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.

Selected References


Websites


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

H. Kurita, T. Toyoshima, Y. Ishikawa*
Niigata University, Japan (*presently JX Nippon Oil & Gas Exploration)
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

Niigata Basin, NE Japan

Development affected by (e.g., Jolivet and Tamaki, 1986)
✓ Miocene rifting (backarc extension) and
✓ post-Miocene intensive compression (inversion)

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)
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 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

OUTLINE

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

<table>
<thead>
<tr>
<th>Series</th>
<th>Formation (thickness in meter)</th>
<th>Generalized section</th>
<th>Description</th>
<th>Geochronologic data and samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shimoseki (120)</td>
<td></td>
<td>Bedded dark-grey siltstone. Partly siliceous.</td>
<td>16.9 – 14.7 Ma for HZK samples by dinoflagellate cysts (This study)</td>
</tr>
<tr>
<td>MIOCENE</td>
<td>Hozakayama Rhyolite</td>
<td></td>
<td>Rhyolite lavas and dykes. Partly perlitic.</td>
<td></td>
</tr>
<tr>
<td>Lower</td>
<td>Kamagui (20 - 700)</td>
<td>Structureless clastic breccia - conglomerate, weakly bedded conglomerate, sandstone, alternating beds of conglomerate and sandstone, alternating beds of sandstone, siltstone and tuff. Partly bioturbated.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kitaoguni (70)</td>
<td>Rhyolitic massive lapilli tuff. Partly welded structures.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>pre-Neogene</td>
<td>Slate, sandstone and chert, interbedded by granuloids.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Post-Rift sandy

Syn-Rift gravelly

Pre-Rift
RESULTS – Stratigraphy & Mapping

New geological map of the basin border
RESULTS – Stratigraphy & Mapping

New geological map of the basin border

Basin center

Basement mountain
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
1: Syn-rift sediments =

- Richness in deposits from gravity processes
- Distinctive lateral changes in facies and thickness
- Both terrestrial and shallow-marine origin
1: Syn-rift sediments= a fan delta system

Subaerial upper fan
Hyperconcentrated flow deposits

Catchment valley
Debris-flow deposits

Subaqueous fan delta lobe
Coarse-grained gravity-flow deposits with burrows and marine dinoflagellates

Sandy shoreface-shelf adjacent to fan delta
Sandy alternation
RESULTS—Sedimentary facies analysis

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

- Fan Delta
- Shelf
- Subaqueous lobes
- Catchment valley
- Strand Plain?
- Slope - basin plain

West
East

Miocene rift-border fault

200m
5km
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

Lateral sediment paths determined by rift-normal faults
Considerable thinning and fining across the faults
Fault Rock Analysis
RESULTS – Fault rock analysis

Faults and fold axis

- Rift-parallel
- Two trends in faults
- Rift-normal
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

Basement (granite)  Miocene conglomerate

South  North

N87W80N
cataclasite  gouge
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
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
During the basin genesis, ...

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
1: During the basin genesis, ...

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
DISCUSSION & SYNTHESIS

Interpretation of geological sections

- Difference in geological structures between north and south of the study area
- Suggests structural segmentation

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.
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.

Central part of Niigata Basin

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

2: During the post-Miocene inversion, ...
### DISCUSSION & SYNTHESIS

**Summary**

<table>
<thead>
<tr>
<th>Elements</th>
<th>Stage of Basin Genesis</th>
<th>Stage of Deformation</th>
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</thead>
<tbody>
<tr>
<td><strong>Rift border fault</strong></td>
<td>created accommodation for deposition</td>
<td>reactivated to form structural high</td>
</tr>
<tr>
<td>(N-S to NNE-SSW)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rift-normal faults</strong></td>
<td>favored lateral clastic supply to fan deltas</td>
<td>behaved as structural segment borders</td>
</tr>
<tr>
<td>(E-W to NW-SE)</td>
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</tbody>
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**Thanks for your attention**