IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Faire avancer la sûreté nucléaire

Krsko I and the potential for surface rupturing

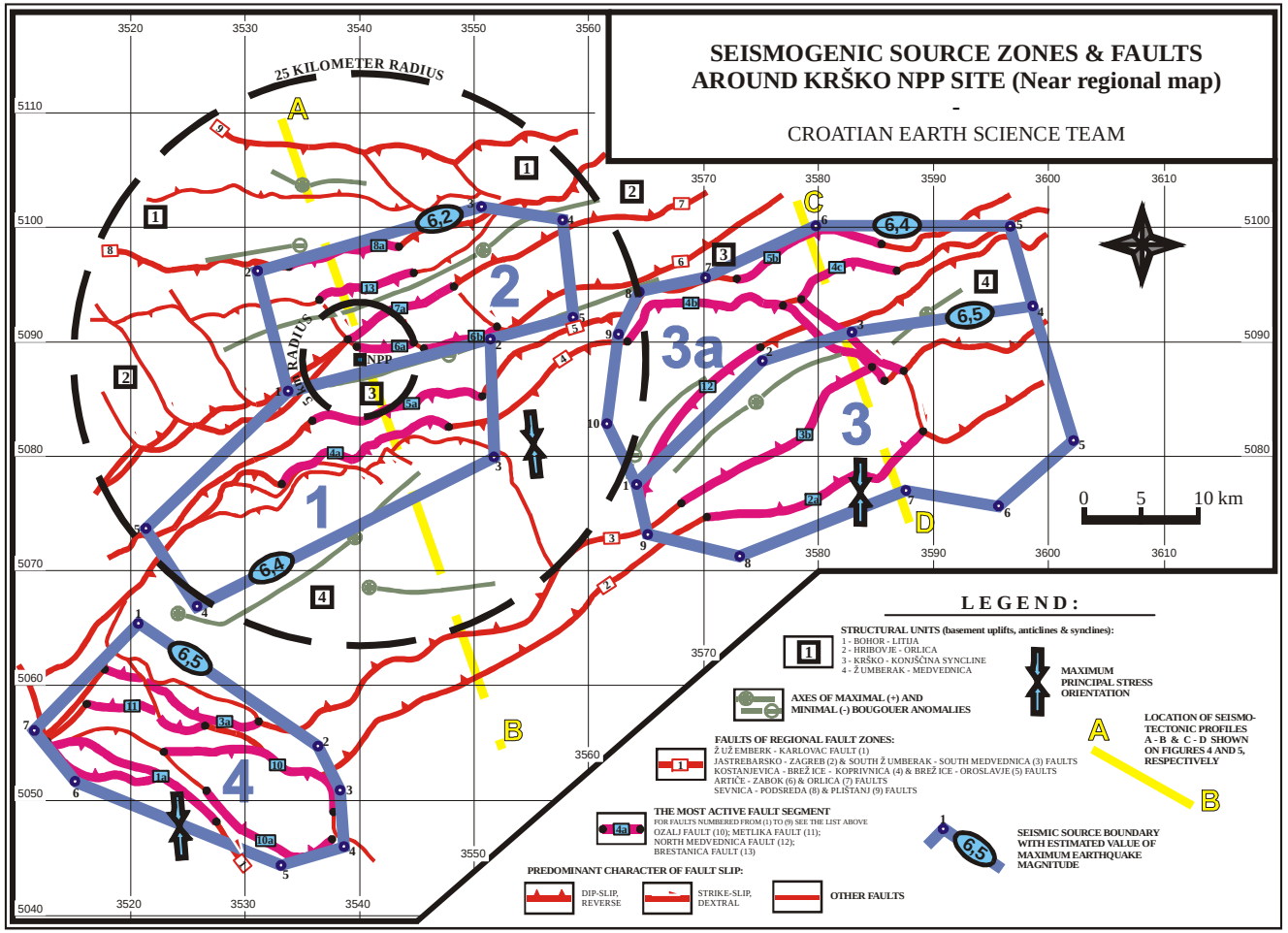
IRSN's perspective

1. 2004 –Krsko 1 - Reviewer of PSHA study in the framework of the PHARE EU project

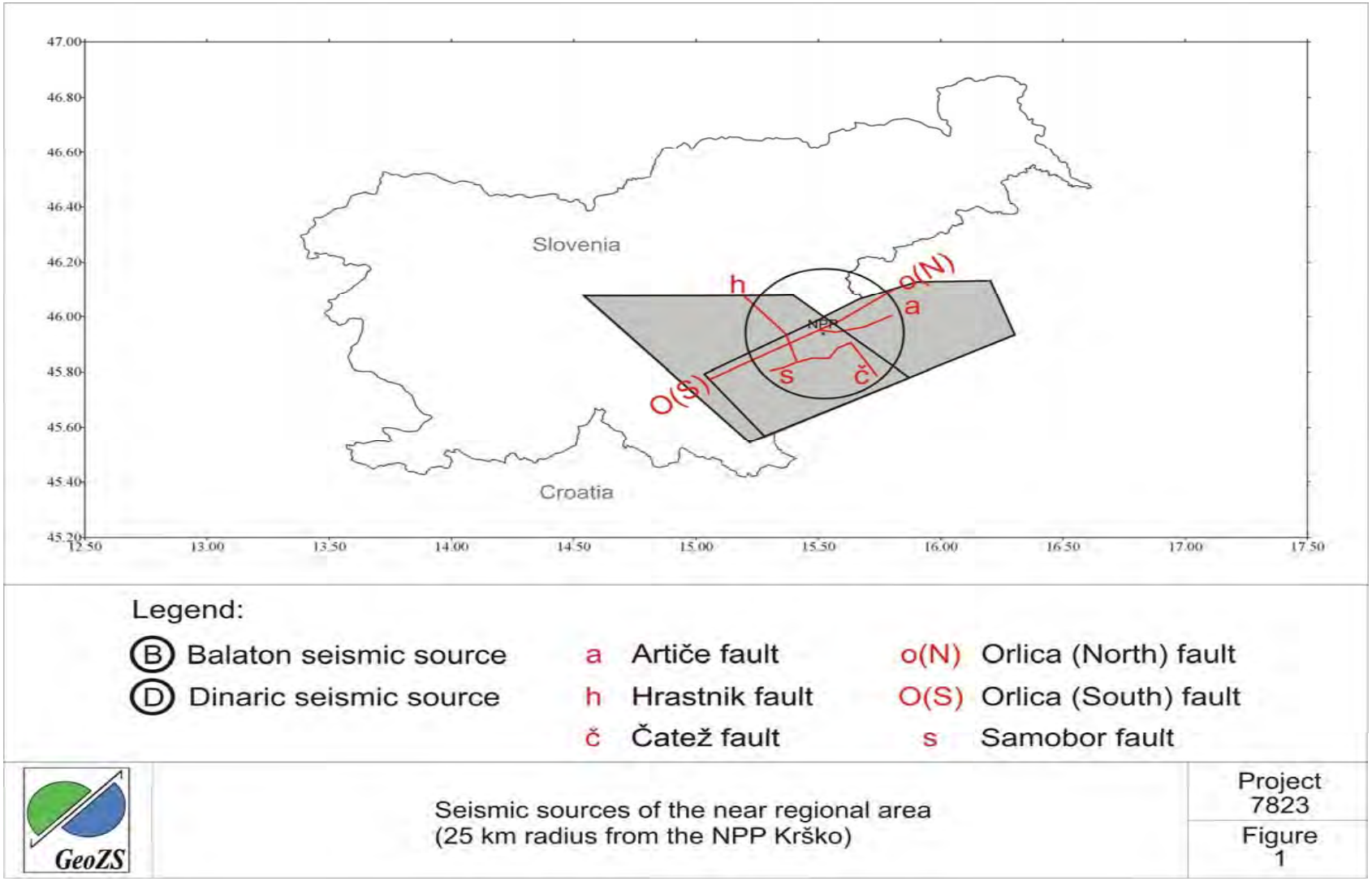
2. 2008-2012 – Member of the BRGM/GeoZs/ZAG/IRSN Consortium for the Krsko II GEN study – in charge of the Seismology Chapter

3. 2013 – Rizzo's preliminary Reports downloaded from the Internet site

CRO team: No fault sources considered in the PSHA calculations



Slovenian team



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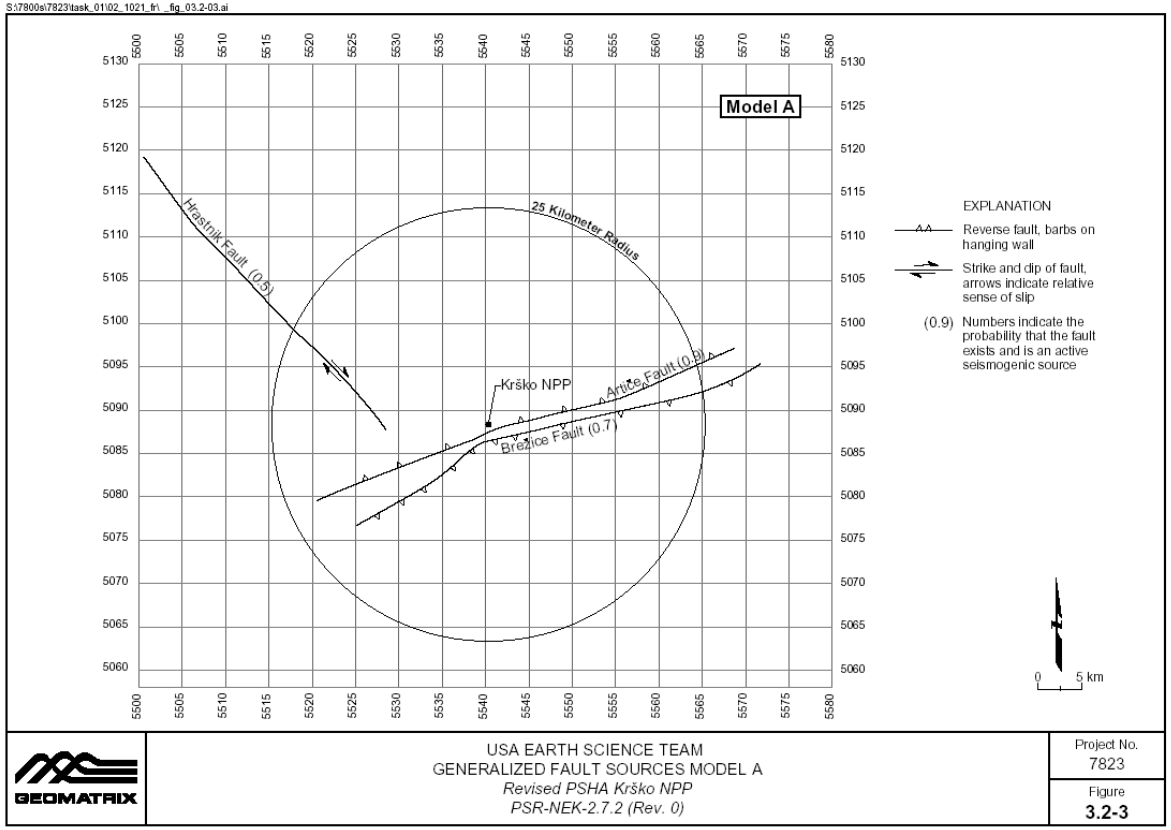
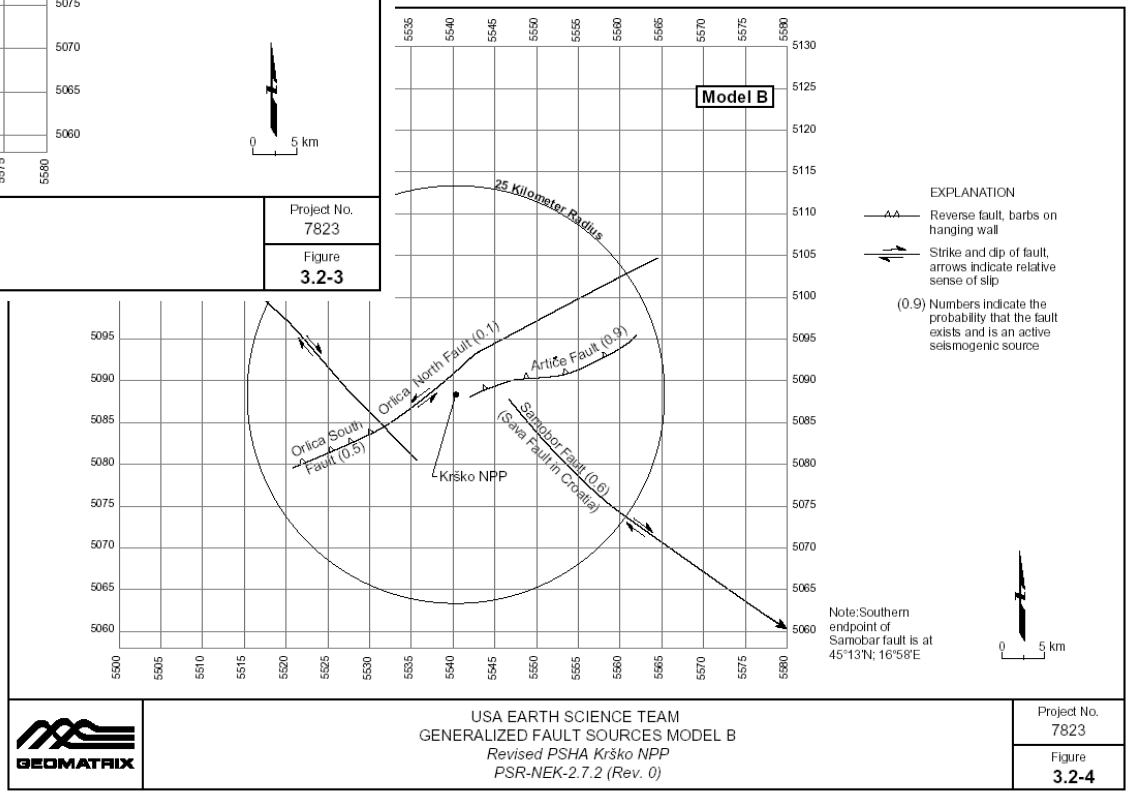


USA team

Two fault source models considered



2004 review - IRSN recommandations concerning Krsko I

Recommendations concerning seismotectonic research

A major effort to improving the quality of the data should be envisaged for the next PSHA study:

IV.1.1 Geology and quaternary deformations

Precise geological investigations on Quaternary deposits should be relevant (sedimentological and stratigraphic studies to evaluate the local deformations, to estimate the subsidence rates, to assess precisely the lateral correlations of terraces for differential displacements evaluations,…).

IV.1.2 Paleoseismicity

Total absence of paleoseismological surveys in the NPP vicinity (Artice fault, Orlica fault) is a crucial weak point of the methodology presented in this report. It is fundamental that studies be envisaged in the future to evaluate potential maximal earthquakes considering state-of-the-art methodologies and to obtain relevant reference deformation rates (eg. geomorphologic, geophysical and trenching approaches).

IV.1.3 Geodetic data

The GPS network should be measured regularly because it could provided vital upper bound limits to fault source modelling.

IV.1.4 Geophysics

Homogenisation of the processing and interpretation of the seismic profiles.

Rapport DEI/SARG n° 04-13

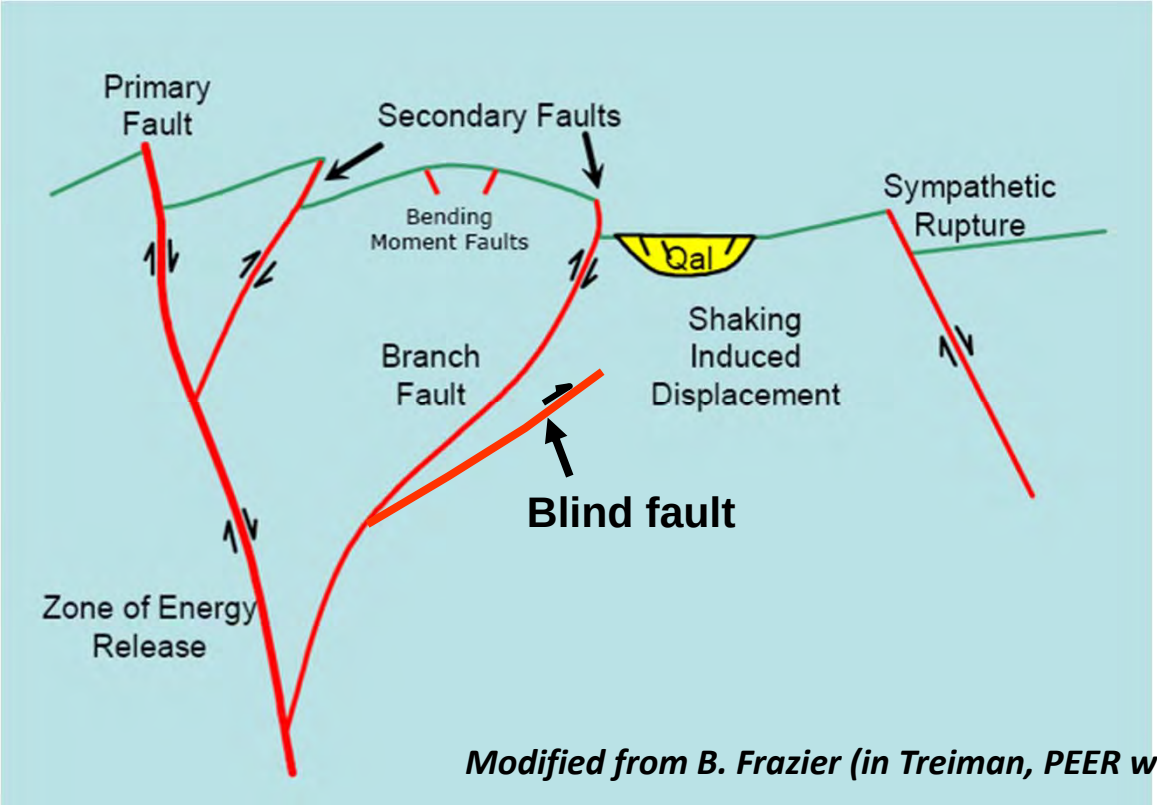
Krsko II – 2008 - 2010 Seismological studies performed by the Consortium

- Installation of a temporary network of seismological stations
- In-depth historical seismicity investigations/ Updating of earthquake catalogue
- Seismic sources characterisations (b-values, Mmax, depth)
- Updating of GMPE
- PSHA update – a two-step procedure:
  - 2003 Seismic sources + 2010 updated GMPE
  - 2010 Seismic sources + updated GMPE (results not published in Phase 1 report)
- DSHA french methodology
- Site – effects study based on DSHA

Each one of these actions was discussed and debated in Workshops

Consortium investigations

- Geomorphology, mapping, geophysics, trenching in the 5 km radius around Krsko
- Capable fault issue Focus on Libna fault



Modified from B. Frazier (in Treiman, PEER workshop, 2009)

2008 Krsko II Geological study

IRSN (scientific) position is the result of

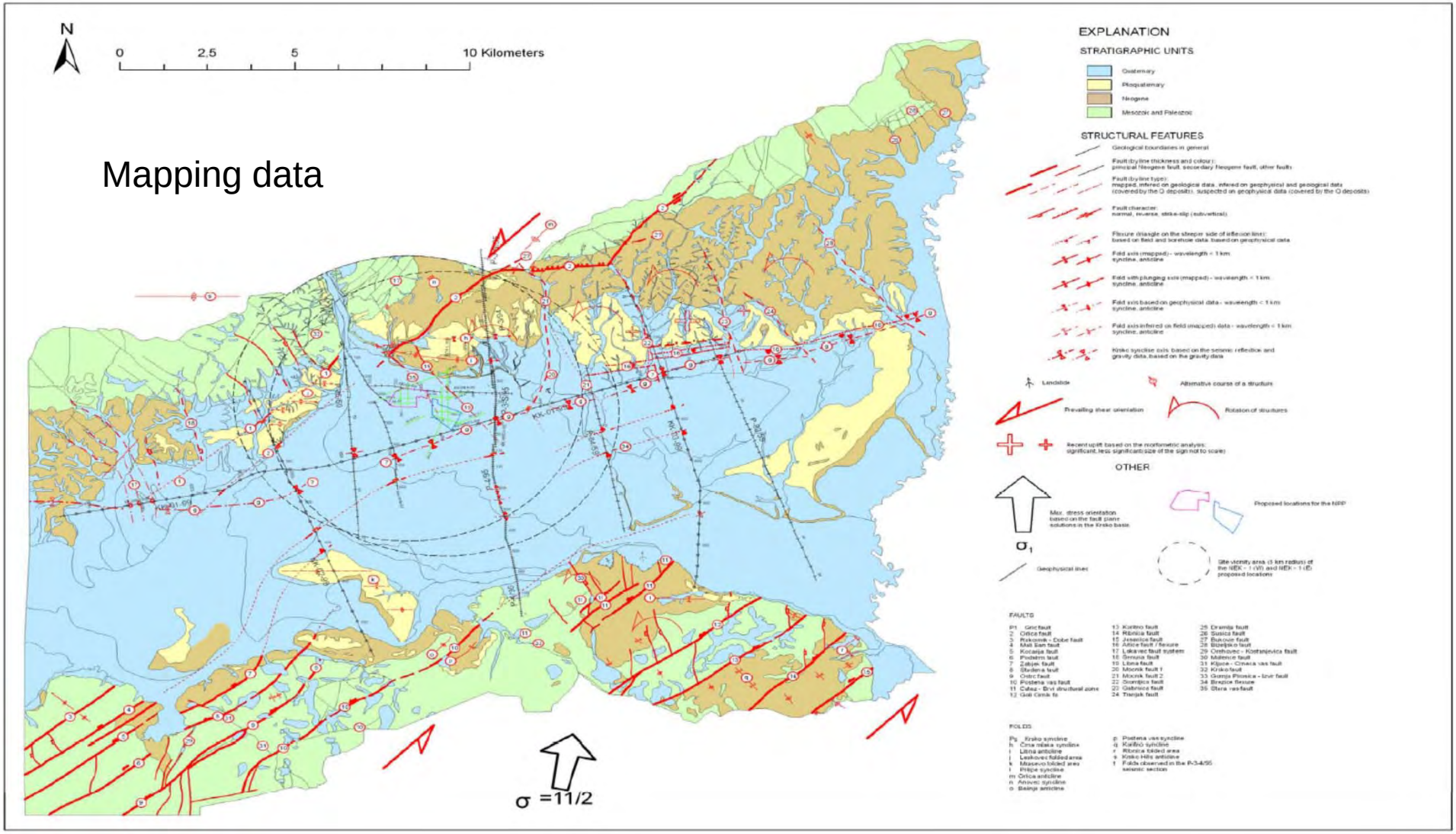
- Consortium workshops during 4 years
- 2 trenching campaigns
- 1 common report signed by each partner

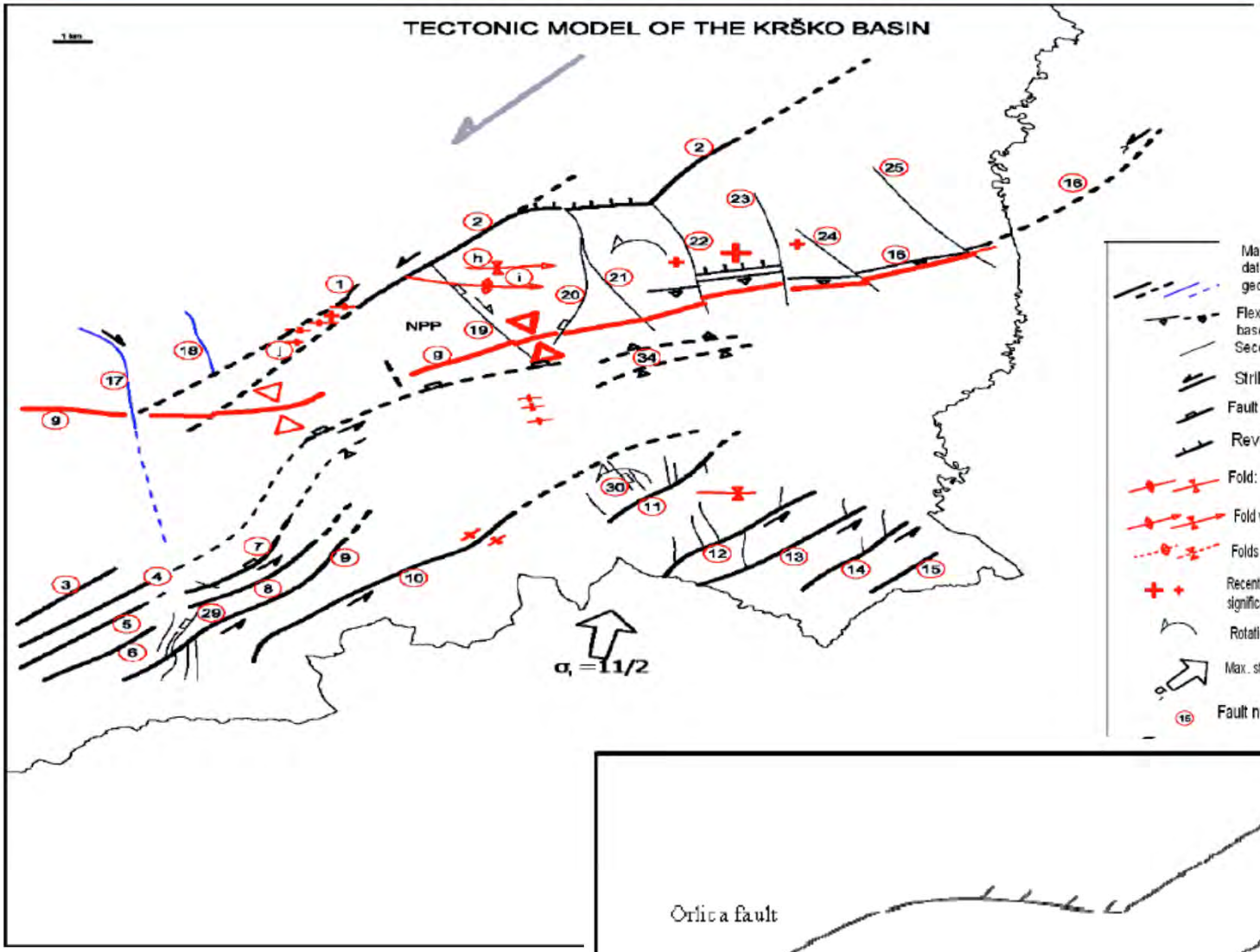
  (IRSN, GeoZS, BRGM, ZAG)

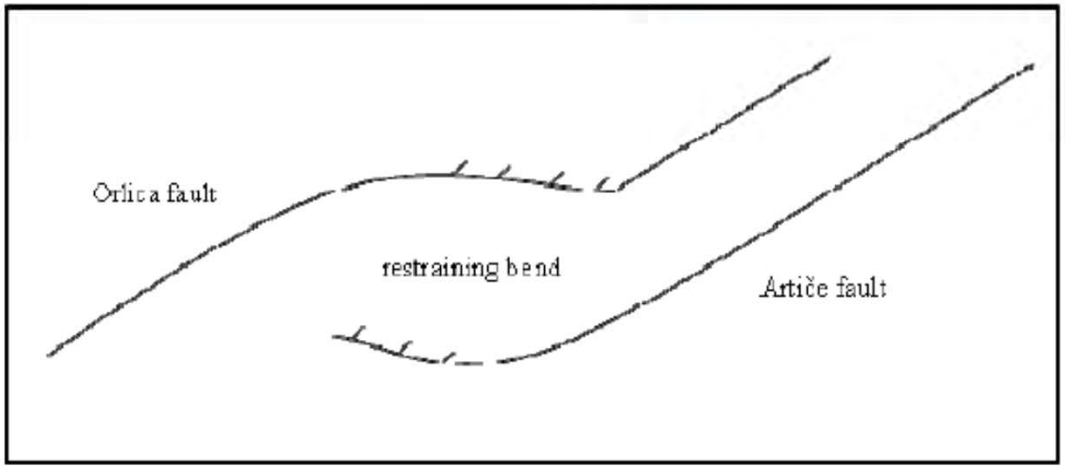
➔ Libna fault is capable

IRSN – capable fault issue at Krsko

- Geological model (Consortium)

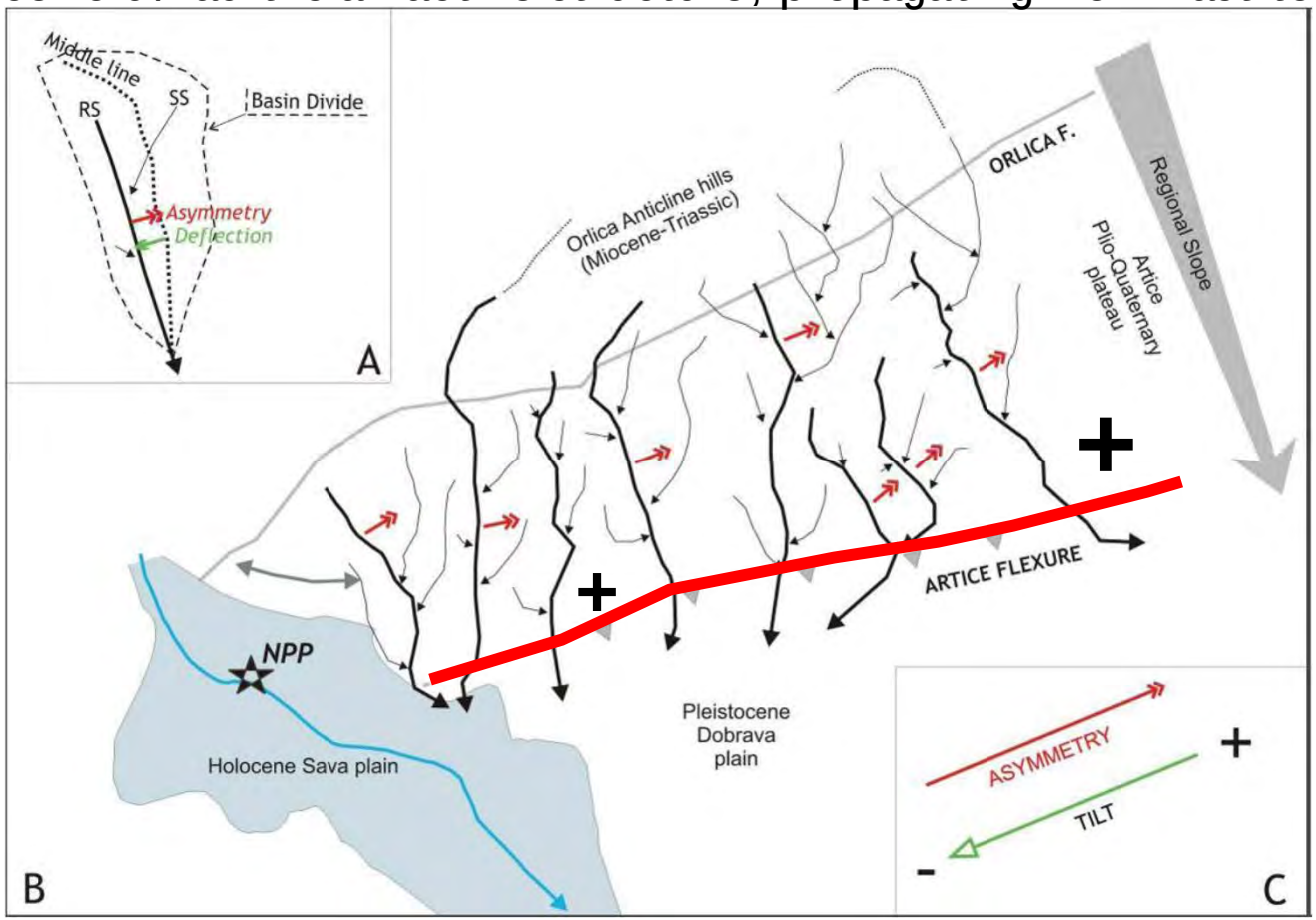



TECTONIC MODEL OF THE KRŠKO BASIN
NPP
σ1 =11/2
Mapped Balaton faults, Balaton faults based on geophysical data and morphology, Dinaric faults, Dinaric faults based on geophysical observation
Flexure; triangle on the steeper side: mapped, based on geophysical observation
Secondary faults
Strike slip fault
Fault with relatively subsided block
Reverse fault
Fold: anticline, syncline
Fold with plunging axis: anticline, syncline
Folds observed only in one seismic section: anticline, syncline
Recent uplift based on the morphometric analysis: significant, less significant
Rotation of structures
Max. stress orientation based on the fault plane solutions in the Kr ko basin
Fault numbers are consistent with the Tectonic map


Orlica fault
restraining bend
Artiče fault

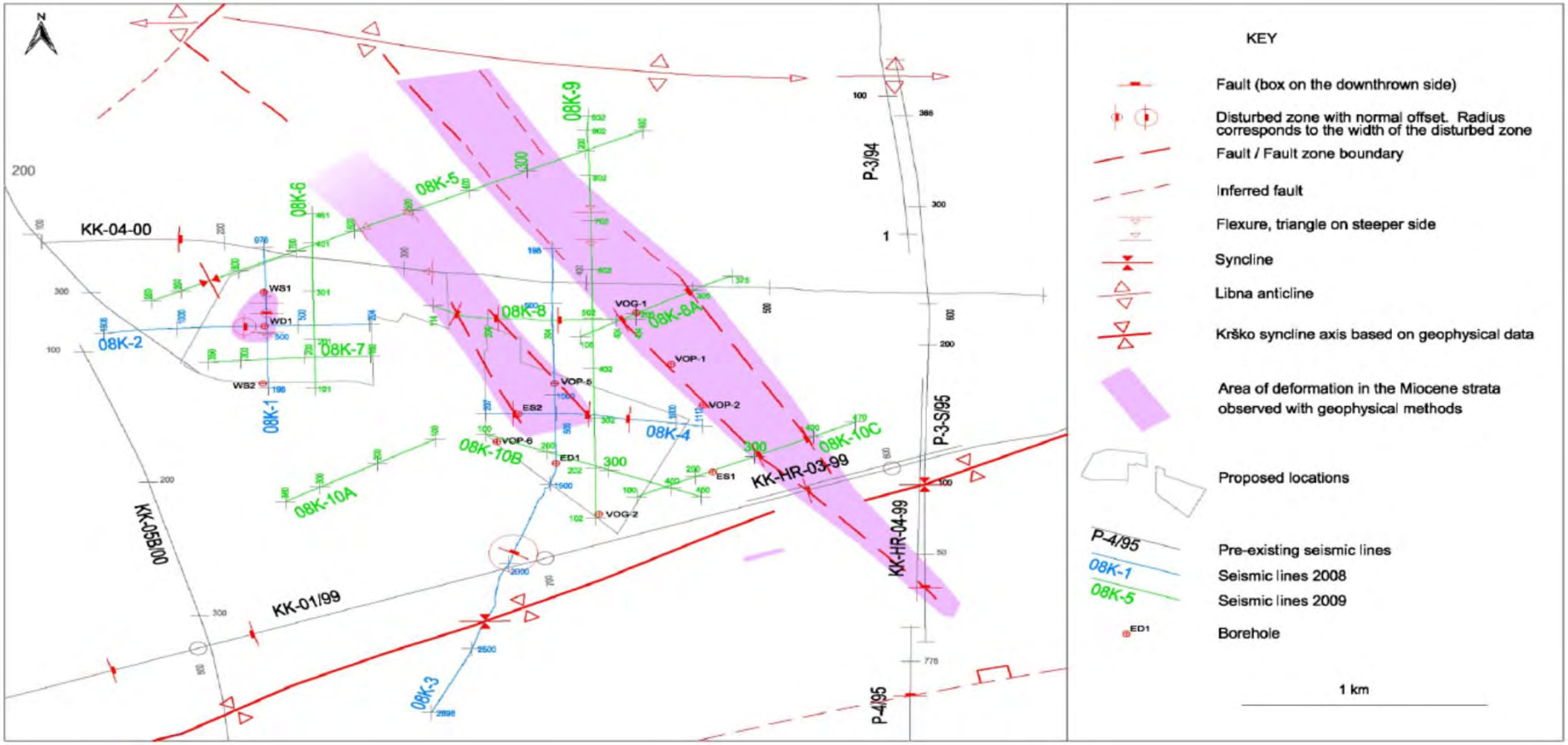
Geological model (Consortium report)

- Geomorphological data feeds the model
- Consistent with geological sections (boreholes and seismics)
- Artice fold/fault is an active structure, propagating from East to West

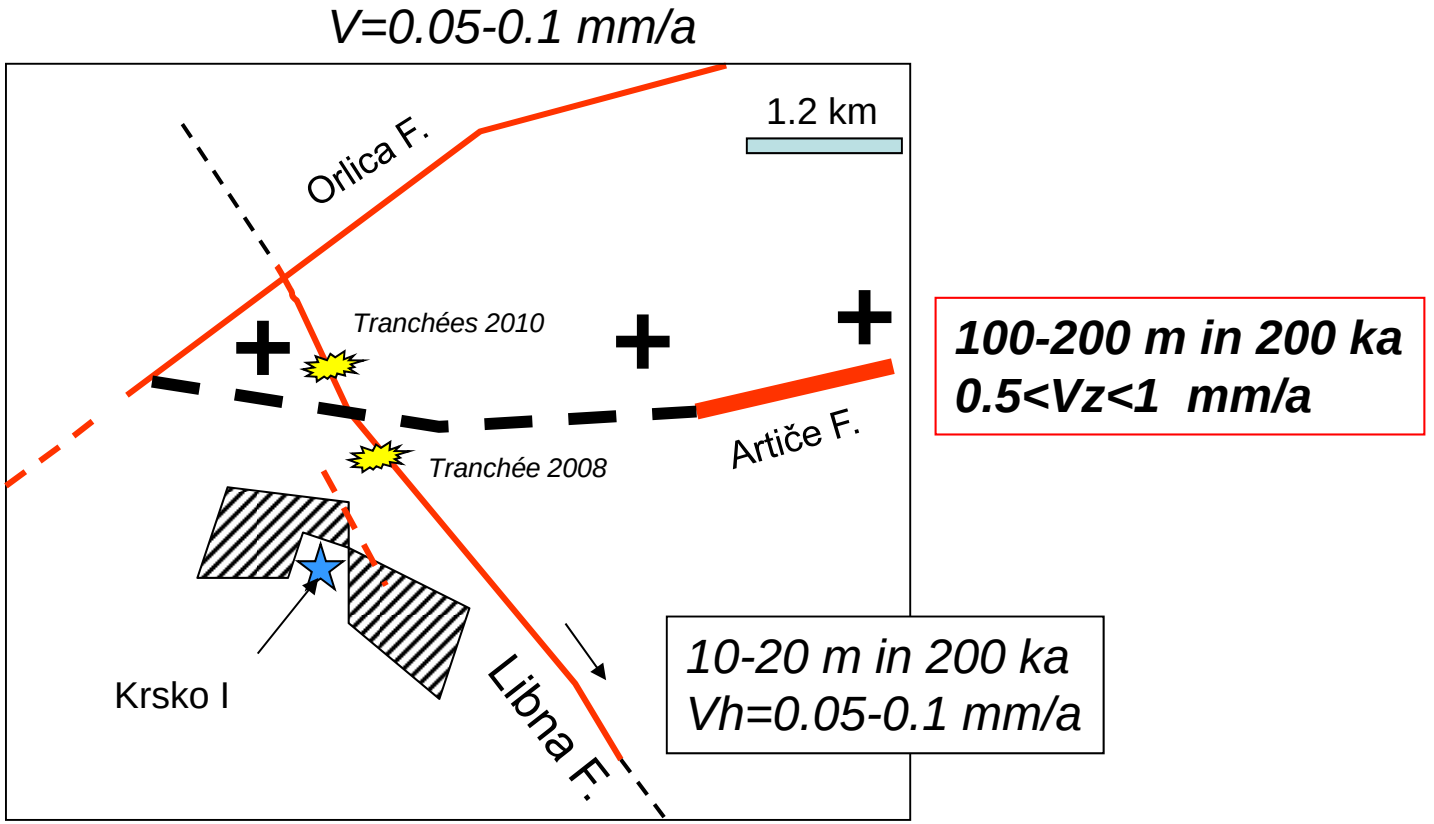


Geological model (Consortium report)

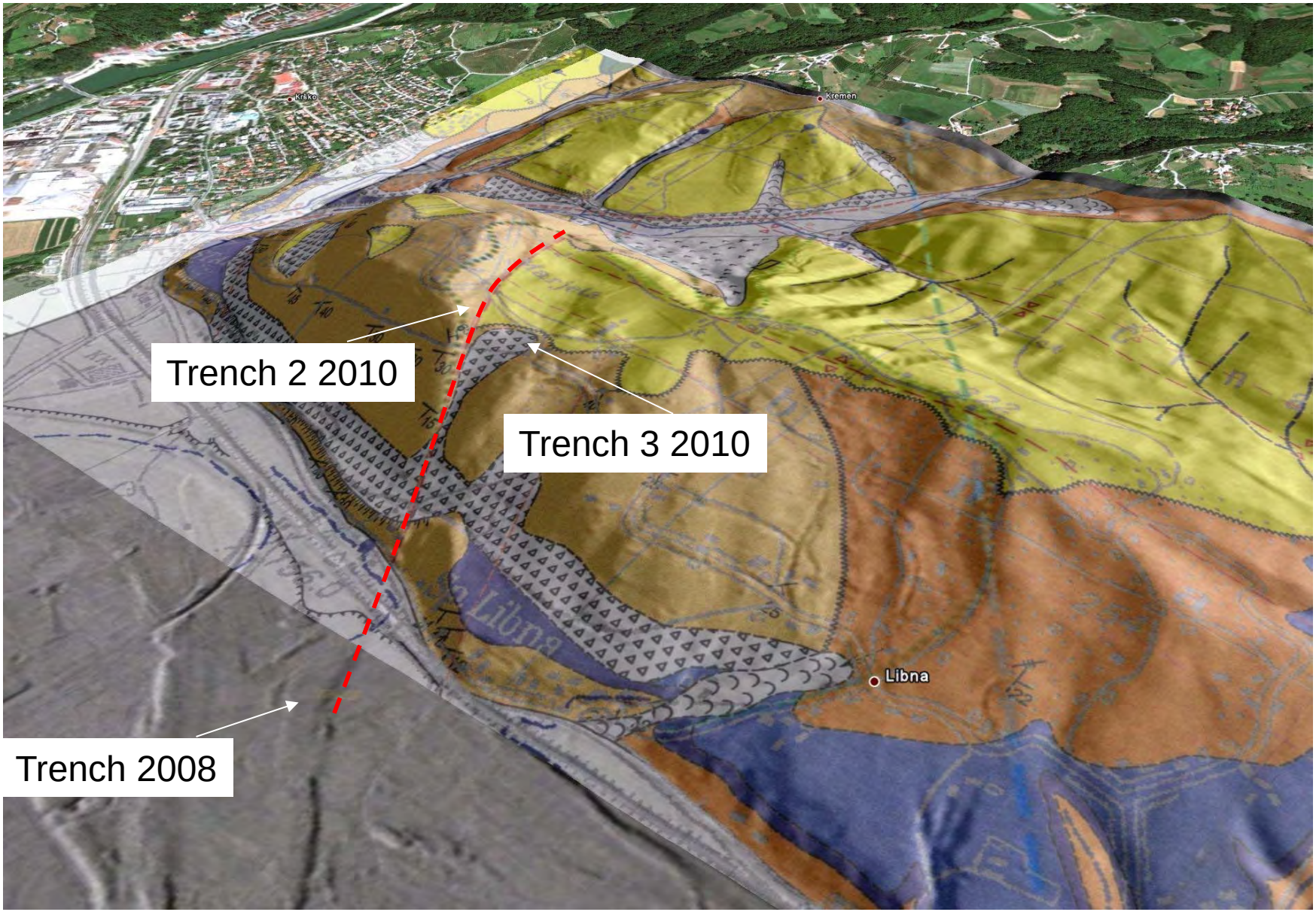
- Geophysical data feeds the model
- According to Consortium, Libna structure is extending southward from Libna Hill



IRSN – capable fault issue at Krsko

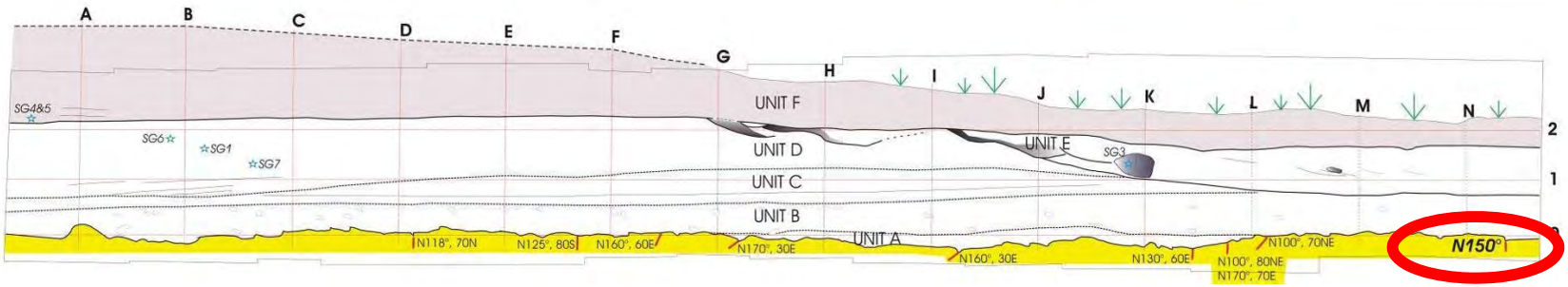


Artice structure is suspected to be the most significant fault.
Investigations were focused on the Libna fault.


Krško
Kremen
Trench 2 2010
Trench 3 2010
Libna
Trench 2008

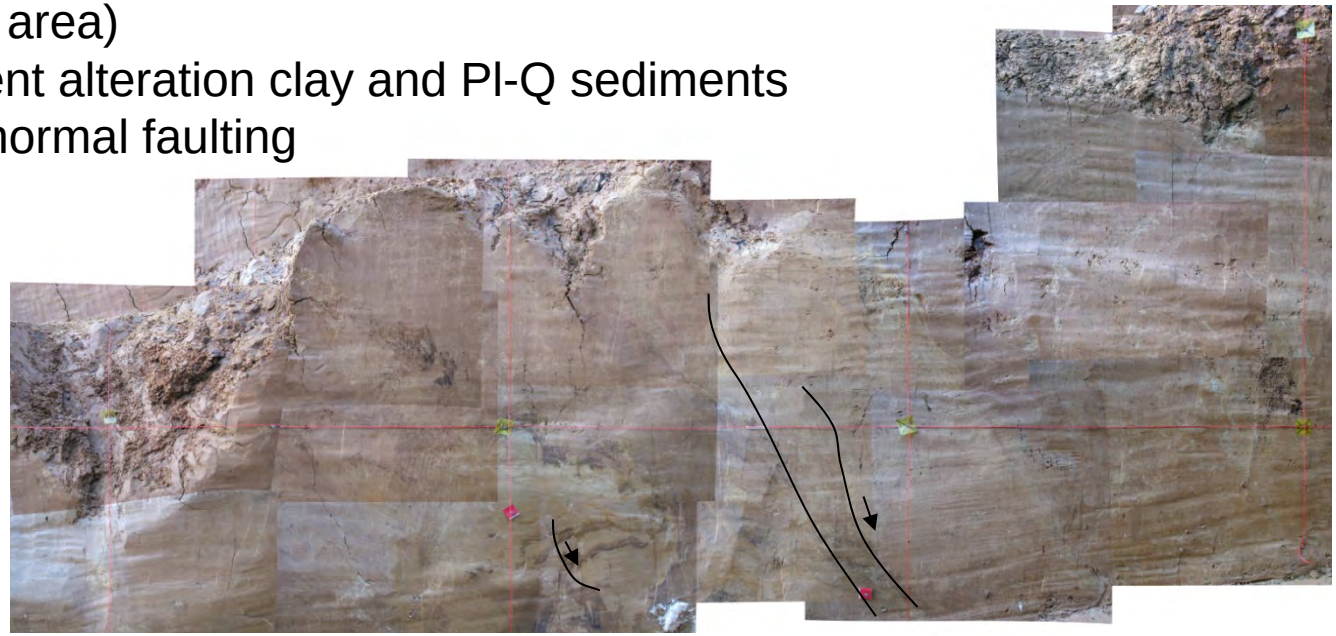
2008 trench in Sava alluvial plain

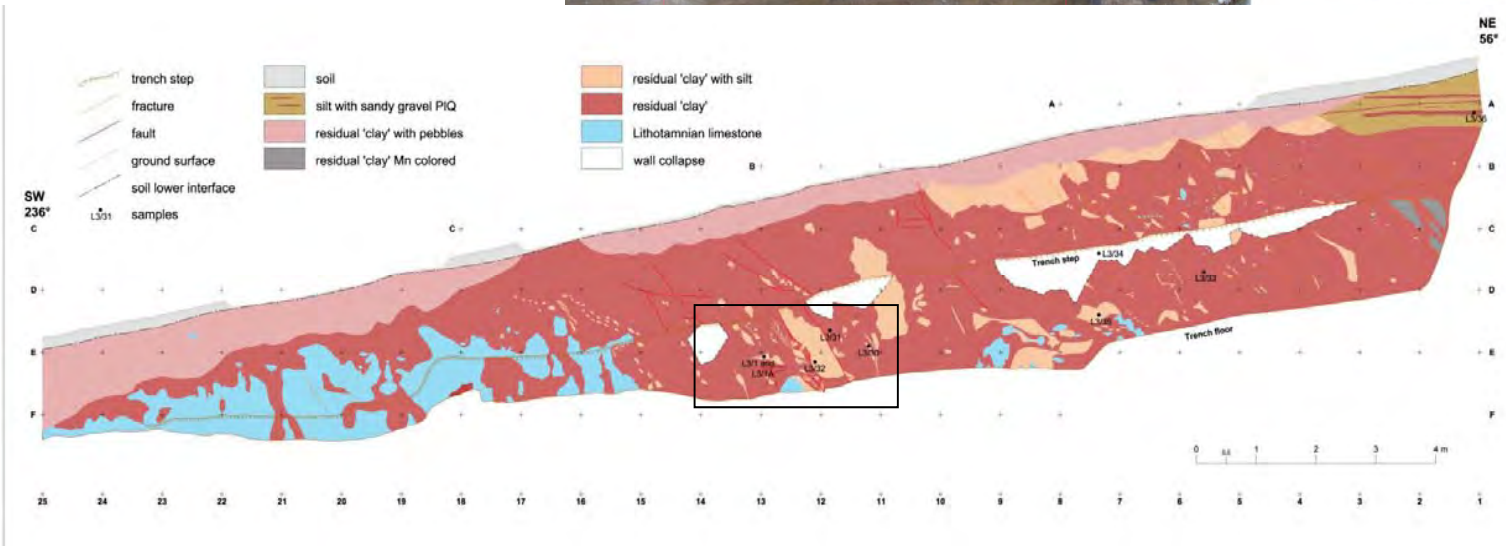
- Fault was observed in Miocene
- Holocene sediments were too young (400 years) to have cumulated visible deformation



2010 trench at the top of Libna Hill

TRENCH 3 (Sinkhole area)
- A mixture of basement alteration clay and Pl-Q sediments
- Listric and diffused normal faulting
- Sinkhole





2010 trench at the top of Libna Hill

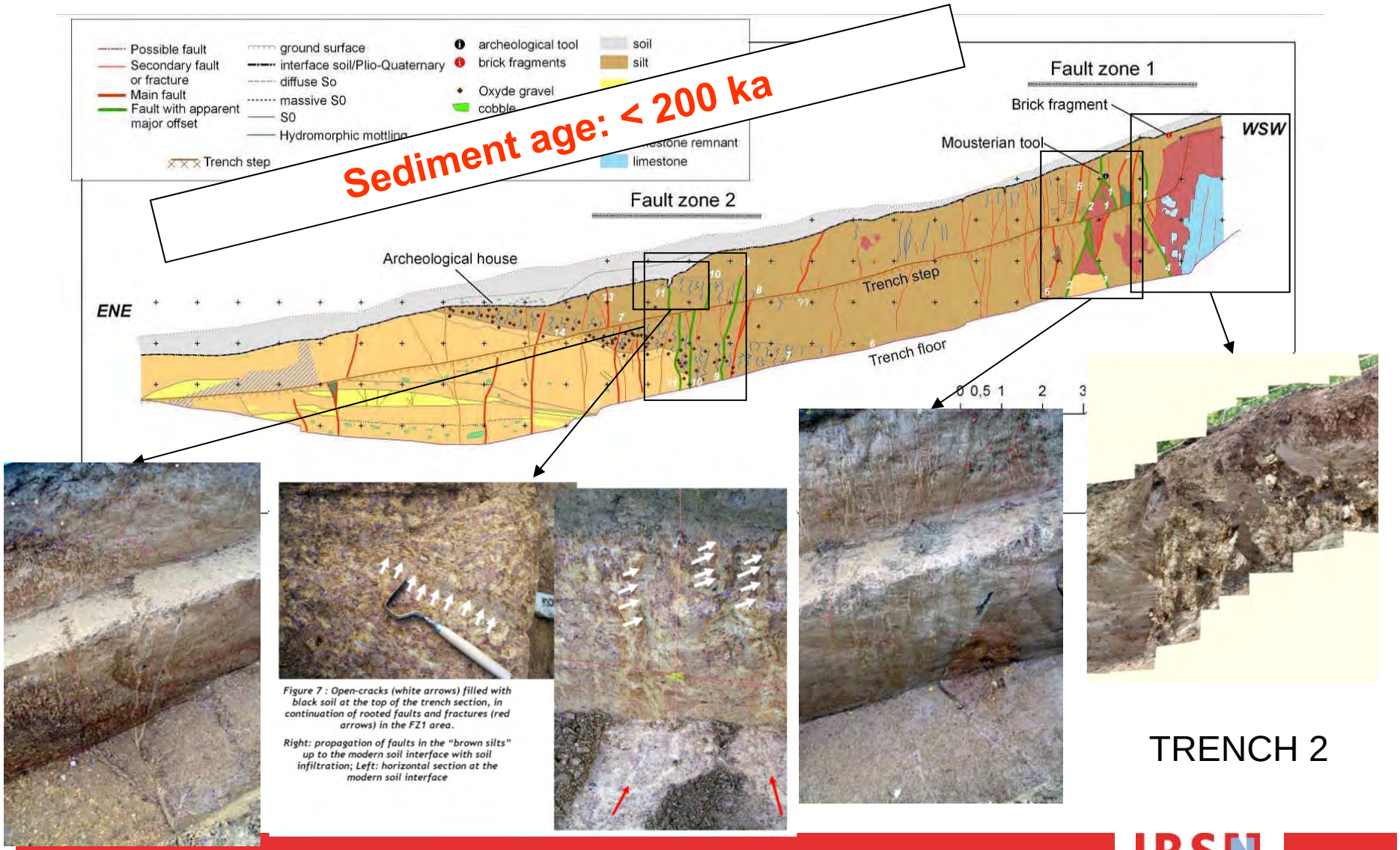


Figure 7 : Open-cracks (white arrows) filled with black soil at the top of the trench section, in continuation of rooted faults and fractures (red arrows) in the FZ1 area.

Right: propagation of faults in the "brown silts" up to the modern soil interface with soil infiltration; Left: horizontal section at the modern soil interface

TRENCH 2

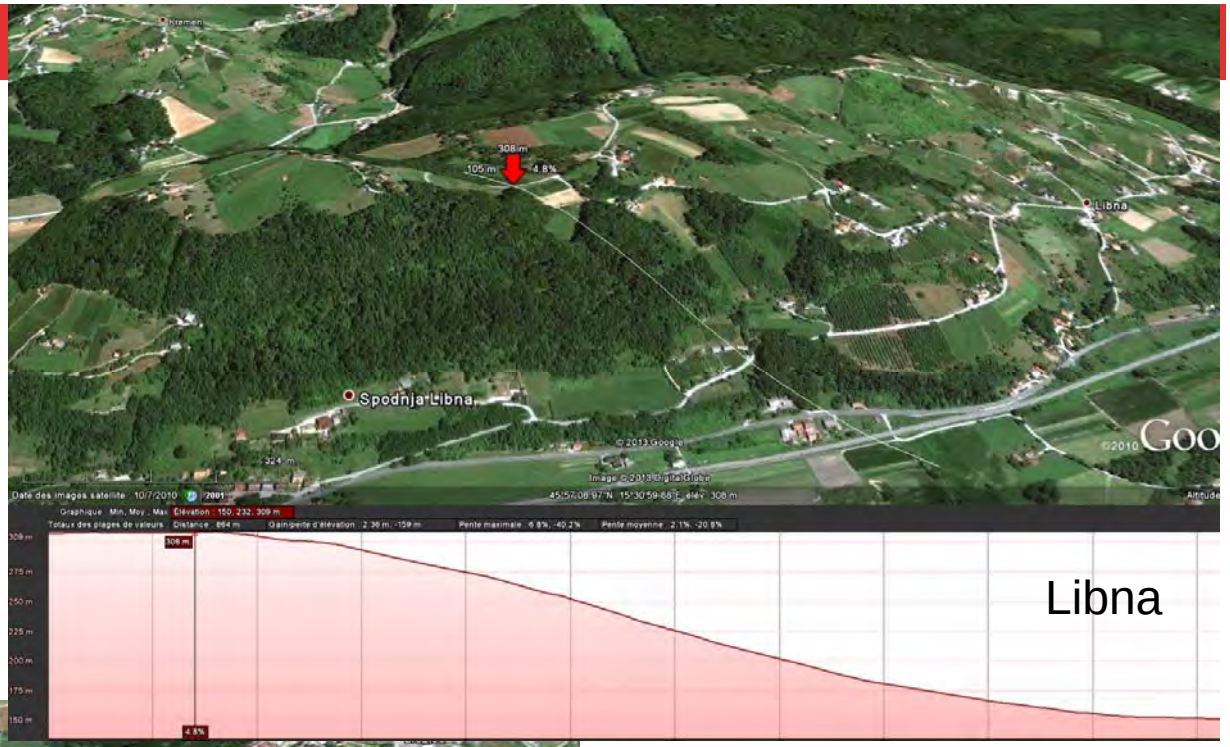
Karst?

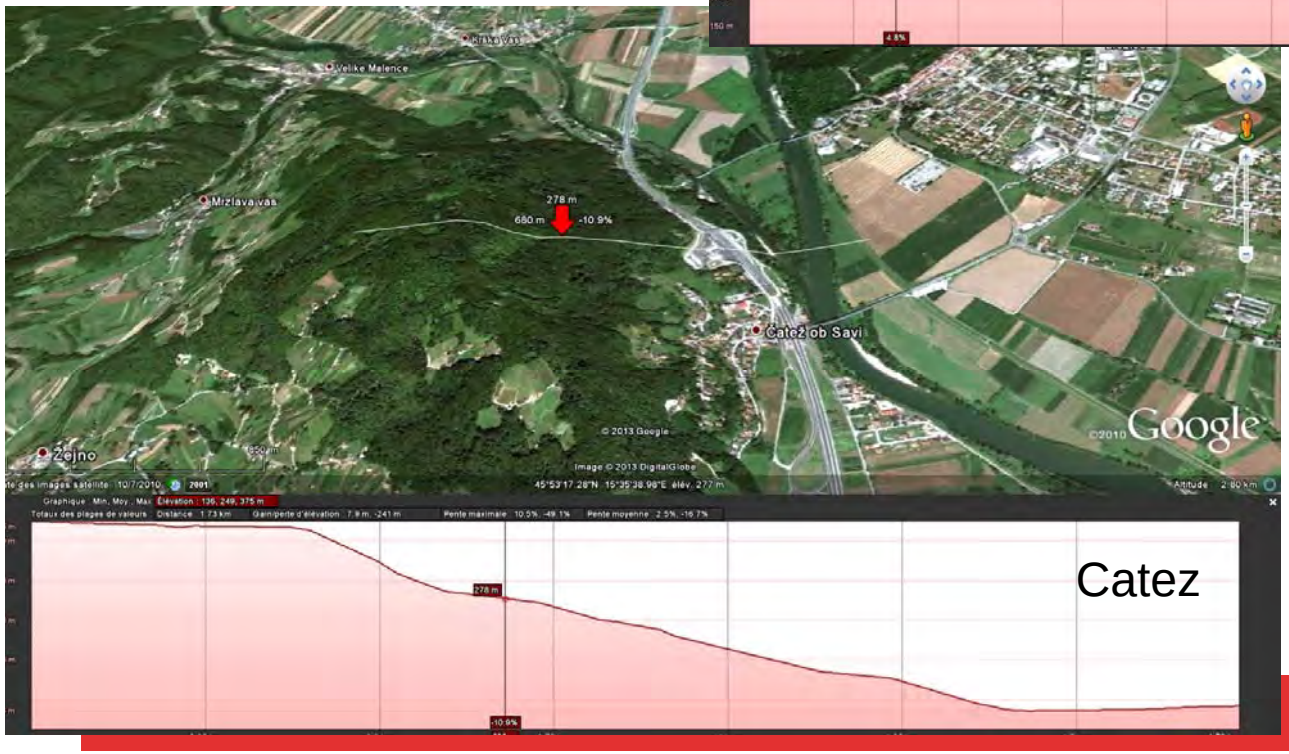
- In trench 2, Lateral displacement , instead of vertical displacement
- In trench 2, Intensity and pattern of deformation ➔ tectonic
- Fault pattern in trench « 2 » has nothing common with the deformation pattern in trench « 3 » where karstic processes are evident
- **<u>Consortium position: Trench 2 – not karstic</u>**

Landslide ?

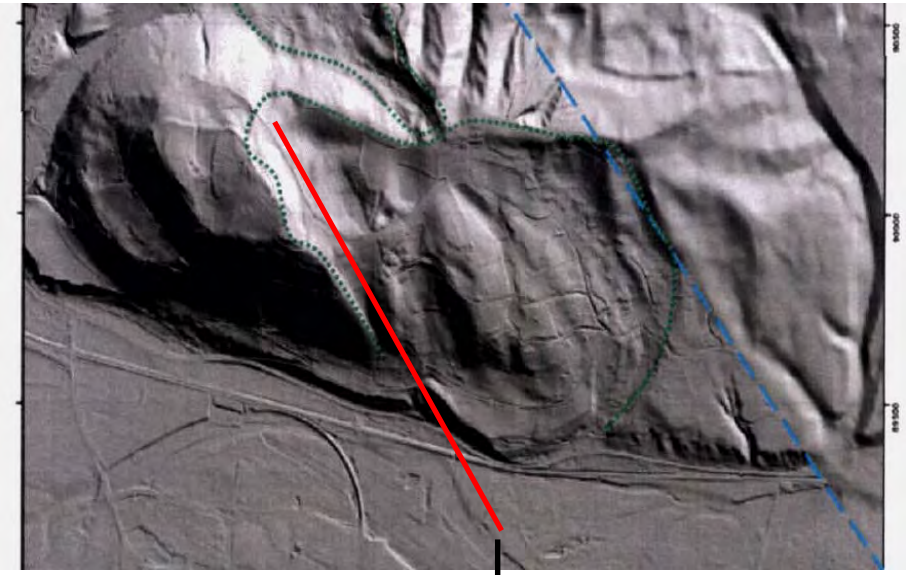
- In trench 2, Lateral displacement, with oblique slickenslides (both dipping to the south and to the north)
- Intensity of deformation and width of fault zone: significant
- Syn-sedimentary deformation in a fluvial environment
- The topography around the Libna fault (from top to bottom) is not emblematic of landsliding processes
- Hillslope outcrops reveal the occurrence of strike-slip faulting in basement limestones
- **Consortium position in 2011: Trench 2, not landslide**
- **Not Karst + Not landslide → Tectonic**

Landslide profile?

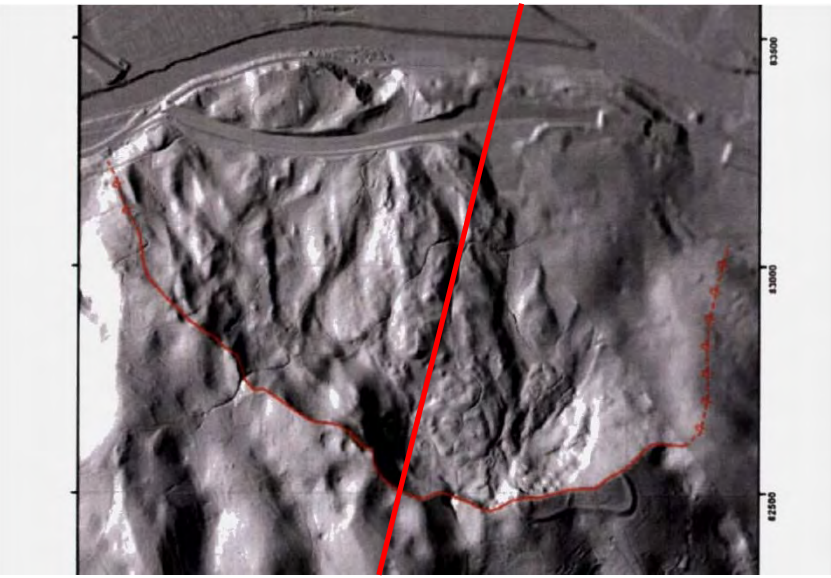


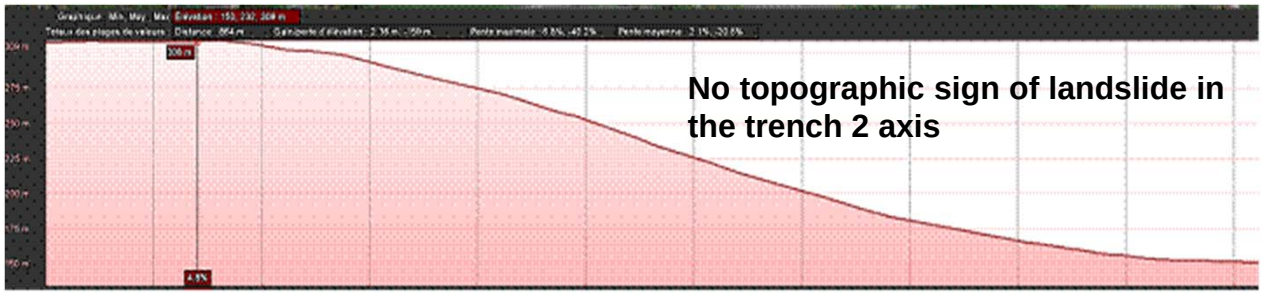


Libna Hill



Catez Hill





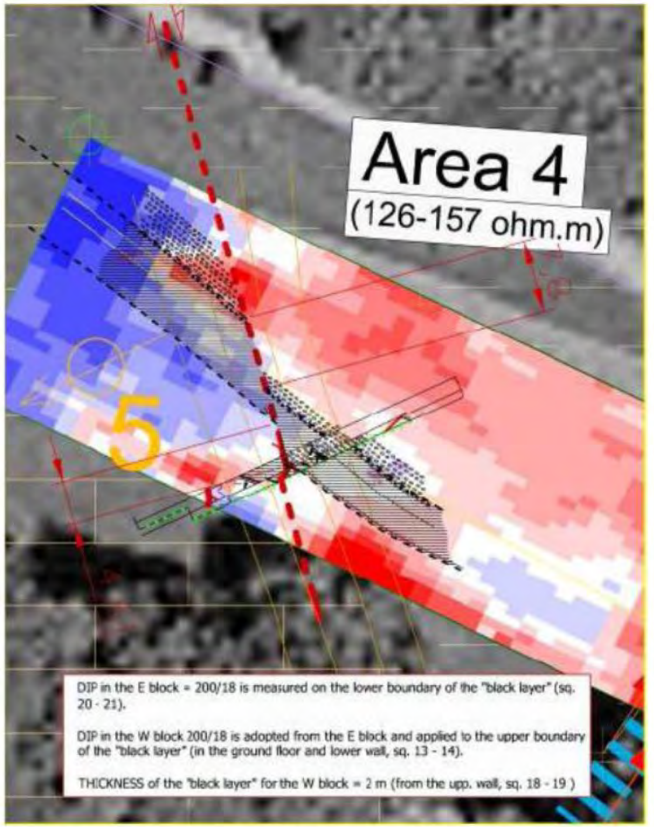
No topographic sign of landslide in the trench 2 axis

Consortium

- post Plio-Quaternary activity (< 1800 ka)
- Strike-slip component
- Horizontal slip rate: 0.1 mm/a
- Known length (geophysics): 5 km
- 2 major strands

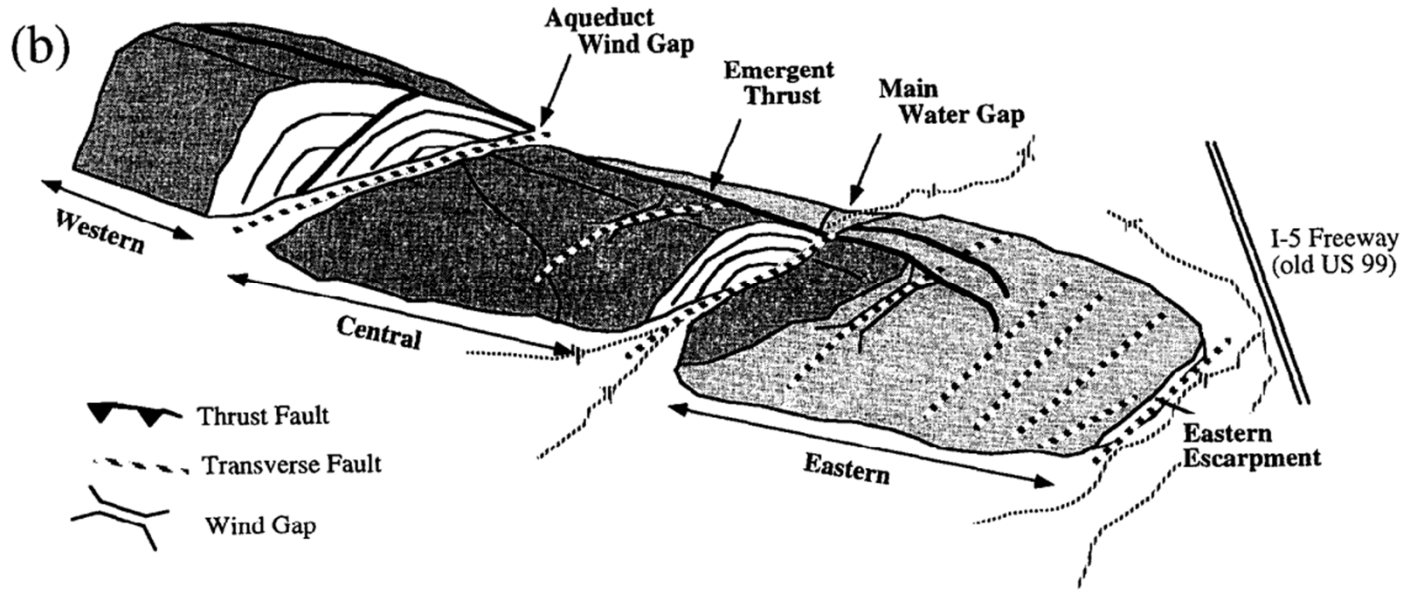
INGV Expert

- Fault is tectonic, with clear strike-slip kinematics
- Prehistoric artefact is concerned by tectonic deformation
- Holocene activity on faults (< 10 ka), and even post-Mousterian event
- Coseismic deformation (open cracks at ground surface), on the Libna fault or on a close fault (Orlica ?)



An analogous model (uplift rate of 1.7 mm/years)

- A growing fault-bend fold, with tear faults



Mueller & Talling, 1997

The largest fault is that generating the fold; but the « secondary » transverse faults also generate surface coseismic displacements

Suggested future investigations

Additional investigations on Libna fault

- Interpretation of displacement observed in trench 2
- Geophysical preliminaries for additional trench on Libna fault
- Trench on the Libna fault at the foothills of Libna Hill
- Morphotectonic study of possible continuation of Libna fault accross the Orlica Fault
- HRS survey on potential southern continuation of the Libna fault

Additional investigations on Artice fault

- Near-surface expression of the fault, with HRS lines and trenches

All of these were proposed to the client in Jan 2011

Thank you for your attention