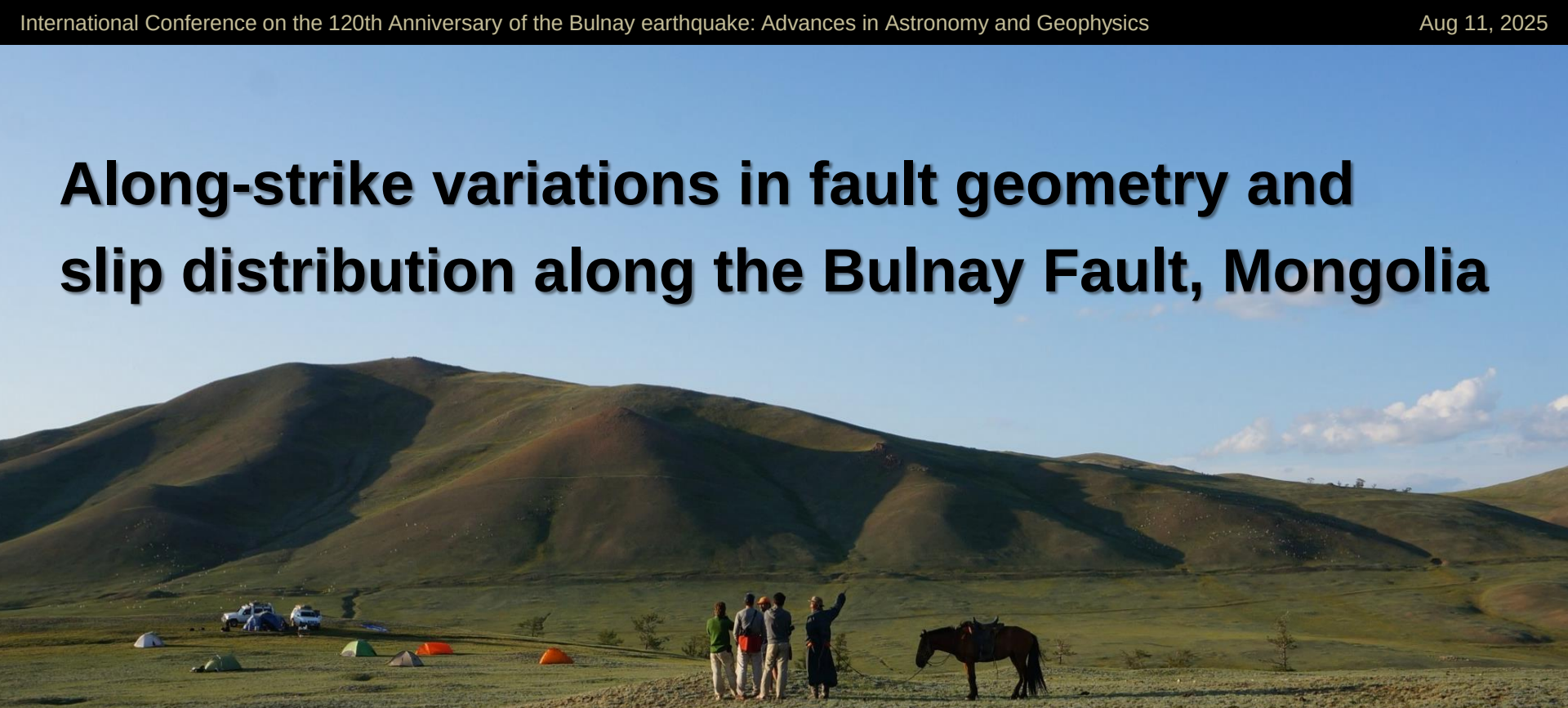
Along-strike variations in fault geometry and slip distribution along the Bulnay Fault, Mongolia



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Collaboration with
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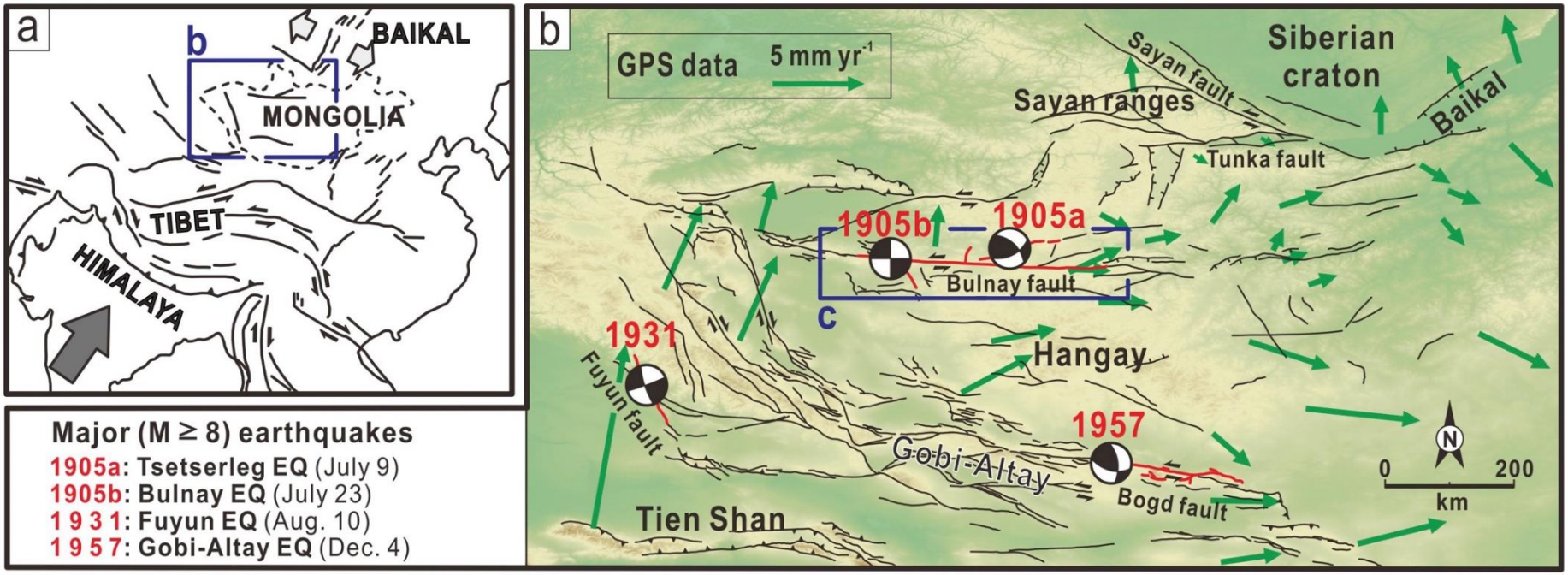
J.-F. Ritz, M. Ferry, R. Kurtz, B. Davaasambuu (GM Montpellier)
M. Rizza (CEREGE)
L. Bollinger (CEA/DAM/DIF)
N. Tsend-Ayush, M. Ulziibat, O. Chimed (IAG, Ulaanbaatar)

Study area



(GPS data from Calais et al., 2003)

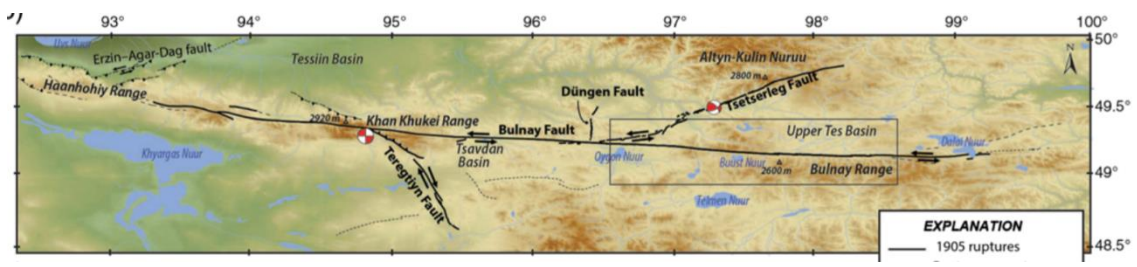
Bulnay fault

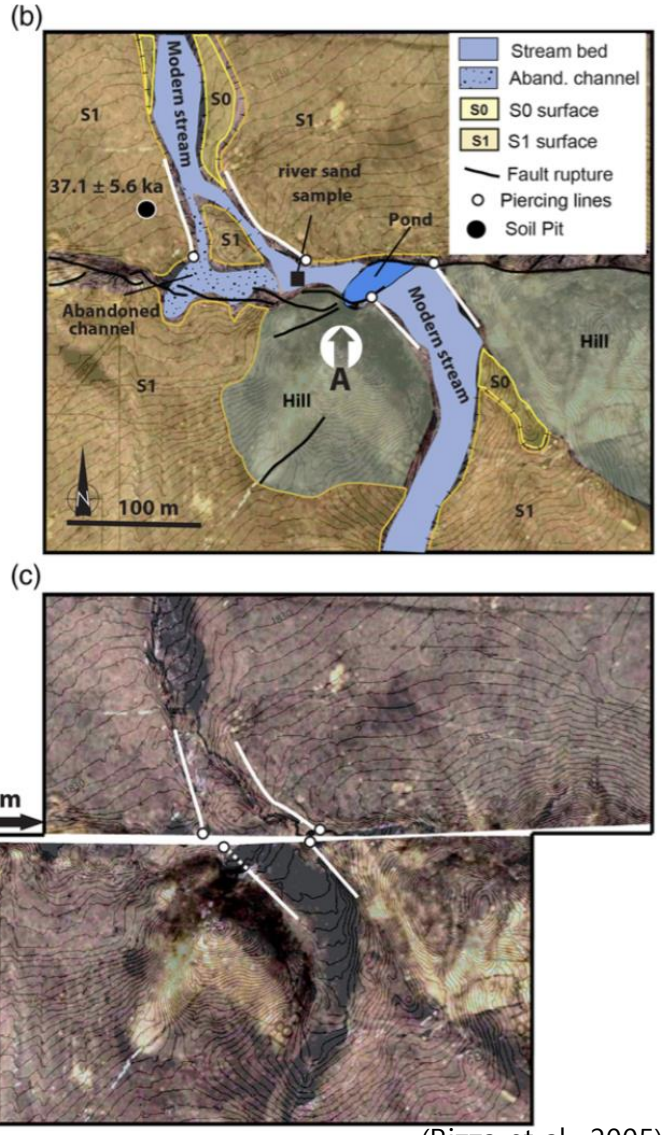
- Slow-moving fault : millimetric slip-rate over the past 10^4-10^5 yrs.
- Recurrence time for large earthquakes : ~ 3,000 yrs (Rizza et al., 2015).

The 1905 earthquake sequence surface ruptures

- Two M > 8 strike-slip earthquakes, 14 days apart, on the Bulnay fault
- Total length of the surface rupture (four individual faults) : > 670 km

Morphotectonic & Paleoseismological studies





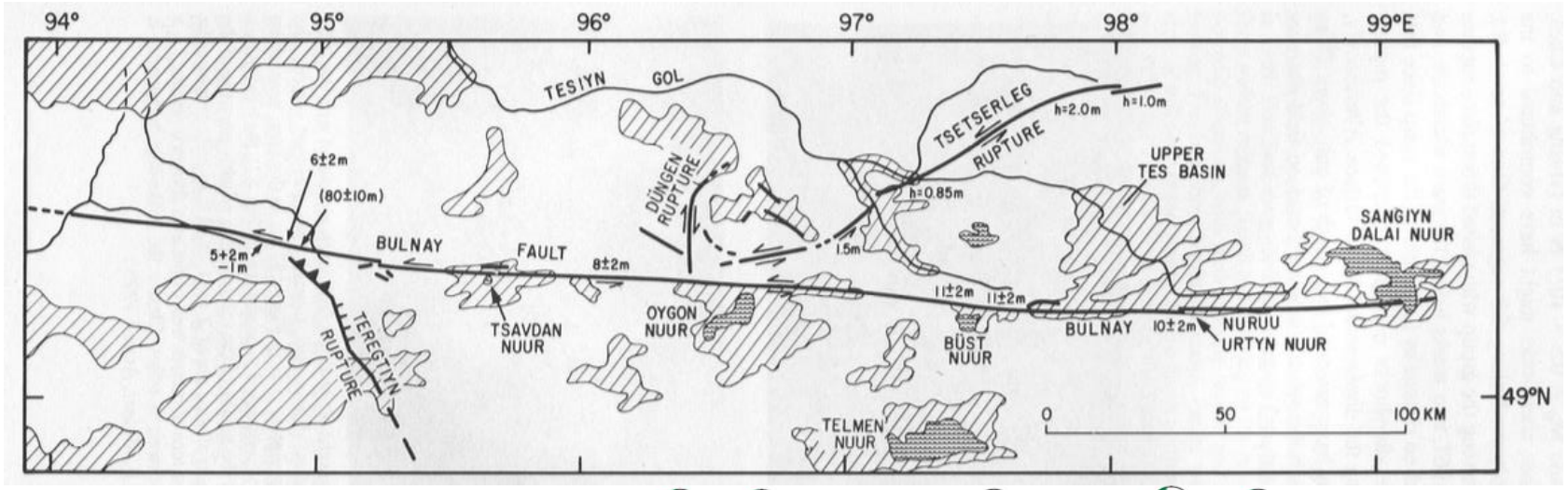
1) Left-lateral slip accumulation by Late Cenozoic reactivations of the Bulnay fault [Badarch et al., 2002; Jolivet et al., 2007]

2) Horizontal slip rate of 3.1 ± 1.7 mm/yr (the Upper Pleistocene–Holocene period) [Rizza et al., 2015]

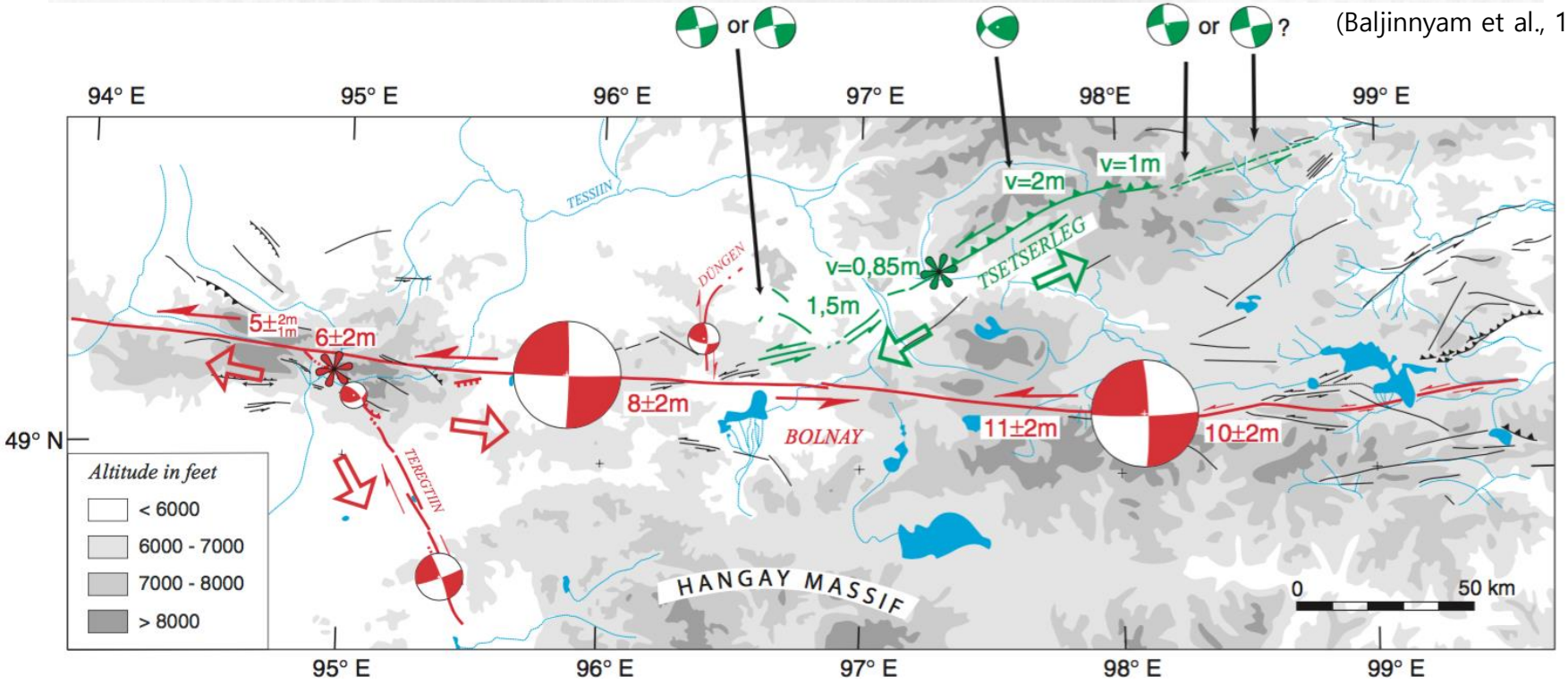
3) The penultimate large earthquake in 2,300 – 3,200 yrs ago [Schwartz et al., 2009; Rizza et al., 2015]

(Rizza et al., 2005)

Previous studies

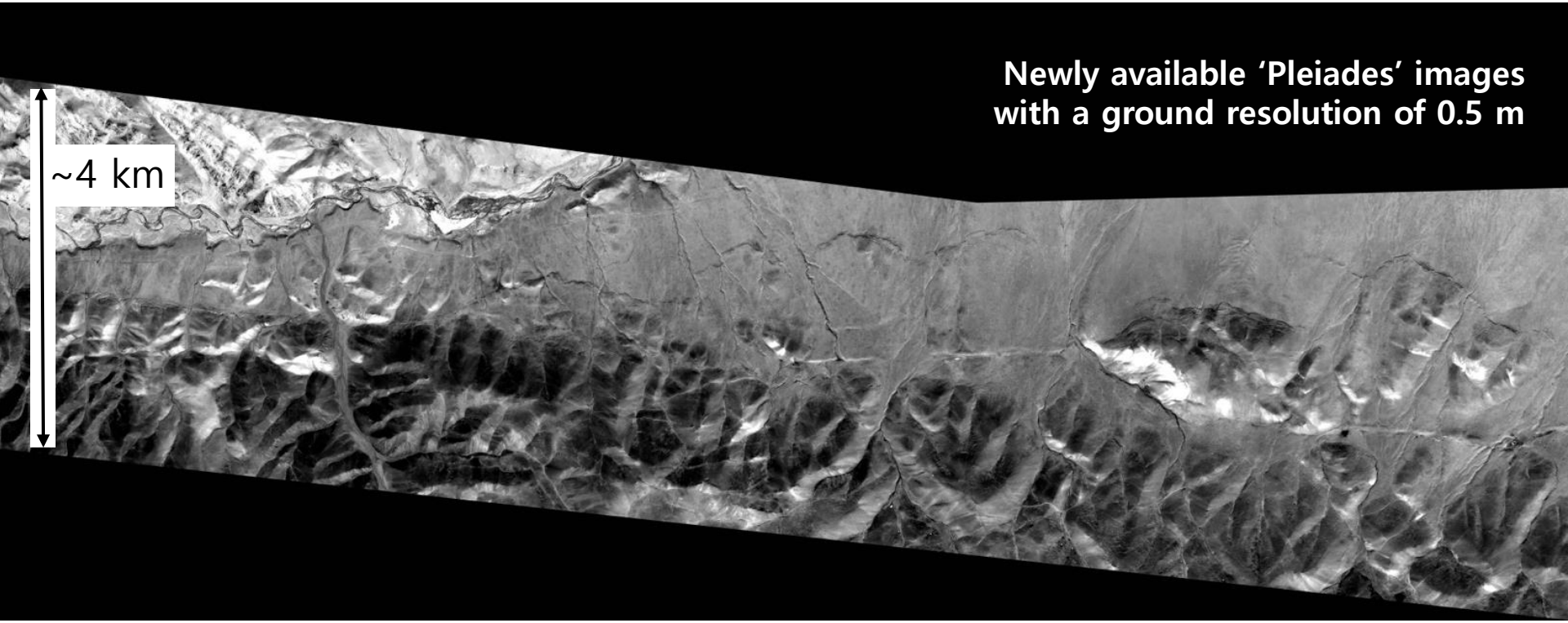


(Baljinnyam et al., 1993)



(Schlupp and Cisternas, 2007)

High-resolution satellite (HRS) imagery mapping



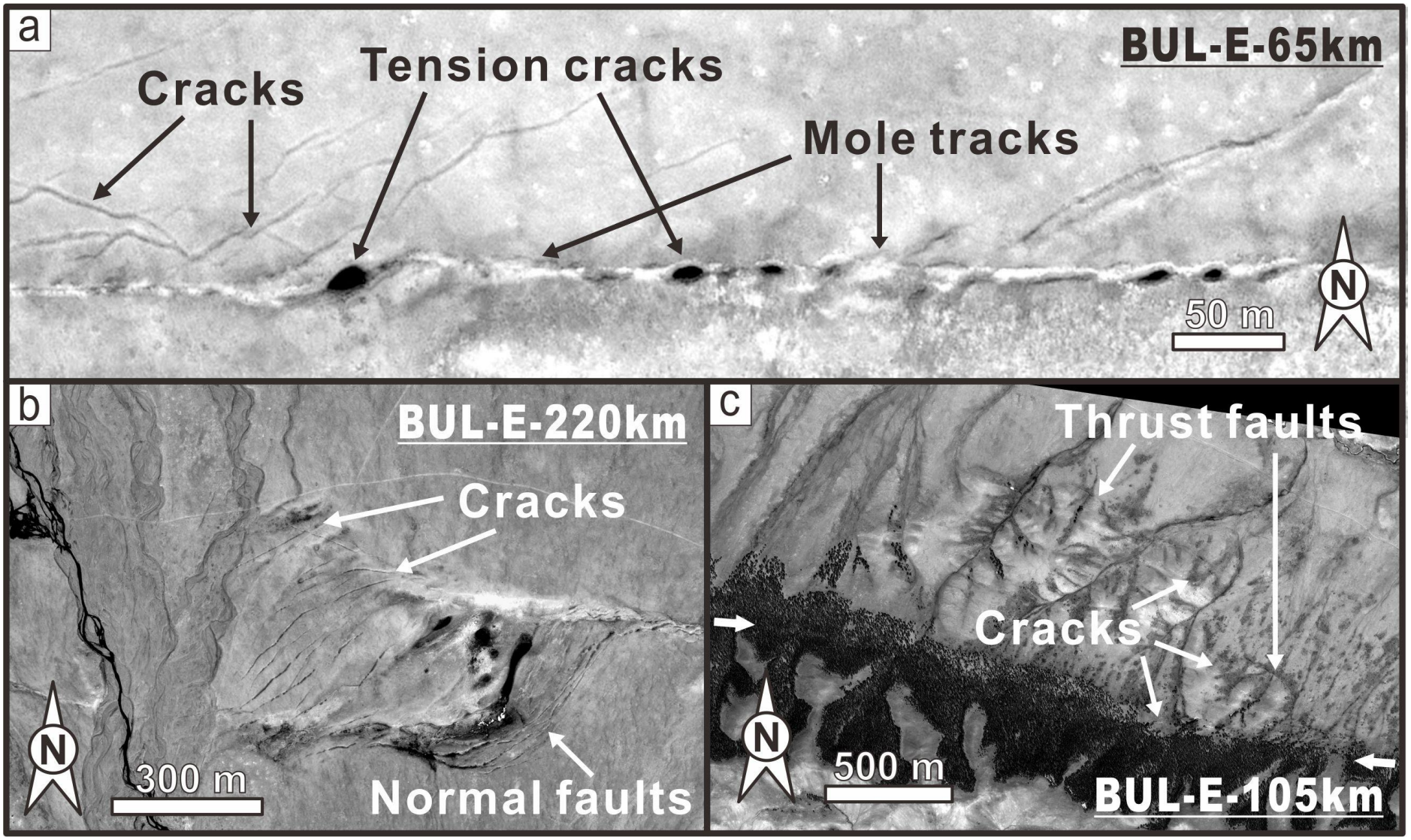
Well-preserved morphology: natural laboratory for studying rupture behaviors!

(1) Rupture complexity

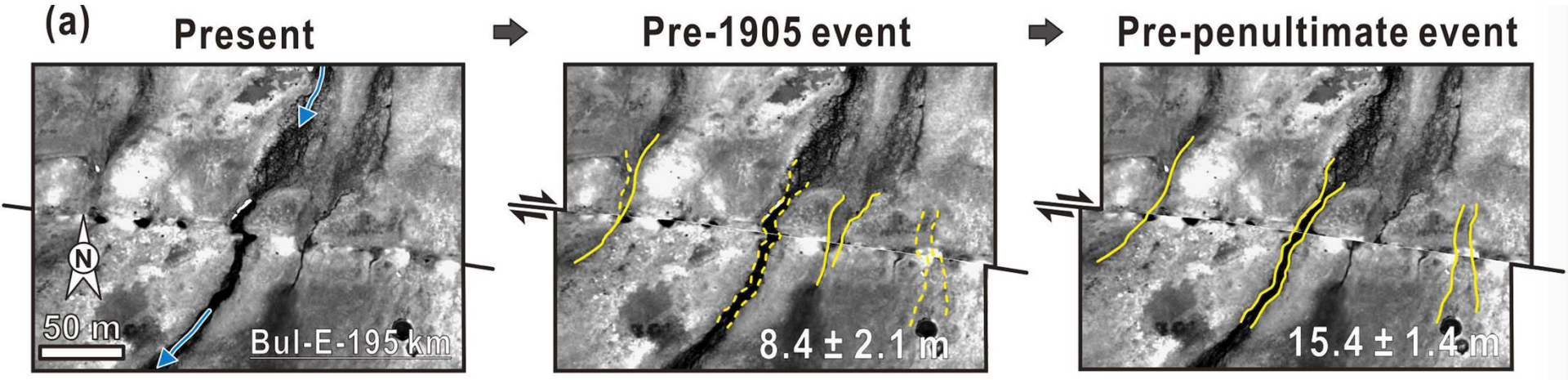
(2) Coseismic slip distribution (the most recent event, 1905)

(3) Cumulative deformations and slip accumulation

Rupture geometry

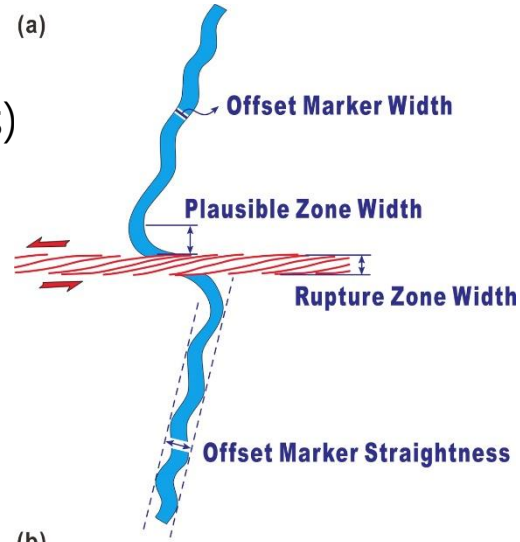


Offset measurements



A dataset of 654 horizontal offsets at 384 sites
(Only one offset at 184 sites & multiple offsets at 200 sites)

⇒ 276 offsets for the most recent event
⇒ 378 offsets for the multiple events



Assessments of data quality (high, moderate, low)

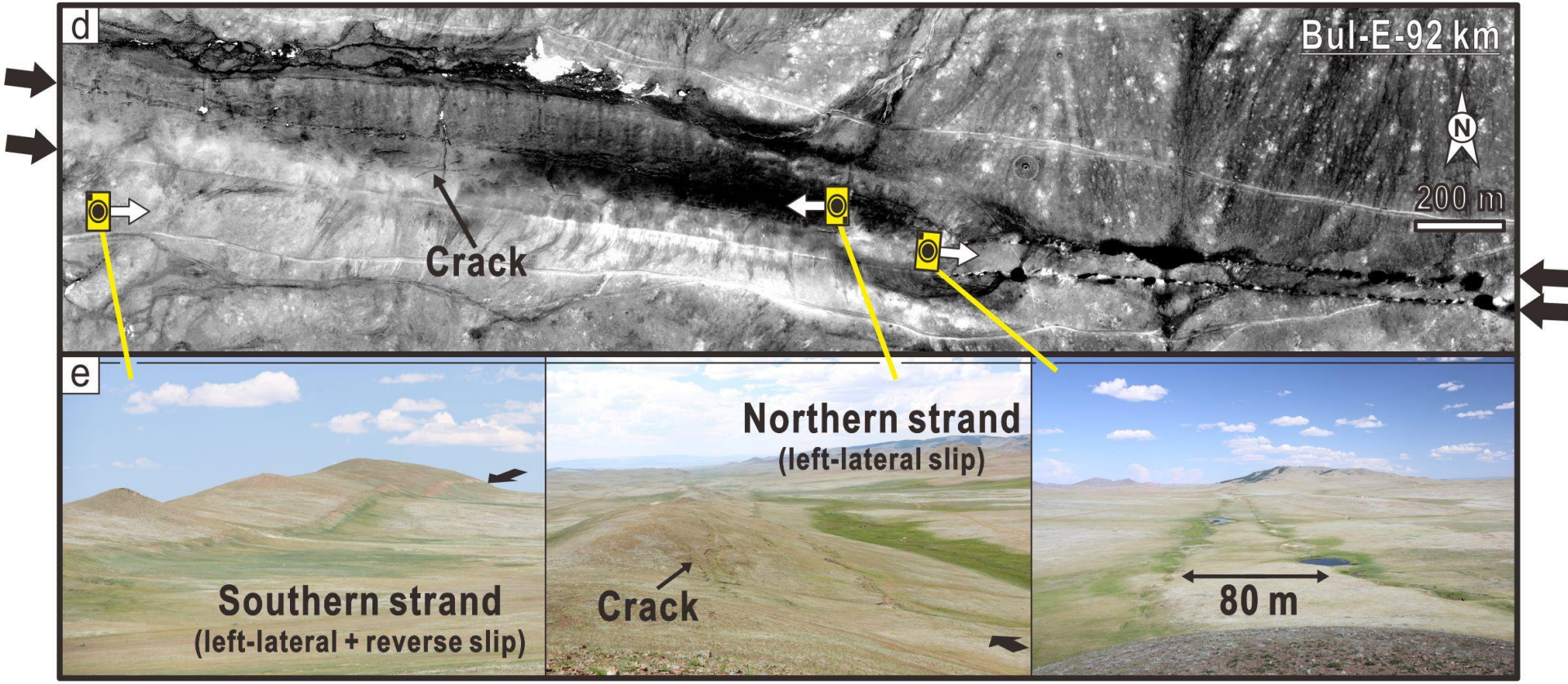
a. Marker width b. Marker straightness/sinuosity
c. Rupture zone width d. Plausible zone width
e. Image visibility (trees, snow, or clouds)

(b)

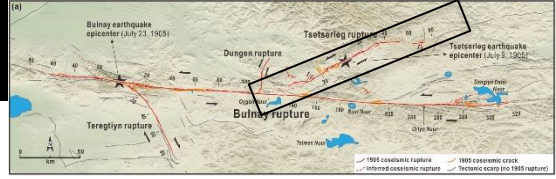
Criteria \ Data Quality	High	Intermediate	Low
Offset Marker Width (OMW)	< 2 m	2 - 5 m	5 m <
Offset Marker Straightness	< 2 x OMW	2 - 5 x OMW	5 x OMW <
Plausible Zone Width	< 2 m	2 - 5 m	5 m <
Rupture Zone Width	< 3 m	3 - 10 m	10 m <
Image Quality	Subjective decision depending mainly on the existence of shadows, clouds, and trees		

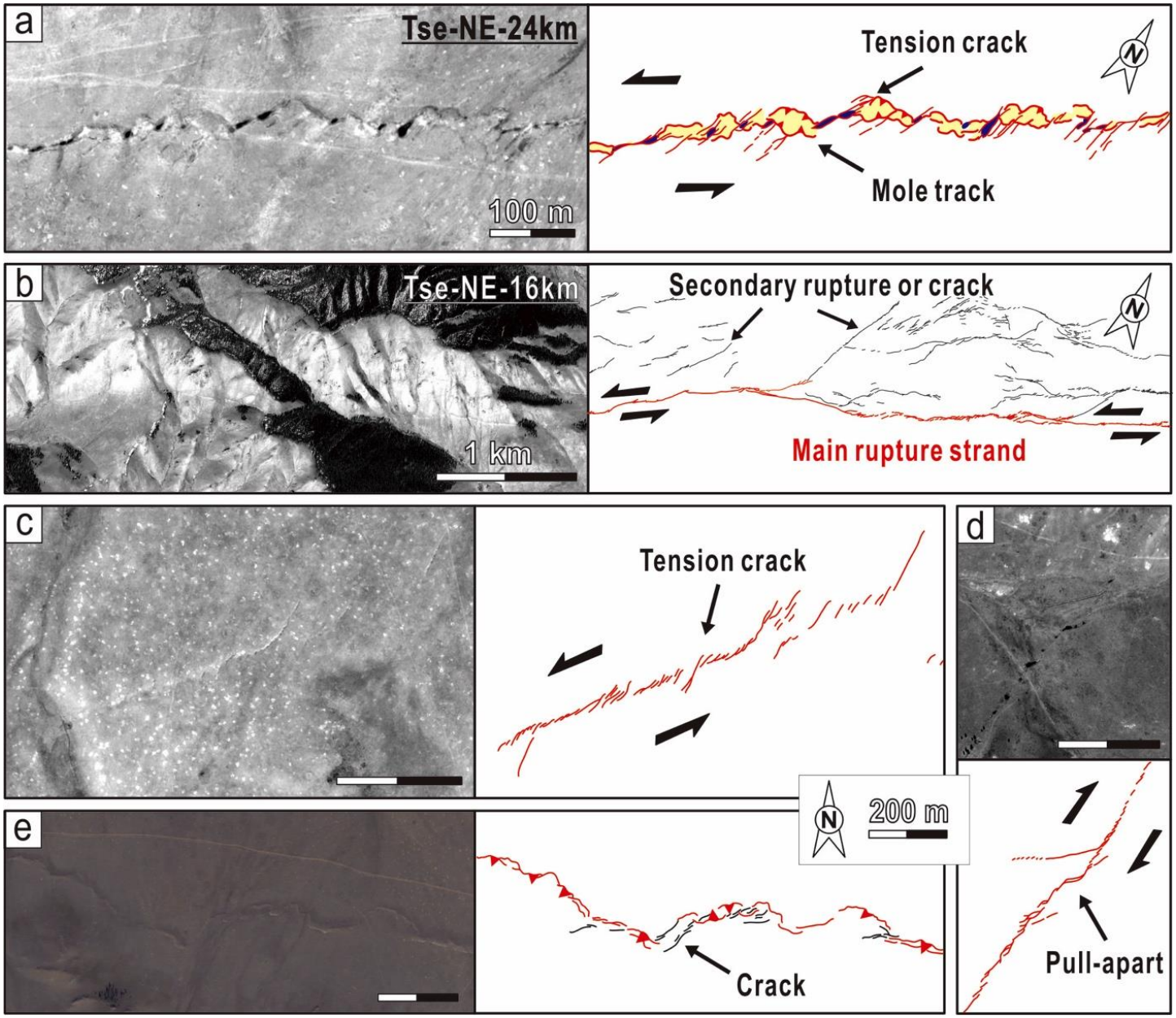
Field observations

Two fieldwork campaigns

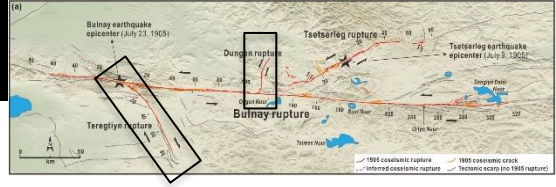


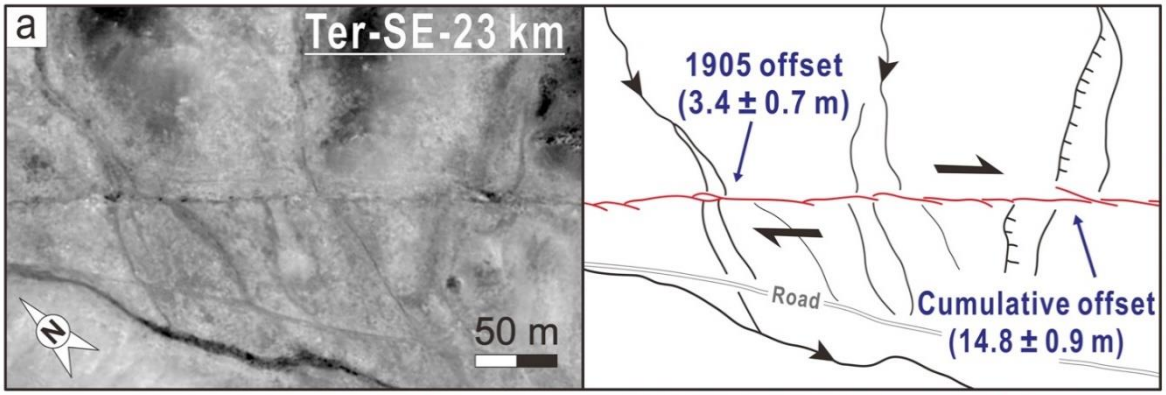
Tsetserleg rupture

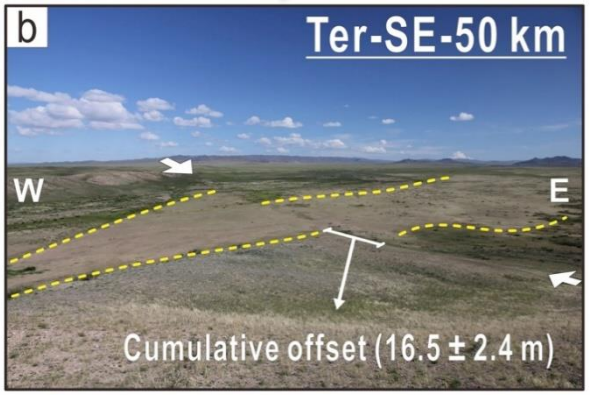


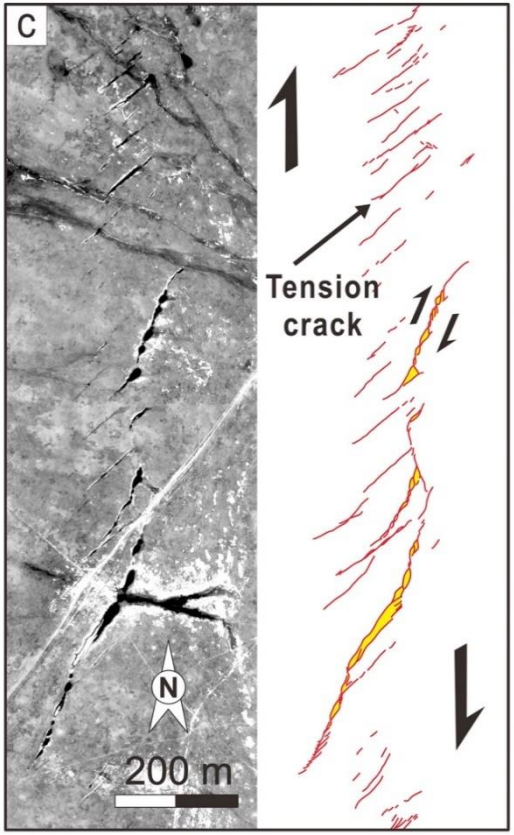


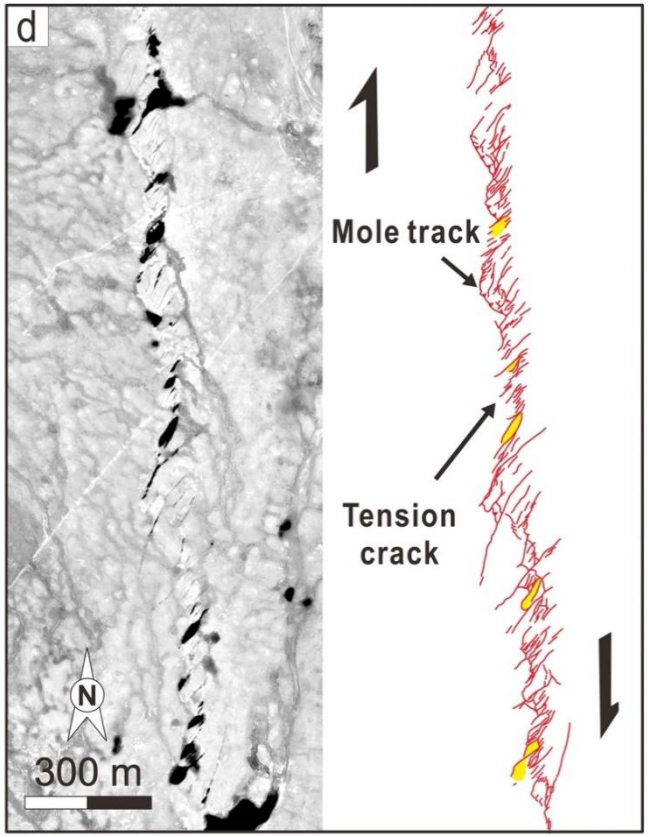
Teregtiyn & Dungen ruptures

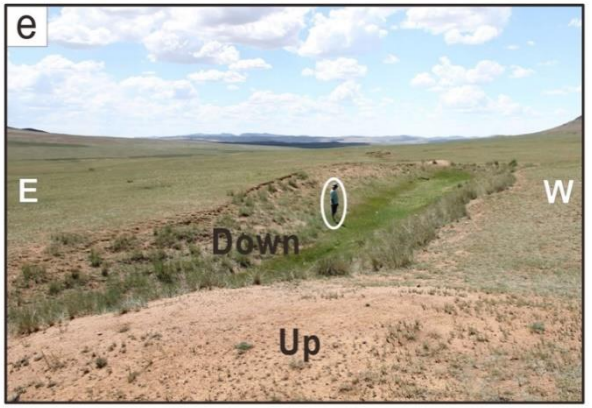


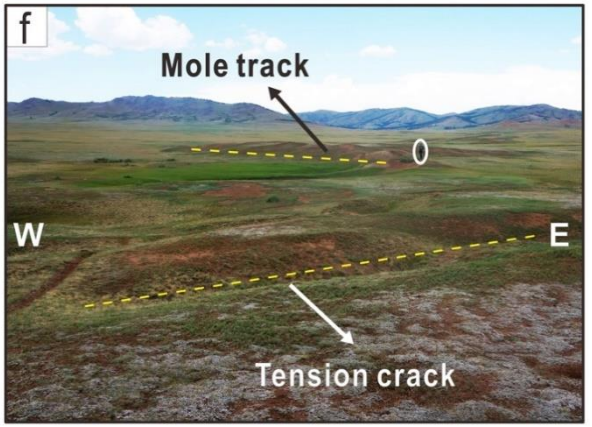




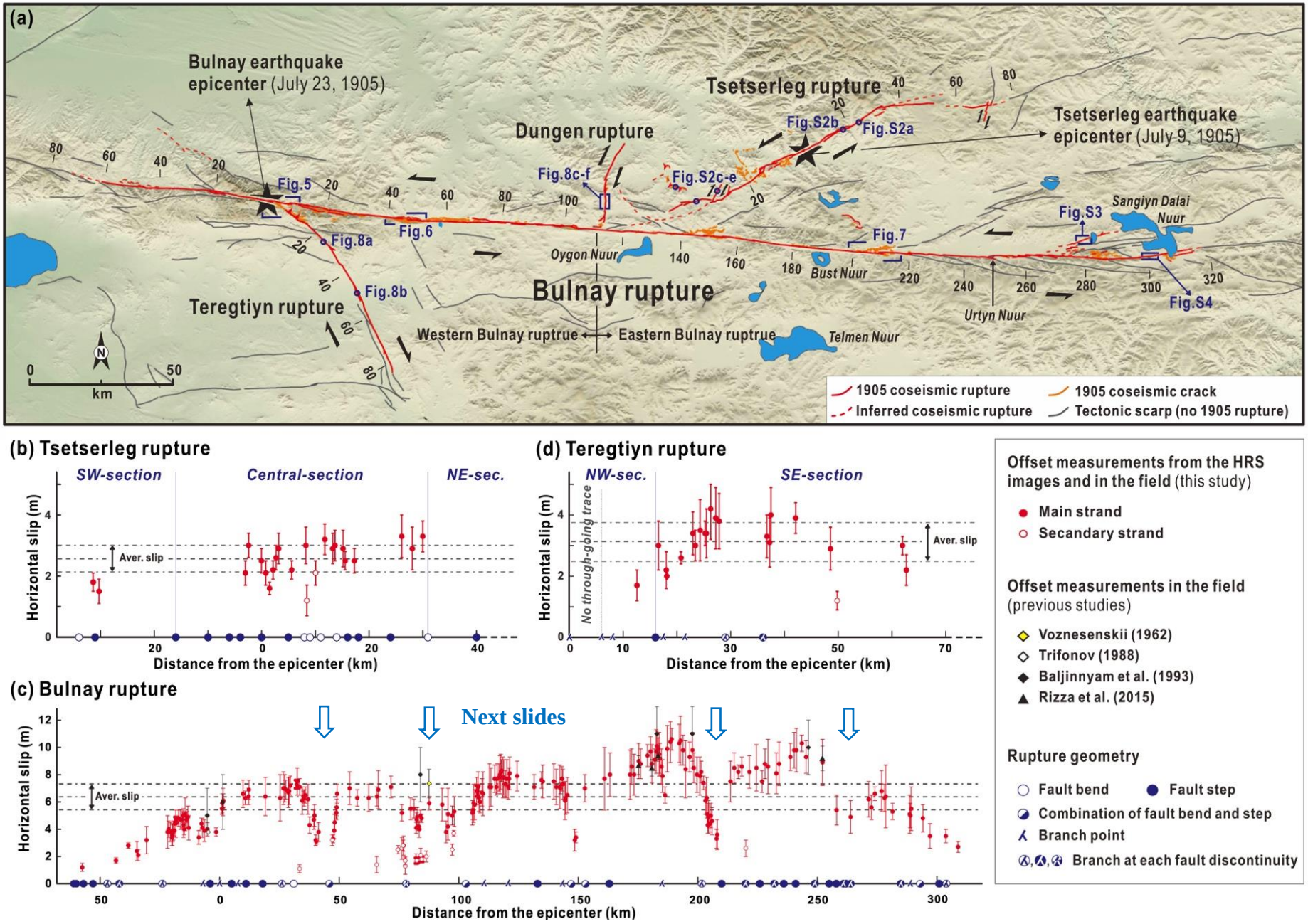




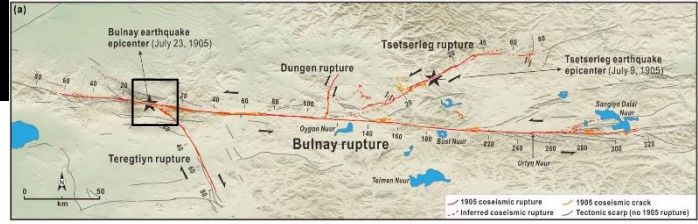




Results: the most recent event



Rupture complexity on the Bulnay fault



Bulnay rupture

Fig. 3b

Teregtiyn rupture

N

1 km

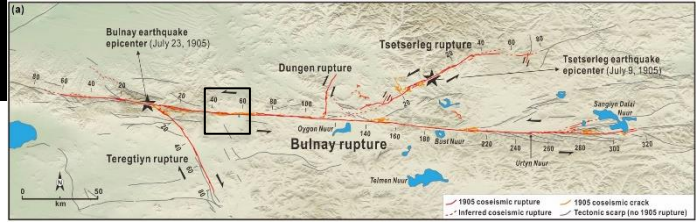
1905 main rupture strand

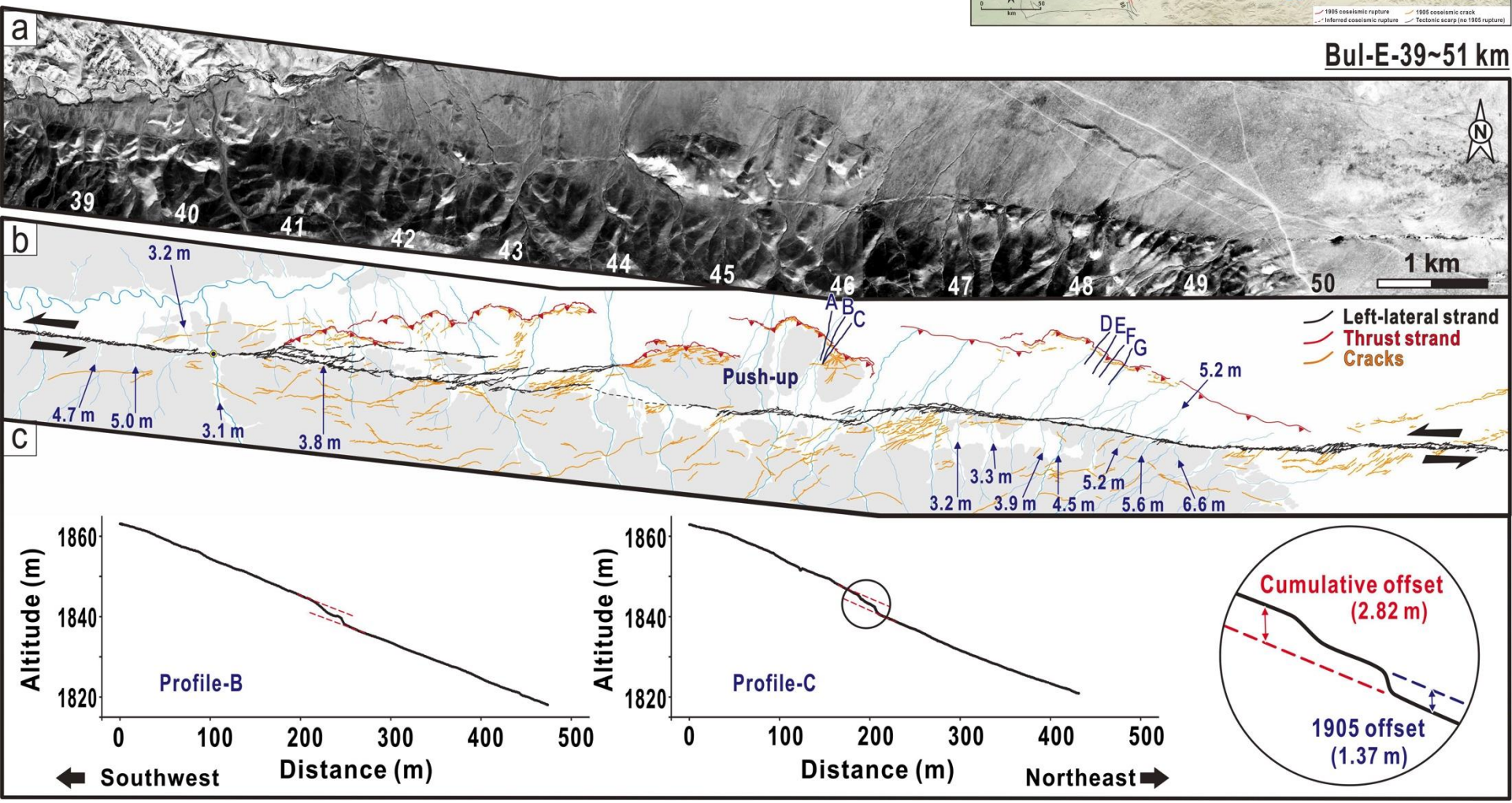
1905 secondary rupture and crack

Tectonic scarp (no 1905 surface break)

Distributed deformations at junction area between two major ruptures

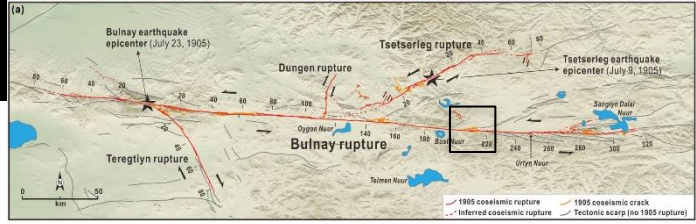
Rupture complexity on the Bulnay fault

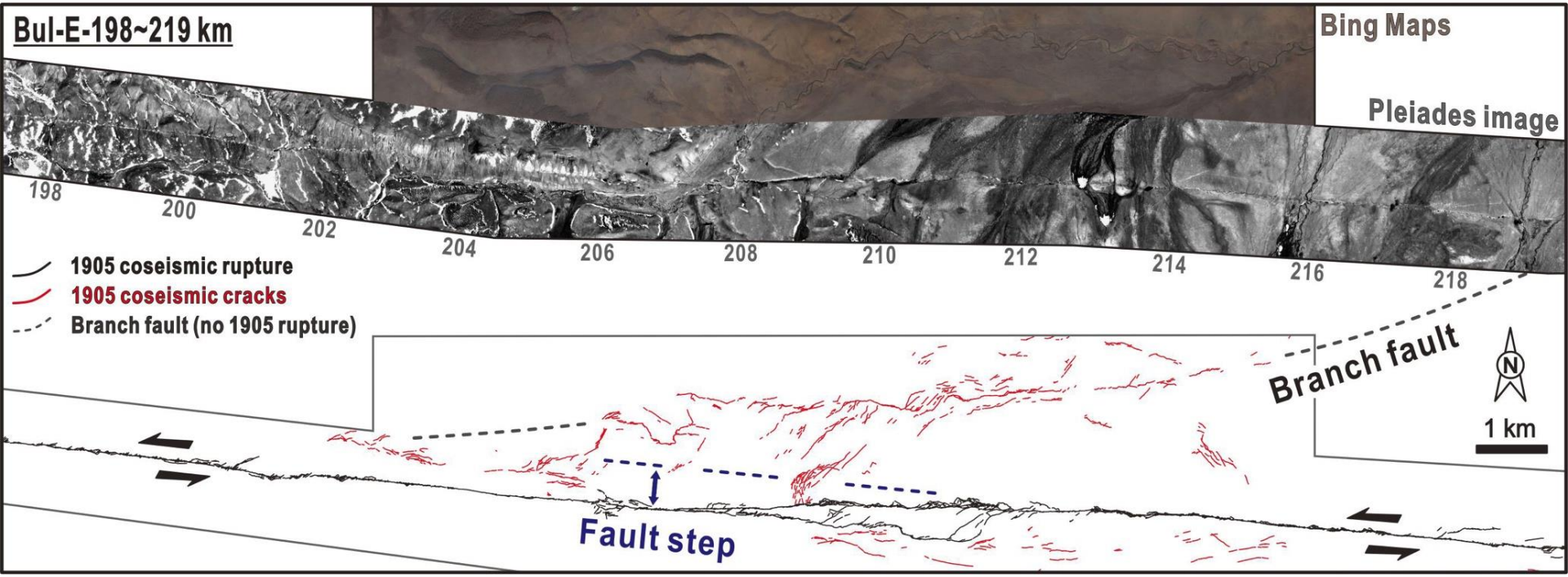




Slip partitioning at a fault bend

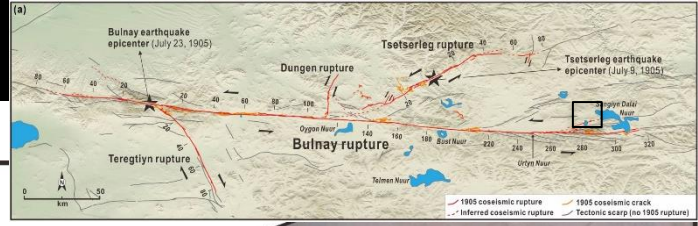
Rupture complexity on the Bulnay fault

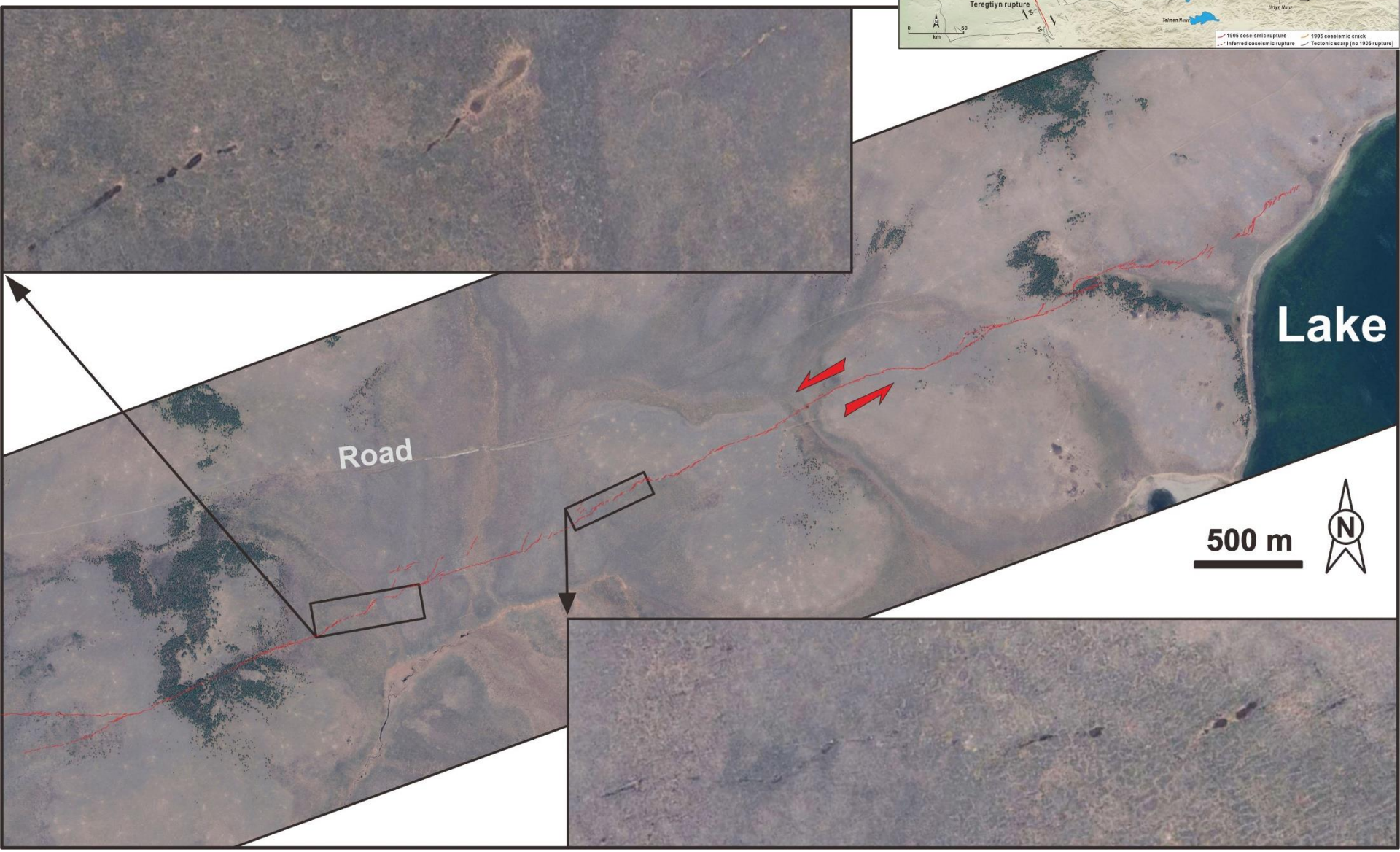




Secondary ruptures at a junction area (no surface break on branch fault)

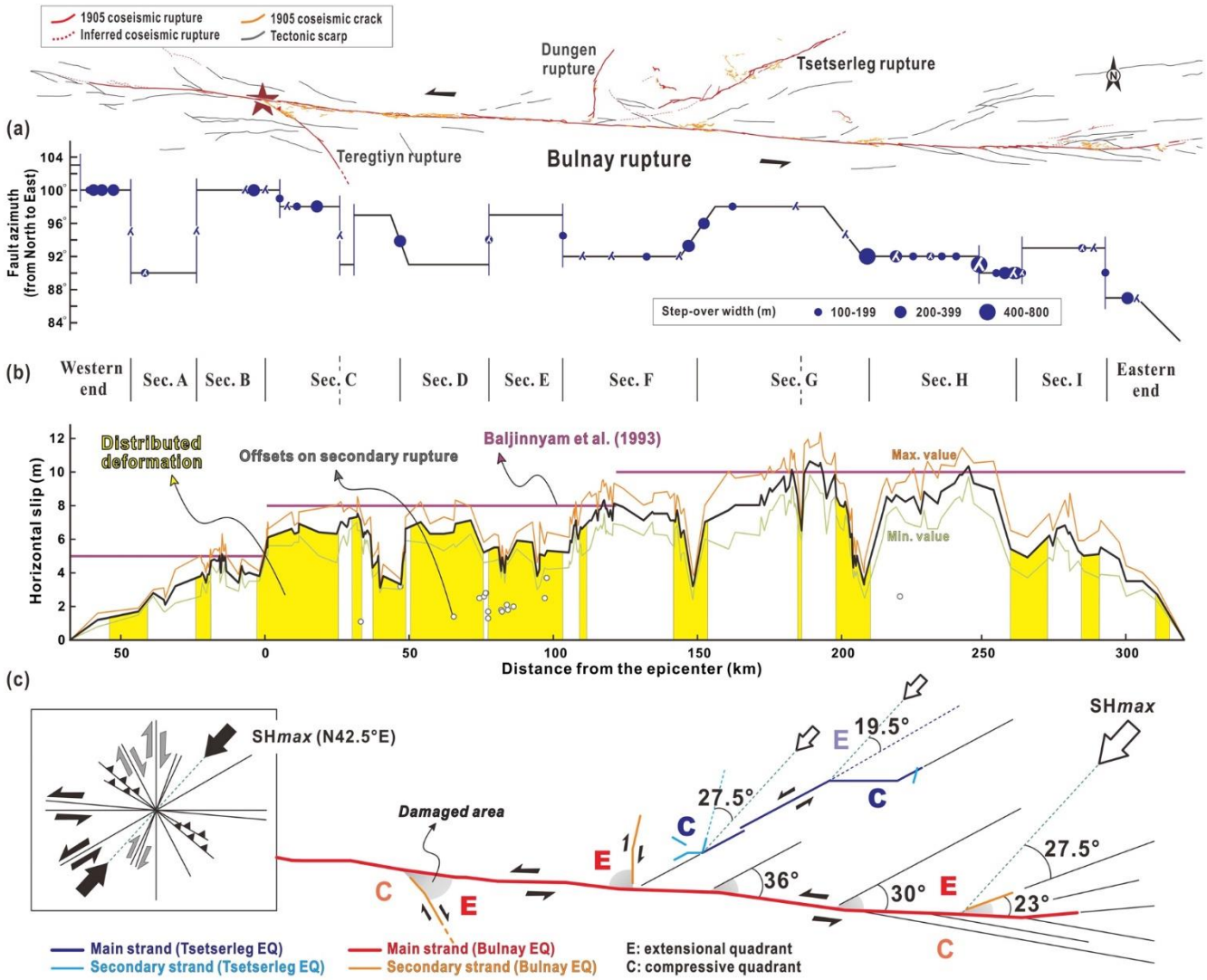
Rupture complexity on the Bulnay fault





Surface rupture along one of the branch fault

Segment geometry and rupture processes



(Choi et al., *in press*)

1) Fault discontinuities: 63

: Change of fault azimuth > 5°
: Width of fault jog > 100 m
: Junction of branch fault

2) Slip distribution

: Local slip deficits related to distributed damages
: Asymmetric patterns, but an overall uniform profile

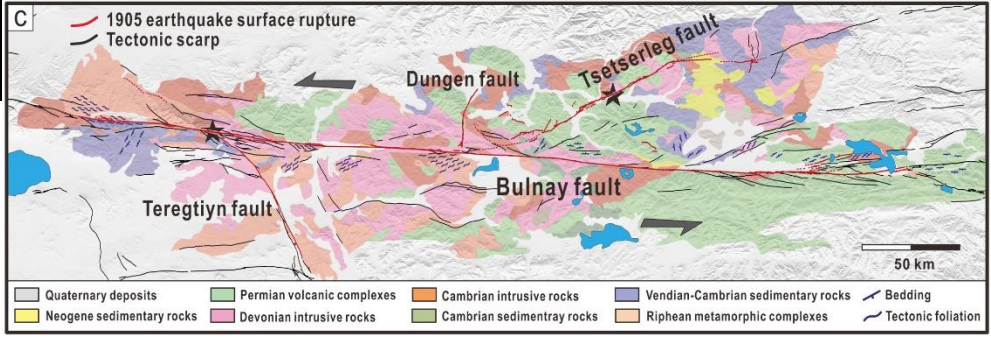
3) Fault segmentation

: 11-13 of distinct segments
: Average length = ~ 29 km
: Changes of fault azimuth
➤ Mature fault zone

4) Rupture propagation

: Attempts to rupture onto branch faults & damages in extensional quadrants

Asymmetry in slip distribution



Distributed deformations at the western section

Localized deformations at the eastern section

1 km

Earthquake moment magnitude

Rupture width*[a] (km)	Rupture section	Length (km)	Slip (m)	$M_O \times 10^{27}$ (dyne cm^2)	Mw
Tsetserleg earthquake					
10	Tsetserleg rupture	114	2.57	0.879	**7.26**
25				2.197	**7.53**
50				4.395	**7.73**
80				7.032	**7.86**
Bulnay earthquake					
10	Bulnay rupture	388	6.37	7.415	**7.91**
	Teregtiyn rupture	80	3.13	0.751	
25	Bulnay rupture	388	6.37	18.537	**8.17**
	Teregtiyn rupture	80	3.13	1.878	
50	Bulnay rupture	388	6.37	37.073	**8.37**
	Teregtiyn rupture	80	3.13	3.756	
80	Bulnay rupture	388	6.37	59.317	**8.51**
	Teregtiyn rupture	80	3.13	6.010	

1) Some bias in wave modeling due to very limited data

2) Rupture propagation deep into the entire crust or more

3) Surface-slip deficit

Conclusions

1. High-resolution satellite imagery of the 1905 Tsetserleg–Bulnay earthquake sequence reveals revised parameters for the coseismic ruptures, including detailed slip distributions, geometric segmentation, and structural complexities along the main fault traces.

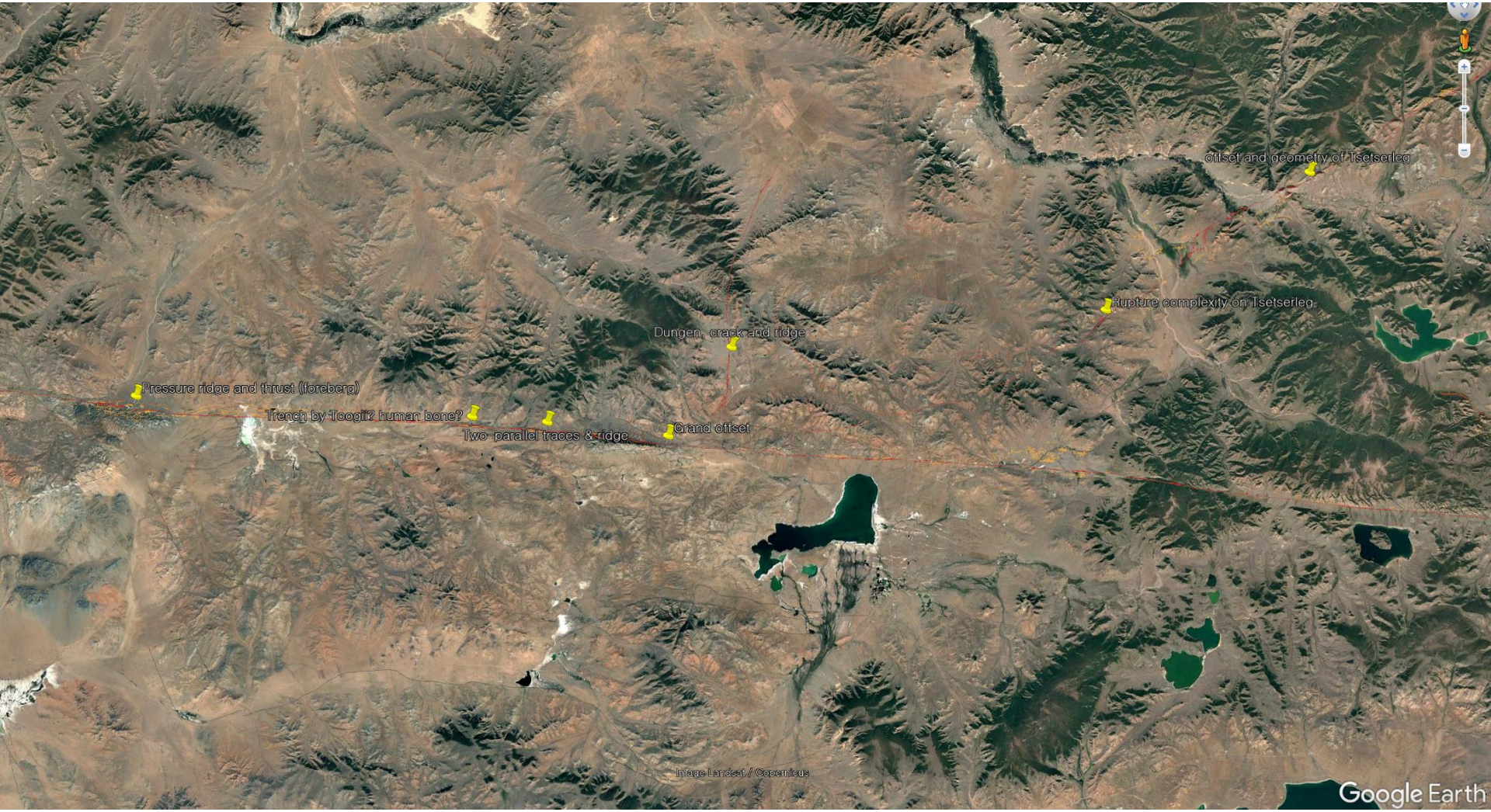
2. The observed variability in slip is largely explained by differences in off-fault damage, which is influenced by local geological structures.

3. These findings highlight the value of incorporating directly observable geological features into earthquake source process analyses to better understand rupture patterns and mechanics.

4. The event immediately preceding the 1905 earthquake exhibits a displacement pattern similar to that of the 1905 event, and high-quality paleoseismic investigation results are required to better constrain earthquake recurrence models.

Field-Trip

Western Bulnay Rupture + Dungen Rupture + Tsetserleg Rupture



Thanks for your attention

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