Geology and Geological Structure of Tsuruga Power Station Site

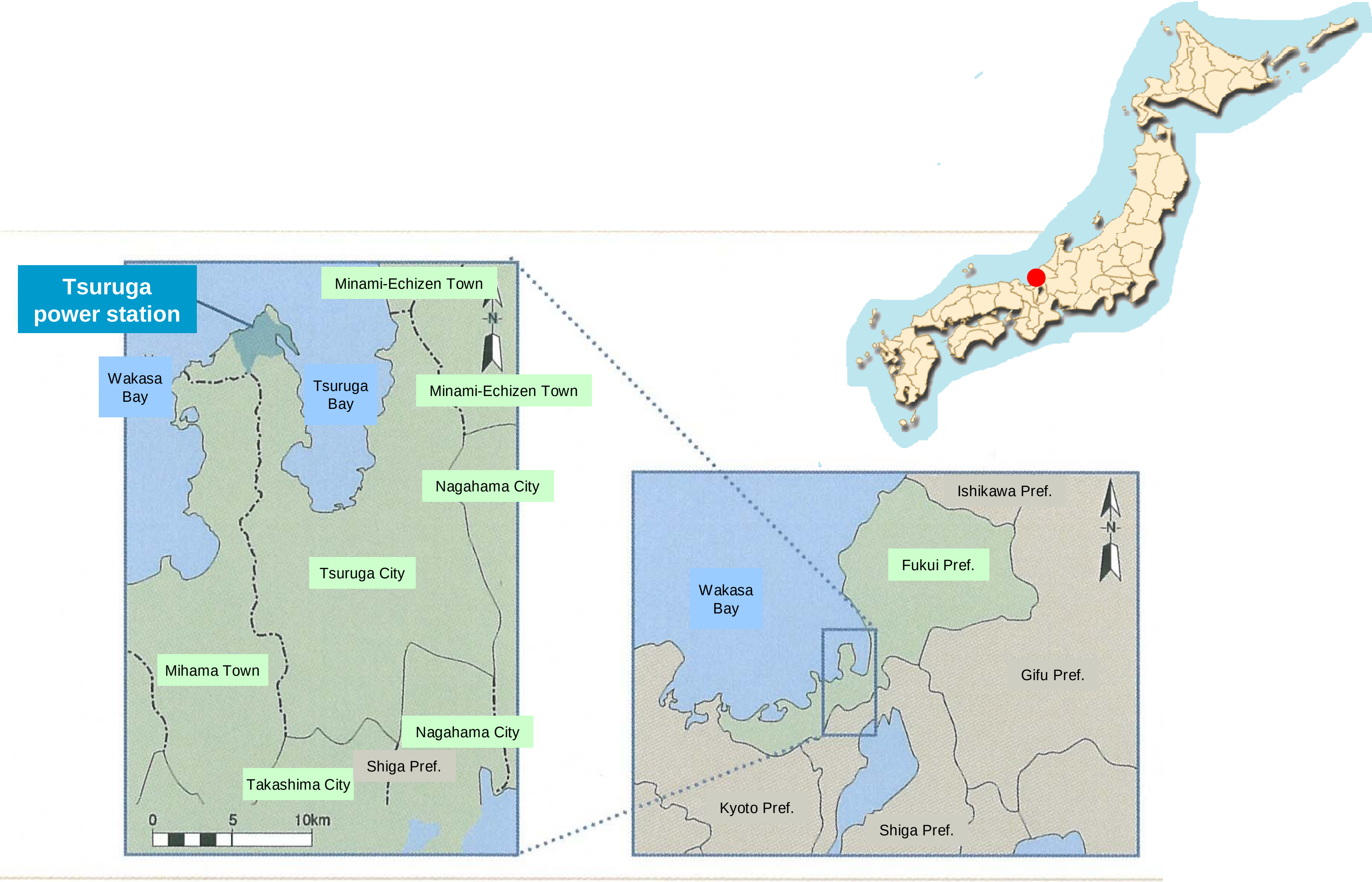
D-1shatter zone（summary）

- Geography, geology and geological structure of the site
- Evaluation of the D-1 shatter zone
  - The additional survey plan
  - JAPC's opinion at the Expert Meeting (Apr. 24, 2013)
  - NRA (Expert Meeting) 's view at the NRA meeting (May 22, 2013)
  - JAPC's opinion in the report submitted Jul.11, 2013

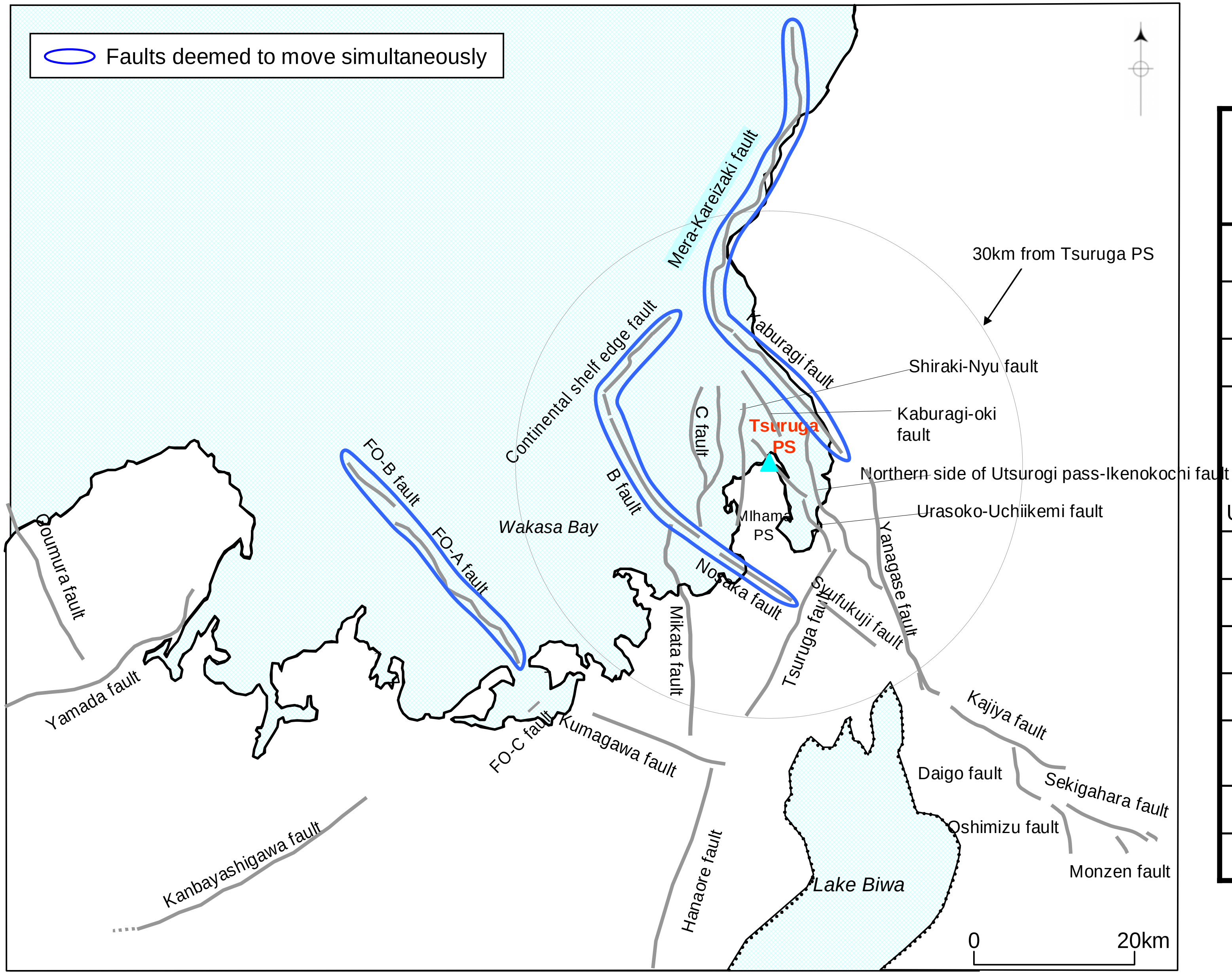
Aug.01, 2013

The Japan Atomic Power Company

Location of Tsuruga power station



Major faults around Wakasa Bay



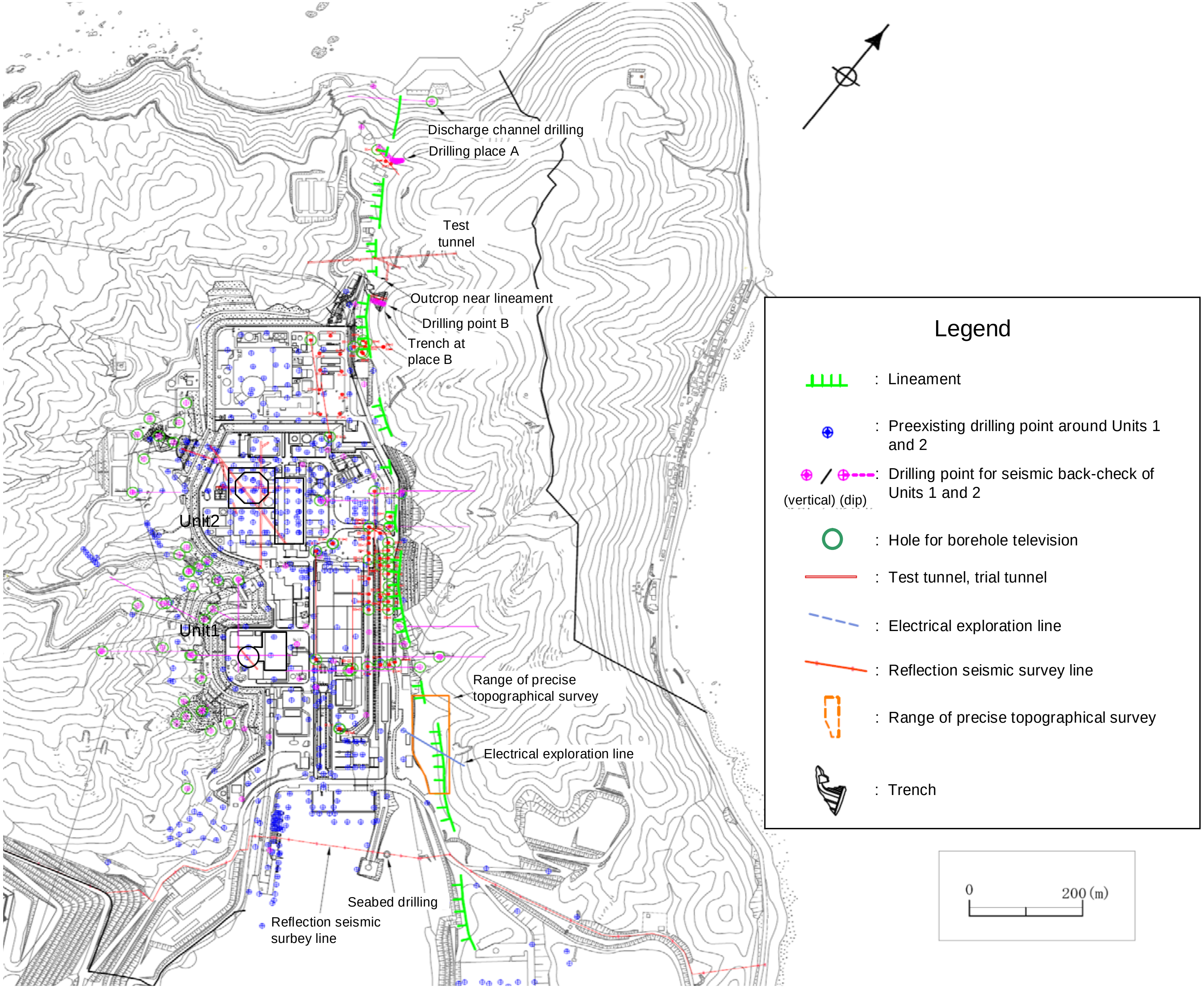
Note: Major faults within about 30km diameter are shown.

Major faults around Tsuruga power station

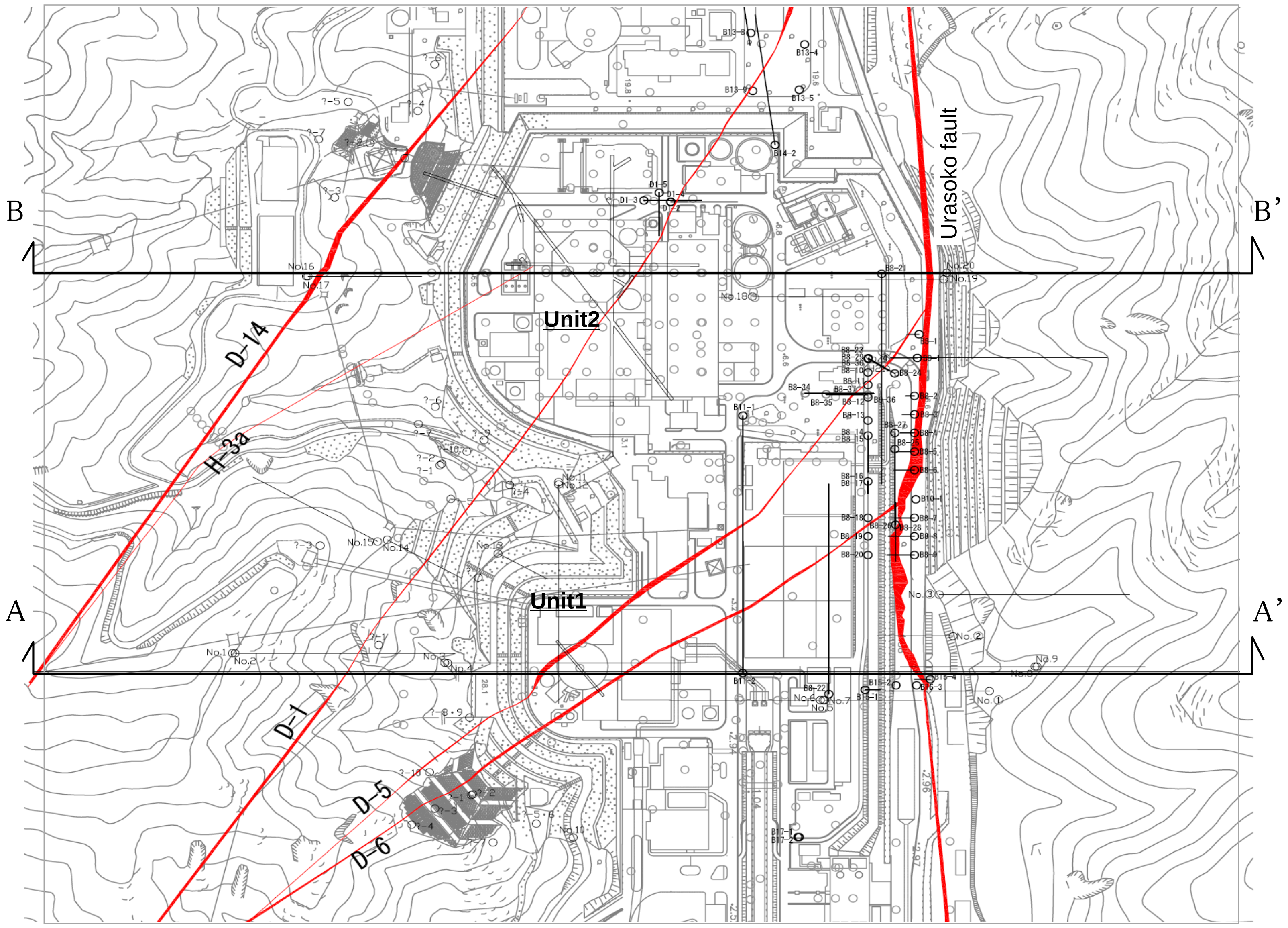
Faults	Length	As moving at a time
Mera-Kareizaki-oki	42 km	60 km
Kaburagi	19 km	
Yanagase	31 km	–
Northern side of Utsurogi pass-Ikenokochi	23 km	–
Urasoko-Uchiikemi	18 km	–
Urasoko-Ikenokochi	25 km	–
Shiraki-Nyu	15 km	–
C	18 km	–
Nosaka	12 km	49 km
B	21 km	
Continental shelf edge	14 km	
Mikata	27 km	–
Tsuruga	23 km	–

Location map of survey on the site (Units 1 and 2 side)

Interim report (No.2) (Mar.15, 2013) is partly retouched.



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



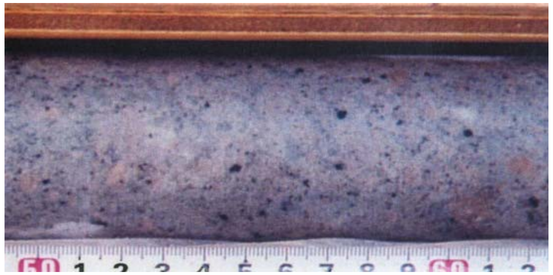
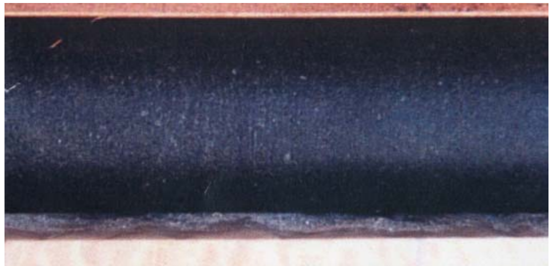
T.P. -15m horizontal section

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

Legend
Shatter zone and its number
Drilling point
(Vertical) (Dip)

0 200 (m)

Identified rock types

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 Cretaceous 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 plagioclase, K-feldspar, quartz and biotite. ・Granite porphyry is judged to be formed in the times between the late Cretaceous and the Paleogene, since the values stand at around 66.3 Ma measured by K-Ar dating.
	Aplite Ap		・Holocrystalline-equiangular texture. ・It contains a small amount of phenocryst and partly has porphyritic texture. ・Groundmass in porphyritic texture is microcrystalline. ・Minerals are mainly composed of quartz, K-feldspar, plagioclase and a very small amount of biotite. ・Aplite is judged to be formed in the times between 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 under 2 mm. ・Minerals are mainly composed of plagioclase, 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.

Classification of fault rocks

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 fragments
Fault breccia	>30%	Megabreccia >256mm Mesobreccia 10-256mm Microbreccia <10mm
Fault gouge	<30%	<10mm in normal
	Proportion of fragments	Grain size of fragment
Protocataclasite Cataclasite Ultracataclasite	>50% 10-50% <10%	<10mm in normal
	Proportion of porphyroclasts	Grain size of matrix mineral
Protomylonite Mylonite Ultramylonite	Variable depending on deformation force and lithology of protolith	>100 μm 20-100 μm <20 μm

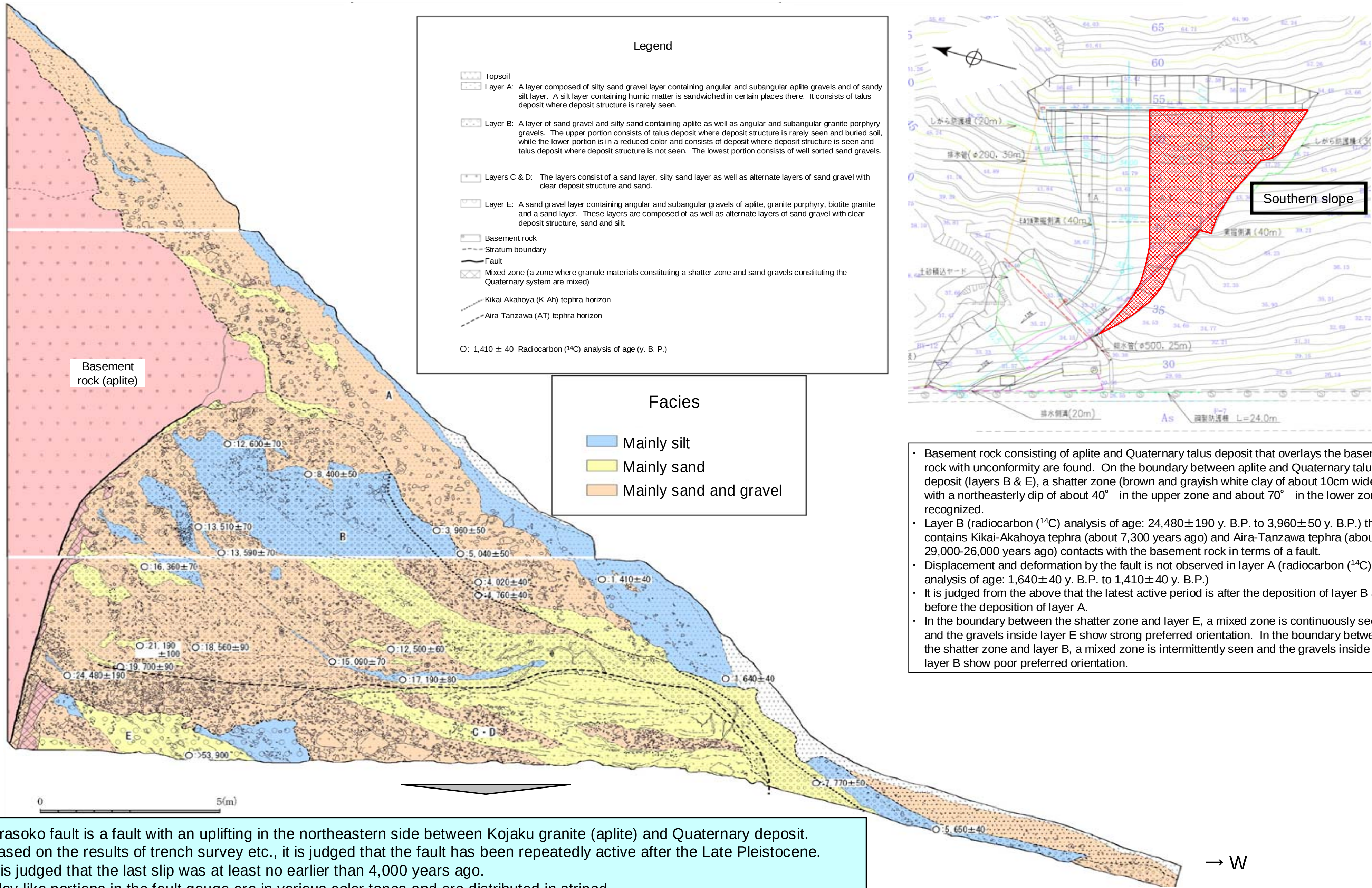
Source: Proposed classification of fault rocks (by Takagi & Kobayashi, 1996)

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

Sketch of Urasoko fault (southern slope of trench at place B)

Interim report (No.2) (Mar.15, 2013) is partly retouched.

E ←



→ W

Legend

- Topsoil
- Layer A: A layer composed of silty sand gravel layer containing angular and subangular aplite gravels and of sandy silt layer. A silt layer containing humic matter is sandwiched in certain places there. It consists of talus deposit where deposit structure is rarely seen.
- Layer B: A layer of sand gravel and silty sand containing aplite as well as angular and subangular granite porphyry gravels. The upper portion consists of talus deposit where deposit structure is rarely seen and buried soil, while the lower portion is in a reduced color and consists of deposit where deposit structure is seen and talus deposit where deposit structure is not seen. The lowest portion consists of well sorted sand gravels.
- Layers C & D: The layers consist of a sand layer, silty sand layer as well as alternate layers of sand gravel with clear deposit structure and sand.
- Layer E: A sand gravel layer containing angular and subangular gravels of aplite, granite porphyry, biotite granite and a sand layer. These layers are composed of as well as alternate layers of sand gravel with clear deposit structure, sand and silt.
- Basement rock
- Stratum boundary
- Fault
- Mixed zone (a zone where granule materials constituting a shatter zone and sand gravels constituting the Quaternary system are mixed)
- Kikai-Akahoya (K-Ah) tephra horizon
- Aira-Tanzawa (AT) tephra horizon
- ○: 1,410 ± 40 Radiocarbon (^{14}C) analysis of age (y. B. P.)

Facies

- Mainly silt
- Mainly sand
- Mainly sand and gravel

- Basement rock consisting of aplite and Quaternary talus deposit that overlays the basement rock with unconformity are found. On the boundary between aplite and Quaternary talus deposit (layers B & E), a shatter zone (brown and grayish white clay of about 10cm wide) with a northeasterly dip of about 40° in the upper zone and about 70° in the lower zone is recognized.
- 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-Tanzawa tephra (about 29,000-26,000 years ago) contacts with the basement rock in terms of a fault.
- Displacement and deformation by the fault is not observed in layer A (radiocarbon (^{14}C) analysis of age: 1,640±40 y. B.P. to 1,410±40 y. B.P.)
- It is judged from the above that the latest active period is after the deposition of layer B and before the deposition of layer A.
- In the boundary between the shatter zone and layer E, a mixed zone is continuously seen and the gravels inside layer E show strong preferred orientation. In the boundary between the shatter zone and layer B, a mixed zone is intermittently seen and the gravels inside layer B show poor preferred orientation.

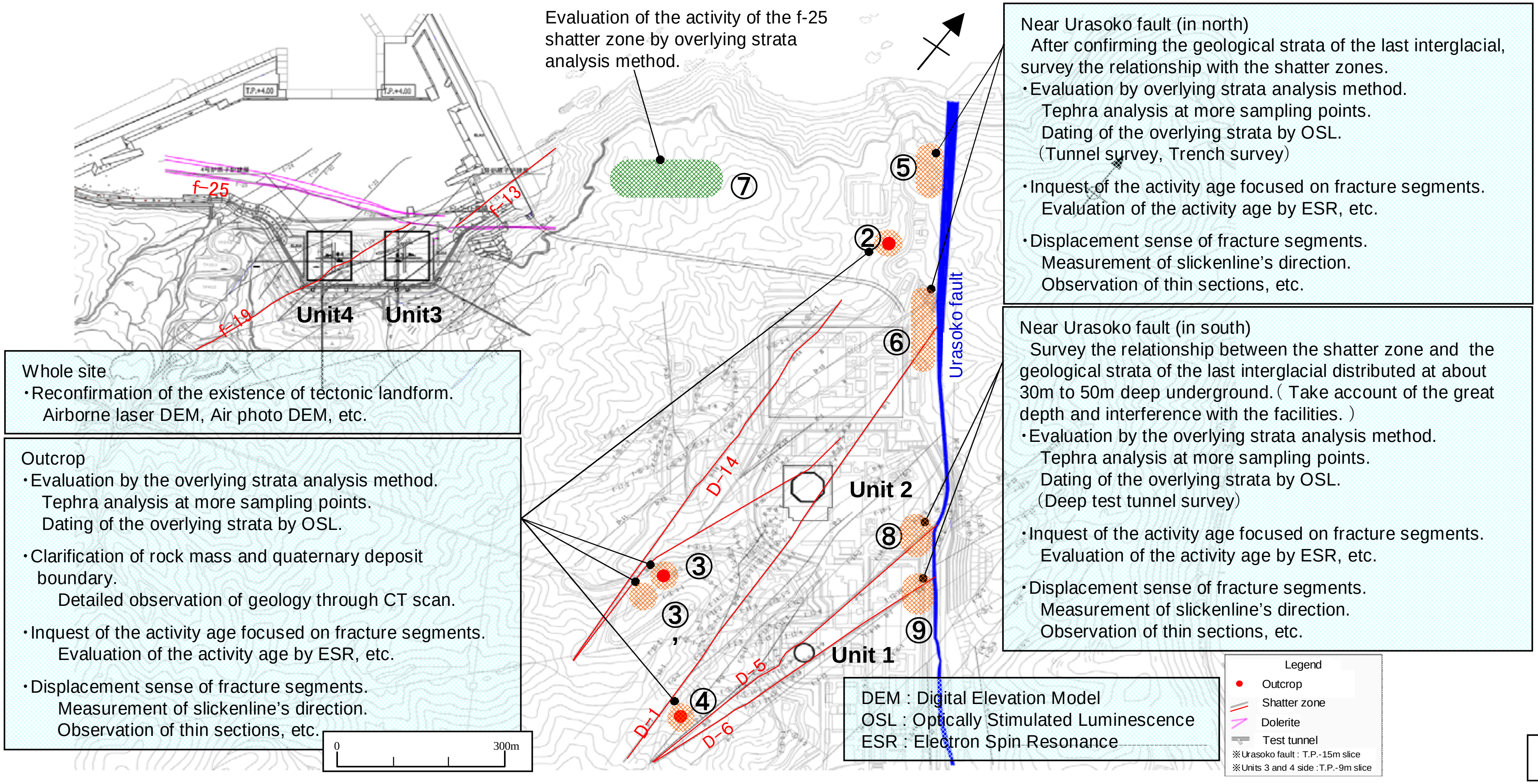
- Urasoko fault is a fault with an uplifting in the northeastern side between Kojaku granite (aplite) and Quaternary deposit.
- Based on the results of trench survey etc., it is judged that the fault has been repeatedly active after the Late Pleistocene.
- It is judged that the last slip was at least no earlier than 4,000 years ago.
- Clay-like portions in the fault gouge are in various color tones and are distributed in striped.
- The fracture segment falling into the lower land side is displaced by a fault in the back.

Background of additional surveys on the shatter zones

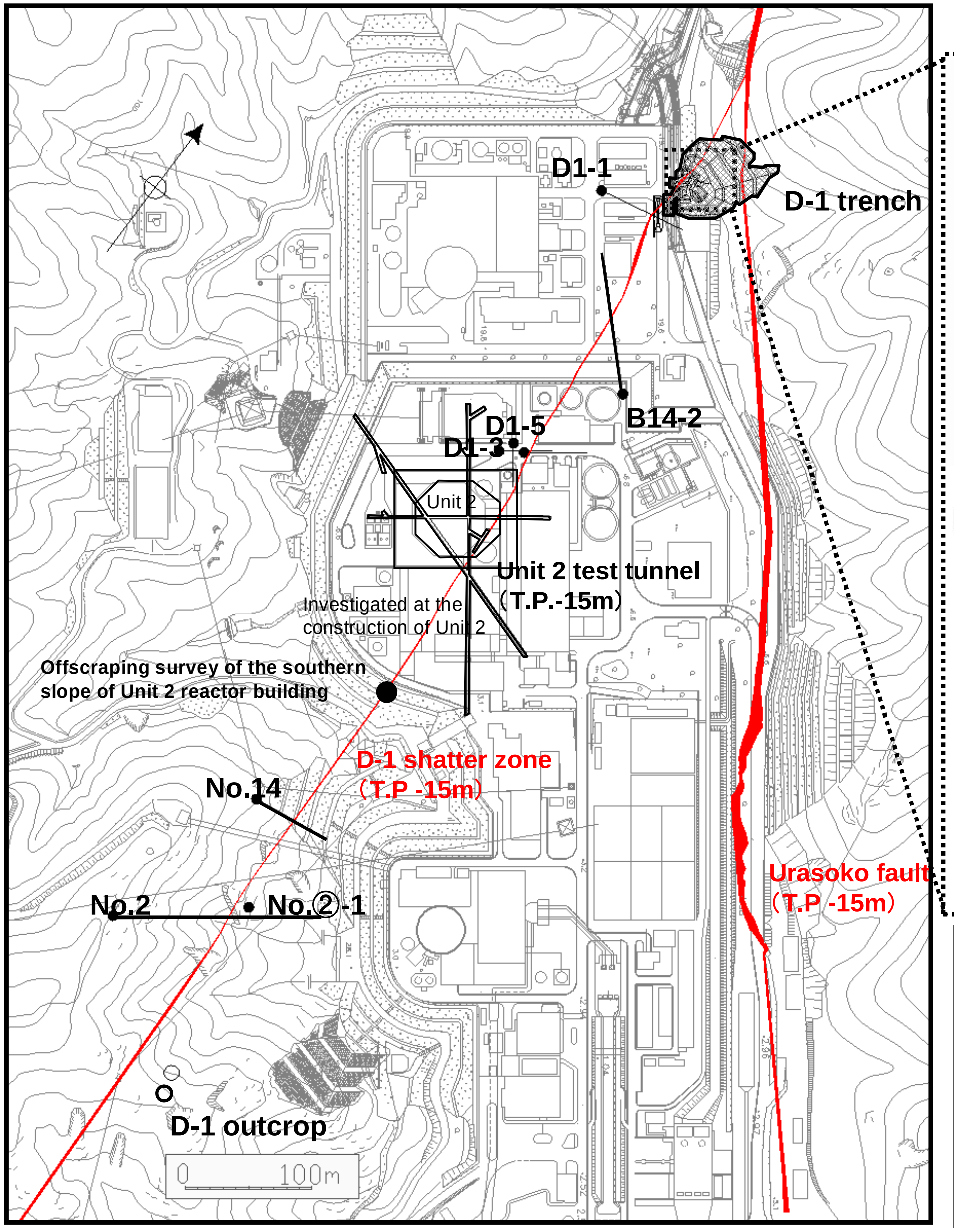
○ The additional geological surveys have been carried out in order to collect additional data based on the opinions expressed by the Nuclear and Industrial Safety Agency (NISA) during the survey on the shatter zones in the site of Tsuruga PS on April 24, 2012 and the instructions issued by NISA,

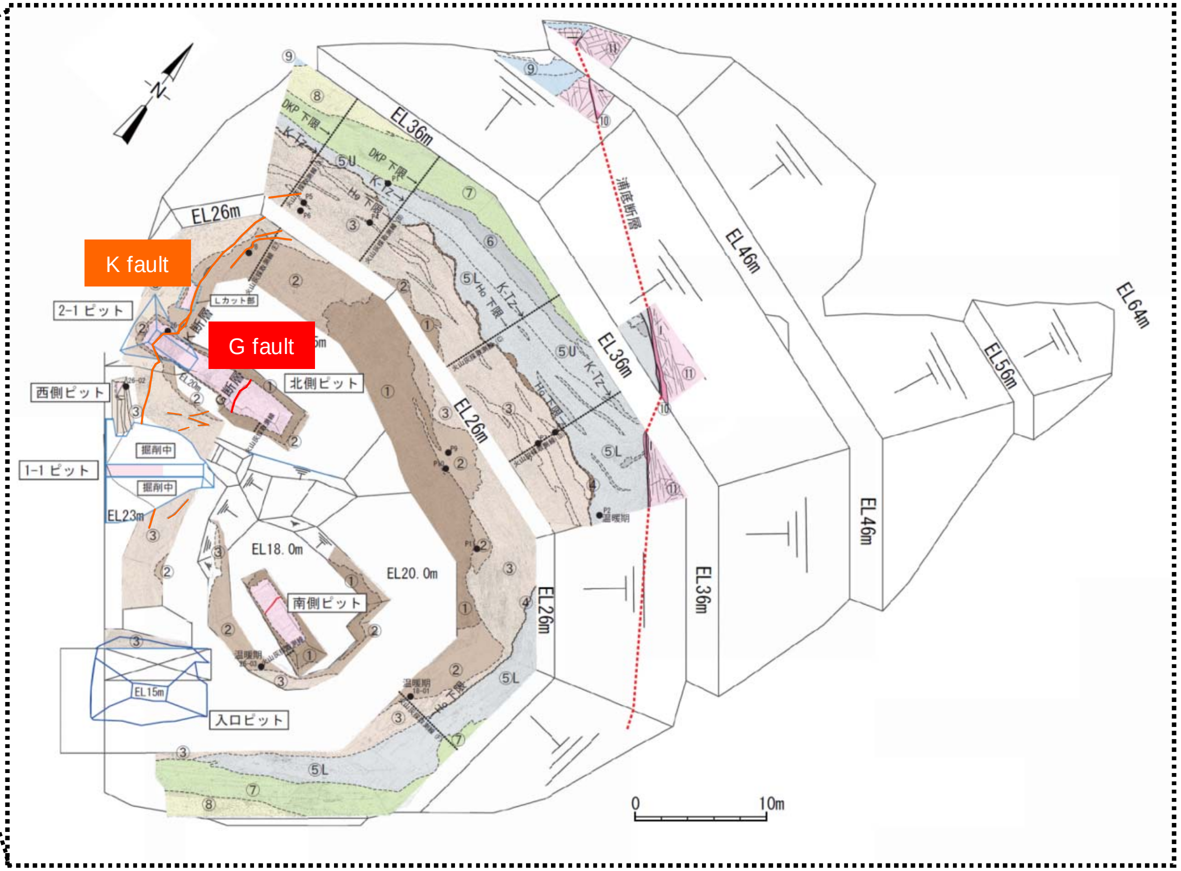
○The basic principles and the specific plan for the additional surveys were explained at the hearing about earthquake and tsunami on May 14, 2012.

- Evaluation of activities of the crush 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.



About the D-1 shatter zone and the G fault, the K fault





- ･In order to evaluate the activity of the D-1 shatter zone, the D-1 trench has been bored.
- ･Expert Meeting call a fault “G fault” which the JAPC considers as the D-1 shatter zone.
- ･Same as the above, Expert Meeting call a shear plane “K fault” which was found at an wall of the D-1 trench and has displaced or deformed Quaternary deposit.

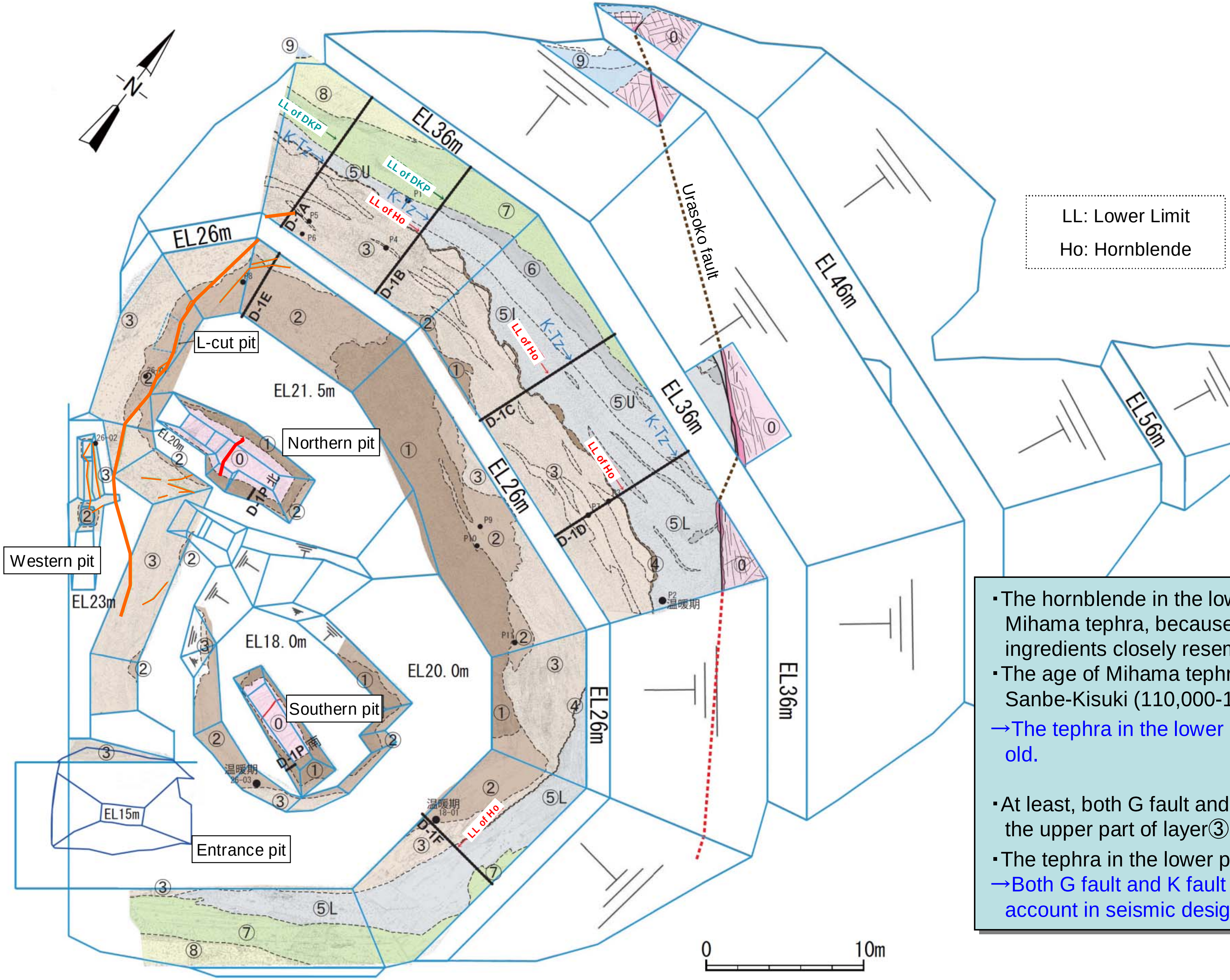
【Issues at the Expert Meeting】

① Depositional ages of the layers in D-1 trench

② Activity period of the fault found in D-1 trench (K fault and G fault)

③ Relations between the fault found in D-1 trench (K fault and G fault) and D-1 shatter zone.

Geological plan of D-1 trench



- ・The hornblende in the lower part of layer⑤ corresponds with Mihama tephra, because their refractive indexes and main ingredients closely resemble each other.
- ・The age of Mihama tephra is pointed out to be earlier than that of Sanbe-Kisuki (110,000-115,000 years old) by Yasuno.T(1991).

→The tephra in the lower part of layer⑤ is about 120,000 years old.

- ・At least, both G fault and K fault haven't displaced or deformed the upper part of layer③ and the lower part of layer⑤.
- ・The tephra in the lower part of layer⑤ is about 120,000 years old.

→Both G fault and K fault are not "active faults to be taken into account in seismic design."

① Depositional ages of the layers in D-1 trench

【JAPC: at Expert Meeting (Apr.24, 2013)】

・The hornblende in the lower part of layer⑤ corresponds with Mihama tephra, because their refractive indexes and main ingredients closely resemble each other.

・The age of Mihama tephra is pointed out to be earlier than that of Sanbe-Kisuki (110,000-115,000 years old) by Yasuno.T(1991).

→The tephra in the lower part of layer⑤ is about 120,000 years old.

【Expert Meeting: at NRA meeting (May 22, 2013)】

・ Regarding the tephra in the lower part of layer⑤ both "identification of its horizon" and "identification of it" are insufficient.
 ― Certification of tephra horizon : content rate of hornblendes is low frequency (under 1 count par 3000 counts).
 ― Identification of volcanic ashes : source volcano, stratigraphic sequence, and formulation age are not fixed.

→It is difficult to identify the lower part of layer⑤ as a layer of about 120,000 years ago.

【JAPC: Survey report (Jul.11, 2013)】

【Identification of tephra horizons】

・Age of tephra are getting younger toward the upper layers.

・The tephra in the lower part of layer⑤ is broadly distributed in a lateral direction.

・The tephra in the lower part of layer⑤ is not found in layer③

→The tephra in the lower part of layer⑤ can be identified as a tephra horizon because it is deposited in an orderly manner without a mixture of other layers.

【Identification of tephras】

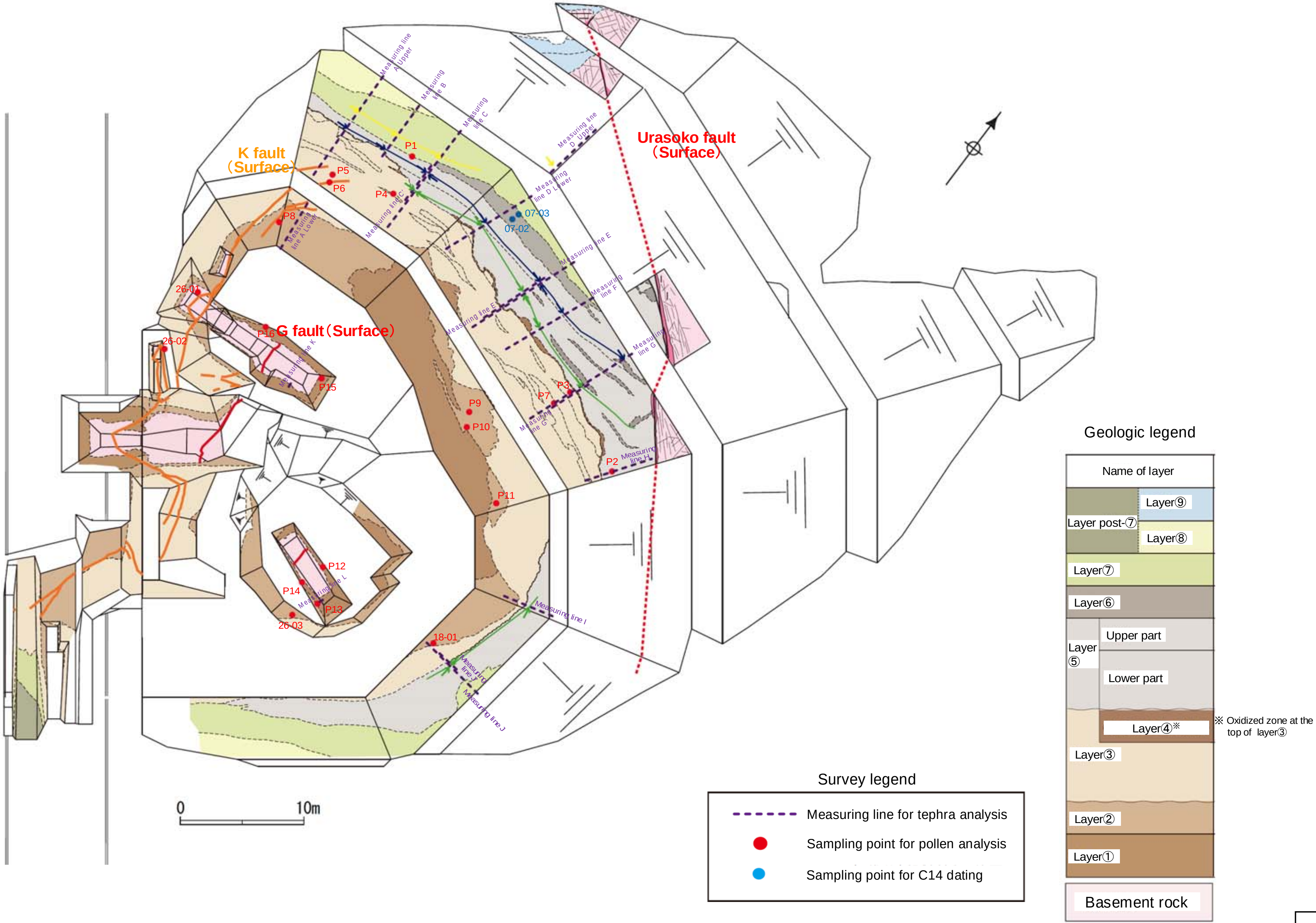
・Mihama tephra and various other tephras are compared each other by using analysis data of them.

→The age of Mihama tephra is identified to be about 127,000 years ago.

→Mihama tephra is identified to have fallen in a wide area.

Locations map of survey at D-1 shatter zone (Near D-1 trench）

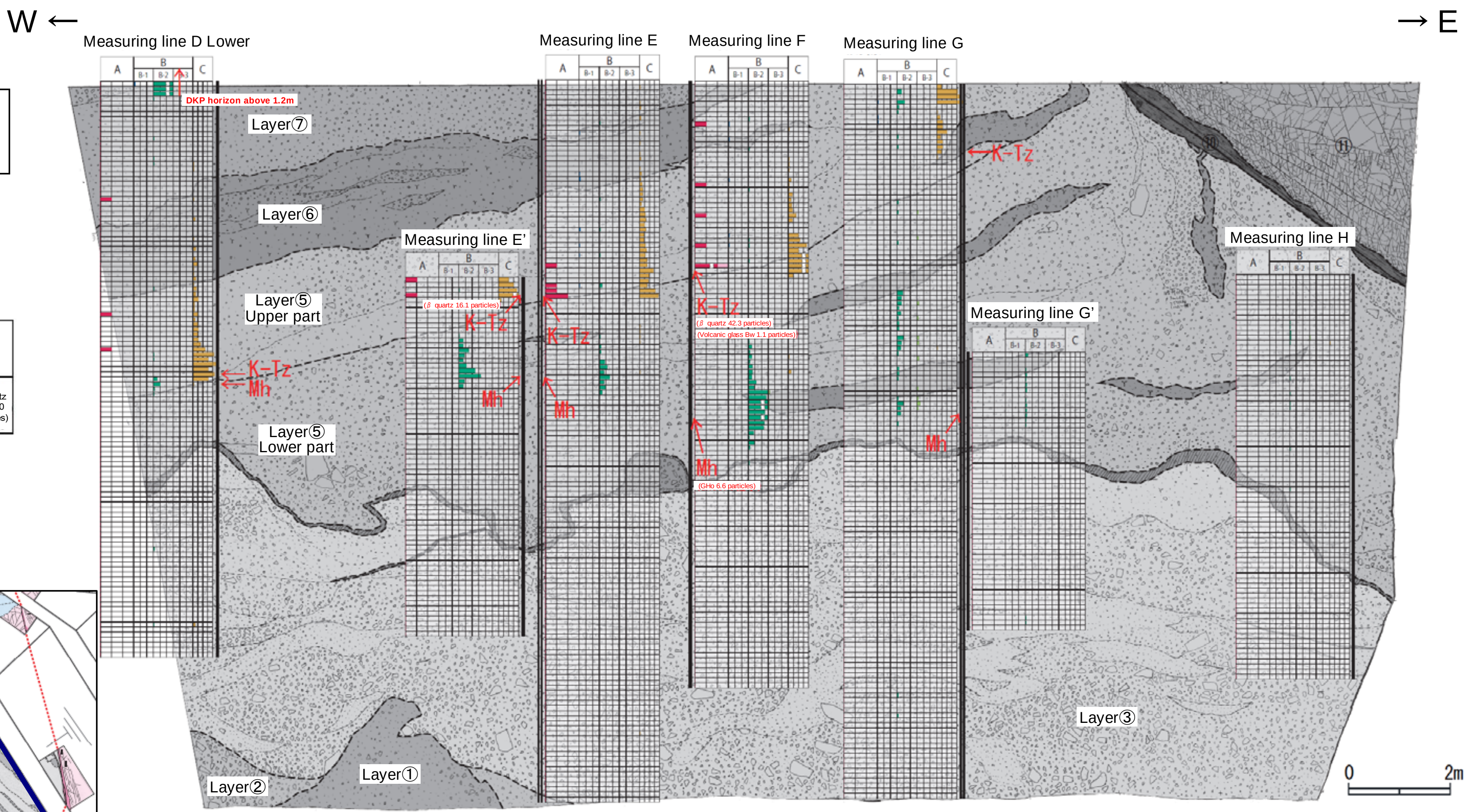
Data obtained after Apr.24, 2013 is reflected.



Tephra analysis at D-1 trench (projection on the slope surface 2/4)

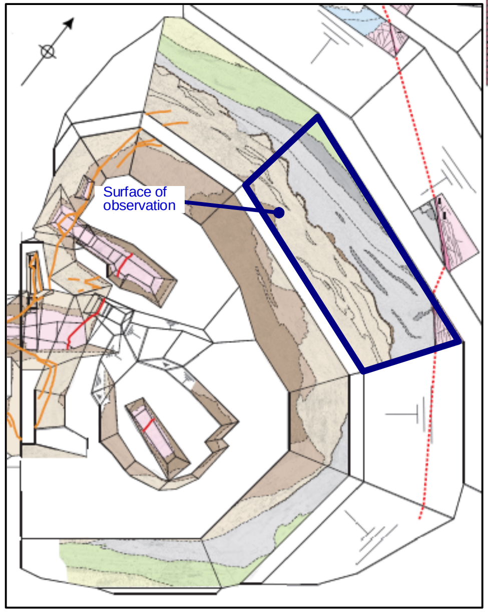
Data obtained after Apr.24, 2013 is reflected.

DKP: about 59ka-58ka
K-Tz: about 95ka
Mihama (Mh): about 127ka



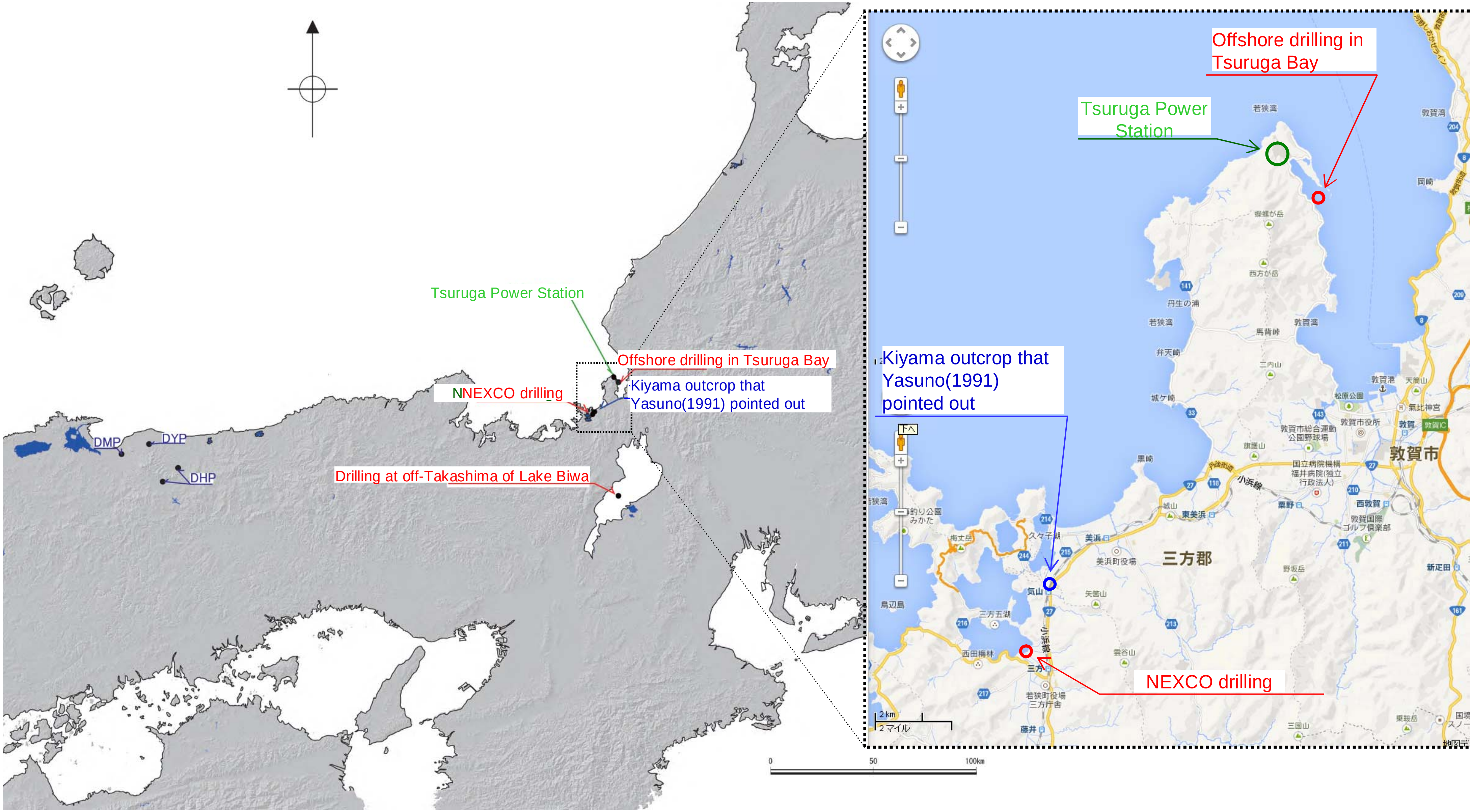
Legend

A	B			C
	B-1	B-2	B-3	
Content of volcanic glass by form (/3,000 particles)	Content of heavy mineral (/3,000 particles)			β quartz (/3,000 particles)
0.1 0.2	Opx 1 2	GHo 1 2	Cum 1 2	



- Tephras are found in the order of DKP, K-Tz and the tephra in the lower part of layer⑤ (Mh) from the upper side, and no inversion is observed in the lower occurrence limits of each tephra.
- The lower occurrence limit of the tephra in the lower part of layer⑤ (Mh) is confirmed to be broadly distributed in a horizontal direction, and the peaks, which correspond to horizons, are found like K-Tz etc, at the multiple measuring lines.
- A small amount of hornblende is found in layer③.

Survey on regional distribution of tephra (location of existing surveys)



・This figure indicates the location of sampling points of tephra of which JAPC implemented main ingredient analysis of hornblende, etc.
・Mihama tephra is detected at Kiyama outcrop that Yasuno(1991) pointed out, then NEXCO80(Lower) at NEXCO drilling, and BT37 at off-Takashima of Lake Biwa, respectively. Offshore drilling in Tsuruga Bay was implemented by JAPC.

Comparison between the tephra in the lower parts of layer ⑤ with tephras distributed through a wide area

Tephras older than K-Tz and with hornblende that indicate similar refraction indexes to that of the lower part of layer⑤.

◆Volcanic atlas（Matida etc.(2003)）

・Daisen Hiruzenbara（DHP）
・Daisen Matsue（DMP）
・Daisen Bessyo（DBP）
・Daisen h2（hpm2）
・Daisen h1（hpm1）
・Daisen Yodoe（DYP）
・Daisen Okutsu（DOP）

◆Other tephra.

・Mihama tephra
・NEXCO80（Lower）
・BT37

} Considered to be same（resemblance of primary components of volcanic glass etc.）

↓

Tehpras with the same primary component of hornblendes

- Mihama tephra
- NEXCO80(Lower)
- BT37（Tephra about 127,000 years ago）

↓

The age of the tephra in the lower part of layer⑤ is about 127,000 years ago.

② Activity period of the fault found in D-1 trench (K fault and G fault)

【JAPC: at Expert Meeting (Apr.24, 2013) 】

・At least, both G fault and K fault haven't displaced or deformed the upper part of layer③ and the lower part of layer⑤.

・The tephra in the lower part of layer⑤ is about 120,000 years old.

→Both G fault and K fault are not "active faults to be taken into account in seismic design."

【Expert Meeting: at NRA meeting (May 22, 2013)】

・Evaluation of the sedimentation period of layer⑤ is insufficient.

・It could be considered that the sedimentation period of layer③ is not much earlier than that of layer⑤ and layer③ a relatively new layer because of the appearance of weathered gravels in it.

→K fault is an "active fault to be taken into account in the seismic design" because the possibility of it to have been active after the Late Pleistocene cannot be denied.

【JAPC: Survey Report (Jul.11, 2013) 】

・The age of Mihama tephra, which corresponds to the tephra in the lower part of layer⑤, is about 127,000 years old.

・The sedimentation period of layer③ is the Middle Pleistocene from the result of offshore drilling in Tsuruga Bay.

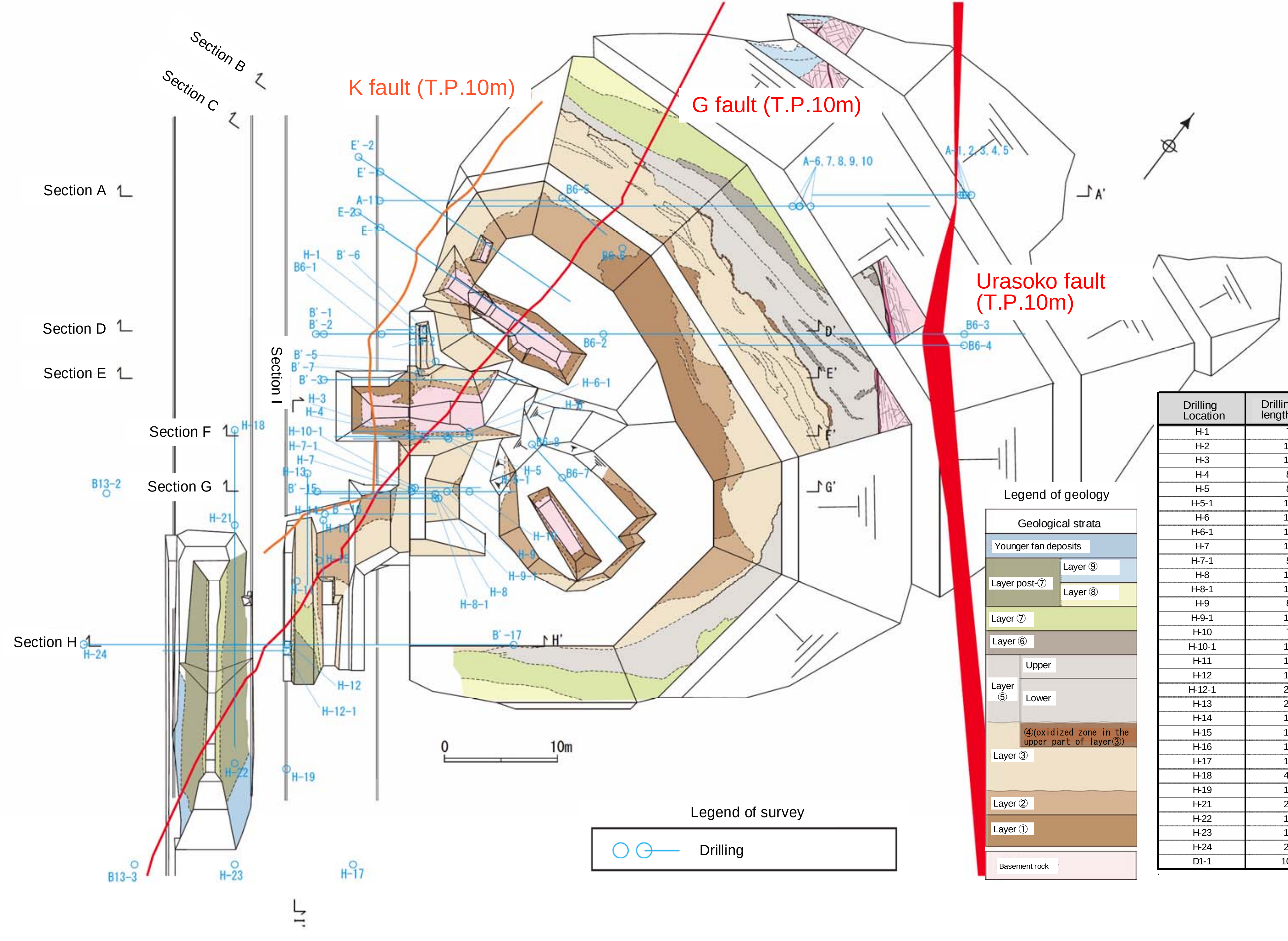
・It is also confirmed that K fault has not displaced or deformed the upper part of layer③ in Genden road pit, though the activity of K fault has been evaluated in only one survey point (the northern wall of D-1 trench).

・K fault has some characteristics: running along a serpentine course in the basement rock near D-1 trench, and decreasing its displacement sharply and disappearing in a quite narrow area.

→It is elucidated that K fault is not an "active fault to be taken into account in the seismic design.

Location map of drilling in D-1 trench

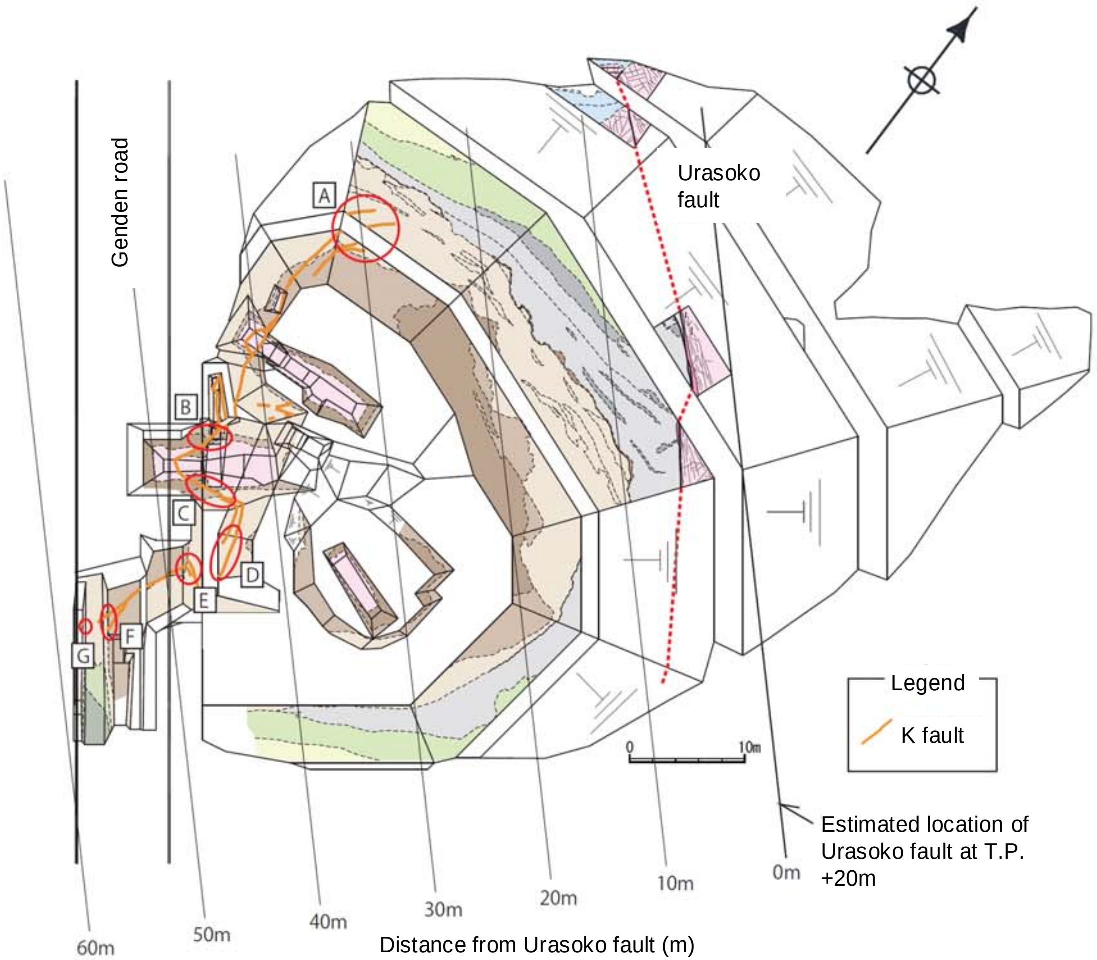
Data obtained after Apr.24, 2013 is reflected.



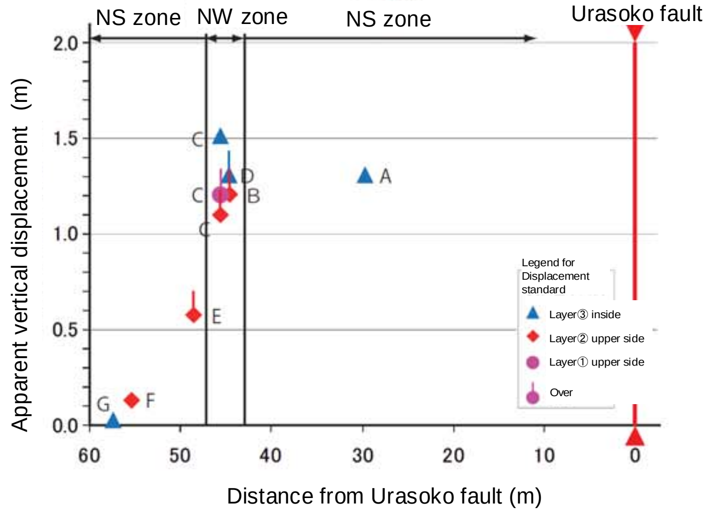
Drilling Location	Drilling length (m)	Angle (°)
H-1	7	70
H-2	10	70
H-3	11	90
H-4	8	90
H-5	8	90
H-5-1	10	45
H-6	17	45
H-6-1	15	45
H-7	11	90
H-7-1	5	90
H-8	17	45
H-8-1	12	45
H-9	8	90
H-9-1	12	60
H-10	7	90
H-10-1	17	70
H-11	11	90
H-12	12	90
H-12-1	20	60
H-13	20	60
H-14	12	90
H-15	16	90
H-16	15	65
H-17	16	90
H-18	40	45
H-19	13	90
H-21	28	45
H-22	13	90
H-23	15	90
H-24	23	50
D1-1	100	45

Displacement of K fault

Data obtained after Apr.24, 2013



The apparent vertical displacement around K fault is over 1.2m to 1.8m, approximately same from northern N-S zone to NW-SE zone. In contrast, at southern NS zone from slope of removed retaining wall, displacement decreases sharply, and is about 0.05 m at west-facing slope of Genden road (G).

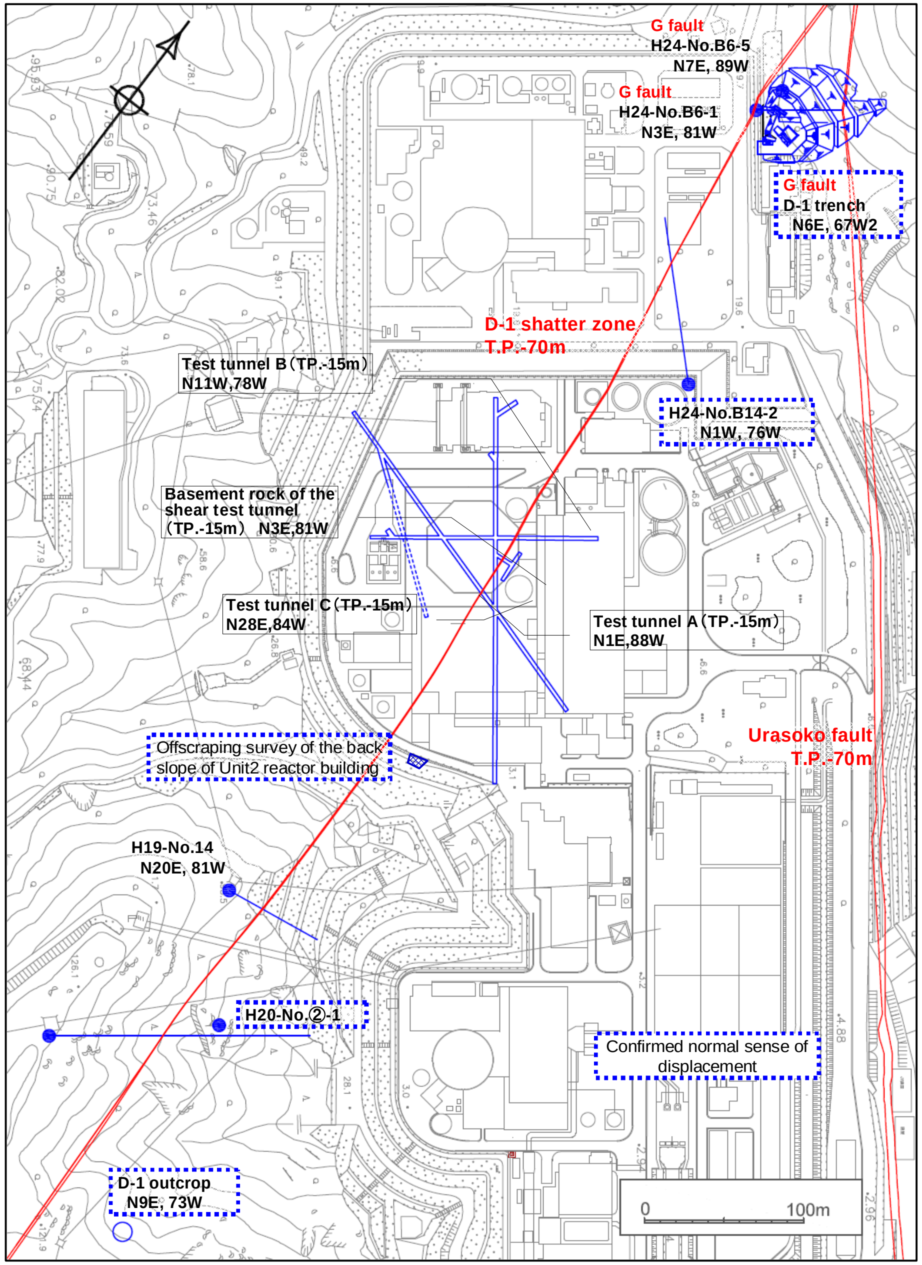


Variation of apparent vertical displacement against distance from Urasoko fault

	Location	Displacement standard	Apparent vertical displacement	Remarks
A	Northern part of K fault	In layer③	1.3m	Sum of the displacements of three branched faults, including flexure
B	Northern wall of 1-1 pit	Upper surface of layer②	Over 1.2m	Estimated over 1.2m including flexure
C	Southern wall of 1-1 pit	Layer① Uppersurface of layer② In layer③	1.2m Over 1.1m 1.5m	Including flexure
D	Backside slope of retaining wall	In layer③	Over 1.3m	Including flexure
E	Slope of removed retaining wall	Upper surface of layer②	Over 0.6m	Sum of the displacements of three branched faults is 0.6 m. Over 0.6m if Including flexure,
F	East-facing slope of Genden street	Upper surface of layer②	0.15m	Sum of the displacements of two branched faults, flexure is not recognized.
G	West-facing slope of Genden street	In layer③	0.05m	Flexure is not recognized.

- The apparent vertical displacement of K fault in the Quaternary deposit decreases sharply in quite narrow area, and is almost disappears in the west-facing slope of Genden road pit.
- K fault has not displaced or deformed the upper part of layer③.

Continuity between D-1 shatter zone, G fault and K fault



③ Relations between the fault found in D-1 trench (K fault and G fault) and D-1 shatter zone

【JAPC: at Expert Meeting (Apr.24, 2013) 】

・'The strike and the dip' and 'the displacement senses of the last slips' of the D-1 shatter zone is similar to the G fault but not to the K fault.
→ The D-1 shatter zone continues to the G fault but not to the K fault.

・The strike of the K fault changes from N-S to NNW-SSE in the D-1 trench.
・At drilling hole B14-2, the fracture segments had the reverse fault senses which is the feature of the K fault has not been recognized.
→ At least, the K fault does not extend southward (i,.e., toward Unit2 reactor building) beyond B14-2 drilling hole.

【Expert Meeting: at NRA meeting (May 22, 2013)】

・It is likely that the JAPC has not appropriately identified the displacement sense of the last slip.
→It cannot be determined that the G fault and the D-1 shatter zone are identical.

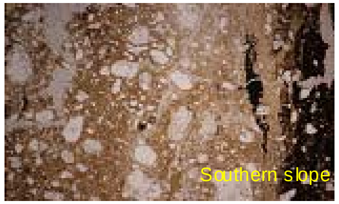
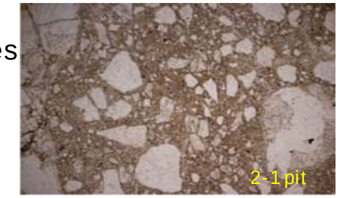
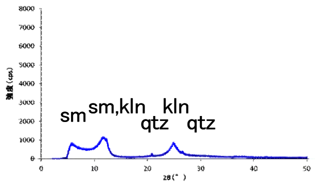
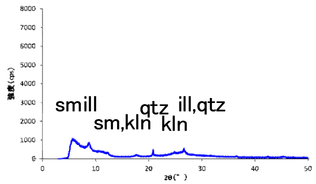
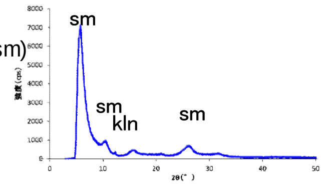
・Both the G fault and the K fault are located near the extension of the D-1 shatter zone, and their shapes (strike and dips) are very similar to that of D-1 shatter zone.
→It is highly likely that G fault and K fault have continuous structure with D-1 shatter zone.

【JAPC: Survey Report (Jul.11, 2013) 】

・Totally considering the continuity between D-1 shatter zone, G fault and K fault with additional viewpoints.
(Viewpoints so far)
"Strike and dip" and "Displacement sense of the last slip"
(Additional viewpoints)
"Structure of fault gouge", "Color tone of fault gouge", "Component minerals of fault gouge", etc.
→ It became much clear that the D-1 shatter zone continues to the G fault but not to the K fault.

Data obtained after Apr.24, 2013 is reflected.

Characteristics of the shatter zones

Characteristic	D-1 shatter zone (Back slope of Unit2 reactor building, D1-2 to D1-5 hole)	G fault (Northern pit of D-1 trench, etc.)	K fault (1-1 pit of D-1 trench, etc.)
Displacement sense	Normal fault	Normal fault	Reverse fault
Microstructure of fault gouge	・Constituent particles are grinded into round. ・Surface structure is developed and comparatively clear.  	・Constituent particles are grinded into round. ・Surface structure is developed and comparatively clear.  	・Constituent particles are angular gravel. ・Surface structures are not clear. 
Structure of fault gouge	Striped  	Striped  	No specific structure 
Color tones of fault gouge	Yellow, brown, etc.  	yellowish orange, brown  	Grayish red, grayish white, etc. 
Width of fault	Narrow	Narrow	Wide
Solidness of fault gouge	Tight	Tight	Soft
Strike	Mainly N-S	N-S	Widely snake in basement rock (between N-S and NE-SW)
X-ray diffraction analysis	Contain - smectite(sm) - kaolinite(kln) - quartz(qtz)  	Contain - smectite(sm) - kaolinite(kln) - quartz(qtz)  	Contain -high volume of smectite(sm) - kaolinite(kln) Not contain - quartz(qtz) 

Evaluation of continuity	**G fault continues to D-1 shatter zone.**	**K fault does not continue to D-1 shatter zone.**
Evaluation of activity	G fault has not displaced or deformed layer①. G fault is not “a fault that has a possibility to be active in the future”.	K fault has not displaced or deformed the lower part of layer⑤. K fault is not “a fault that has a possibility to be active in the future”.

On the issues below shown in the view of the Expert Meeting at May 22, the evaluation is implemented based on the survey results as of the eng of June.

① Depositional ages of the layers in D-1 trench

➢ The tephra in the lower part of layer⑤ is identified as a tephra horizon.

- Age of tephra are getting younger toward the upper layers.
- The tephra in the lower part of layer⑤ is broadly distributed in a lateral direction.
- The tephra in the lower part of layer⑤ is not found in layer③

➢ The age of Mihama tephra is identified to be about 127,000 years ago.

- Mihama tephra and various other tephras are compared each other.

② Activity period of the fault found in D-1 trench (K fault and G fault)

➢ K fault is not an "active faults to be taken into account in seismic design."

- The age of Mihama tephra in the lower part of layer⑤ is about 127,000 years old.
- The sedimentation period of layer③ is the Middle Pleistocene.
- It is confirmed that K fault has not displaced or deformed at the two survey points.
- K fault has some characteristics: running along a serpentine course in the basement rock near D-1 trench, and decreasing its displacement sharply and disappearing in a quite narrow area.

③ Relations between the fault found in D-1 trench (K fault and G fault) and D-1 shatter zone

➢ It became much clear that D-1 shatter zone continues to G fault but not to K fault.

(Viewpoints so far)
"Strike and dip" and "Displacement sense of the last slip"

(Additional viewpoints)
"Structure of fault gouge", "Color tone of fault gouge", "Component minerals of fault gouge", etc.

It is elucidated that both D-1 shatter zone (including G fault) and K fault are not "active faults to be taken into account in the seismic design.