogeneity and non-linearity of the geography and the ground were taken into account to reflect the results of existing geological surveys and tests on the physical property of the ground.

(1) Vertical two-dimensional FEM analysis

In the result of study based on the “elasticity theory of dislocation,” a vertical two-dimensional analysis has been achieved in order to give the maximum a dip at the location of the Unit 2 reactor building. The location of section used for analysis was set as vertical plane perpendicular to the reactor building (B-B’ section), which is an almost vertical plane perpendicular to the Urasoko fault.

As a result of analyses, developments of shear failure and tensile stress are estimated in the shatter zone near the Urasoko fault. But, as such area is limited and the local safety factors near the reactor building show sufficient safety margin, the ground would have enough bearing capacity. [Data-80]

(2) Horizontal two-dimensional FEM analysis

In order to make an in-depth study on an effect of strike slip of fault, in the result of study based on the “elasticity theory of dislocation,” a horizontal two-dimensional analysis has been achieved in order to give the maximum horizontal shearing strain at the location of the Unit 2 reactor building. The location of topographic profile used for analysis was set at the level of the Unit 2 reactor building (T.P.-15.0 m).

As a result of analysis, developments of shear fracture and tensile stress are estimated in the shatter zone near the Urasoko fault. But as such area is limited and the local safety factors near the reactor building show sufficient safety margin, the ground is would have enough bearing capacity. [Data-81]

3.4.2.3 Summary

Evaluations of bearing capacity of the grounds have been carried out including the D-1 shatter zone, in relation to the activity of the Urasoko fault by numerical analysis. As a result, developments of shear failure and tensile stress are estimated in the shatter zone near the Urasoko fault, but such area is limited and the local safety factors near the reactor building show sufficient safety margin. Thereby, it is confirmed that the ground has enough bearing capacity against the activity of the Urasoko fault.

Based on the above understandings, the D-1 shatter zone is judged not to be displaced by the activity of the Urasoko fault.

3.5 Overall judgment

Based on the facts of the crossing route, characteristics, strike and dip of the D-1 shatter zone, and the displacement sense of the last slip showing normal fault and right-lateral slip sense, the D-1 shatter zone located just beneath the Unit 2 reactor building would continue to the G fault at the northern pit of the D-1 trench. In addition, it is confirmed by using the overlying strata analysis method at the northern pit of the D-1 trench that the D-1 shatter zone has not displaced or deformed layer① which is located lower than the lower part of layer⑤ which is a strata containing Mihama-tephra about 120,000 years ago.

Also, as the tectonic landform corresponding to the D-1 shatter zone was not recognized by the tectonic landform survey, and the displacement sense of the last slip in the shatter zone shows a normal front sense, it is judged that it was not formed by the present regional stress field, which could be produced through East-West compression.

Moreover, in the light of activity history and dynamics, it is judged that the D-1 shatter zone would not be displaced in conjunction with the activity of the Urasoko fault.

Therefore, the D-1 shatter zone is not an active fault that should be taken into account in the seismic design.

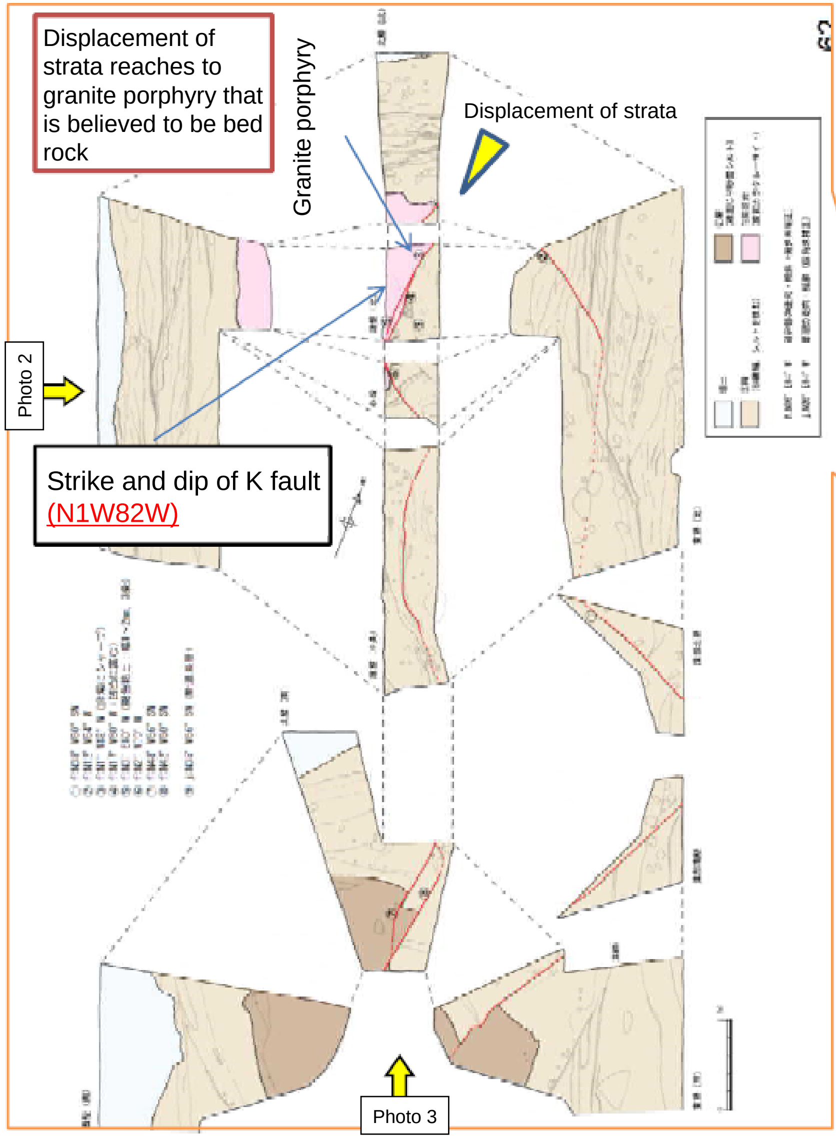
By applying the overlying strata analysis method, it is confirmed that the K fault has not displaced or deformed at least the lower part of layer⑤, that contains Mihama-tephra which is at least about 120,000 years ago, in the north wall of the D-1 trench.

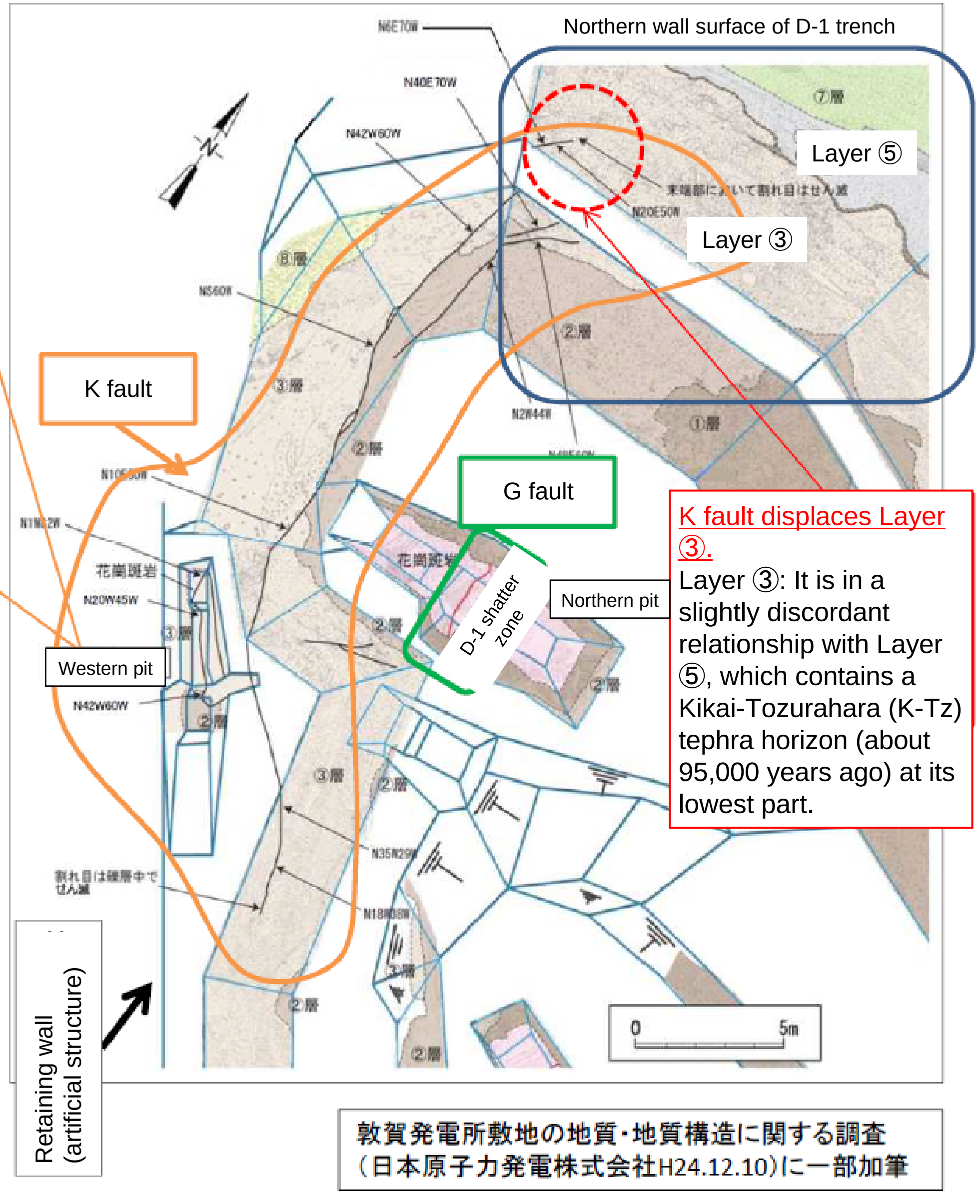
In addition, in order to confirm whether the K fault extends to the south or not, the drilling core B14-2, which crosses between the Unit 2 reactor building and the K fault, has been investigated. As a result, the K fault could NOT extend to the south at least beyond B14-2, since no observation of a reverse fault has been found in the drilling core data.

Based on these facts, the K fault is not an active fault and should not be taken into account in the seismic design. [Data-82]

Lastly, the distribution of the K fault and its genesis are still under investigation, and thus the result will be reported after examination. [Data-82]

Development drawing (extended) of western pit (K fault)





敦賀発電所敷地の地質・地質構造に関する調査
（日本原子力発電株式会社H24.12.10)に一部加筆

25

Fig. 7: K fault near western pit of D-1 trench

「日本原子力発電株式会社敦賀発電所の敷地内破砕帯の評価について（案）平成25年1月28日
原子力規制委員会　敦賀発電所敷地内破砕帯に関する有識者会合」資料より抜粋

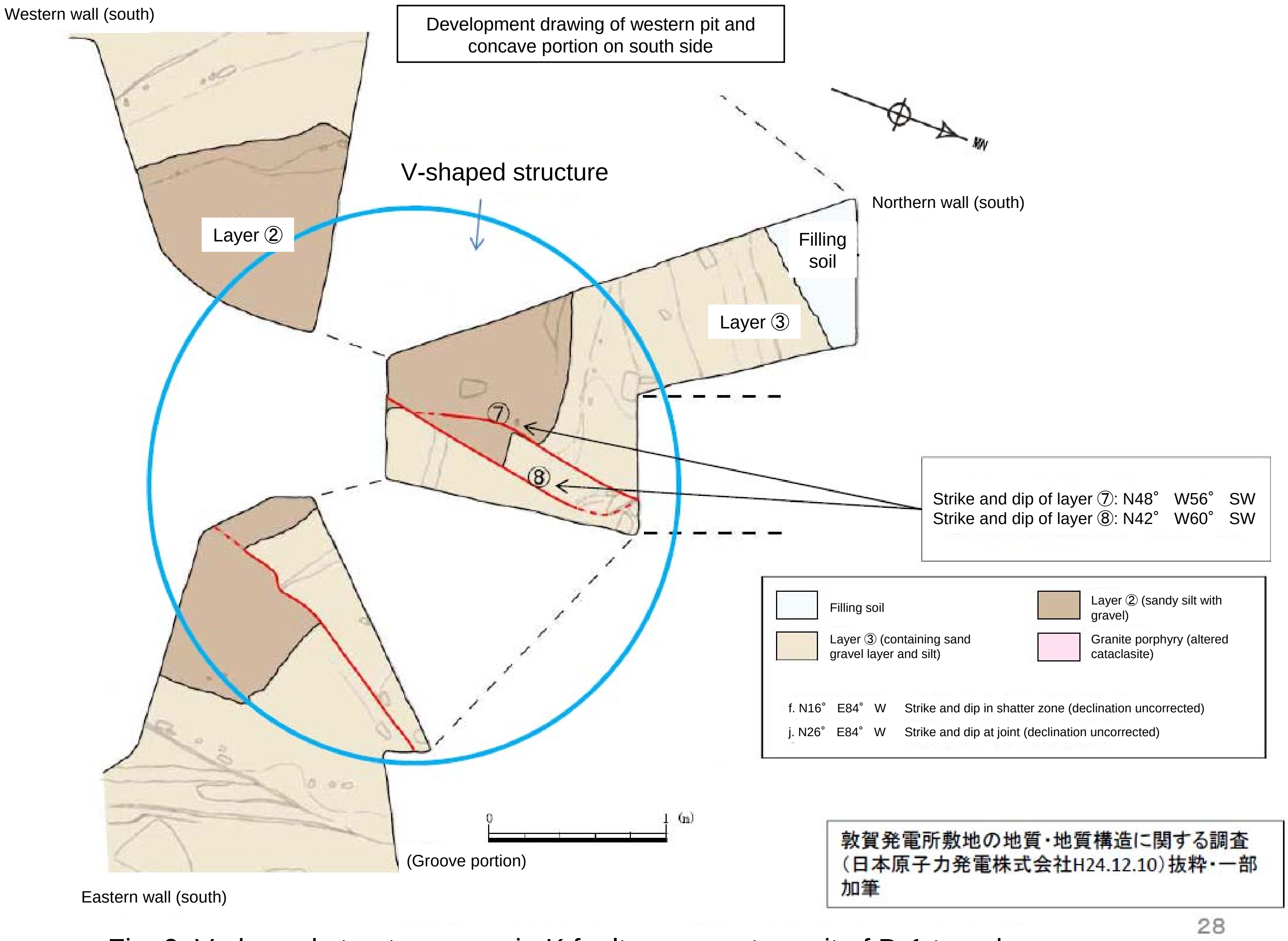
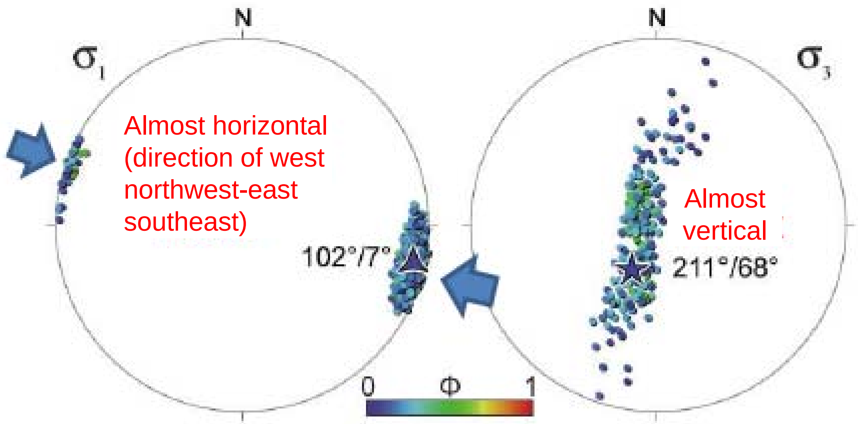


Fig. 9: V-shaped structure seen in K fault near western pit of D-1 trench

「日本原子力発電株式会社敦賀発電所の敷地内破砕帯の評価について（案）平成25年1月28日
原子力規制委員会　敦賀発電所敷地内破砕帯に関する有識者会合」資料より抜粋

Regional stress fields of Chubu and Kinki regions based on stress inversion analysis

Regional stress fields are calculated for the maximum principal stress, $\sigma 1$ in an almost horizontal direction of west northwest-east southeast and for the minimum principal stress, $\sigma 3$ in an almost vertical direction.



Regional stress fields (compressed stress fields in a direction of west northwest-east southeast) of Chubu and Kinki regions in the Late Quaternary, based on the stress inversion analysis of the data about the active faults existing in Chubu and Kinki regions, are shown.
Reverse fault displacement with strike slip, which is estimated from the structure of K fault, is in harmony with the style of displacement of K fault, if it moves in this stress field.

Tsutsumi et al.
Fig. 4 of “Stability of the regional stress field in central Japan during the Late Quaternary inferred from the stress inversion of the active fault data” is partially retouched.

Source: GEOPHYSICAL RESEARCH LETTERS, VOL. 39, L23303, doi: 10.1029/2012GL054094, 2012

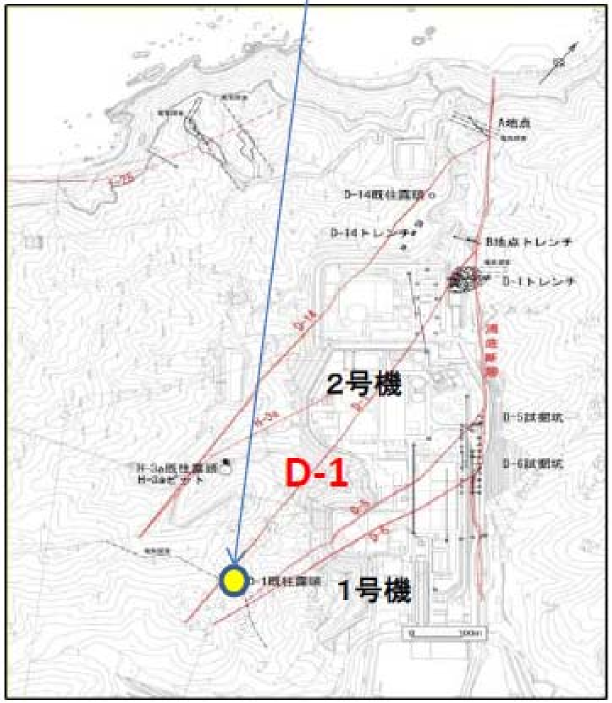
Fig. 11: Regional stress fields in central Japan in the Late Quaternary

30

「日本原子力発電株式会社敦賀発電所の敷地内破砕帯の評価について（案）平成25年1月28日
原子力規制委員会　敦賀発電所敷地内破砕帯に関する有識者会合」資料より抜粋

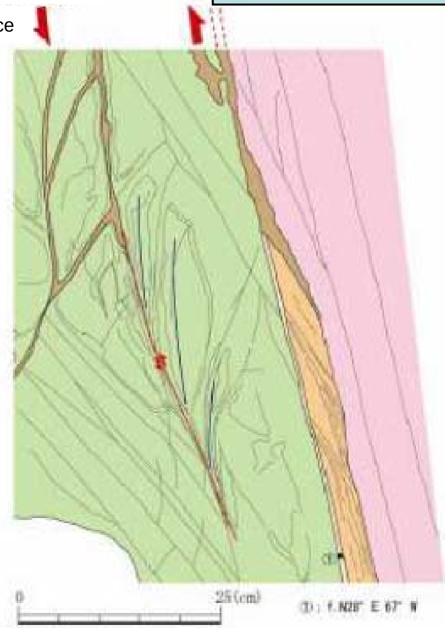
D-1 outcrop (observation of deformed structure)

Location of D-1 preexisting outcrop



Result of observation of deformed structure 2

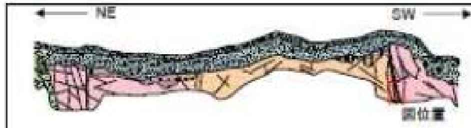
Sketch of wall surface



- In the sense of vertical displacement of cataclasite, <u>reverse fault components</u> with going up in the west and going down in the east <u>are recognized</u>.

	Clay (brown clay (inflow))		Fractured portion of sandy breccia (Sandy-brecciated cataclasite)
	Fractured portion of clay (light brown gouge)		Slightly deformed-nondeformed granite porphyry
	Fractured portion of sandy breccia (foliated cataclasite)	P Shear	R1 Shear
	f. N16° E84° W		Strike and dip in shatter zone (declination uncorrected)

Photo of wall surface



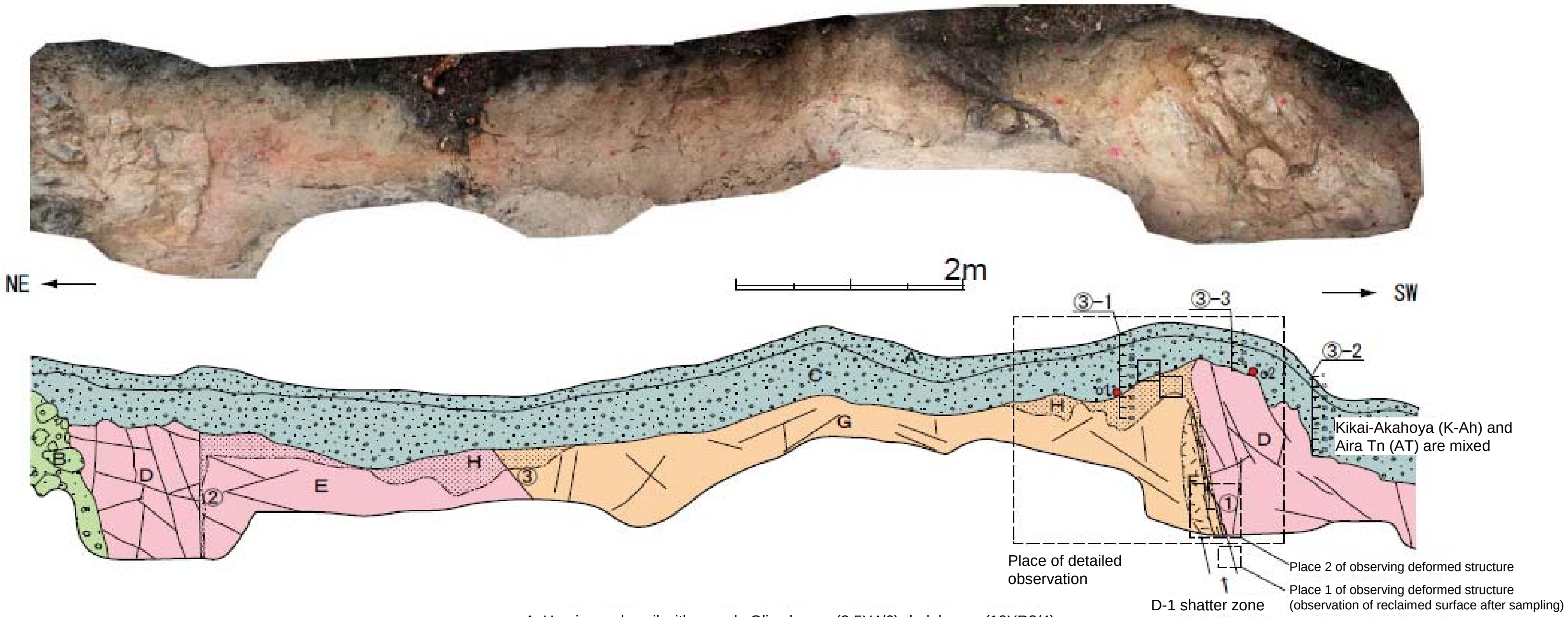
Sketch of outcrop

敦賀発電所敷地の地質・地質構造に関する調査
(日本原子力発電株式会社H24.12.10)に一部加筆

Fig. 13: Field observation of D-1 outcrop

「日本原子力発電株式会社敦賀発電所の敷地内破砕帯の評価について(案)平成25年1月28日
原子力規制委員会 敦賀発電所敷地内破砕帯に関する有識者会合」資料より抜粋

D-1 outcrop



A: Humic sandy soil with gravel. Olive brown (2.5Y4/6)-dark brown (10YR3/4)
B: Gravel (colluvial soil). Ratio of gravel 70%
C: Silty sand with gravel. Bright brownish yellow (10YR6/6)-darkish yellow orange (10YR6/4)
D: Granite porphyry
E: Slightly fractured portion of granite porphyry (subject to alteration)
F: Aplite cataclasite
G: Slightly fractured portion of aplite (subject to alteration)
H: Unclear portion of texture due to strong weathering
① f: N16° E73° W Fault gouge (light brown clay: 2-5 mm wide)
② f: N38° E85° W
③ f: N22° E36° W Boundary between granite porphyry and aplite

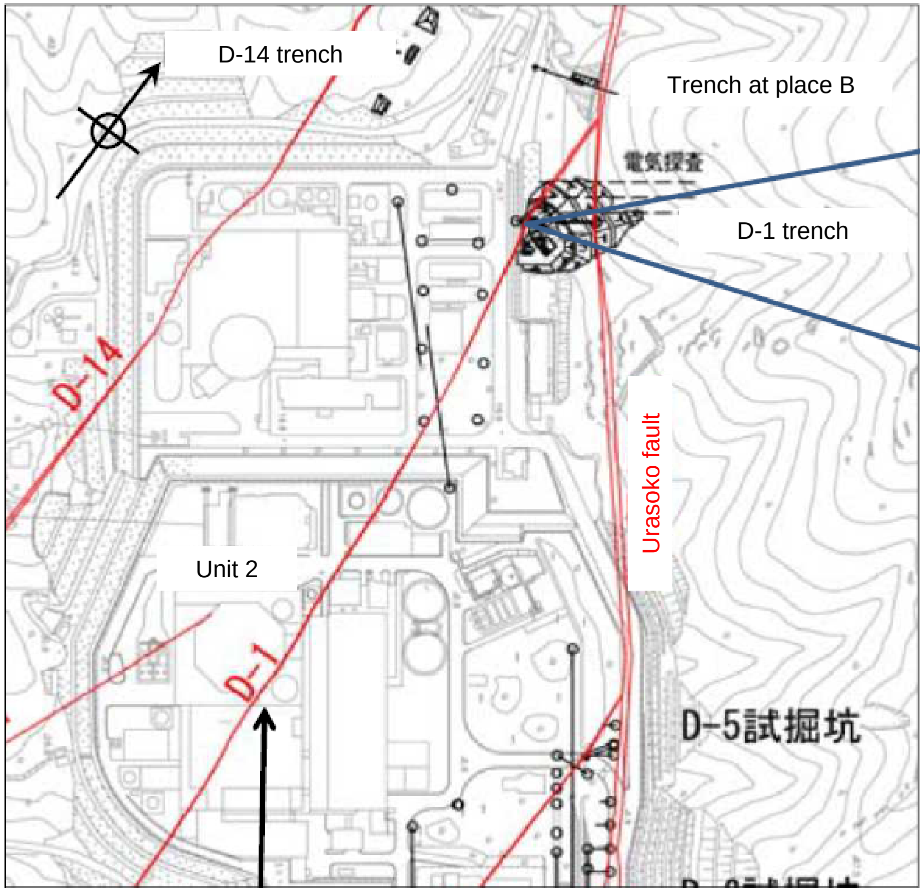
Legend
- Talus deposit
- Older fun deposit 2
- Granite porphyry
- Aplite
- Cataclasite
- Unclear portion of structure due to strong weathering
- Sampling place for CT scan
- Place for continual sampling of volcanic ash
- Sampling place for Optically Stimulated Luminescence (OSL) chronology

敦賀発電所敷地の地質・地質構造に関する調査
（日本原子力発電株式会社H24.12.10）に一部加筆

- The shatter zone has not displaced or deformed any strata, which was deposited after Kikai-Akahoya (K-Ah) (some 7,300 years ago).

Fig. 6: Result of observation of D-1 outcrop
(result of measuring the age of tephra deposits, sketches, etc.)

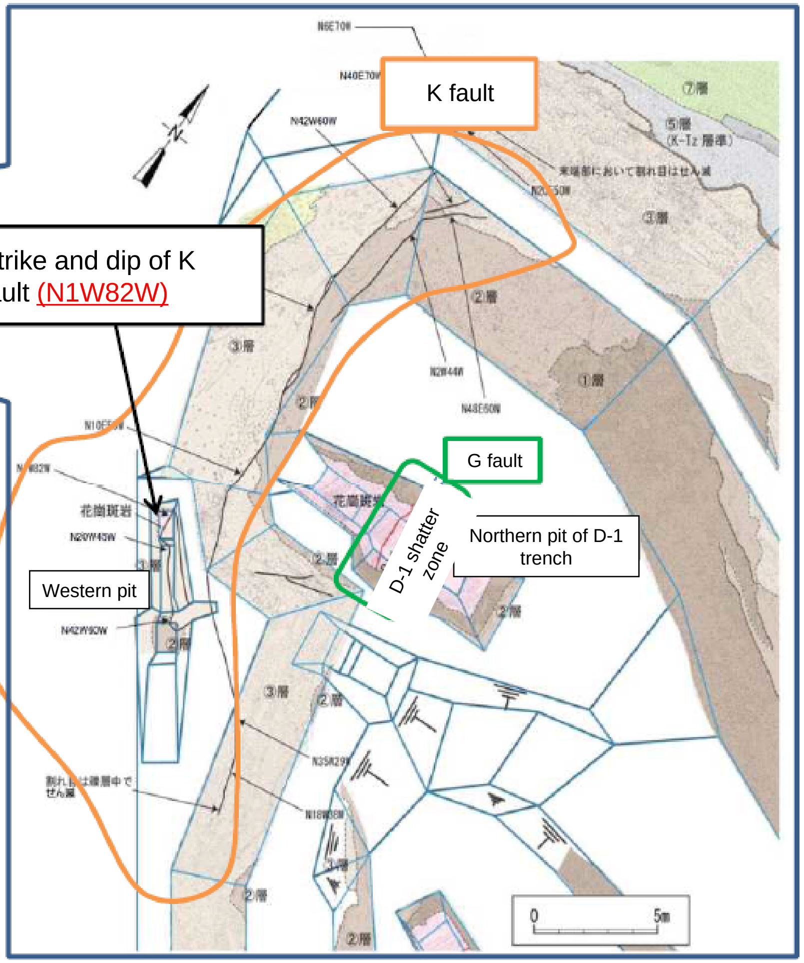
「日本原子力発電株式会社敦賀発電所の敷地内破砕帯の評価について（案）平成25年1月28日
原子力規制委員会　敦賀発電所敷地内破砕帯に関する有識者会合」資料より抜粋



Fault identified as D-1 shatter zone by JAPC (it is called as "H-6a shatter zone" in the application for installation of its Tsuruga Power Station Unit 2 Reactor with strike and dip of N6E78W)

(Urasoko fault, D-14, D-1, D-5, D-6, H-3a and T.P.-15 m slice)

0 100m



Development drawing of D-1 trench

敦賀発電所敷地の地質･地質構造に関する調査
（日本原子力発電株式会社H24.12.10）
に引用･加筆

Fig. 8: Relations between K fault and G fault

27

「日本原子力発電株式会社敦賀発電所の敷地内破砕帯の評価について（案）平成25年1月28日
原子力規制委員会　敦賀発電所敷地内破砕帯に関する有識者会合」資料より抜粋

Comparison of “Draft of evaluation meeting report of Tsuruga Experts Meeting” and “JAPC’s opinion”

<table>
<tr><th colspan="2">Item</th><th>Draft of evaluation meeting report of Tsuruga Experts Meeting</th><th>JAPC’s opinions</th></tr>
<tr><td rowspan="2">Continuity</td><td>G fault and D-1 shatter zone</td><td><u>As the grounds used by the operator to define G fault as D-1 shatter zone are unclear, the activity of G fault cannot be used to evaluate the activity of D-1 shatter zone.</u>

Grounds:
・The relation between G fault and D-1 shatter zone are unclear.</td><td><u>G fault is D-1 shatter zone.</u>

Grounds:
・G fault has same strike and dip as D-1 shatter zone (N-S strikes, high-angle westerly dips)
・It has been confirmed at four points on the north side and south side of the reactor building that the vertical and horizontal displacement senses of the last slips consistently agree with the normal fault and right-lateral slip sense.

＊To increase the density of survey data based on the matters pointed out at the second evaluation meeting, a survey is being conducted by adding survey points.</td></tr>
<tr><td>K fault and D-1 shatter zone</td><td><u>K fault would be D-1 shatter zone or a part of extension thereof.</u>

Grounds:
・K fault is located close to the fault defined as D-1 shatter zone.
・The strike and dip of K fault are similar to those of D-1 shatter zone.

Matters pointed out by the second evaluation meeting
It was pointed out that “if data that show significant changes in the strike of K fault are obtained in the future, it is necessary to review anew the relations between K fault and D-1 shatter zone.”</td><td><u>K fault is not D-1 shatter zone (including G fault).</u>

Grounds:
・K fault extends into the rock mass, the direction of its strikes changes from N-S to NNW-SSW.
・From the observation on thin section, It has been confirmed that K fault and D-1 shatter zone has different displacement senses of the last slips. (K-fault: reverse fault with strike slip, D-1 shatter zone (including G fault): normal fault and right-lateral slip)
・K fault with reverse fault sense dose not extend to southern direction at least beyond B14-2 boring.
＊Genesis of K-fault is under investigation
＊To grasp the shape and strike of K fault in detail based on the matters pointed out at the second evaluation meeting, a survey is being conducted by adding survey points around D-1 trench.</td></tr>
<tr><td rowspan="2">Activity</td><td>G fault</td><td><u>Activity before about 95,000 years ago</u>

Grounds:
・G fault has not displaced or deformed layer ①.
・Layer① is older than layer⑤, which is evaluated about 95,000 years old by the first evaluating meeting.</td><td><u>No Activity in and after the Late Pleistocene (covered by layer ①)</u>

Grounds:
・G fault has not displaced or deformed layer ①.
・Layer① is older than about 120,000 years ago because it is located lower than layer ⑤ (A tephra, which deposited before about 120,000 years ago, has been found in the bottom of layer ⑤)</td></tr>
<tr><td>K fault</td><td><u>Activity in and after the Late Pleistocene cannot be denied.</u>

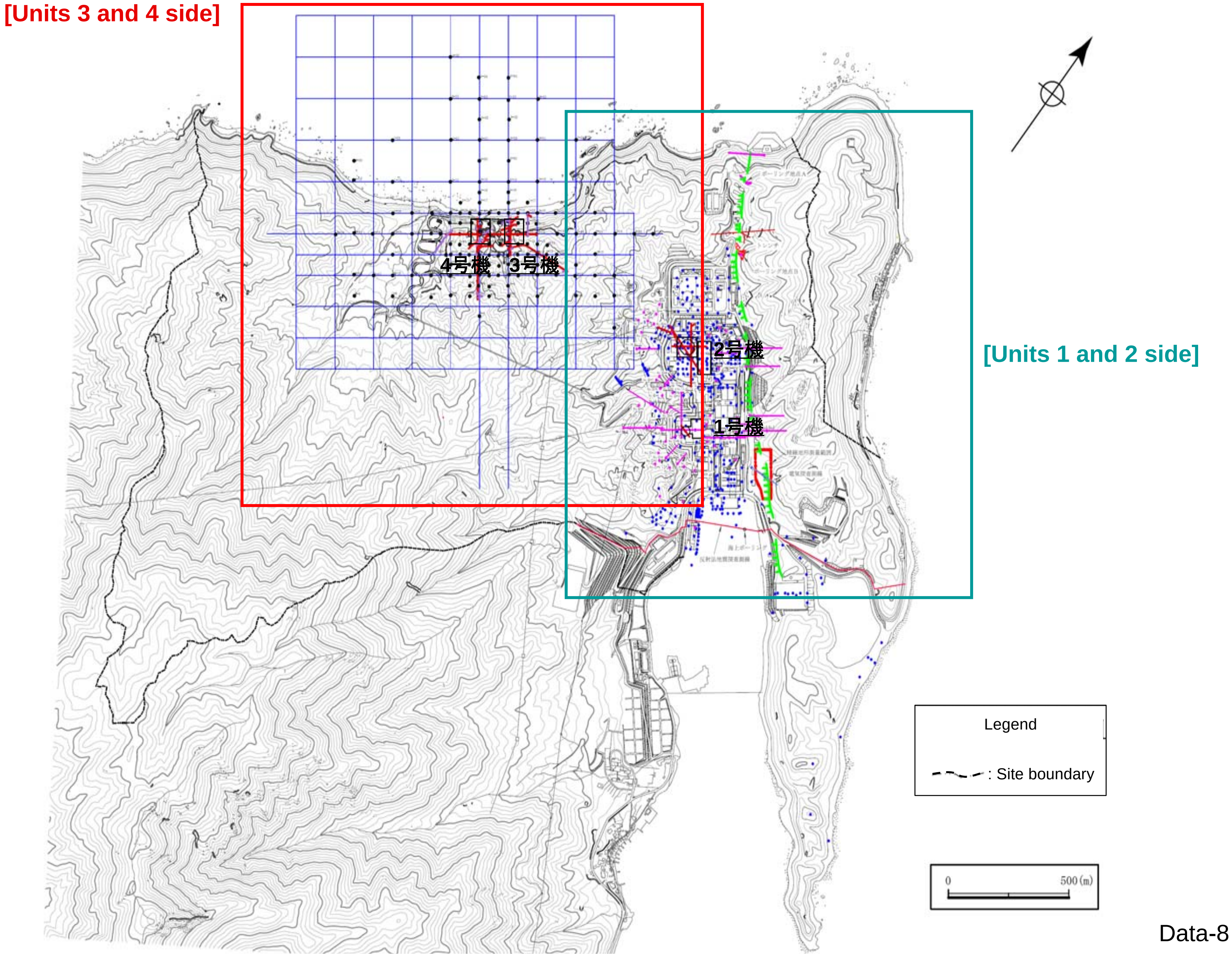
Grounds:
・Gravel of layer③ is relatively as flesh as that of layer⑤, which is evaluated about 95,000 years old by the first evaluating meeting.</td><td><u>No Activity in and after the Late Pleistocene (covered by layer ⑤)</u>

Grounds:
・K fault has not displaced or deformed layer ①.
・Layer ③ is older than about 120,000 years ago because it is located lower than layer ⑤ (A tephra, which deposited before about 120,000 years ago, has been found in the bottom of layer ⑤)</td></tr>
</table>

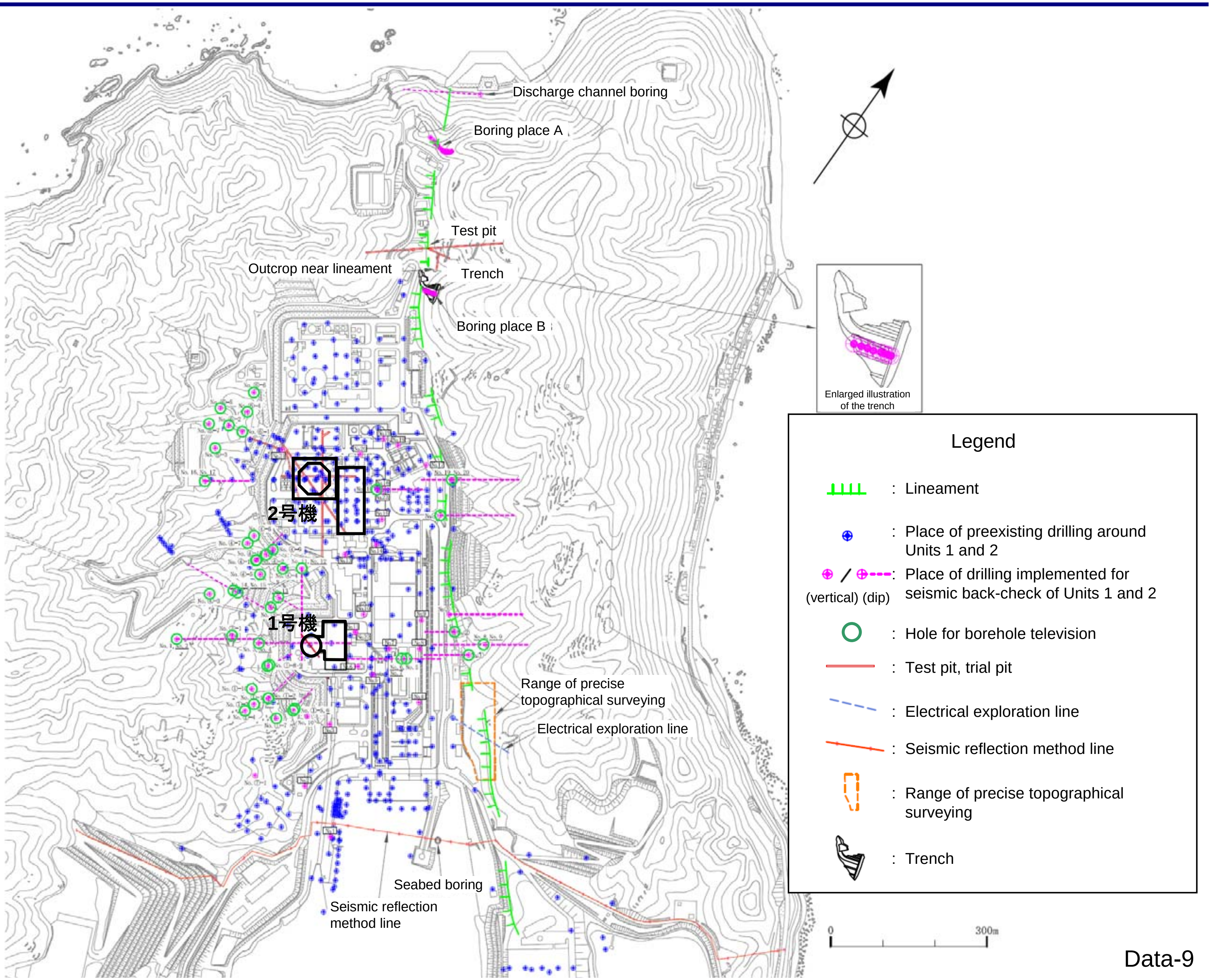
↓

comprehensive evaluation	D-1 shatter zone is likely to be an active fault that should be taken into consideration from the viewpoint of earthquake-resistant design as a conservative judgment.	D-1 shatter zone and K-fault are not active faults that should be taken into consideration for the seismic design.

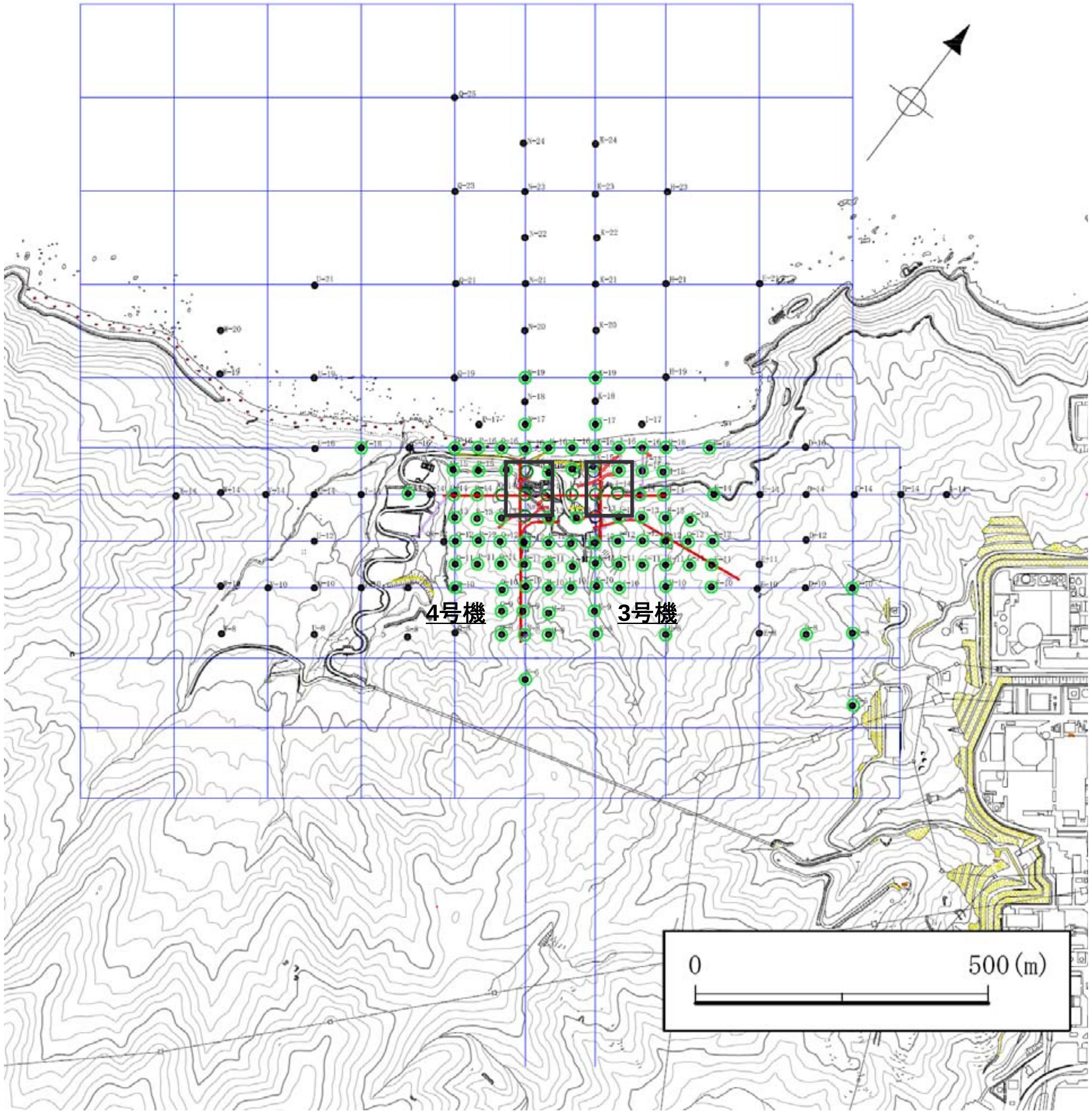
Location map of preexisting survey on the site



Survey on the site (preexisting survey on Units 1 and 2 side)



Survey on the site (preexisting survey on Units 3 and 4 side)



Legend

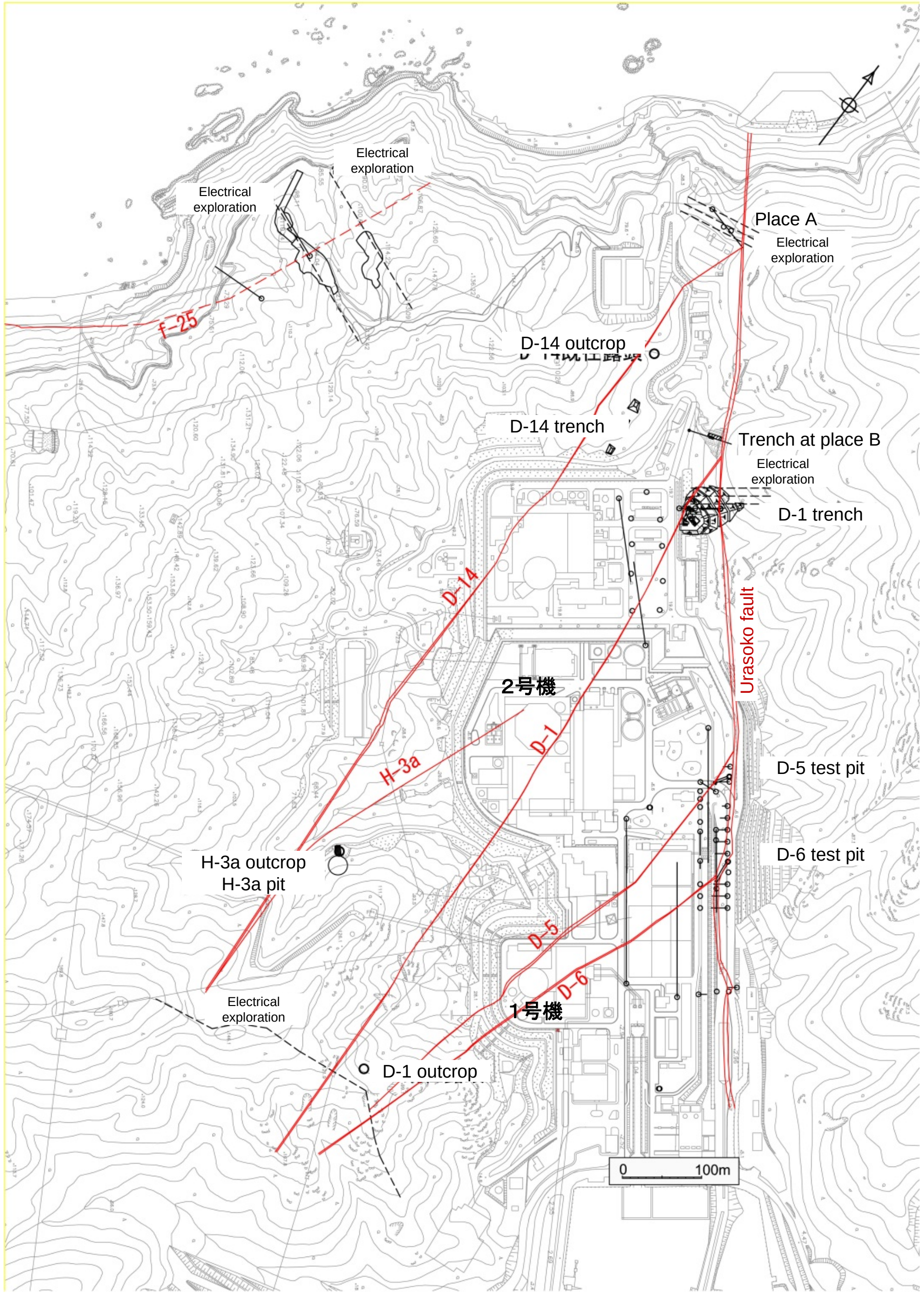
- : Place of drilling
- : Place of reactor core drilling
- : Place of seabed drilling
- : Hole for borehole television
- : Place of elastic waves survey line
- : Location of reactor building
- : Test pit, trial pit
- : Supplemental test pit
- : Trench

Response to comments expressed by the former Nuclear and Industrial Safety Agency during field survey on April 24, 2012

・Evaluation of activities of the shatter zone after the Late Pleistocene should be based on the evaluation by the overlying strata analysis method.
・If evaluation based on the overlying strata analysis method is difficult, evaluation should be carried out in a comprehensive manner, based on the results of various geological analysis and numerical analysis.

Item				Item of additional survey
1	Reconfirmation whether tectonic landform exists or not			・Reconfirmation whether tectonic landform exists or not by checking again the aerial photography taken before artificial changes were made ・Production of Digital Elevation Model (DEM) based on the aerial photography taken before artificial changes were made ・Production of Digital Elevation Model (DEM) based on airborne laser survey ・Study of whether tectonic landform exists or not by using the above Digital Elevation Model (DEM)
2	Enhanced reliability of evaluation by adoption of overlying strata analysis method	Outcrop		・Evaluation of the ages of the Quaternary deposits overlying the shatter zone by higher density tephra analysis D-14 (outcrop), H-3a (outcrop), H-3a (pit), D-1 (outcrop): Existing 10 cm pitch for analysis is changed to 2 cm pitch * Additionally implemented, as required
				・Clarification of the boundary between the rock mass and the Quaternary deposits through observation of thin section and CT scan. D-14 (outcrop), H-3a (outcrop), H-3a (pit), D-1 (outcrop)
				・Evaluation of the ages of the Quaternary deposits overlying the shatter zone by Optically Stimulated Luminescence (OSL) D-14 (outcrop), H-3a (outcrop), D-1 (outcrop): Field work ended and analyzing work is currently underway.
3		Near Urasoko fault	In north	・Pit survey and trench survey near Urasoko fault D-14 (trench): Excavation ended in the south. Excavation still continues in the north and the midland. Tephra analysis and CT scan start in the south and the north. D-1 (trench): Excavation ended. Tephra analysis and CT scan are underway.
			In south	・Survey through a deep test pit near Urasoko fault Tunneling is still underway.
4	Analysis of the times when the shatter zone was active with looking at the materials in the fault			・Evaluation of the times when the shatter zone was active with putting focus on the materials such as Electron Spin Resonance (ESR) constituting the shatter zone Observation of Electron Spin Resonance (ESR) and the surface structure of quartz particle D-14 (outcrop), H-3a (outcrop), D-1 (outcrop): Field work ended and analysis is now underway. D-14 (trench), D-1 (trench): Based on the result of tephra analysis, to be implemented as required.
5	Enhancement of reliability in evaluation of displacement sense across shatter zones			・Measurement of the direction of slickenline ・Additional observation of strips and slices Currently underway in all places

Map of additional survey locations (since June 2012*)



Locations of shatter zones near Units 1 and 2

T. P.-15 m slice

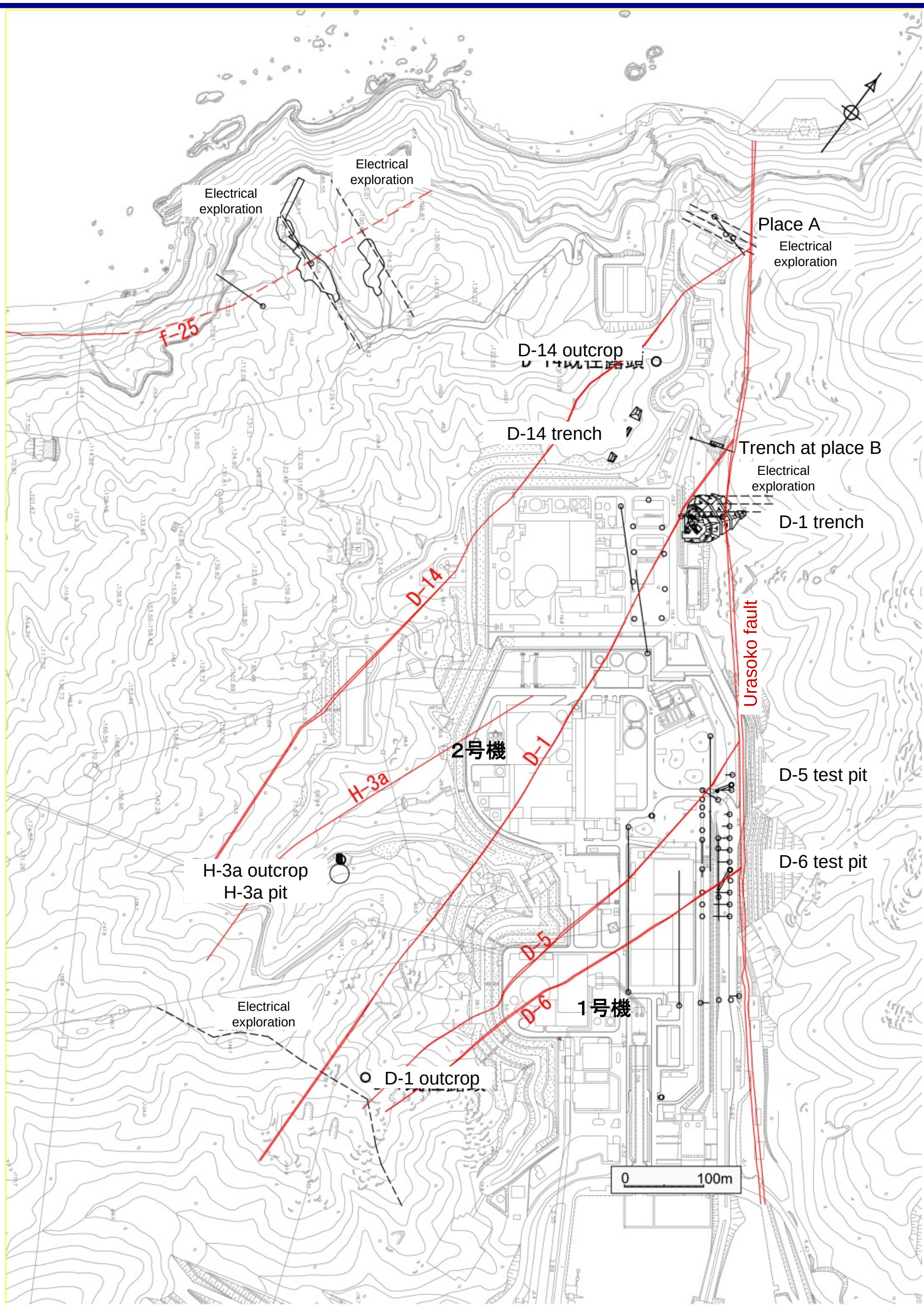
Legend

- Drilling point (vertical) (dip)
- Electrical exploration line
- shatter zones to be surveyed

Units 1 and 2 side (Urasoko fault, D-14, D-1, D-5, D-6 and H-3a)
T.P.-15 m slice
Units 3 and 4 side (f-25)
T.P.-9 m slice

* Survey work has been conducted after obtaining a survey plan approval from the former Nuclear and Industrial Safety Agency at the occasion of the hearing about the earthquake and tsunami on May 14, 2012.

Map of additional survey locations (since June 2012*)



Locations of shatter zones near Units 1 and 2

T. P.-70 m slice

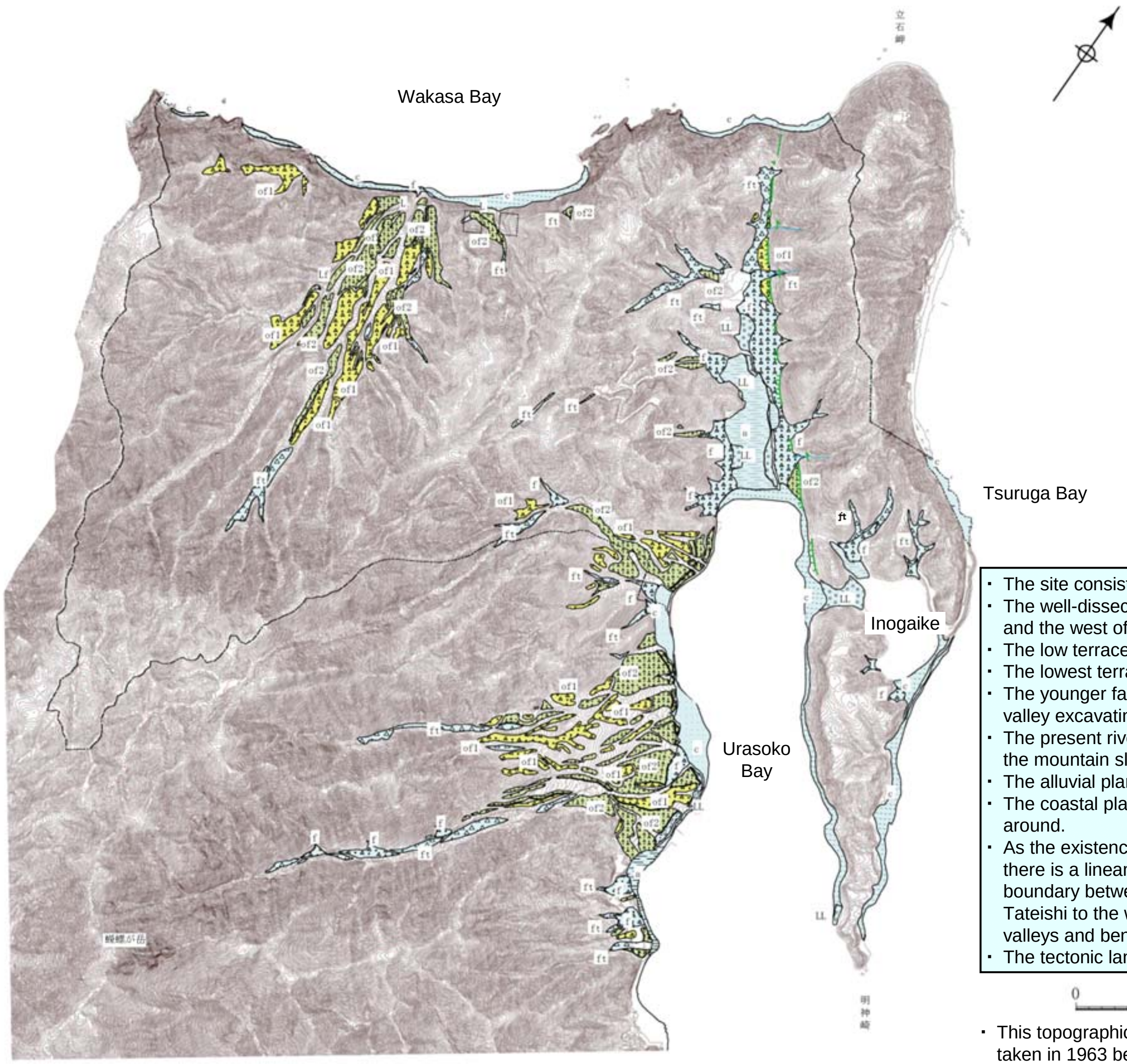
Legend

(vertical) (dip)	Drilling point
- - - -	Electrical exploration line
(red line)	shatter zones to be surveyed

Units 1 and 2 side (Urasoko fault, D-14, D-1, D-5, D-6 and H-3a)
T.P.-70 m slice
Units 3 and 4 side (f-25)
T.P.-9 m slice

* Survey work has been conducted after obtaining a survey plan approval from the former Nuclear and Industrial Safety Agency at the occasion of the hearing about the earthquake and tsunami on May 14, 2012.

Geography of the site (Classification drawing of geographical surface)



Legend

- Coastal plain surface (c)
- Alluvial plain surface (a)
- Present river bed and Talus (ft)
- Younger fan surface (f)
- Lowest terrace surface (LL)
- Low terrace surface (L)
- Older fan surface 2 (of2)
- Older fan surface 1 (of1)
- Lineament
  Short lines indicate geologically low side and arrows indicate directions of curvature in ridges and valleys.
- Bending of river valleys
- Site boundary

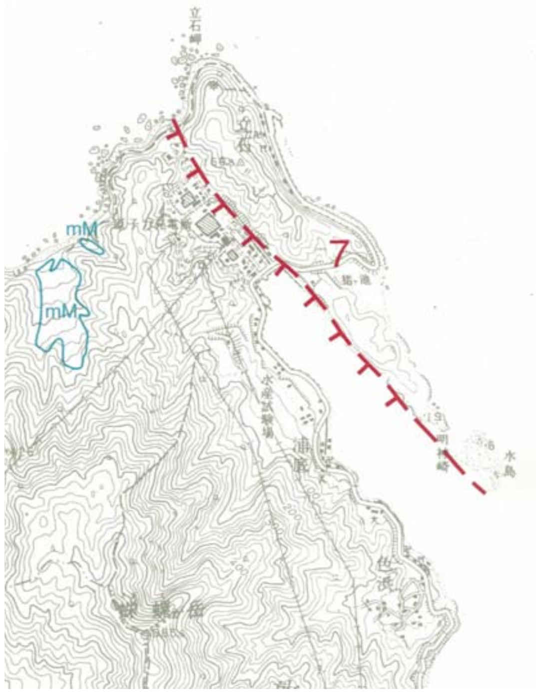
- The site consists mainly of a mountainous area.
- The well-dissected older fan surfaces are found mainly along the Wakasa Bay and the west of Urasoko Bay.
- The low terrace surfaces are found in a very small scale along the Wakasa Bay.
- The lowest terrace surfaces are found in the east coast of Urasoko Bay.
- The younger fan surfaces are found in a small scale in the downstream of a valley excavating mountains.
- The present river bed and talus are found in valleys excavating mountains and the mountain slopes.
- The alluvial plane surfaces extends around the lowland around Urasoko Bay.
- The coastal plane surfaces consisting of beaches and beach ridges extends around.
- As the existence of Urasoko fault is indicated by the documents, it is learned that there is a lineament in a direction of northwest-southeast, which runs through a boundary between the mountains and the lowlands that extend from Cape Tateishi to the west of Inogaike, consisting of steep cliffs, saddles, straight valleys and bending of river valleys.
- The tectonic landform corresponding to shatter zones are not recognized.

0 0.5 1 (km)

- This topographical map was produced, based on the one-20,000th aerial photos taken in 1963 before the topographic change took place, due to construction of the power station, as well as airborne laser survey.
- Airborne laser survey: measurement density of two points/m^2 (without duplication), measurement density of six points/m^2 (with duplication).

Bibliography of active faults near the site

"New Edition: Active Faults in Japan (1991)" by Active Fault Research Group	"Active Faults in Kinki (2000)" by Okada & Togo	"Detailed Digital Maps of Active Faults (2002)" by Nakada & Imaizumi



Fault name	Length	Certainty	Direction of displacement
61 Urasoko	3 km	I	Elevation in northeast

Degree of certainty I: Those that are surely active faults
Degree of certainty II: Those that are estimated to be active faults
Degree of certainty III: Those that are suspected to be active faults

Fault name	Length	Certainty	Direction of displacement
7 Urasoko	3.5 km	II	Elevation in northeast

Degree of certainty I: Those that are surely active faults
Degree of certainty II: Those that are estimated to be active faults

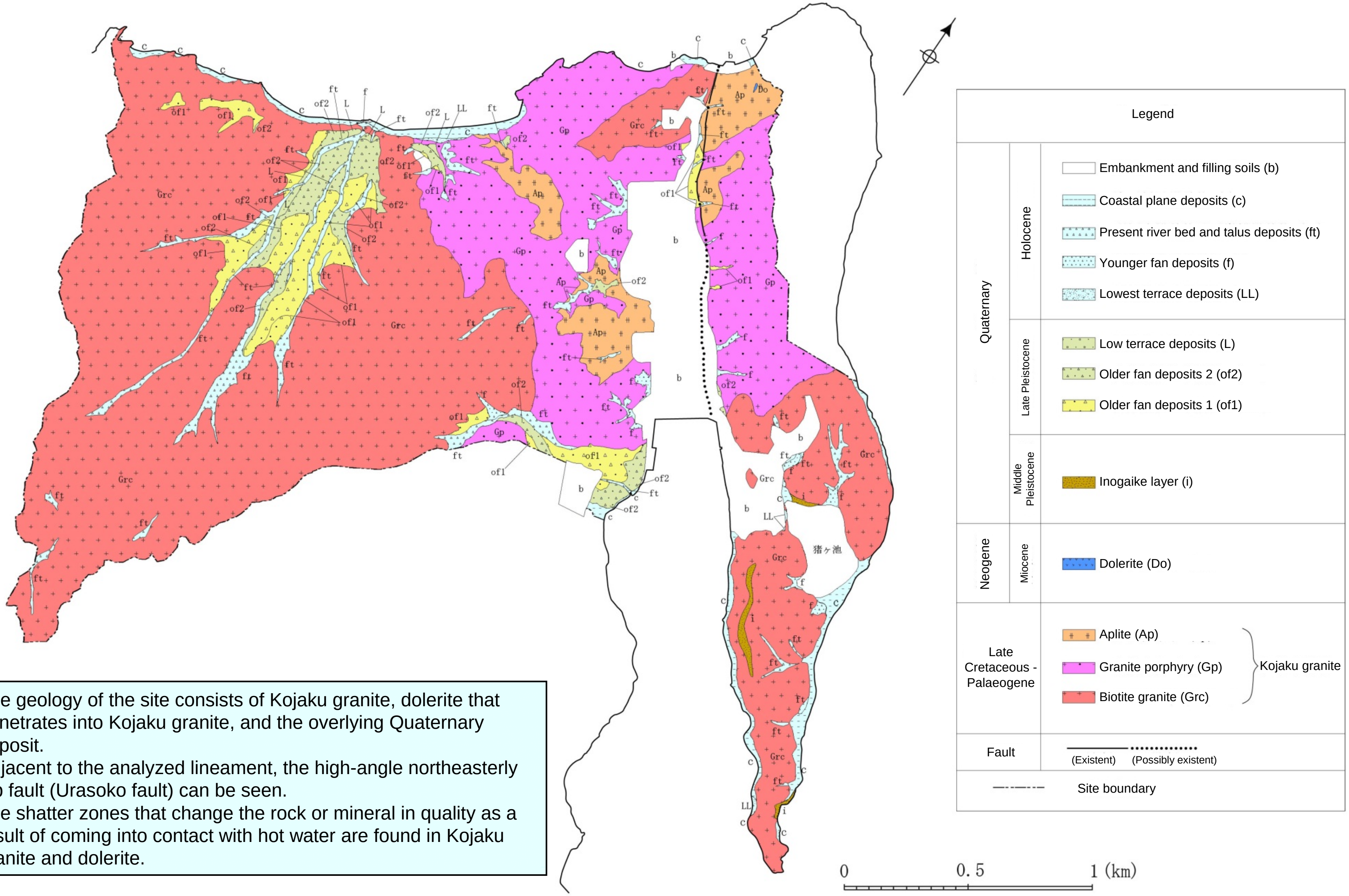
Fault name	Length	Classification	Direction of displacement
① No name	About 3 km (Map reading)	Possible active fault	Elevation in northeast

Active fault: A fault with the signature of repeated movements in the past shown in geography and is expected to repeatedly move in the future

Possible active fault: Though it is possible to exist, based on geographical features, it cannot clearly be identified at present.

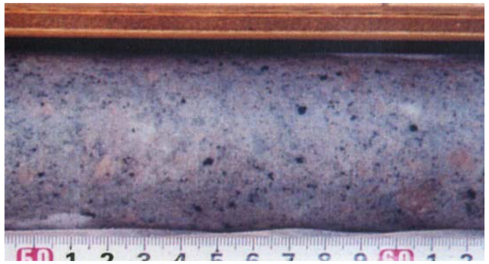
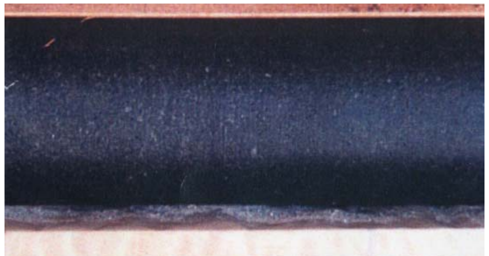
- Existence of Urasoko fault in and around the site is pointed out.
- Tectonic landform other than Urasoko fault (corresponding to the shatter zone) is not pointed out.

Geology of the site



- The geology of the site consists of Kojaku granite, dolerite that penetrates into Kojaku granite, and the overlying Quaternary deposit.
- Adjacent to the analyzed lineament, the high-angle northeasterly dip fault (Urasoko fault) can be seen.
- The shatter zones that change the rock or mineral in quality as a result of coming into contact with hot water are found in Kojaku granite and dolerite.

Types of rocks that are identified

Name of rock type Geology code		Photo (drilling core)	Characteristics
Kojaku granite	**Biotite granite** **Gr**		･Holocrystalline-equiangular texture. ･Grain size of minerals is about 5mm. ･Minerals are mainly composed of K-feldspar, plagioclase, quartz and biotite. ･Biotite granite is judged to be formed in the times between the late Crataceous and the Paleogene, since the values stand at around 66.6 Ma measured by K-Ar dating.
	Granite porphyry **Gp**		･Holocrystalline-porphyritic texture. ･Grain size of phenocryst ranges 2-10 mm. ･Grain size of groundmass is 1 mm or smaller. ･Minerals are mainly composed of K-feldspar, plagioclase, quartz and biotite. ･Granite porphyry is judged to be formed in the times between the the late Cretaceous and the Paleogene, since the values stand at around 66.3 Ma measured by K-Ar dating.
	Aplite **Ap**		･Holocrystalline-epuiangular texture. ･It contains a small amount of of phenocryst and partly has porphyritic texture. ･Groundmass in porphyritic texture is microcrystalline. ･Minerals are mainly composed of quartz, plagioclase and a very small amount of biotite. ･Aplite is judged to be formed in the times between the the late Cretaceous and the Paleogene, since the values stand at around 64.2 Ma measured by K-Ar dating.
Dolerite **Do**			･Intersertal texture. ･Grain size is 2 mm or smaller. ･Minerals are mainly composed of K-feldspar, pyroxene and a very small amount of opaque minerals. ･Dolerite is judged to be formed during the Neogene (Miocene), since the values stand at around 21.1 Ma measured by K-Ar dating.

Characteristics of fault gouge (X-ray diffraction analysis)

Units 1 and 2 side (fault gouge)

Category	shatter zone to be surveyed	Minerals name / Sampling place	Chlorite	Muscovites	Kaolinite	Minerals in muscovites/smectite mixed-layer	Smectite	Laumontite	Quartz	Plagioclase	Potassium	Calcite	Pyrite	Siderite
In Kojaku granite	[illegible]	No. ① hole			[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	No. ② hole		[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	No. ③ hole		[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	No. ②-1 hole		[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	No. ③-1 hole		[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	No. 3 hole					[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	①-10 hole			[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	No. ①-9 hole		[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	No. ①-4 hole		[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	No. 4 hole		[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	No. 17 hole		[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	No. 17 hole		[illegible]	[illegible]		[illegible]		[illegible]		[illegible]			
	[illegible]	No. 16 hole			[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	No. 17 hole			[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
		D-14 preexisting outcrop			[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	No. 17 hole		[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	No. 17 hole		[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	No. 17 hole		[illegible]	[illegible]				[illegible]	[illegible]	[illegible]			
	[illegible]	No. 17 hole		[illegible]	[illegible]				[illegible]	[illegible]	[illegible]			
	[illegible]	No. ①-4 hole		[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	No. ④-5 hole			[illegible]				[illegible]		[illegible]			
	[illegible]	No. ④-5 hole			[illegible]		[illegible]		[illegible]		[illegible]			
	[illegible]	No. ⑥-1 hole			[illegible]				[illegible]	[illegible]	[illegible]			
	[illegible]	No. ⑥-2 hole		[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	No. 7 hole			[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	No. 8 hole					[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	No. 8 hole		[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	No. 19 hole			[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	No. ④-7 hole			[illegible]				[illegible]		[illegible]			
	[illegible]	No. ④ hole			[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	No. ④ hole			[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	H-3a preexisting outcrop		[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			

* It can be identified only during water elutriation.

Units 3 and 4 side (fault gouge)

Category	shatter zone to be studied	Minerals name / Sampling place	Chlorite	Muscovites	Kaolinite	Smectite	Laumontite	Quartz	Plagioclase	Potassium	Calcite	Pyrite	Siderite
In Kojaku granite	[illegible]	F-10 hole	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]		
	[illegible]	H-10 hole			[illegible]	[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	Test pit B2			[illegible]	[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	H-11 hole		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]		
	[illegible]	Test pit B1			[illegible]	[illegible]		[illegible]		[illegible]			
	[illegible]	Test pit B1		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	O-9 hole		[illegible]	[illegible]			[illegible]	[illegible]	[illegible]			
	[illegible]	Test pit C2		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]				
	[illegible]	Test pit B1		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	Test pit C2		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	Test pit B1			[illegible]	[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	Test pit A1			[illegible]	[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	Supplemental test pit A4		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	Test pit C1		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	Test pit C1		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	Test pit A3 Mountain side		[illegible]		[illegible]		[illegible]		[illegible]	[illegible]	[illegible]	
	[illegible]	Test pit A3 Mountain side			[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]		
	[illegible]	Trial pit i		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	Supplemental test pit f		[illegible]	[illegible]	[illegible]		[illegible]		[illegible]	[illegible]		
	[illegible]	O-13 hole		[illegible]	[illegible]			[illegible]	[illegible]	[illegible]			
	[illegible]	Test pit A1		[illegible]	[illegible]	[illegible]		[illegible]		[illegible]			[illegible]
	[illegible]	Supplemental test pit A5		[illegible]	[illegible]	[illegible]		[illegible]		[illegible]			
	[illegible]	S-14 hole		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]	K-19 hole		[illegible]	[illegible]	[illegible]		[illegible]		[illegible]	[illegible]		
In dolerite	[illegible]	Trial pit m		[illegible]		[illegible]	[illegible]	[illegible]			[illegible]		

Relative content:
◎: Large volume
○: Medium volume
△: Small volume
・: Very small volume

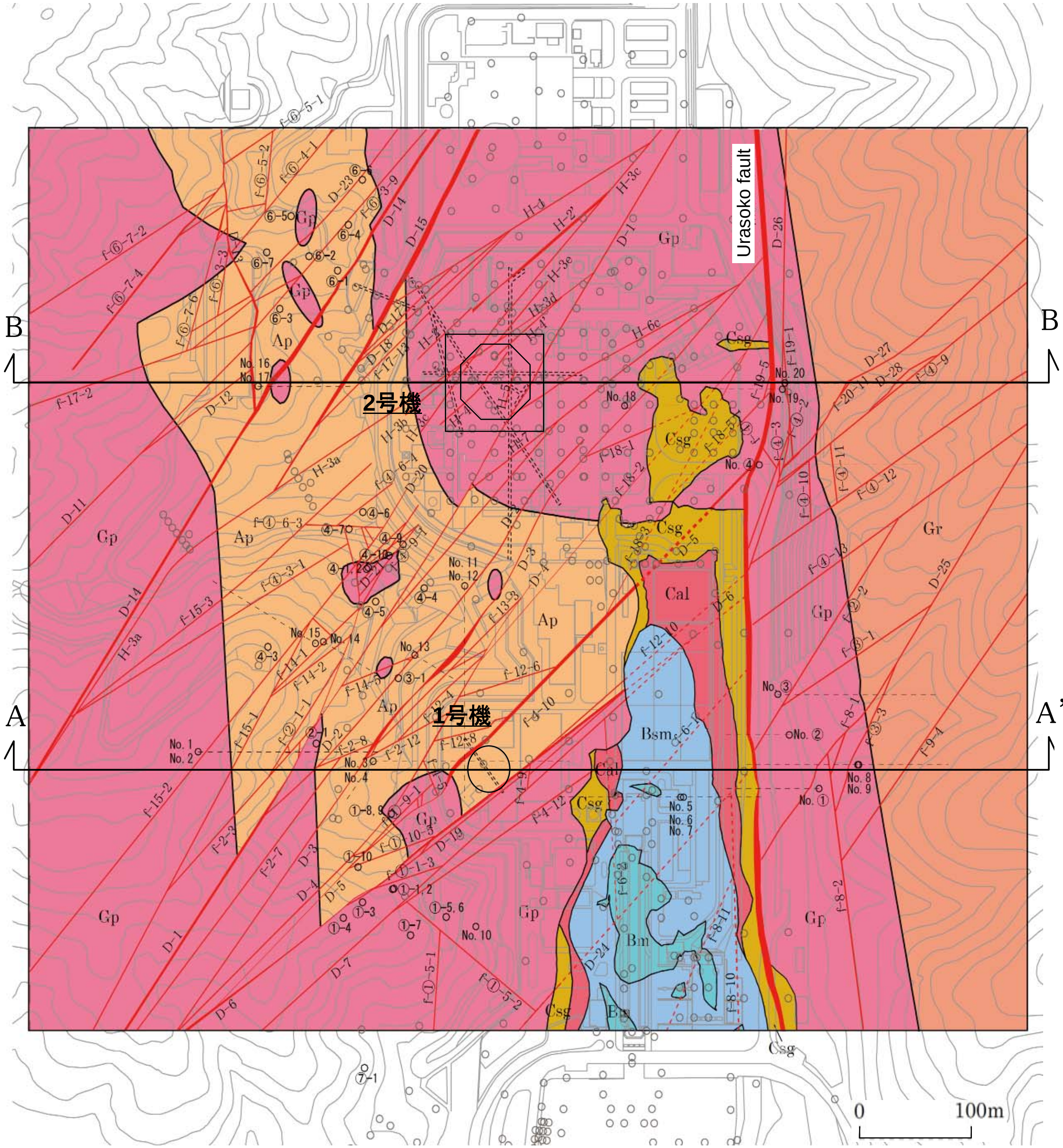
Urasoko fault

Sampling place	Sample name	Chlorite	Mica clay mineral	Kaolinite	Minerals in muscovites/smectite mixed-layer	Smectite	Laumontite	Quartz	Plagioclase	Potassium	Calcite	Pyrite	Siderite
B trench	[illegible]			[illegible]				[illegible]		[illegible]			
	[illegible]			[illegible]				[illegible]	[illegible]	[illegible]			
	[illegible]		[illegible]	[illegible]		[illegible]		[illegible]		[illegible]			
	[illegible]			[illegible]		[illegible]		[illegible]		[illegible]			
	[illegible]		[illegible]	[illegible]		[illegible]		[illegible]		[illegible]			
M outcrop	[illegible]		[illegible]	[illegible]		[illegible]		[illegible]		[illegible]			
Northern saddle of Urasoko fault	[illegible]			[illegible]				[illegible]	[illegible]	[illegible]			
Arrayed boring at B trench	[illegible]		[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]			[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]		[illegible]	[illegible]		[illegible]		[illegible]		[illegible]			
	[illegible]			[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]			[illegible]		[illegible]		[illegible]		[illegible]			
	[illegible]			[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]			[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			
	[illegible]			[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			

* It can be identified in a fixed direction.

- The fault gouges in granite on the Units 1 and 2 side as well as on the Units 3 and 4 side contain quartz, K-feldspar, plagioclase, muscovite, kaolinite and smectite. Measured values of clay mineral by K-Ar dating (the time of rock or mineral changing in quality as a result of coming into contact with hot water) resulted in some 54.6-61.4 Ma.
- The fault gouge in the Urasoko fault contains quartz, K-feldspar, plagioclase, muscovite, kaolinite and smectite. Measured value of clay mineral by K-Ar dating (the time of rock or mineral changing in quality as a result of coming into contact with hot water) resulted in some 50.3 Ma.
- The fault gouge in dolerite contains high volume of smectite, medium volume of calcite and laumontite. Measured value of clay mineral by K-Ar dating (the time of rock or mineral changing in quality as a result of coming into contact with hot water) resulted in some 18.9 Ma.

Geological plan (Units 1 and 2 side)



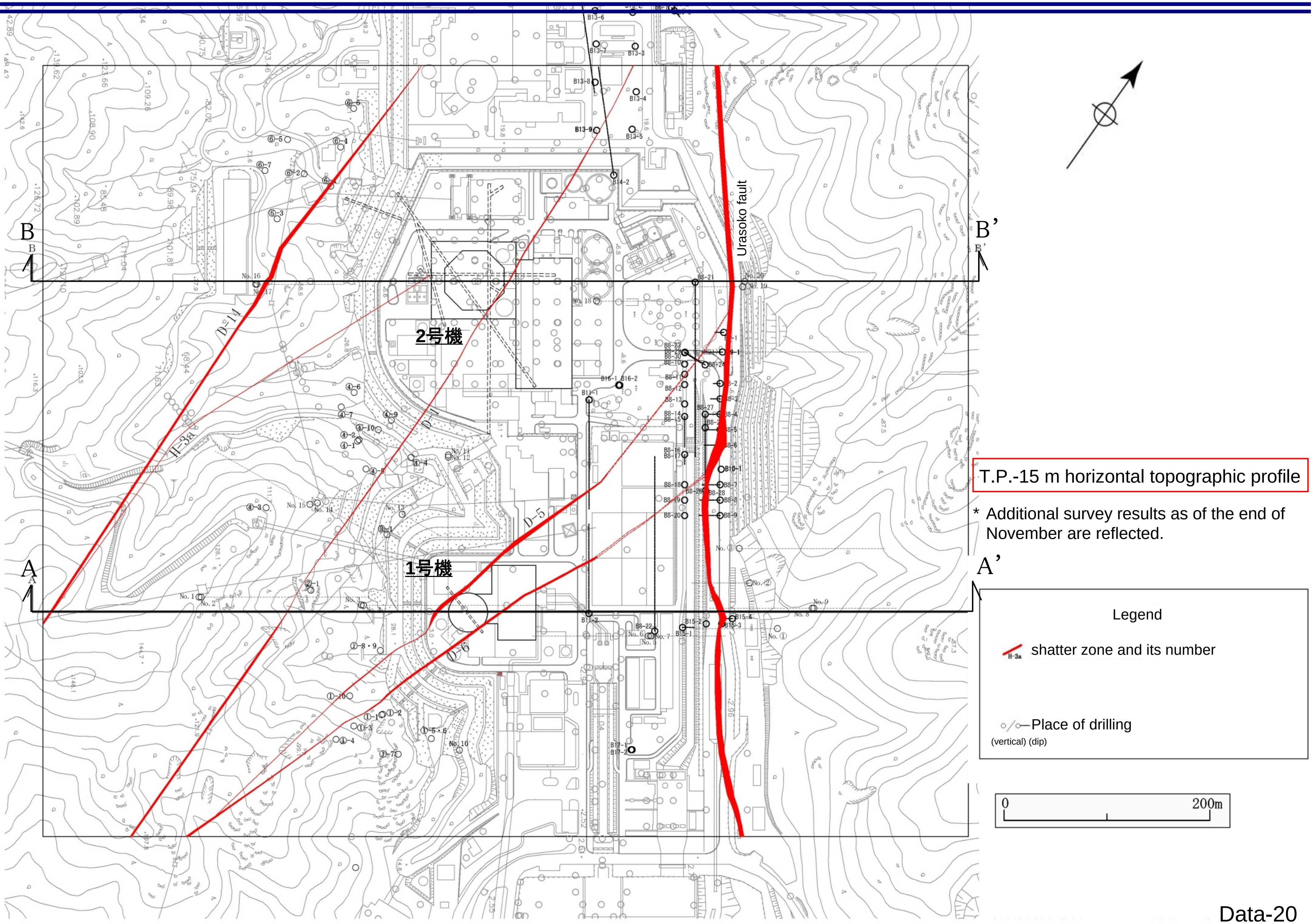
Geological classification legend

Bm	Bm layer:	Enclosed bay deposits (that contains silt, fine sand and shell)	Holocene	Quaternary system
Bsm	Bsm layer:	Enclosed bay deposits (that contains medium sand, coarse sand, granule, silt and shell)	Holocene	
Cal	Cal layer:	Lowland deposits (that contains a large volume of fine sand, medium sand and humus)	Holocene Pleistocene	
Csg	Csg layer:	Fan deposits (that mainly contain gravel, coarse sand, medium sand and humus)	Holocene Pleistocene	
Ap	Aplite		Kojaku granite	
Gp	Granite porphyry			
Gr	Biotite granite			
H-3a	shatter zone and its number			

T.P.-15 m horizontal topographic profile

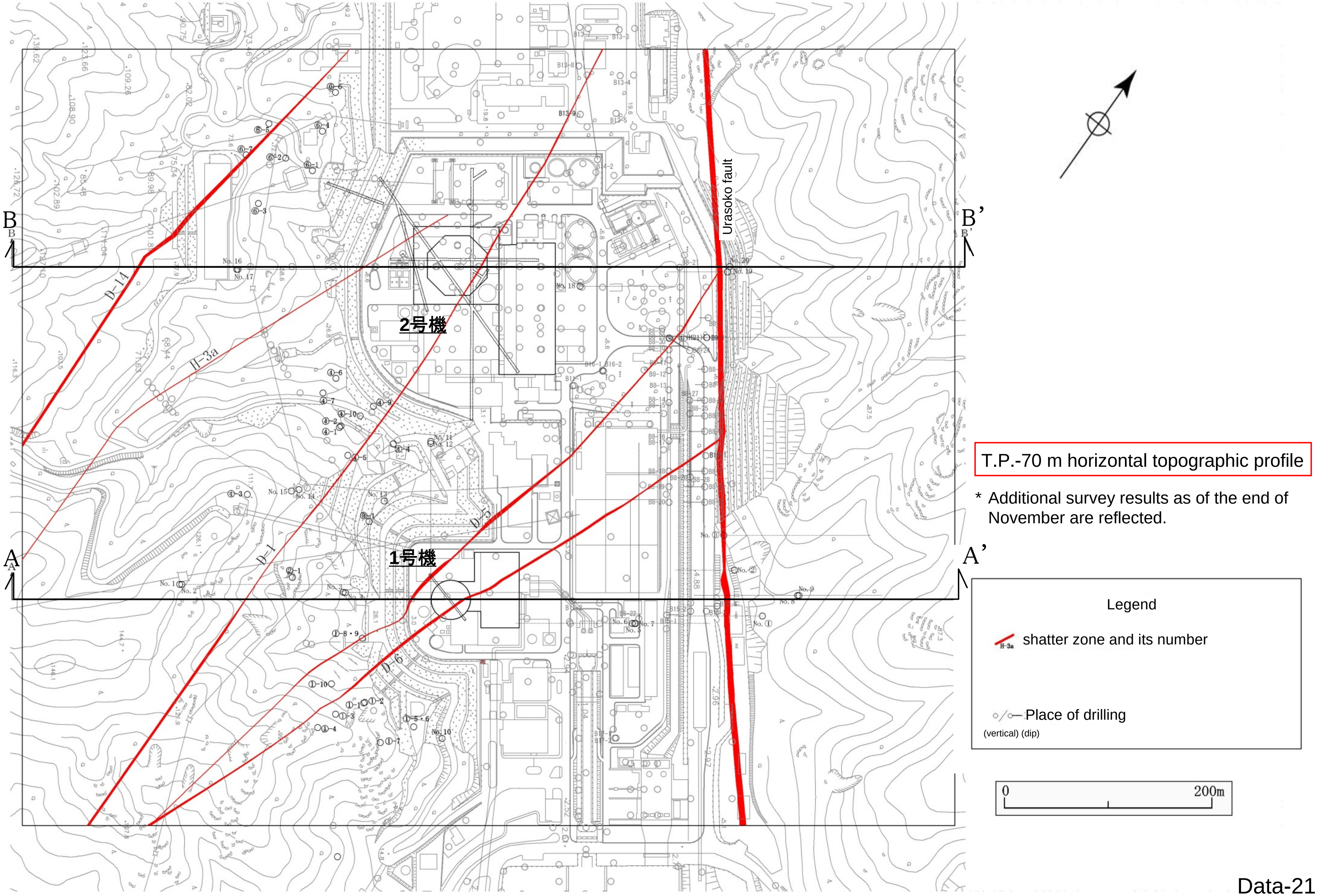
* Before reflection of additional survey results

Distribution of major shatter zones based on additional survey result (Units 1 and 2 side)



* Additional survey results as of the end of November are reflected.

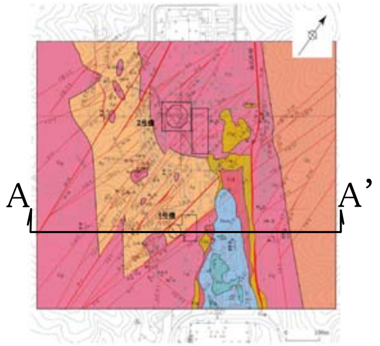
Distribution of major shatter zones based on additional survey result (Units 1 and 2 side)



T.P.-70 m horizontal topographic profile

* Additional survey results as of the end of November are reflected.

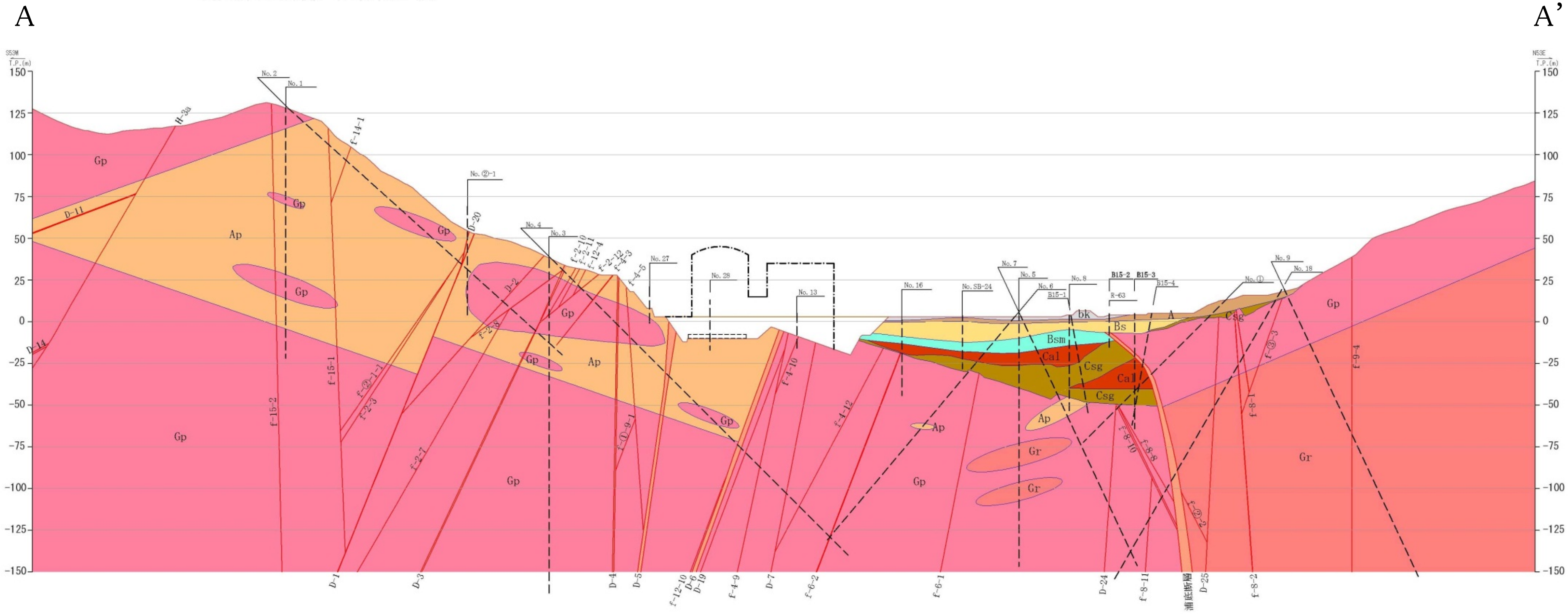
Geological profile (Unit 1 side)



Geological classification legend

Symbol	Layer	Description	Age	
bk	Surface soil and fillig soil			Quaternary system
A	A layer:	Alluvial plain deposits, fan deposits and talus deposits (that may contain sand, gravel, silt, humus and humic matters)	Holocene	
Bs	Bs layer:	Deltaic deposits (that contains coarse sand, medium sand and shell)	Holocene	
Bsm	Bsm layer:	Enclosed bay deposits (that contains medium sand, coarse sand, granule, silt and shell)	Holocene	
Cal	Cal layer:	Lowland deposits (that contains a large volume of fine sand, medium sand and humus)	Holocene Pleistocene	
Csg	Csg layer:	Fan deposits (that may contain gravel, coarse sand, medium sand and humus)	Holocene Pleistocene	

Symbol	Name	
Ap	Aplite	Kojaku granite
Gp	Granite porphyry	
Gr	Biotite granite	
H-3a	shatter zone and its number	
	Geological boundary	

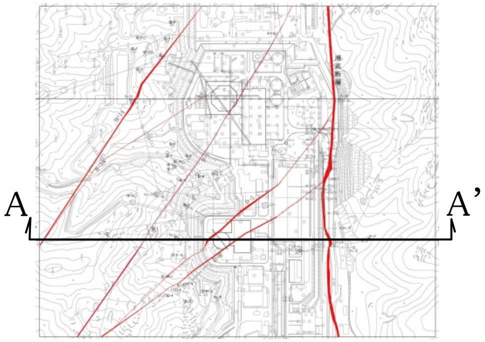


・Many of the shatter zones are high-angle westerly dip.
・The shatter zones have displaced the boundary between rock types (Gp/Ap boundary) into one like a normal fault.

Geological profile around Unit 1 A-A' profile

＊ Before reflection of additional survey results

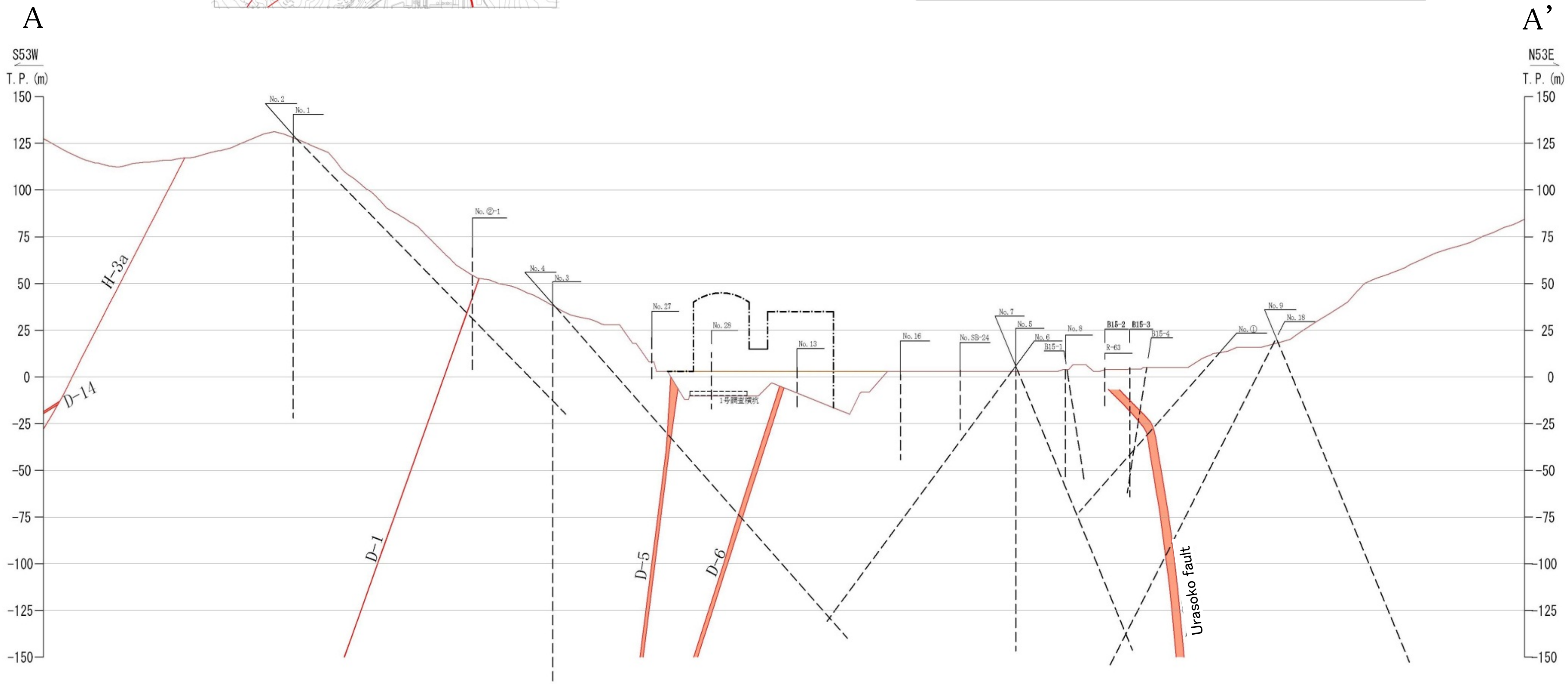
Profile of distribution of major shatter zones based on additional survey result (Unit 1 side)



Geological classification legend

shatter zone and its number

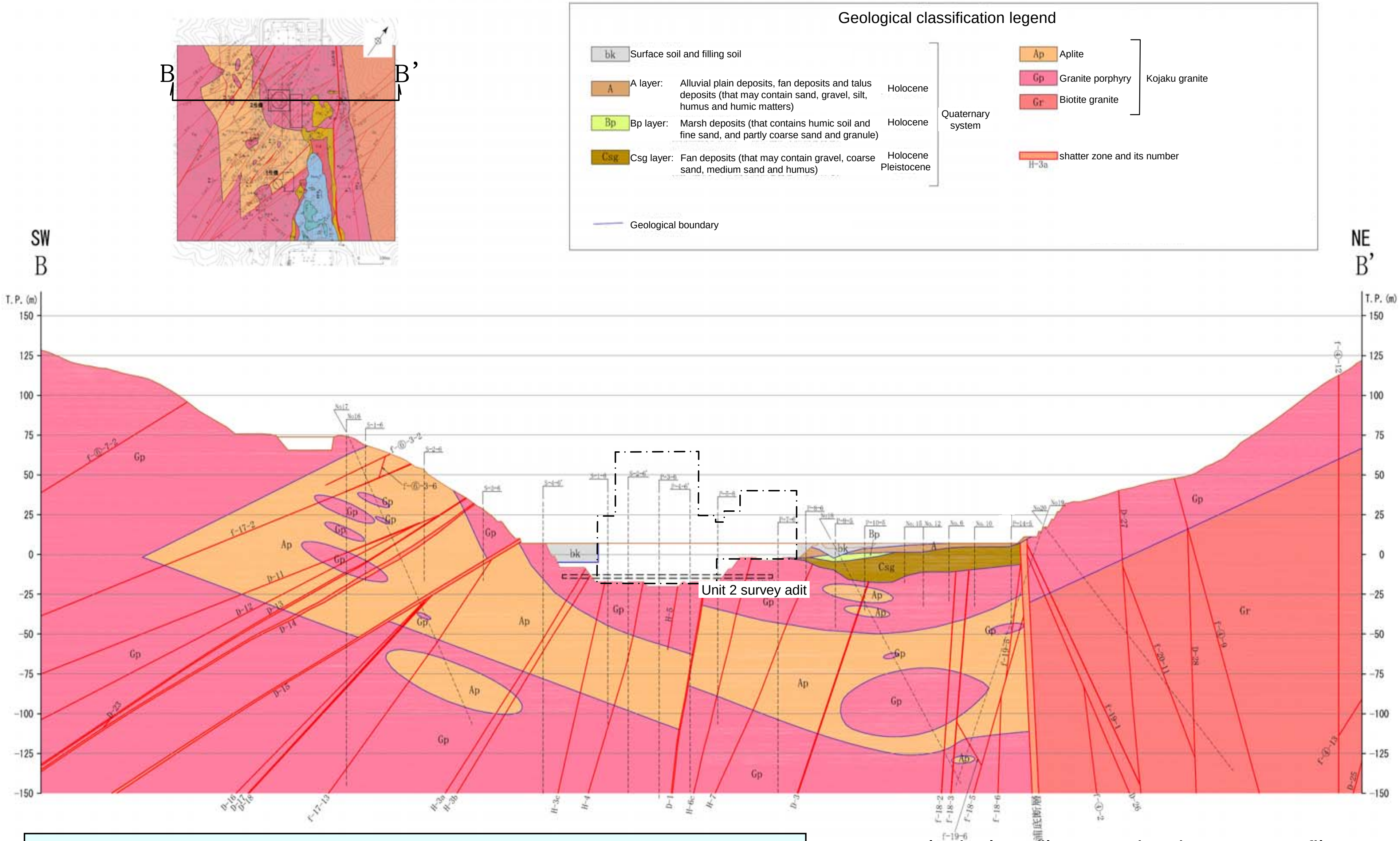
D-6



Geological profile around Unit 1 A-A' profile

* Additional survey results as of the end of November are reflected.

Geological profile (Unit 2 side)



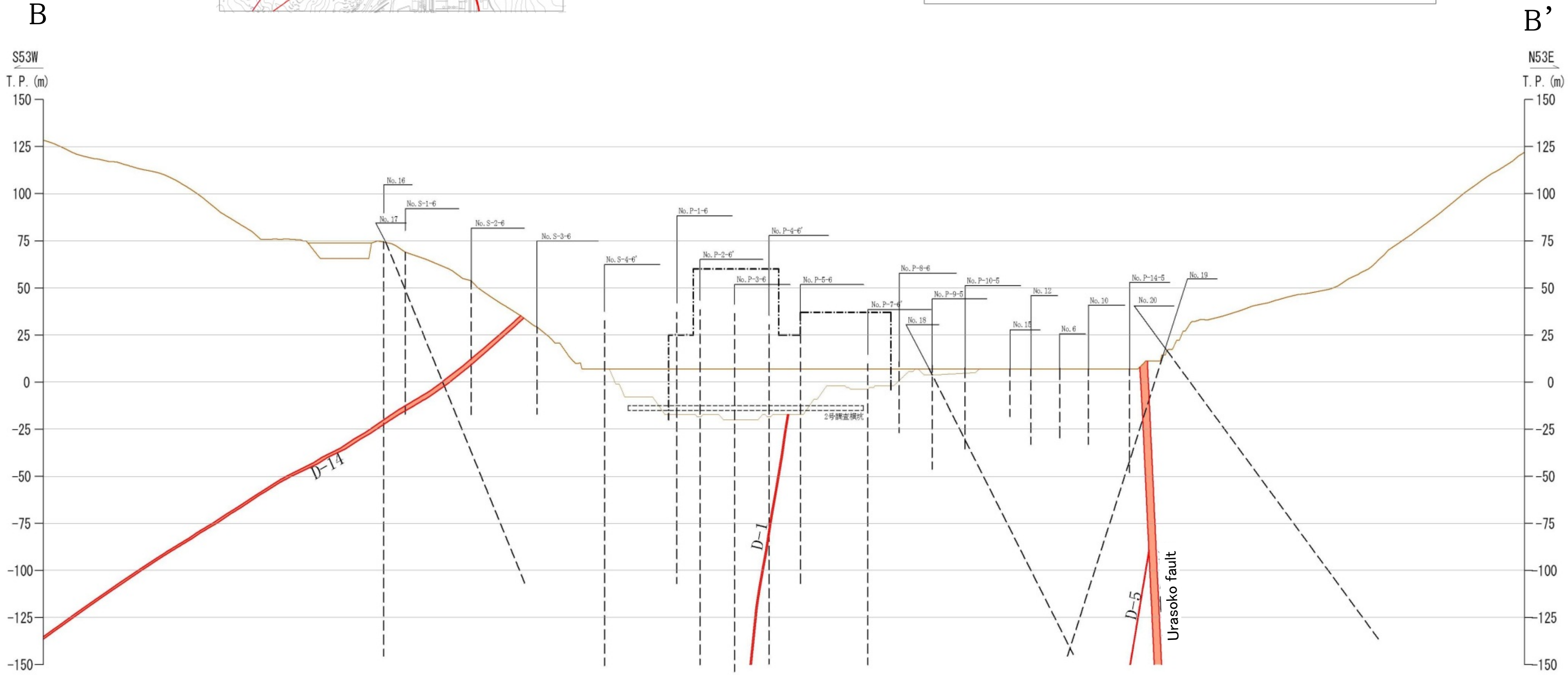
- Many of the shatter zones are high-angle westerly dip.
- The shatter zones have displaced the boundary between rock types (Gp/Ap boundary) into one like a normal fault.

Geological profile around Unit 2 B-B' profile

* Before reflection of additional survey results

Profile of distribution of major shatter zones based on additional survey result (Unit 2 side)

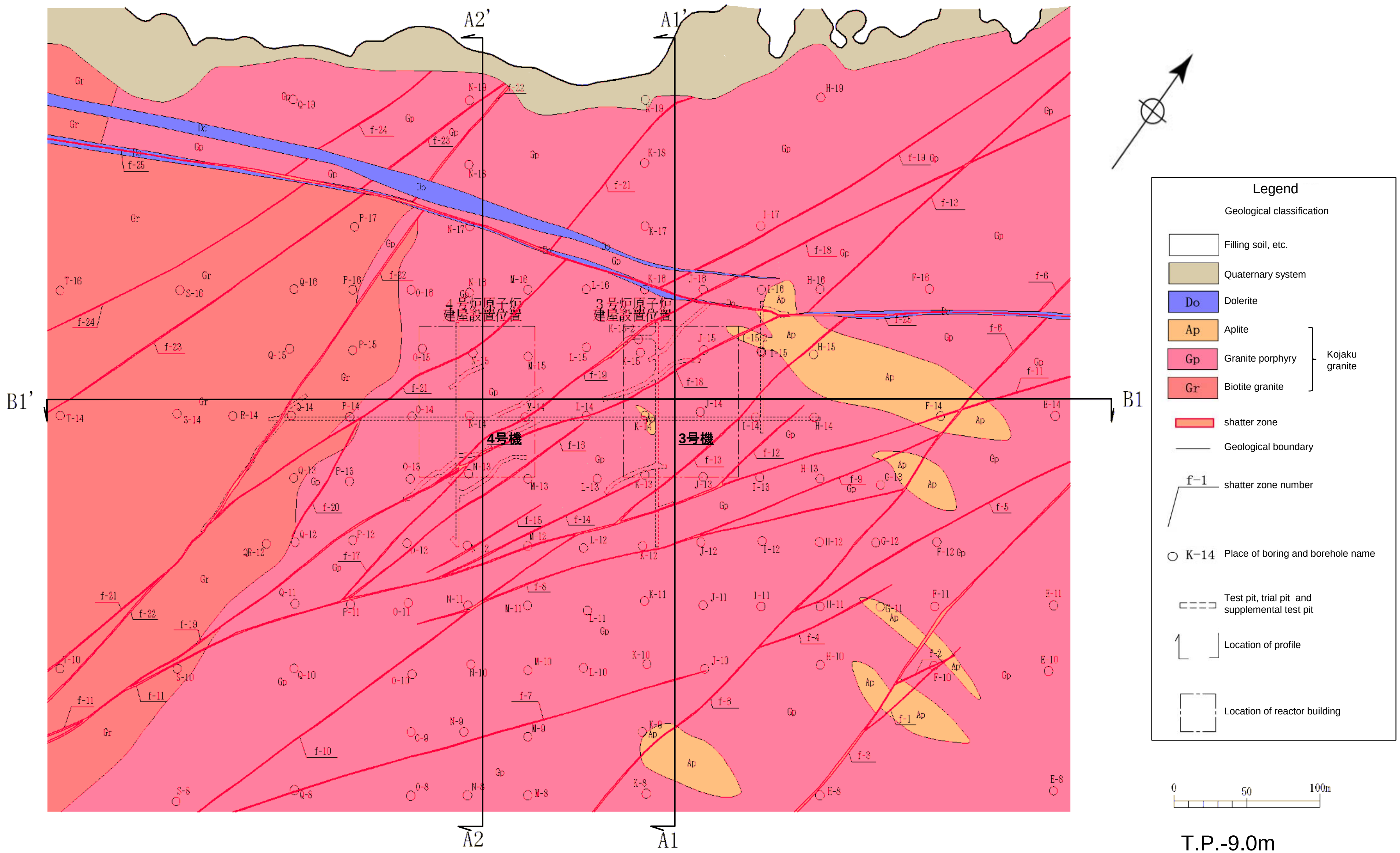
Geological classification legend



Geological profile around Unit 2 B-B’ profile

* Additional survey results as of the end of November are reflected.

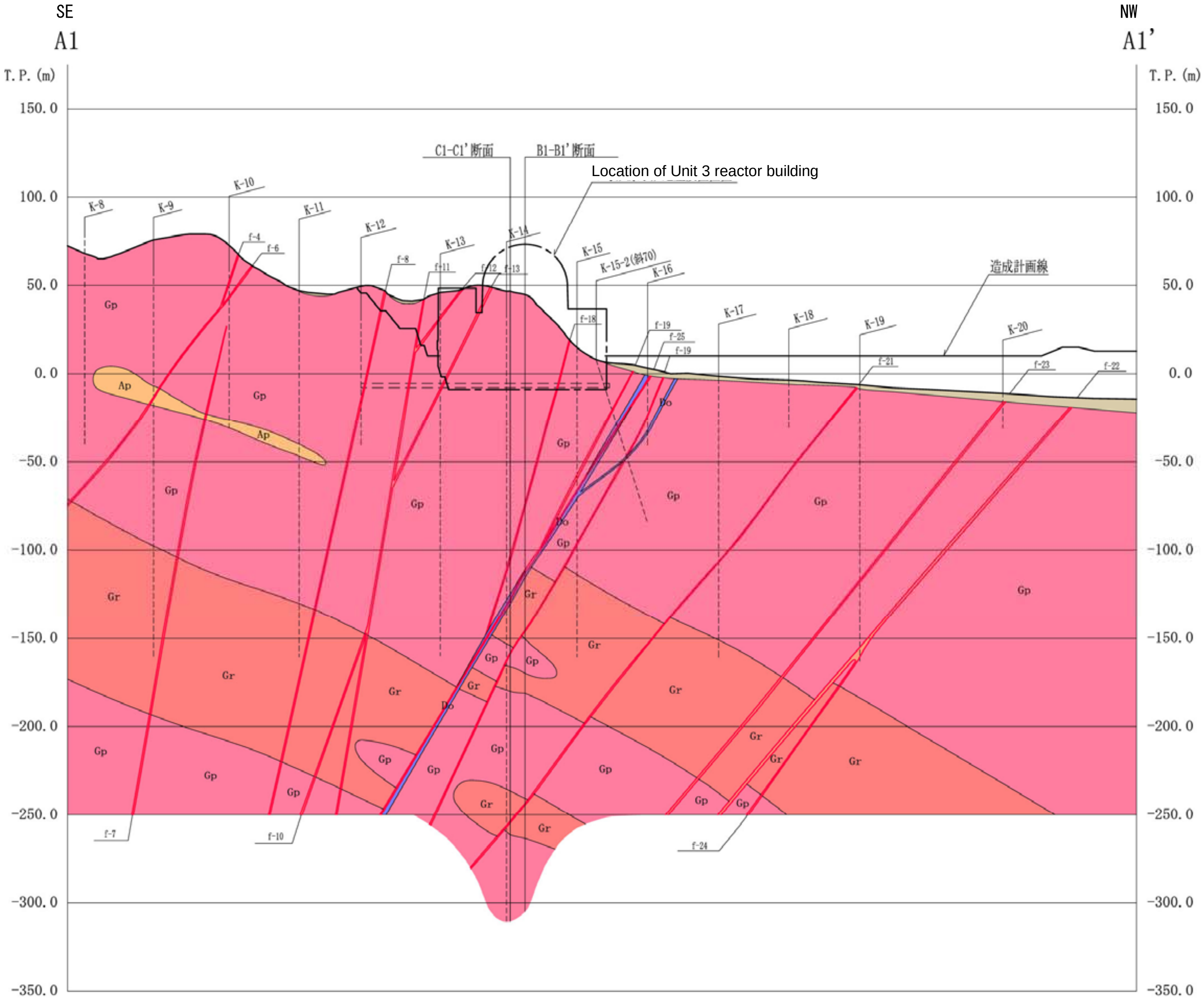
Geological plan (Units 3 and 4 side)

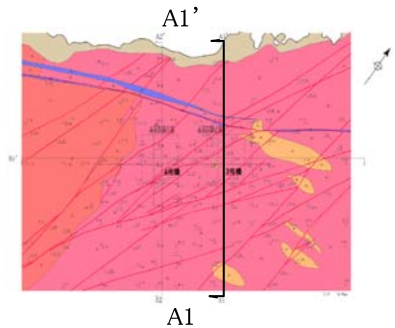


T.P.-9.0m

- The shatter zones running in the directions between N-S and NE-SW are predominant.
- In dolerite, the shatter zones running in the direction of ENE-WSW are found, which have displaced the shatter zones running in the direction between N-S and NE-SW.

Geological profile (Unit 3 side: A1-A1')





Legend

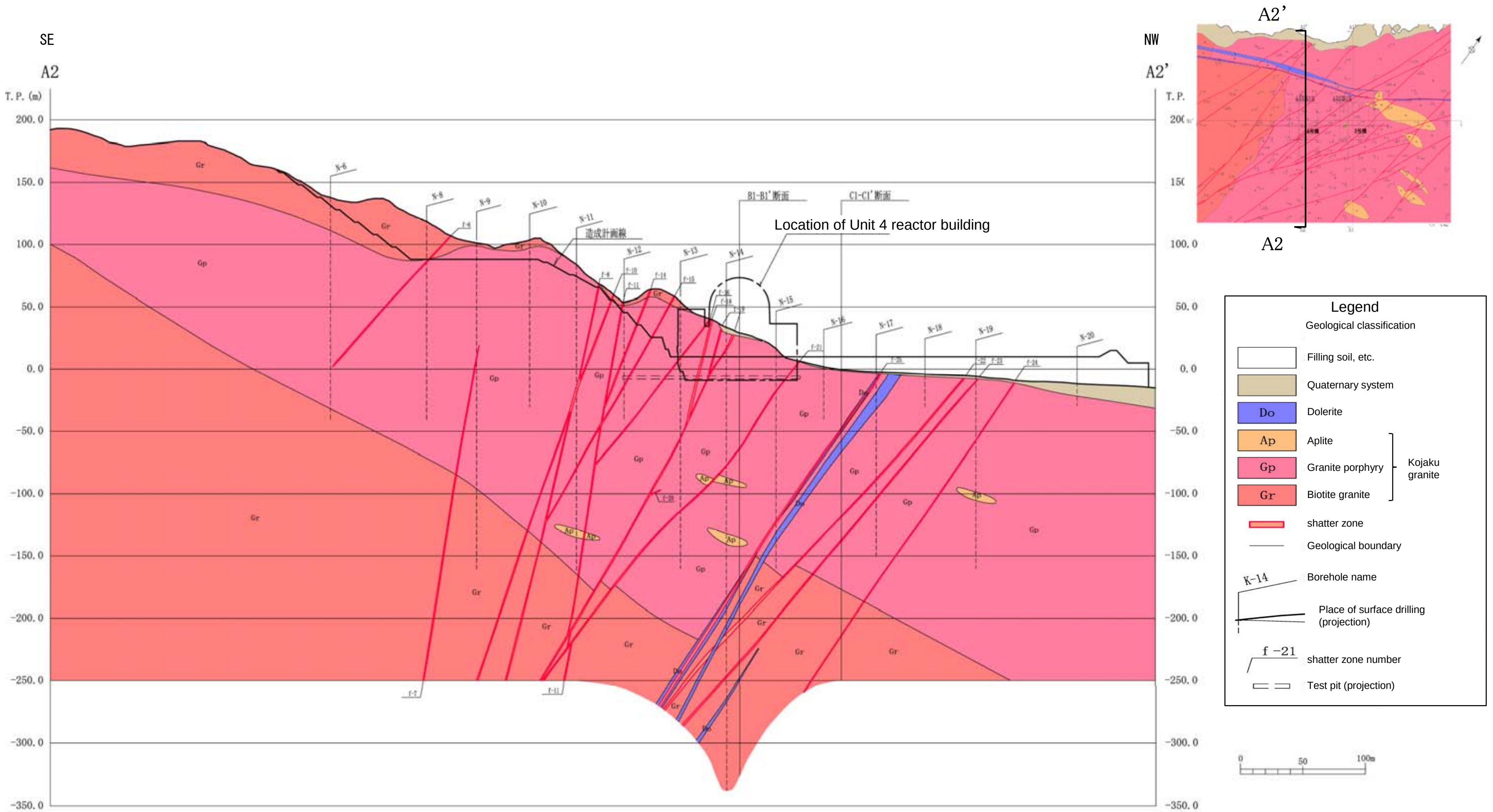
Geological classification

- Filling soil, etc.
- Quaternary system
- Do: Dolerite
- Ap: Aplite (Kojaku granite)
- Gp: Granite porphyry (Kojaku granite)
- Gr: Biotite granite (Kojaku granite)
- shatter zone
- Geological boundary
- Borehole name
- Place of surface drilling (projection)
- shatter zone number
- Test pit (projection)

0 50 100m

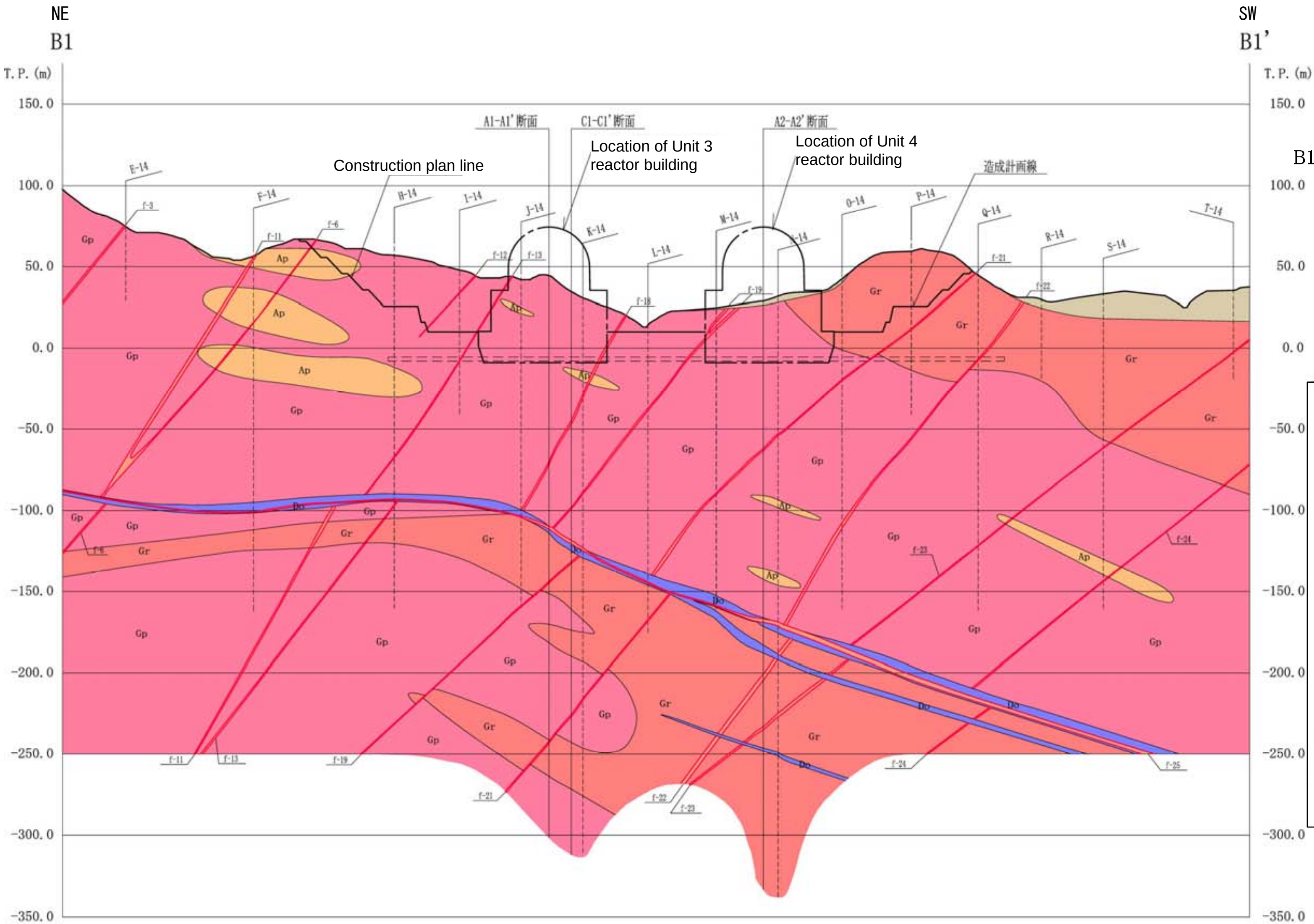
・The shatter zones are high-angle easterly dip.
・The shatter zones have displaced the boundary between rock types (Gr/Gp boundary) into one like a normal fault.

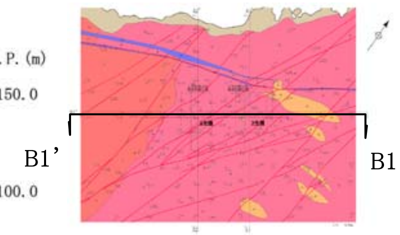
Geological profile (Unit 4 side: A2-A2’)

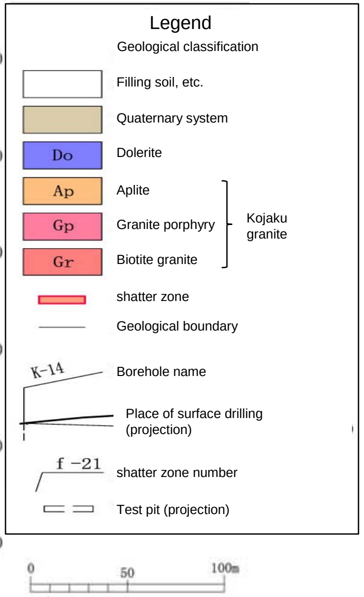


・The shatter zones are high-angle easterly dip.
・The shatter zones have displaced the boundary between rock types (Gr/Gp boundary) into one like a normal fault.

Geological profile (Units 3 and 4 side: B1-B1')





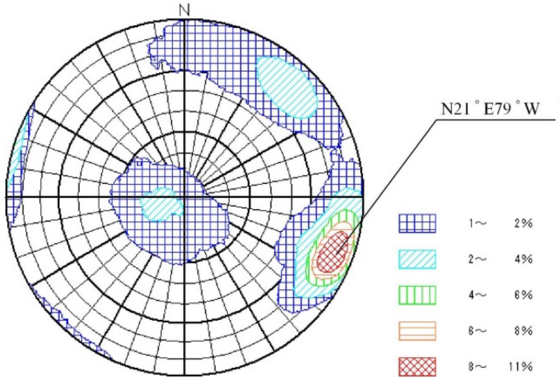


・The shatter zones show easterly dip.
・The shatter zones have displaced the boundary between rock types (Gr/Gp boundary) into one like a normal fault.

Strikes and dips of joints and shatter zones (Schmidt net, lower hemisphere projection)

Joint

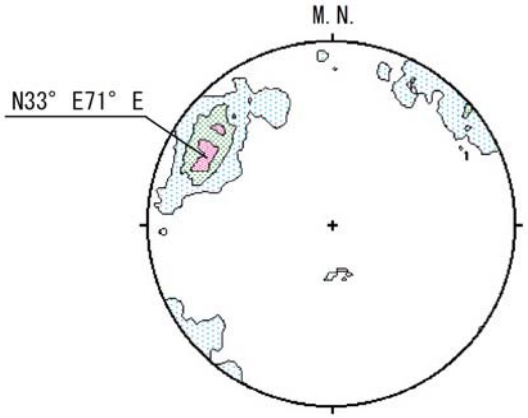
Joint on Units 1 and 2 side



Total number of data 16424

Of the back-check borings, the lower portion of Urasoko fault

Joint on Units 3 and 4 side



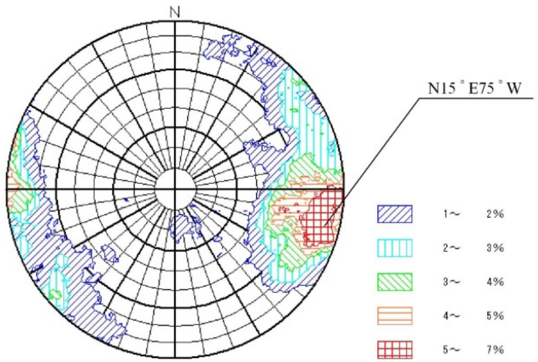
Surface joints N = 427

2.0-4.0%
4.0-6.0%
6.0-8.0%

- The joints run in the directions between N-S and NE-SW, NNW-SSE and E-W. Among them, those running in the directions between N-S and NE-SW are predominant.
- As for dip, many of those adjacent to the Units 1 and 2 are high-angle westerly dips, while those adjacent to the Unit 3 and 4, which are high-angle easterly dips, are predominant.

shatter zone

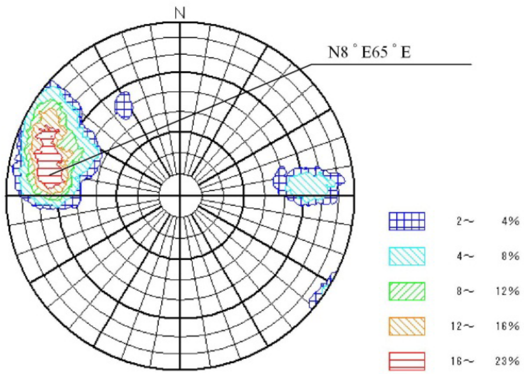
shatter zone on Units 1 and 2 side



Total number of data 883

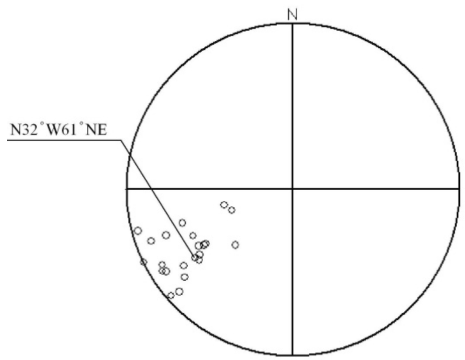
Of the back-check borings, the lower portion of Urasoko fault

shatter zone on Units 3 and 4 side



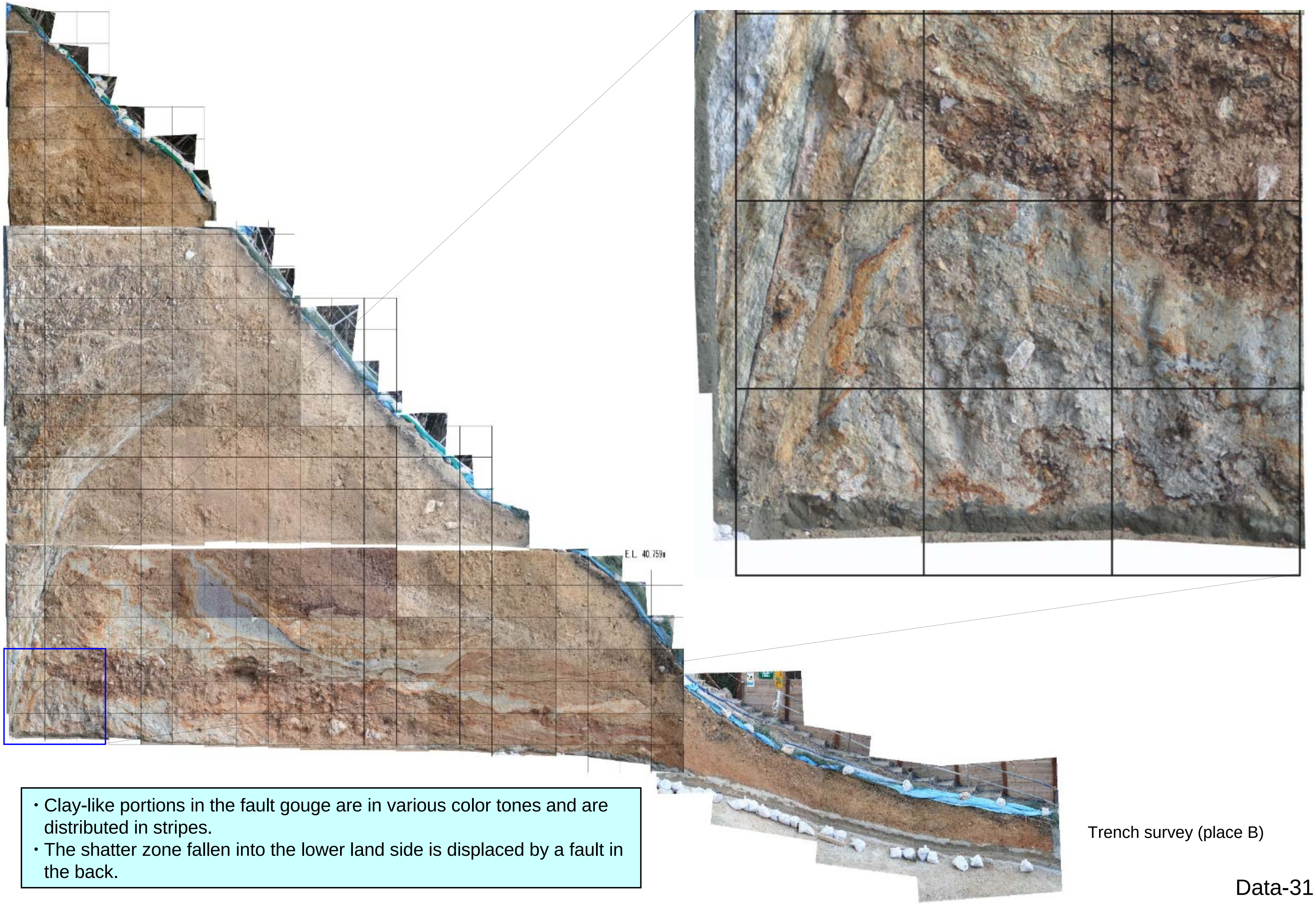
Surface shatter zones around Units 3 and 4 N = 16
shatter zones just beneath the locations of Units 3 and 4 N = 142

Urasoko fault



- The shatter zones other than Urasoko fault run mainly in the directions between N-S and NE-SW, in harmony with the direction that joints are predominant.
- Urasoko fault generally runs in a direction of NW-SE and is vertical to high-angle easterly dip.

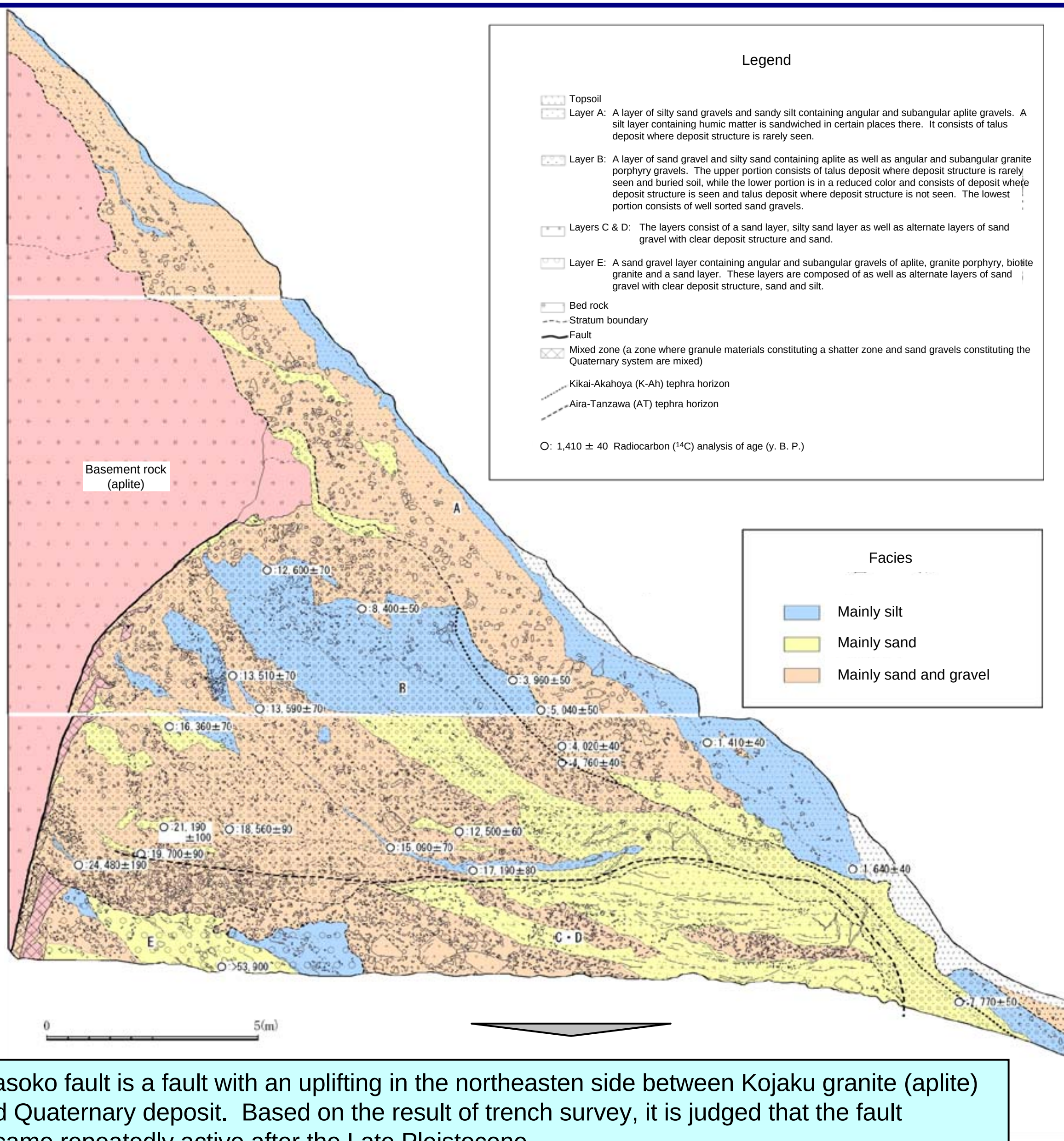
Urasoko fault (trench at place B)

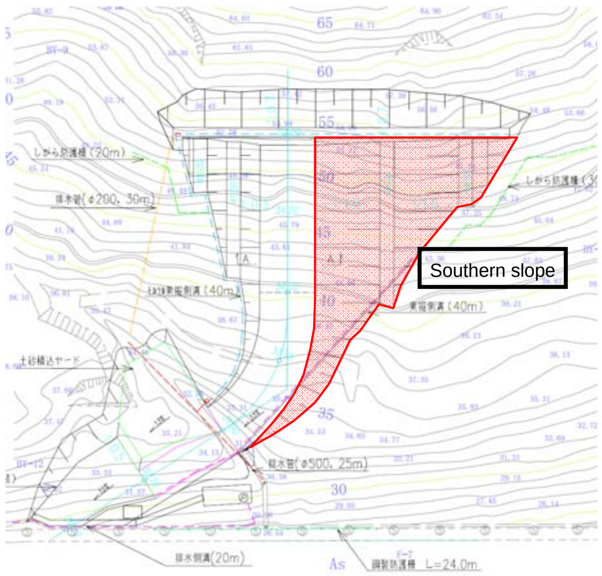


・Clay-like portions in the fault gouge are in various color tones and are distributed in stripes.
・The shatter zone fallen into the lower land side is displaced by a fault in the back.

Trench survey (place B)

Urasoko fault (trench at place B)





Sketch of B1 trench southern slope

- Basement rock consisting of aplite as well as Quaternary talus deposit that overlays disconformably are found. On the boundary between aplite as well as Quaternary talus deposit (layers B & E), a shatter zone (brown and ash gray clay of about 10 cm wide) with a northeasterly dip of about 40° in the upper zone and about 70° in the lower zone is recognized.
- The layer B (radiocarbon (^{14}C) analysis of age: 24,480 ± 190 y. B.P. to 3,960 ± 50 y. B.P.) that contains Kikai-Akahoya tephra (about 7,300 years ago) and Aira Tn tephra (about 29,000 - 26,000 years ago) contacts the basement rock in terms of a fault.
- Displacement and deformation by a fault is not recognized in the layer A (radiocarbon (^{14}C) analysis of age: 1,640 ± 40 y. B.P. to 1,410 ± 40 y. B.P.)
- We can see from the above that the latest active period was after the layer B was deposited and before the layer A was deposited.
- In the boundary between the shatter zone and the layer E, a mixed zone is continuously seen and the gravels inside the layer E show strong preferred orientation. In the boundary between the shatter zone and the layer B, a mixed zone is intermittently seen and the gravels inside the layer B show poor preferred orientation.

- Urasoko fault is a fault with an uplifting in the northeasten side between Kojaku granite (aplite) and Quaternary deposit. Based on the result of trench survey, it is judged that the fault became repeatedly active after the Late Pleistocene.

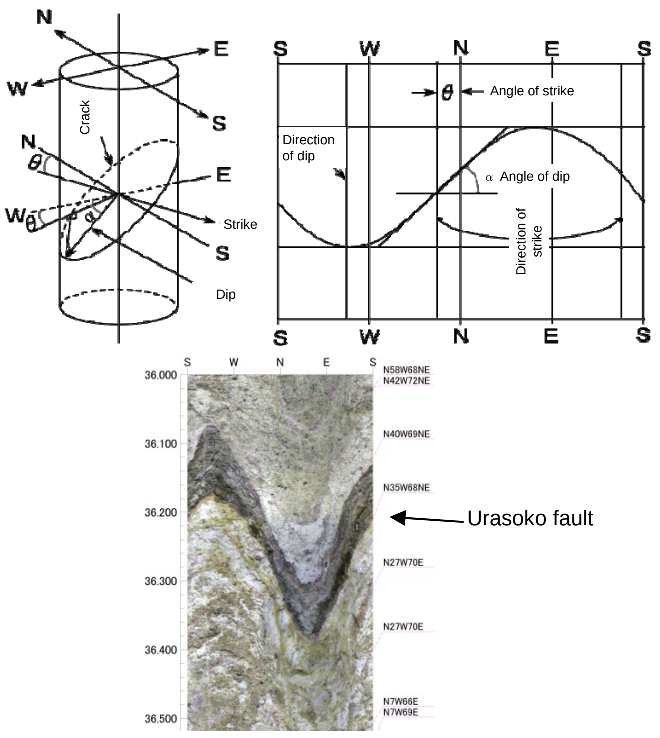
Concept of evaluating continuity of shatter zones

① The identified shatter zones should be extended, following their strikes and dips.
－ For strike and dip, values measured by a borehole television (BHTV), surficial geology survey and test pit survey should be used.
－ If there is no rational reason to bend it, it should be extended linearly in principle.

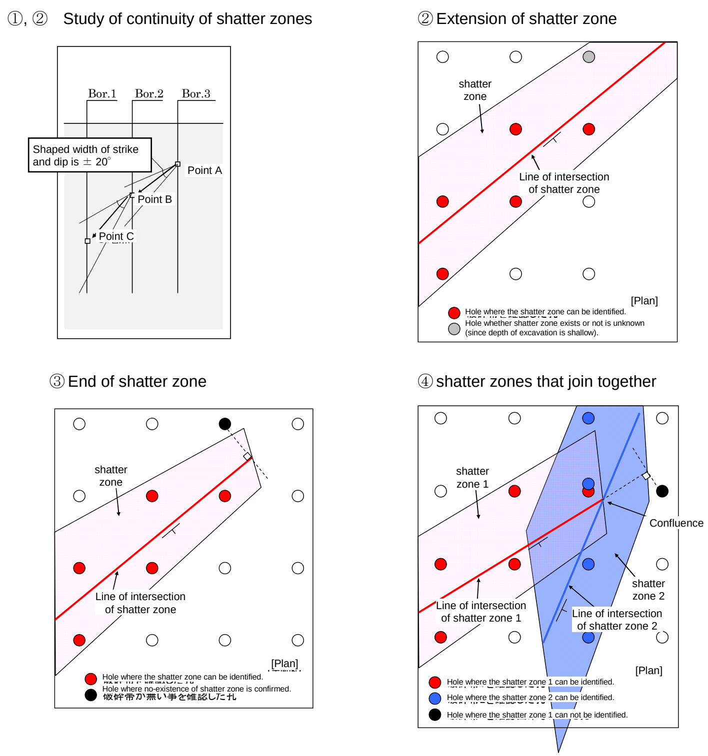
② If "a shatter zone that has similar strike and dip exists" in the extended location, and "a shatter zone whose strike and dip are unknown exists," it should be evaluated as being continuous.
－ It should be deemed as being continuous on the assumption that a strike and dip change locally (changes in strike and dip are estimated within a range of ± 20°).
－ In the case of the characteristics (whether a fault gouge exists or not, linearity, etc.) of shatter zones being different, if strike and dip are similar, it should be deemed as an extension and being continuous.
－ If in the extended location "the existence of a shatter zone is unknown," it should be extended directly.

③ In cases that in the extended location "the shatter zone is not identified," and "a shatter zone with a different strike and dip exists," it should not be extended further.

④ In case that in the extended location "the corresponding shatter zone is not identified and a different shatter zone is judged to cross," it should be deemed that the shatter zones are consolidated.



Example of measuring strike and dip of shatter zone by BHTV



Frame format of concept of evaluating continuity

Classification of fault rock

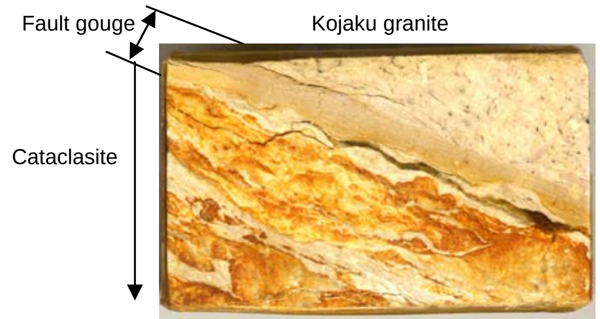
Crushing		Fusion	Recrystallization
Random fabric or foliated			Foliated
Incohesive	Cohesive		
Fault breccia Fault gouge	Protocataclasite Cataclasite Ultracataclasite	Pseudotachylyte	Protomylonite Mylonite Ultramylonite

Grain-size reduction ↓

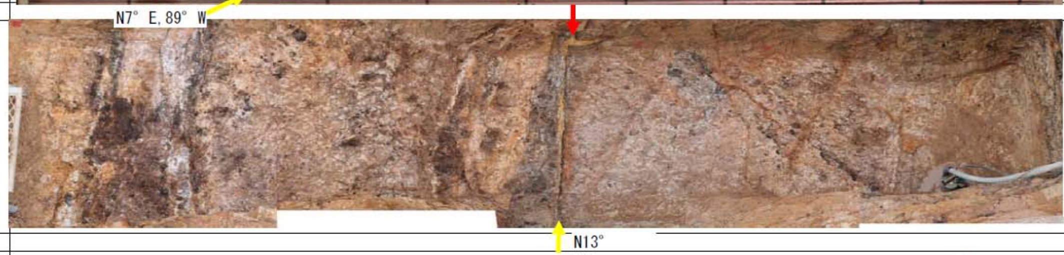
Boundary values for sub-classification		
Name	Proportion of visible fragments	Grain size of fragment
Fault breccia	>30%	Megabreccia >256 mm Mesobreccia 10-256 mm Microbreccia <10 mm
Fault gouge	<30%	<10 mm in normal
	Proportion of fragments	Grain size of fragment
Protocataclasite Cataclasite Ultracataclasite	>50% 10-50% <10%	<10 mm in normal
	Proportion of porphyroclasts	Grain size of matrix mineral
Protomylonite Mylonite Ultramylonite	Variable depending on the lithology of protolith	>100 μm 20-100 μm <20 μm

Source: Proposed classification of fault rocks (by Takagi & Kobayashi, 1996)

In Kojaku granite that is found in the site, white fault gouge and cataclasite are distributed, while black fault gouge is distributed along dolerite.

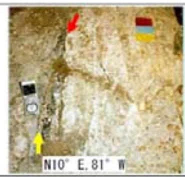
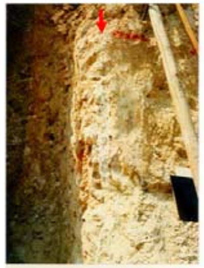
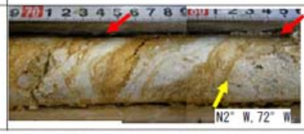


D-1 shatter zone catalog (1/2)

<table>
<tr><th rowspan="2">shatter zone No.</th><th rowspan="2">Confirmation hole</th><th colspan="2">shatter zone range</th><th rowspan="2">Crushing width (cm)</th><th rowspan="2">Property (from hanging wall side)</th><th colspan="2">Color tone</th><th rowspan="2">Strike * Magnetic north</th><th rowspan="2">Dip</th><th colspan="2">Displacement sense</th><th rowspan="2">Photos of core and polished section : Fault gouge : Measurement place for strike and dip</th></tr>
<tr><th>Hanging wall depth (m)</th><th>Foot wall depth (m)</th><th>Fault gouge</th><th>Cataclasite</th><th>Vertical</th><th>Horizontal</th></tr>
<tr><td rowspan="4">D-1</td><td>B6-5</td><td>12.28</td><td>16.35</td><td>172</td><td>Fault gouge and cataclasite</td><td>Yellowish-white, gray-brown</td><td>Gray-brown, ash gay, orange, reddish brown, light gray green</td><td>N7E</td><td>89W</td><td>—</td><td>—</td><td></td></tr>
<tr><td>D-1 Trench / Northern pit</td><td>—</td><td>—</td><td>100</td><td>Fault gouge and cataclasite</td><td>Gray-brown</td><td>Brown-yellow, ash gay, light reddish brown, dark brown</td><td>N13E ※</td><td>67W</td><td>Normal fault</td><td>Right-lateral slip</td><td></td></tr>
<tr><td>B6-1</td><td>14.76</td><td>15.58</td><td>63</td><td>Fault gouge and cataclasite</td><td>Brown, Yellowish-white</td><td>dark brown, dull-orange</td><td>N3E</td><td>81W</td><td>—</td><td>—</td><td></td></tr>
<tr><td>B14-2</td><td>109.16</td><td>109.46</td><td>8</td><td>Cataclasite occurred between fault gouges</td><td>Bright gray green</td><td>Ash gray, bright gray green</td><td>N1W</td><td>76W</td><td>Normal fault</td><td>Right-lateral slip</td><td></td></tr>
</table>

D-1 shatter zones consist of cataclasite and fault gouge, run roughly in a direction of N-S, are high-angle westerly dip.

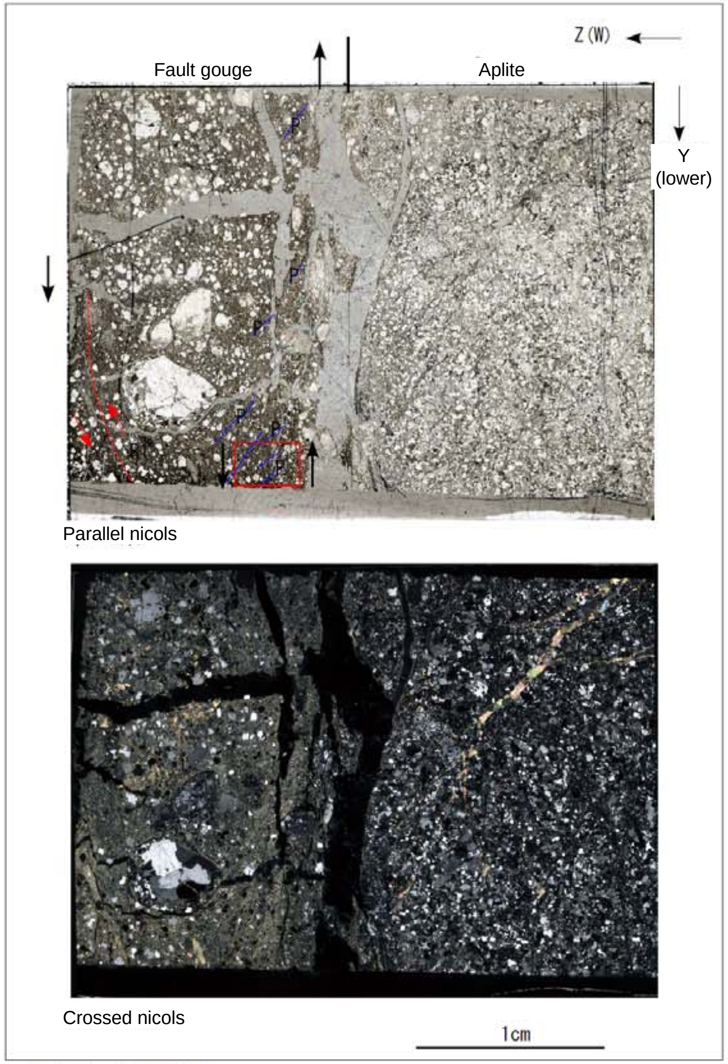
D-1 shatter zone catalog (2/2)

shatter zone No.	Confirmation hole	shatter zone range		Crushing width (cm)	Property (from hanging wall side)	Color tone		Strike * Magnetic north	Dip	Displacement sense		Photos of core and polished section (red arrow: Fault gouge; yellow arrow: Measurement place for strike and dip)
		Hanging wall depth (m)	Foot wall depth (m)			Fault gouge	Cataclasite			Vertical	Horizontal	
D-1	H-6a (test tunnel)	–	–	10～120	Fault gouge and cataclasite	light gray green, brown-green	Ash gay, light brownish-yellow, yellowish-white	N10E ※	81W	–	–	
	H-6 (bottom surface of Unit 2)	–	–	–	Fault gouge and cataclasite	Yellowish-white, slight - brownish - yellow	Light brown, yellowish-white	N10E～5W ※	75～80W	–	–	 shatter zone H-6  shatter zone H-6a closeup
	No.14	86.12	87.03	51	Cataclasite occurred between fault gouges	Ash gay, grayish brown -yellow	Light white-pink, gray	N20E	81W	–	–	
	②-1	49.21	51.10	80	Stripe texture of fault gouge and cataclasite	Ash gray, orange	Yellowish-white, light brown, light pinkish-gray	–	–	Normal fault	Right-lateral slip	 Unable to measure strike and dip
	No.2	149.71	149.84	8.0	Fault gouge	Ash gray, brown	Brownish-yellow, ash gray	N2W	72W	–	–	
	outcrop	–	–	50.0	Fault gouge and cataclasite	Dark gray	Light yellowish-white, light pinkish-gray, brown, ash gray, brownish-yellow	N16E ※	73W	Normal fault	Right-lateral slip	

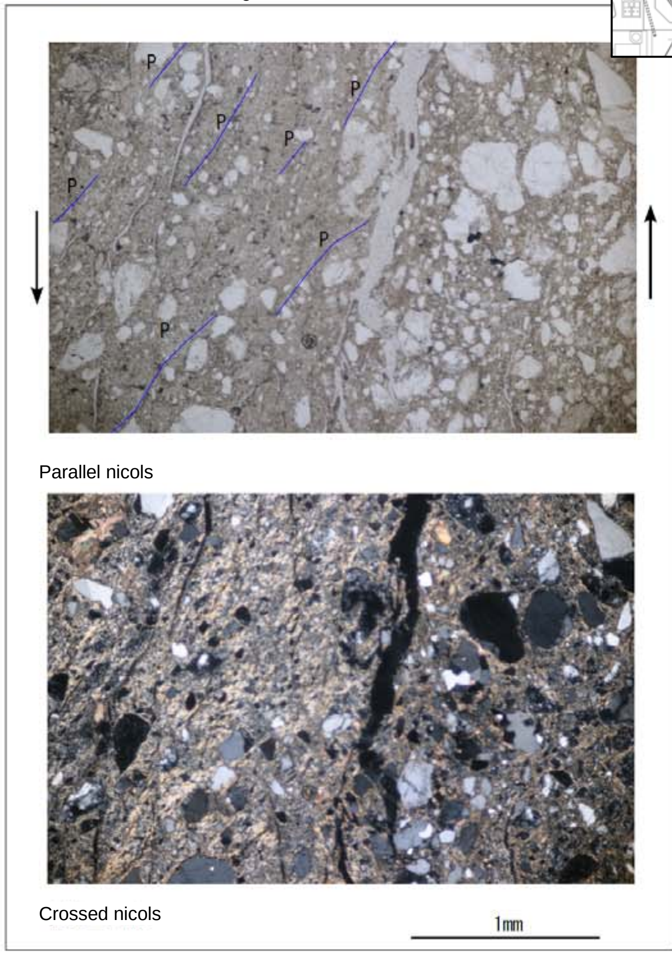
D-1 shatter zones consist of cataclasite and fault gouge, run roughly in a direction of N-S, are high-angle westerly dip.

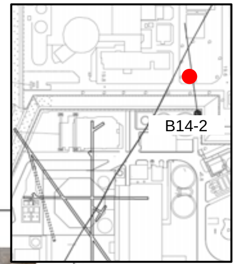
[Displacement sense of shatter zone] Results of observation of thin section collected from B-14-2 hole (vertical components)

B14-2 hole YZ direction



Area within red frame is enlarged

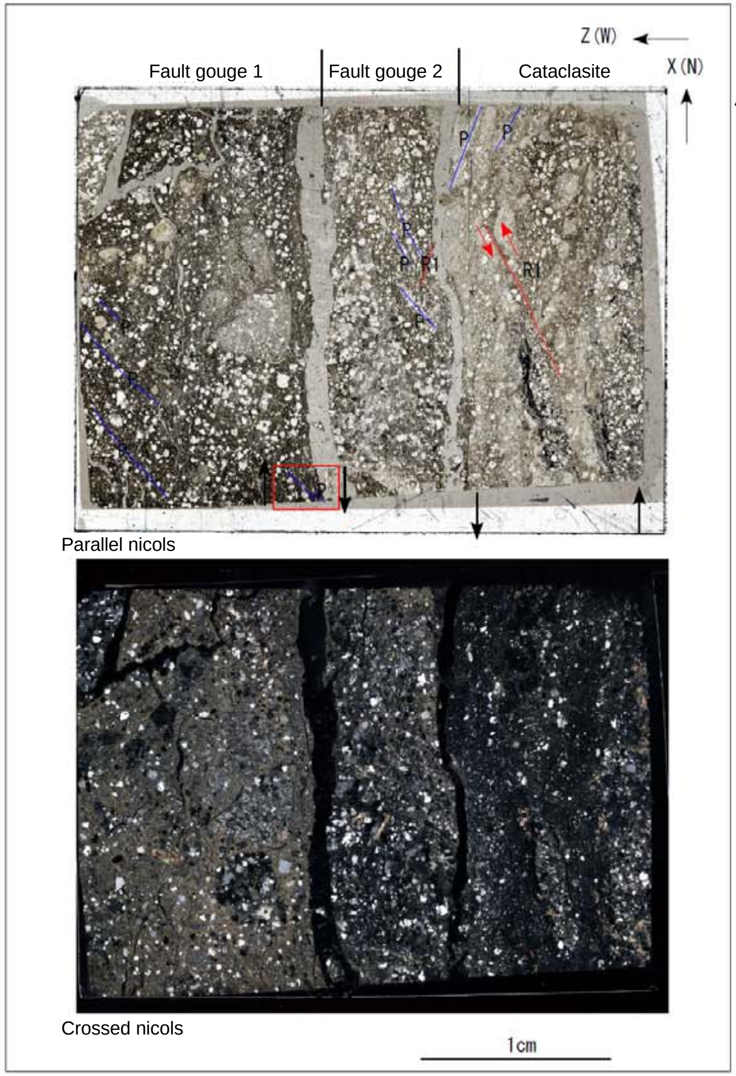




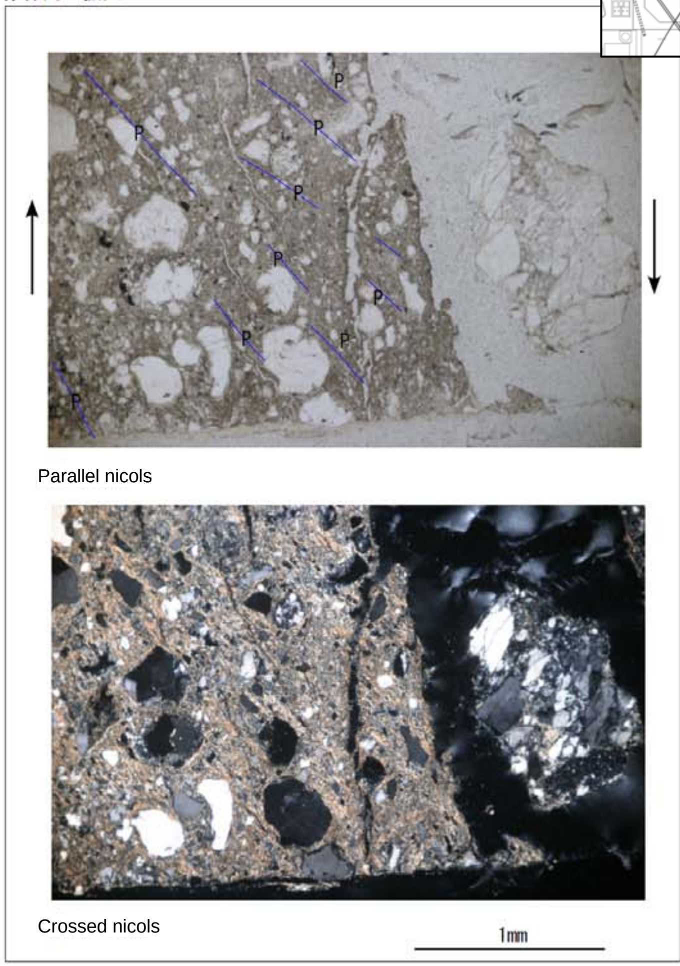
- Fault gouge (last slip)
  Consists of the brown-gray matrix of fine grain, as well as quartz, feldspar, cataclasite fragment and calcite that are semi-circular gravels or sub-angular gravels with diameters of 0.1 to 5 mm. The matrix contains lots of clay minerals and calcite. The displacement sense of normal fault can be recognized from R1 and P.
- Aplite
  Contains fine grains of quartz, potassium feldspar, plagioclase, biotite, muscovite and calcite.

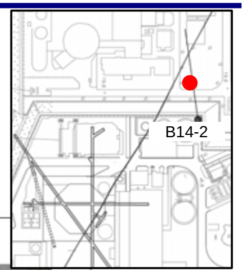
[Displacement sense of shatter zone] Results of observation of thin section collected from B-14-2 hole (horizontal components)

B14-2 hole XZ direction



Area within red frame is enlarged

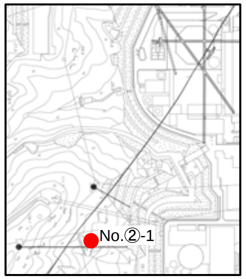


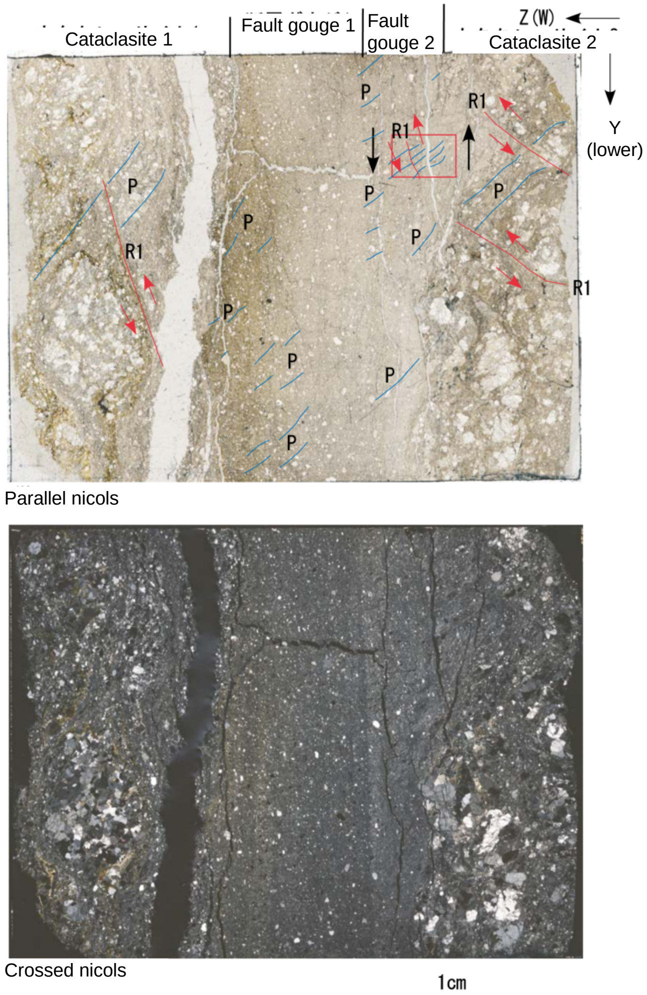


- Fault gouge 1 (last slip)
  Consists of the brown-gray matrix of fine grain, as well as quartz, feldspar, cataclasite fragment and calcite that are semi-circular gravels or sub-angular gravels with diameters of 0.1 to 5 mm. The matrix contains lots of clay minerals and calcite. The displacement sense of right-lateral slip can be recognized from P.
- Fault gouge 2
  Consists of the brown-gray matrix of fine grain, as well as quartz, feldspar, cataclasite fragment and calcite that are semi-circular gravels or sub-angular gravels with diameters of 0.1 to 10 mm. Ratio of fragments is higher than in fault gouge 1. The matrix contains lots of clay minerals and calcite. The displacement sense of right-lateral slip can be recognized from R1 and P.
- Cataclasite
  Consists of the gray-white matrix of fine grain, as well as cataclasite fragments, quartz, feldspar and calcite fragments that are sub-angular gravels with diameters of 0.1 to 2 mm. The matrix contains less clay minerals.

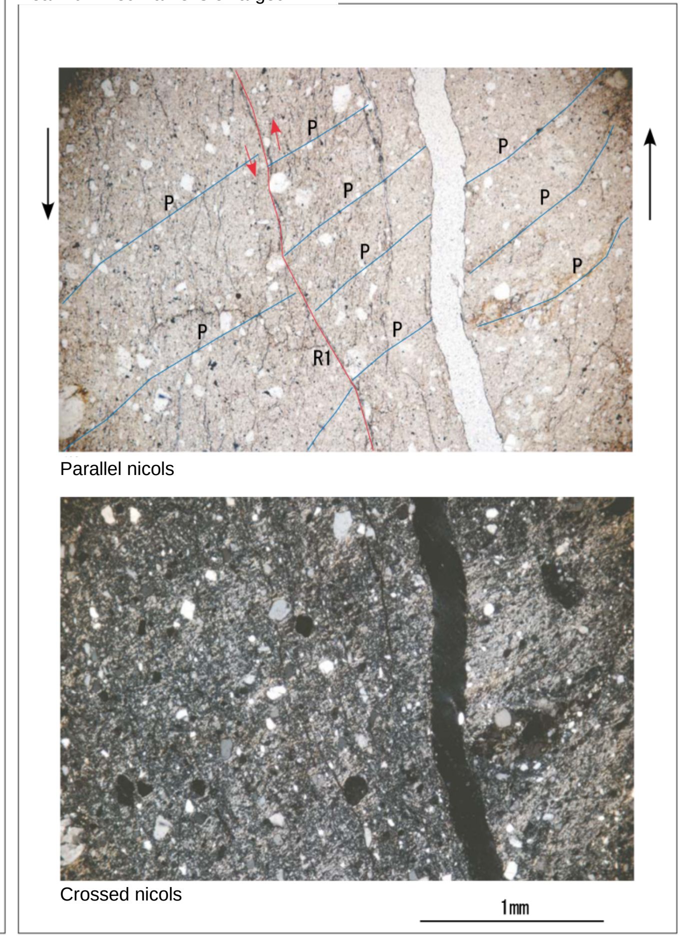
[Sense of displacement of shatter zone] Results of observation of thin section collected from No. ②-1 hole (vertical components)

No. ②-1 hole YZ direction





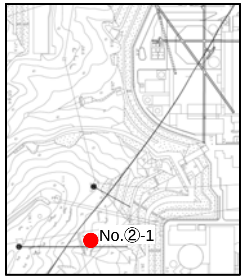
Area within red frame is enlarged

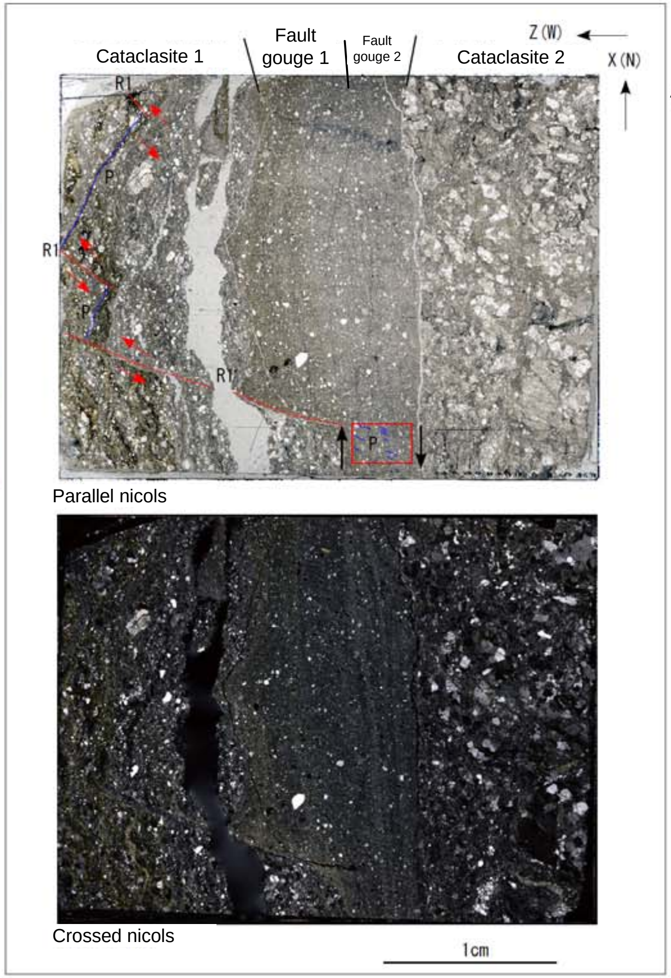


- Cataclasite 1
  Consists of the gray-white matrix of fine grain, as well as granite fragments, quartz and feldspar fragments that are sub-angular gravels with diameters of 0.1 to 9 mm. Contains lots of clay minerals in stripes. The displacement sense of normal fault can be recognized from P and its cut-off of R1.
- Fault gouge 1
  Consists of the brown-gray matrix of fine grain, as well as quartz and feldspar fragments that are sub-angular or semi-circular gravels with diameters of 0.1 to 0.5 mm. Contains lots of clay minerals. The displacement sense of normal fault can be recognized from P. There are some unclear areas.
- Fault gouge 2 (last slip)
  Consists of the brown-gray matrix of fine grain, as well as quartz and feldspar fragments that are semi-circular or sub-angular gravels with diameters of 0.1 to 0.5 mm. Contains lots of clay minerals. In the matrix, clay minerals in stripes are seen. The displacement sense of normal fault can be recognized from P and R1.
- Cataclasite 2
  Consists of the gray-white matrix of fine grain, as well as granite fragments, quartz and feldspar fragments that are sub-angular gravels with diameters of 1 to 10 mm. Contains less clay minerals. The displacement sense of normal fault can be recognized from P and R1.

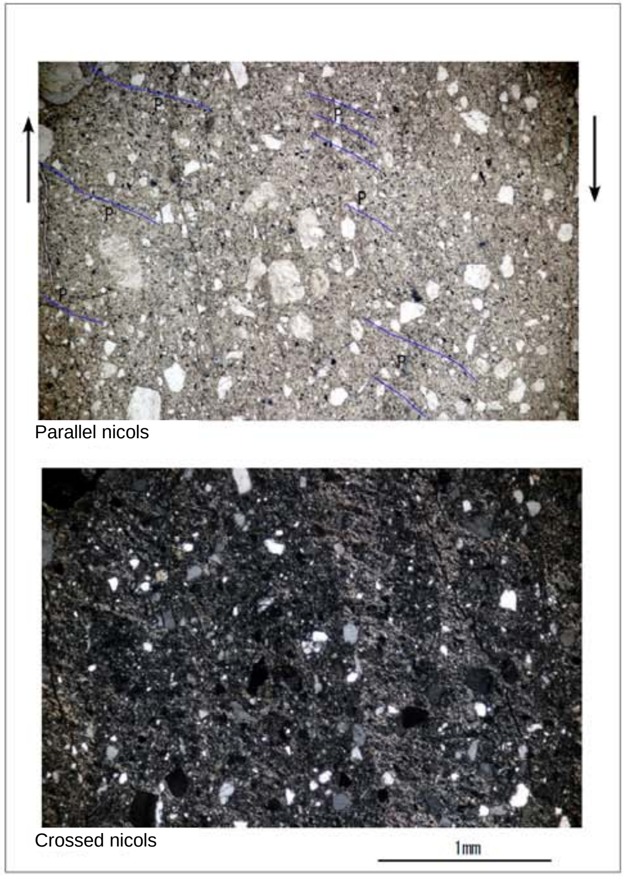
[Sense of displacement of shatter zone] Results of observation of thin section collected from No. ②-1 hole (horizontal components)

No. ②-1 hole XZ direction



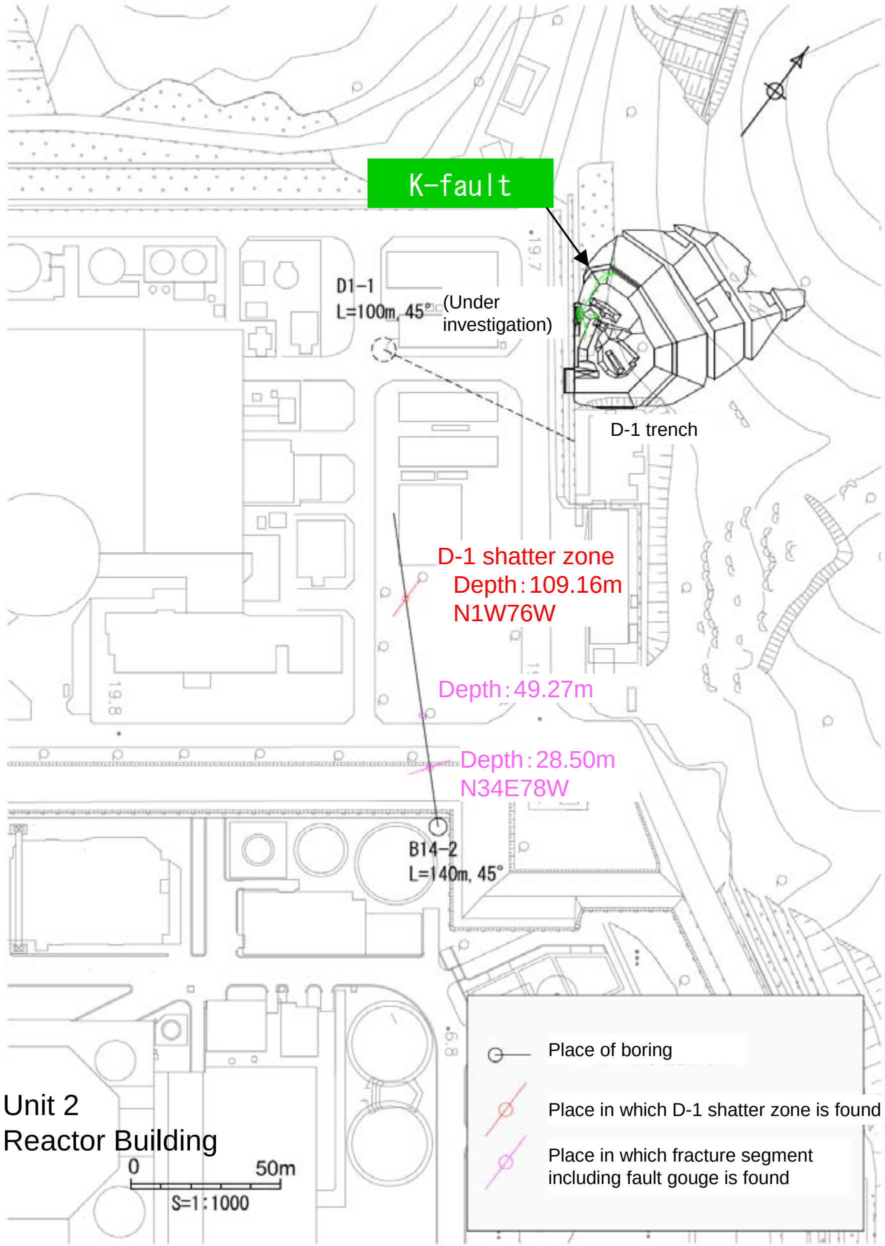


Area within red frame is enlarged



- Cataclasite 1
  Consists of the gray-white matrix of fine grain, as well as granite fragments, quartz and feldspar fragments that are sub-angular gravels with diameters of 0.1 to 2 mm. Contains lots of clay minerals in stripes. The displacement sense of left-lateral slip can be recognized from P and its cut-off of R1.
- Fault gouge 1
  Consists of the brown-gray matrix of fine grain, as well as quartz and feldspar fragments that are sub-angular or semi-circular gravels with diameters of 0.1 to 1 mm. Contains lots of clay minerals. The displacement sense of left-lateral slip can be recognized from R1.
- Fault gouge 2 (last slip)
  Consists of the brown-gray matrix of fine grain, as well as quartz and feldspar fragments that are semi-circular or sub-angular gravels with diameters of 0.1 to 0.3 mm. Contains lots of clay minerals. In the matrix, clay minerals in stripes are seen. The displacement sense of right-lateral slip can be recognized from P.
- Cataclasite 2
  Consists of the gray-white matrix of fine grain, as well as granite fragments, quartz and feldspar fragments that are sub-angular gravels with diameters of 1 to 10 mm. Contains less clay minerals.

Discussion about K-fault's extension to the southward



- Three fracture segments with fault gouge have been confirmed at B14-2 drilling, that cross the line between Unit 2 reactor building and K-fault.
- Displacement sense of the last slip has normal fault sense at each fracture segments.

- K-fault, that has reverse fault sense, does not extend to the southward from at least B14-2 drilling place.

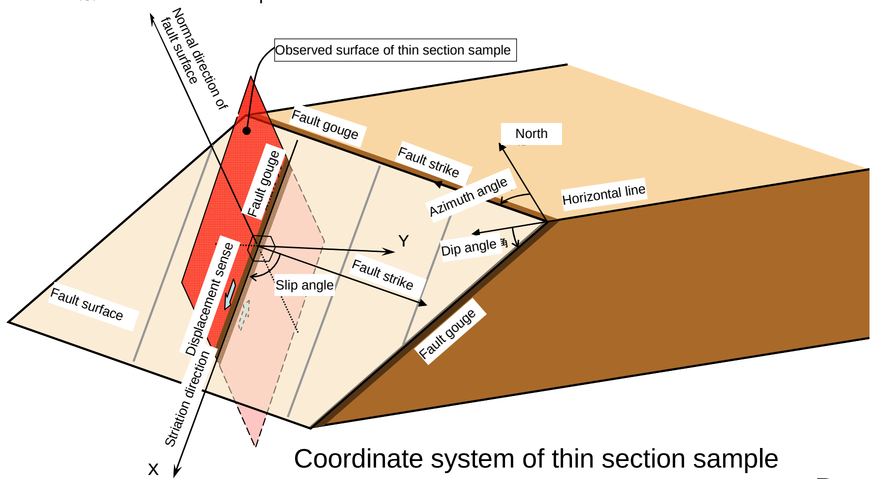
※To enhance the data, drilling at D1-1 is undergoing.

Displacement sense of fracture segment with fault gouge at B14-2

Place	Name of shatter zone	Depth (m)	Strike and dip	Striation direction	Displacement sense (Observation on striation direction of thin section)
B14-2	–	28.50	N34E78W	50S	Normal fault, left-lateral slip
	–	49.27	N44E80SE ※1	75S ※1	Normal fault ※1
	D-1	109.16	N1W76W	–	Normal fault, right-lateral slip※2

※1: Fault surface is assumed to be high-angle dip like K-fault, because it was impossible to measure strike and dip by bore-hole TV

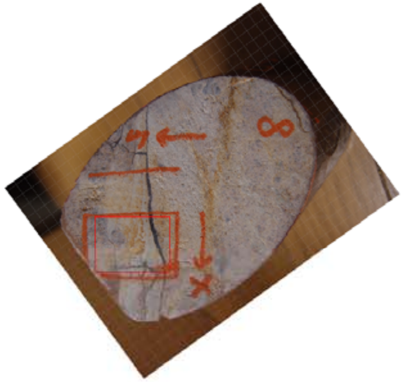
※2: Thin section samples are made in the lateral and horizontal direction.

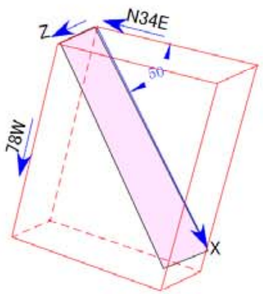


Coordinate system of thin section sample in the striation direction

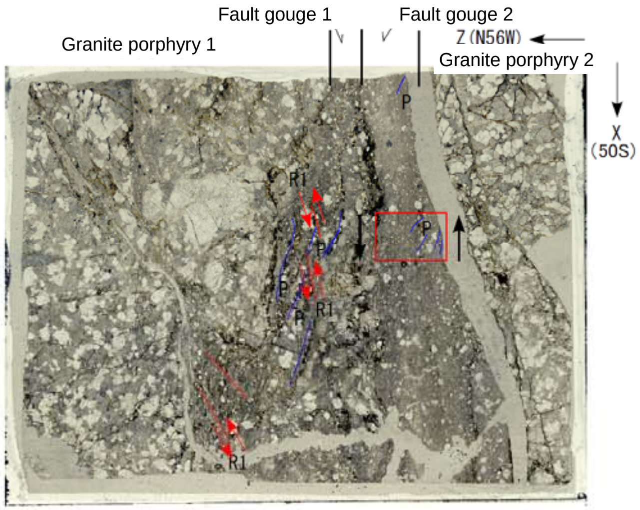
[Displacement sense of shatter zone]
Observation of thin section of B14-2 depth 28.50m (middle-angle southerly dips components)

Newly obtained data after February 5, 2013

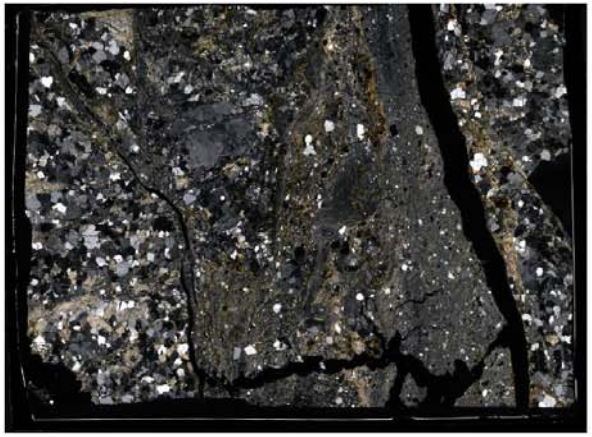




10cm



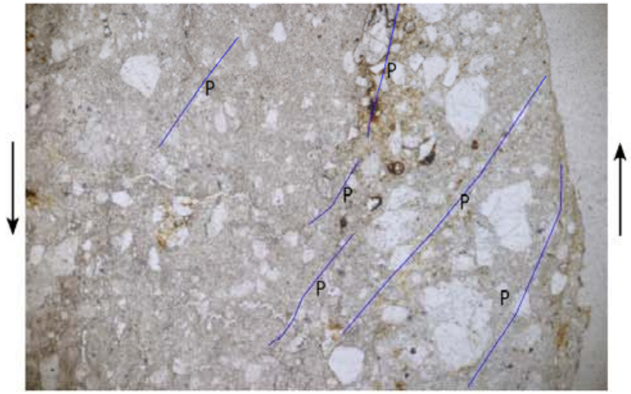
Parallel nicols



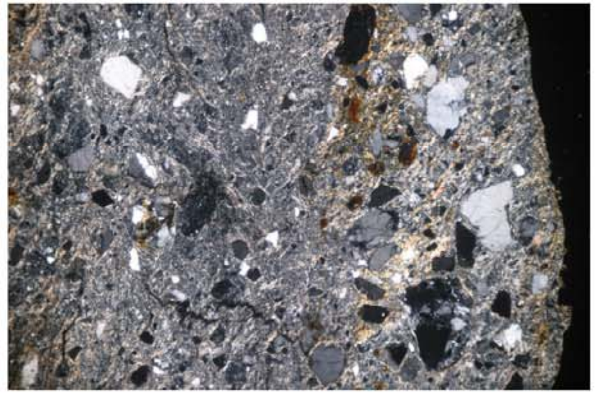
Crossed nicols

1cm

Area within red frame is enlarged



Parallel nicols



Crossed nicols

1mm

・Granite porphyry 1
Consist of quarts, potassium feldspar, plagioclase and muscorite with alternation.

・Fault gouge 1
Consists of the brown-gray matrix of fine grain, as well as quartz, feldspar and cataclasite fragments and that are semi-circular or sub-angular gravels with diameters of 0.02 to 3 mm. The matrix contains lots of clay minerals. The displacement sense of westerly dip (normal fault) and left-lateral slip can be recognized from R1 and P.

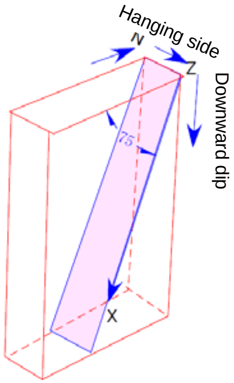
・Fault gouge 2 (last slip)
Consists of the brown-gray matrix of fine grain, as well as quartz, feldspar, granite porphyry and cataclasite fragments and that are semi-circular or sub-angular gravels with diameters of 0.01 to 1 mm. The matrix contains lots of clay minerals. The displacement sense of westerly dip (normal fault) and left-lateral slip can be recognized from P.

・Granite porphyry 2
Consist of quarts, potassium feldspar, plagioclase and muscorite with alternation.

B14-2_28.50m_8-1_XZ方向

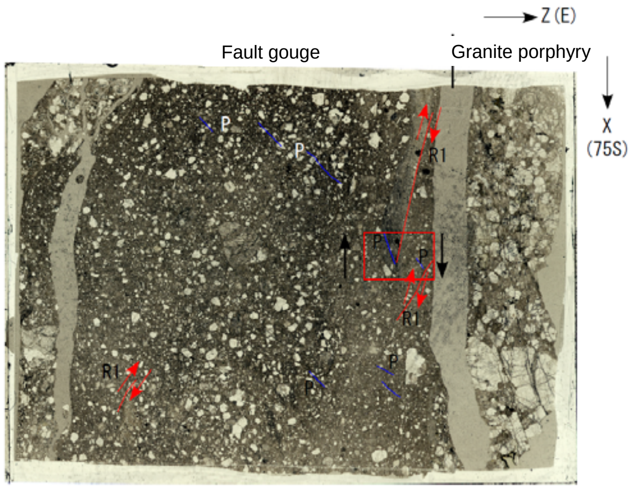
[Displacement sense of shatter zone]
Observation of thin section of B14-2 depth 49.27m (high-angle southerly dips components)

Newly obtained data after February 5, 2013

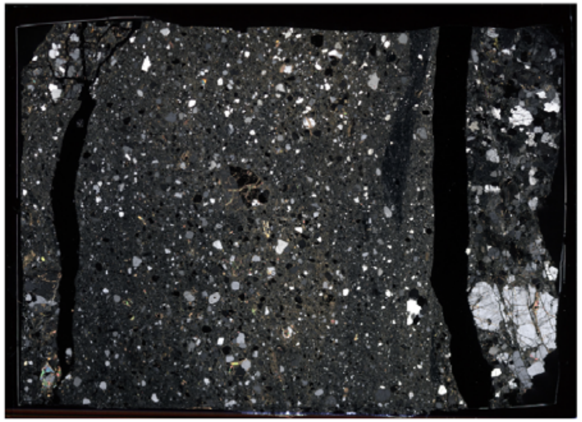


※)Fault surface is assumed to be high-angle dip like K-fault, because it was impossible to measure strike and dip by bore-hole TV

10cm



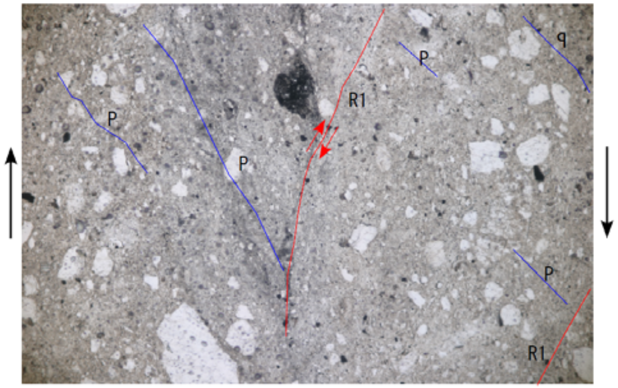
Parallel nicols



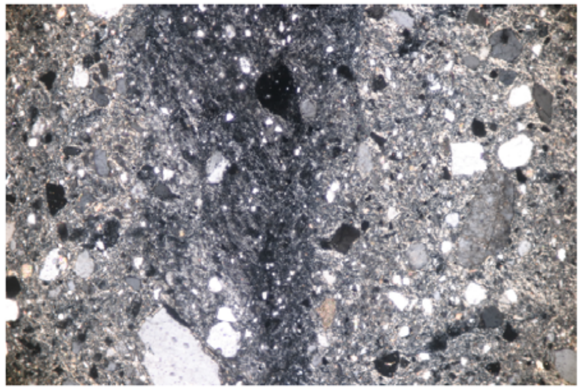
Crossed nicols

1cm

Area within red frame is enlarged



Parallel nicols



Crossed nicols

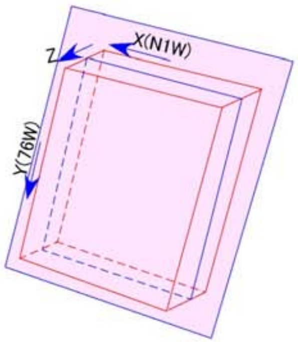
1mm

・Fault gouge (last slip)
Consists of the brown matrix of fine grain, as well as quartz, feldspar, cataclasite and granite porphyry fragments and that are semi-circular or sub-angular gravels with diameters of 0.02 mm to 5mm. The matrix contains lots of clay minerals and calcite. The displacement sense of easterly dip (normal fault) and right-lateral slip can be recognized from R1 and P.

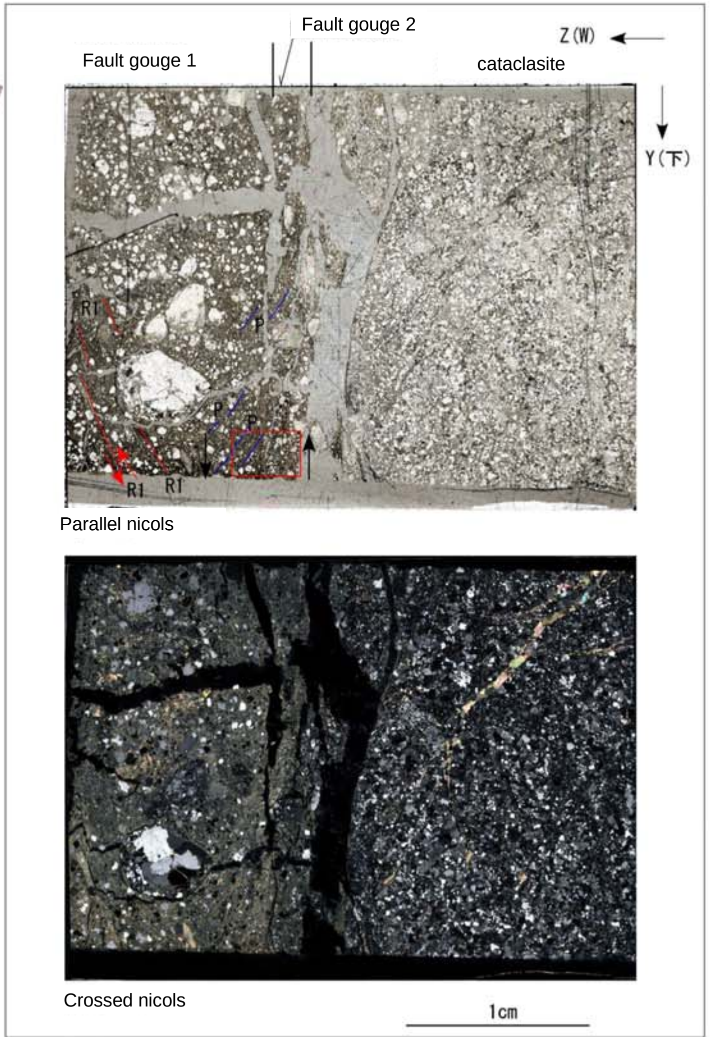
・Granite porphyry
Consist of quarts, potassium feldspar, plagioclase and biotite

B14-2_49.27m_10-1_XZ方向

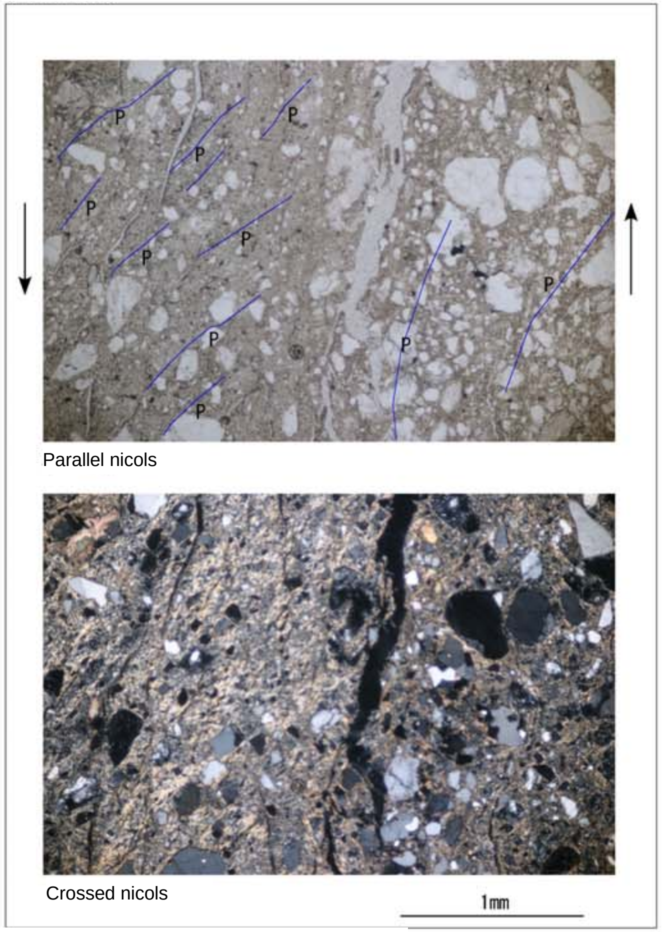
[Displacement sense of shatter zone]
Observation of thin section of B14-2 depth 109.16m (vertical components)



10cm



Area within red frame is enlarged



・Fault gouge 1

Consists of the brown matrix of fine grain, as well as quartz, feldspar, granite porphyry and cataclasite fragments and that are semi-circular or sub-angular gravels with diameters of 0.02 mm to 5mm. The matrix contains lots of clay minerals and calcite. The displacement sense of normal fault can be recognized from R1 and P.

・Fault gouge 2

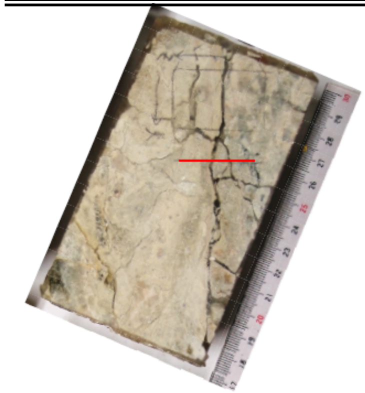
Consists of the brown matrix of fine grain, as well as quartz, feldspar, cataclasite fragments and that are semi-circular or sub-angular gravels with diameters of 0.02 mm to 1mm. The matrix contains lots of clay minerals. The displacement sense of normal fault can be recognized from P.

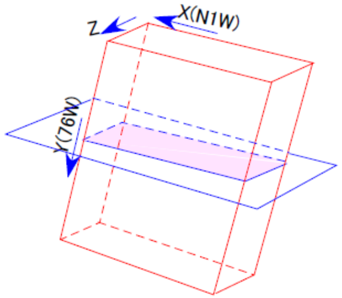
・Cataclasite

Consists of the gray matrix of fine grain, as well as quartz, feldspar, aplite and cataclasite fragments and that are sub-angular or semi-circular gravels with diameters of 0.1mm to 1mm. The matrix doesn't contain much clay minerals. Calcite vein can be recognized.

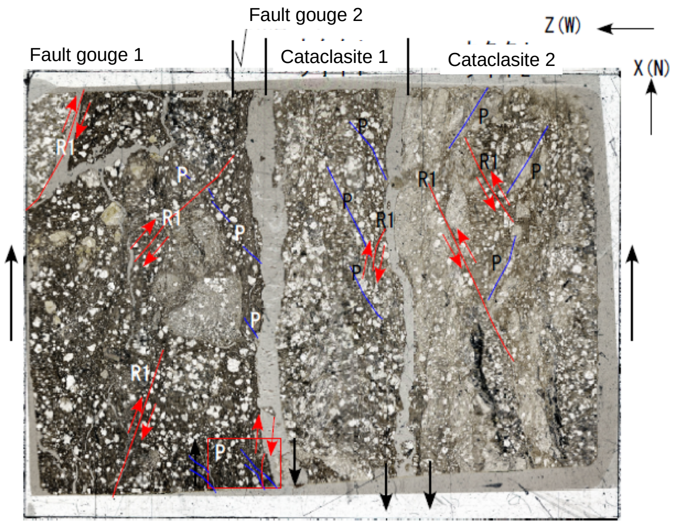
D-1 B14-2 109.16m_2_YZ方向

[Displacement sense of shatter zone]
Observation of thin section of B14-2 depth 109.16m (horizontal components)

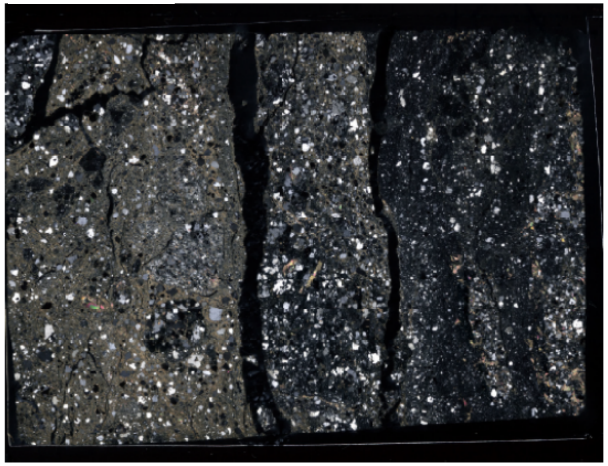




10cm



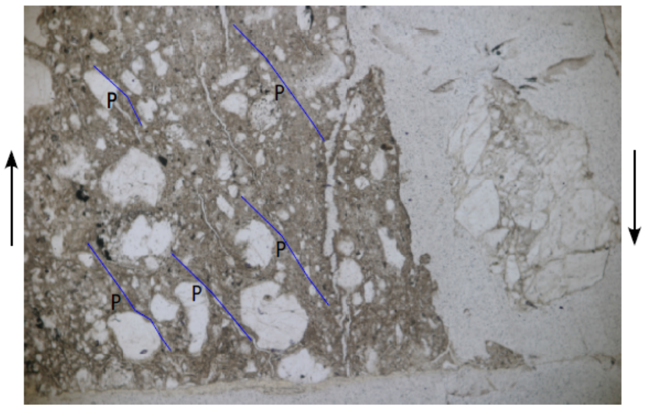
Parallel nicols



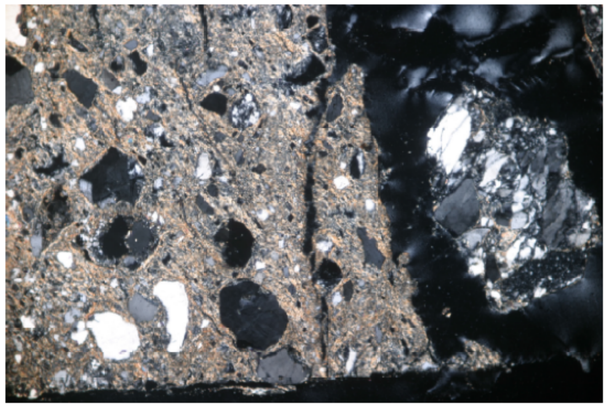
Crossed nicols

1cm

Area within red frame is enlarged



Parallel nicols



Crossed nicols

1mm

・Fault gouge 1
Consists of the brown matrix of fine grain, as well as quartz, feldspar, aplite and cataclasite fragments and that are semi-circular or sub-angular gravels with diameters of 0.02 mm to 7mm. The matrix contains lots of clay minerals and calcite. The displacement sense of right-lateral slip can be recognized from R1 and P.

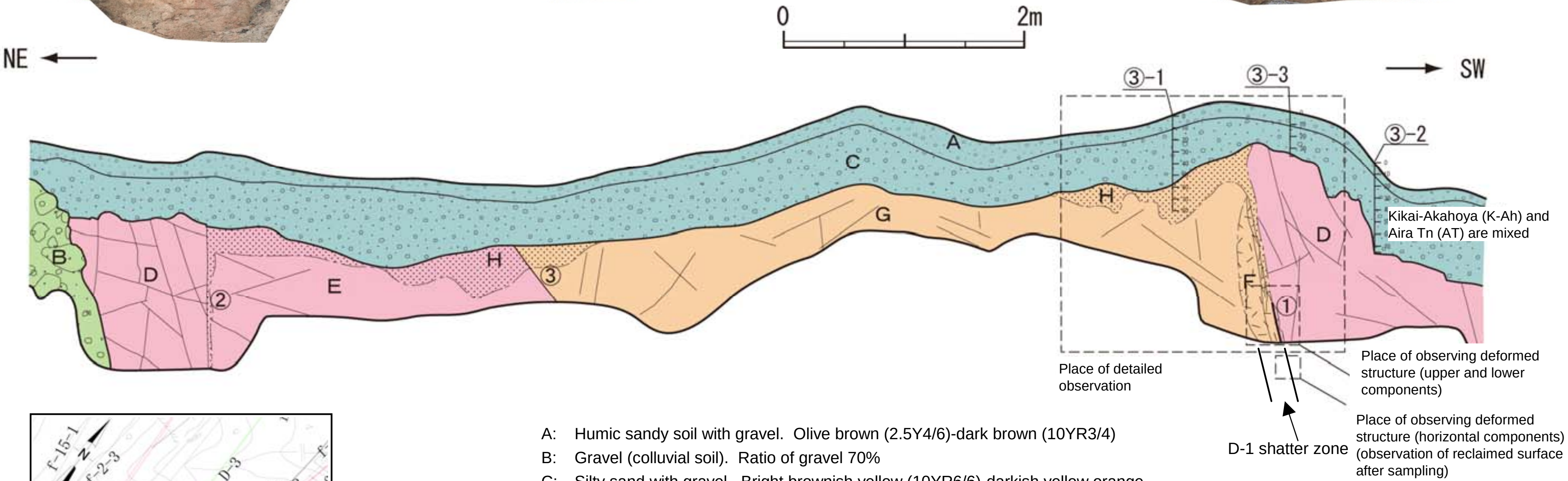
・Fault Gauge 2 (last slip)
Consists of the brown matrix of fine grain, as well as quartz, feldspar, cataclasite fragments and that are semi-circular or sub-angular gravels with diameters of 0.02 mm to 1mm. The matrix contains lots of clay minerals. The displacement sense of right-lateral slip can be recognized from R1 and P.

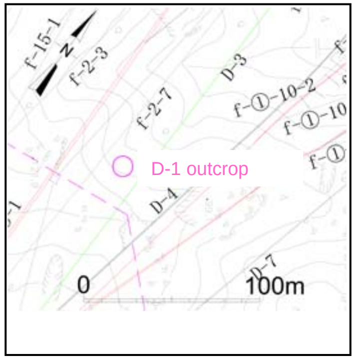
・Cataclasite 1
Consists of the brown-gray matrix of fine grain, as well as quartz, feldspar, aplite and cataclasite and that are sub-angular or semi-circular gravels with diameters of 0.1 mm to 8mm. The matrix contains lots of clay minerals and calcite. The displacement sense of right-lateral slip can be recognized from R1 and P.

・Cataclasite 2
Consists of the brown-gray of fine grain, as well as quartz, feldspar, cataclasite and aplite fragments and that are sub-angular or semi-circular gravels with diameters of 0.1 mm to 8mm. The matrix doesn't contain many clay minerals but it contains lots of calcite. The displacement sense of left-lateral slip can be recognized from R1 and P.

D-1 B14-2 109.16m_2 XZ方向

D-1 outcrop





Map of outcrop location

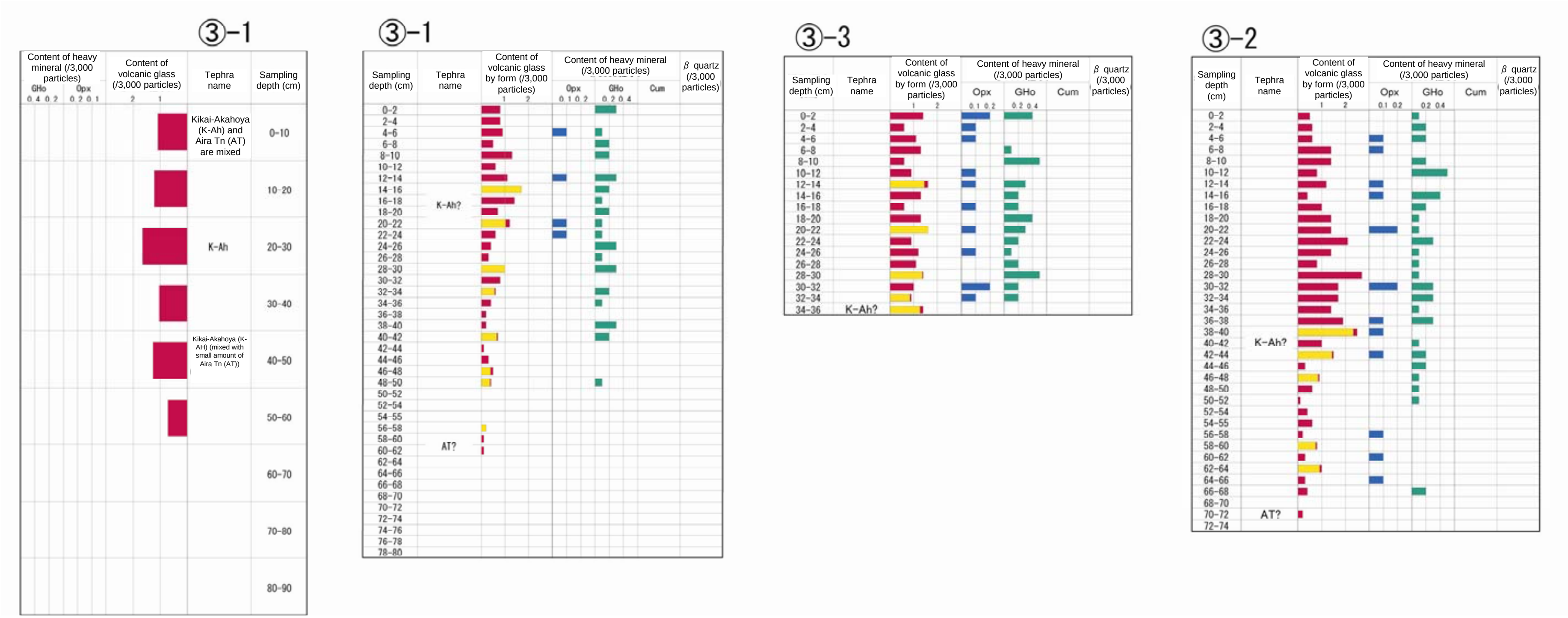
A: Humic sandy soil with gravel. Olive brown (2.5Y4/6)-dark brown (10YR3/4)
B: Gravel (colluvial soil). Ratio of gravel 70%
C: Silty sand with gravel. Bright brownish yellow (10YR6/6)-darkish yellow orange (10YR6/4)
D: Granite porphyry
E: Slightly fractured portion of granite porphyry (subject to alteration)
F: Aplite cataclasite
G: Slightly fractured portion of aplite (subject to alteration)
H: Unclear portion of texture due to strong weathering
① f: N16° E73° W Fault gouge (light brown clay: 2-5 mm wide)
② f: N38° E85° W
③ f: N22° E36° W Boundary between granite porphyry and aplite

Legend

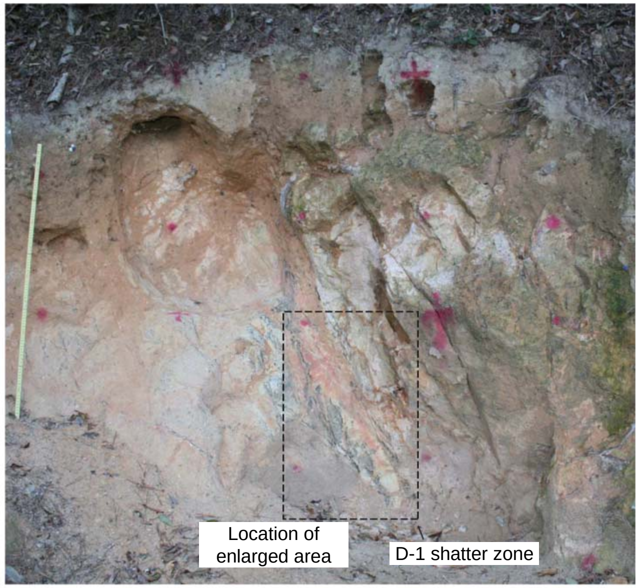
- Talus deposit
- Older fan deposit 2
- Granite porphyry
- Aplite
- Cataclasite
- Unclear portion of structure due to strong weathering
- Place for continual sampling of tephra

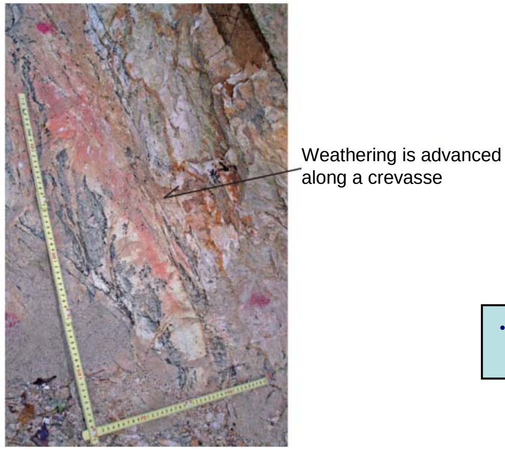
- The shatter zone has not displaced or deformed the stratum, which was deposited after Kikai-Akahoya (K-Ah) (about 7,300 years ago).

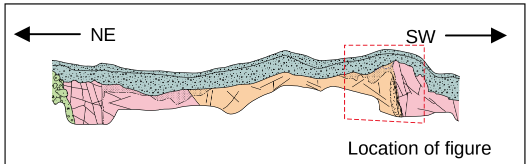
D-1 outcrop (result of tephra analysis)



Detailed observation of D-1 outcrop







Sketch of outcrop

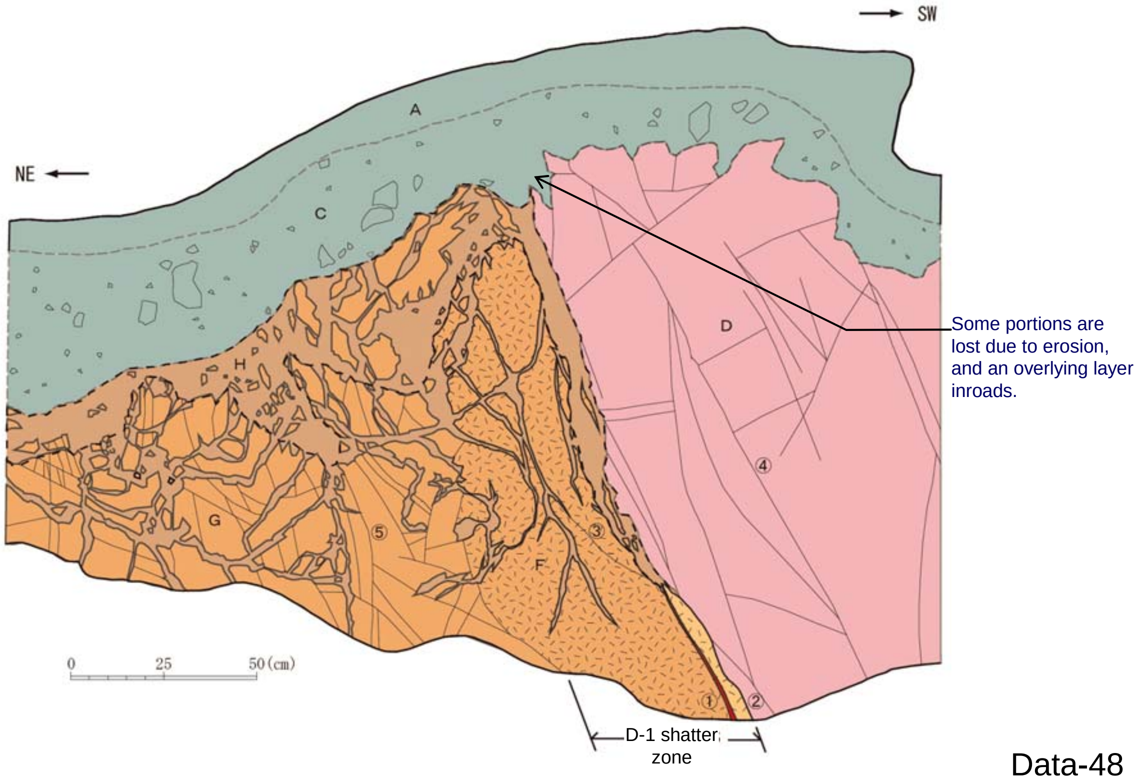
- Texture of gouge of the shatter zone is unclear, due to weathering in the upper part of rock mass.

Legend

- Talus deposit
- Aplite
- Granite porphyry
- Cataclasite
- Unclear portion of structure due to strong weathering

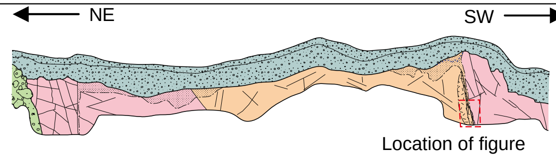
A: Humic silty sand. Brownish yellow (10YR5/2)
C: Silty sand with gravel. Darkish yellow orange (10YR6/4). Ratio of gravel: 10%
D: Granite porphyry. Slight yellow orange (7.5YR8/3)
F: Aplite cataclasite
G: Aplite (weathered and soft). Slight yellow orange (10YR8/4)
H: Aplite (highly weathered portion) sandy silt. Slight yellow orange (10YR8/4)-orange (7.5YR7/6)

① f: N28° E57° W	Fault gouge (light brown clay: 2-5 mm wide)
② f: N26° E66° W	Fault gouge (light brown clay: 0-1 mm wide)
③ j: N6° E63° W	Manganese adhered
④ j: N27° E66° W	
⑤ j: N28° E65° W	Manganese adhered



D-1 outcrop (observation of deformed structure) (vertical components)

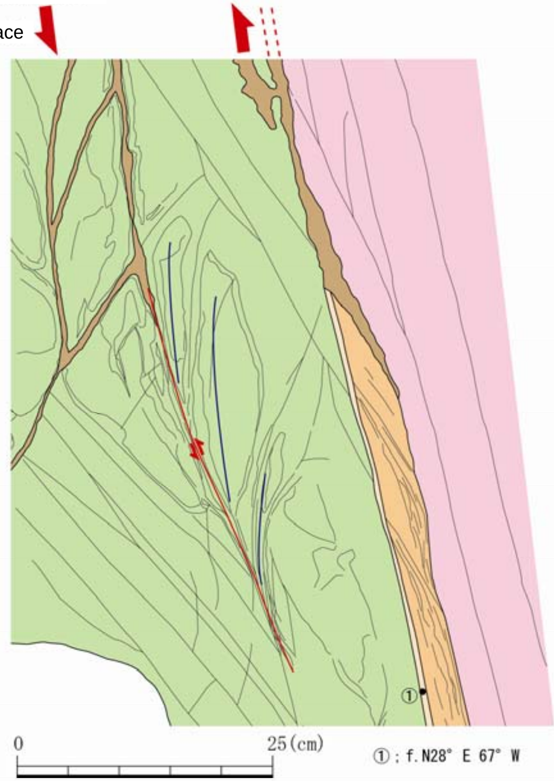
・In the sense of vertical displacement of cataclasite, reverse fault components with going up in the west and going down in the east are recognized.



Sketch of outcrop

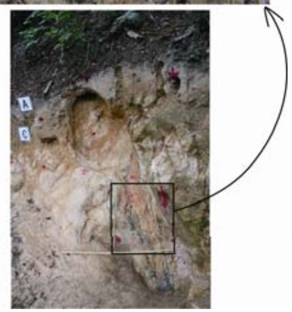
Result of observation of deformed structure 2

Sketch of wall surface



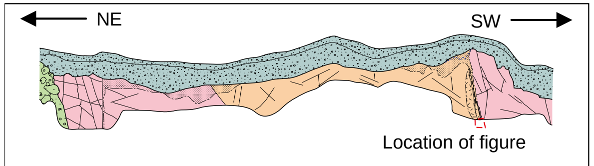
Clay (brown clay (inflow))		Fractured portion of sandy breccia (sandy-brecciated cataclasite)	
Fractured portion of clay (light brown gouge)		Slightly deformed-nondeformed granite porphyry	
Fractured portion of sandy breccia (foliated cataclasite)		P Shear	R1 Shear
		f. N16° E84° W	Strike and dip in shatter zone (declination uncorrected)

Photo of wall surface



D-1 outcrop (observation of deformed structure) (horizontal components)

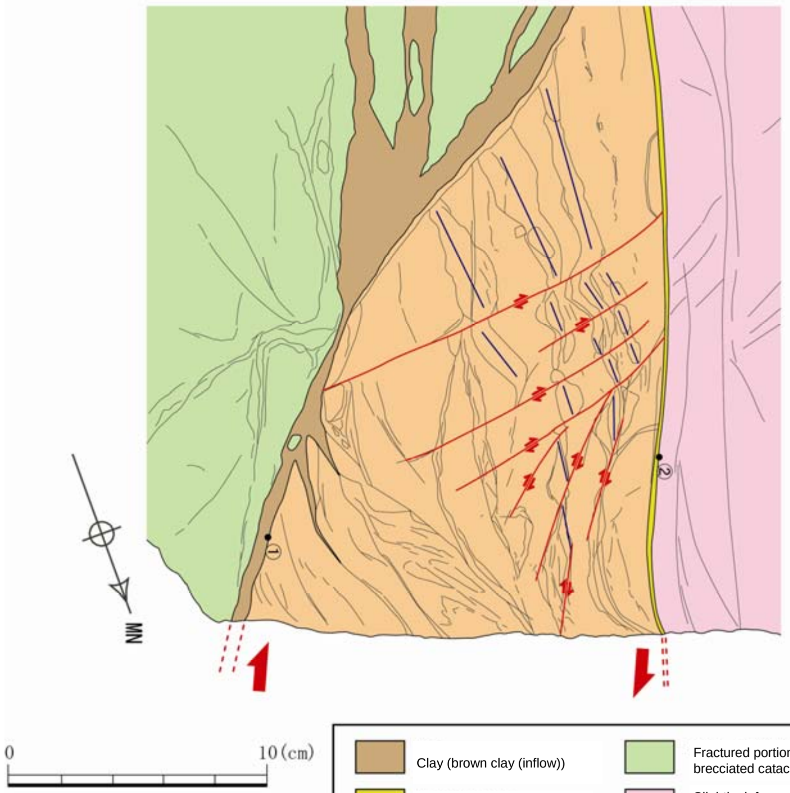
・The sense of horizontal displacement in cataclasite incorporates a component of right-lateral slip.



Sketch of outcrop

Result of observation of deformed structure 1

Sketch of wall surface



①; f. N32° E 75° NW
②; f. N20° E 58° W

Clay (brown clay (inflow))

Fractured portion of clay (light brown gouge)

Fractured portion of sandy breccia (foliated cataclasite)

Fractured portion of sandy breccia (sandy-brecciated cataclasite)

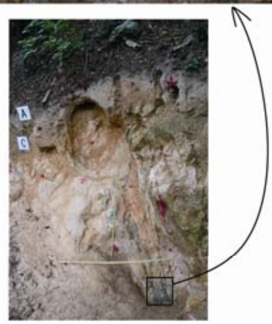
Slightly deformed-nondeformed granite porphyry

P Shear

R1 Shear

f. N16° E84° W Strike and dip in shatter zone (declination uncorrected)

Photo of batholith



[Displacement sense of shatter zone] Location of collecting thin section from D-1 outcrop

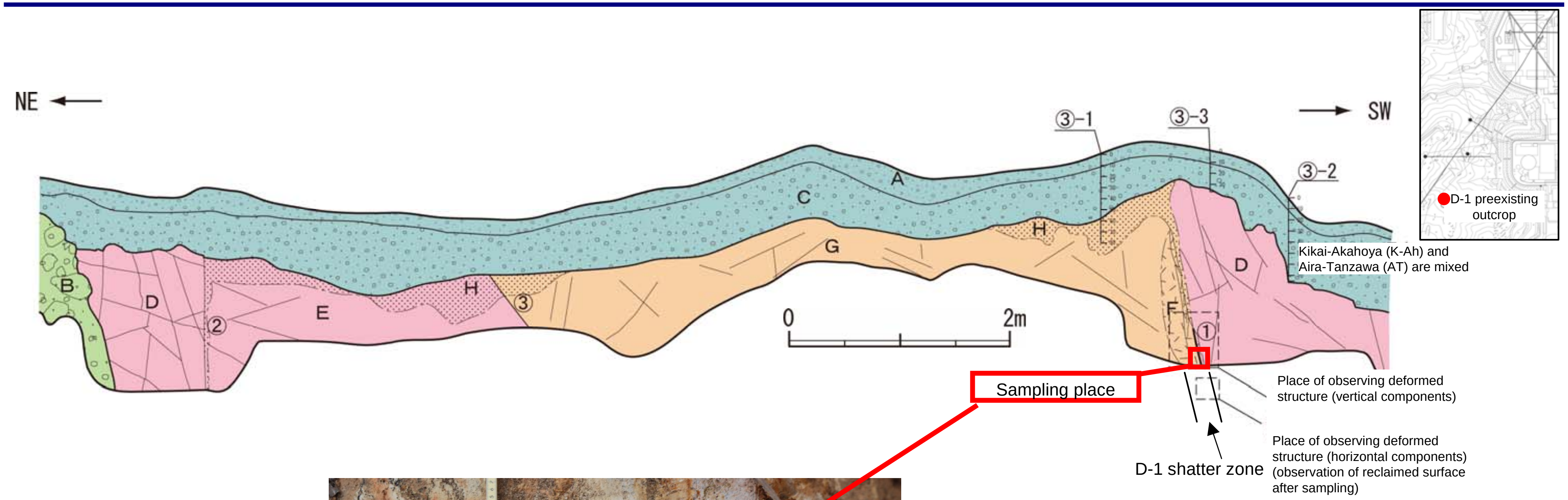
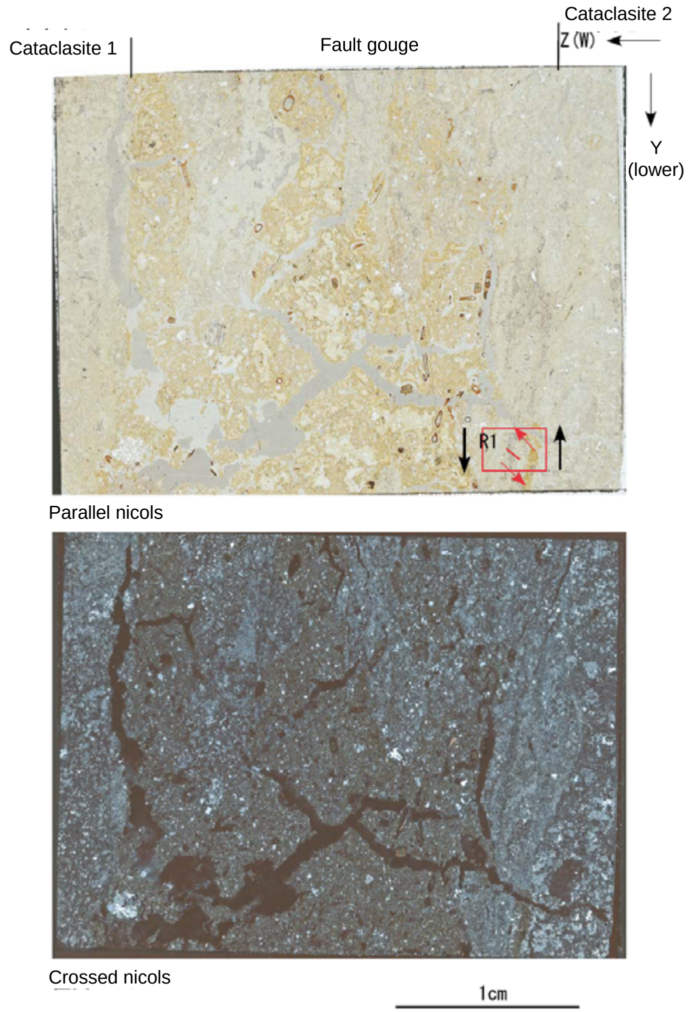


Photo of sampling place

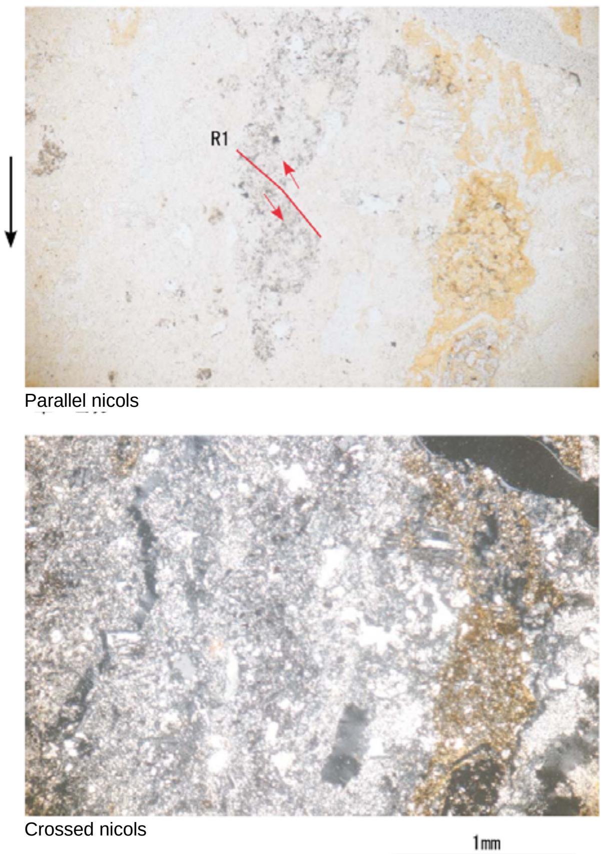
Legend

- Talus deposit
- Older fan deposit 2
- Granite porphyry
- Aplite
- Cataclasite
- Unclear portion of structure due to strong weathering
- Place for continual sampling of tephra

[Sense of displacement of shatter zone] Observation results of thin section from D-1 outcrop (vertical components)

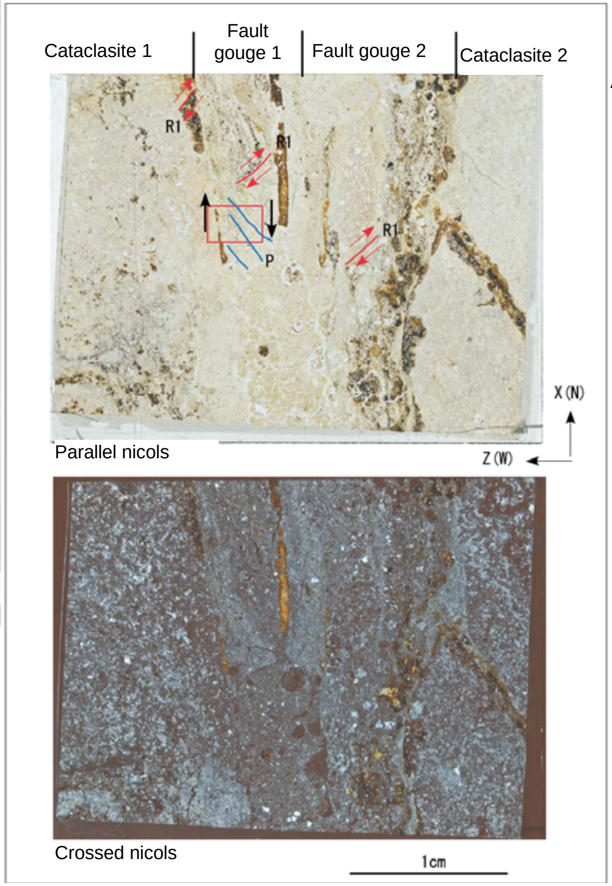


Area within red frame is enlarged

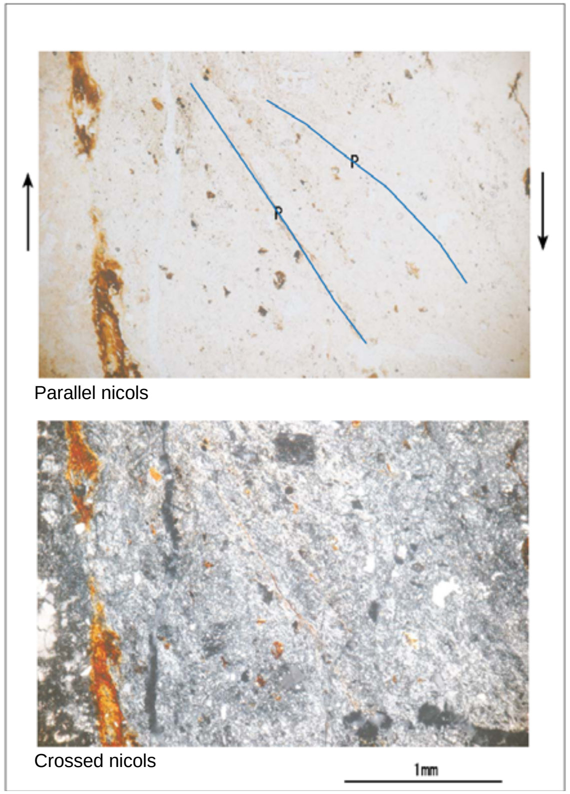


- Cataclasite 1
  Consists of the gray-white matrix of fine grain, as well as granite fragments, quartz, feldspar and cataclasite fragments that are sub-angular gravels with diameters of 0.1 to 2 mm. Contains less clay minerals.
- Fault gouge (last slip)
  Consists of the brown-gray matrix of fine grain, as well as quartz, feldspar and cataclasite fragments that are sub-angular or semi-circular gravels with diameters of 0.1 to 1 mm. Contains lots of clay minerals. The sense of displacement of normal fault can be recognized from R1.
- Cataclasite 2
  Consists of the gray-white matrix of fine grain, as well as granite fragments, quartz and feldspar fragments that are sub-angular gravels with diameters of 0.1 to 2 mm. Contains less clay minerals.

[Sense of displacement of shatter zone] Observation results of thin section from D-1 outcrop (horizontal components)



Area within red frame is enlarged



- Cataclasite 1
  Consists of the gray-white matrix of fine grain, as well as granite porphyry fragments, quartz and feldspar fragments that are sub-angular gravels with diameters of 0.1 to 2 mm. Contains less clay minerals.
- Fault gouge 1 (last slip)
  Consists of the brown-gray matrix of fine grain, as well as quartz, feldspar and cataclasite fragments that are sub-angular or semi-circular gravels with diameters of 0.1 to 1 mm. Contains lots of clay minerals. The displacement sense of right-lateral slip can be recognized from R1 and P.
- Fault gouge 2
  Consists of the brown-gray matrix of fine grain, as well as quartz, feldspar and cataclasite fragments that are sub-angular or semi-circular gravels with diameters of 0.1 to 2 mm. Ratio of fragments is higher than in fault gouge 1. Contains lots of clay minerals. The displacement sense of right-lateral slip can be recognized from R1.
- Cataclasite 2
  Consists of the gray-white matrix of fine grain, as well as granite porphyry fragments, quartz and feldspar fragments that are sub-angular gravels with diameters of 0.1 to 2 mm.

Photo of D-1 trench

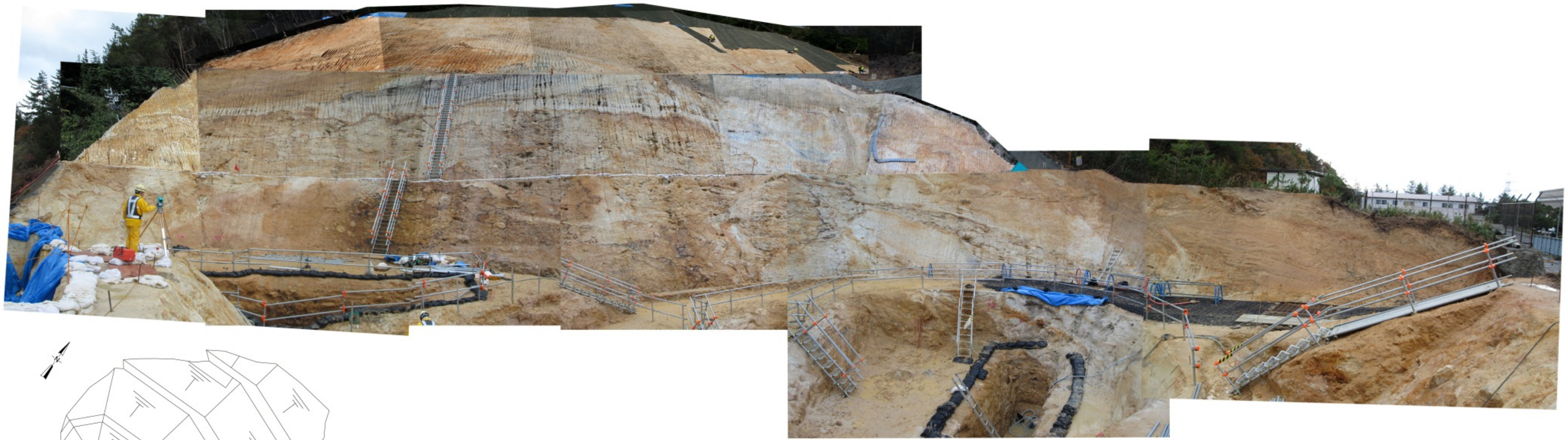
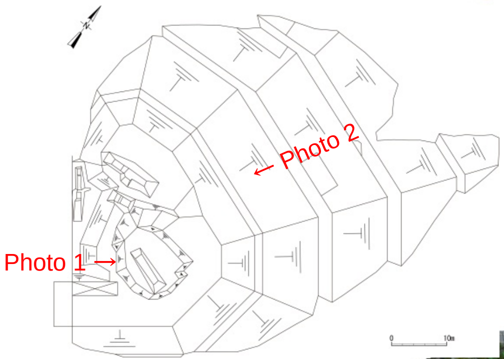


Photo 1

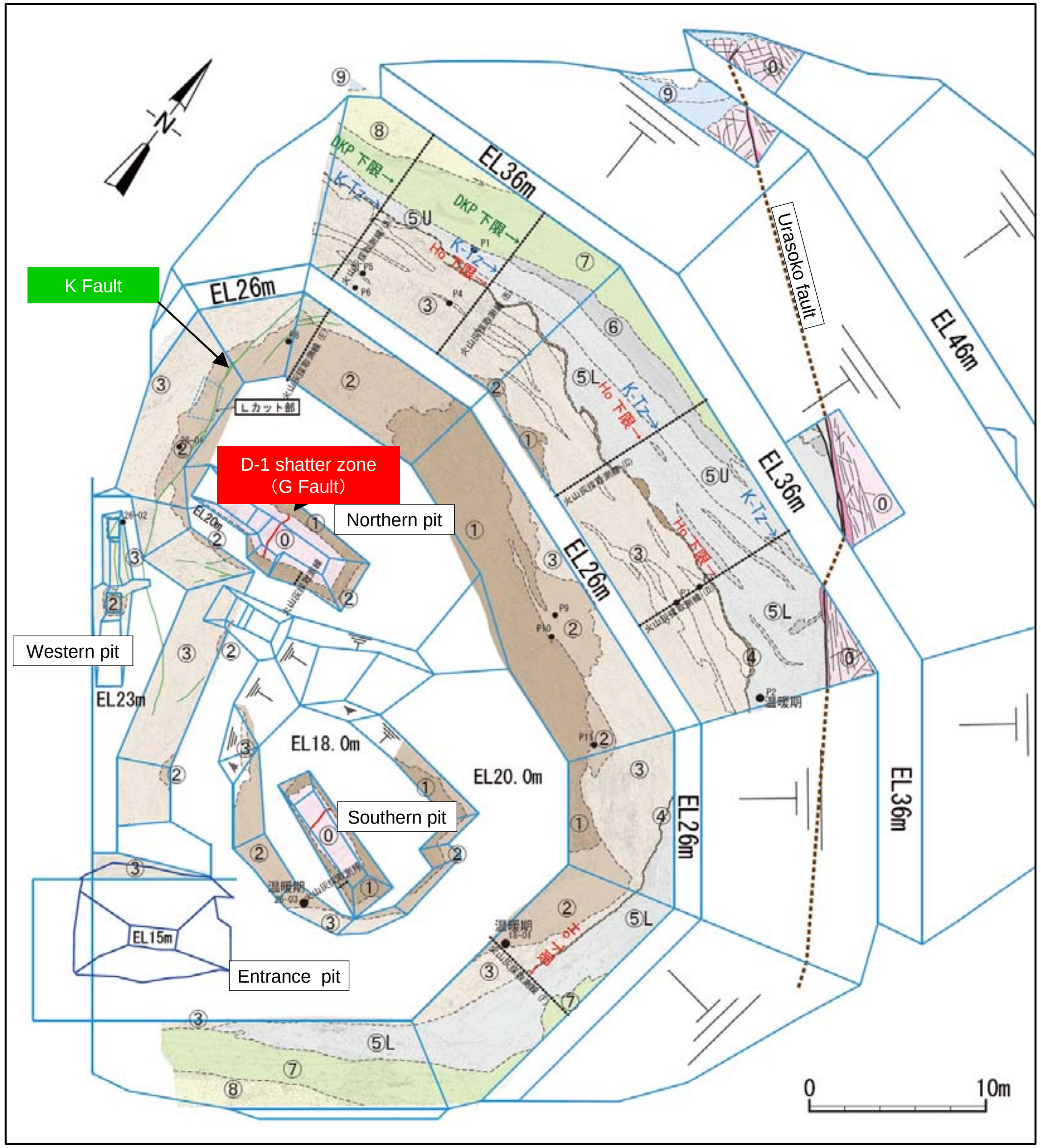


Trench shape diagram

Photo 2

Plan drawing of D-1 trench

Newly obtained data after February 5, 2013



- K Fault has displaced lower part of layer ③ but has not displaced upper part of layer ③ and layer ⑤ that is located above layer ③.

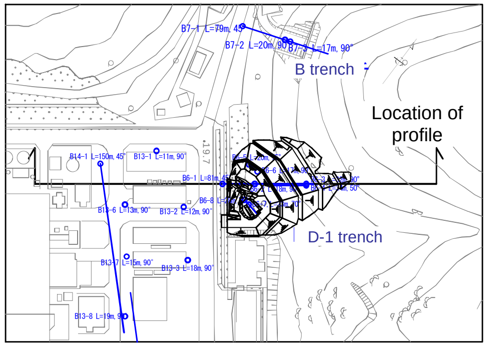
- A tephra consist of hornblende is recognized at lower part of layer ⑤.
- That tephra has a correlation with Mihama-tephra from refractive index and ingredient composition.
- Accordingly, the depositional age of lower part of layer⑤can be considered stage5e.

- K-fault was not been active at least in and after the Late Pleistocene (about 120,000-130,000 years ago).

Layer name		Color tone	Facies
Layer ⑨		Brown -darkish yellow brown	Sandy silt with gravel. Contact with lower layer in the horizontal unconformity surface.
Layer ⑧		Brown -yellow orange	Mainly composed of gravel. Matrix is silty sand. Stratification structure is partly seen. Contact with lower layer in the horizontal unconformity surface.
Layer ⑦		Brown -brownish gray	Sandy silt with gravel - Silty sand with gravel. Contact with lower layer in the horizontal unconformity surface.
Layer ⑥		Gray-dark gray	Humic sandy silt-silty sand Contains lots of wood chips. Contact with lower layer in the horizontal unconformity surface.
Layer ⑤	U (Upper part)	Ash gray -slight yellow orange	Mainly composed of silty gravel.
	L (Lower part)	Ash gray -slight yellow orange	Mainly composed of silty gravel. Silty gravel layer and silt layer present discontinuous alteration. Erode layer ③ and contact with it in the unconformity surface
Layer ③	Layer ④※	Brown	Mainly composed of oxidized gravel. Distributed just beneath unconformity surface with undulation and denudation.
		Slight yellow orange -orange	Mainly composed of gravel. Silt layer and sand layer occur in a lenticular and laminae form. Contact with unconformity surface denuding lower layer.
Layer ②		Darkish orange-ash gray	Sandy silt-silty sand that is massive structure and contains lots of decayed gravel
Layer ①		Darkish red brown -bright brownish yellow	Mainly composed of gravel. Insufficient sorting and very tight
Layer ⓪ Kojaku granite		Ash gray- Brown	Rock mass that constitutes basement. Consist of biotite granite, granite porphyry and aplite.

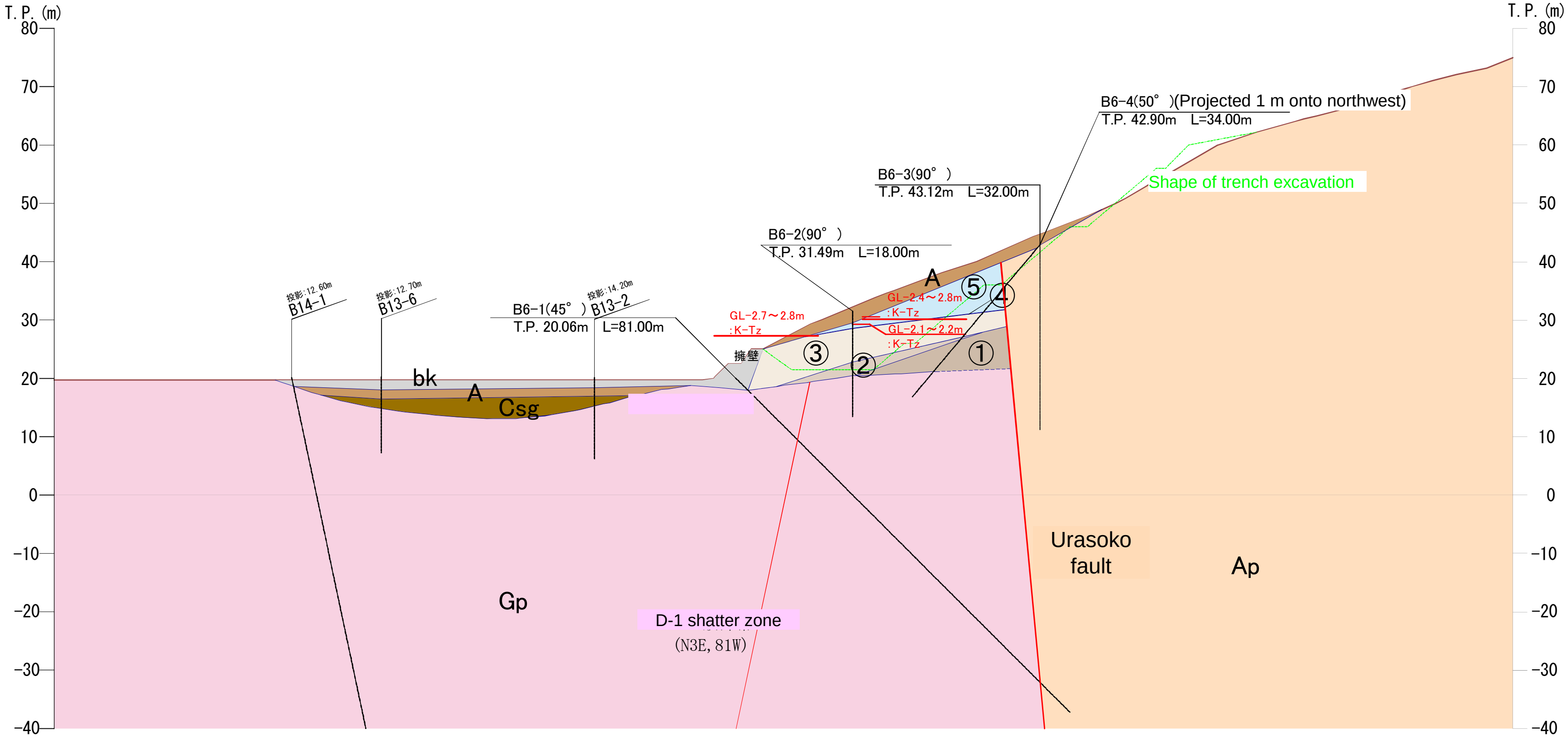
※ Oxidized zone of upper end of layer ③ located just beneath unconformity surface.

D-1 trench (geological profile)



Geological classification legend

- bk — Filling soil
- A — A layer: Alluvial lowland deposit, fan deposit and talus deposit (that may contain sand, gravel, silt, humus and humic matters)
- Csg — Csg layer: Fan deposit (that may contain gravel, coarse sand, medium sand and humus)
- Gp — Granite porphyry
- Ap — Aplite
- ⑤ — Layer ⑤: Mainly composed of silty gravel. Silty gravel layer and silt layer present discontinuous alteration. Contains Kikai-Kuzuhara (K-Tz) tephra horizon. Produces pollen in warm period from the bottom.
- ③ ④ — Layer ③: Mainly composed of gravel. Silt layer and sand layer occur in a lenticular and laminae form.
  Layer ④: oxidized zone
- ② — Layer ②: Mainly composed of sandy silt with gravel-silty sand that is massive structure.
- ① — Layer ①: Mainly composed of gravel with characteristics of insufficient sorting and very tight
- shatter zone (red line)
- Geological boundary (blue line)



H:V=1:1

Newly obtained data after February 5, 2013

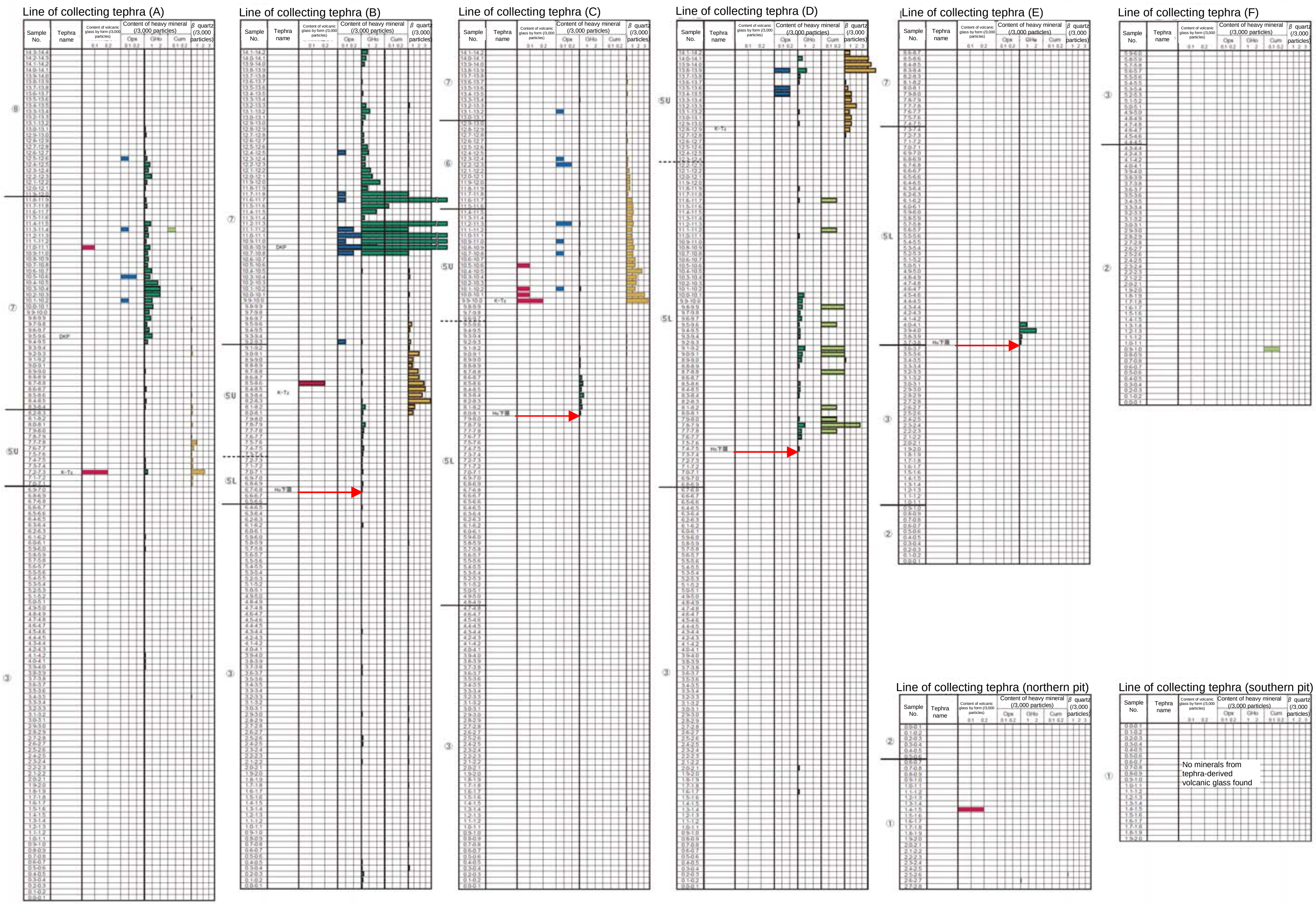
Geologic stratigraphic sequence of D-1 trench

Layer name		Color tone	Facies	Chronometric indicator: Tephra	Chronometric indicator: Pollen	depositional age
Layer ⑨		Brown -darkish yellow brown	Sandy silt with gravel. Contact with lower layer in the horizontal unconformity surface.	–	–	After stage 4
Layer ⑧		Brown -yellow orange	Mainly composed of gravel. Matrix is silty sand. Stratification structure is partly seen. Contact with lower layer in the horizontal unconformity surface.	–	–	After stage 4
Layer ⑦		Brown -brownish gray	Sandy silt with gravel - Silty sand with gravel. Contact with lower layer in the horizontal unconformity surface.	Including DKP	–	After stage 4
Layer ⑥		Gray-dark gray	Humic sandy silt-silty sand Contains lots of wood chips. Contact with lower layer in the horizontal unconformity surface.	–	–	Stage 5b
Layer ⑤	U (Upper part)	Ash gray -slight yellow orange	Mainly composed of silty gravel.	Including K-Tz	–	Stage 5c
Layer ⑤	L (Lower part)	Ash gray -slight yellow orange	Mainly composed of silty gravel. Silty gravel layer and silt layer present discontinuous alteration. Erode layer③ and contact with it in the unconformity surface	Including Mihama-tephra		Stage 5e
Layer ③	Layer ④※	Brown	Mainly composed of oxidized gravel. Distributed just beneath unconformity surface with undulation and denudation.	–	–	Stage 6
Layer ③		Slight yellow orange -orange	Mainly composed of gravel. Silt layer and sand layer occur in a lenticular and laminae form. Contact with unconformity surface denuding lower layer.	–	–	Stage 6
Layer ②		Darkish orange-ash gray	Sandy silt-silty sand that is massive structure and contains lots of decayed gravel	–		Stage 7
Layer ①		Darkish red brown -bright brownish yellow	Mainly composed of gravel. Insufficient sorting and very tight	–	–	Before stage 7
⓪ Kojaku granite		Ash gray- Brown	Rock mass that constitutes basement. Consist of biotite granite, granite porphyry and aplite.	–	–	Late Cretaceous -Paleogene

※ Oxidized zone of upper end of layer ③ located just beneath unconformity surface.

Newly obtained data after February 5, 2013

D-1 trench (result of tephra analysis)



Refractive index and main ingredient analysis

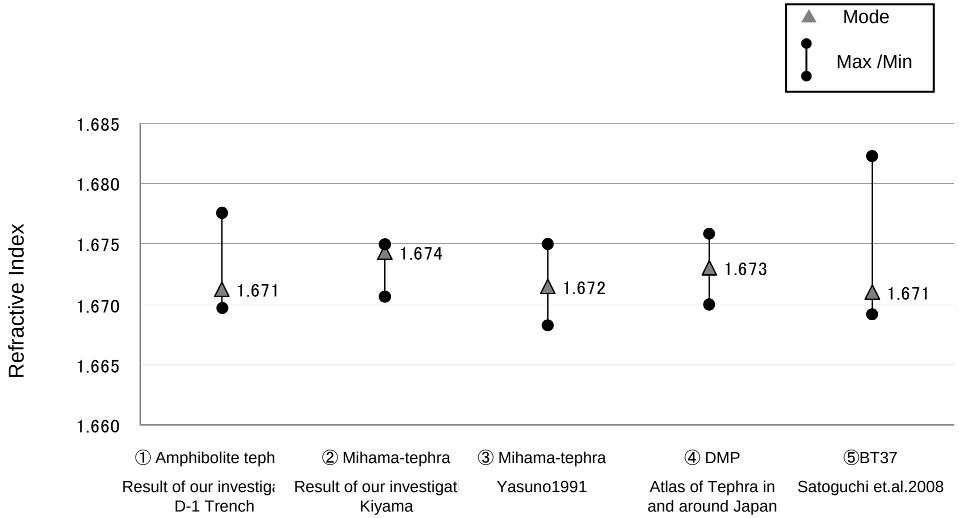
Newly obtained data after February 5, 2013

・Refractive index of hornblende tephra that is detected from lower part of layer⑤ beneath K-Tz ash fall layer is 1.670-1.678.

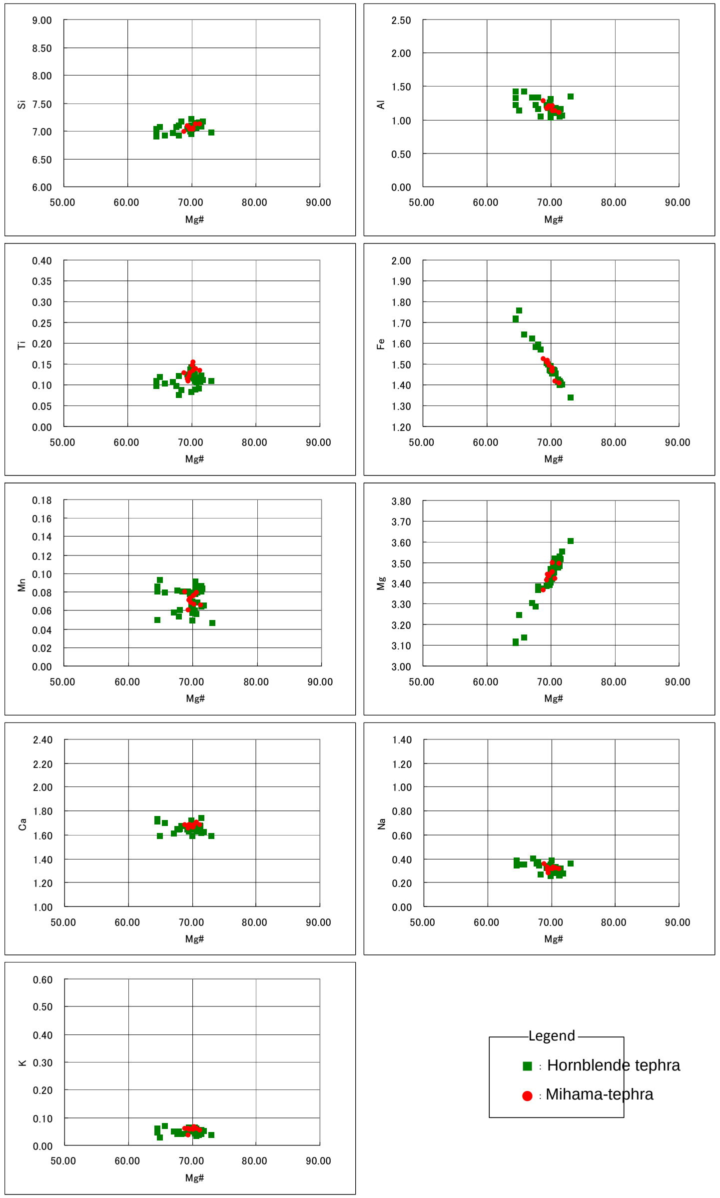
・From the data of refractive index, there is a possibility that the hornblende tephra has a correlation with the following three tephras:
- Mihama-tephra (located in lower part of median terrace marine deposit beneath SK (Sanbe-Kisuki, 110-115ka [Atlas of Tephra in and around Japan])[Yasuno1991])
- DMP (Daisen-Matsue, <130ka [Atlas of Tephra in and around Japan])
- BT37 (Lake Biwa-Takasima oki boring, 127.6ka [Nagahasi, et al.])

・The main ingredient component of the hornblende tephra is almost same as that of Mihama-tephra, which occurs around power station.

・Because a hornblende tephra of lower part of layer⑤ has a correlation with Mihama-tephra, the depositional age of lower part of layer⑤ can be considered stage5e.



Comparison of Refractive Index



Comparison of main ingredient component between hornblende tephra and Mihama-tephra

（参考文献）

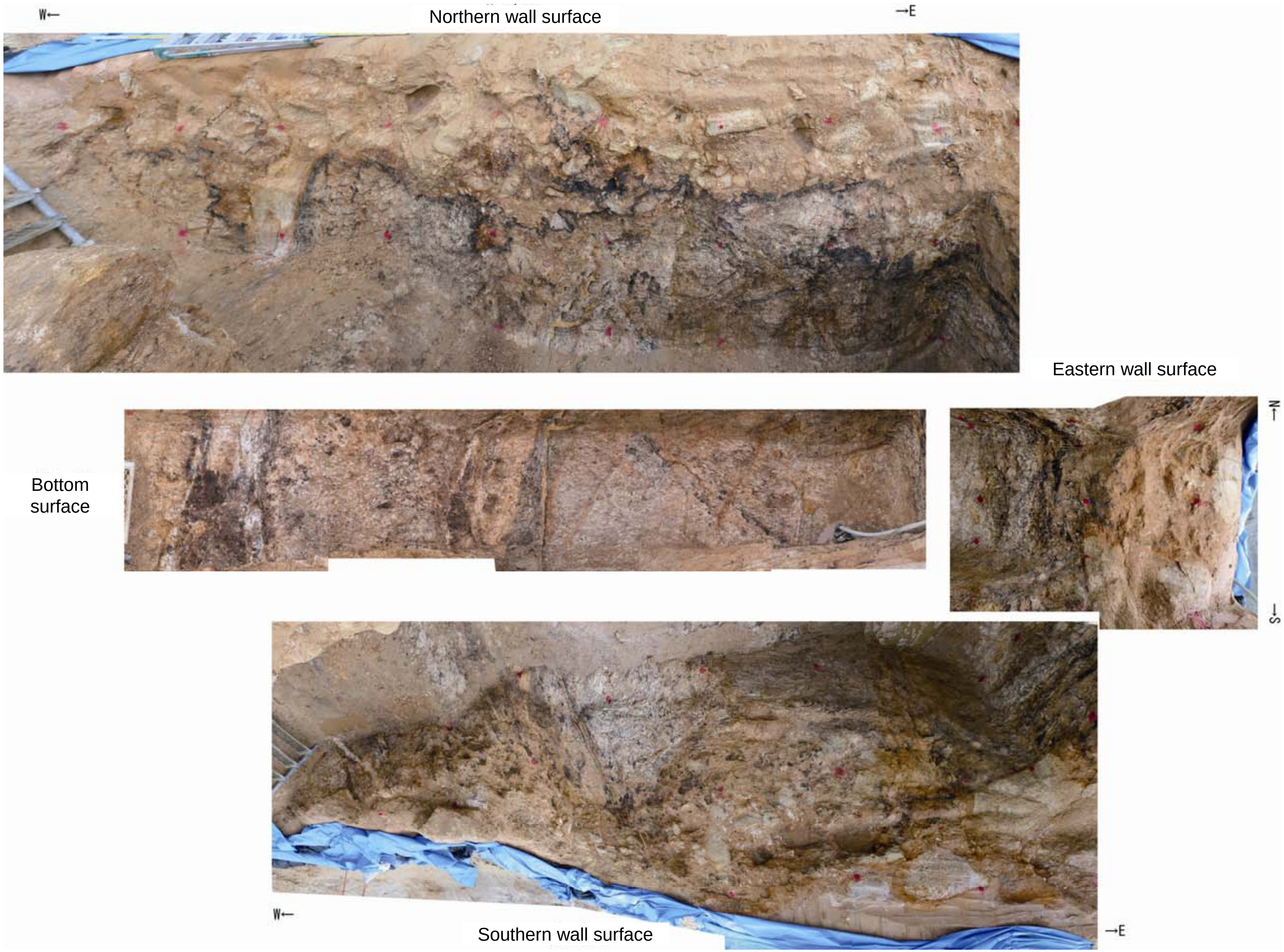
・Yasuno. T, 1991, Discovery of Molluscan Fossils and a Tephra Layer from the Late Pleistocene Kiyama Formation in West of Fukui Prefecture, Central Japan, Bull.Fukui Mus. Nat.Hist., No.38:9-14

・Satoguchi. Y, et.al., 2008, The Middle Pleistocene to Holocene tephrostratigraphy of the Takashima-oki core from Lake Biwa, central Japan, Journal of Geosciences, Osaka City University, Vol.51, Art. 6, p.47-58

・Machida. H, and Arai. F, 2003, Atlas of Tephra in and around Japan. Univ. Tokyo Press, Tokyo

・Nagahasi. Y, et al., 2004, 近畿地方および八ヶ岳山麓における過去43万年間の広域テフラの層序と編年 ーEDS分析による火山ガラス片の主要成分化学組成ー, 第四紀研究, 43, 15-35

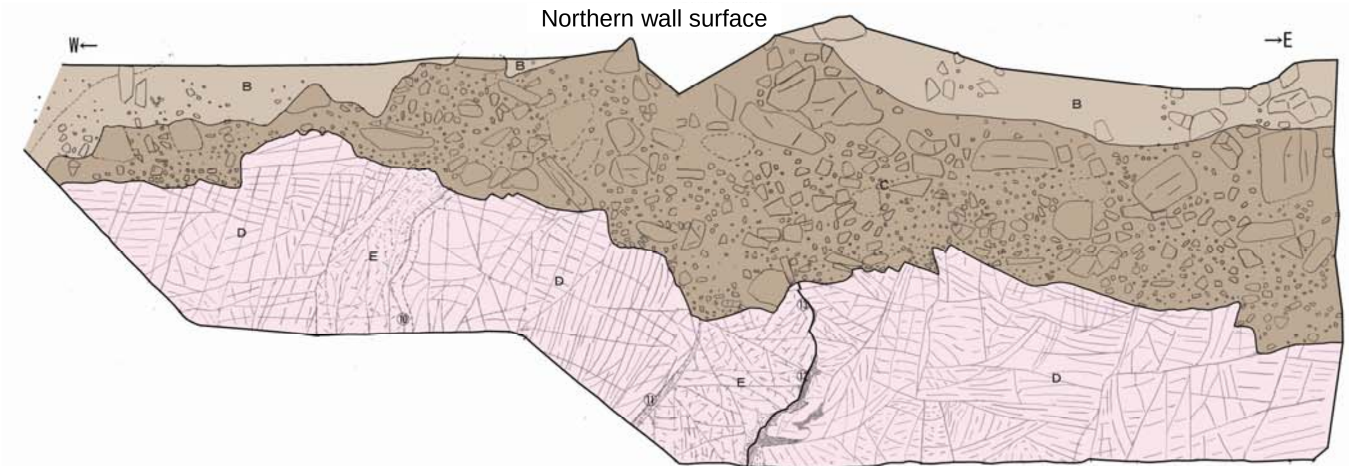
D-1 trench (photo of northern pit)

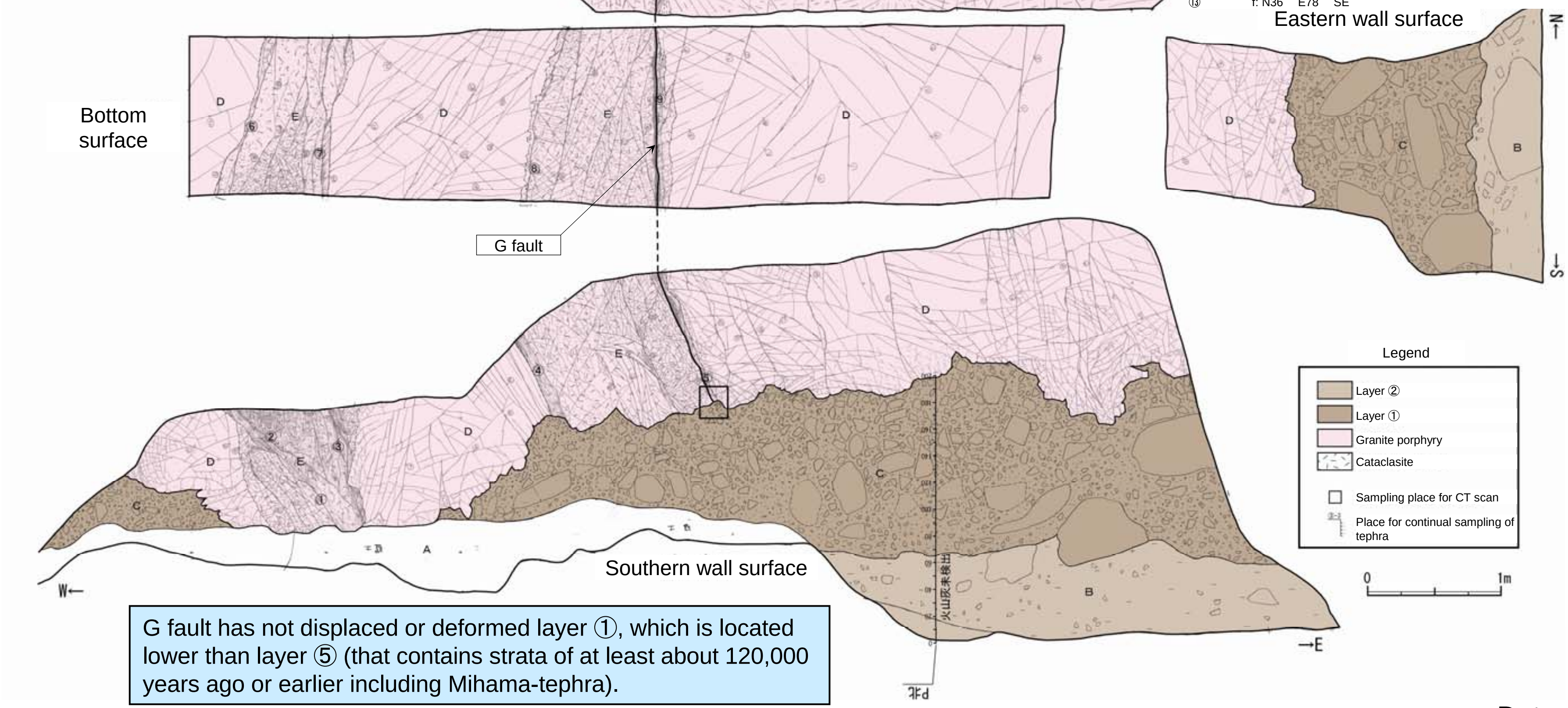


D-1 trench (sketch of northern pit)

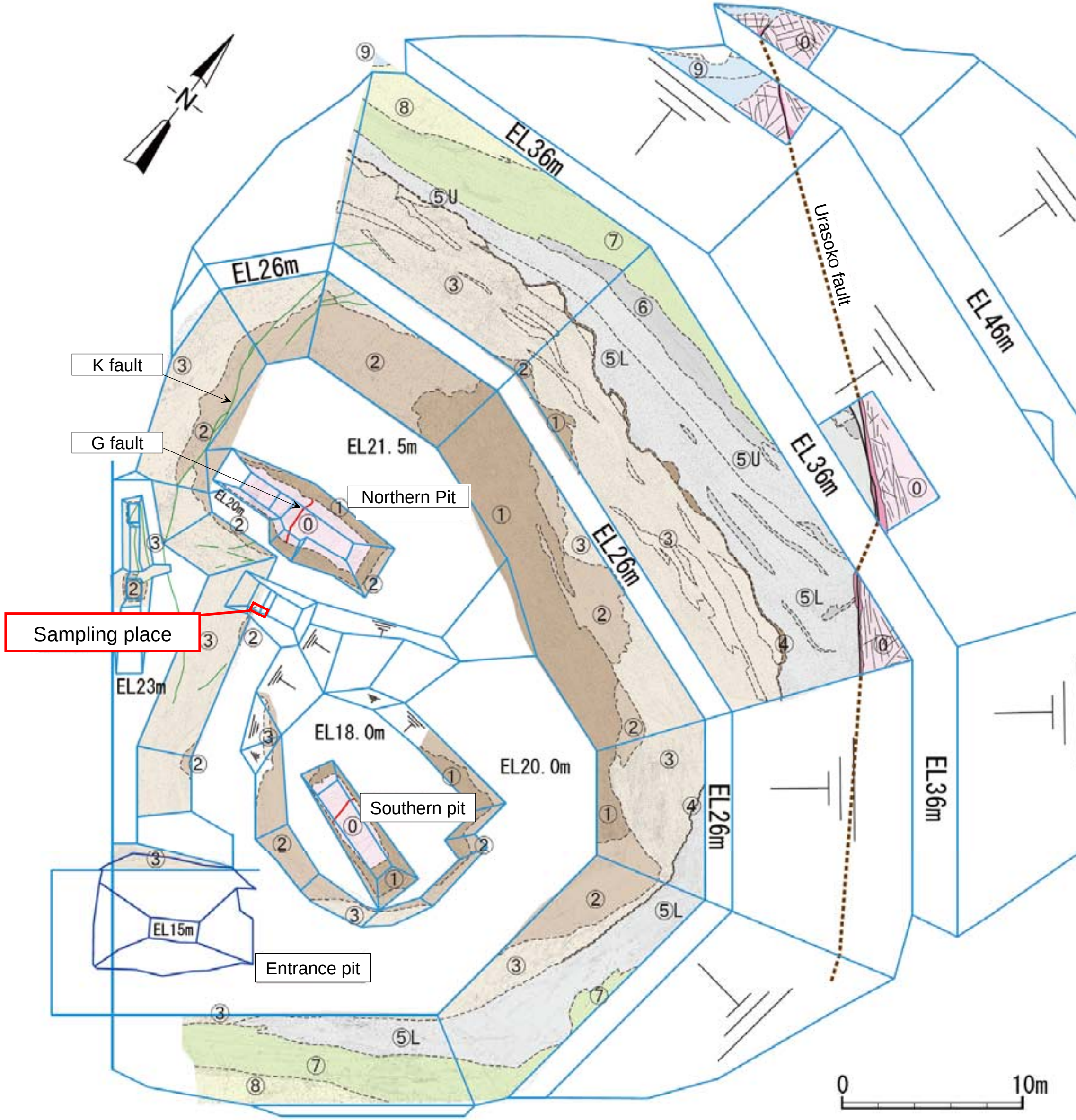
A: Embankment
B: Silt and clay with gravel and sand: Orange (7.5YR6/6). Mainly composed of silt and clay. Mainly composed of gravel with diameters of 5 cm or smaller. Contains boulder with diameters of 10-80 cm near matrix.
C: Sand gravel: orange (7.5YR7/6). Ratio of gravel: 30-60%. Mainly composed of gravel with diameters of 20 cm or smaller. Very poor sorting. Matrix is mainly composed of fine sand and coarse sand, and partly mixed with silt in upper part.
D: Granite porphyry: slight yellow orange (7.5YR8/3). Weathered entirely (significantly in upper end) and relatively large number of cracks.
E: Granite porphyry cataclasite: Generally brecciated and sometimes include granule with silt. Silty condition with granule around fault.

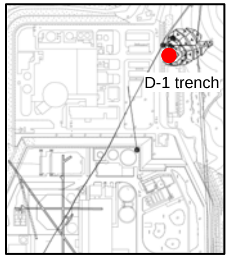
① f: N21° E63° W
② j: N7° E53° W
③ f: N2° E76° W Fault gouge (ash gray clay: 1 mm wide)
④ f: N12° E64° W Fault gouge in bottom (yellowish gray clay: 15 mm or smaller wide)
⑤ f: N6° E73° W Fault gouge (yellow orange clay: 8 mm wide)
⑥ f: N30° E54° NW
⑦ f: N16° E72° W Fault gouge (clay: 10 mm wide)
⑧ f: N27° E54° NW Fault gouge (reddish brown clay: 1-5 mm wide)
⑨ f: N8° E67° W Fault gouge (yellow orange clay: 10-50 mm wide)
⑩ f: N30° E76° SE
⑪ f: N50° E76° NW (Fractured portion of silt-sand like layer: 30-60 mm wide)
⑫ f: NS50° W
⑬ f: N36° E78° SE





[Displacement sense of shatter zone] Location of collecting thin section from G fault in the south of northern pit of D-1 trench

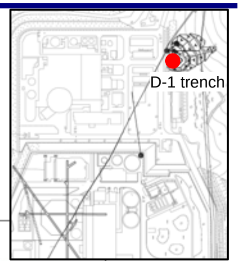




Sampling place

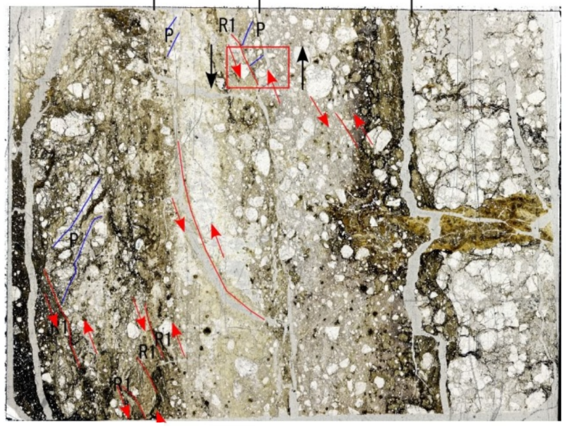
Photo of sampling place

[Displacement sense of shatter zone] Observation results of thin section from G fault in the south of northern pit of D-1 trench (vertical components)



D-1 trench YZ direction

10cm

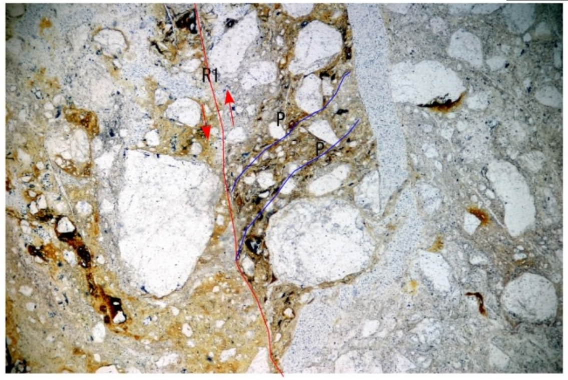


Parallel nicols

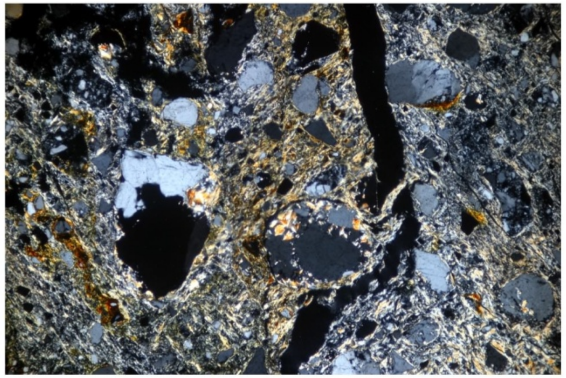
Crossed nicols

1cm

Area within red frame is enlarged



Parallel nicols

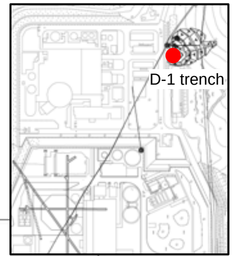


Crossed nicols

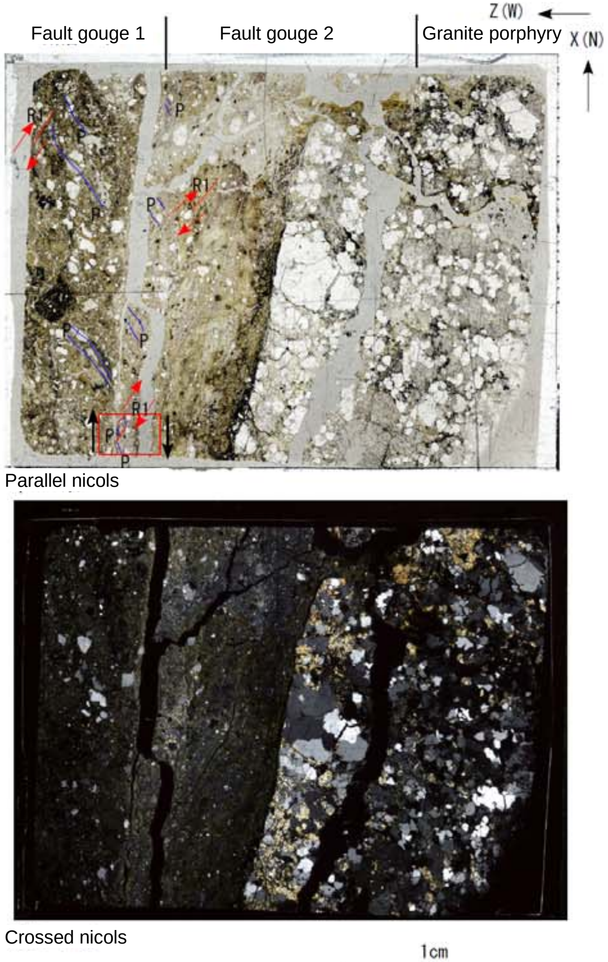
1mm

- Cataclasite
  Consists of the brown-gray matrix of fine grain, as well as quartz, feldspar and cataclasite fragments that are sub-angular or semi-circular gravels with diameters of 0.1 to 3 mm. The matrix contains less clay minerals. The displacement sense of normal fault can be recognized from R1 and P.
- Fault gouge 1 (last slip)
  Consists of the brown-gray matrix of fine grain, as well as quartz, feldspar and cataclasite fragments that are semi-circular or sub-angular gravels with diameters of 0.1 to 10 mm. The matrix contains lots of clay minerals. The displacement sense of normal fault can be recognized from R1 and P.
- Fault gouge 2
  Consists of the brown-gray matrix of fine grain, as well as quartz, feldspar and cataclasite fragments that are semi-circular or sub-angular gravels with diameters of 0.1 to 2 mm. Ratio of fragments is lower than in fault gouge 1. The matrix contains lots of clay minerals. The displacement sense of unclear normal fault can be recognized from R1.
- Granite porphyry
  Consists of granite porphyry, quartz and feldspar fragments with diameters of 0.1 to 2 mm.

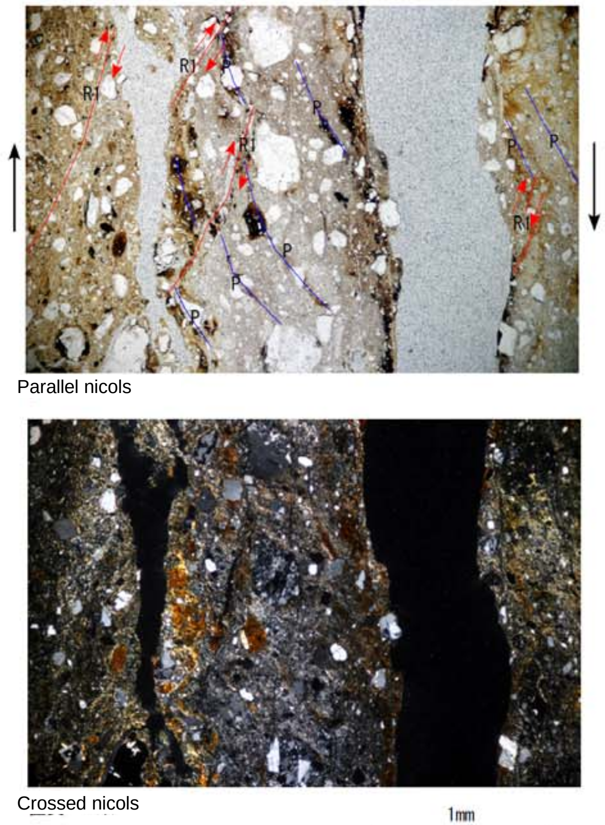
[Displacement sense of shatter zone] Observation results of thin section from G fault in the south of northern pit of D-1 trench (horizontal components)



D-1 trench XZ direction



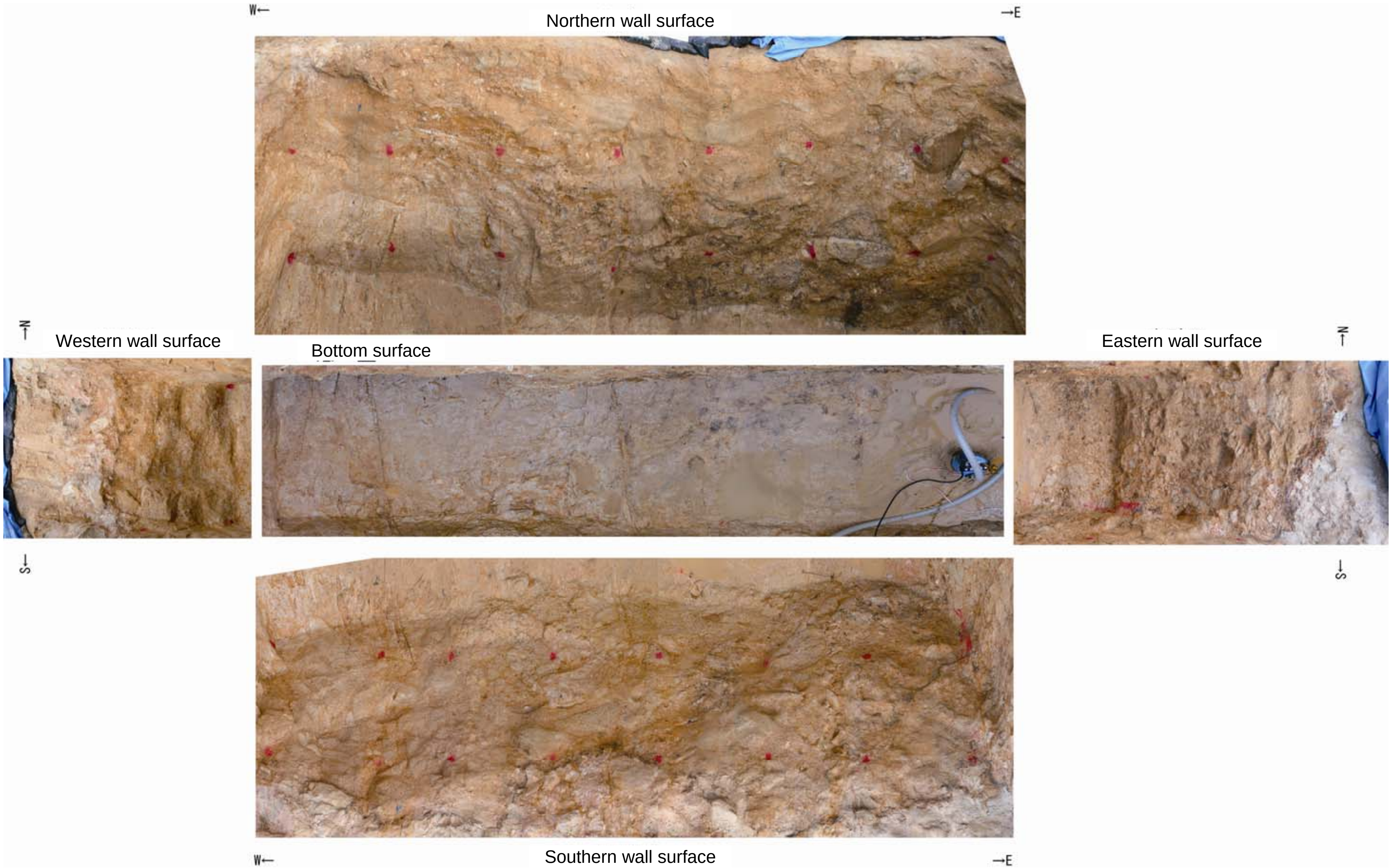
Area within red frame is enlarged



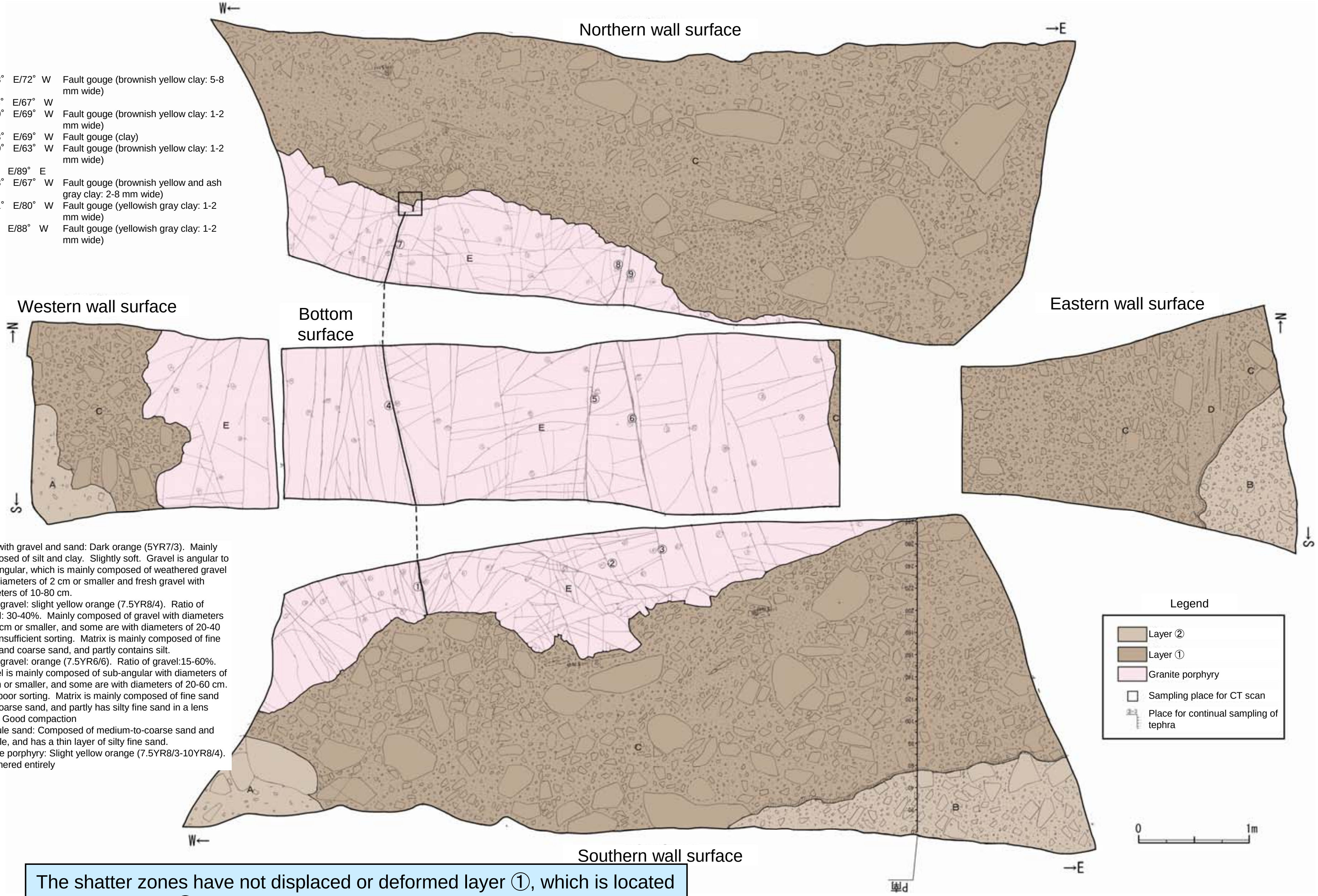
10cm

- Fault gouge 1
  Consists of the brown-gray matrix of fine grain, as well as quartz, feldspar and cataclasite fragments that are sub-angular or semi-circular gravels with diameters of 0.1 to 3 mm. The matrix contains lots of clay minerals. The displacement sense of right-lateral slip can be recognized from R1 and P.
- Fault gouge 2 (last slip)
  Consists of the brown-gray matrix of fine grain, as well as quartz, feldspar and cataclasite fragments that are semi-circular or sub-angular gravels with diameters of 0.1 to 2 mm. Ratio of fragments is lower than in fault gouge 1. The matrix contains lots of clay minerals. The displacement sense of right-lateral slip can be recognized from R1 and P.
- Granite porphyry
  Consists of granite porphyry, quartz and feldspar fragments with diameters of 0.1 to 2 mm.

D-1 trench (photo of southern pit)



D-1 trench (sketch of southern pit)



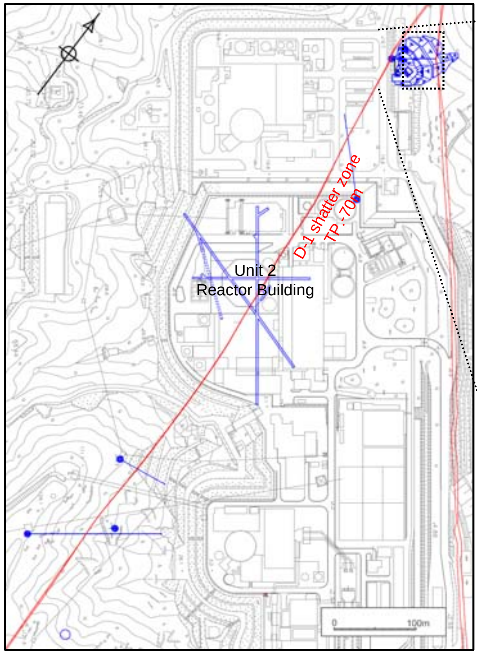
① f: N13° E/72° W Fault gouge (brownish yellow clay: 5-8 mm wide)
② j: N24° E/67° W
③ f: N10° E/69° W Fault gouge (brownish yellow clay: 1-2 mm wide)
④ f: N13° E/69° W Fault gouge (clay)
⑤ f: N20° E/63° W Fault gouge (brownish yellow clay: 1-2 mm wide)
⑥ f: N9° E/89° E
⑦ f: N13° E/67° W Fault gouge (brownish yellow and ash gray clay: 2-8 mm wide)
⑧ f: N21° E/80° W Fault gouge (yellowish gray clay: 1-2 mm wide)
⑨ f: N7° E/88° W Fault gouge (yellowish gray clay: 1-2 mm wide)

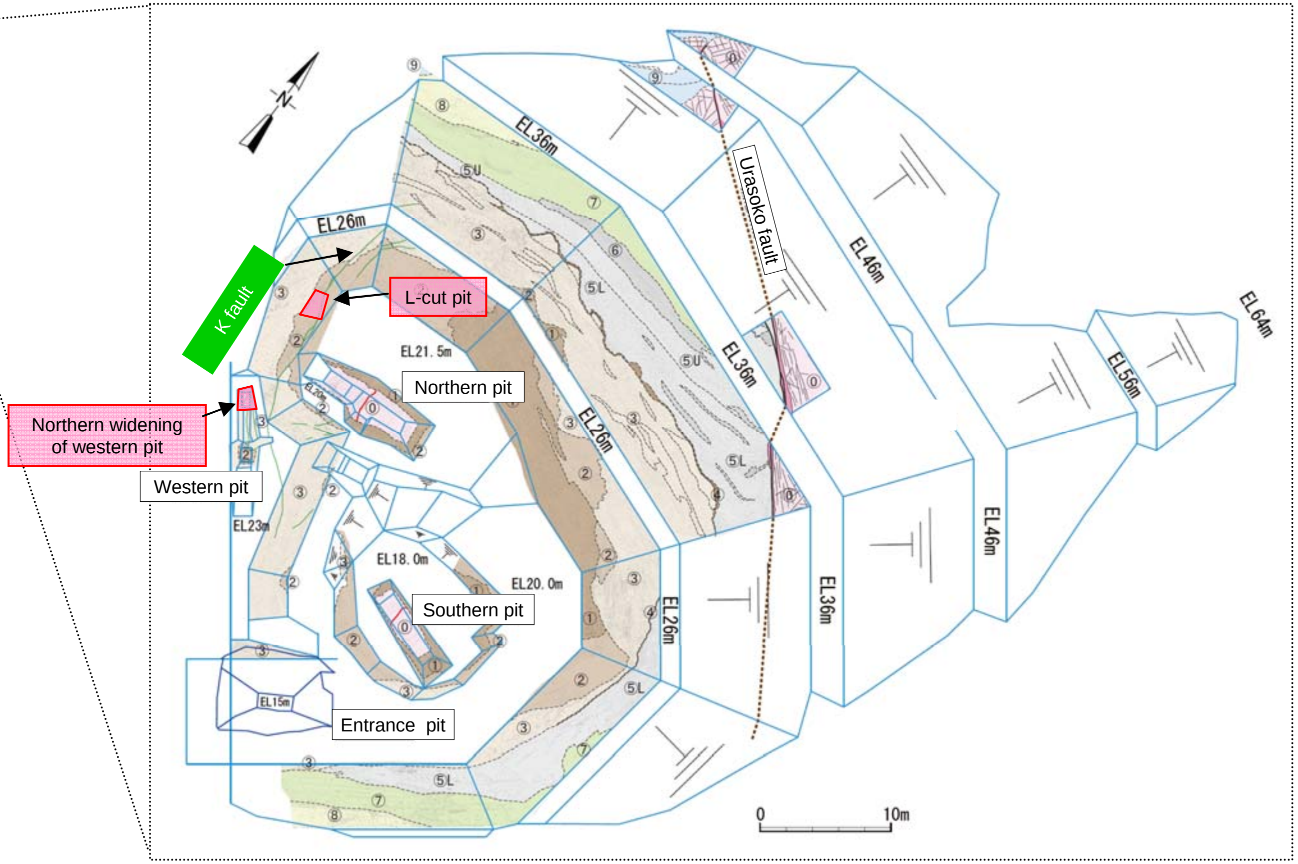
A: Clay with gravel and sand: Dark orange (5YR7/3). Mainly composed of silt and clay. Slightly soft. Gravel is angular to sub-angular, which is mainly composed of weathered gravel with diameters of 2 cm or smaller and fresh gravel with diameters of 10-80 cm.
B: Sand gravel: slight yellow orange (7.5YR8/4). Ratio of gravel: 30-40%. Mainly composed of gravel with diameters of 20 cm or smaller, and some are with diameters of 20-40 cm. Insufficient sorting. Matrix is mainly composed of fine sand and coarse sand, and partly contains silt.
C: Sand gravel: orange (7.5YR6/6). Ratio of gravel:15-60%. Gravel is mainly composed of sub-angular with diameters of 20 cm or smaller, and some are with diameters of 20-60 cm. Very poor sorting. Matrix is mainly composed of fine sand and coarse sand, and partly has silty fine sand in a lens form. Good compaction
D: Granule sand: Composed of medium-to-coarse sand and granule, and has a thin layer of silty fine sand.
E: Granite porphyry: Slight yellow orange (7.5YR8/3-10YR8/4). Weathered entirely

The shatter zones have not displaced or deformed layer ①, which is located lower than layer ⑤ (that contains strata of at least 120,000 years ago or earlier including Mihama-tephra).

Evaluation on continuity of K fault

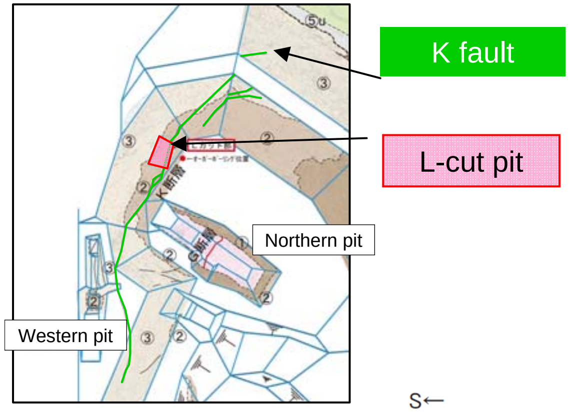
Newly obtained data after February 5, 2013

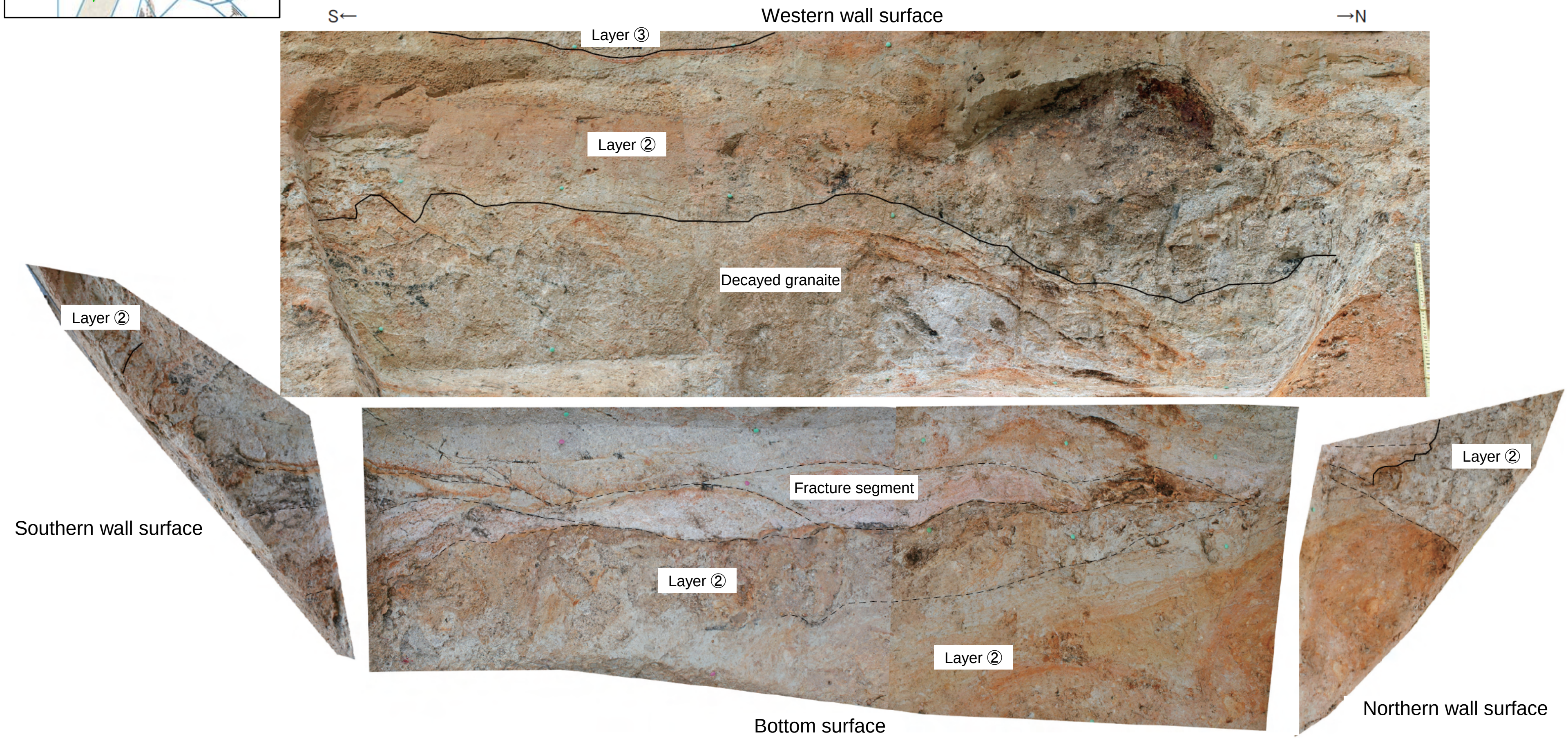




- At the K fault, a reverse fault, which is located between basement rock and deposit, can be recognized from observation of L-cut pit and northern widening of western pit.
- It can be recognized that fault strike is a direction of N-S in L-cut pit but it changes to a direction NNW-SSE in northern widening of western pit. It is suggested that the K fault does not extend to the direction of Unit 2 rector building.
- Additional drilling and pit investigation are undergoing now. To study continuity and cause of K fault, additional data is being obtained.

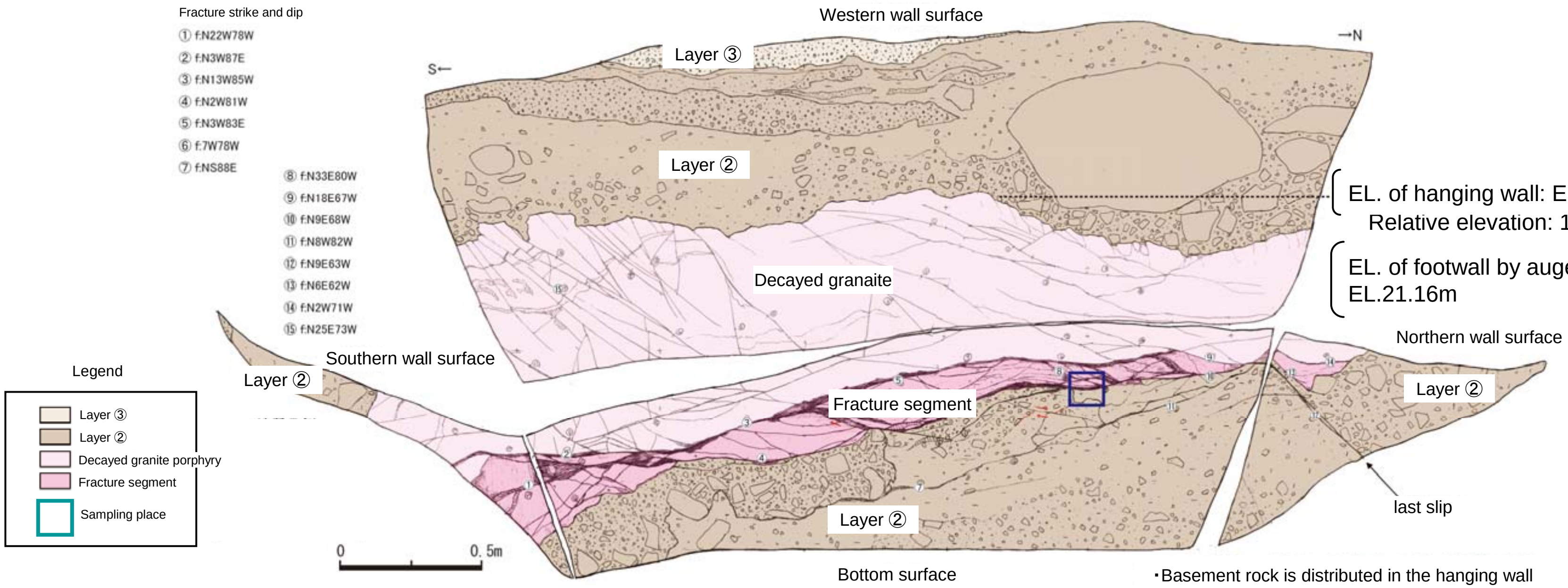
Photographs of L-cut pit



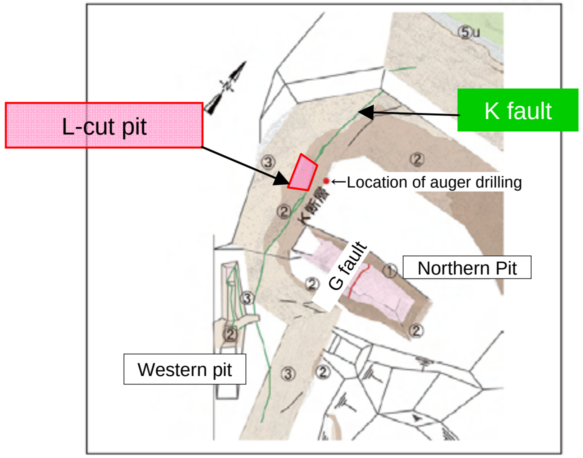


Sketch of L-cut pit

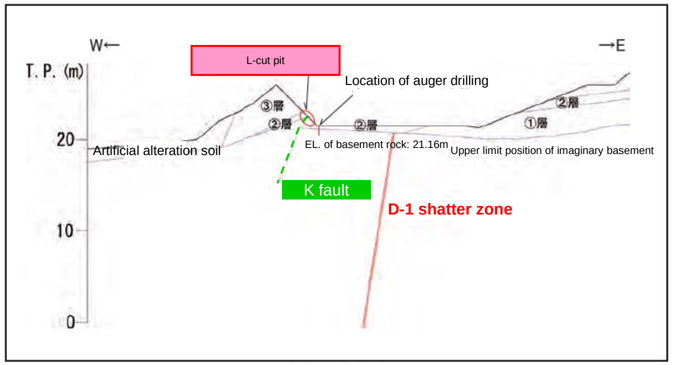
Newly obtained data after February 5, 2013



・Basement rock is distributed in the hanging wall of the shear plane, deposit is distributed in the footwall.



Plain view



Cross-section view

・In the hanging wall above a shear plane, 10-30cm width fracture segment is distributed. In the deposit (Layer ②), fracture and shear structure is developing along the line of a boundary plane with the basement. A linear fault gouge is not recognized. The R1 planes with a few centimeters displacement finely slips the shear planes.

・At the R1 plane in the fracture segment and the deposit (Layer ②), right-lateral slips are observed.

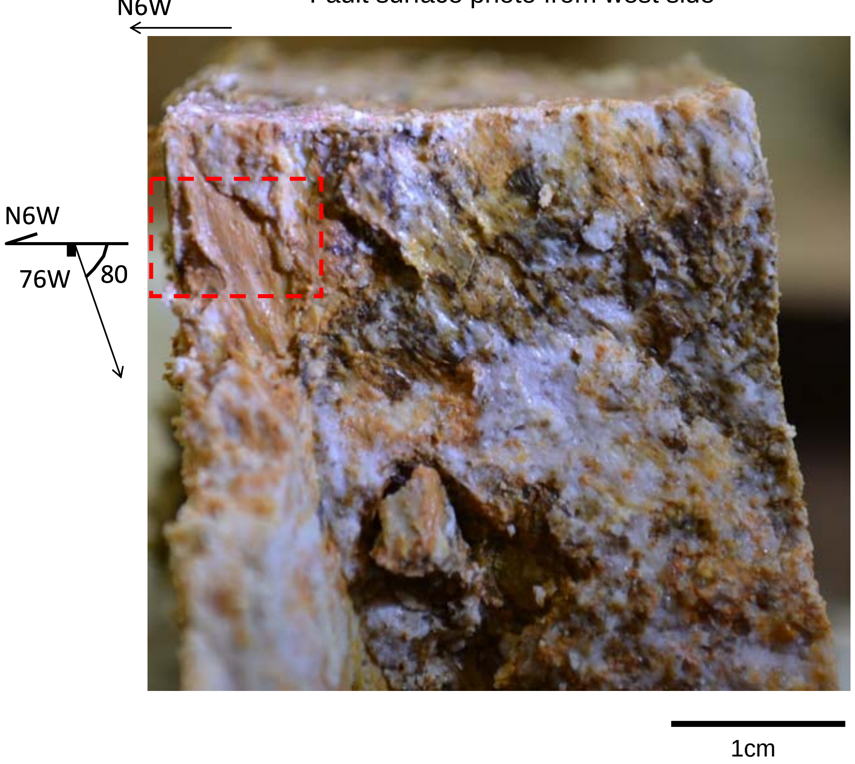
・The relative vertical is 1.79m, that is calculated from the upper limit surface of the hanging wall and auger boring close to the footwall.

・K fault was recognized between decayed granite porphyry and layer ② at L-cut pit.
・Strike and dip of K fault is a direction of N-S and high-angle westerly dip. K fault consist of gray fracture segments with hydrothermal alteration.
・K fault is a reverse fault with right-lateral slip. Relative vertical displacement of basement rock is about 1.8m.

The slickenline of K fault in the L-cut pit (photo)

Newly obtained data after February 5, 2013

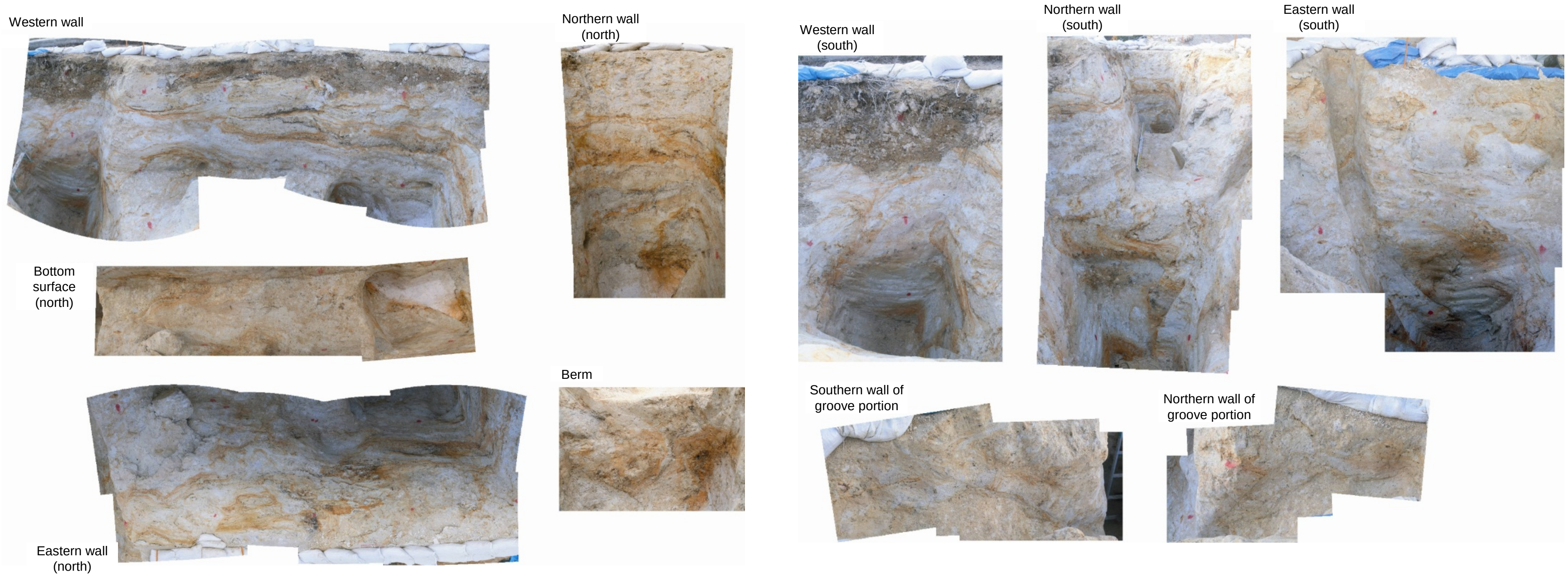
Fault surface photo from west side



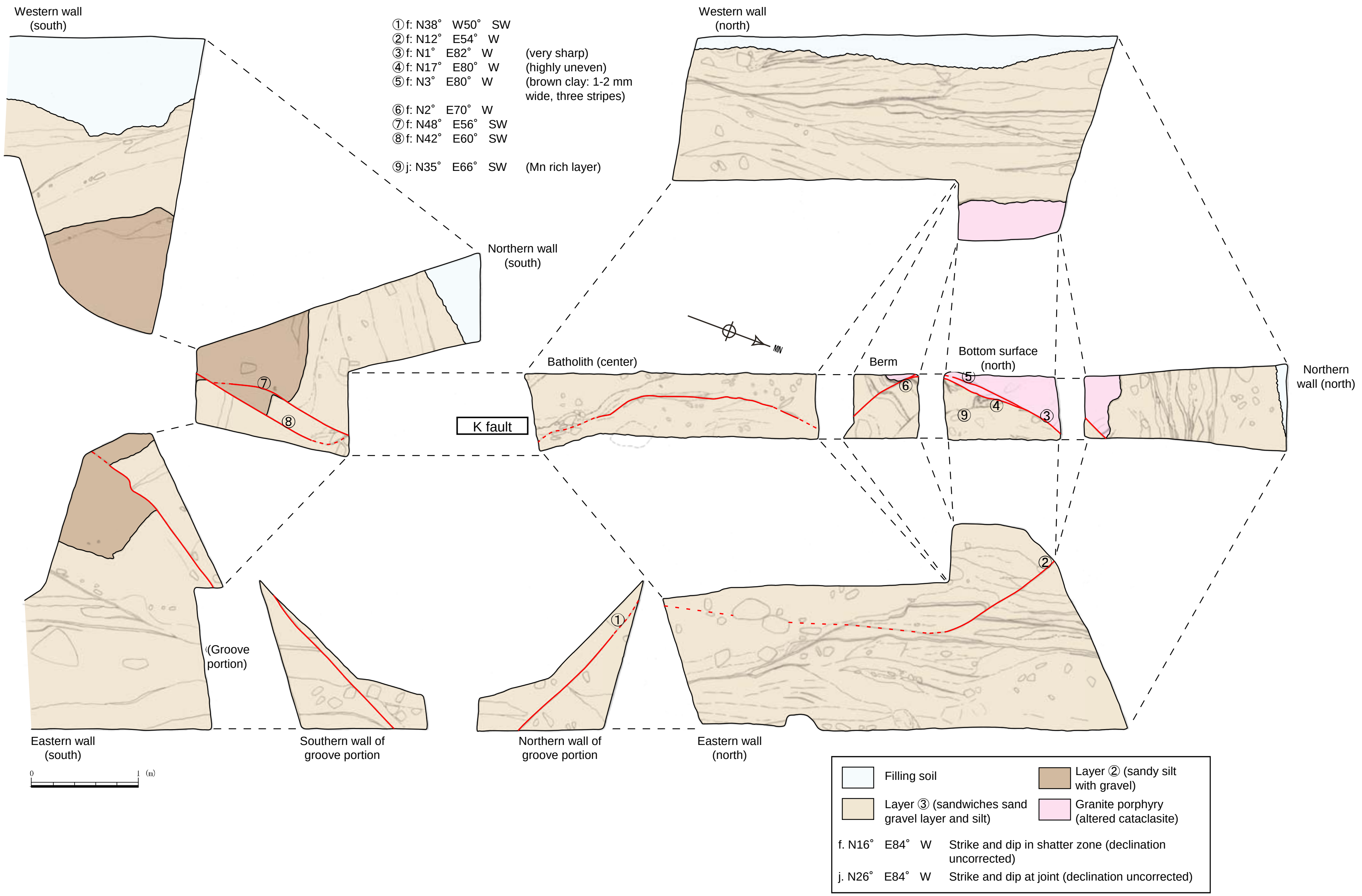
Fault surface photo from west side (enlarged)

- At the L-cut pit, a block of K-fault (N-S strike) was sampled and slickenline of the last slip was observed.
- In the result, it is confirmed that the reverse fault displacement component is dominant.

D-1 trench (photo of western pit)

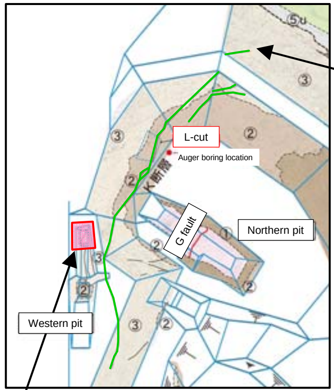


D-1 trench (sketch of western pit)



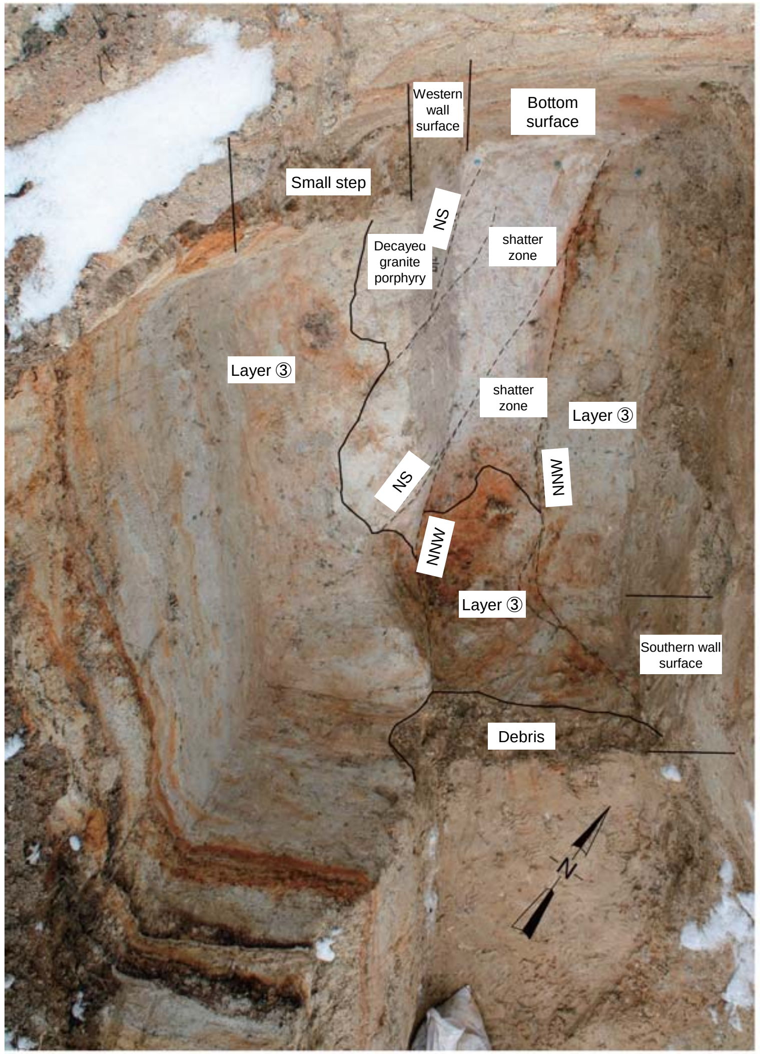
Northern widening of western pit（photo）

Newly obtained data after February 5, 2013

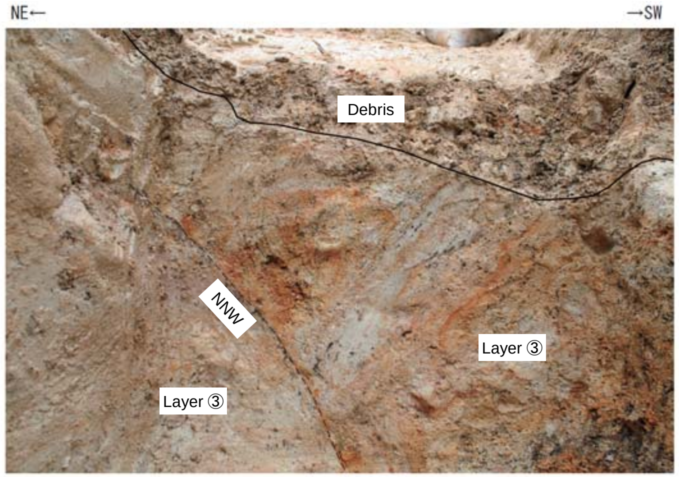


K fault

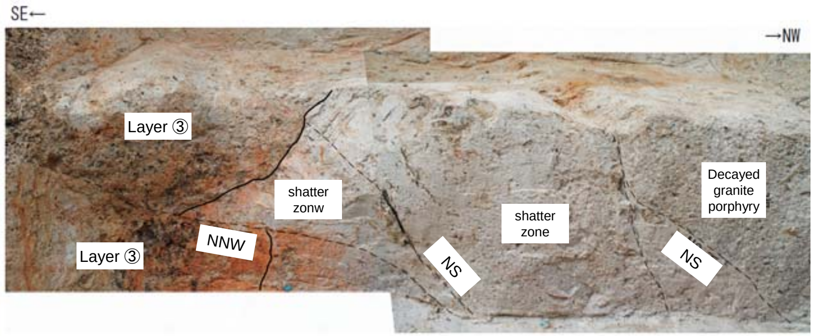
Northern widening of western pit



Northern widening of northern pit



Southern wall surface



Western wall surface (lower part)

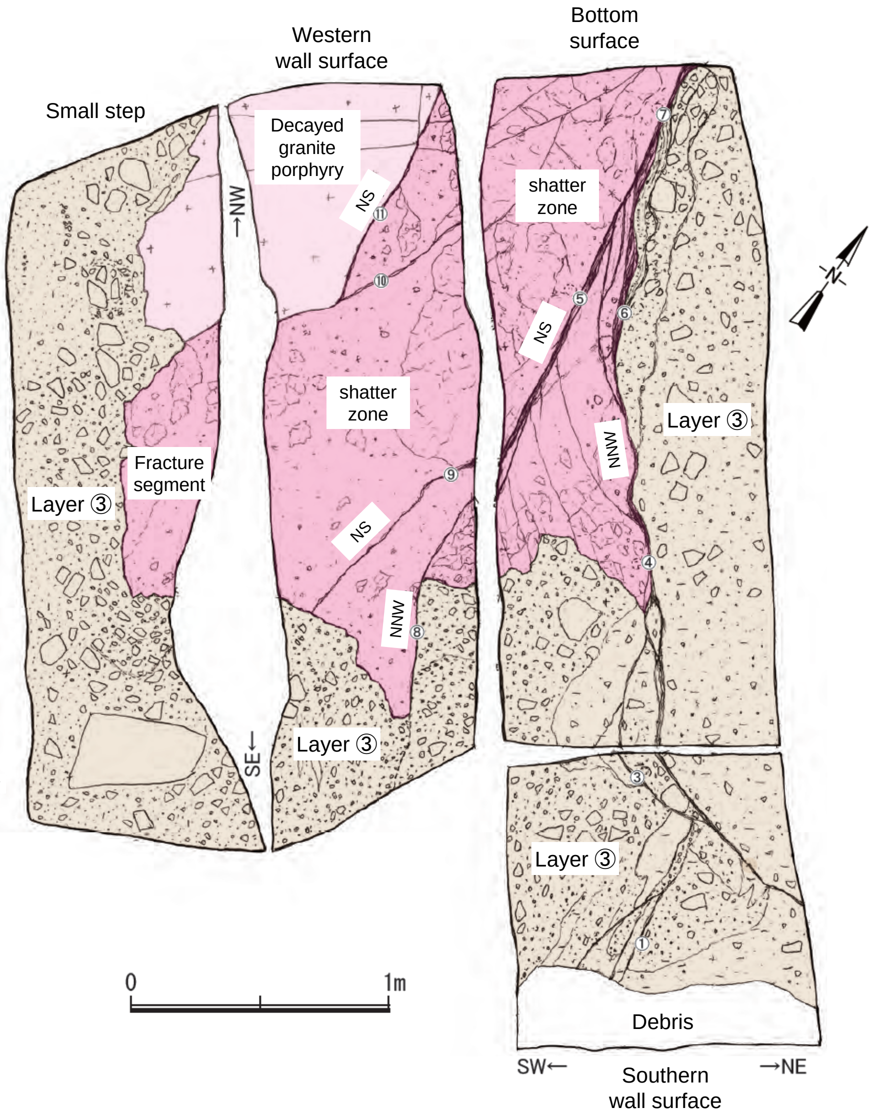
Northern widening of western pit（sketch）

Newly obtained data after February 5, 2013

Fracture strike and dip
(declination is not adjusted)

① f:N19W50E (A slip along to the deposit structure)
② f:N54W53S（NNW 系）
③ f:N11W43W（NNW 系）
④ f:N42W62W（NNW 系）
⑤ f:N7W83W（NS 系）
⑥ f:N27W67W（NNW 系）
⑦ f:N13W72W（NS 系）
⑧ f:N18W38W（NNW 系）
⑨ f:N2W86W（NS 系）
⑩ f:N10E81E
⑪ f:N7W71W（NS 系）

Legend
- Layer ③
- Decayed granite porphyry
- Fracture segment



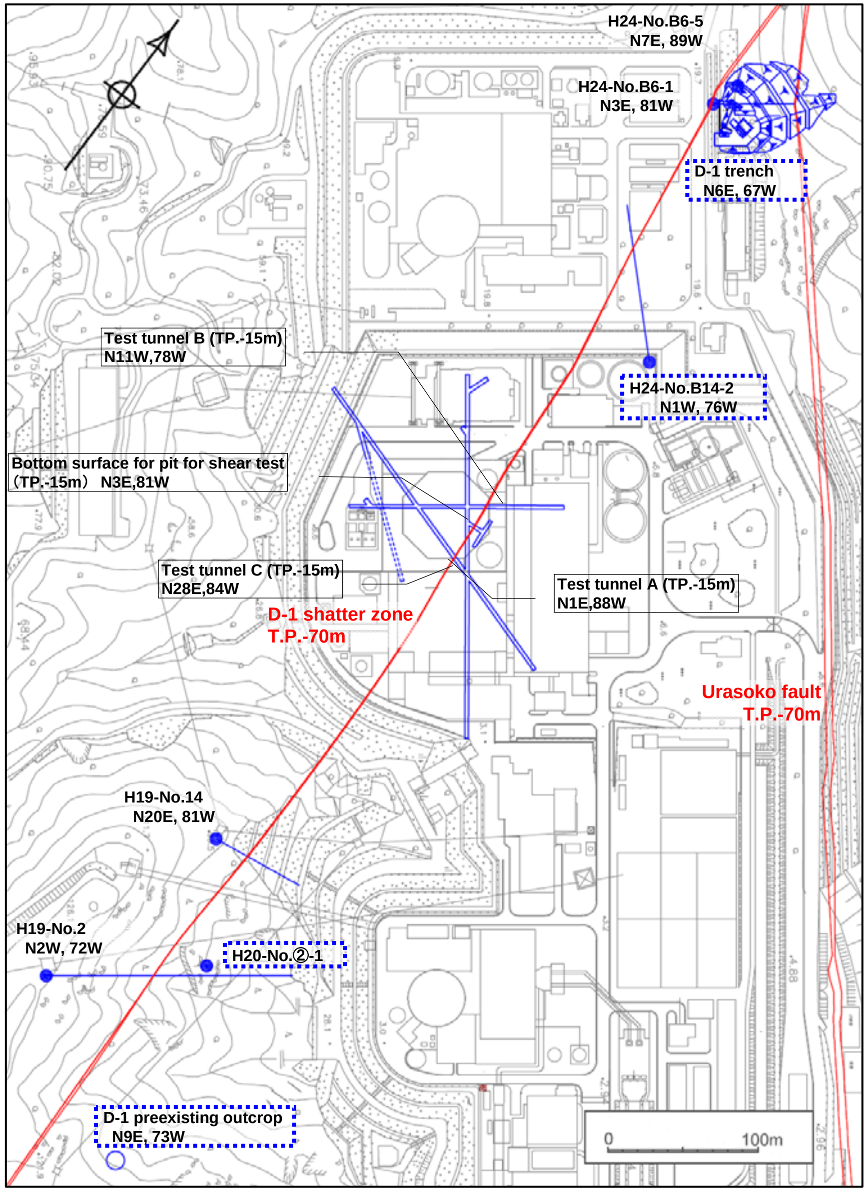
・The shatter zones running to the directions of N-S and NNW-SSW are recognized in the basement rock at the northern widening of western pit.

・The K fault, which displaces and deform layer ③, has N-S direction strike in the basement rock at the northern widening of western pit. The strike changes its direction to NNW-SSW in the western pit.

・The fracture segment with N-S direction strike does not displace and deform layer ③ in the south part from the bend.

Result of evaluating continuity of D-1 shatter zone

Material newly presented after December 10, 2012



Position where the sense of displacement of normal fault was confirmed

- The shatter zones identified as D-1 shatter zone run roughly in a direction of N-S, are high-angle westerly dip, and have excellent continuity. Both consist of cataclasite and fault gouge.
- Observation of fault gouges of the last slips reveals that D-1 shatter zone and G fault have the sense of normal fault. On the other hand, K fault is a reverse fault, showing a reverse sense of displacement.
- Thus, we judge that the K fault is different from D-1 shatter zone and G fault and D-1 shatter zone compose of a series of shatter zones.

Flow of evaluation employing numerical analysis

・Simultaneous activity (future activity) of the shatter zones and Urasoko fault was evaluated with employing numerical analysis
・In conducting numerical analysis, conditions of study were organized. Based on the "elasticity theory of dislocation," "basic study" and "study taking uncertainty into account" were conducted.
・In study of the "elasticity theory of dislocation," the conditions of study that would produce the severest results in evaluation of bearing capacity of the ground we studied with using a Finite Element Method (FEM) model.

[Organization of the conditions of study] * Organization of basic parameters and margin of uncertainty
・Geometric shape of fault (length of fault, width of fault, dip angle, depth of the top of fault)
・Slip of fault (slip angle, slip volume)
・Ground model (ground structure, Poisson's ratio)

↓

Elasticity theory of dislocation

[Basic study with assuming the ground as an elastic body]
・Conduct calculation with basic parameters
・Decide the slip direction of fault that produces the maximum result (inclination, etc.)

[Basic study with assuming the ground as an elastic body and taking uncertainty into account]
・Study the above slip direction with taking into account the uncertainty of computational parameters

↓ Severest result of study for reactor facility

FEM

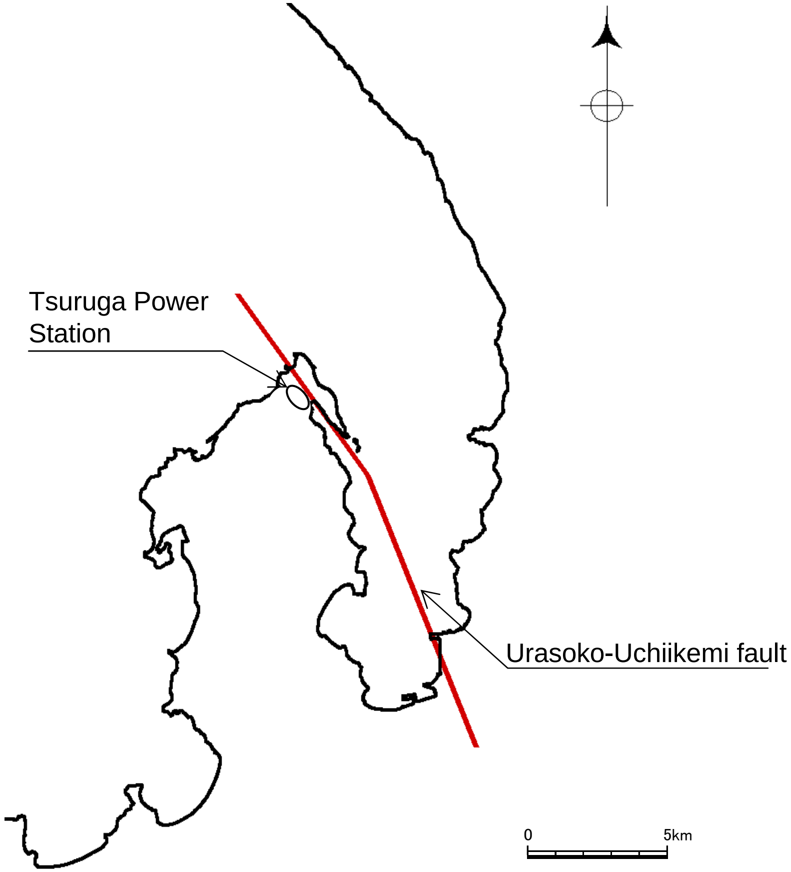
[Study with taking into account the ground's non-homogeneity and non-linear characteristics]
・Detailed modeling of the ground near fault (reflecting rock classes, shatter zones, etc.)
・Of the results of study based on the elasticity theory of dislocation, the case producing the severest result was studied (vertical and horizontal directions)

Flow of evaluation employing numerical analysis

Modelled fault to be analyzed

- Based on the elasticity theory of dislocation, we studied vertical displacement (inclination) and horizontal deformation (shearing strain) of the foundation for reactor building to be caused by the activity of Urasoko fault.
- We set the conditions of study with using the concept of Tsunami Evaluation Method* as a reference.
- In conducting study, we also took into consideration the uncertainties of parameters (length of fault, angle of dip, width of fault, etc.) that are used in analysis.

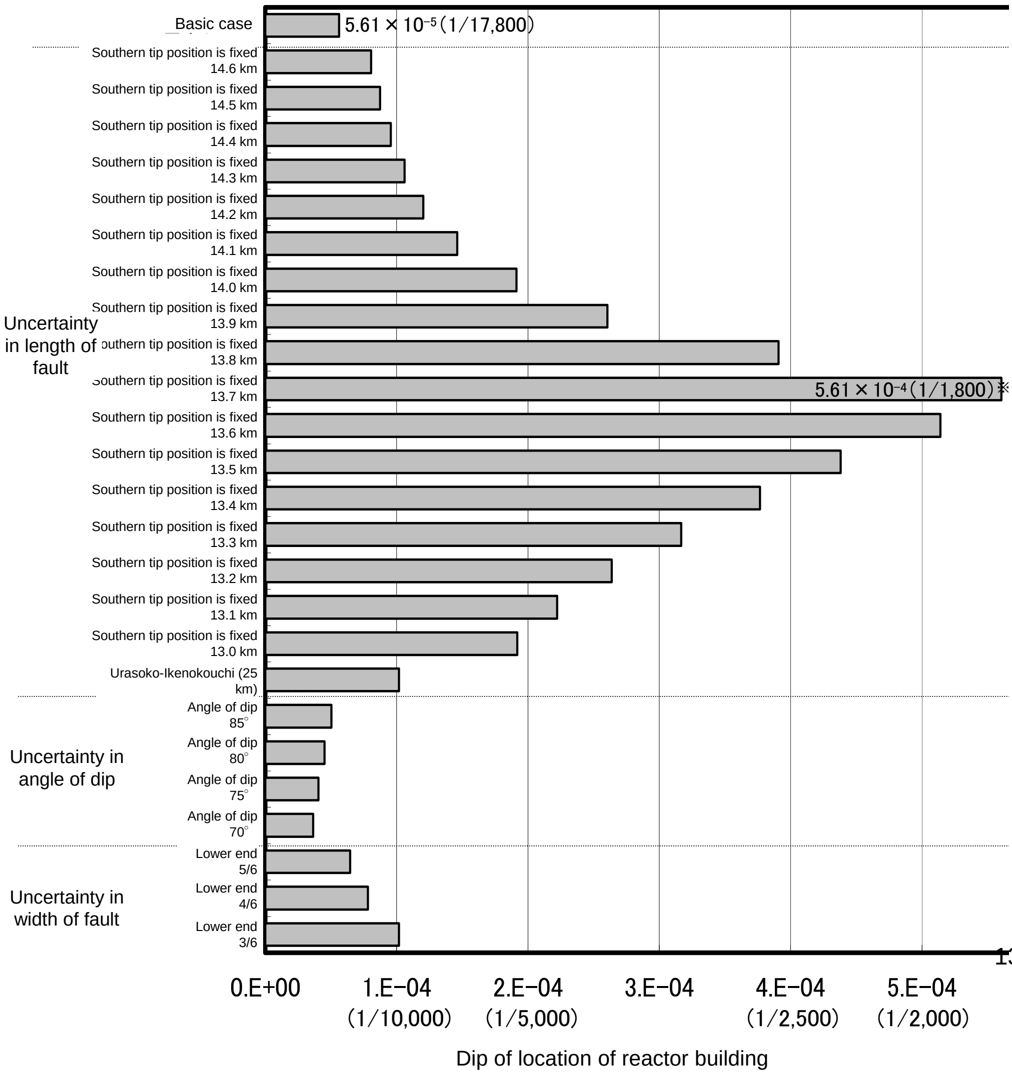
* Tsunami Evaluation Subcommittee, Nuclear Civil Engineering Committee, Japan Society of Civil Engineers (2002)



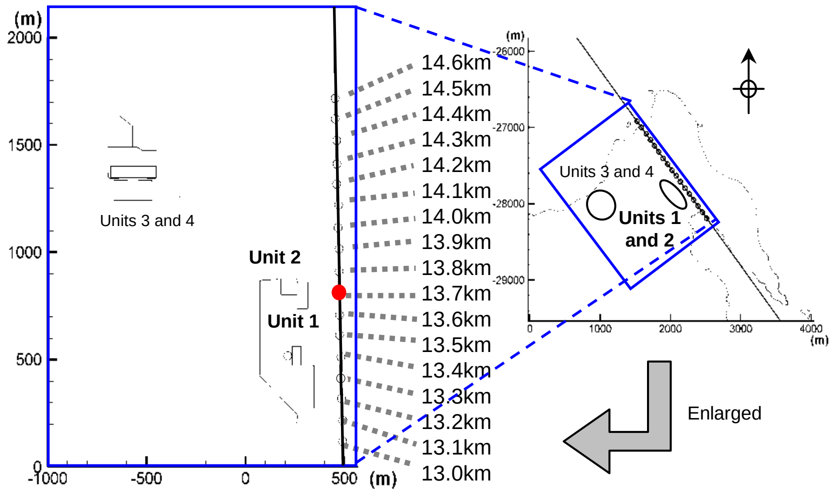
Modelled fault to be analyzed

Result of analysis based on elasticity theory of dislocation (dip of location of reactor building: Unit 2 reactor building)

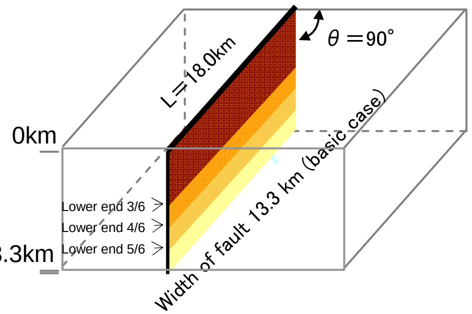
- In basic study, as for the case of p-axis = 90° that represents the maximum dip, we carried out the study with taking into account uncertainties of length of fault, angle of dip and width of fault.
- As a result, a dip becomes maximum in the case of 13.7 km (the southern tip position is fixed), and is about 1/1,800 at Unit 2 reactor building.



* Dip in the direction of maximum dip is 5.61 x 10^{-4} (1/1,800)



As Tsuruga Power Station is located in the north of Urasoko-Uchiikemi fault, a length of fault (slip volume) becomes larger by fixing the location of the southern end of the fault with changing the location of the northern end. Thus, study was done with fixing the location of the southern end of the fault.

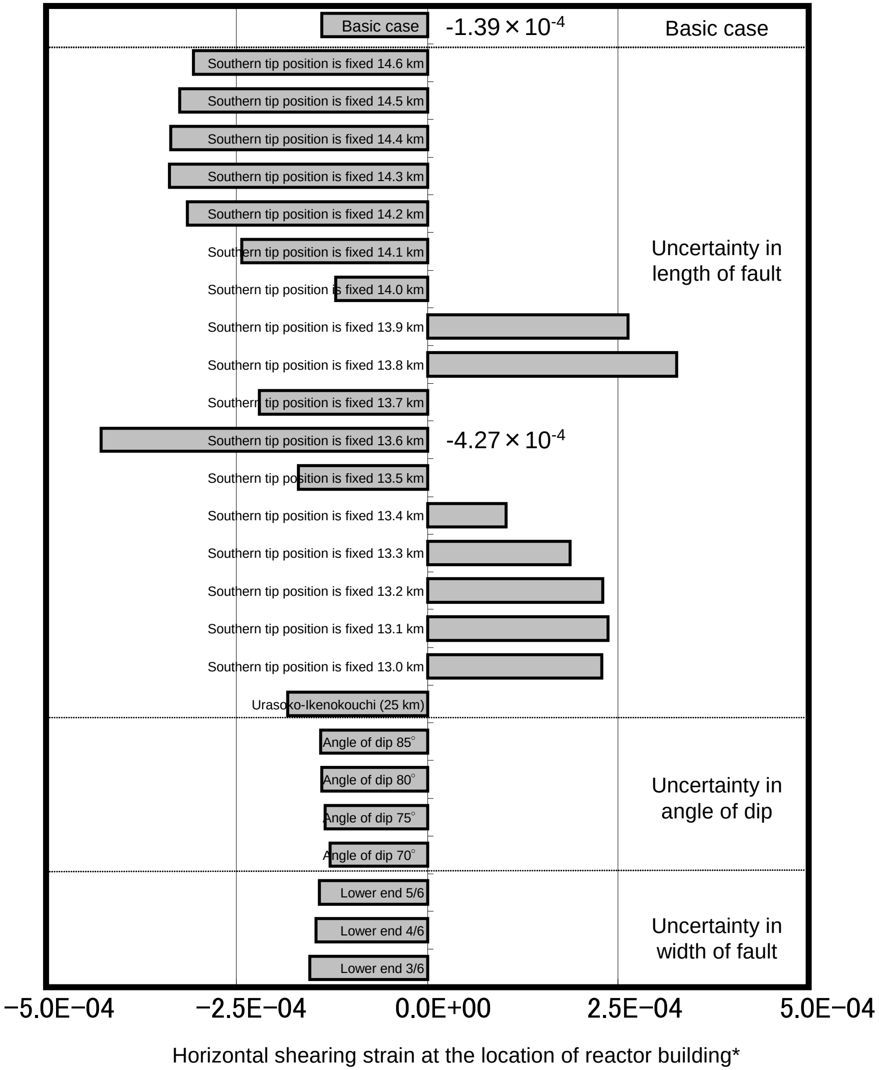


Width of fault W 13.3 km (basic case)
① 5/6 W = 11.1 km
② 4/6 W = 8.9 km
③ 3/6 W = 6.7 km

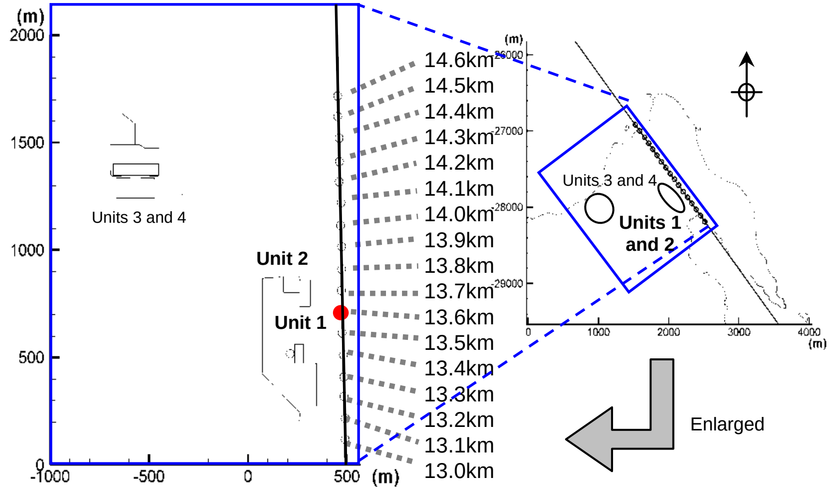
Dip with taking uncertainty into account (Unit 2 reactor building)

Result of analysis based on elasticity theory of dislocation (horizontal shearing strain at location of reactor building: Unit 2 reactor building)

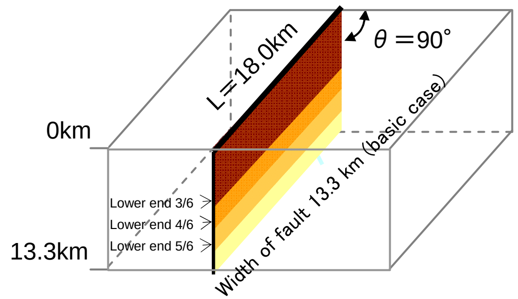
- In basic study, as for the case of p-axis = 115° that represents the maximum shearing strain, we carried out the study with taking into account uncertainties of length of fault, angle of dip and width of fault.
- As a result, a shearing strain becomes maximum in the case of 13.6 km (the southern tip position is fixed), and is -4.27×10^{-4} at Unit 2 reactor building.



* Horizontal shearing strain acquired with a reactor building scale (Unit 2: about 80 m x about 75 m)



As Tsuruga Power Station is located in the north of Urasoko-Uchiikemi fault, study was done with fixing the location of the southern end of the fault with changing the location of the northern end.



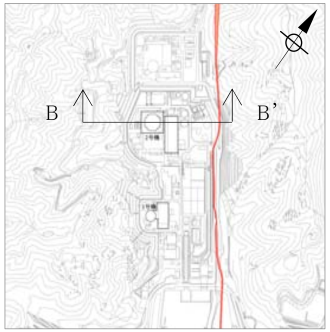
Width of fault W 13.3 km (basic case)
① 5/6 W = 11.1 km
② 4/6 W = 8.9 km
③ 3/6 W = 6.7 km

Horizontal shearing strain with taking uncertainty into account (Unit 2 reactor building)

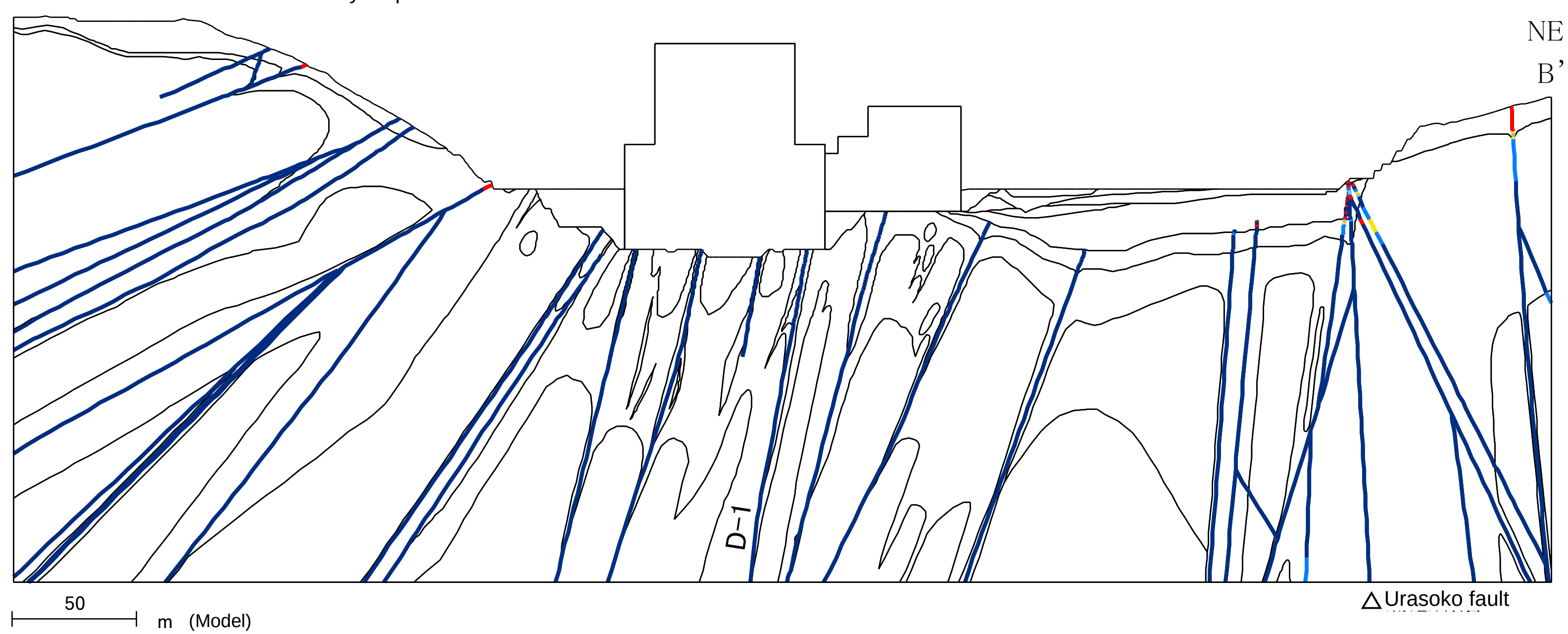
Result of analysis using vertical two-dimensional FEM model (local safety factors of shatter zone: profile of Unit 2)

In the result of study based on the “elasticity theory of dislocation,” we performed an analysis of the case that a dip at the location of reactor building becomes maximum.

[The case of maximum dip at the location of Unit 2’s R/B]
P axis: 90° length of fault: 13.7 km



Fault locality map



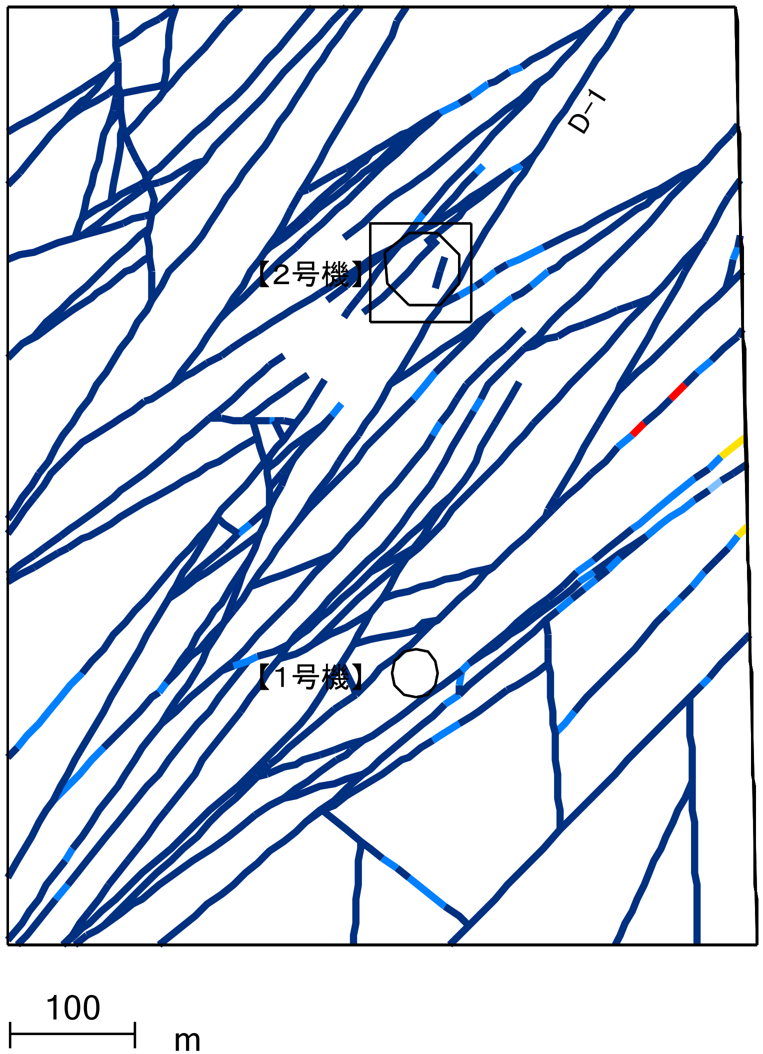
Distribution of local safety factors of shatter zone (profile of Unit 2)

Developments of shear fracture and tensile stress are seen in the shatter zone near Urasoko fault. But, as such area is limited and the local safety factors near the reactor building show enough margin of safety, the ground is believed to have enough bearing capacity.

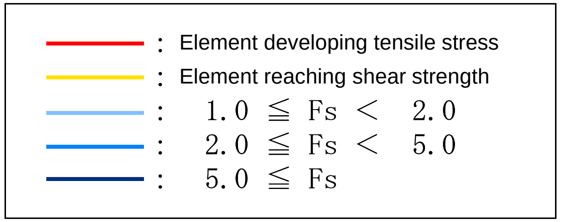
Result of analysis using horizontal two-dimensional FEM model (local safety factors of shatter zone)

In the result of study based on the “elasticity theory of dislocation,” we performed an analysis of the case that a horizontal shear strain at the location of reactor building becomes maximum.

[The case of maximum horizontal shear strain at the location of Unit 2’s R/B]
P axis: 90° length of fault: 13.7 km



Distribution of local safety factors of shatter zone



Developments of shear fracture and tensile stress are seen in the shatter zone near Urasoko fault. But, as such area is limited and the local safety factors near the reactor building show enough margin of safety, the ground is believed to have enough bearing capacity.

Comprehensive evaluation of D-1 shatter zone and K fault

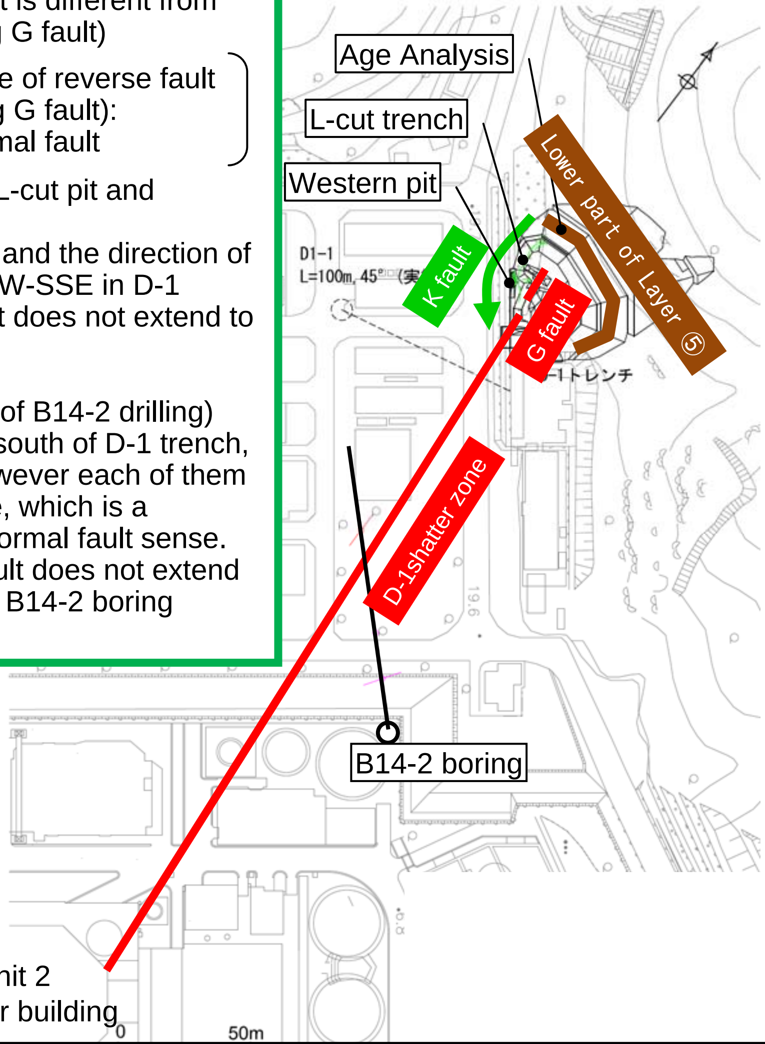
◆ K fault is not D-1 shatter zone and does not extend to the reactor building of Unit 2.

(Thin section observation)
- The displacement sense of K fault is different from that of D-1 shatter zone (including G fault)

  K fault: displacement sense of reverse fault
  D-1 shatter zone (including G fault): displacement sense of normal fault

(Additional geologic observation of L-cut pit and western pit)
- K fault reaches to basement rock and the direction of its strike changes from N-S to NNW-SSE in D-1 trench. It is suggested that K fault does not extend to the reactor building of Unit 2.

(Additional thin section observation of B14-2 drilling)
- At B14-2, which is located to the south of D-1 trench, three fault gouges are found. However each of them does not have reverse fault sense, which is a characteristic of K fault, but has normal fault sense.
- Accordingly, It is judged that K fault does not extend to southern direction at least from B14-2 boring location.



◆ G fault is D-1 shatter zone.

- Strike and dip is similar to each other

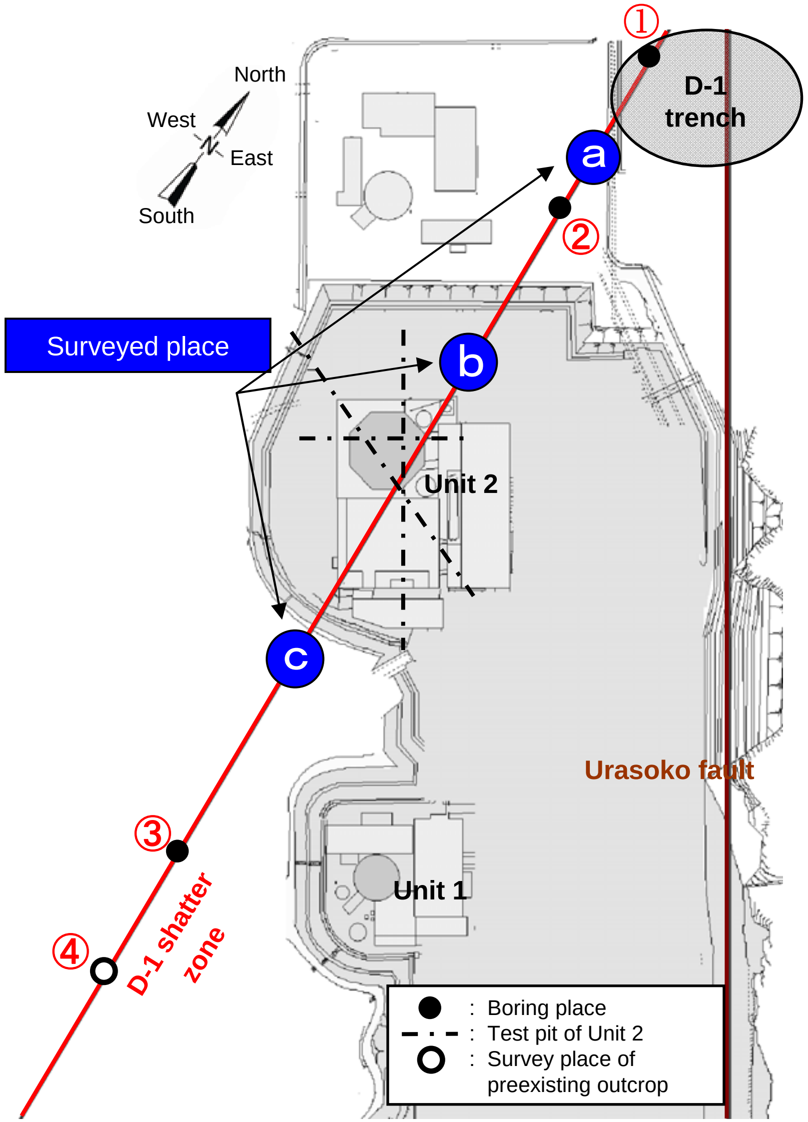
(Additional thin section observation)
- Additional thin section observations were performed on the facture segments that is considered to be D-1 shatter zone (D-1 outcrop, drillings and D-1 trench)
- So both of D-1 shatter zone and G fault have displacement sense of normal fault that G fault is D-1 shatter zone.

◆ D-1 shatter zone (including G fault) and K fault were not active in and after the Late Pleistocene.

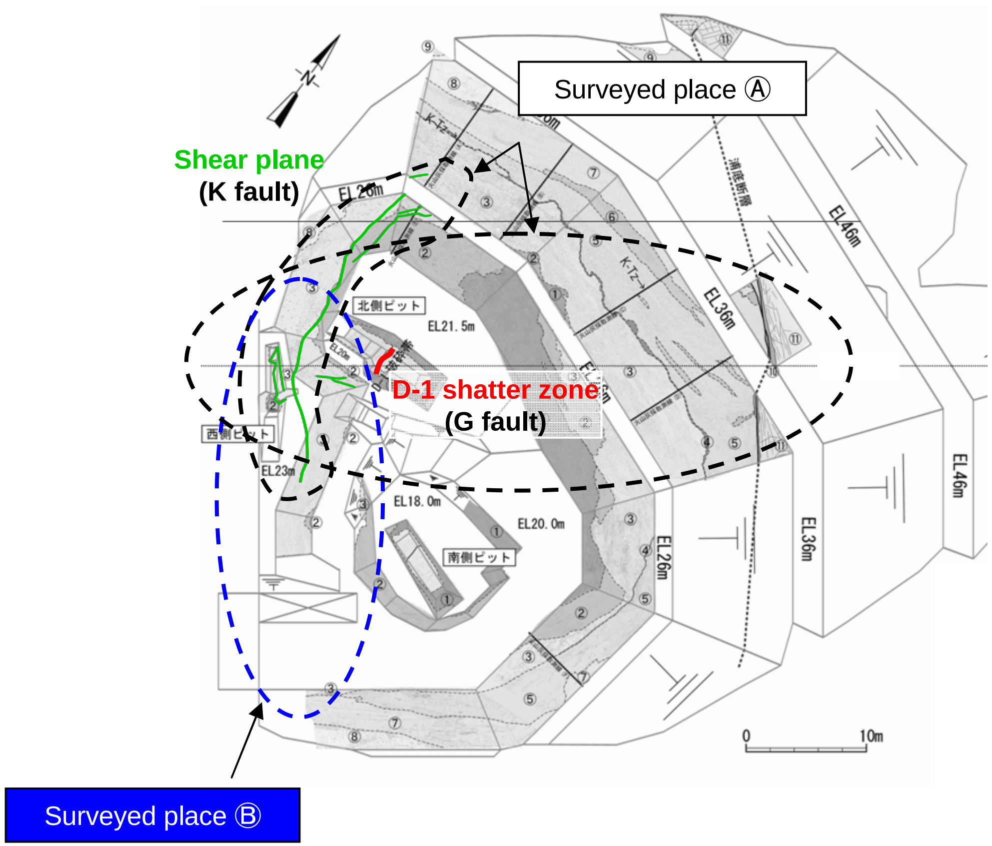
(Additional dating of D-1 trench)
- Both of D-1 shatter zone (including G fault) and K fault is covered by lower part of Layer ⑤. (Both of them have not been active since deposition of lower part of layer ⑤)
- From the results of additional dating on the lower part of layer ⑤, it is judged that the lower part of layer ⑤ was deposited about 120,000 – 130,000 years ago. (Miahama-tephra was detected.)
- Accordingly, both of D-1 shatter zone (including G fault) and K fault, which are covered by lower part of Layer ⑤, have not been active since about 120,000 – 130,000 years ago.

D-1 shatter zone and K fault were not active in and after Late Pleistocene. Therefore D-1 shatter zone and K fault are not active faults that should be taken into consideration for the seismic design.

Survey plan

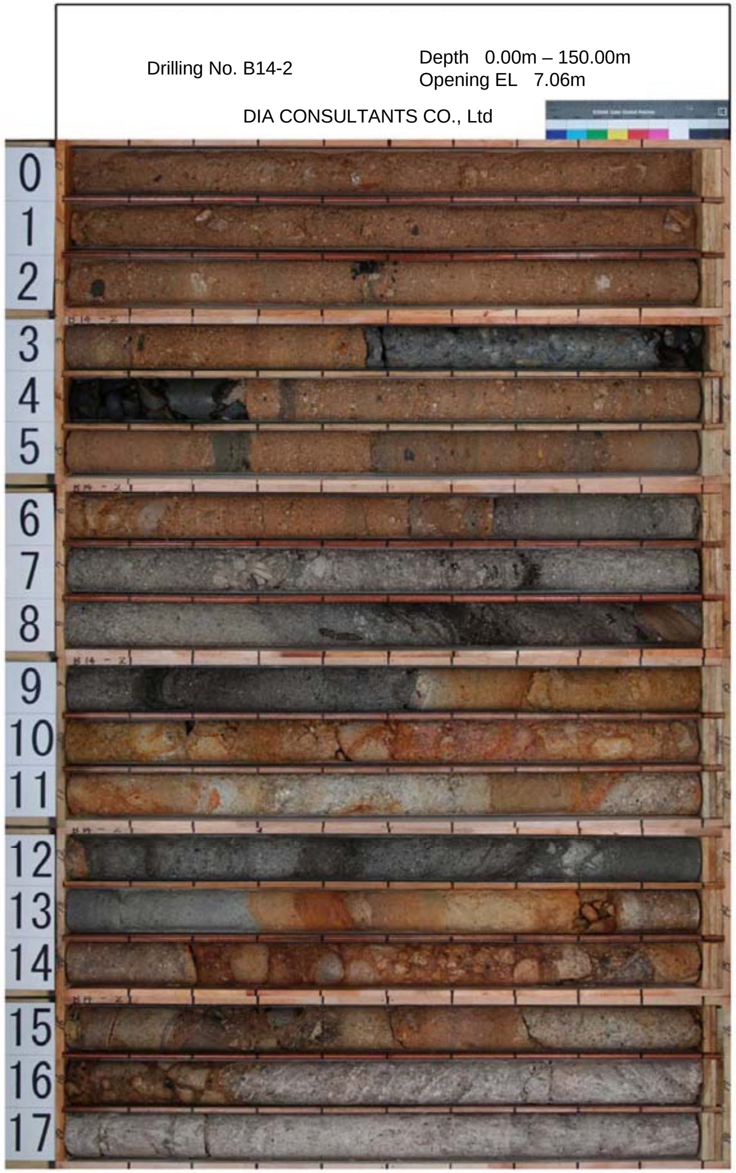


Positional relations between power station and D-1 shatter zone (Image)



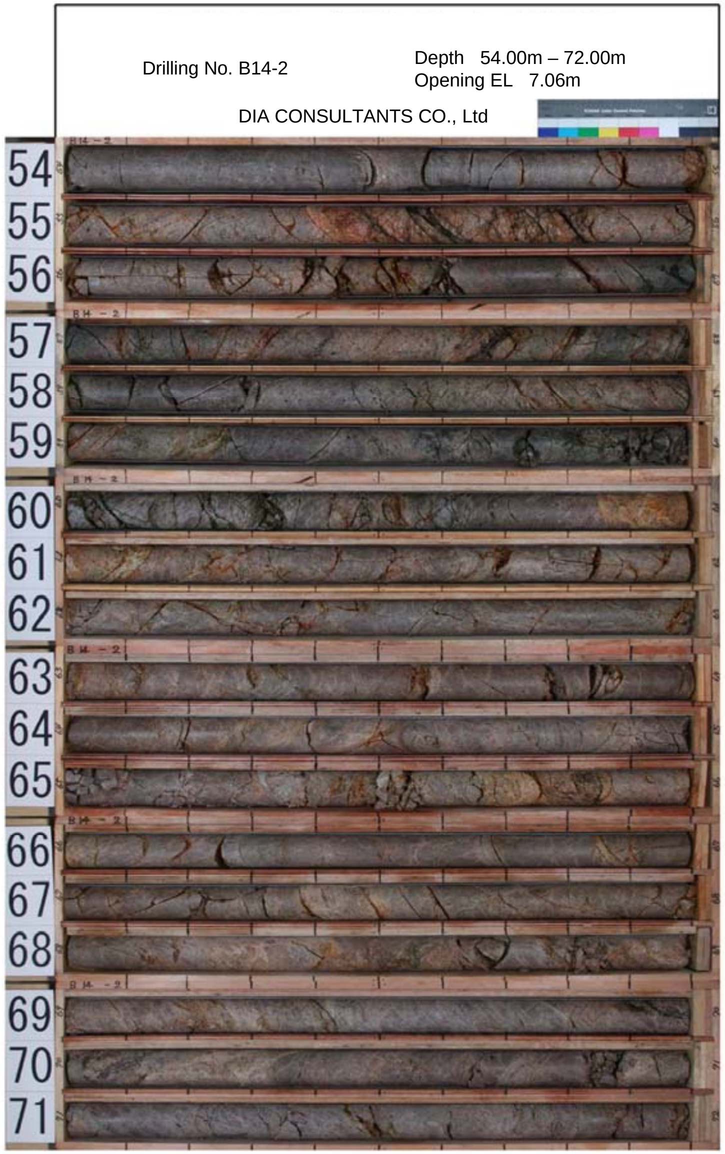
Enlarged view of D-1 trench

(Reference) B14-2 drilling core photograph (1/5)



28.50m※
N34E78W

※) Fracture segment with fault gouge



※) Fracture segment with fault gouge

(Reference) B14-2 drilling core photograph (3/5)

(Reference) B14-2 drilling core photograph (4/5)

D-1 shatter zones
109.16m※
N1W76W

※）断層ガウジを有する破砕部

Drilling No. B14-2

Depth 144.00m – 150.00m
Opening EL 7.06m

DIA CONSULTANTS CO., Ltd