International Review of the 2nd JAPC Report (July 2013) on Fracturing at the Tsuruga Nuclear Power Plant

Headline Findings

- **JAPC has responded to our previous recommendations and collected new geological information about the Tsuruga site;**
- **there is clear evidence that the K and G/D-1 faults at the Tsuruga NPP are not active: they have not moved in at least the last 120,000 to 130,000 years;**
- **there is a sound scientific basis for JAPC and NRA to enter a dialogue on continuing and improving (*kaizen*) the seismic safety evaluation and management of the Tsuruga NPP.**

K. Berryman, N. Chapman, W. Epstein, H. Kato, K. Okumura, P. Villamor and P. Yanev

28th August 2013

Contents

1 Context

This report brings together the review comments of two separate and independent reviews of the second JAPC report on fracturing at the Tsuruga NPP:

> *"Geology and Geological Structure of Tsuruga Power Station Site: Survey Report", July 11, 2013, The Japan Atomic Power Company.*

The two review groups (the IRG: International Review Group) and the TRM (Third-party Review Meeting) were established in March 2013 to review the interim reports on fracturing ('shatter zones') at the Tsuruga site, which were produced in March 2013 by JAPC.

The July report by JAPC presents substantial new information based on the results of additional work at the site and additional analyses of geologic materials.

The sub-group of members of the IRG and TRM who were able both to review the July JAPC report and visit the Tsuruga site on July 29th to see the geological evidence and have discussions with JAPC scientists were:

Dr Kelvin Berryman	GNS Sciences, New Zealand: IRG
Professor Neil Chapman	MCM Consulting, Switzerland and University of Sheffield, UK (IRG Project Manager & Report Compiler)
Mr Woody Epstein	Lloyd's Register Consulting, Japan (TRM project manager)
Dr Hirokazu Kato	Emeritus Researcher, AIST, Japan: TRM
Professor Koji Okumura	Hiroshima University: TRM
Dr Pilar Villamor	GNS Sciences, New Zealand: IRG
Dr Peter Yanev	Yanev Associates, California:TRM

This team comprises scientists who are experts in geosciences, earthquake engineering, risk assessment and nuclear power; they work widely with government agencies, the nuclear power industry, nuclear regulatory authorities and international agencies, such as the IAEA. Members of the team are experienced in the provision of independent scientific advice to both industry and regulatory decision-makers who require clear, unbiased scientific information.

Some members of this international team had a previous opportunity to visit the site during March and May 2013 to see the earlier work carried out by JAPC.

1.1 Aim and Approach

The aim of this review was to give JAPC an objective and unbiased assessment of the validity of the geological arguments presented in the new report, based on the team's assessment of the geological information and of the scientific approaches that had been used to evaluate these data.

We reviewed the July report produced by JAPC staff on geological aspects of the fractures at Tsuruga and visited the site to make a close examination of the rock formations and fractures in trenches, outcrops and drill-core. We had detailed discussions in Tokyo and Tsuruga with JAPC's staff and some of its geological consultants.

We are also familiar with the arguments presented by the NRA expert group on the fractures at the site and the differences in interpretation between these scientists and JAPC staff. We have read the relevant NRA reports but do not review or comment on these.

The following sections present a summary our findings, followed by more detailed comments in Annex 1. Annex 2 includes presentations made by team members at the August 1st Symposium held in Tokyo.

Our international team was also able to make suggestions to JAPC and NRA with respect to possible future work to ensure nuclear safety with respect to seismic hazard (Annexes 3 & 4).

2 Summary of the Main Findings

1. JAPC has carried out careful scientific investigations of the fractures that are of concern to NRA. These investigations have been designed to answer specific issues raised by NRA as well as to provide a background geological understanding of the fractures.
2. The latest report by JAPC contains substantial new and additional geological information gathered during May and June 2013, which clarifies issues raised by NRA experts in May 2013. We consider this new information to be a solid basis for renewed dialogue between JAPC and the NRA.
3. The main concern of NRA is that fractures 'K', 'G' and 'D-1' that lie close to or pass beneath Unit 2 could be 'active faults' or are fractures that could move sympathetically with an earthquake on the Urasoko Fault (which is known to have had episodic surface rupture every few thousand years).
4. We find that the JAPC investigations are sufficient to answer these specific concerns of NRA, although they do not comprise a comprehensive geological investigation. We return to this point later, in Section 5 of this report.
5. JAPC has provided adequate and convincing evidence, in particular in the additional work that it has carried out since May 2013, that the fractures of concern to NRA are not 'active faults', as defined by NRA.
6. We have seen clear evidence that these fractures have not moved at the site during at least the last 120,000 to 130,000 years – possibly longer.
7. We thus consider that the single, simple evaluation criterion of the presence or not of an 'active fault' beneath the NPP Unit 2 has been resolved and is not, in itself, a basis for action.

3 Commentary

3.1 High-Level Comments

1. The new evidence presented supports and strengthens the conclusions that were drawn from the March JAPC reports. None of the new evidence contradicts or changes those conclusions.
2. JAPC's counter-arguments to what it calls NRA's 'observational' comments ('observational' is assumed to be the meaning of "sensory" in JAPC's open letter of May 22nd) seem to be firmly based on new scientific evidence.
3. We found the structural evidence and the stratigraphic chronological evidence for the age of the last movements of the K and G structures to be compelling and powerful. This evidence was seen in the report and in the field. We also saw evidence that G and D-1 are structurally connected (hereafter, G/D-1).
4. The apparent NRA requirement simply to prove 'active' or 'not active', has been clearly resolved by this new evidence demonstrating considerable (120 - 130 ka or greater) age for the last movements of the K and G/D-1 structures.
5. Given that neither structure has moved in response to repeated movements (perhaps of the order of 20 or more) of the Urasoko Fault over this period, the probability of these structures moving in the next displacement of the Urasoko Fault is low.

3.2 More detailed comments

The key topics that need to be addressed in order to understand whether structures are active or not concern their geometry and physical properties, and the dating evidence for their movement (chronology), which comes from the overlying Quaternary stratigraphy, supplemented by marine borehole core data. We deal with these two areas separately below.

3.2.1 Fault and Fracture Geometry

1. The connectivity of G with D-1 across the site is based on data from trench D-1, the exposure south of Unit 2, the original mapping of the foundation excavations for Unit 2 and interpretations from numerous drill holes. Thus, it is well-established that the G fault and the D-1 shatter zone are the same structure. The fact that this G/D-1 structure is very old and does not cut the Late Pleistocene sediments is unequivocally illustrated in the new pits in trench D-1. The obvious conclusion that D-1 is not an active structure seems not to be in contention.

2. Statistical analyses were carried out on the attitudes of the shear zones and associated joints and striations. The results indicate that the G fault and the D-1 shatter zone have the same attitudes and accompany identical joint systems. The K fault has considerably different characteristics from the G/D-1 fault. The strike of the K fault changes markedly between NW-SE to NNE-SSW. The dip of the K fault decreases (to a low angle) near the ground surface,, a phenomenon that is common in reverse faults that displace deposits in surface layers. Slickenline data and displacement of Layers 1, 2, and 3 confirm that the K fault has dominantly reverse movement with a small left-lateral component. The technical procedures and the results of the microscopic analyses of the most recent rupture surfaces were thoroughly reevaluated and were judged as appropriate. The resulting microscopic analyses lead to the same conclusion as the statistical analyses.

3. The south termination of the K fault is confirmed around the NE boundary of the Fugen site (Genden road pit). The K fault in the D-1 trench shows a rather sinuous trace, with changing strike (N-S, then NW-SE, then NNE-SSW and then N-S, in a southward direction away from the Urasoko fault) and dip. The displacement of Layer 2 decreases from about 1.2 m to <0.05 m, from north to south. The decrease of displacement, as well as the changing strike, suggests fault termination. No other strands of the fault displacing Layers 1, 2, and 3 are observed along the section that shows both the decreasing separation and its south section. This indicates that there are no other Late Pleistocene fault strands to which the slip of the K fault is transferred. Many cored boreholes are arranged in a fan shape to intersect any possible continuation of the K fault. They show no evidence of fault activity similar to the K fault in the bedrock. The K fault thus does not continue towards Unit 2.

4. The evaluation of ‘other shatter zones’ (D-5, 6, 15; H-3a etc) in JAPC’s new report is currently inconclusive, as there are insufficient data to make definitive statements about their movement history and ‘activity’.

3.2.2 Chronology

1. Much of the argument presented is based on new data on tephra ages. In particular, the absolute and relative ages of the ash in Layers 3 and 5 are critical. After carefully evaluating the data, we confirm that the highest level conclusions drawn by JAPC are sound: i.e., that the tephra units are different, but that both ash layers are 120 to 130 ka or older. The inclusion of marine sediment core data has been valuable. But there are some minor issues with the scope and presentation of the approach to comparing units in order to correlate them, in particular using the hornblende compositional data:

    a. the report talks of principal component analyses on hornblende, but they are actually only cross-plots of major element concentrations: a more rigorous statistical analysis of the chemical analytical data would increase confidence that all of the conclusions drawn from these comparisons are correct (e.g. with respect to the Layer 5 comparison with DMP, hpm1, hpm2, DOP);

    b. In recent studies on tephra correlations (e.g. extensive work over the last 20 years in New Zealand, Europe, the USA and Japan), comprehensive statistical analyses of geochemical analytical data from more minerals (e.g. titano-magnetites, orthopyroxene) and volcanic glass are used. The approach can be used in the correlation of Mihama tephra, NEXCO-80 core and Lake Biwa Takashima-oki core. Also, analytical data (in addition to the hornblende compositional data) would be obtained from the tephra layer that mainly comprises hornblende of Layer 5 and 3.

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2. We have discussed these issues with JAPC and we understand that they are rectifying them. Regardless of these matters, we find the evidence supporting the following critical conclusions is strongly illustrated by the stratigraphic and geochemical data. The horizon of the Mihama tephra in the Layer 5 is confirmed as a clear horizon of concentrated, unique hornblende phenocrysts. Direct correlations among samples from Layer 5, the submarine drill core in Tsuruga Bay south of the site, the Kiyama type locality of the Mihama tephra and the NEXCO-80 core at Mikata were carried out. Also, indirect correlation with the Lake Biwa Takashima-oki scientific drilling and the Suigetsu 2006 scientific drilling was evaluated. All the results show the age of the Mihama tephra to be between MIS6 and MIS5e. Correlation using only hornblende phenocrysts is a developing technology challenge and uncertainty remains. However, there is no contradictory evidence for the inference that the hornblende in Layer 5, the hornblende layer identified in the offshore core equivalent to MIS5e and the Mihama tephra are correlated, and that all of these tephra are MIS5e.

3. We thus highlight the following key chronology findings:

   a. Layer 3 and Layer 5 contain particles of phenocryst minerals that come from different tephra;

   b. The phenocryst particles from the tephra in Layer 3 probably correlate with those of the MIS6 tephra identified in the offshore core;

   c. The phenocryst particles from the tephra in Lower Layer 5 correlate well with those from the tephra identified in the offshore core and those of the Mihama tephra of MIS5e age from other regional sites;

   d. All of these tephra are in the 120 to 130 ka age range or older (Middle Pleistocene to the beginning of Late Pleistocene) range.

4. Combined with the physical evidence that *(a)* G and D-1 are the same (with dominant evidence for normal faulting) structure (see below) and do not displace these layers and *(b)* that K (a wandering reverse fault with no apparent connection to G/D-1, terminating well before reaching Unit 2) also does not displace these layers, this is strong additional evidence that there are no detected 'active' structures beneath Unit 2. Based on the trench exposures observed, the last activity of the K fault took place in the Middle Pleistocene and it is thus not an active fault as defined by the NRA and (as noted in 3.1 Bullet 5) we consider it unlikely to be activated in the next movement of the Urasoko Fault.

5. The palynology data are sparse and do not yet provide strong support to the age measurements across all of the critical parts of the sequence of Layers. The preservation of the pollen is likely to be much more complete in the marine core, and if the tephra are well correlated then the palynology could also be used much more effectively to anchor the chronology of the sediment units.

6. We have more detailed comments, which are contained in Annex 1 to this report.

4 Conclusions

Based on our review, we draw the following headline conclusions:

- **JAPC has responded to our previous recommendations and collected new geological information about the Tsuruga site;**
- **there is clear evidence that the K and G/D-1 fractures at the Tsuruga NPP are not active: they have not moved in at least the last 120,000 to 130,000 years;**
- **there is a sound scientific basis for JAPC and NRA to enter a dialogue on continuing and improving (*'kaizen'*) the seismic safety evaluation and management of the Tsuruga NPP.**

5 Suggested Approaches to Future Work

As stated above, we conclude that the geological uncertainty on whether the K, G and D-1 fractures are active, with respect to NRA's definition, has been resolved by new obtained information, which elucidates them to be inactive. We understand that only this simple investigation was requested by the NRA and this has now been completed. However, we consider that the proper engineering approach to assessing and managing seismic hazards and their impact on nuclear safety at the Tsuruga NPP site requires broader considerations than just the simple investigation of fault activity.

At present both the NRA and the JAPC have concentrated on the activity of specific structures at the site. Best-practice approaches for re-evaluation of existing NPPs recommended by the IAEA[1] are to carry out a much fuller analysis of the hazards as a basis for decision-making based on scientific and engineering reasoning. This might include an analysis of the likelihood of future movement of the Urasoko Fault and the possibility of any associated distributed fault displacements, which could be used to evaluate potential impacts on structures at the NPP and engineering measures to mitigate these. This risk-informed fault displacement hazard analysis should bring together more and better-prepared data, and the views of a wider range of experts, under a formal expert elicitation scheme, to look at the nature and likelihoods of displacements in and near the NPP site. Together with assessment of conditional impacts on the NPPs (i.e. conditional on various scenarios of displacement of features present at the site), this will provide a risk-informed basis for rational, science-based decision-making.

In Annex 3, we make preliminary suggestions on some of the types of work that might be considered if NRA agrees to such a more comprehensive and regularly updated seismic risk evaluation. We consider that the scope of such work would need to be defined via dialogue between JAPC and the NRA, so we recognise that these suggestions would only be one input to such discussions.

We thus make the following recommendations.

1. We recommend that the seismic hazard analysis of the NPP should be continually improved and updated with new data and techniques, as they arise ('living safety assessment'). It should be broadened to include all aspects of seismic hazards (in addition to seismic shaking), including the possibility of distributed fracture displacement near the facilities in the event of movement on the Urasoko Fault. We consider this to be in-line with international best-practice, as recommended by the IAEA in its Safety Standards documents.

2. We consider that JAPC and the NRA should work closely together to define and agree the scope and structure of such an assessment. This is a similar approach to the Long Term Seismic Program used by the USNRC and Pacific Gas and Electric at the Diablo Canyon Nuclear Power Plant in California (see Annex 4).

3. We consider that it would be valuable to subject this work to independent peer review.

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[1] In this context IAEA safety Guide SSG-9 gives clear guidance on re-evaluation of existing facilities where there is uncertainty about fault capability: *"However, it may be the case that information comes to light that requires a new assessment of fault displacement potential to be made. In such circumstances, efforts should first be made to acquire further data relating to the fault of concern. It may be that, by using the definition and the deterministic methodology described in paras 8.3–8.7, no sufficient basis is provided to decide conclusively that the fault is not capable. In this case, with the totality of the available data, probabilistic methods analogous to and consistent with those used for the ground motion hazard assessment should be used to obtain an estimate of the annual frequency of exceedance of various amounts of displacement at or near the surface"*.

Annex 1: Detailed Comments Pertaining to Section 3

The following comments relate to topics outlined in Section 3.

Continuity of the D-1 shatter zone

1. The correlation of the D-1 shatter zone in outcrops, on the base map and in drill cores in the interim report seems to be correct but needs better documentation.
2. Fault zone structure: In macroscopic observations, on the southern slope south of the Unit 2 reactor building the D-1 shatter zone consists of a distinctive shear plane with greyish-brown to white fault gouge (10-20 mm thick) of N20°-30°E strike and steep westward dip and a ca. 1 m wide cataclasite zone with fractures or joints with N-S and N20°-30°E strike, dipping steeply to the west. The shear plane with fault gouge juxtaposes granitic rocks of a different colour and texture, indicating a significant amount of total slip. One or both sides of the white fault gouge zone are bordered by black bands. These characteristics are important to correlate the D-1 shatter zone with the G fault, and distinguish the D-1 shatter zone from the K fault. As a basis for the examination of microscopic features, it is important to confirm such macroscopic fault zone structures in drill cores and existing maps and photos.
3. Okamura has interpreted the D-1 shatter zone as N-S striking shear planes connected by right-stepping en-echelon N20°-30°E striking oblique shear planes within a network of joint systems of N-S and N20°-30°E strike. This model needs improvement and verification by structural geologists.

G fault characteristics and continuity to D-1 shatter zone

1. The G fault in the North pit of the D-1 trench and the D-1 shatter zone on the outcrop just south of the Unit 2 are identical for their macroscopic structural characteristics. This indicates the high probability that they were formed at the same time and location under the same geological conditions. In macroscopic observations, the G fault in the North pit accompanies a shatter zone that consists of a distinctive shear plane with yellowish-white fault gouge (ca. 20 mm thick) of N13°E strike dipping steeply to west and a ~1 m thick cataclasite zone with fractures or joints of N-S and N20°-30°E strike and steep westward dip. The shear plane with fault gouge juxtaposes granitic rocks of different colour and texture, indicating significant amount of slip. One side of the yellowish white fault gouge zone is bordered by a black band.
2. The continuity of the D-1 shatter zone has been demonstrated across the footprint of Unit 2 and is along strike of the G fault in the D-1 trench. Continuity north of Unit 2 toward the D-1 trench relies on drill hole control. The continuity of the D-1 shatter zone with the G fault can be more clearly shown with explicit compilation of all of the control points along their lengths.

K fault in D-1 trench

1. Displacements of the K fault occurred at or near Earth's surface, much shallower and fewer times than those on the D-1 shatter zone, judging by the much weaker development of fault rocks and gouge.
2. There is a very thin (10 mm or less) fault gouge along a clear shear plane, but there is no brecciation related to the shear plane. Sparse joints and cataclasite around the K fault appear to be old and discontinuous structures. The fault gouge and the shatter zone are much thinner than the Urasoko Fault. The fault trace curves significantly from N-S to NW-SE near its termination in the south. The NW-SE trend is different from the G fault and the D-1 shatter zone. The curvature created N-S to NNW-SSE oriented fractures. Thus, the K fault developed in a different manner to the G fault.
3. The upper termination of the K fault within Layer 3 has a lower dip angle and shows an upward bifurcation that are common features of reverse faults in unconsolidated sediments near the surface.
4. The difference in sedimentary layer thickness (of the order of centimetres) across the K fault plane in Layer 3 may indicate small amounts of strike-slip movement, which are due to the

curvature of the fault trace. However, there is no significant strike-slip movement, as indicated by multiple slickenline measurements.

5. The reason for movement of the K fault, in close proximity to the Urasoko Fault is intriguing. Hypothetically, an irregularity in the geometry of the Urasoko Fault could cause localized compression in its footwall (or hanging wall) and generate the reverse displacement we observe on the K fault. From observations of co-seismic surface ruptures, a restraining jog, bend, or salient of metre-scale might generate a 10-m-scale localized stress field in the area around the irregular fault geometry. The curvature and dying-out of the K fault indicate such localized tectonic conditions.

Regional tectonics and formation of individual structures.

1. Microscopic observations and outcrop-scale to hand specimen-scale observations of the kinematics of the G/D-1 structure and the K fault need to be compiled systematically and discussed with respect to the contemporary approximately E-W compressional stress field in the region of the Tsuruga Peninsula.
2. Under the E-W compressional stress field, the N-S striking and W-dipping D-1 shatter zone and G fault are likely to only be reactivated as a west-side-up reverse fault in the current tectonic setting. A minor left lateral strike-slip component may accompany the dip-slip component, but dip-slip should be predominant, considering the strike and the stress field.
3. Microscopic structural analyses of the D-1 shatter zone and G fault are indicative of predominantly normal faulting and slickenlines suggest lesser right-lateral strike-slip. Further thorough analyses should be carried out to exclude the possibility of over printed reverse faulting.
4. An E-W extensional stress field is observed in a wide region of Japan in the Middle Miocene from 20 to 15 Ma (million years ago) when the Sea of Japan opened. Tectonic movement within an E-W compressional stress field was initiated in the Pliocene (6 to 2.6 Ma) and culminated in the Quaternary. E-W extensional and E-W compressional are stress fields occurred in the different periods of geological time. Tectonic inversion, or reactivation of a N-S normal fault as a reverse fault under changing stress field from E-W extension to E-W compression occurred on a number of structures in the northeast region of Japan.

Stratigraphy and Chronology

1. The time horizon of 120-130 ka in the new safety guide is still the basic criterion to judge the future activity of a structure, with 400 ka as a secondary time horizon to supplement the 120-130 ka criterion in case there are no Quaternary deposits of 120-130 ka. If this is the rule, then the latest activity of the K fault is clearly older than 120-130 ka based on the weight of both tephra and palaeoclimate data from the site and the site area. The Mihama tephra seems to be a reliable time-marker, but its identification at the site is based solely on the presence of hornblende grains that are a single diagnostic of the tephra. The number of hornblende grains identified has been increased with substantial further sampling within the D-1 trench. These new data need to be assembled in a comprehensive way and correlated with statistical uncertainty to other occurrences of the Mihama tephra in the region.

Annex 2: Presentations from the August 1st Symposium

Late Quaternary Sediments in the Tsuruga NPP
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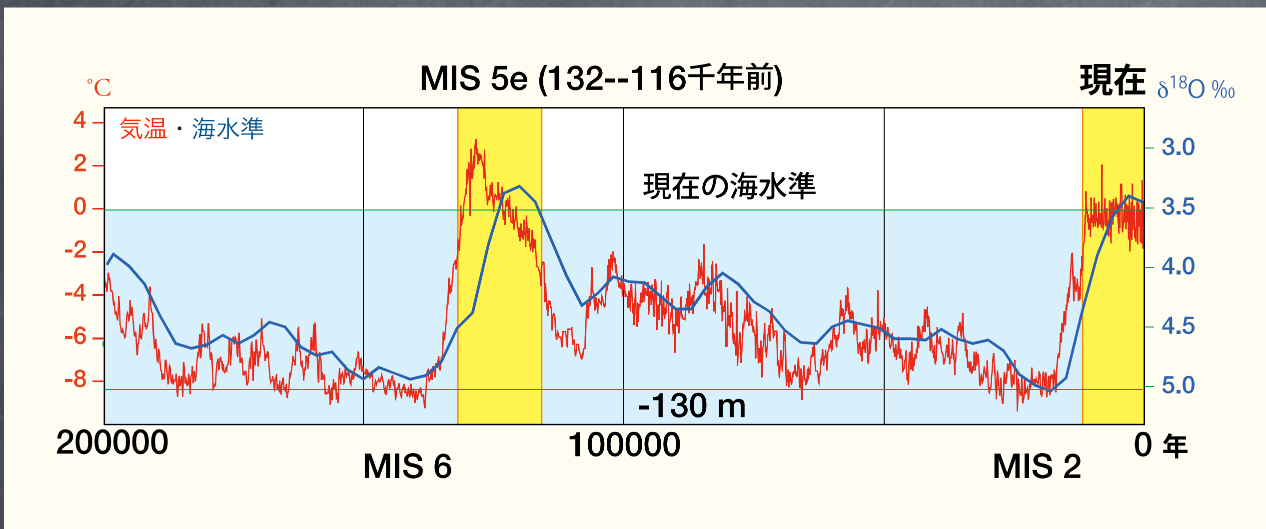
Sea-level changes, environmental changes, and chronology

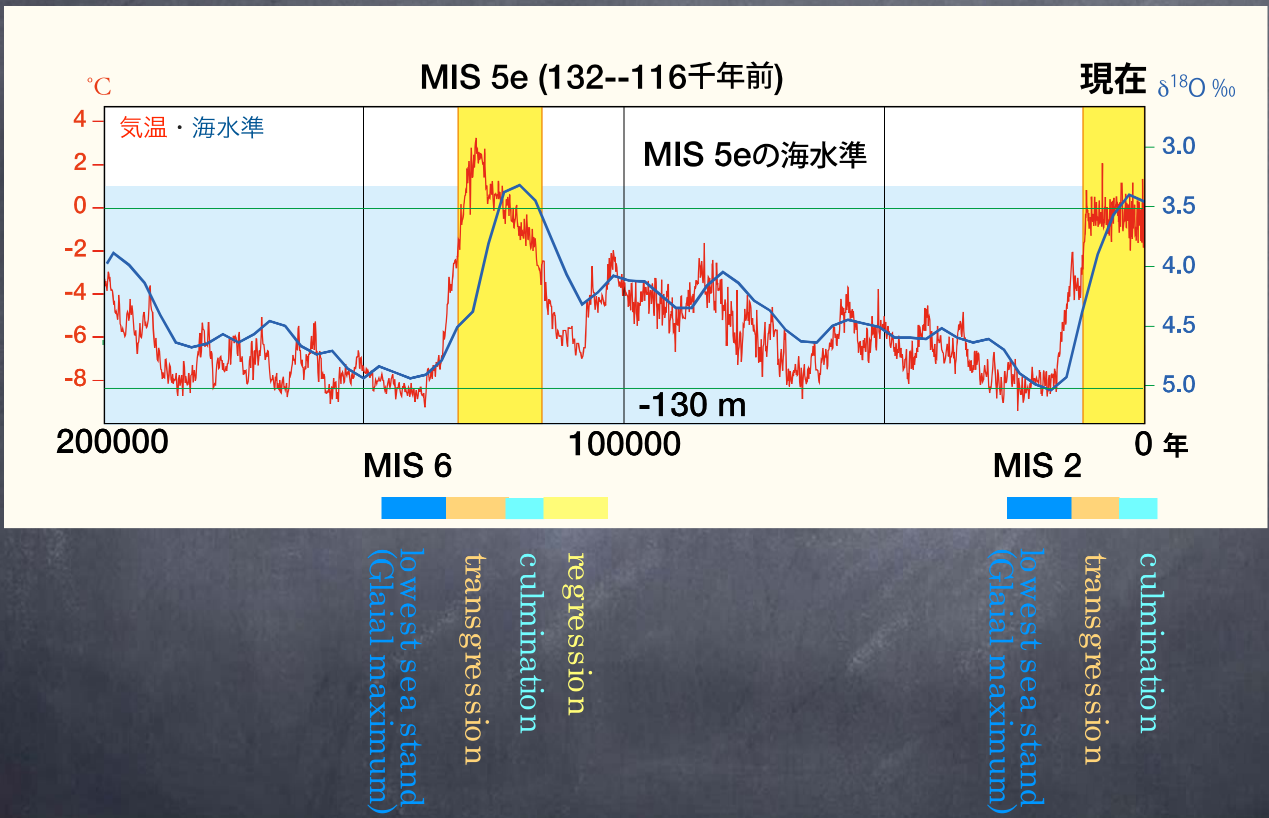
Koji Okumura (Hiroshima Univ., TRM)

MIS: Marine Istope Stag

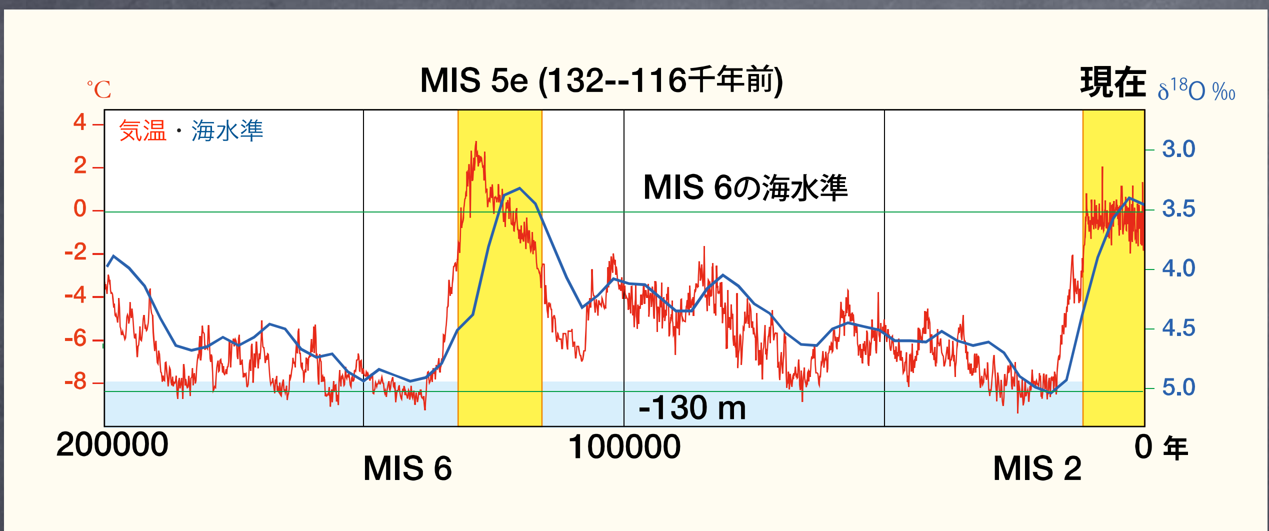


Potential faults and so on for the future activities
(Active faults to be considered for seismic design)

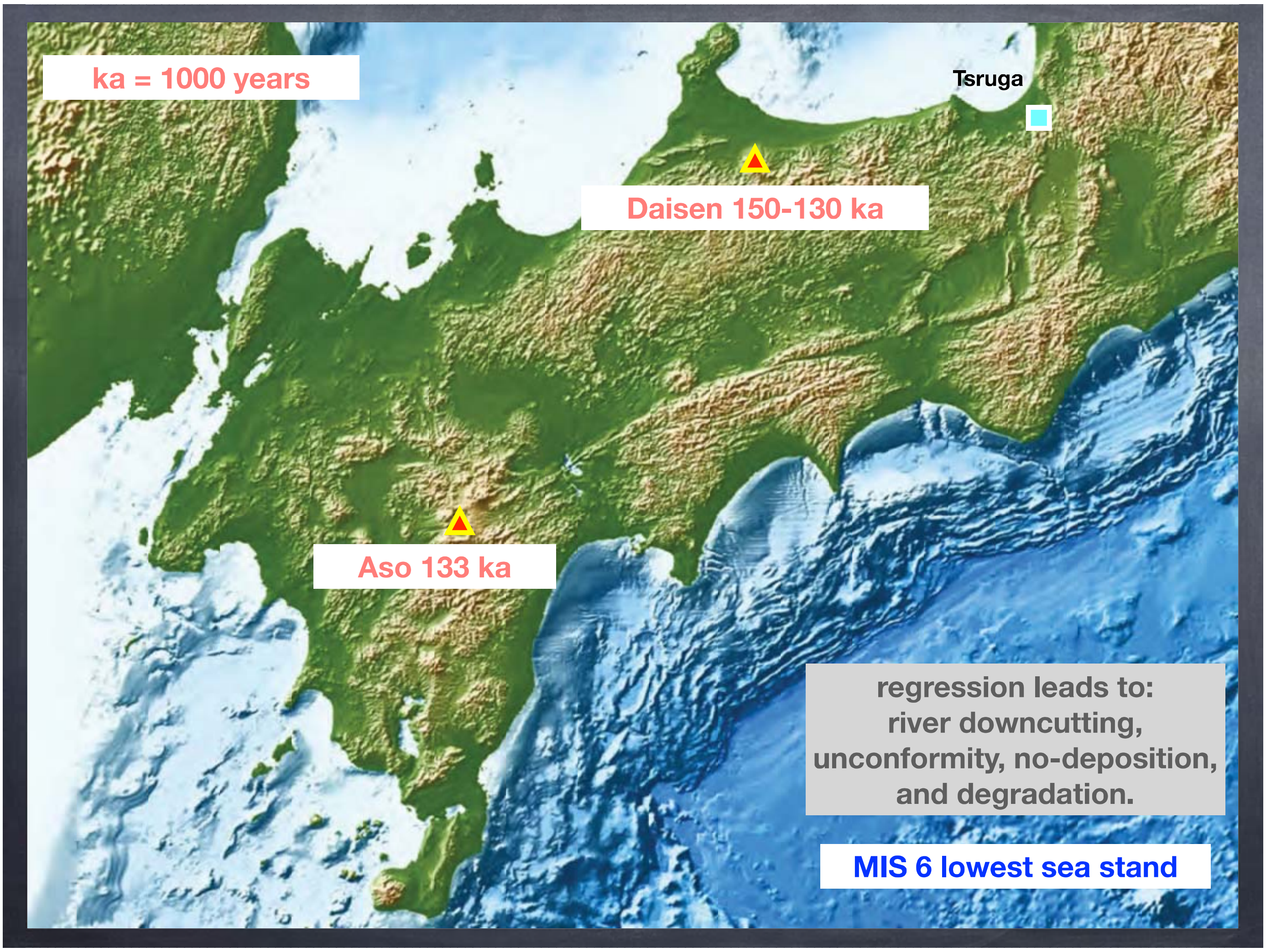
Temperature (Vostok Core, Antarctica) and Sea-level (Stucked benthic foraminifera records) changes in the past 200,000 years.

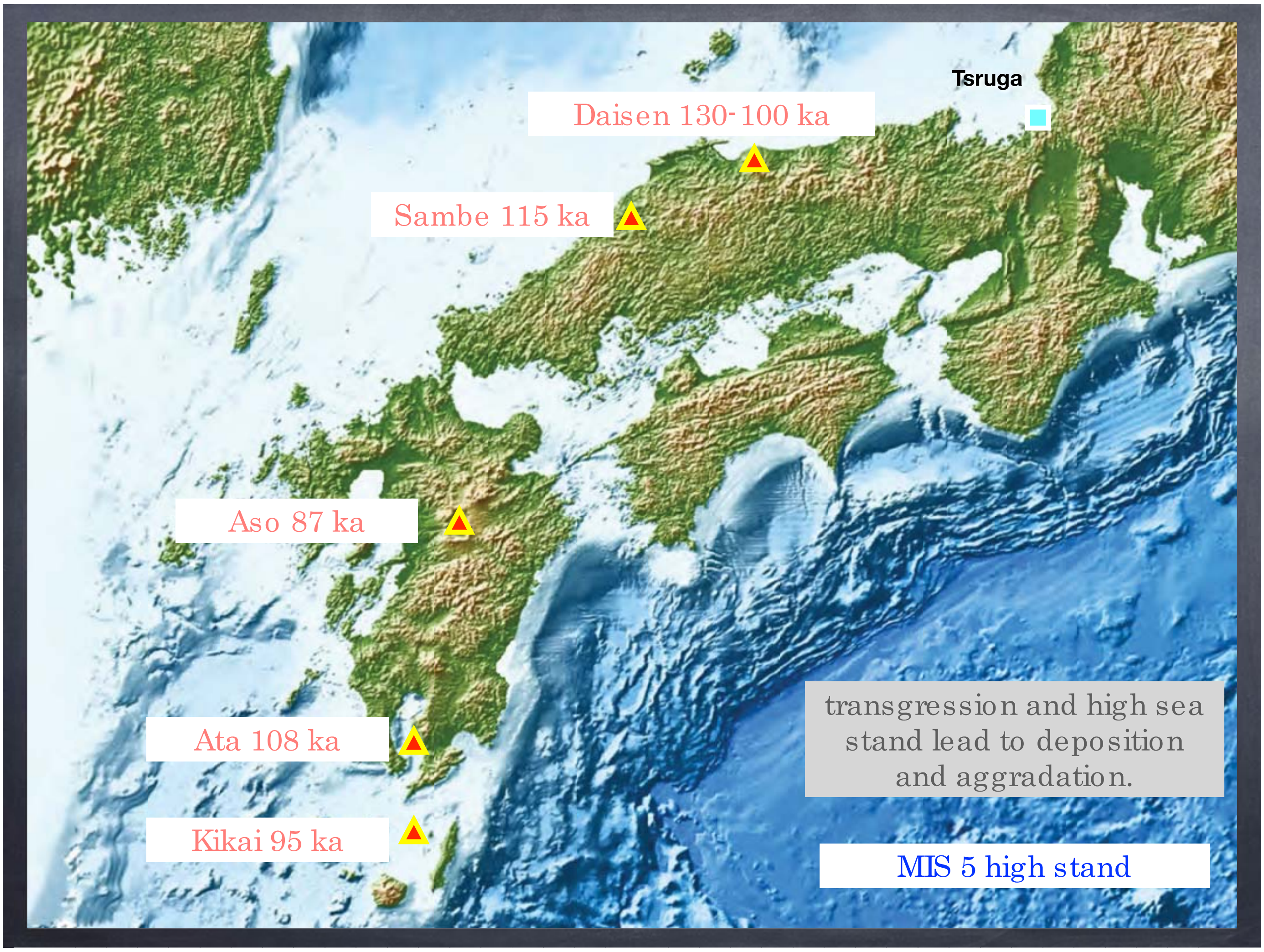


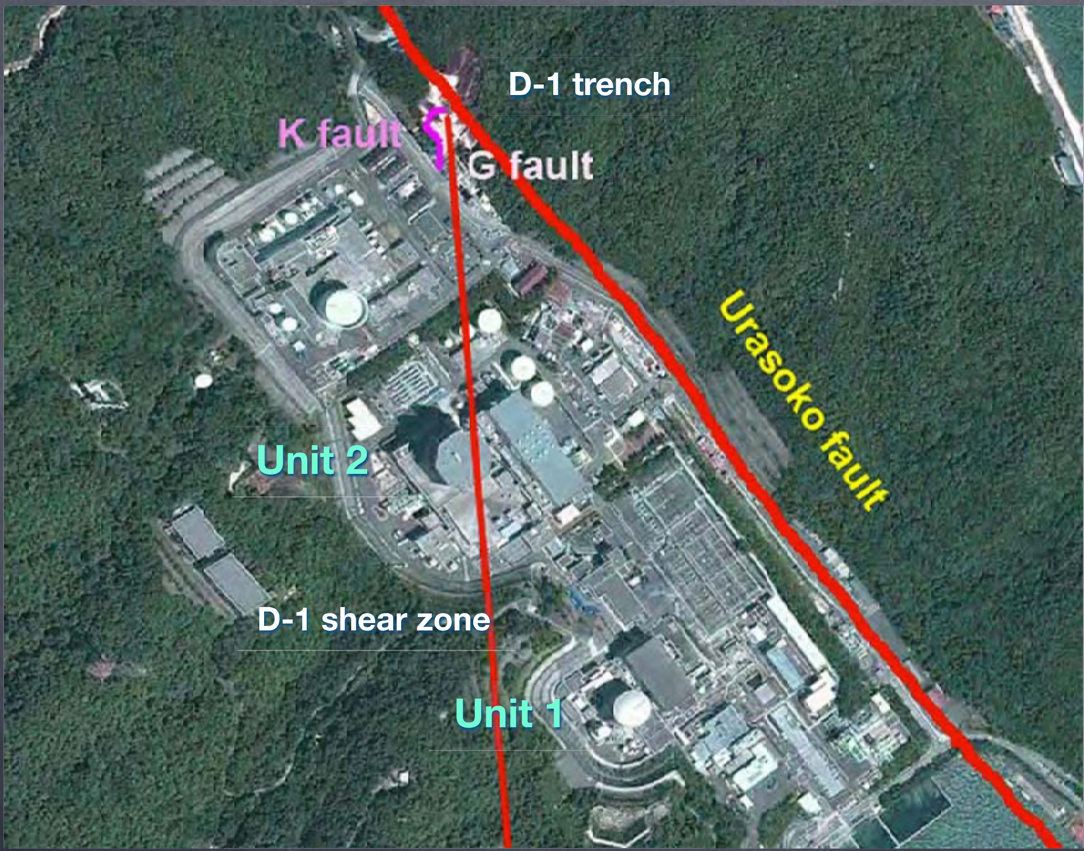
It takes ~10,000 year from the lowest stand to the culmination, which lasts ~5000 year.

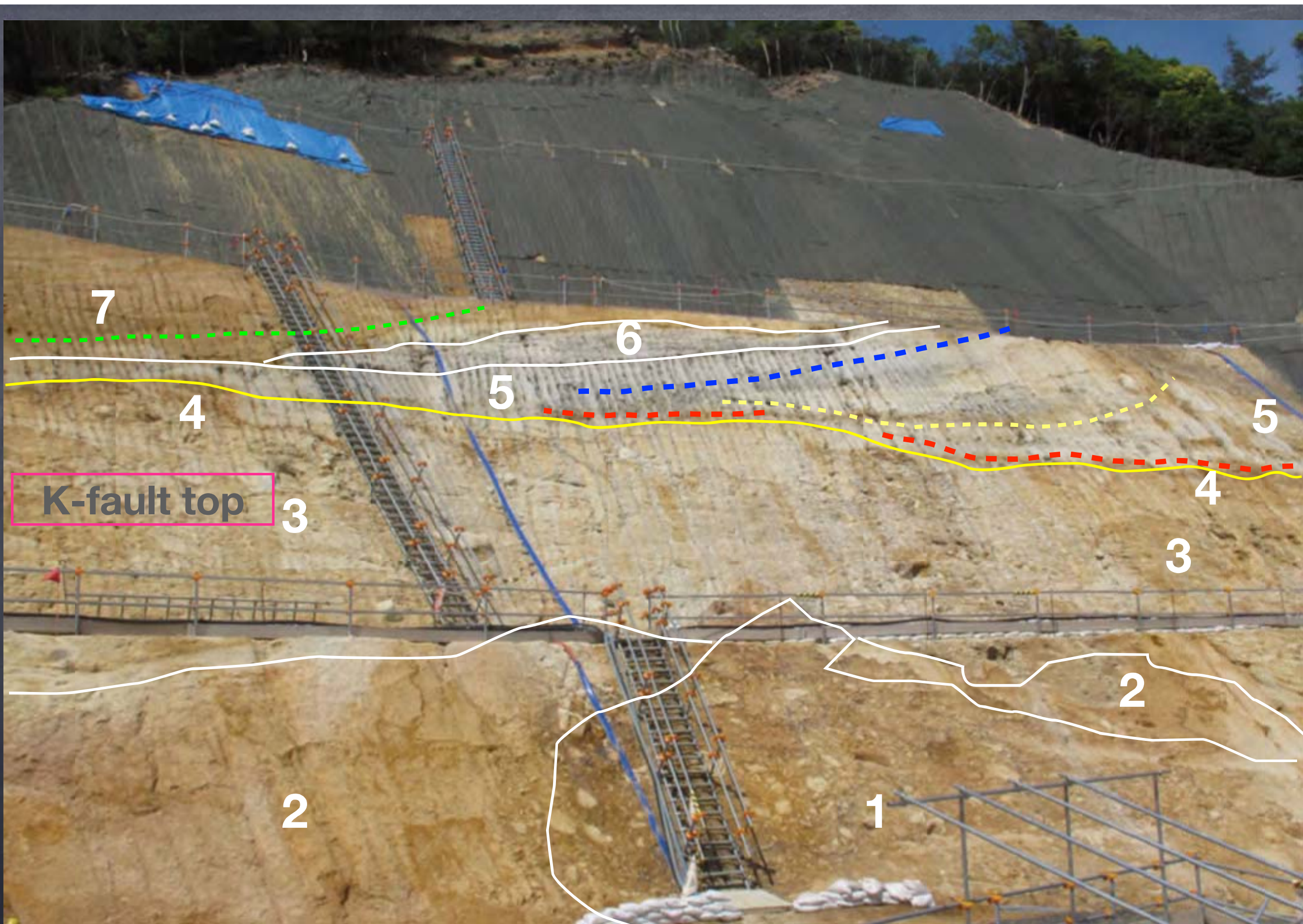


Lowest sea stand (MIS 6 and MIS 2) sea-level is 120 to 130 m below present level.

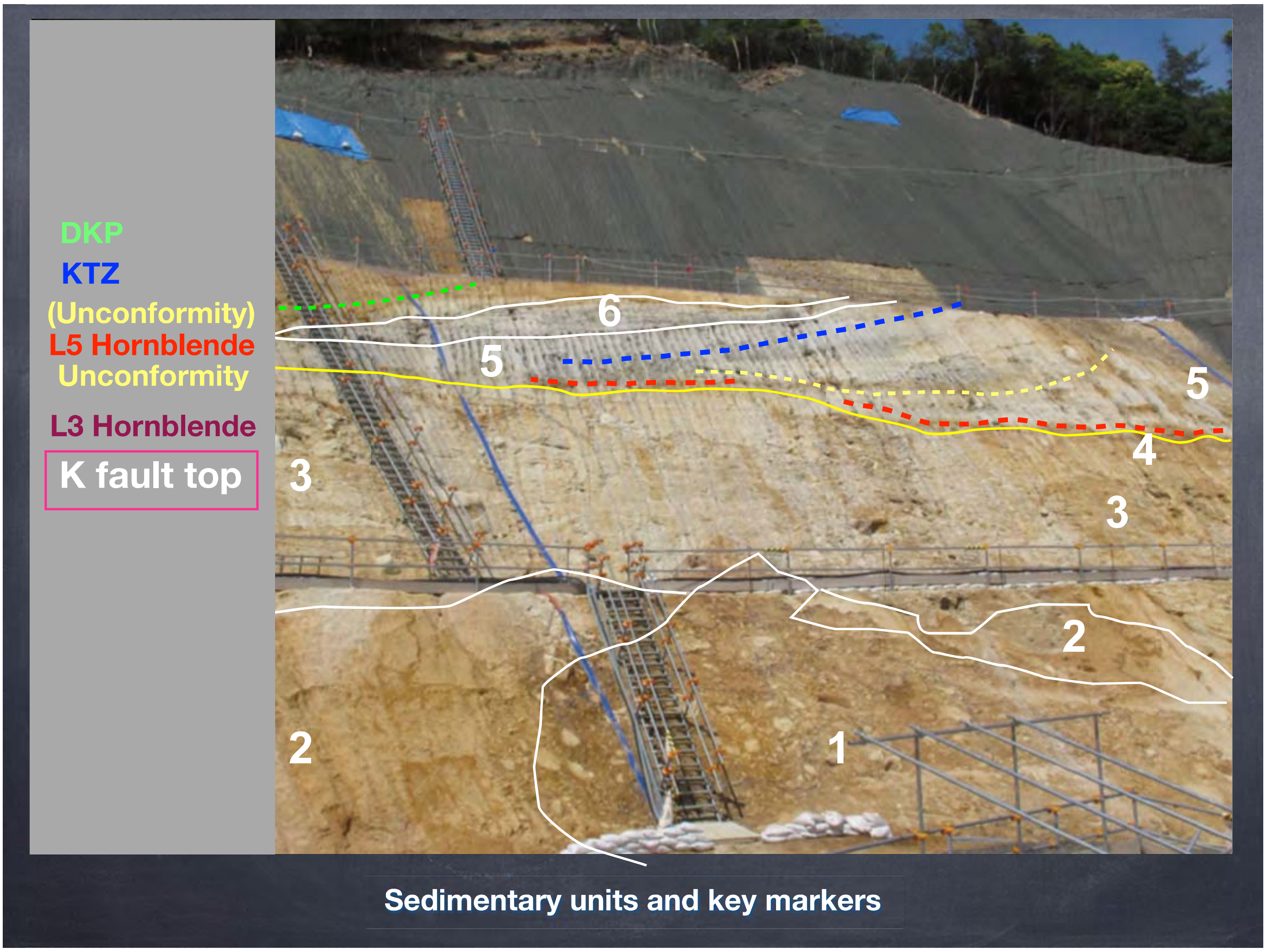

ka = 1000 years
Tsruga
Daisen 150-130 ka
Aso 133 ka
regression leads to:
river downcutting,
unconformity, no-deposition,
and degradation.
MIS 6 lowest sea stand

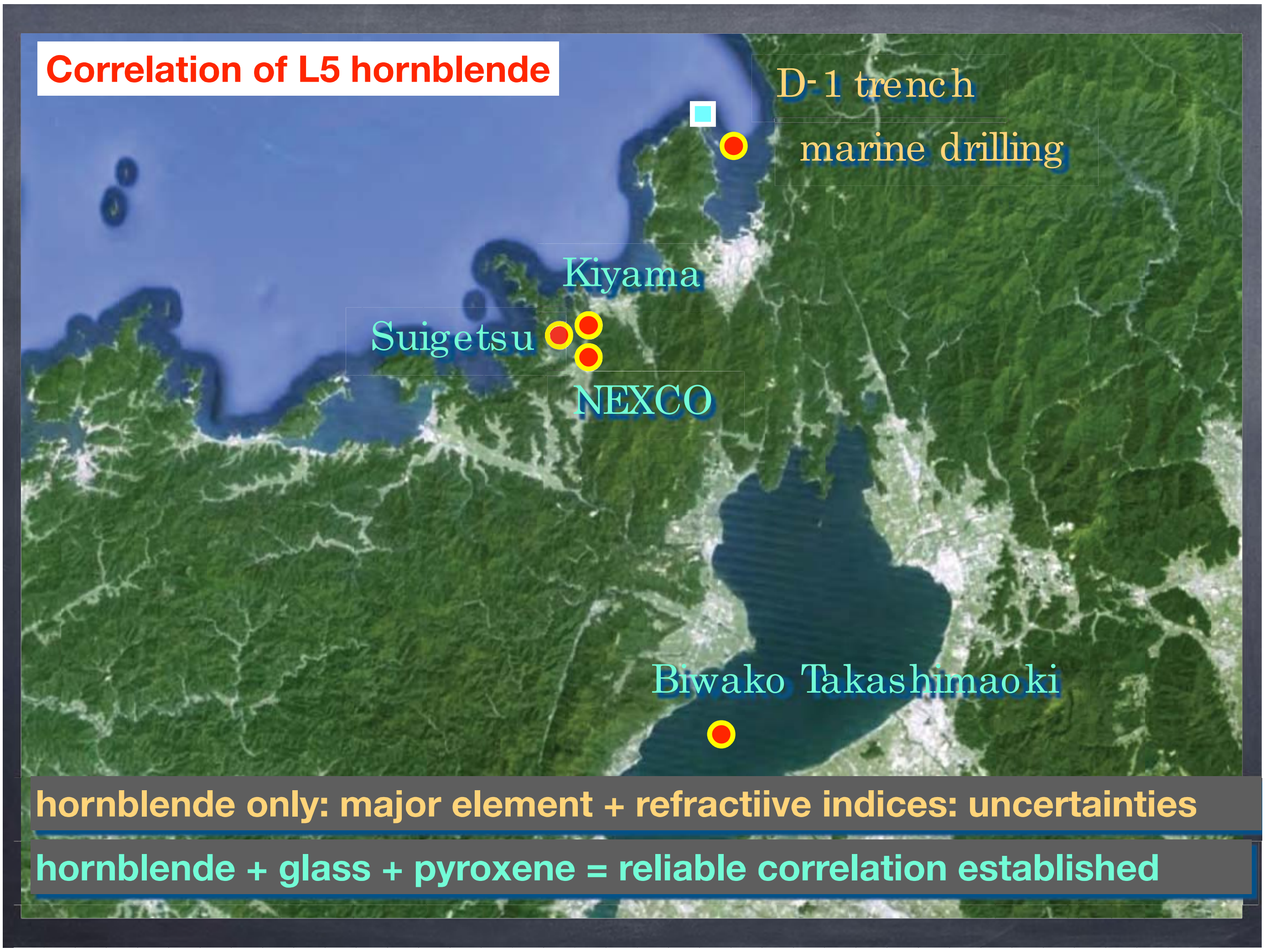

Tsruga
Daisen 130-100 ka
Sambe 115 ka
Aso 87 ka
Ata 108 ka
Kikai 95 ka
transgression and high sea
stand lead to deposition
and aggradation.
MIS 5 high stand

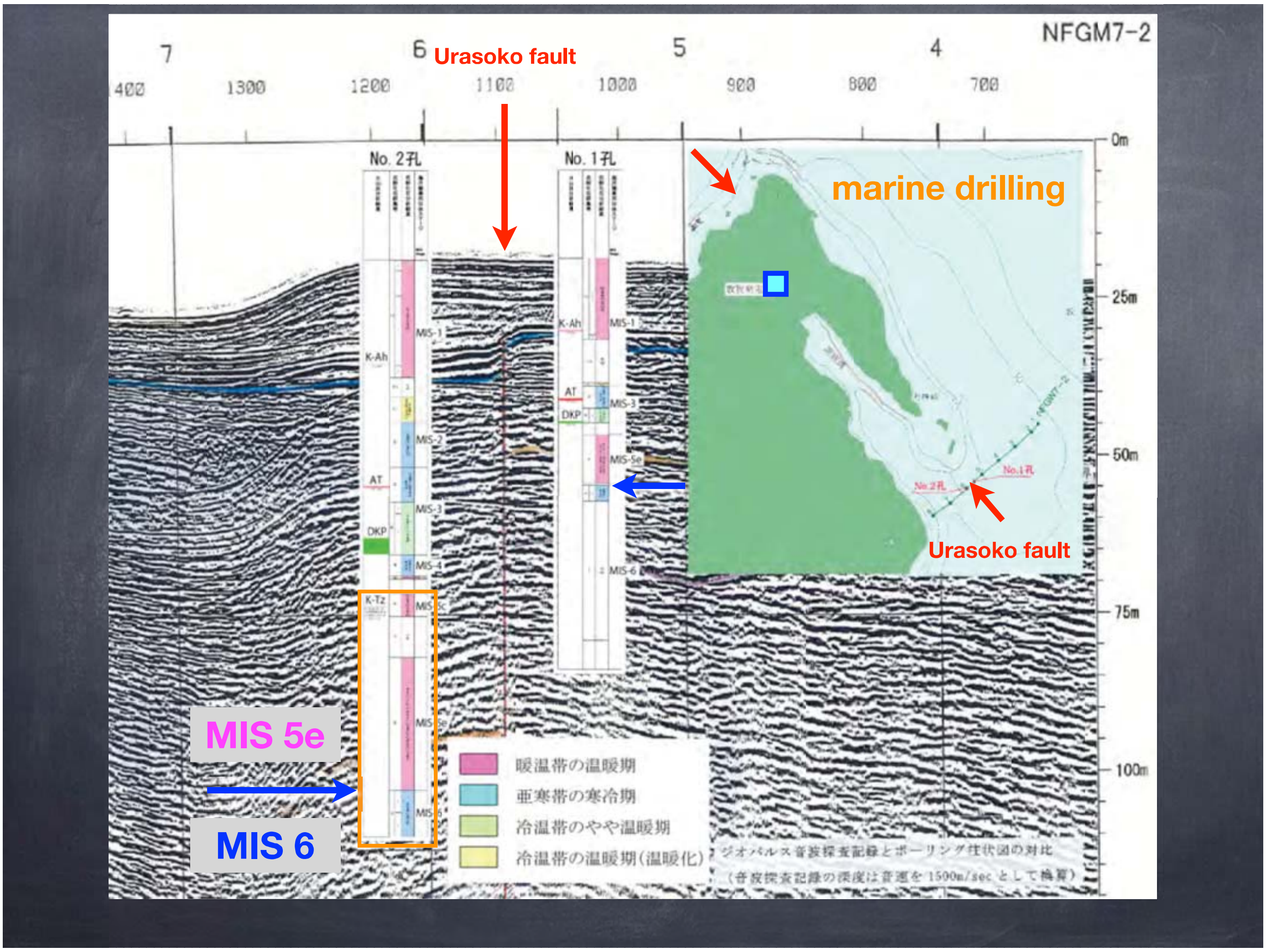


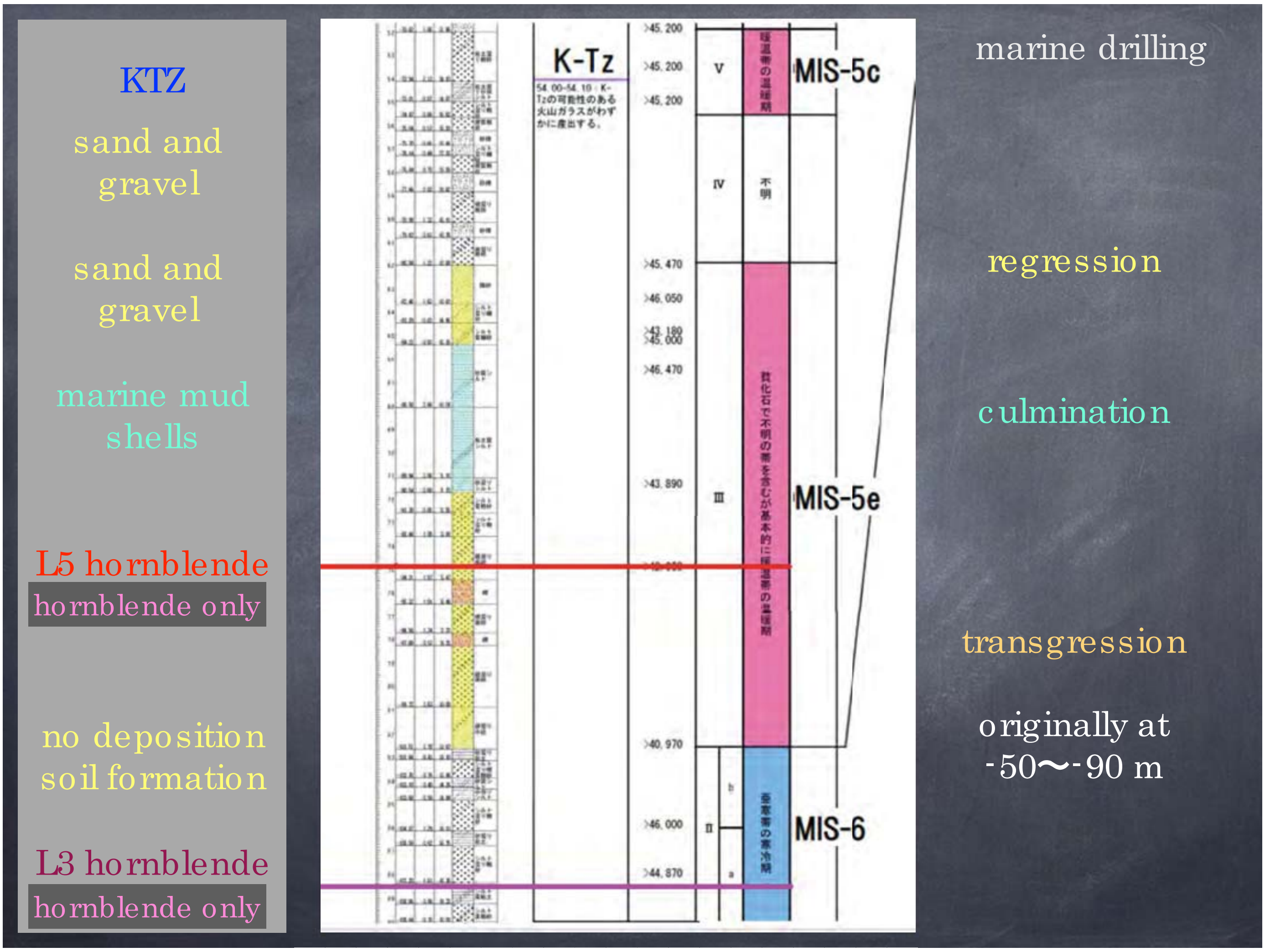


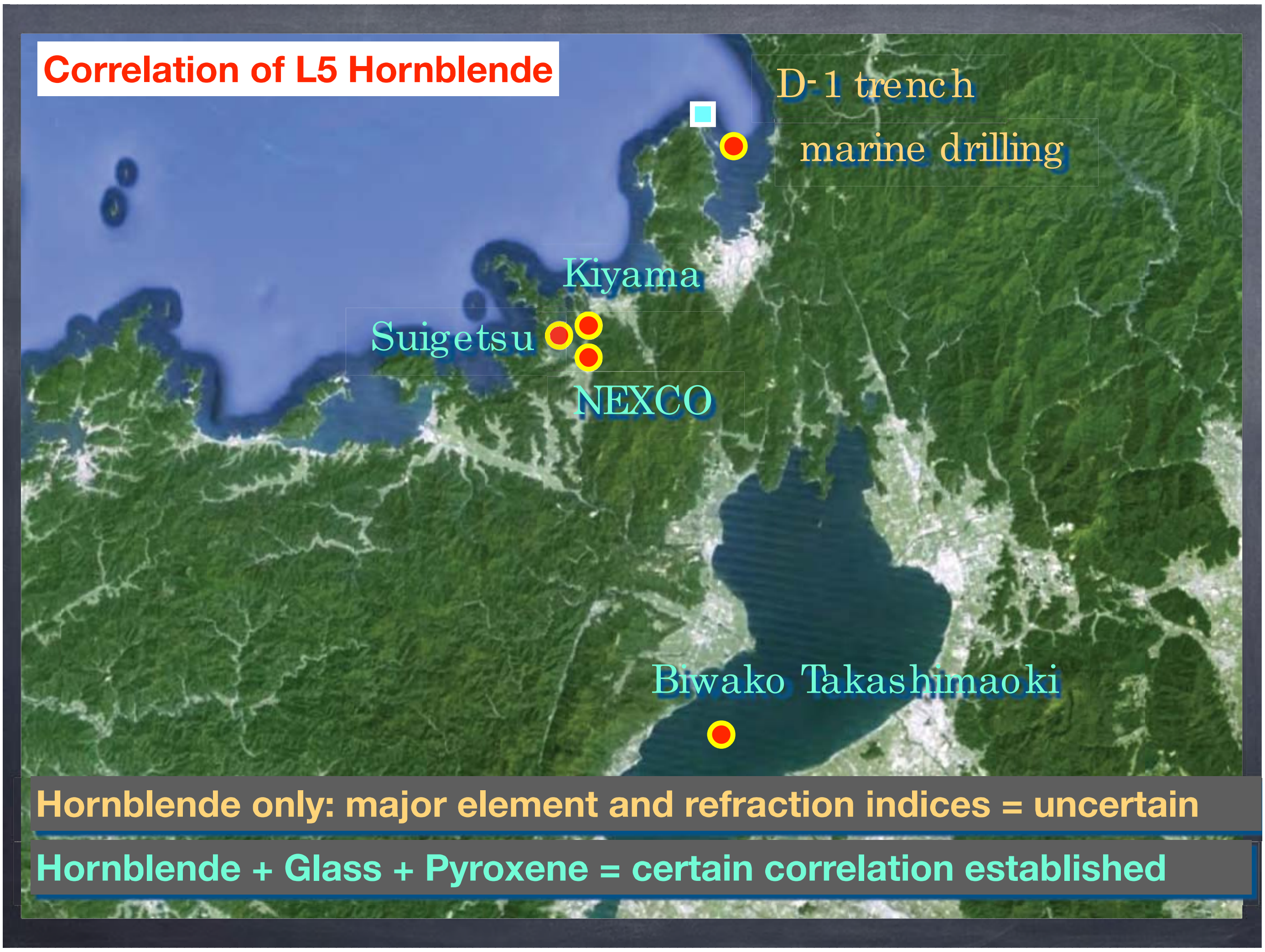
Late Quaternary sediments in the D-1 trench


DKP
KTZ
(Unconformity)
L5 Hornblende
Unconformity
L3 Hornblende
K fault top
6
5
5
3
4
3
2
2
1
Sedimentary units and key markers


Correlation of L5 hornblende
D-1 trench
marine drilling
Kiyama
Suigetsu
NEXCO
Biwako Takashimaoki
hornblende only: major element + refractiive indices: uncertainties
hornblende + glass + pyroxene = reliable correlation established


NFGM7-2
7
6
5
4
Urasoko fault
400
1300
1200
1100
1000
900
800
700
0m
25m
50m
75m
100m
No. 2孔
No. 1孔
K-Ah
AT
DKP
K-Tz
MIS-1
MIS-2
MIS-3
MIS-4
MIS-5e
MIS-6
marine drilling
Urasoko fault
MIS 5e
MIS 6
暖温帯の温暖期
亜寒帯の寒冷期
冷温帯のやや温暖期
冷温帯の温暖期(温暖化)
ジオパルス音波探査記録とボーリング柱状図の対比
(音波探査記録の深度は音速を1500m/secとして換算)


KTZ
sand and gravel
sand and gravel
marine mud shells
L5 hornblende
hornblende only
no deposition soil formation
L3 hornblende
hornblende only
K-Tz
MIS-5c
MIS-5e
MIS-6
marine drilling
regression
culmination
transgression
originally at -50〜-90 m



marine drilling	Kiyama
KTZ	
sand and gravel	sand and gravel
marine mud shells	marine mud shells and trace fossils
L5 hornblende hornblende only	Mihama ash
no deposition soil formation	unconformity
L3 hornblende	sand and gravel

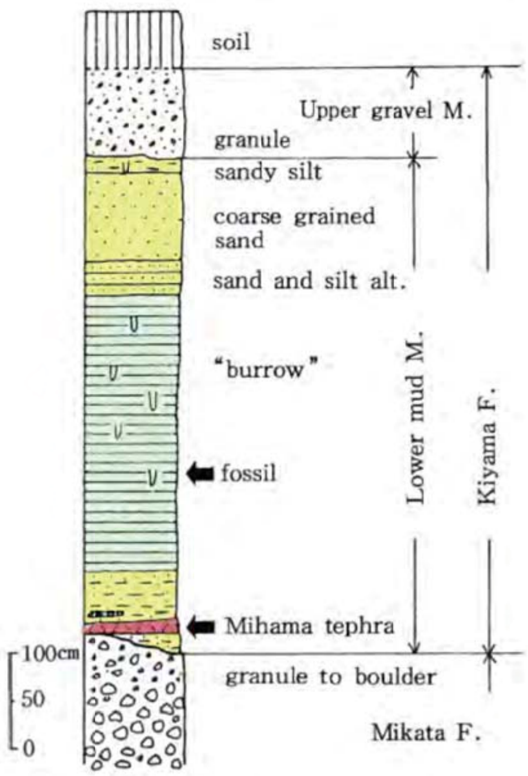
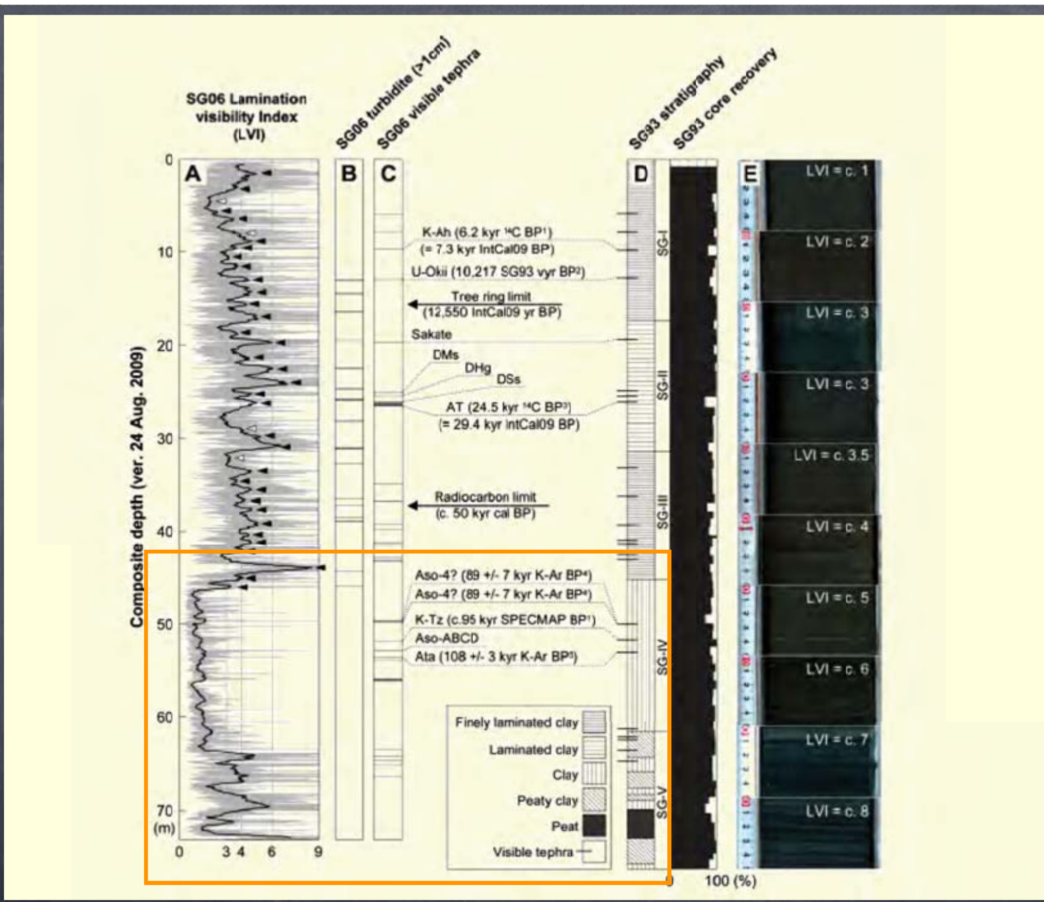
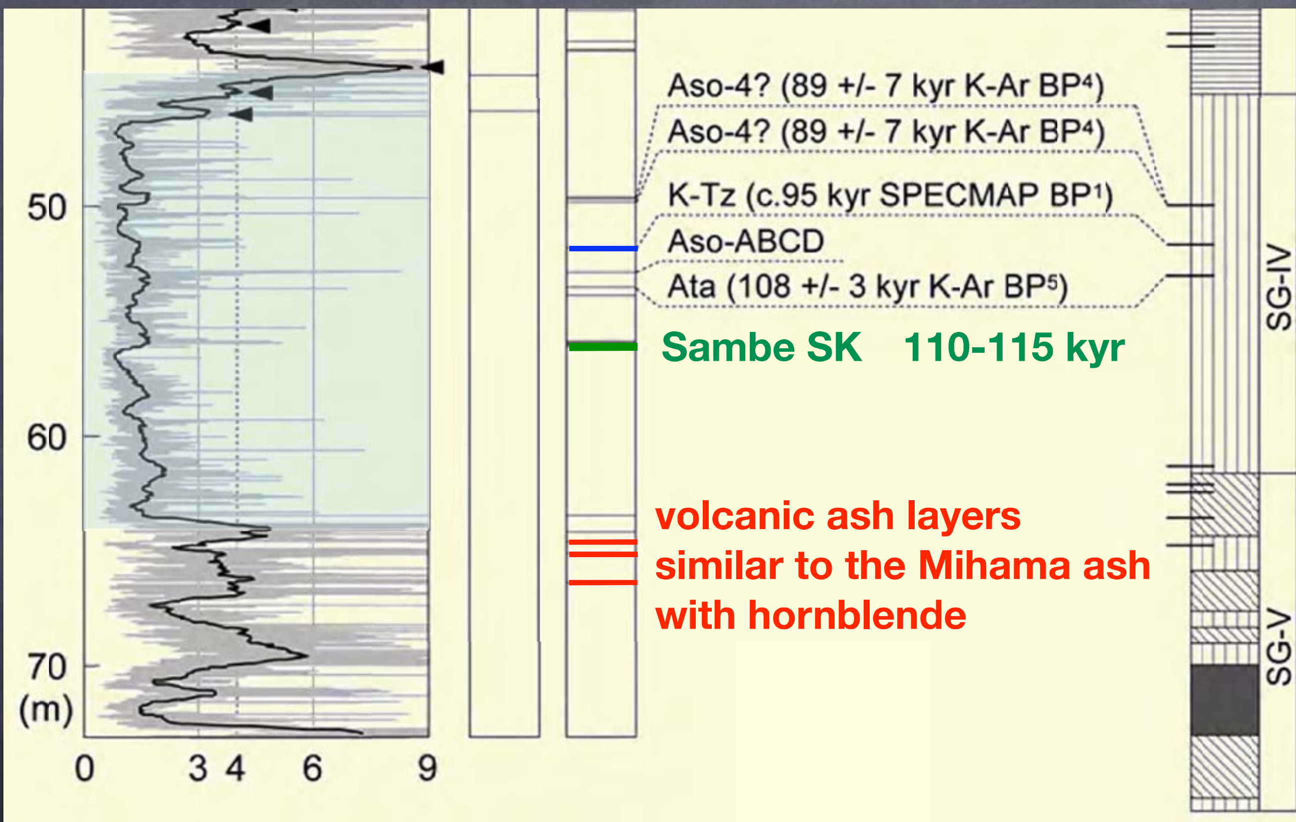


Fig. 2 Schematic columnar section bearing fossils and the Mihama tephra.

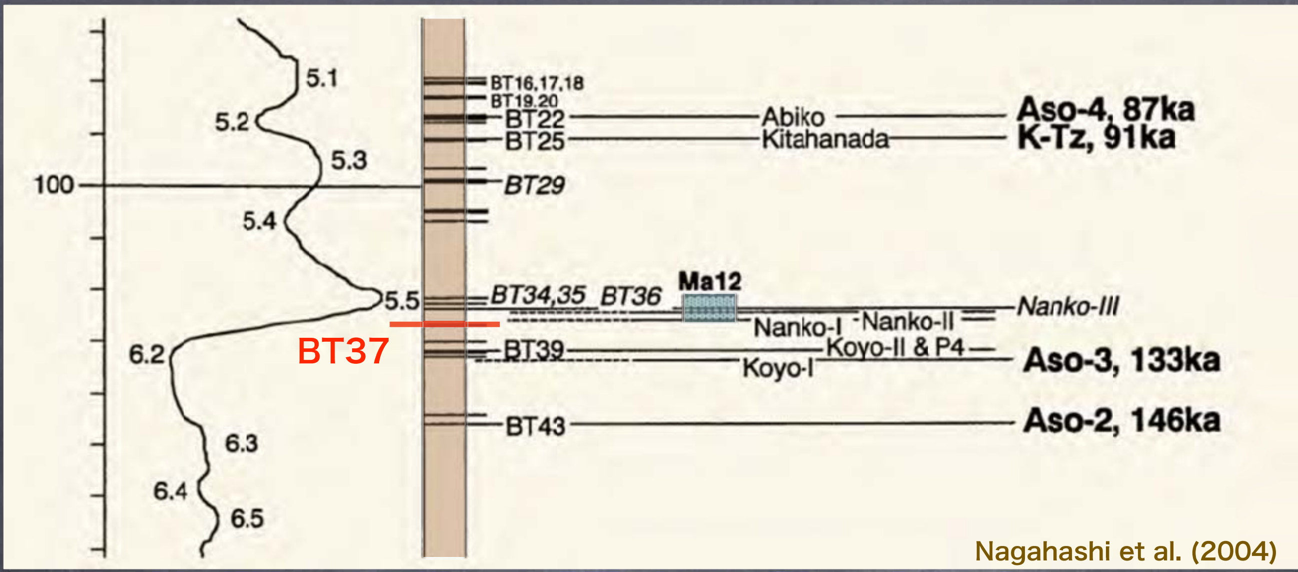
Yasuno (1991)



Suigetsu 2006 drilling (Nakagawa et al., 2012)



Dambara (2013; personal communication)



Biwako Takashimaoki　Osaka

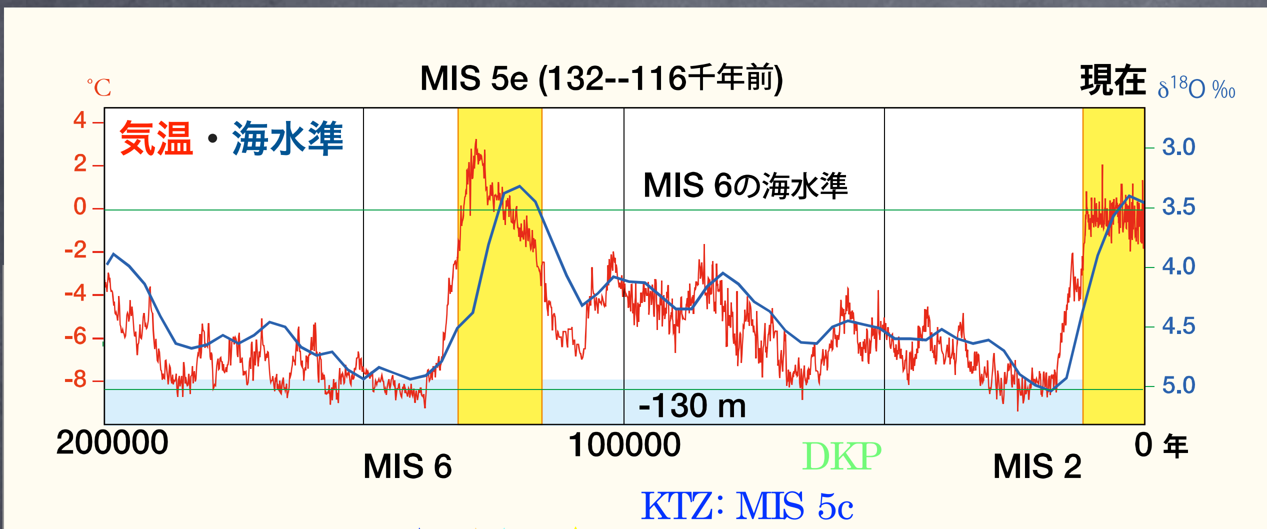
BT37 Glass major element composition is identical with the Mihama ash.

Osaka: Ma12 = MIS 5e culmination is above BT36.

BT36 is 125000--130000 years ago.

BT37 is below BT36 in a transgression phase.

Nagahashi et al. (2004) estimated BT37 to be 127,600 year ago.



L3 hornblende

(MIS 5d regression: unconformity)

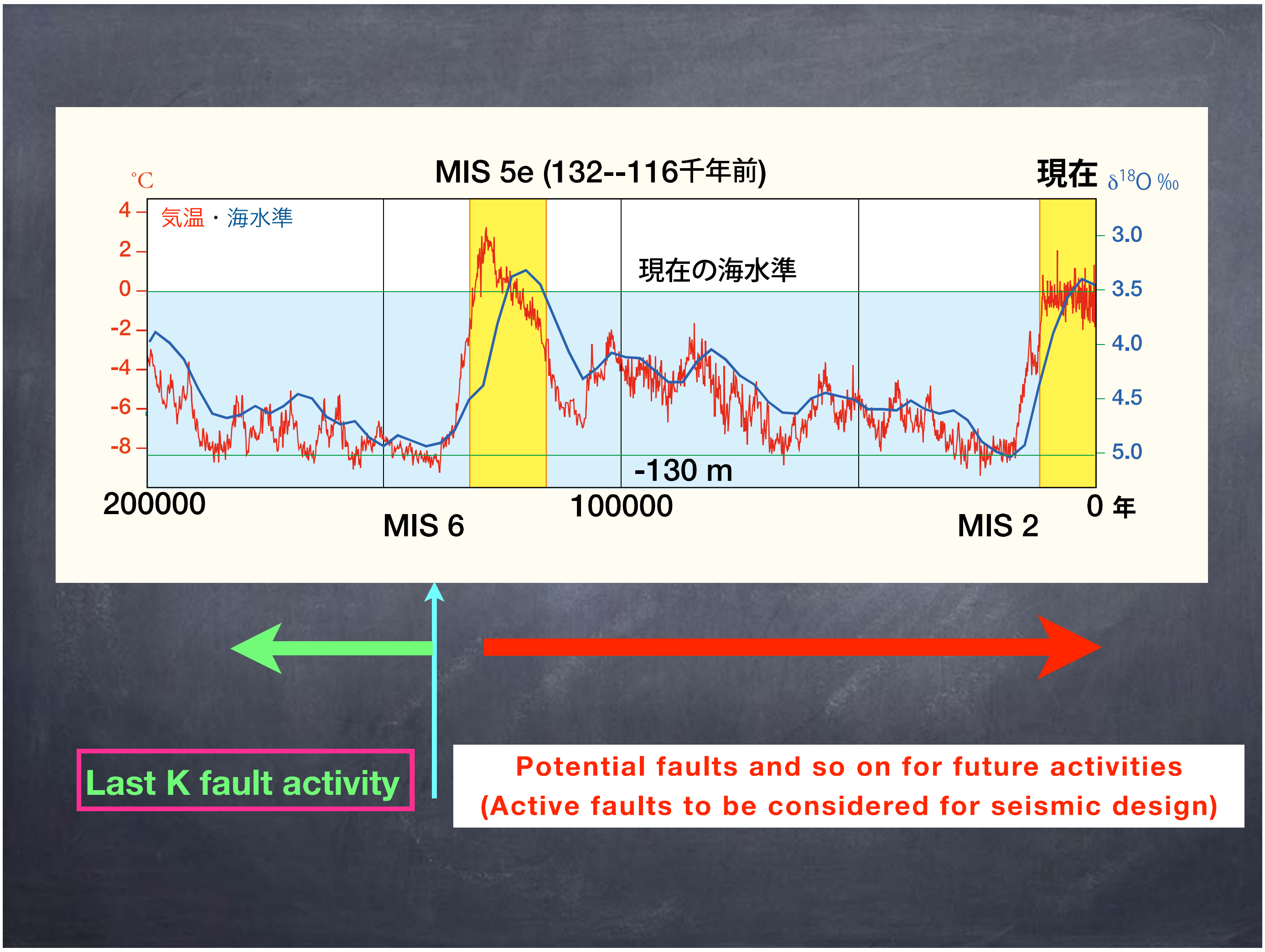
Culmination 5e: 120,000--130,000

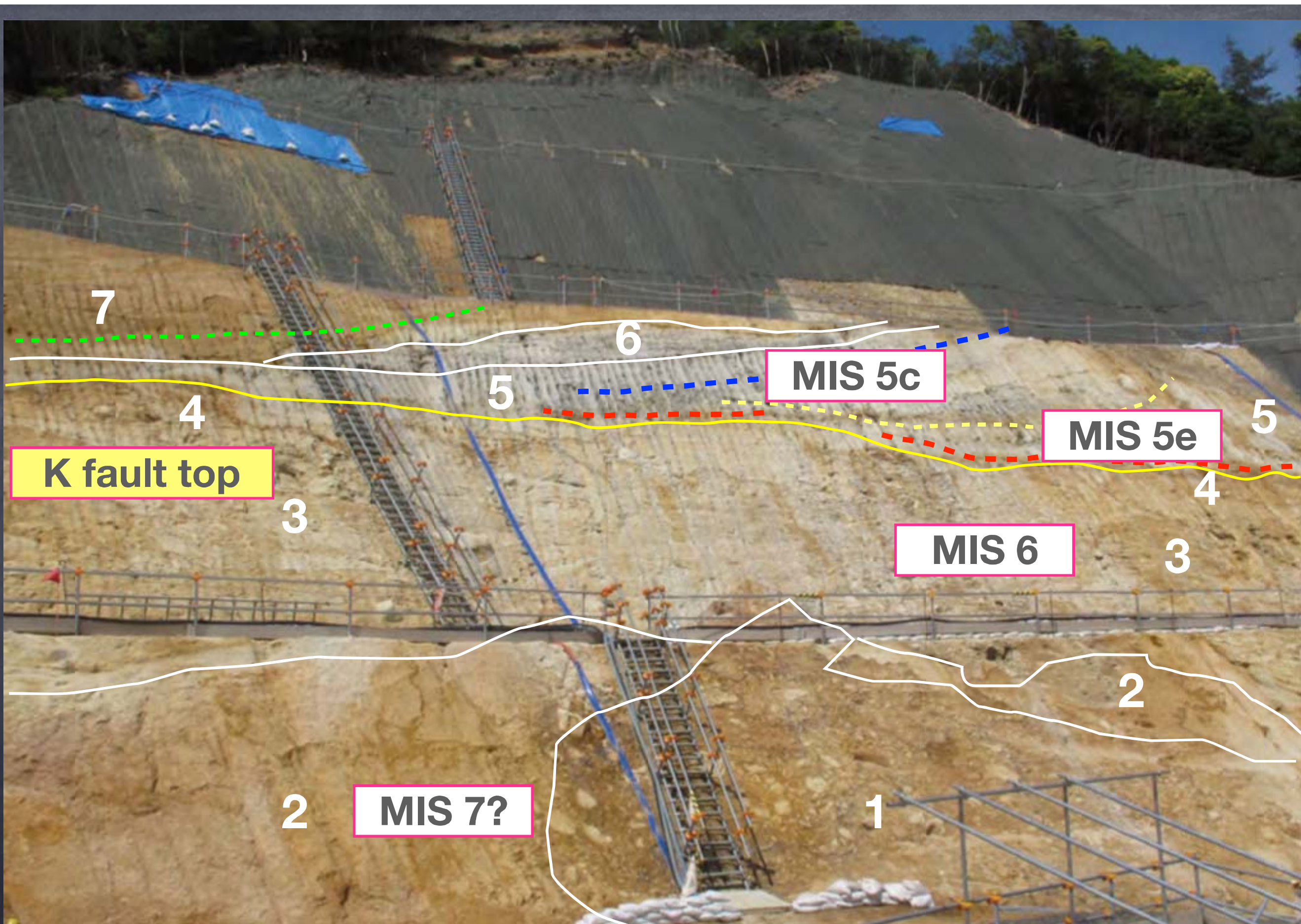
Last K fault activity

Transgression　L5 hornblende = Mihama ash

Lowest sea stand: 135000--150000

L4/L5 unconformity, No-deposition





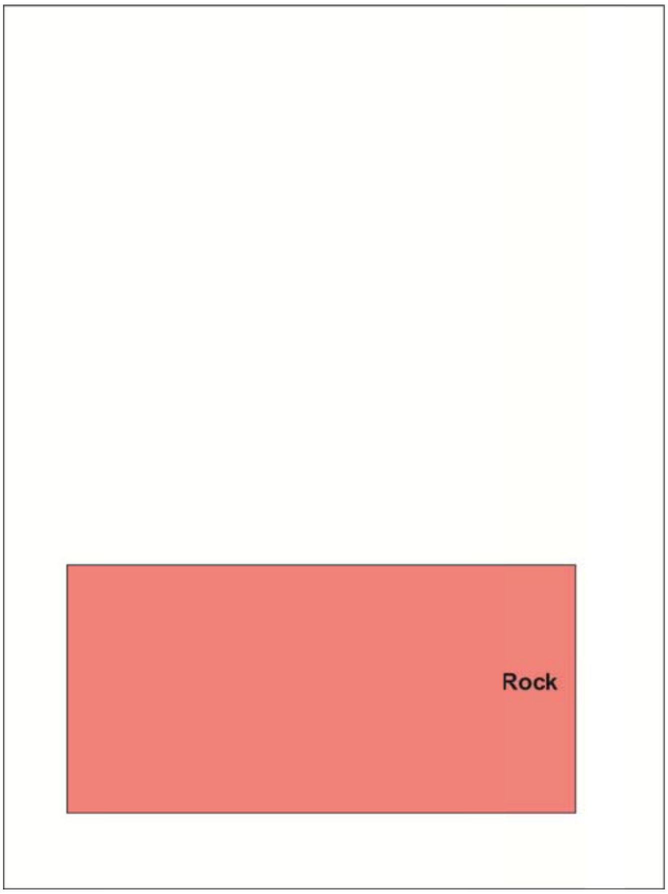
Late Quaternary sediments in the D-1 trench

STRUCTURAL RELATIONSHIPS

- **1)** FAULT UPWARD TERMINATION: **WHEN WAS THE LAST FAULT MOVEMENT IN RELATION TO THE DEPOSITION OF SEDIMENTS?**
- **2)** FAULT ALONG – STRIKE EXTENSION: **DO THE FAULTS EXPOSED IN THE NEW TRENCHES LINK TO THOSE MAPPED DURING UNIT 2 CONSTRUCTIONS?**
- **3)** FAULT DISPLACEMENT SENSE: **IS THE FAULT NORMAL, REVERSE OR LATERAL? THIS HELPS TO UNDERSTAND THE LINKS BETWEEN FAULTS EXPOSED IN THE TRENCHES AND THE BOREHOLES**

G fault

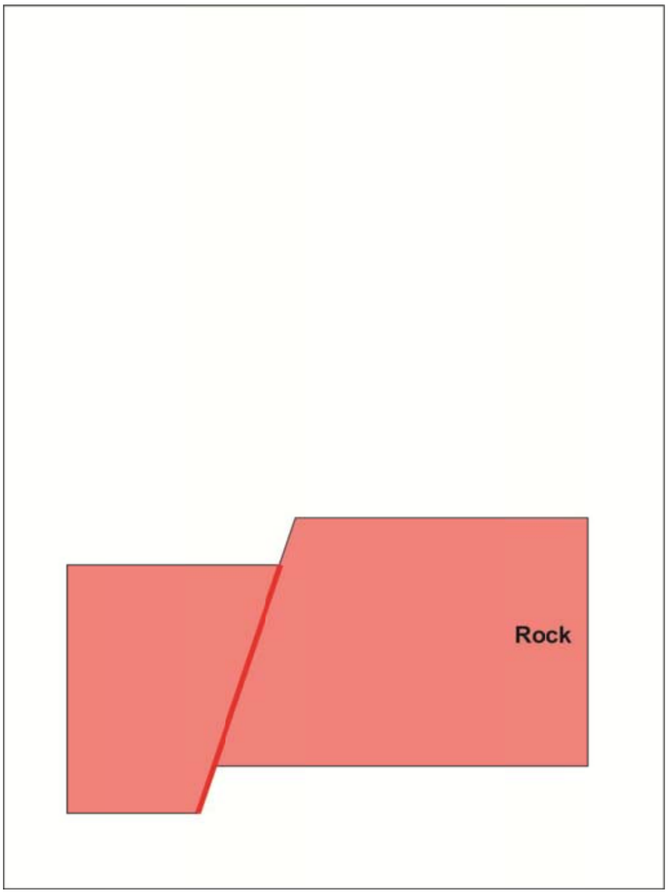
When did the last fault movement occur?



1) STRUCTURAL RELATIONSHIPS: FAULT UPWARD TERMINATION

G fault

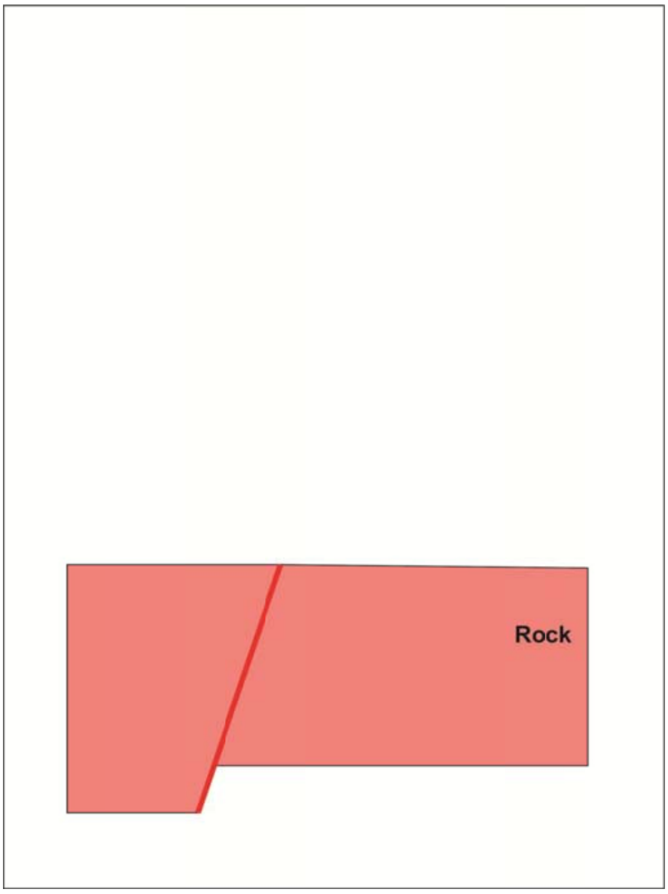
When did the last fault movement occur?



1) STRUCTURAL RELATIONSHIPS: FAULT UPWARD TERMINATION

G fault

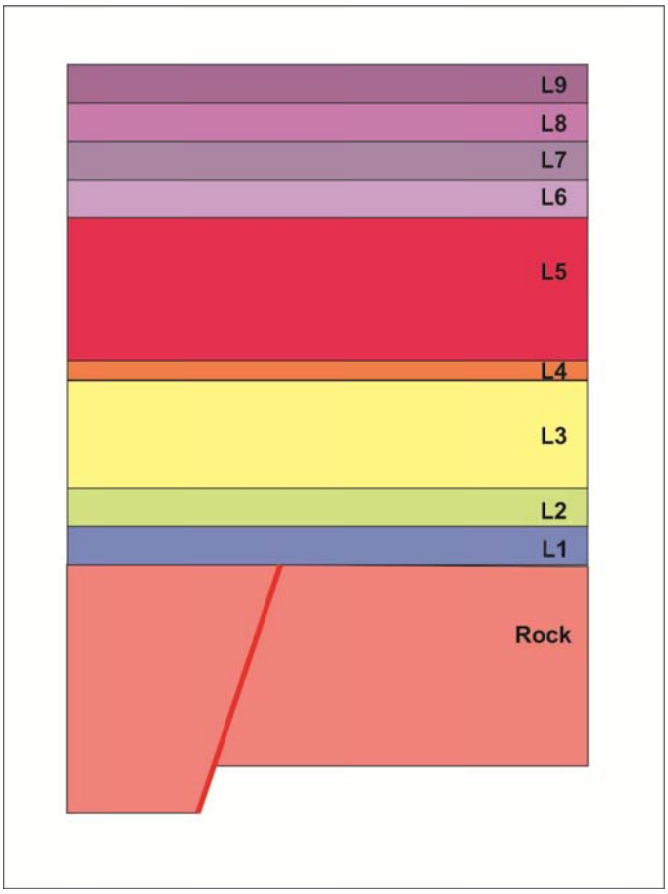
When did the last fault movement occur?



1) STRUCTURAL RELATIONSHIPS: FAULT UPWARD TERMINATION

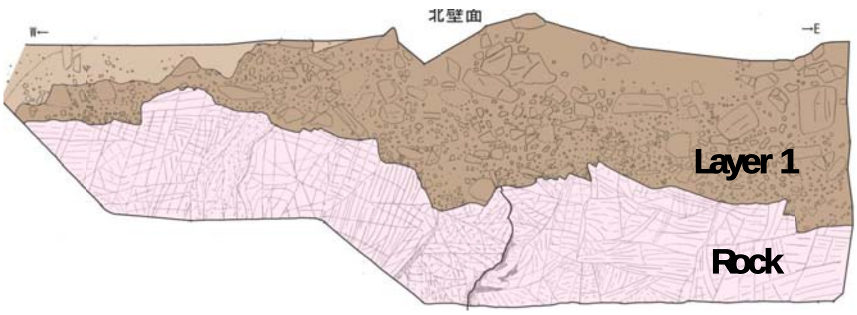
G fault

LAST OBSERVED FAULT MOVEMENT BEFORE DEPOSITON OF LAYER 1



1) STRUCTURAL RELATIONSHIPS: FAULT UPWARD TERMINATION

G fault



LAST OBSERVED FAULT MOVEMENT BEFORE DEPOSITON OF LAYER 1

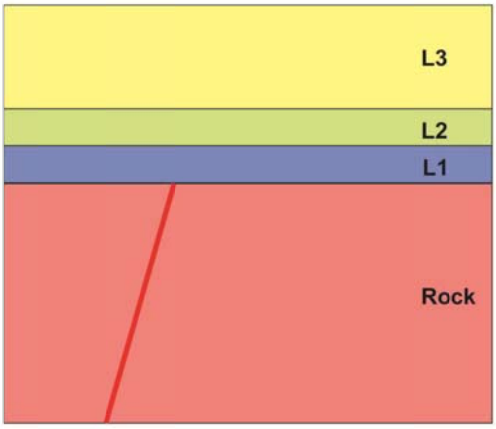
Layer 1

Rock

1) STRUCTURAL RELATIONSHIPS: FAULT UPWARD TERMINATION

K fault

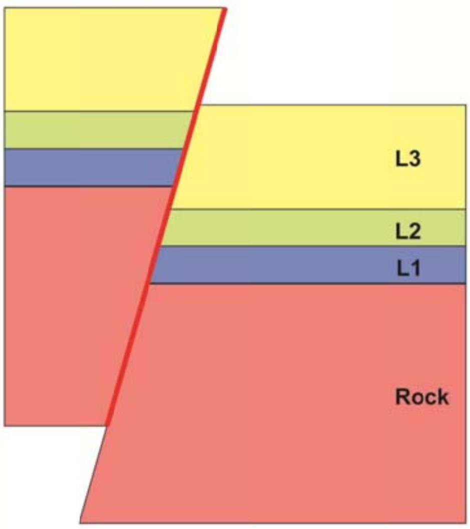
When did the last fault movement occur?



1) STRUCTURAL RELATIONSHIPS: FAULT UPWARD TERMINATION

K fault

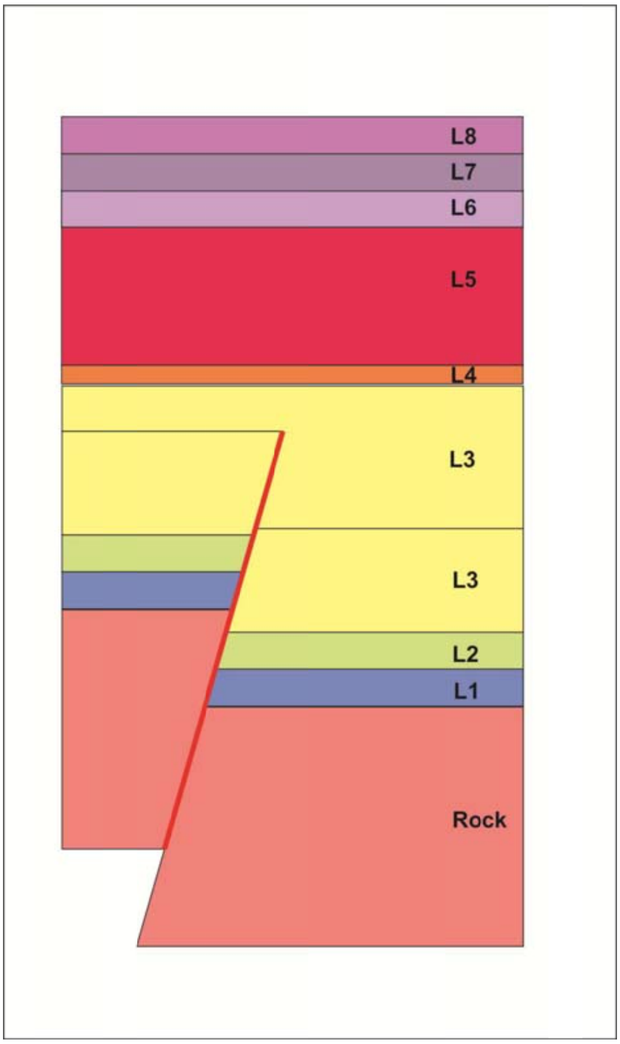
When did the last fault movement occur?



1) STRUCTURAL RELATIONSHIPS: FAULT UPWARD TERMINATION

K fault

LAST OBSERVED FAULT MOVEMENT OCCURRED:
- **AFTER DEPOSITION OF MOST OF LAYER 3**
- **BEFORE DEPOSITON OF LAYER 5**



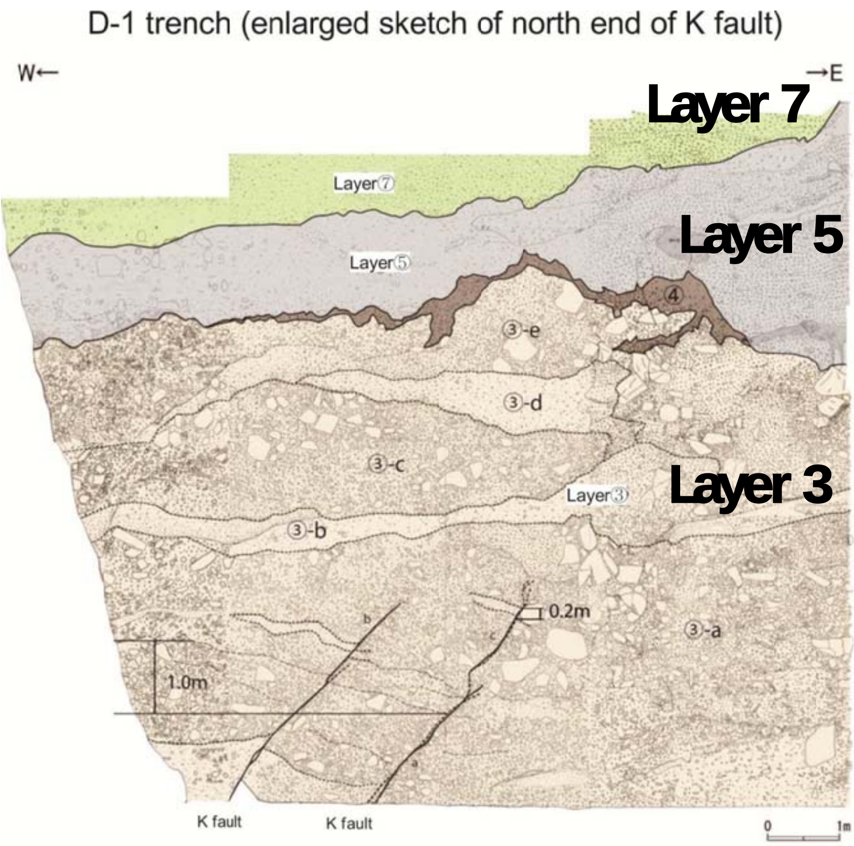
1) STRUCTURAL RELATIONSHIPS: FAULT UPWARD TERMINATION

K fault

LAST OBSERVED FAULT MOVEMENT OCCURRED:

- **AFTER DEPOSITION OF MOST OF LAYER 3**

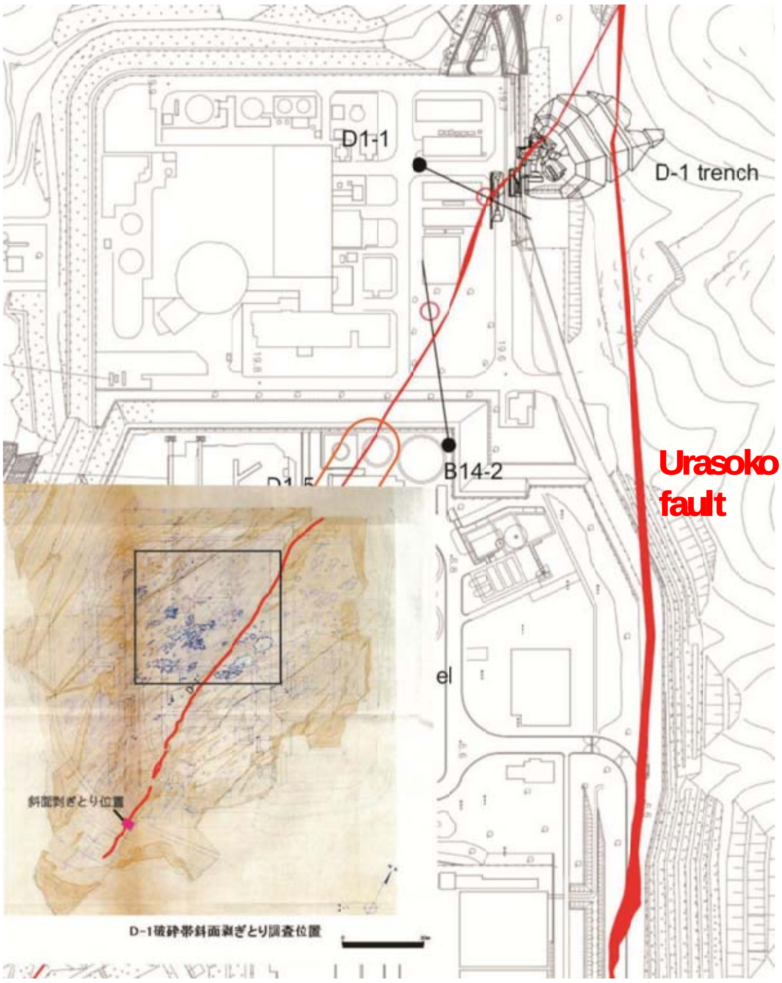
- **BEFORE DEPOSITON OF LAYER 5**



1) STRUCTURAL RELATIONSHIPS: FAULT UPWARD TERMINATION

D-1 shatter zone connects with G fault:

- Mapping during construction showed the location and continuity of the D-1 shatter zone
- Characteristics of the D-1 shatter zone in the gap between the end of this map and the new excavation further north can now be studied in outcrop and in drill cores
- New excavation (D-1 trench) exposes the G fault



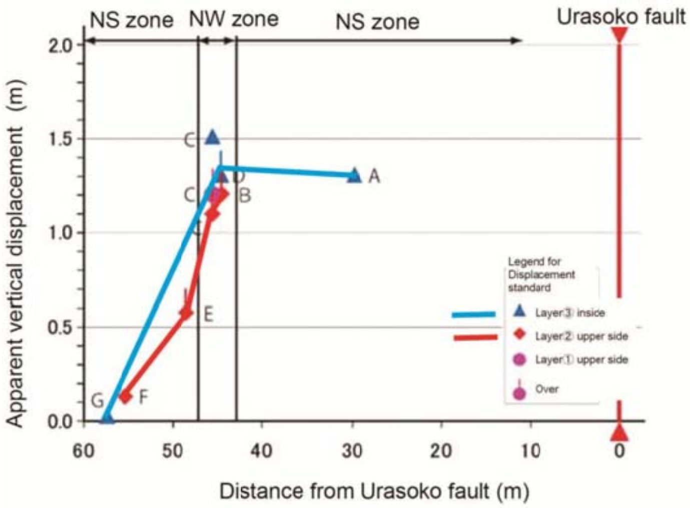
2) STRUCTURAL RELATIONSHIPS: FAULT ALONG-STRIKE EXTENSION

K fault does not continue to the south:

-Displacement decreases towards the south suggesting that the K fault ends

-Drilling further south has not found an extension of the K fault

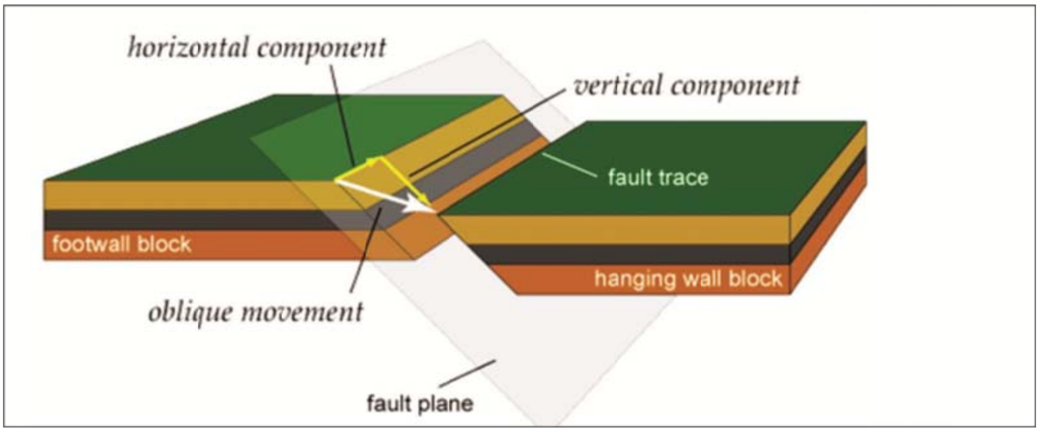
- In the D-1 trench the K-1 fault clearly changes direction from N-S close to the Urasoko fault, to SW further away from Urasoko fault



Variation of apparent vertical displacement against distance from Urasoko fault

2) STRUCTURAL RELATIONSHIPS: FAULT ALONG-STRIKE EXTENSION

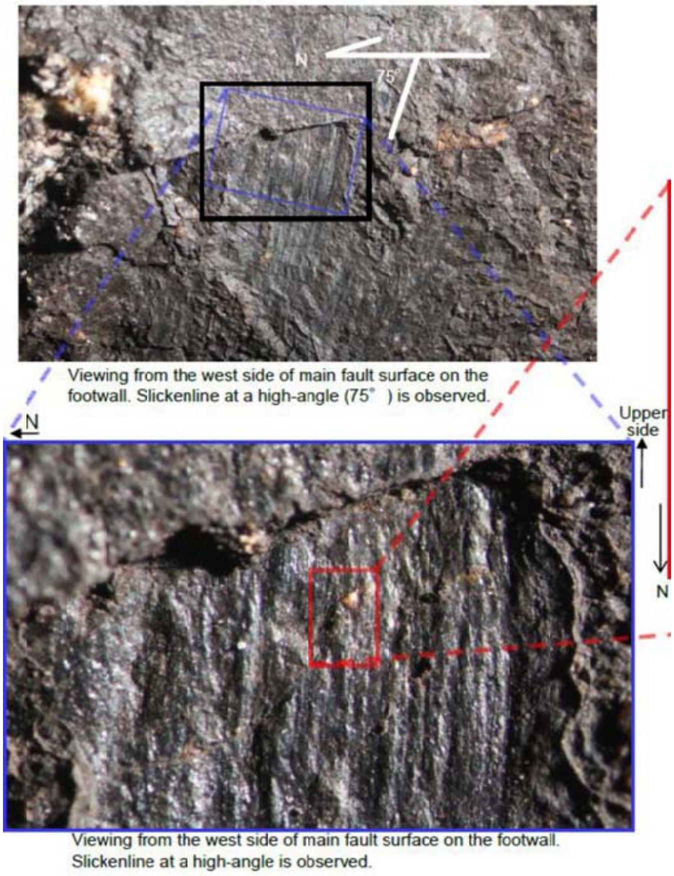
Slickensides / Slickenlines (scratch marks)



3) STRUCTURAL RELATIONSHIPS: FAULT DISPLACEMENT SENSE

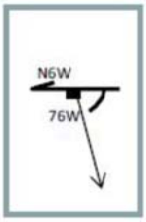
The movement sense of the D-1 shatter zone is mainly dip-slip

- Example of D-1 shatter zone slickenlines from an exposure on the south side of Unit 2
- Total number of measurements: 13
- Steep or moderate plunges are predominant

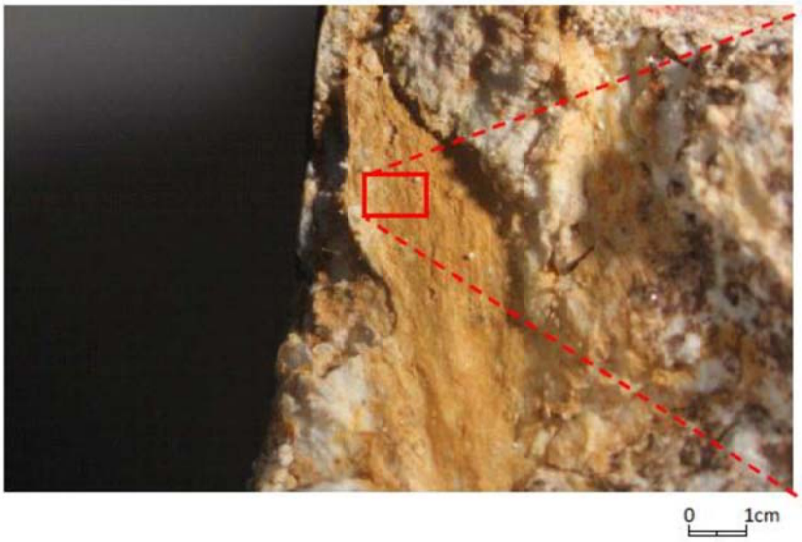


STRUCTURAL RELATIONSHIPS: FAULT DISPLACEMENT SENSE

The movement sense of the K fault is reverse



- Example of K fault slickenlines from the D1 trench
- Total number of measurements: 16
- Steep or moderate plunges are predominant
- Exposure in the trench: reverse fault

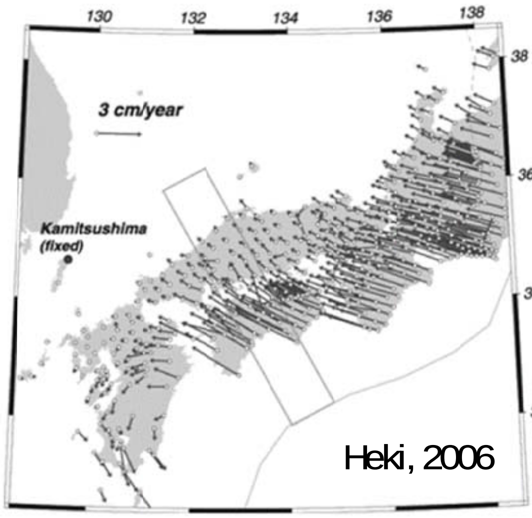


View of K fault at L-cut pit, from west side to east side of the footwall of the last slip.

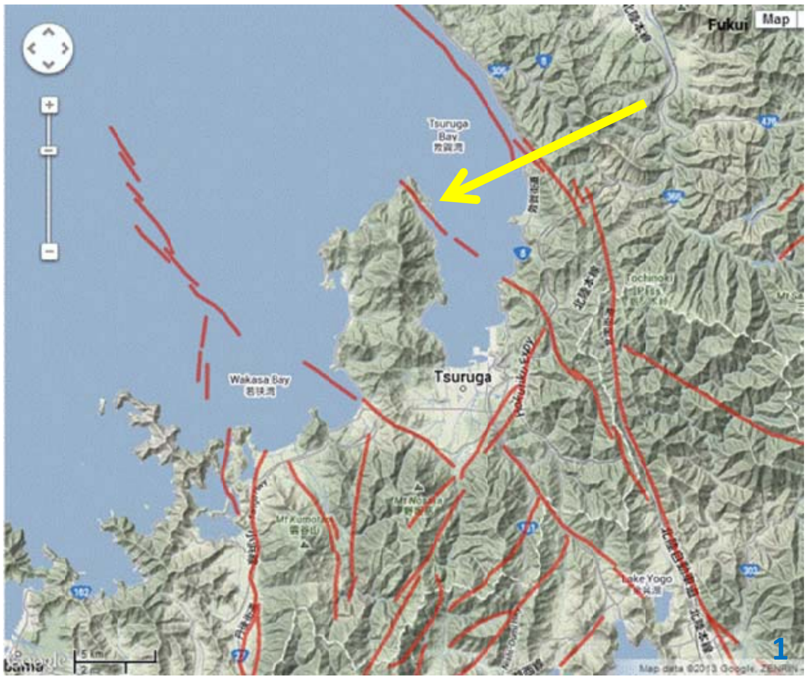
High angle slickenlines is observed on the main fault surface.

Comments from the Review Panel Experts on new results

1. Dr Villamor – evaluation of faults G/D-1 and K
2. Prof Okumura – evaluation of tephra and paleoclimate
3. Dr Berryman – summary



Heki, 2006



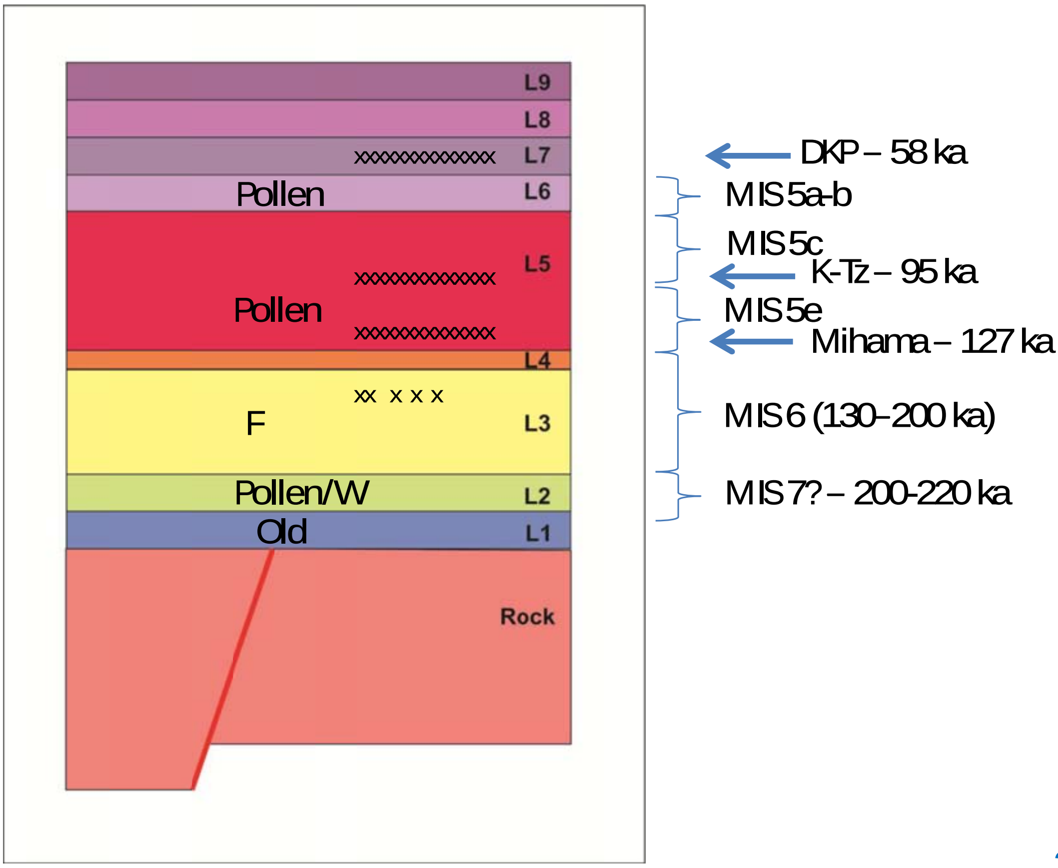
AIST active fault database

Background

1. The international review panel has evaluated two reports prepared by JAPC (March 2013 & July 2013), has undertaken field examinations at the Tsuruga site, and read the NRA's reports.
2. We find that the work undertaken by JAPC and their contractors has been to a good international standard.
3. The review team has had access to a wide range of technical information, and we have had numerous opportunities to question JAPC's geological team.
4. Since May 2013 significant new work has been undertaken and the international review team presents here the results of that review today.

Summary comments on the G/D-1 Fault

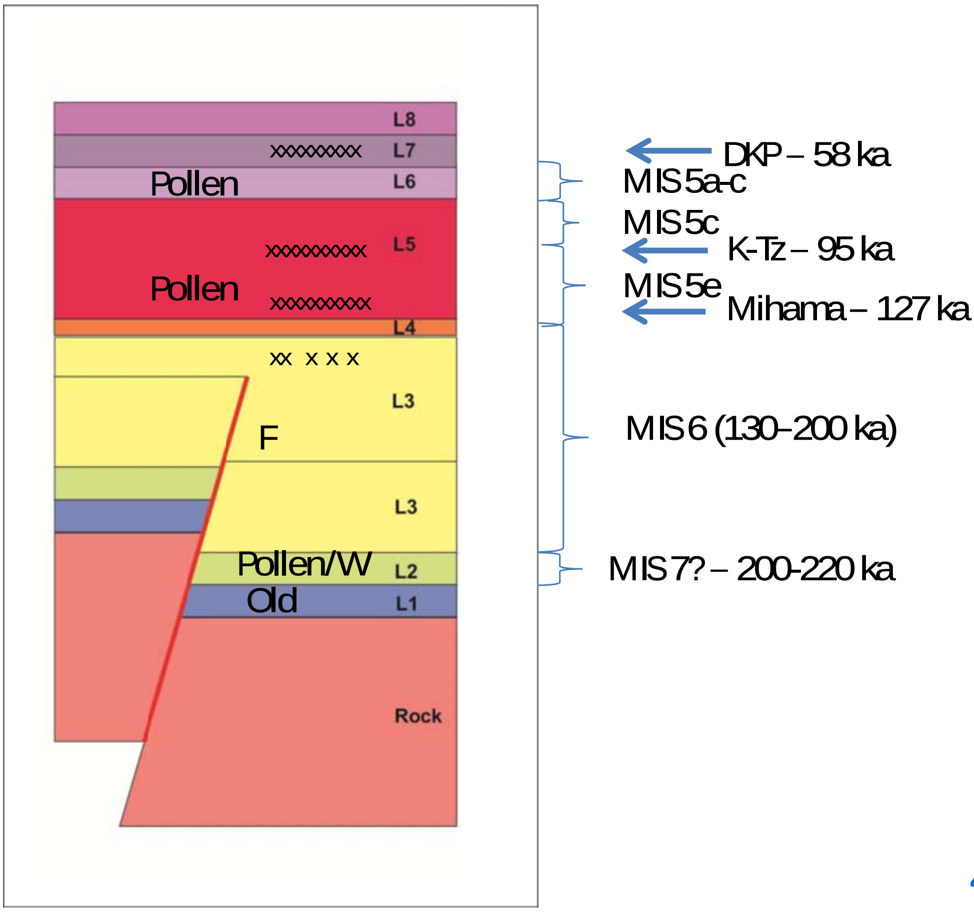
LAST OBSERVED MOVEMENT WAS BEFORE DEPOSITON OF LAYER 1



3

Summary Comments on the K Fault

LAST OBSERVED MOVEMENT IS AFTER DEPOSITION OF MOST OF LAYER 3 AND BEFORE DEPOSITION OF LAYER 5



4

Prior Recommendations

Recommendations of the review team were provided to JAPC in May 2013. The main points were:

(i) Need to continue with structural analysis of the fractures and old faults ✓

(ii) Need to track the K fault southward toward Unit 2 ✓

(iii) Continue investigations of the tephra layers that have been discovered within the soil layers at the site and within the region ✓

(iv) Continue mechanical and kinematic analyses of induced rupture associated with movement on the Urasoko Fault – these have begun and more is needed for the future

(v) For an international best practice seismic hazard assessment of the Tsuruga NPP, active faults, earthquake occurrence, and geodetic strain measurements in an a region beyond the NPP (30–50 km radius may be appropriate) is needed - these have begun and more is needed for the future

5

Conclusions

1. Detailed field studies show that neither the G/D-1 shatter zone, nor the K fault can be classified as active faults.
2. There is no evidence that the G/D-1 shatter zone or K fault have had sympathetic movement in association with fault movement of the Urasoko fault for at least the past 130 thousand years.
3. There is a possibility that future movements of the Urasoko fault could induce sympathetic rupture of fractures and old faults near to the Urasoko fault. If a comprehensive seismic hazard evaluation were to be conducted in future this aspect should be included.

6

Annex 3: Suggested Approaches to Future Work

Future seismic hazard analyses should include at a minimum:

a) geological, seismological, and geophysical studies;

b) fault displacement hazard analysis;

c) earthquake magnitude and seismic source characterization;

d) ground motion studies;

e) seismic margin and fragility evaluations, both deterministic and probabilistic

This Annex makes a preliminary identification of some of the geological topics under (a) that should be considered as the basis for future work for the seismic risk evaluation. We do not discuss here the scope and nature of the work that would be required for items (b) to (e).

1. A broader aerial and ground survey of topographical evidence for fault and shatter zones in a region of some kilometres around the site. A good starting point to accompany further mapping is to carry out an airborne LiDAR (Light Detection And Ranging) survey at sufficiently high resolution to detect weakly expressed lineaments.
2. Continued micro- to macro-scale studies of the internal structure of faults and fractures of interest, allowing comparisons of their genesis and relative movement histories.
3. In-situ stress measurements in the bedrock to determine principal stress directions and magnitudes, combined with consideration of changes in the stress field in the past.
4. Further mechanical analyses of the susceptibility of structures with various properties and orientations to respond to the regional stress field by strain and the conditions under which this might occur. Geological evidence of rupturing and deformation should constrain the models and analyses. Synthesis of onshore and offshore tephra data gathering and analysis, with broader regional correlations would be valuable. A critical review on the age of Mihama tephra accompanied with more information on the analytical results will support the chronology. Other geo-chronological information should be integrated to support the proposed age model.
5. Development of a comprehensive description of the evolution of the site over the last ~200,000 years, focussing especially on the impacts of sea-level and climate fluctuation, and uplift and movement on the Urasoko Fault on the local terrestrial and marine sedimentation pattern that has given rise to the sedimentary layers, that underpin the fracture displacement analysis. Information on the origin of these layers and their correlations within the wider area could help to place them in a chronology based on a geomorphic and sedimentary history of the larger area. Further information about how the layers are distinguished (sorting, grading, clast size, clast composition, matrix composition) and the criteria to define the contacts (layers boundaries) would be useful, as the results rely strongly on the definition of these boundaries.
6. An eventual objective would be the development of a site structural history that explains the origin and development of the shatter zones and their relationships to each other and the Urasoko Fault. At the site of Units 3 and 4 the dolerite dikes are observed to offset the northeast trending shatter zones, similar to D-1. This adds to the richness of data available to develop the history of tectonic movements at the site.

We consider that it would be valuable to subject this work to continued independent peer review.

Annex 4: The Diablo Canyon Nuclear Power Plant Long Term Seismic Program (LTSP) and a Probabilistic Risk-Informed Approach

1 Diablo Canyon Nuclear Power Plant's Long Term Seismic Program as a Model for JAPC and the Tsuruga NPP

On July 14, 1978, the NRC Advisory Committee on Reactor Safety (ACRS) recommended that a seismic hazard and risk update of the Diablo Canyon NPP should be done within 10 years to incorporate new science and new data.

In 1985, following the discovery of the Hosgri Fault near the Diablo Canyon Nuclear Power Plant (DCNPP), PG&E agreed with the US NRC to conduct a Long Term Seismic Program (LTSP) to study and re-evaluate the seismic design criteria for DCNPP as a basis for continuing operations.

There are two key points about this process we wish to bring to the attention of both JAPC and the NRA:

1. The NRC allowed DCNPP to continue to operate and it was not shut down during the LTSP;
2. DCNPP was required to:
    a. Identify, examine, and evaluate all relevant geologic and seismic data, information, and interpretations developed since the 1979 ASLB (Atomic Safety and Licensing Board) hearings;
    b. re-evaluate the magnitude of the earthquake used for the DCNPP seismic design basis;
    c. re-evaluate the ground motion studies;
    d. assess the significance of the conclusions from the above seismic re-evaluation studies, utilizing both probabilistic and deterministic risk analyses, as necessary, to assure the adequacy of the seismic margins.

It should be noted again that the DCNPP Plant continued to operate during the LTSP.

The LTSP has been a great success. The NRC stated in June 1991 – Appendix C, U.S. Geological Survey Review:

> *"The LTSP was planned and implemented to address a set of pre-defined, geologic issues, and considerable flexibility was demonstrated in responding to some new and unexpected findings such as the Los Osos and San Luis Bay faults. The broad range of methods used, the aerial extent of the study, and the depth to which critical issues were probed mark this as an unusually comprehensive site study of earthquake hazards. The credit for this effort belongs to the able and highly professional team assembled by PG&E."*
>
> *"The NRC staff finds that the geological, seismological, and geophysical investigation and analysis conducted by PG&E for the LTSP are the most extensive, thorough, and complete ever conducted for a nuclear facility in the United States. PG&E has advanced the state of knowledge in these disciplines significantly."*

The DCNPP case history is most relevant to the Tsuruga NPP shutdown and regulatory restart process. From commissioning in 1973, through the discovery of the active Hosgri fault in 1985 near DCNPP, to 1991, the full-power license was threatened by active fault and related seismic safety challenges. The LTSP continues today with ongoing investigation of the nearby Shoreline fault using ocean bottom seismographs and seismic reflection marine surveys as part of DCNPP's "living safety assessment".

The end result has been that PG&E have adequately addressed all licensing issues under the LTSP and the USNRC have continued to grant permanent Full-Power Licenses.

The most important lesson for the JAPC and the NRA is the lesson of dialogue between the utilities, the regulator, and the public. The example of DCNPP and the US NRC should be followed. DCNPP and NRC, and related advisors, agreed on a process to openly discuss the active fault challenges and develop a program to resolve all challenges. The program was open and transparent, with full disclosure of past mistakes or inadequacies, and a commitment by DCNPP to work with the NRC.

We strongly recommend that since the "active fault" questions have been successfully answered by the JAPC, that the NRA should now re-evaluate their position concerning this issue based on the new evidence presented to us and the independent review contained in this report. Then the NRA and the JAPC should begin to enter into dialogue concerning continuing seismic safety evaluations at the Tsuruga NPP modeled after the LTSP agreed upon by the NRC and PG&E.

2 A Probabilistic Risk-Informed Approach

Probabilistic risk assessments (including equipment breaking, earthquakes, flooding, loss of external power etc.) are considered "best practice" and essential by regulators from all over the world and the IAEA.

The NRC decided to implement "risk-informed" approaches in 1993. As a result, when the NRC proposed a new regulation, a risk-based approach was required among the alternative approaches.

In 1995 the "PRA Policy Statement" (60 FR 42622, August 16, 1995) formalized the Commission's commitment to risk-informed regulation through the expanded use of PRA. The PRA Policy Statement includes, in part:

> *"The use of PRA technology should be increased in all regulatory matters to the extent supported by the state of the art in PRA methods and data, and in a manner that complements the NRC's deterministic approach and supports the NRC's traditional defence-in-depth philosophy."*

When doing an external event PRA for earthquakes, it is common practice to use probabilistic seismic hazard analysis (PSHA). PSHA is a method for calculating the range of ground motions that may impact an NPP and is well known in the nuclear power industry to analyze both ground motion and fragilities. It is accepted by the US NRC, the IAEA, the Swiss Federal Nuclear Safety Inspectorate, and L'Autorite de surete nucleaire in France. Also, in Mexico, the Commission Federal Electrdad (CFE) required PSHA for the Laguna Verde Nuclear Power Plant (LVNPP). PSHA was first implemented in 1985 and has continued with significant success to the present.

With regard to the Tsuruga NPP we recommend that if the additional data gathering now completed and discussions with the NRA do not lead to resolution and agreement over the fault issues, then a probabilistic fault displacement hazard analysis (PFDHA) could lead to establishing a clear, risk-informed decision on the fault issues.

Probabilistic fault displacement hazard analysis (PFDHA) is not as well known as PSHA, however, it has been used successfully at Yucca Mountain, the Krsko NPP in Slovenia, at high hazard hydro dams in New Zealand and in R&D studies in Japan for examining procedures for waste repository site suitability. Its use is accepted by the US NRC.

A comprehensive seismic hazard analysis that incorporates fault displacement hazard evaluation would require the following intermediate steps:

(1) looking at the likelihood of fault activation (PFDHA);

(2) the probability of displacements of different magnitudes over different time periods;

(3) probabilistic ground motion studies (PSHA);

(4) probabilistic fragility analyses to understand the strength of the structures, systems, and components;

(5) and integration into the plant specific probabilistic and deterministic risk assessments.