

Implications of Long-Term Reactivation of Faults Normal to Rift Axis for Coarse-grained Clastic Systems and Structural Segmentation in the Niigata Basin, Japan*

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Abstract

In the study of the Niigata back-arc basin, central Japan, considerable attention has been paid to the principal trend of the NNE-SSW to N-S rift axis that dominated the Miocene rifting as well as the post-Pliocene tectonic inversion. This study investigates the significance of faults approximately normal to the rift axis (NE-SW to NW-SE; “rift-normal faults” herein), by performing surface mapping, sedimentary facies analysis, and fault rock analysis on upper lower - lower middle Miocene (ca. 17-15 Ma) clastic rocks and basement granitoids in the northern part of the basin.

The basal part of the Miocene includes thick breccia facies of fan-delta systems, rich in debris-flow deposits. This coarse-grained facies occurs only in narrow areas, each of which is bordered by rift-normal faults. It should be noted that, typically, coeval sediments are very thin and fine-grained. These lateral changes in the sediments occur abruptly across the faults. Paleocurrent data of the breccia facies show clastic supply from the east along the rift-normal faults. Thus, these faults during the deposition of the basal Miocene developed as growth faults and constrained the loci of prominent lateral clastic supply.

Most of these rift-normal faults are characterized by fault gouges and breccias, with a rare presence of cataclasites. The thickness of the fault rocks suggests that the net slip of each fault is up to several tens of meters. Deformation structures of the faults indicate changes in the sense of shear from reverse to sinistral and finally dextral. These changes, as well as the net slip, suggest a long-term history of reactivation of the rift-normal fault system. Moreover, the largest rift-normal fault separates two structural segments in the study area. This segmentation is likely to have developed during the inversion-related deformation. A similar segmentation with the NW-SE faults has also been estimated within the upper crust by the observation of a recent earthquake in the other area of the basin.

Therefore, we emphasize the importance of structural elements normal to the rift axis of the Niigata basin. Within the long-term reactivation history, these elements functioned as tectonically controlled pathways of lateral clastic supply to the graben during the Miocene rifting. Then,

they bordered structural segments, which may be analogous to the geological constraints of the present intra-crustal seismicity in the backarc region.

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Implications of Long-term Reactivation of Faults Normal to Rift Axis for Coarse-grained Clastic Systems and Structural Segmentation in the Niigata Basin, Japan

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QUESTION:

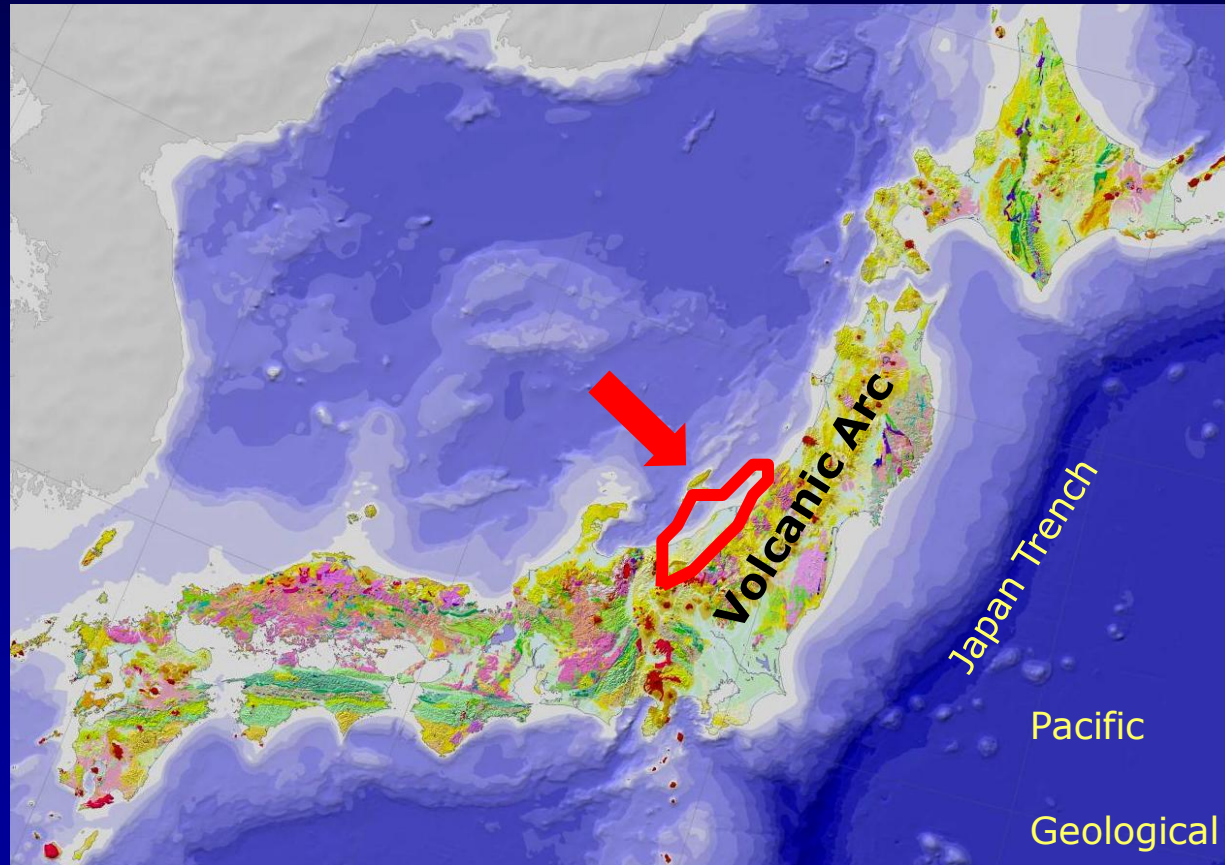
What's the role of **RIFT-NORMAL FAULTS in sedimentation and later deformation?**

... in the backarc setting where rifting was rapid and intensive inversion took place afterward.



Niigata Basin, NE Japan

Thick accumulation of clastic Neogene in the backarc setting



- ✓ Thick sediments up to 6,000 m
- ✓ High-heat flow
- ✓ Post-Miocene deformation

➡ Most oil/gas productive area in Japan

Geological Survey of Japan (2003)

Niigata Basin, NE Japan

Development affected by (e.g., Jolivet and Tamaki, 1986)

- ✓ Miocene rifting (backarc extension) and
- ✓ post-Miocene intensive compression (inversion)

| TECTONOSTRATIGRAPHY | | | | | | | | | |
|---------------------|-----------------|-----------------|---|----------------------------------|--------------------------------|---------------------------|--------------------------------------|--|--------------------------------------|
| Stage | Age | Unit | Depositional Characters | | Sedimentation Control Factors | | | | Basin Tectonics Stress Field |
| | | | Main Depositional System | Stacking Pattern | Accumulation vs. Accommodation | Estimated Sediment Supply | Subsidence Pattern | | |
| STAGE IV | Present 1Ma | UNIT IV | Restriction of depositional area | Progradational | Accumulation >> Accommodation | | uplift | | Intense Compression |
| STAGE III | 1Ma 6.5Ma | UNIT III | Fluvial Near Shore Delta Shelf Trough-fill Turbidite | Progradational (Regression) | Accumulation > Accommodation | | Variable patterns Slow subsidence | | Incipient Compression Compression |
| STAGE II | 6.5Ma 13.5Ma | UNIT II | Submarine fan Fan delta | Vertical (Aggradational) | Accumulation = Accommodation | | Slow subsidence (thermal subsidence) | | Post-rift |
| STAGE I | 13.5Ma 16Ma | UNIT I | Slope to basin floor Pyroclastics | Retrogradational (Transgression) | Accumulation << Accommodation | | Rapid subsidence | | Syn-rift Tension |

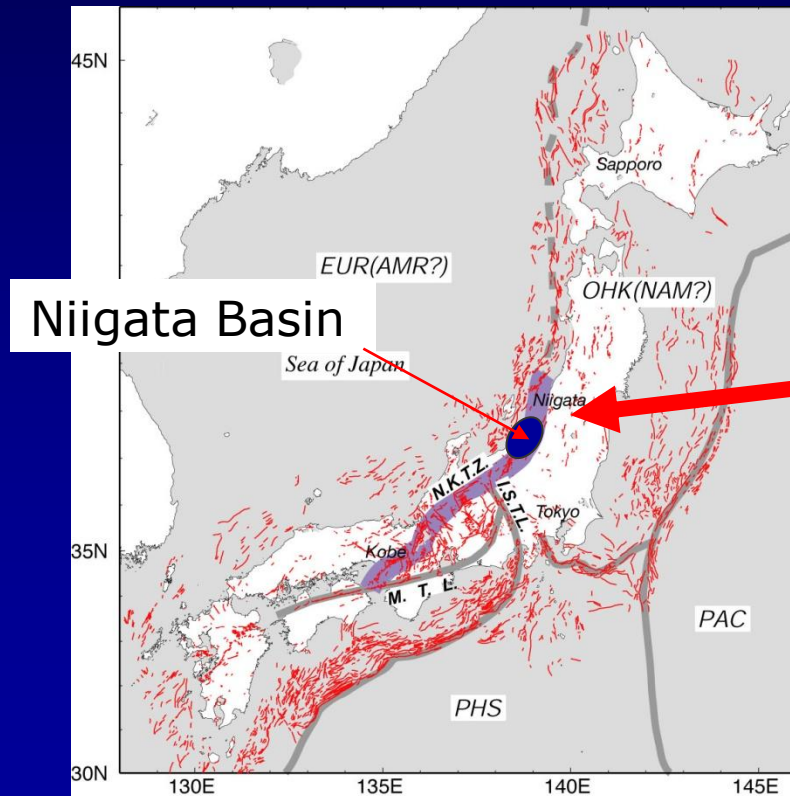
Tectonostratigraphic stages in the Niigata Basin by Takano (2002)

- ✓ Compressional (Stages III & IV)
- ✓ Post-Rift (Stage II)
- ✓ Syn-Rift (Stage I)

Niigata Basin, NE Japan

Basin development affected by (e.g., Jolivet and Tamaki, 1986)

- ✓ Miocene rifting (backarc extension) and
- ✓ post-Miocene intensive compression (inversion)



Part of a zone of highest strain rate within the island arc – seismicity most active today

“NKTZ: Niigata – Kobe Tectonic Zone” by Tada et al. (1997), Sagiya et al. (2000)

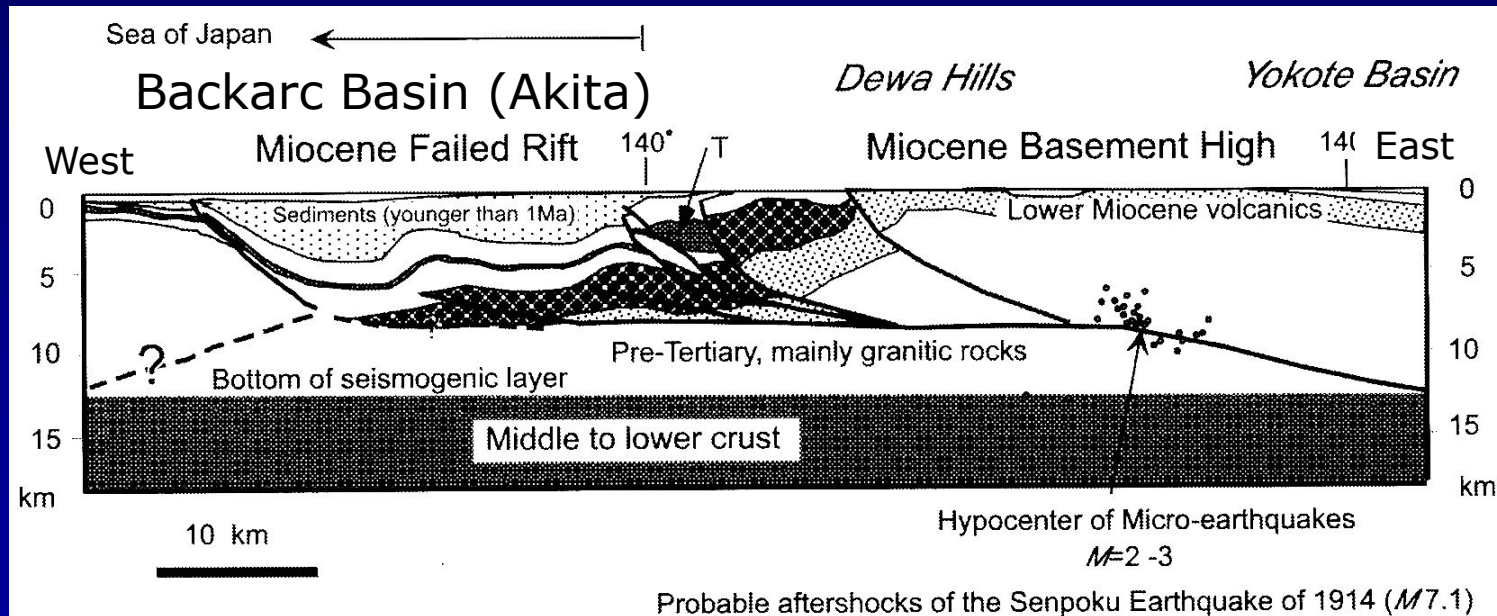
Neotectonics:

Active faults (red lines) and plate configuration around Japan by MLIT-GSI (2003)

Niigata Basin, NE Japan

Previous geological studies in the backarc of NE Japan: Much attention to the rift axis trend (NNE–SSW to N–S) that determines the size and location of inversion-related folds.

Structures are analyzed in rift-normal (E–W) sections.



Sato et al. (2004)

OBJECTIVES

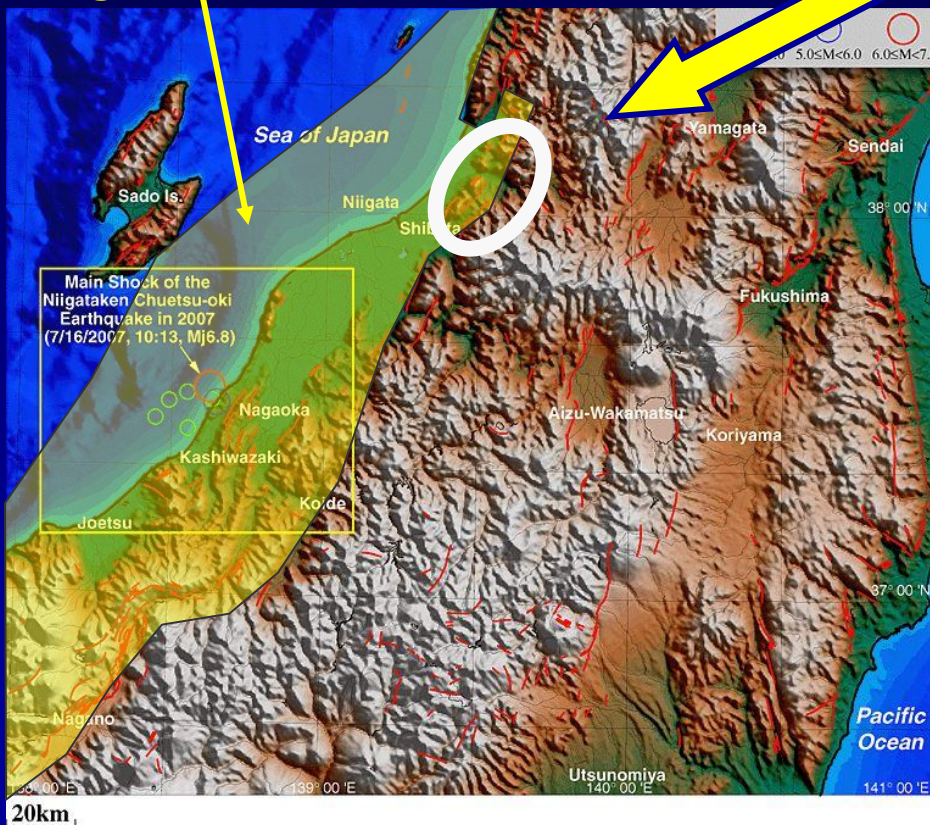
The present study investigates

- ✓ implications of faults approximately normal to the rift axis (NE–SW to NW–SE; “rift-normal faults” herein) to deposition and deformation of sediments
- ✓ by performing
 - ✓ surface mapping
 - ✓ sedimentary facies analysis
 - ✓ fault rock analysis
- ✓ on upper lower – lower middle Miocene (ca. 16 Ma) clastic rocks and basement granitoids (Cretaceous–Paleogene) in the northern part of the basin

OBJECTIVES

The present study investigates

Niigata Basin



the basin border
in the northern part

where we expect:

- ✓ clastic rocks of ca. 16 Ma that recorded rapid subsidence during the rifting
- ✓ inversion-related deformation

Ohkuma (2007, AIST web)
after Kishimoto (1999)

RESULTS

- ✓ Stratigraphy & Mapping
- ✓ Sedimentary Facies Analysis
- ✓ Fault Rock Analysis

DISCUSSION & SYNTHESIS

What happened...

- ✓ During the basin genesis
- ✓ During the post-Miocene inversion

SUMMARY

Stratigraphy & Mapping

RESULTS –Stratigraphy & Mapping

The basal Miocene –Coarse clastics

- ✓ Kamagui Formation – Syn-rift sediments
- ✓ Dated as ca. 16 Ma by fission-track dating and dinoflagellate cyst biostratigraphy

| Series | Formation (thickness in meter) | Generalized section | Description | Geochronologic data and samples |
|---------|-----------------------------------|---------------------|--|---|
| MIOCENE | Uchisugawa (20+) | | Massive grey siltstone. Partly bioturbated. | (1)(2) FT dating by (1) Sato and Muramatsu (1998), (2) Iwano et al. (2003) |
| | Shimoseki (120) | | Bedded dark-grey siltstone. Partly siliceous. | 16.9 - 14.7 Ma for HZK samples by dinoflagellate cysts (This study) |
| | Hozakayama Rhyolite | | Rhyolite lavas and dykes. Partly perlitic. | ← HZK-04 ← 15.1±0.7 Ma (1) ← 15.5±0.9 Ma (1) ← HZK-03 |
| | Kamagui (20 - 700) | | Structureless elastic breccia - conglomerate, weakly bedded conglomerate, sandstone, alternating beds of conglomerate and sandstone, alternating beds of sandstone, siltstone and tuff. Partly bioturbated. | ← HZK-01,02 |
| | Kitaoguni (70) | | Rhyolitic massive lapilli tuff. Partly welded structures. | ← 21.9±0.8 Ma (2) ← 22.5±0.8 Ma (2) |
| | | | Shale, sandstone and chert, intruded by granitoids. | |

pre-Neogene ∩ indicates tubular burrows and bioturbation.

Post-Rift

sandy

Syn-Rift

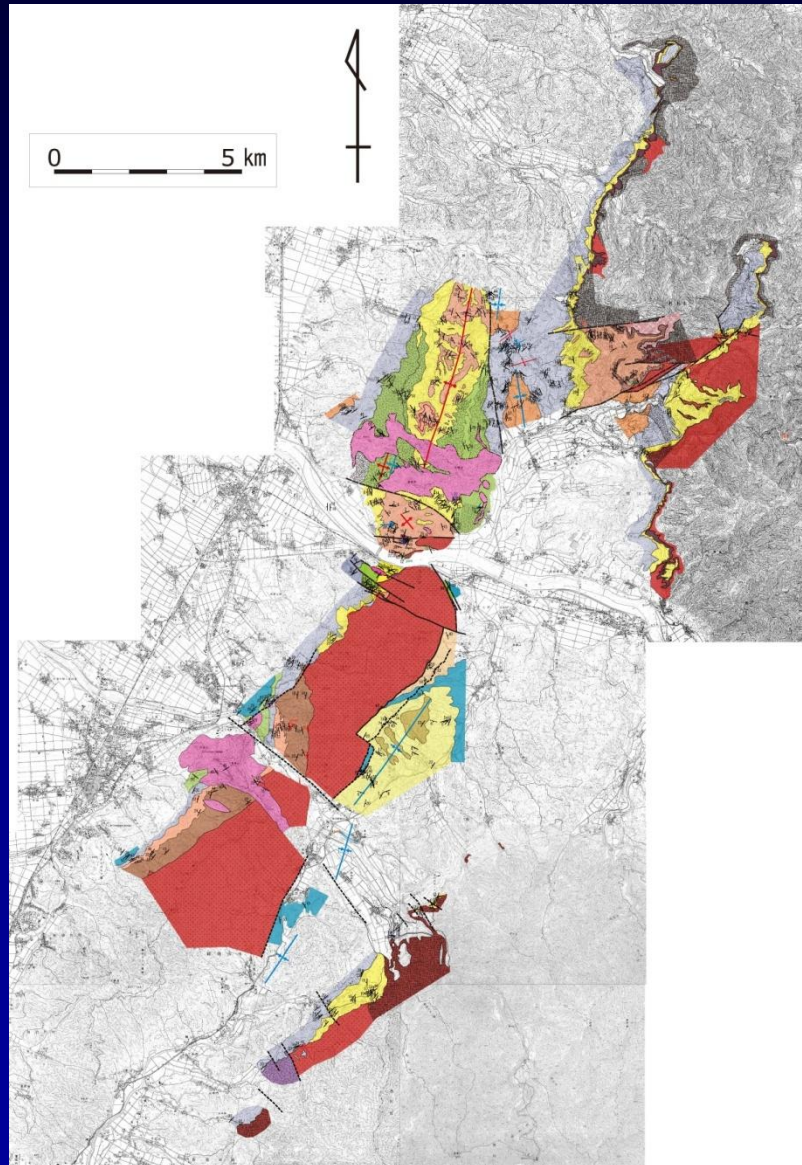
gravelly

Pre-Rift

RESULTS –Stratigraphy & Mapping

New geological map of the basin border

Basin center

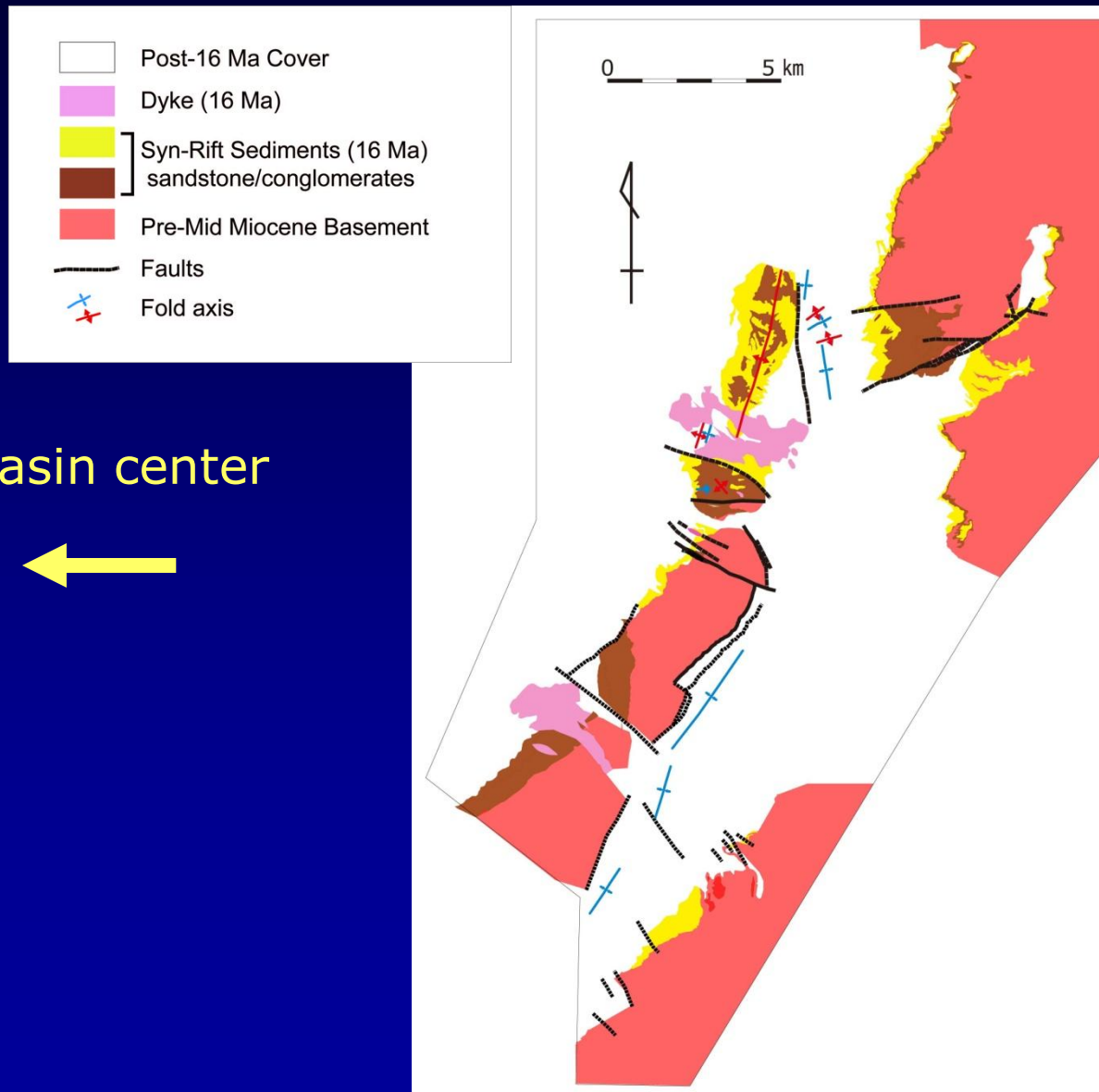


Basement
mountain



RESULTS –Stratigraphy & Mapping

New geological map of the basin border



Basin center



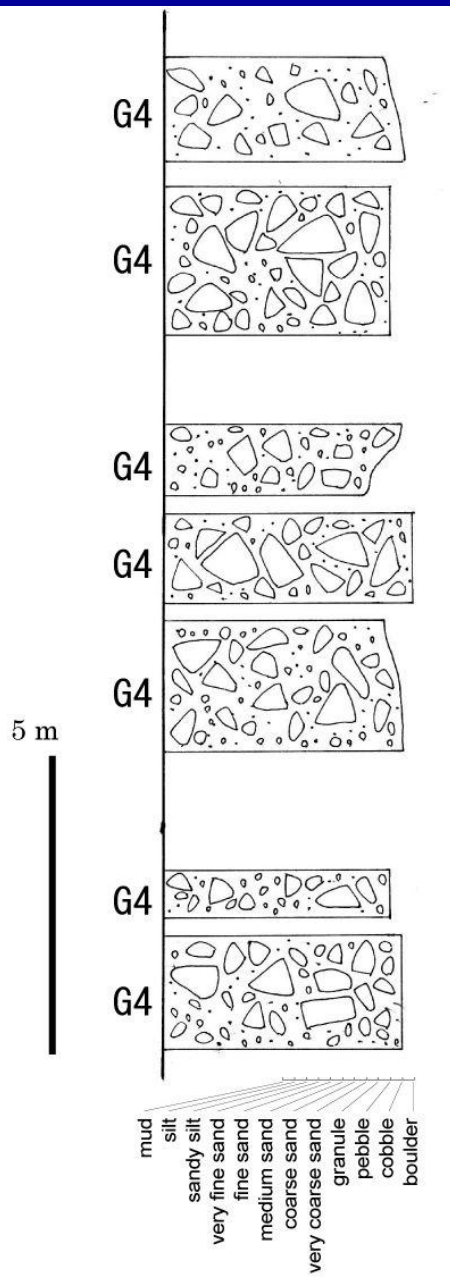
Basement mountain



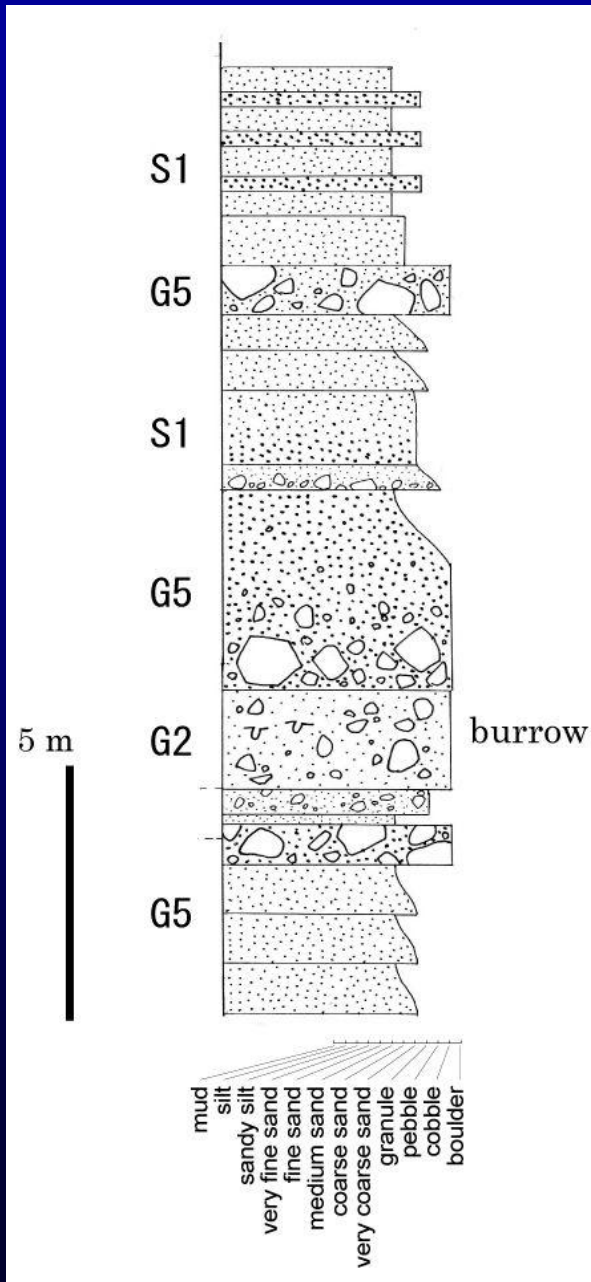
Sedimentary Facies Analysis

RESULTS–Sedimentary facies analysis

Facies Association 2 (FA2): Very poorly sorted clastic breccia = debris-flow deposits under subaerial environment (+ confined distribution)



RESULTS–Sedimentary facies analysis



Facies Association 4 (FA4): graded conglomerate-sandstone with frequent outsized-clasts and burrows = gravity-flow deposits under shallow-marine environment



RESULTS–Sedimentary facies analysis

1: Syn-rift sediments=

- ✓ Richness in deposits from gravity processes
- ✓ Distinctive lateral changes in facies and thickness
- ✓ Both terrestrial and shallow-marine origin

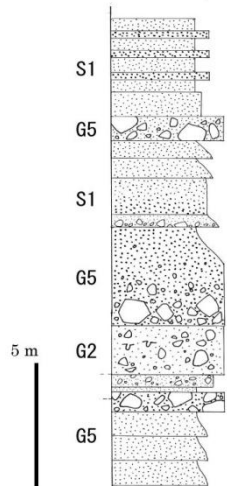
RESULTS–Sedimentary facies analysis

1: Syn-rift sediments= a fan delta system

Subaerial upper fan

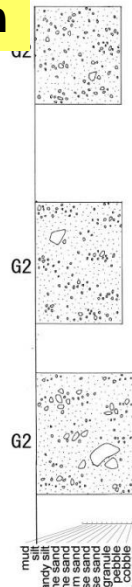
Hyperconcentrated
flow deposits

FA4



mud
silt
sandy silt
very fine sand
fine sand
medium sand
coarse sand
very coarse sand
granule
pebble
boulder

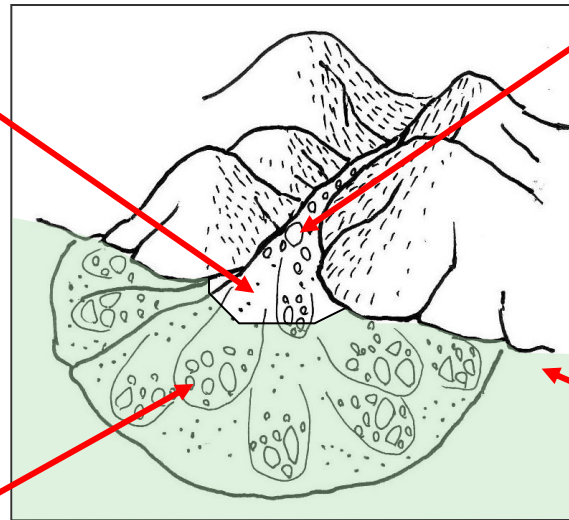
FA3



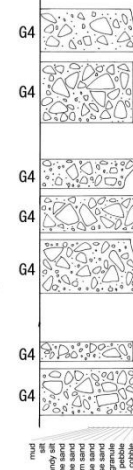
mud
sandy silt
very fine sand
fine sand
medium sand
coarse sand
very coarse sand
granule
pebble
boulder

Catchment valley

Debris-flow deposits

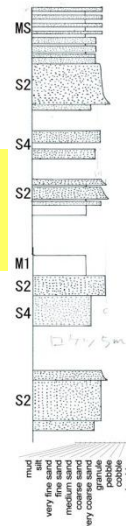


FA2



mud
sandy silt
very fine sand
fine sand
medium sand
coarse sand
very coarse sand
granule
pebble
boulder

FA6



mud
silt
sandy silt
very fine sand
fine sand
medium sand
coarse sand
very coarse sand
granule
pebble
boulder

**Sandy shoreface- shelf
adjacent to fan delta**

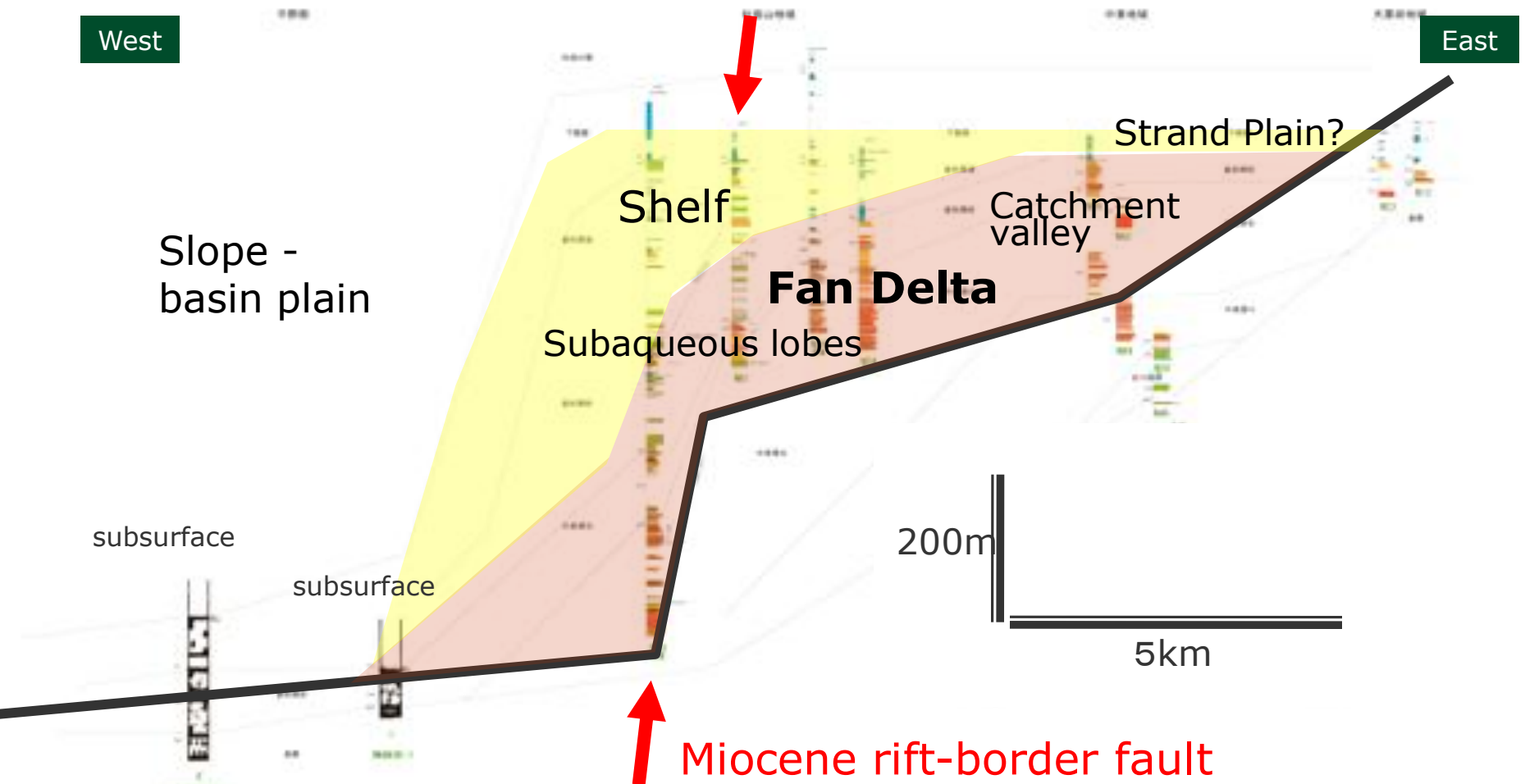
sandy alternation

Subaqueous fan delta lobe

coarse-grained gravity-flow deposits
with burrows and marine dinoflagellates

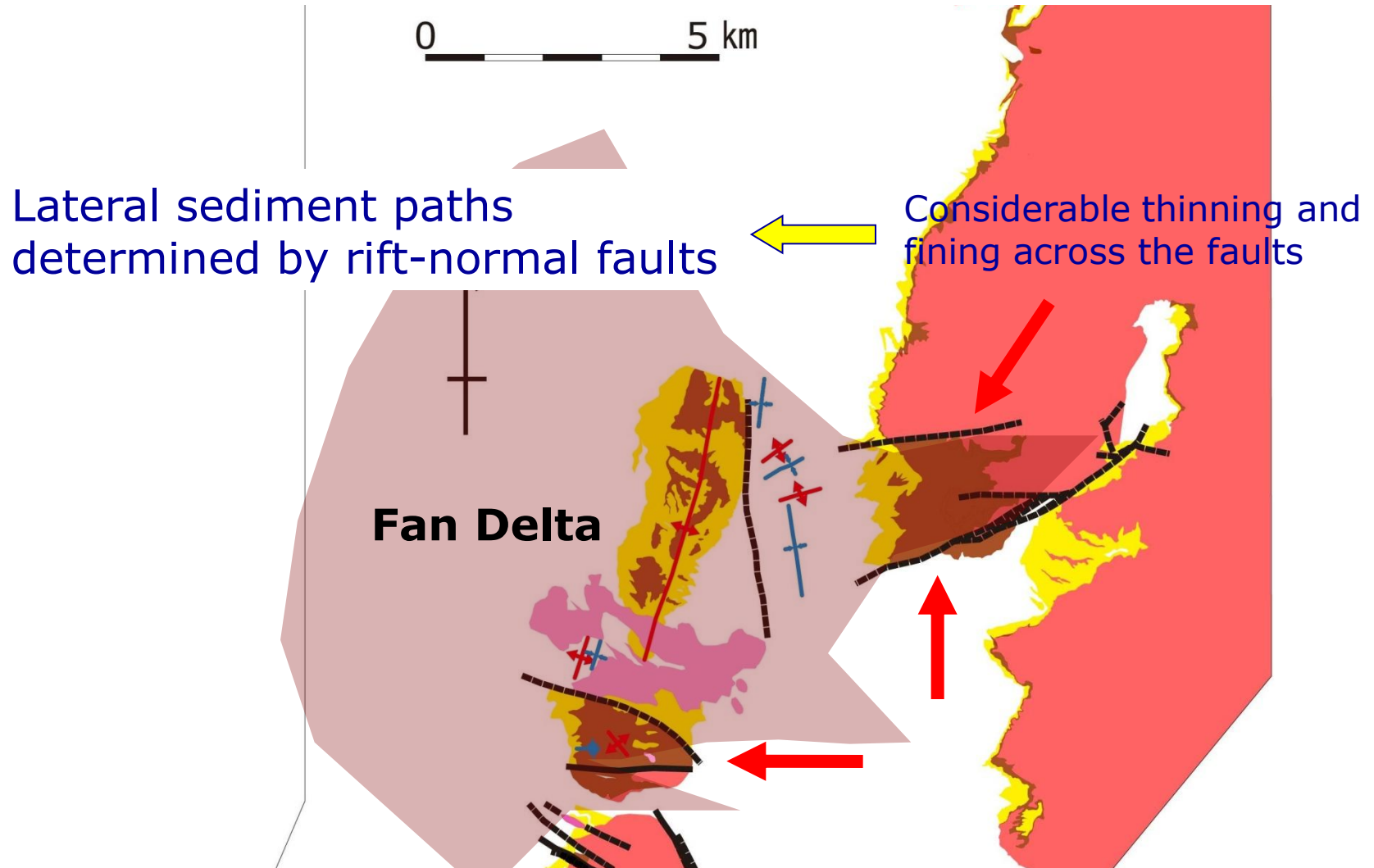
RESULTS–Sedimentary facies analysis

- 1: Syn-rift sediments= a fan delta system
- 2: Break in thickening trend = locus of rift-border fault



RESULTS–Sedimentary facies analysis

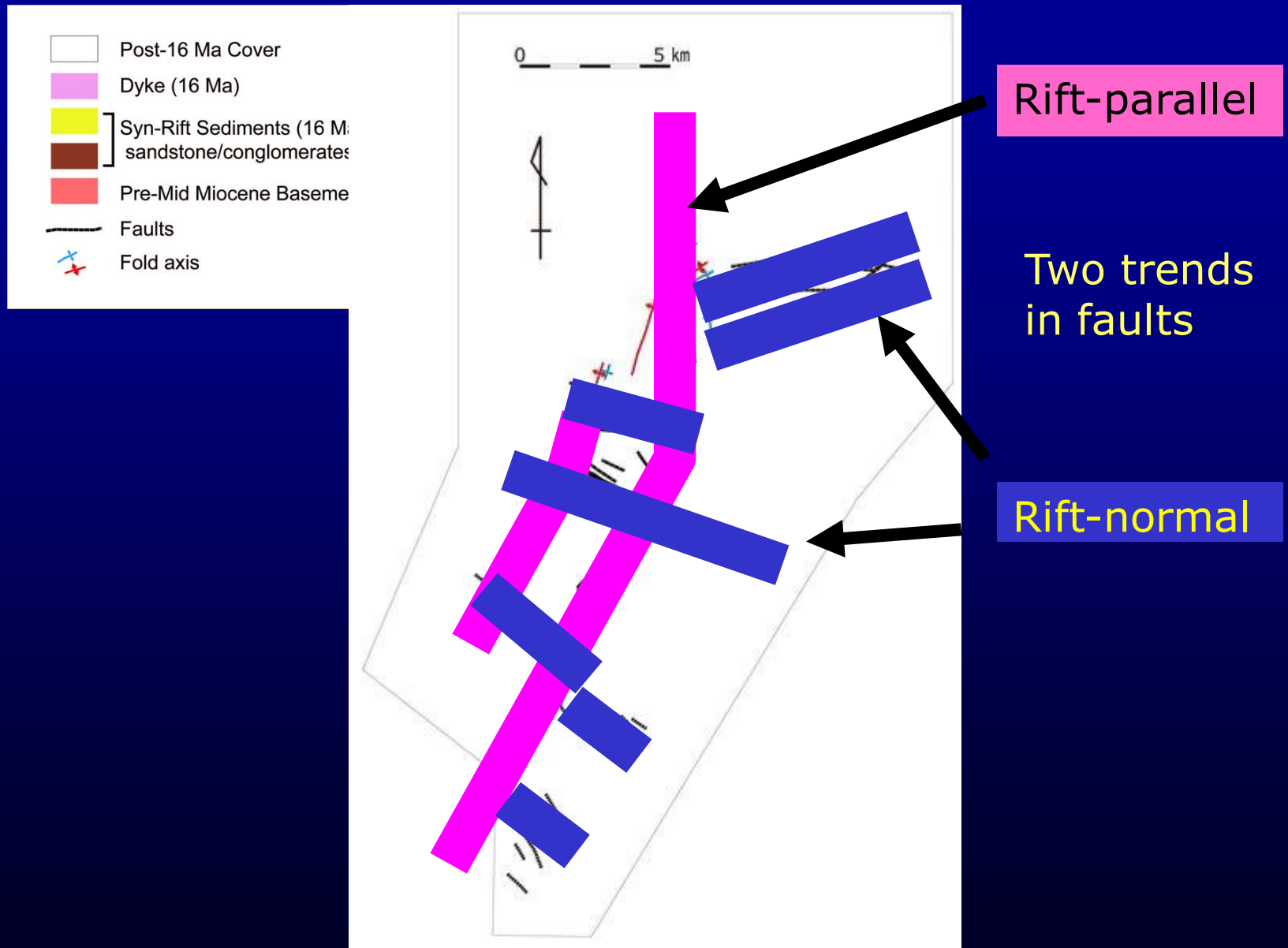
- 1: Syn-rift sediments= a fan delta system
- 2: Break in thickening trend = locus of rift-border fault
- 3: Fan delta body is bordered by rift-normal faults



Fault Rock Analysis

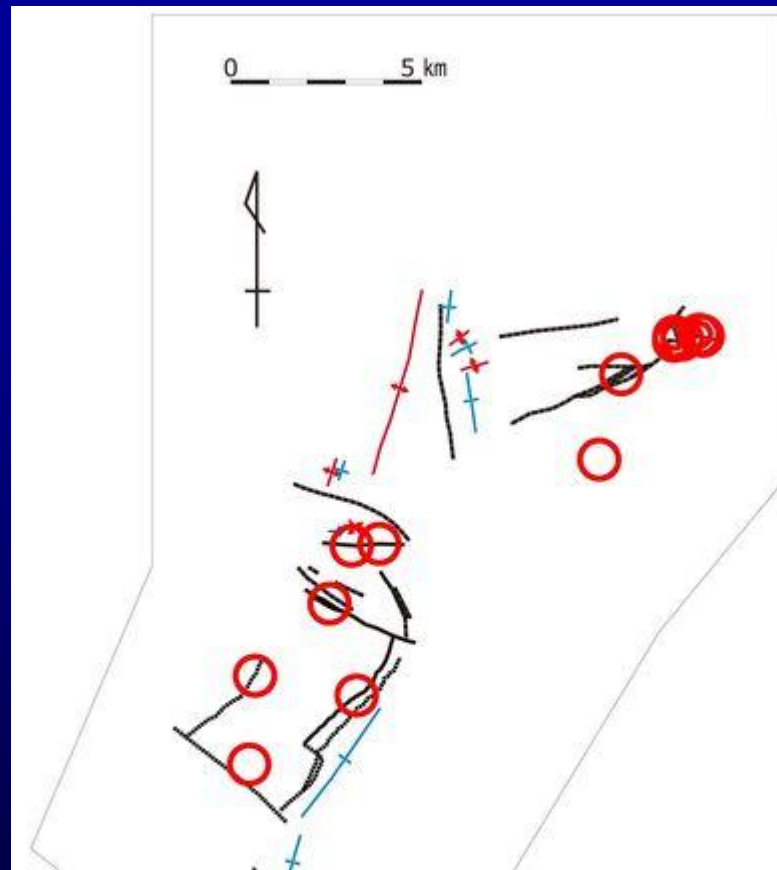
RESULTS –Fault rock analysis

Faults and fold axis



RESULTS –Fault rock analysis

● Outcrops of fault rocks

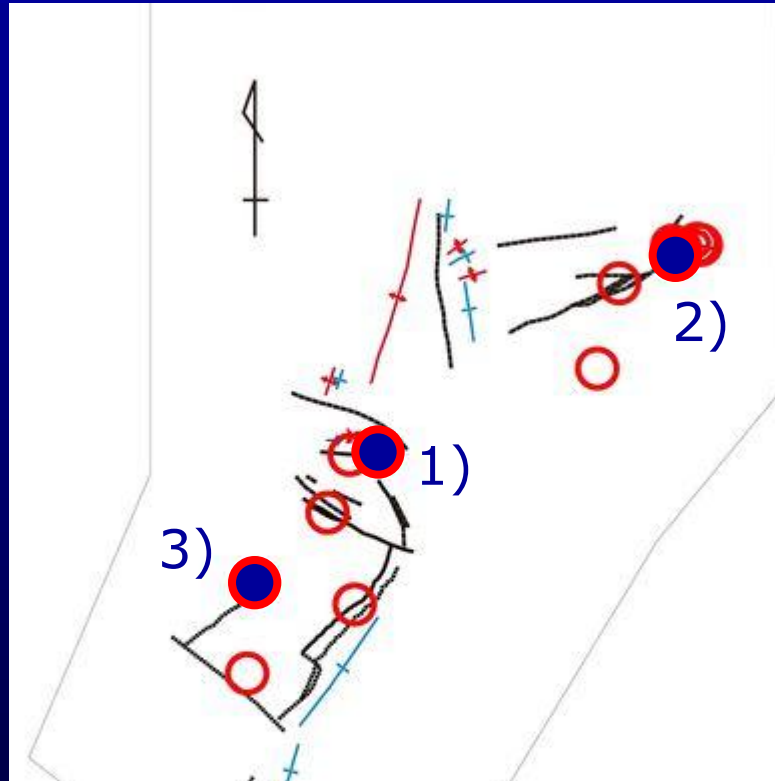


Fault rocks:

- ✓ found in both rift-parallel and rift-normal trends.
- ✓ mostly fault gouges and breccias, occasionally with cataclasites along the same fault planes.

RESULTS –Fault rock analysis

3 examples ○ of faults
that border the basement and Miocene conglomerate



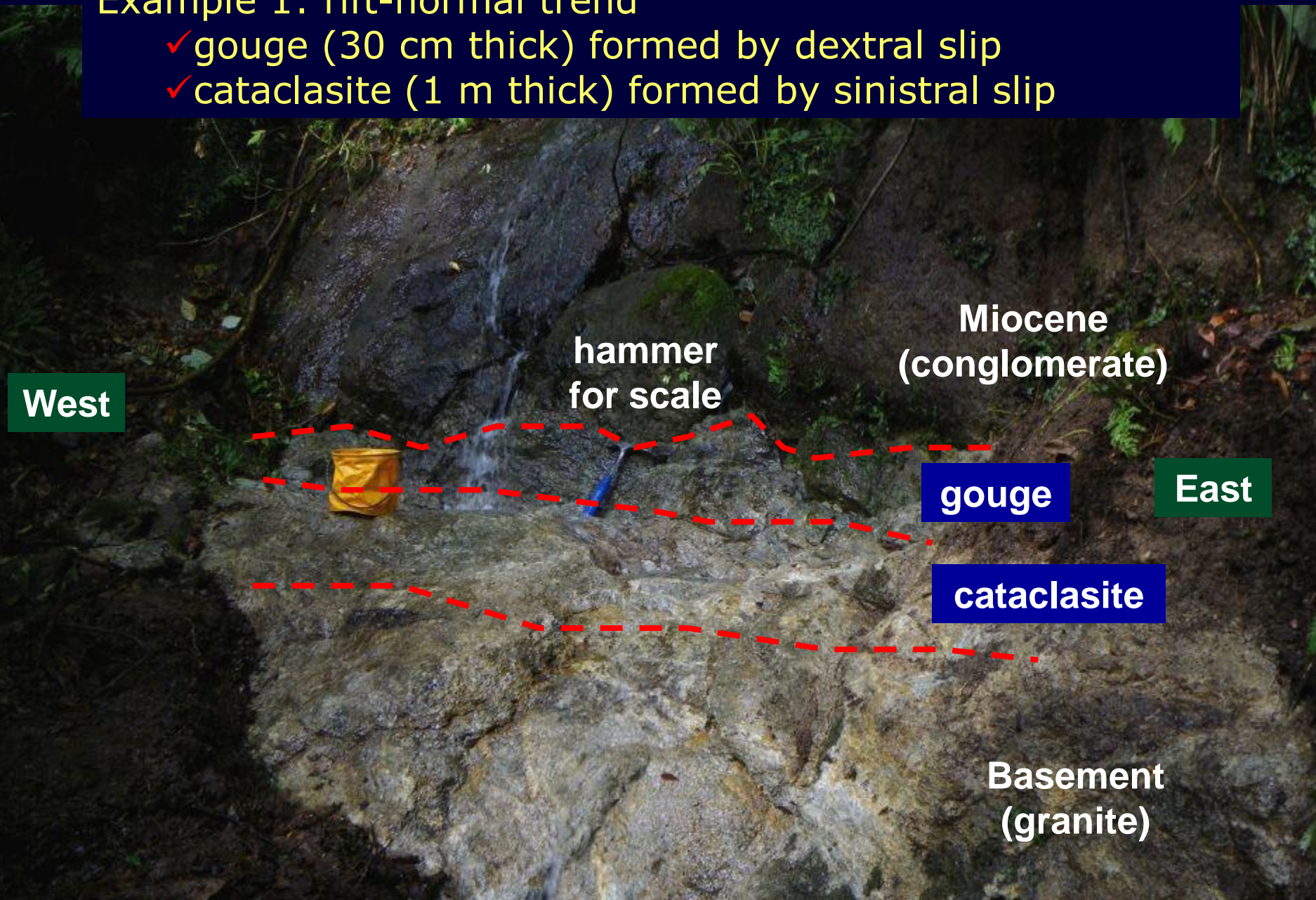
Fault rocks:

- ✓ found in both rift-parallel and rift-normal trends.
- ✓ mostly fault gouges and breccias, occasionally with cataclasites along the same fault planes.

RESULTS –Fault rock analysis

Example 1: rift-normal trend

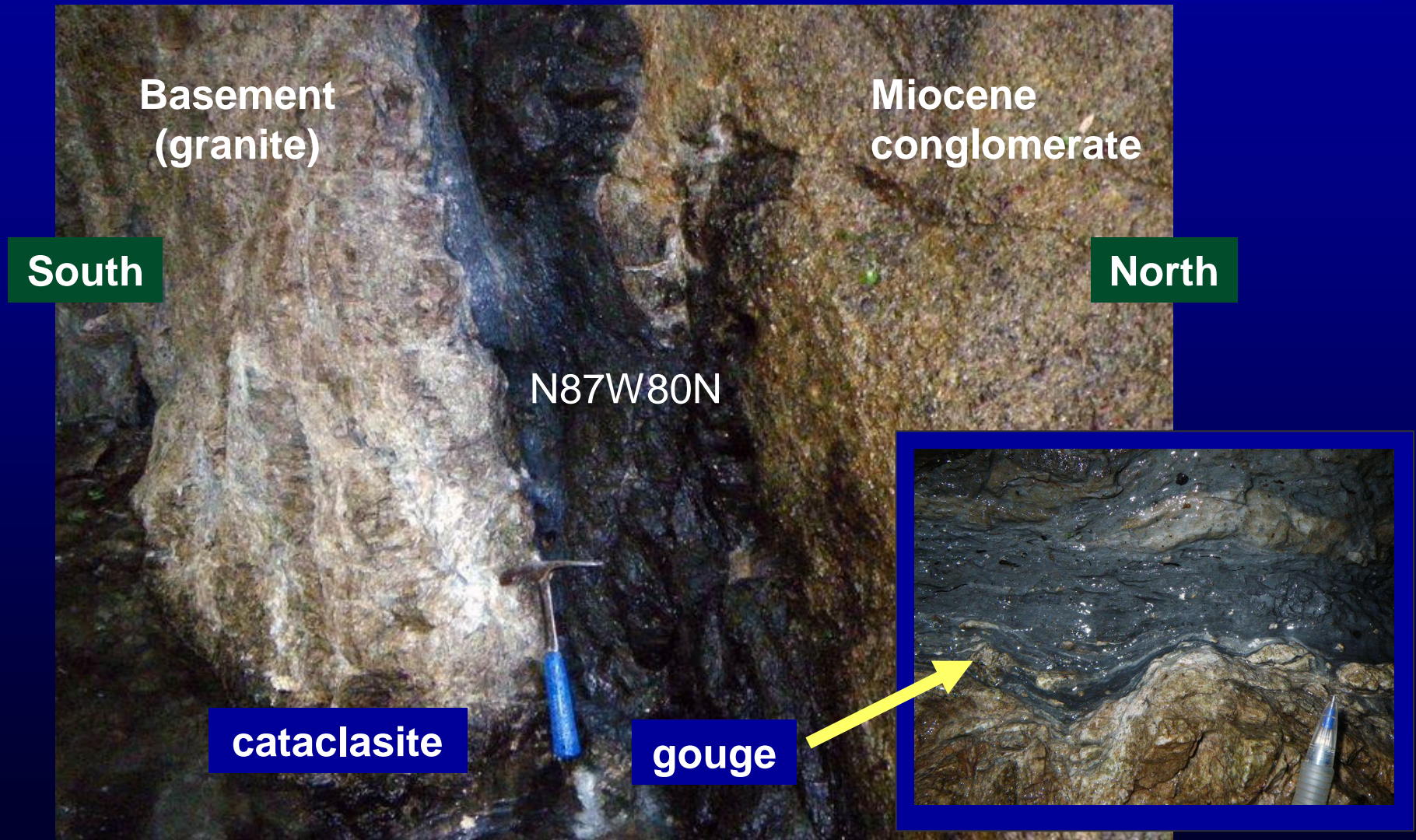
- ✓ gouge (30 cm thick) formed by dextral slip
- ✓ cataclasite (1 m thick) formed by sinistral slip



RESULTS –Fault rock analysis

Example 2: rift-normal trend

- ✓cataclasite and gouge of granite
- ✓sense of slip: first reverse, and then dextral

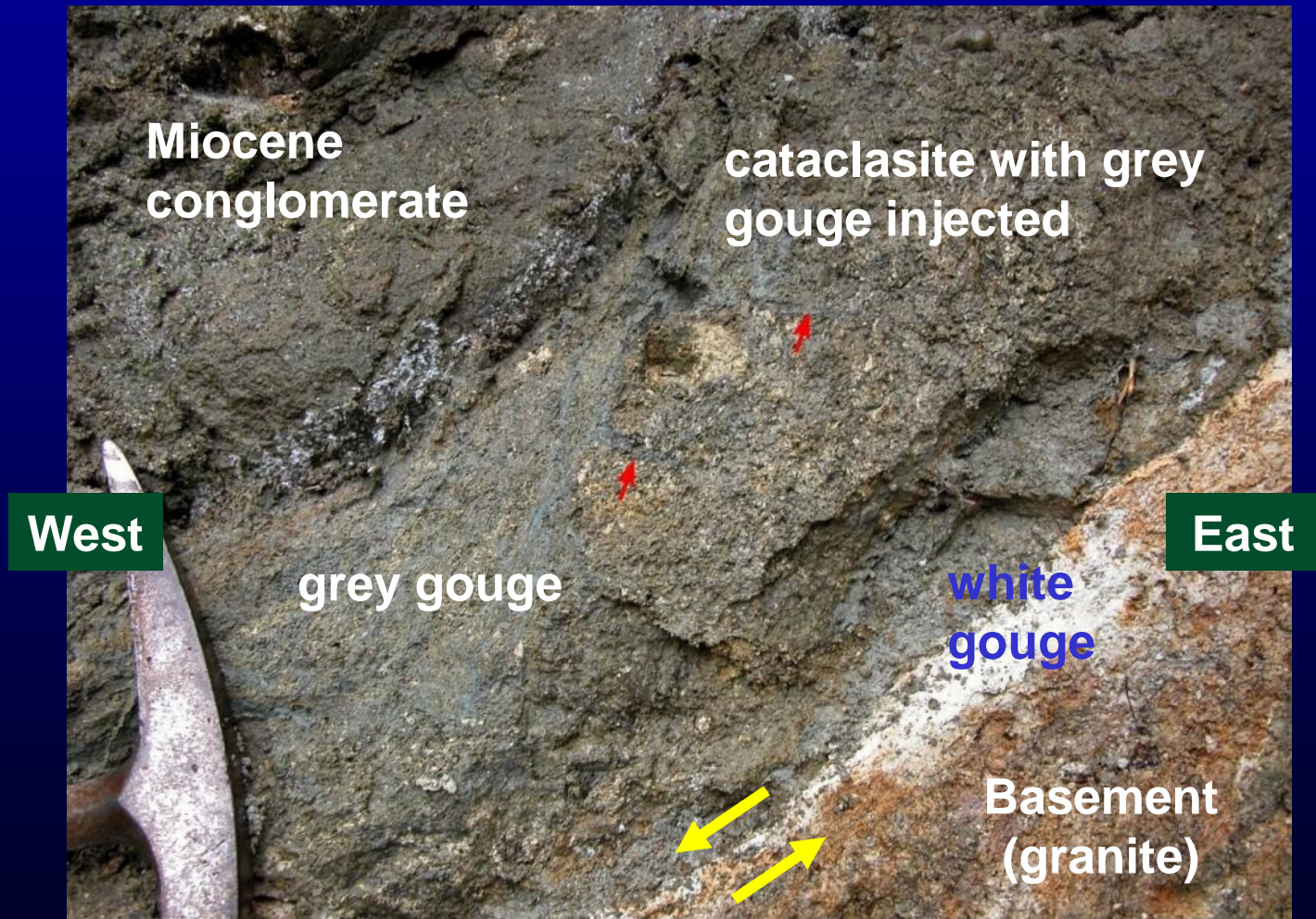


RESULTS –Fault rock analysis

Example 3: rift-parallel trend

- ✓cataclasite injected (red arrows) by grey gouge
- ✓another white gouge along the principal fault plane
- ✓sense of latest slip is normal

N46E53W



RESULTS –Fault rock analysis

----- Rift-normal faults -----

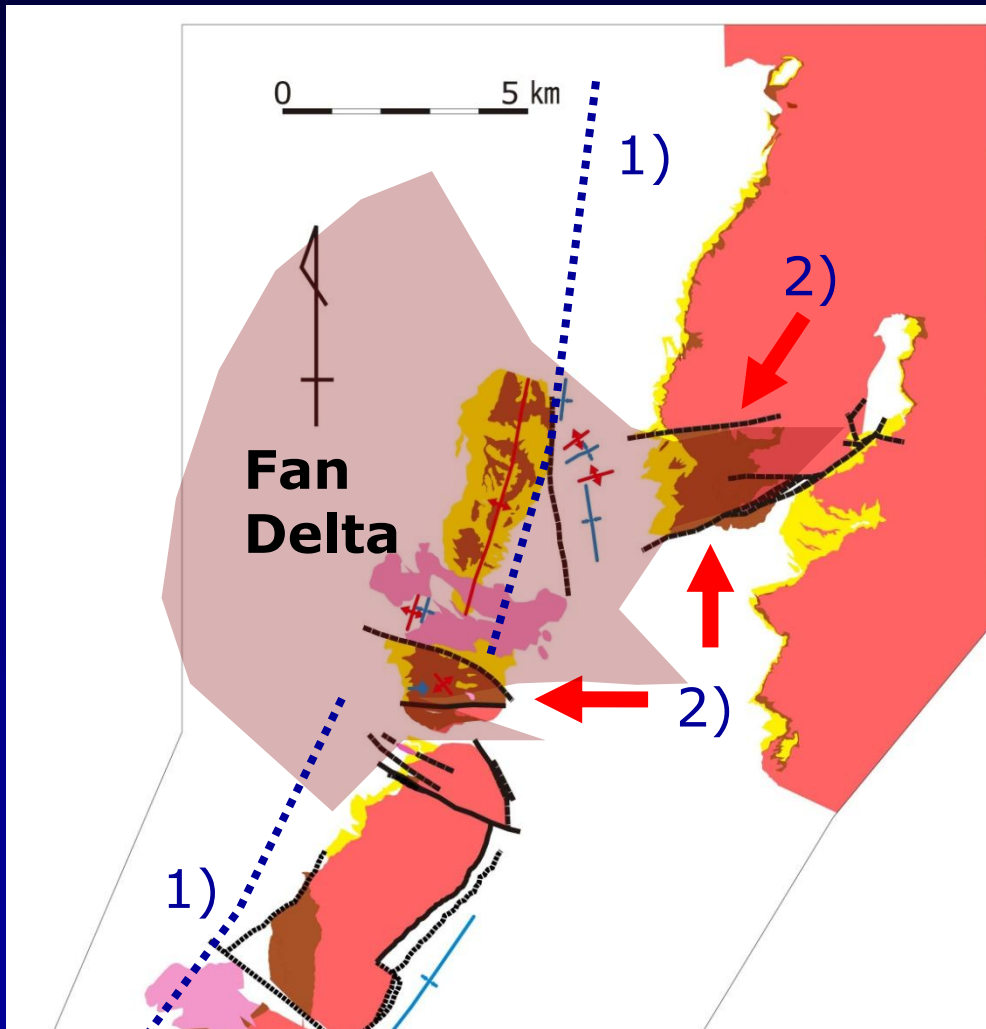
- ✓ Net slip of each fault up to several tens of meters ← from thickness of fault rocks
- ✓ Multiple events of shearing: from reverse to sinistral and finally dextral.
← from composite planar and linear fabrics
- ✓ A long-term (Cretaceous? to post-Miocene) history of reactivation.
← from combination of fault rocks of different depth levels at single fault

DISCUSSION & SYNTHESIS

DISCUSSION & SYNTHESIS

1: During the basin genesis, ...

Geological Map



1) Fan delta systems developed at the rift-border faults

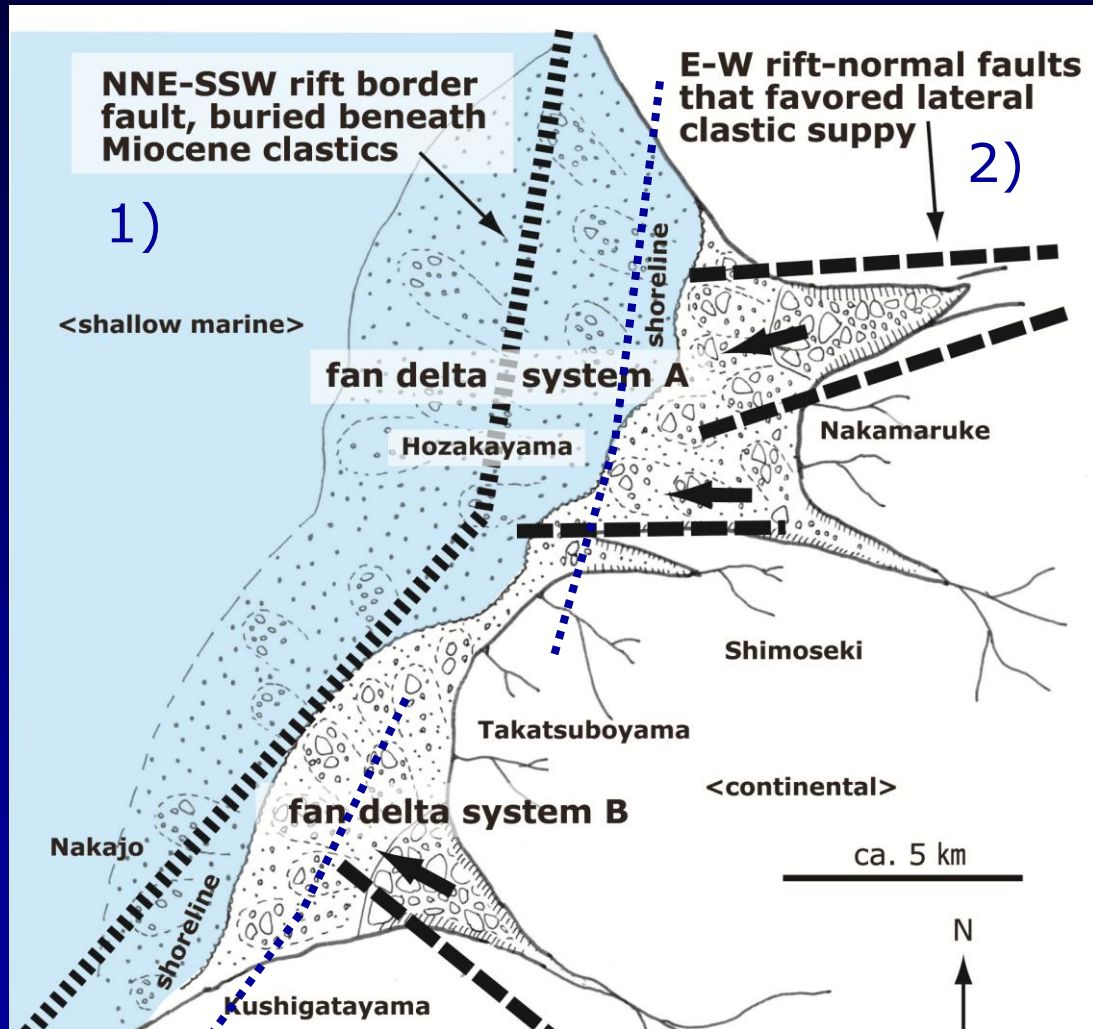
2) Rift-normal faults confined the major sources of lateral clastic supply

... by reactivation of older faults

DISCUSSION & SYNTHESIS

1: During the basin genesis, ...

Reconstruction



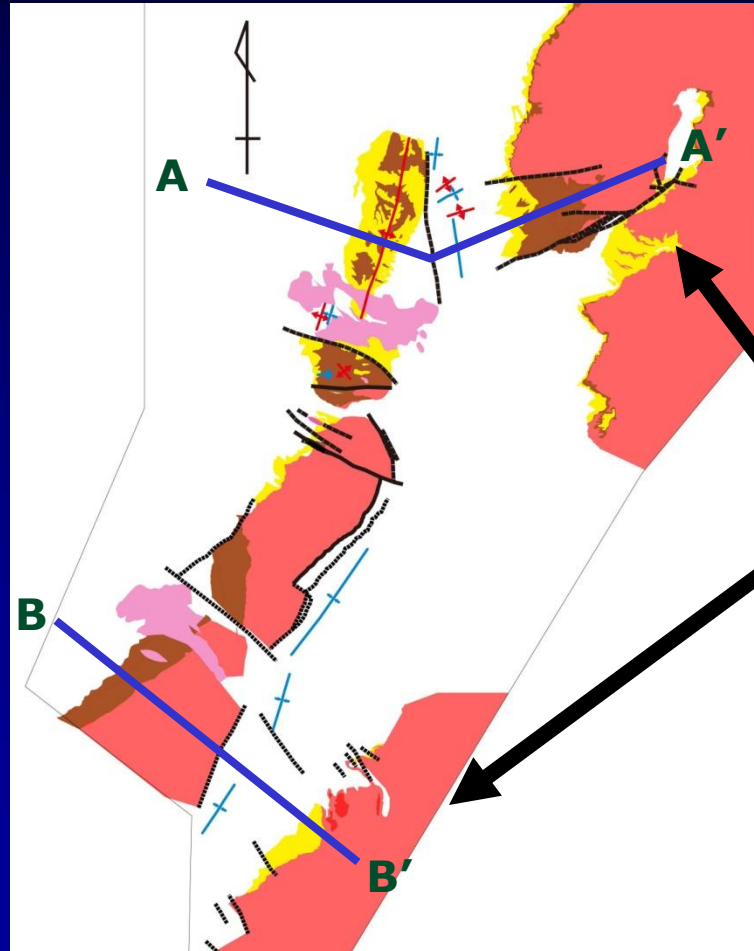
1) Fan delta systems developed at the rift-border faults

2) Rift-normal faults confined the major sources of lateral clastic supply

... by reactivation of older faults

DISCUSSION & SYNTHESIS

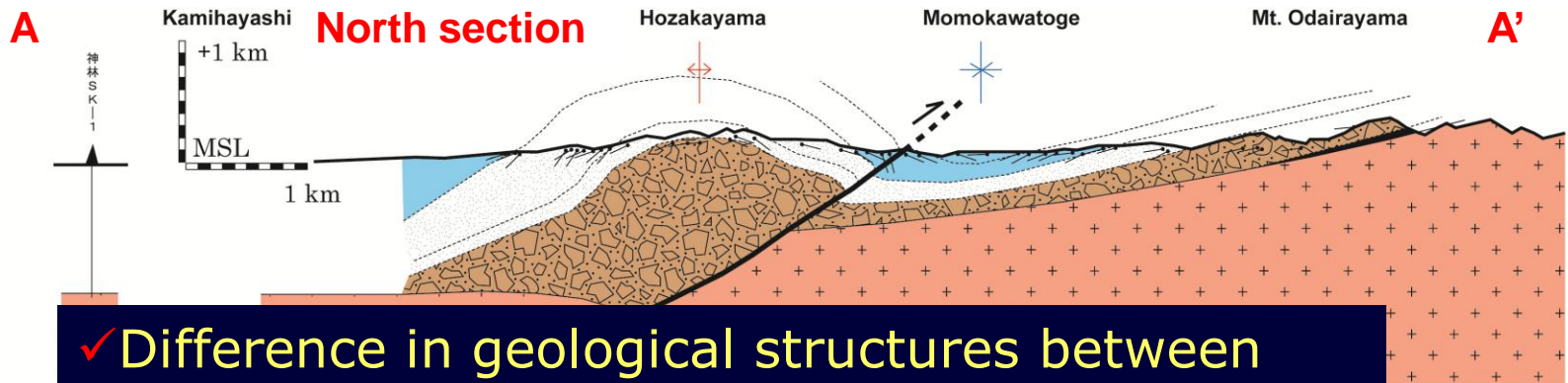
Interpretation of geological sections



Section lines

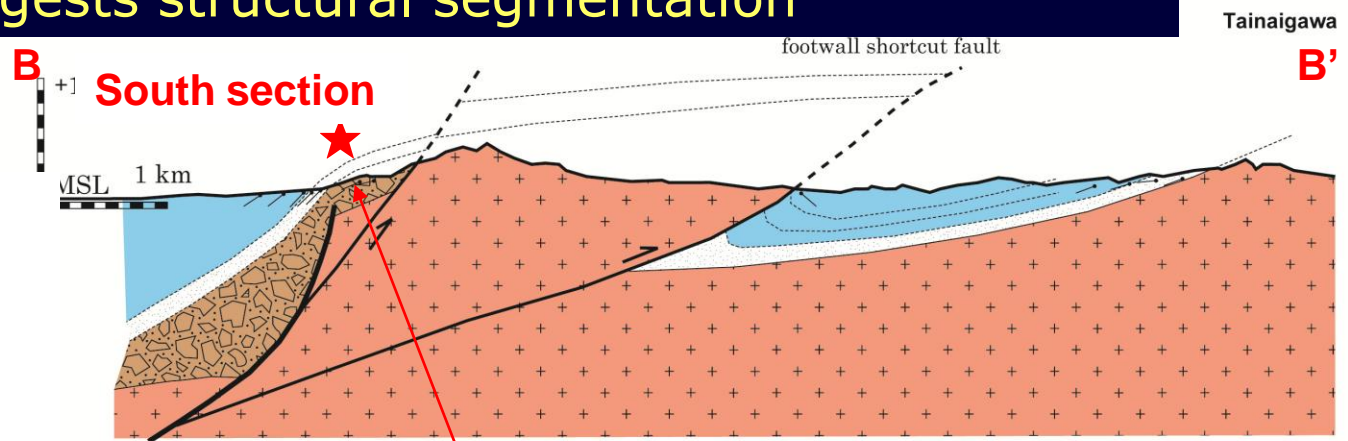
DISCUSSION & SYNTHESIS

Interpretation of geological sections



✓ Difference in geological structures between north and south of the study area

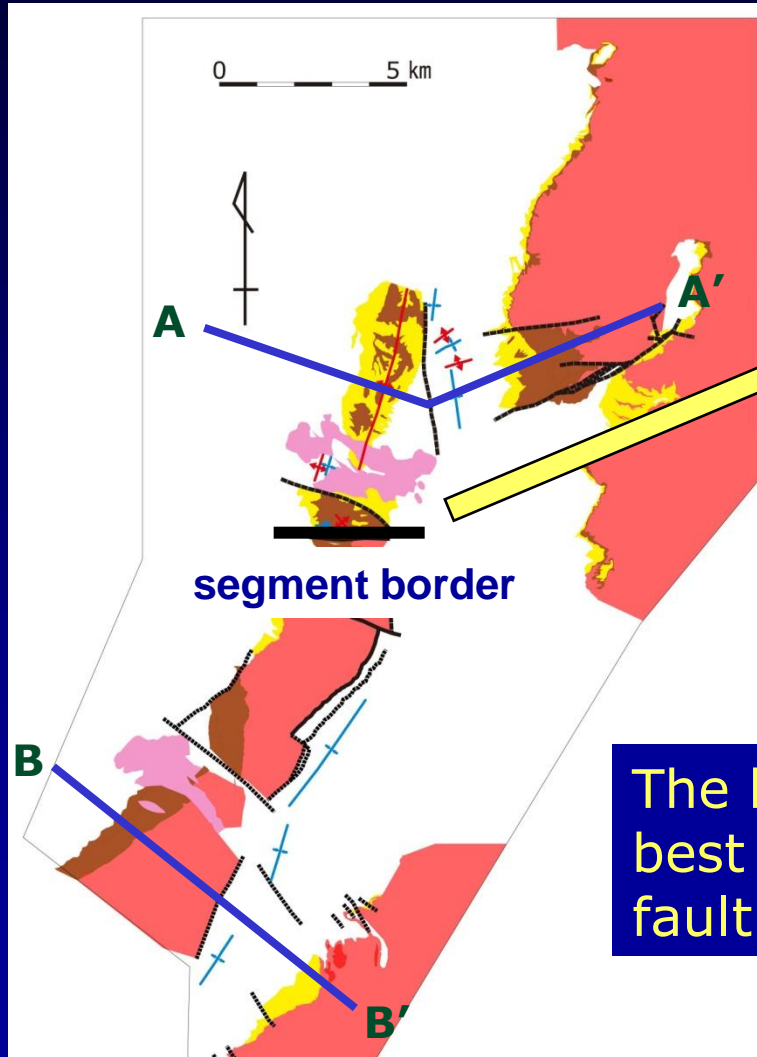
✓ Suggests structural segmentation



- Post-rift
- Syn-rift
- Pre-rift
- Basement
- Latest sense of slip

Active normal fault confirmed by trench survey (Komatsubara et al., 2007)

Recognition of structural segments

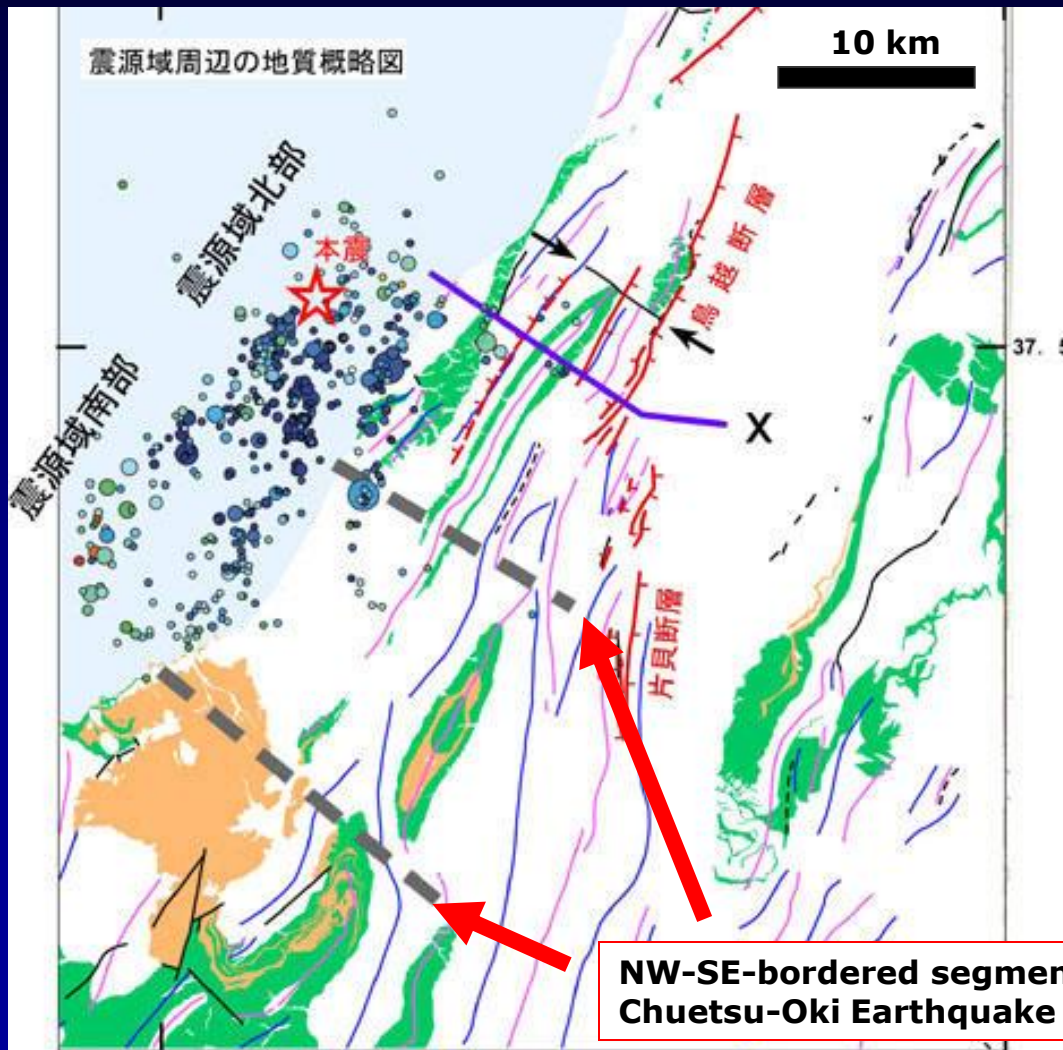


The border of these segments can be best placed at the largest rift-normal fault in the study area.

DISCUSSION & SYNTHESIS

Analog to the recent seismicity

Central part of Niigata Basin

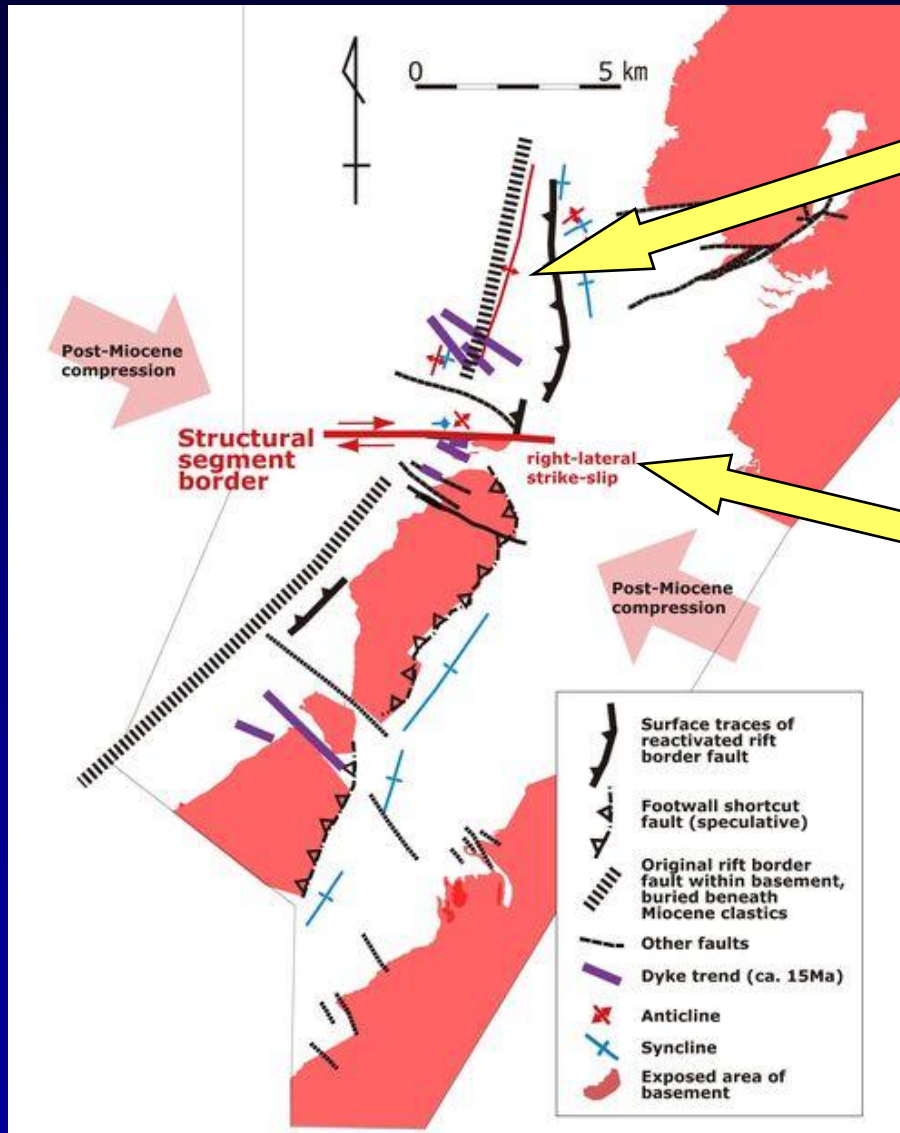


A similar segmentation by the NW-SE faults (normal to the inversion-related fold axis) has also been estimated within the upper crust by the observation of a recent earthquake in the other area of the basin.

NW-SE-bordered segments suggested by aftershock foci of Chuetsu-Oki Earthquake 2007 (Mj 6.8); Hirata et al. (2007)

DISCUSSION & SYNTHESIS

2: During the post-Miocene inversion, ...



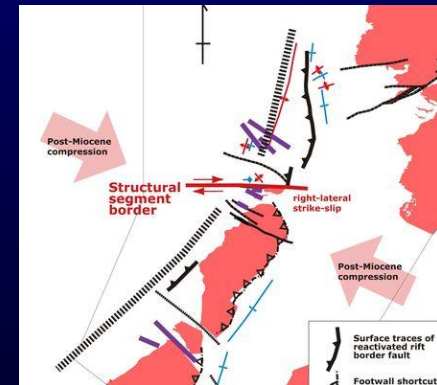
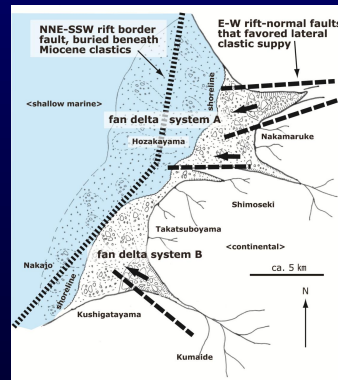
1) Reactivation of the rift-border fault gave rise to rift-parallel folds and basement uplifts.

2) The rift-normal faults functioned as segment borders.

DISCUSSION & SYNTHESIS

Summary

| elements | stage of basin genesis | stage of deformation |
|--|---|--|
| Rift border fault (N-S to NNE-SSW) | created accommodation for deposition | reactivated to form structural high |
| Rift-normal faults (E-W to NW-SE) | favored lateral clastic supply to fan deltas | behaved as structural segment borders |



Thanks for your attention