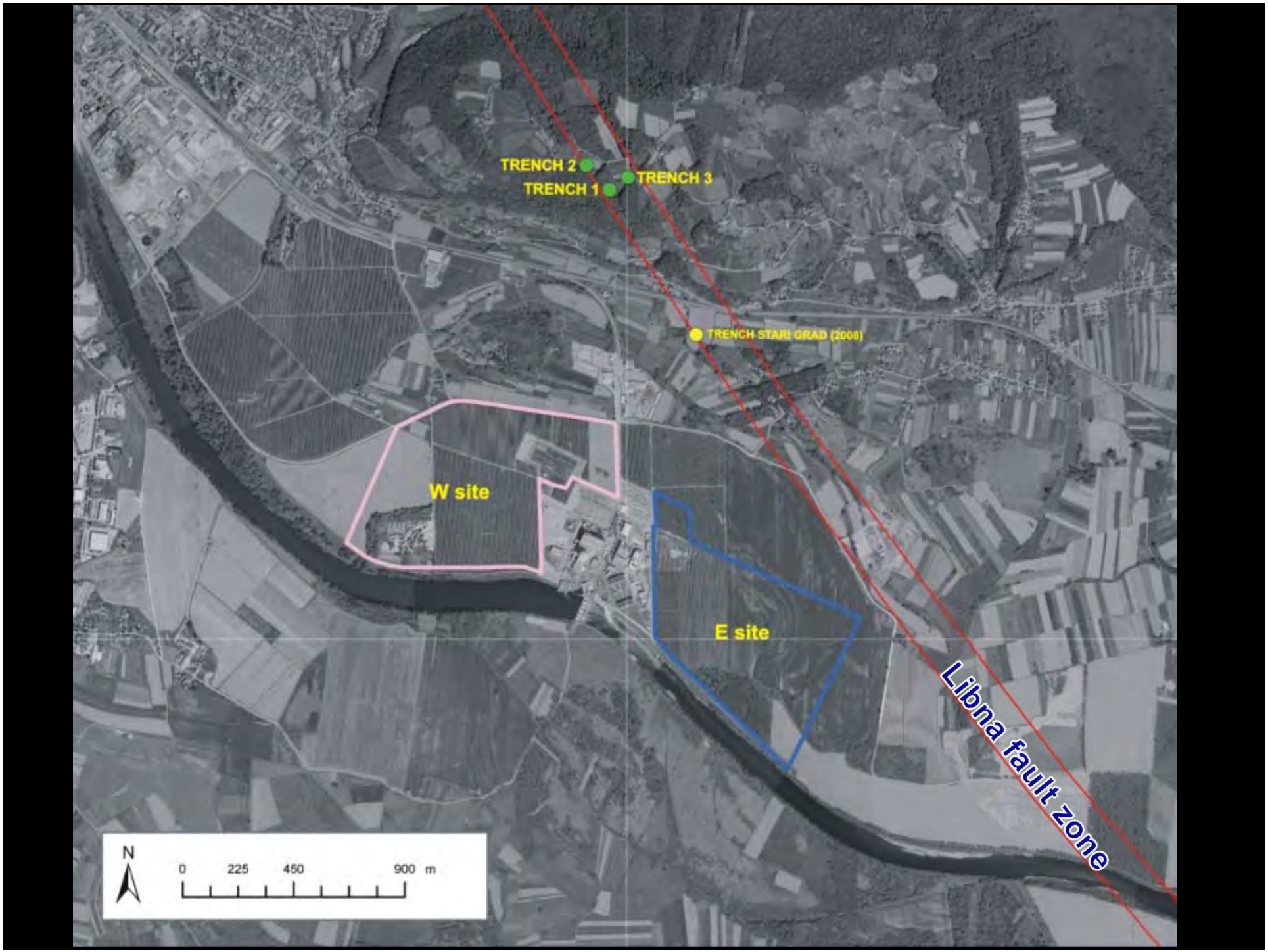
LIBNA FAULT

An overview and some comments regarding the IRSN position

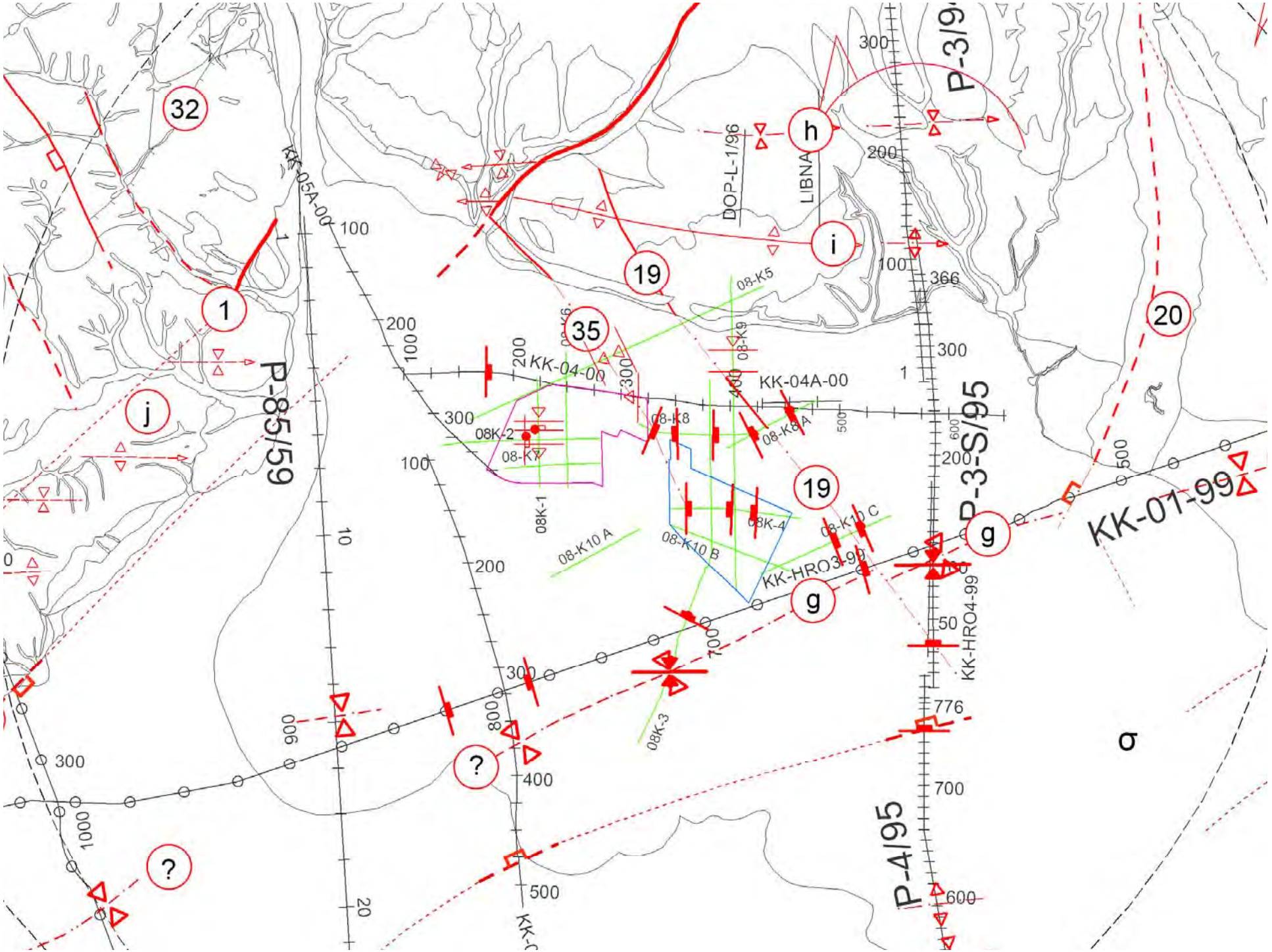
Geološki zavod Slovenije

Ljubljana, Apr. 26, 2013


TRENCH 2
TRENCH 3
TRENCH 1
TRENCH STARI GRAD (2008)
W site
E site
Libna fault zone
N
0
225
450
900 m

Libna fault zone:

- mapped (field mapping) on the Libna Hill within the Miocene
- Is interpreted between the crest of Libna Mt and Sava River.
- Fault observed in P-3-4/95, KK-01-99, 08K-10C and 08K-8A .
- To the NW the fault line can not be traced due to poor data quality across the KK-04-00 and 08K-5 lines.
- NE limit of the fault zone is reliable between 08K-10C and 08K-8A lines.
- Considered to be structurally unimportant (a second order structure)
- According to the current tectonic model, the potential displacement is not distributed evenly along the whole length of the Libna fault. It is concentrated mostly to differential folding along the Libna anticline and most deformation should be taken up there (on the Libna anticline).


32
1
j
?
?
19
35
19
h
i
g
g
20
σ
P-85/59
P-3/9
P-3-S/95
P-4/95
KK-05A-00
KK-04-00
KK-04A-00
KK-07-99
KK-HRO3-99
KK-HRO4-99
DOP-L-1/96
LIBNA
08-K5
08-K6
08-K9
08-K8
08-K8A
08K-2
08-K7
08K-1
08-K10 A
08-K10 B
08K-4
08-K10 C
08K-3
100
200
300
400
500
600
700
776
366
1000
800
900
10
20
50
1

Key

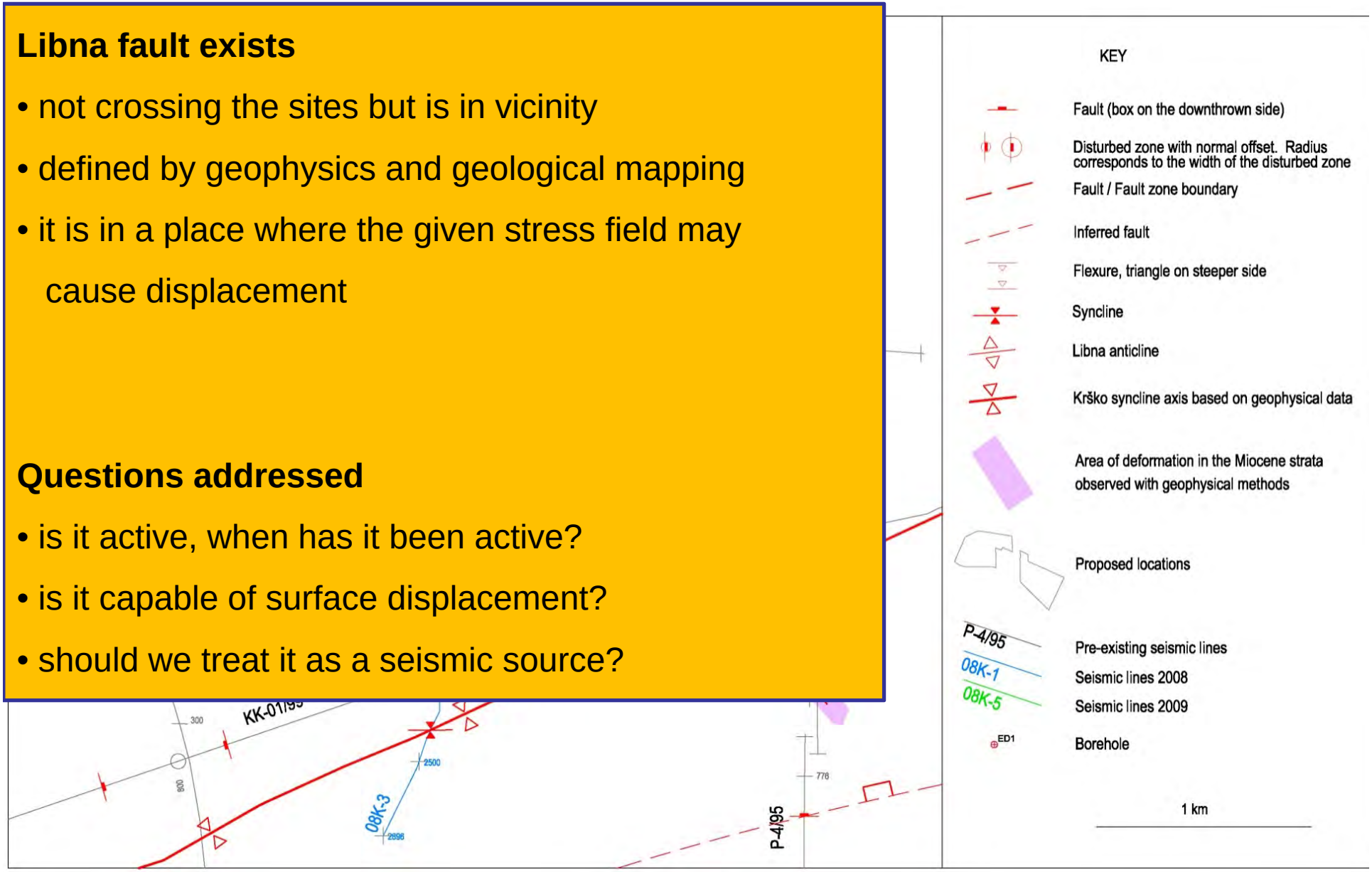
- Temporary accelerographs (ES2)
- Boreholes 2009
- Stari grad trench geophysica
- HRS sections
- 2D ERT sections
- GPR profiles
- GPR profiles
- Trench at Stari grad
- Test pits on Libna
- E site
- W site
- MASW profile
- Resistivity mapping
- ARAO Boreholes (VOG-2)

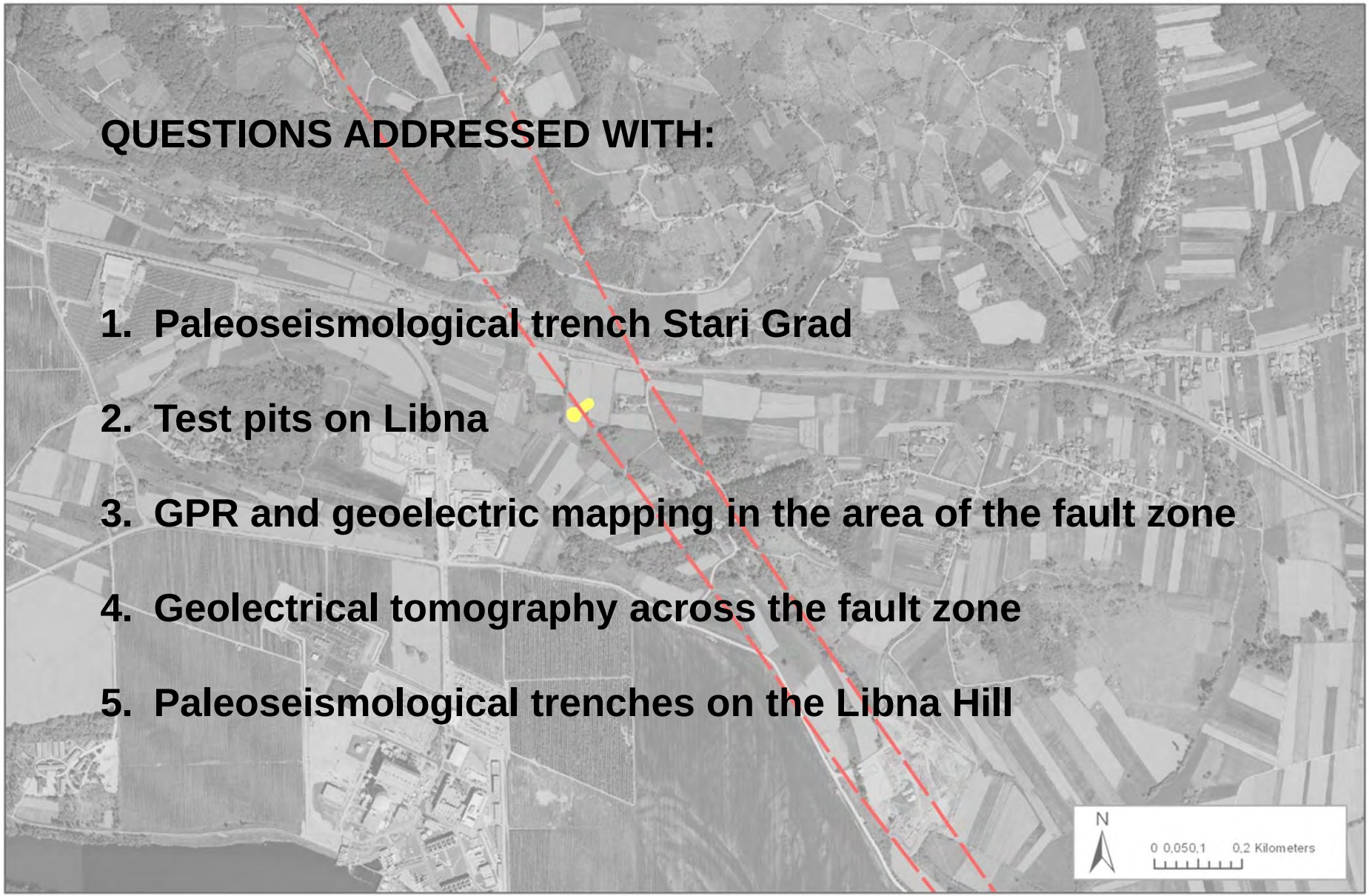
Libna fault exists

- not crossing the sites but is in vicinity
- defined by geophysics and geological mapping
- it is in a place where the given stress field may cause displacement

Questions addressed

- is it active, when has it been active?
- is it capable of surface displacement?
- should we treat it as a seismic source?



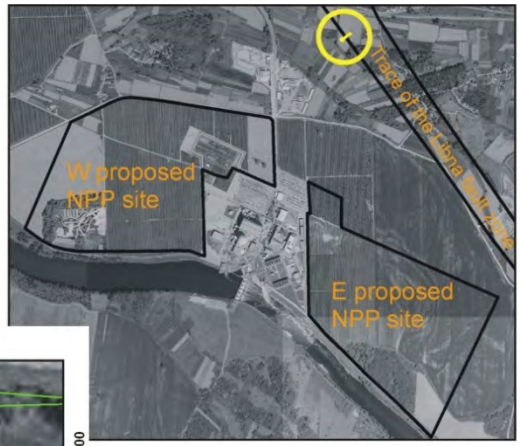


QUESTIONS ADDRESSED WITH:

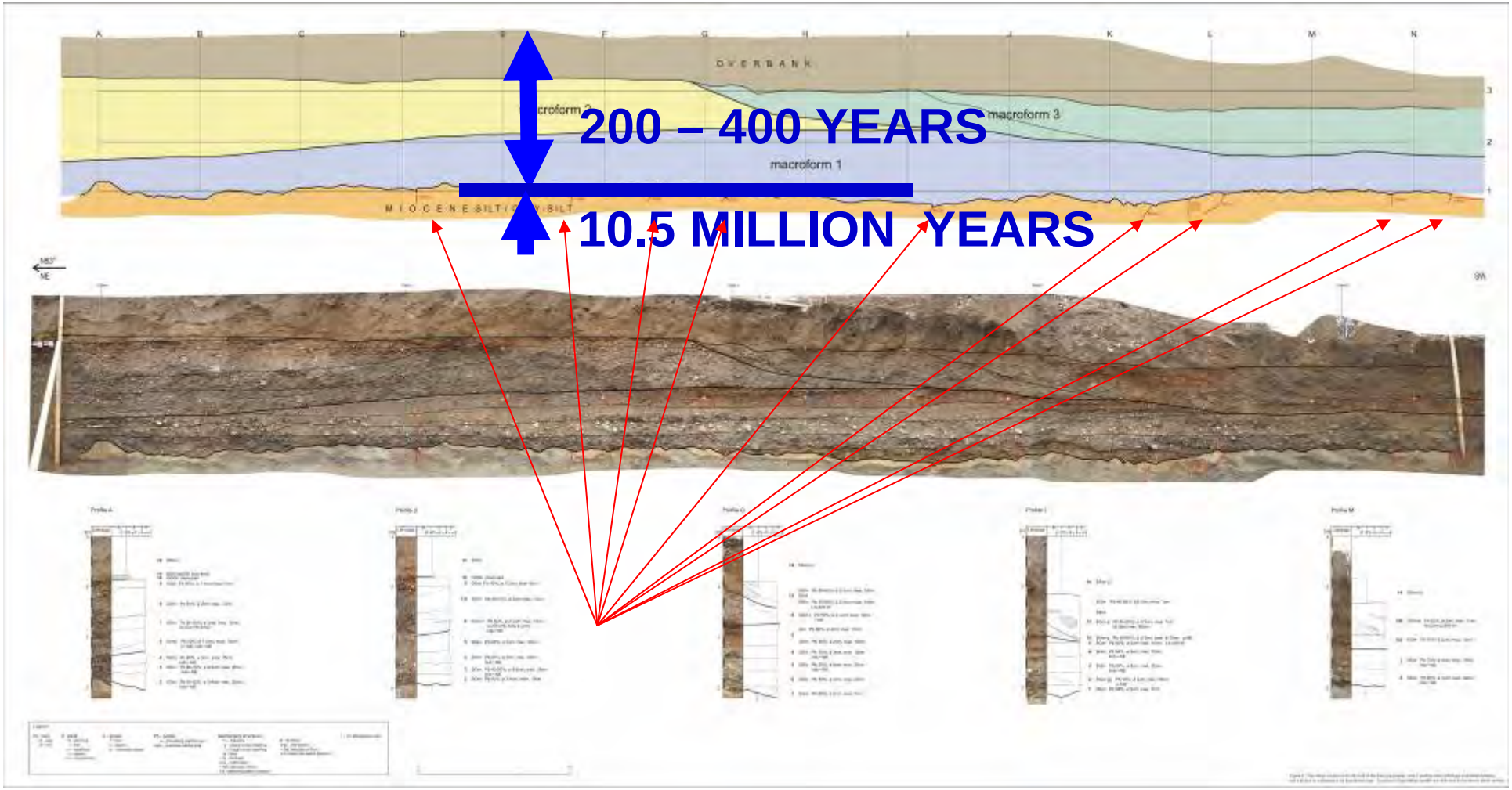
1. Paleoseismological trench Stari Grad
2. Test pits on Libna
3. GPR and geoelectric mapping in the area of the fault zone
4. Geolectrical tomography across the fault zone
5. Paleoseismological trenches on the Libna Hill

Trench in the Holocene aluvial plane

Stari Grad

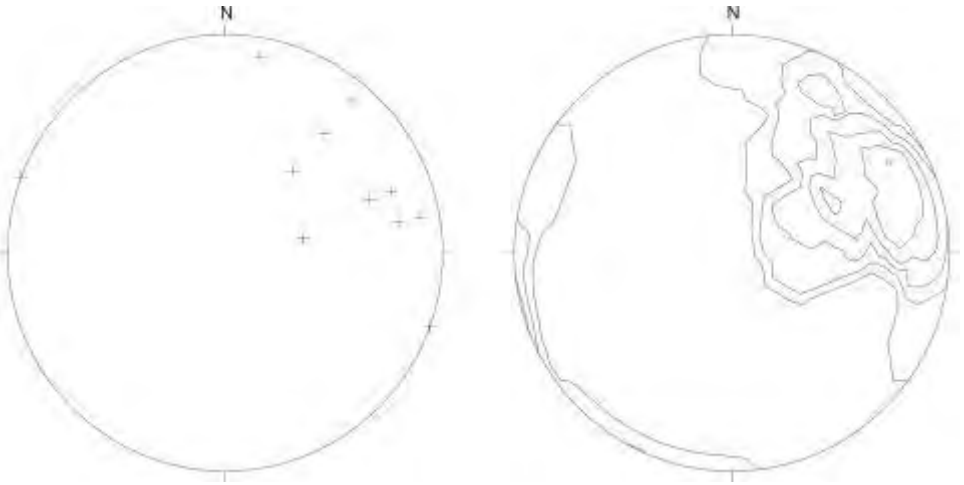


Above: Location sketch with trench site indicated in yellow.
Left: Survey site in detail. Gauss - Krueger coordinate system.


OVERBANK
macroform 3
macroform 1
200 – 400 YEARS
10.5 MILLION YEARS

Numerous fractures within the Miocene unit

- coincide with general orientation of the Libna fault (NNW – SSE)
- generally coincide with scour casts at erosional upper surface (fluvial erosion)
- striae (2º to 5º toward S) indicate strike slip kinematics
- do not propagate into the Holocene gravel
- no displacement of the Miocene / Holocene boundary **however**



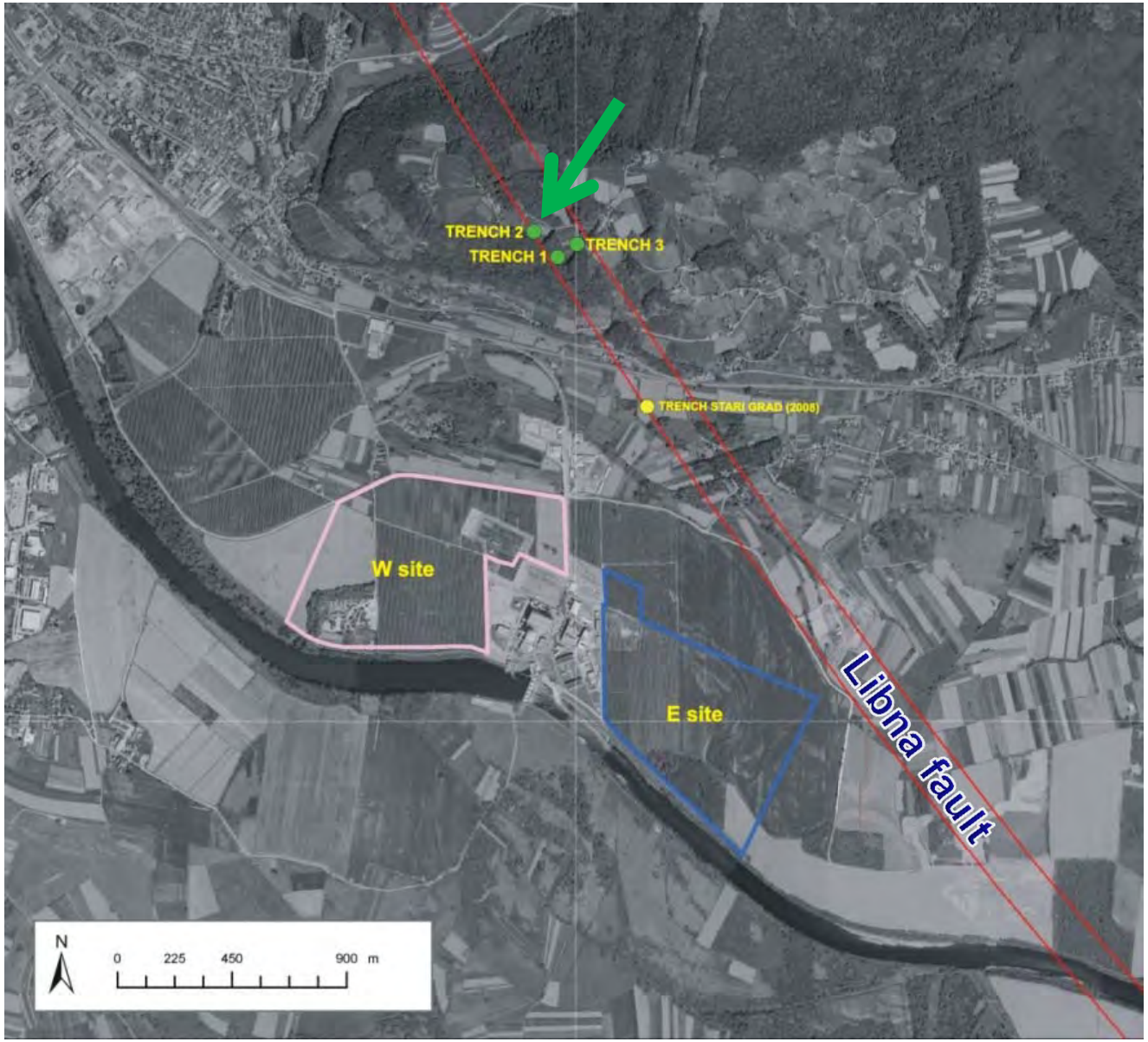
- **at the SW tip of the trench a step (up to 8 cm high) at the Miocene Upper layer was found that lies dierctly above a fracture**

- **step is diminishing toward the SE**

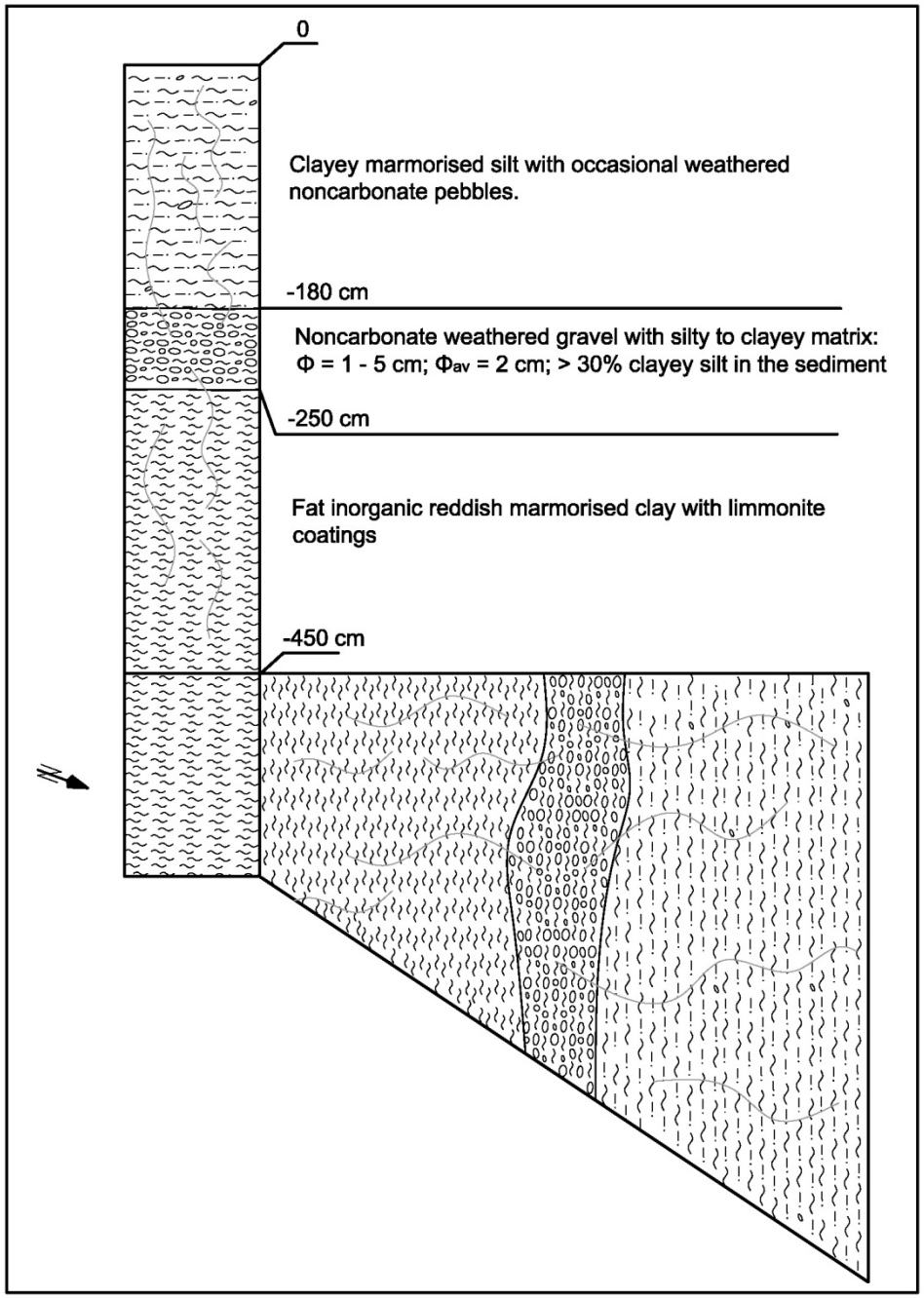
- **imprints are found that could be interpreted as pebble grooves**

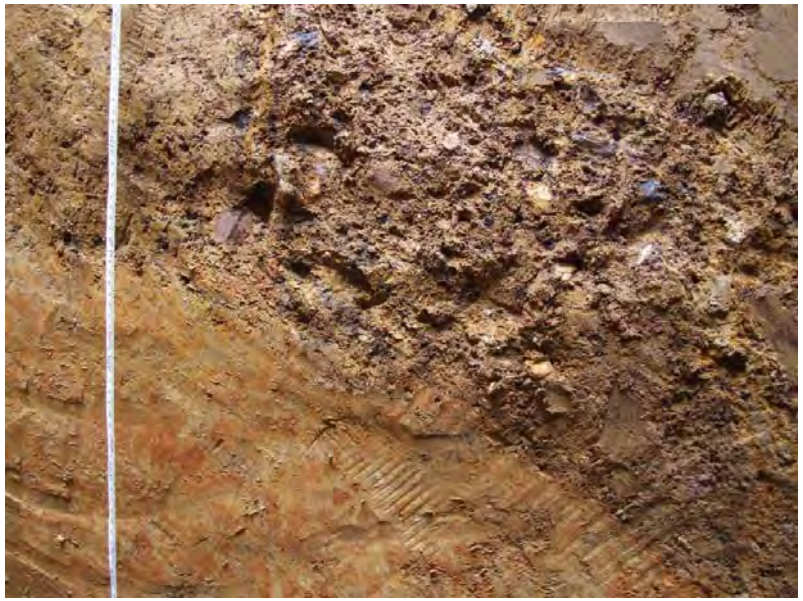
- **no evident displacement in overlying Holocene succession**

Libna Hill


TRENCH 2
TRENCH 1
TRENCH 3
TRENCH STARI GRAD (2008)
W site
E site
Libna fault
N
0
225
450
900 m

L-6-09


0
Clayey marmorised silt with occasional weathered noncarbonate pebbles.
-180 cm
Noncarbonate weathered gravel with silty to clayey matrix:
Φ = 1 - 5 cm; Φav = 2 cm; > 30% clayey silt in the sediment
-250 cm
Fat inorganic reddish marmorised clay with limmonite coatings
-450 cm



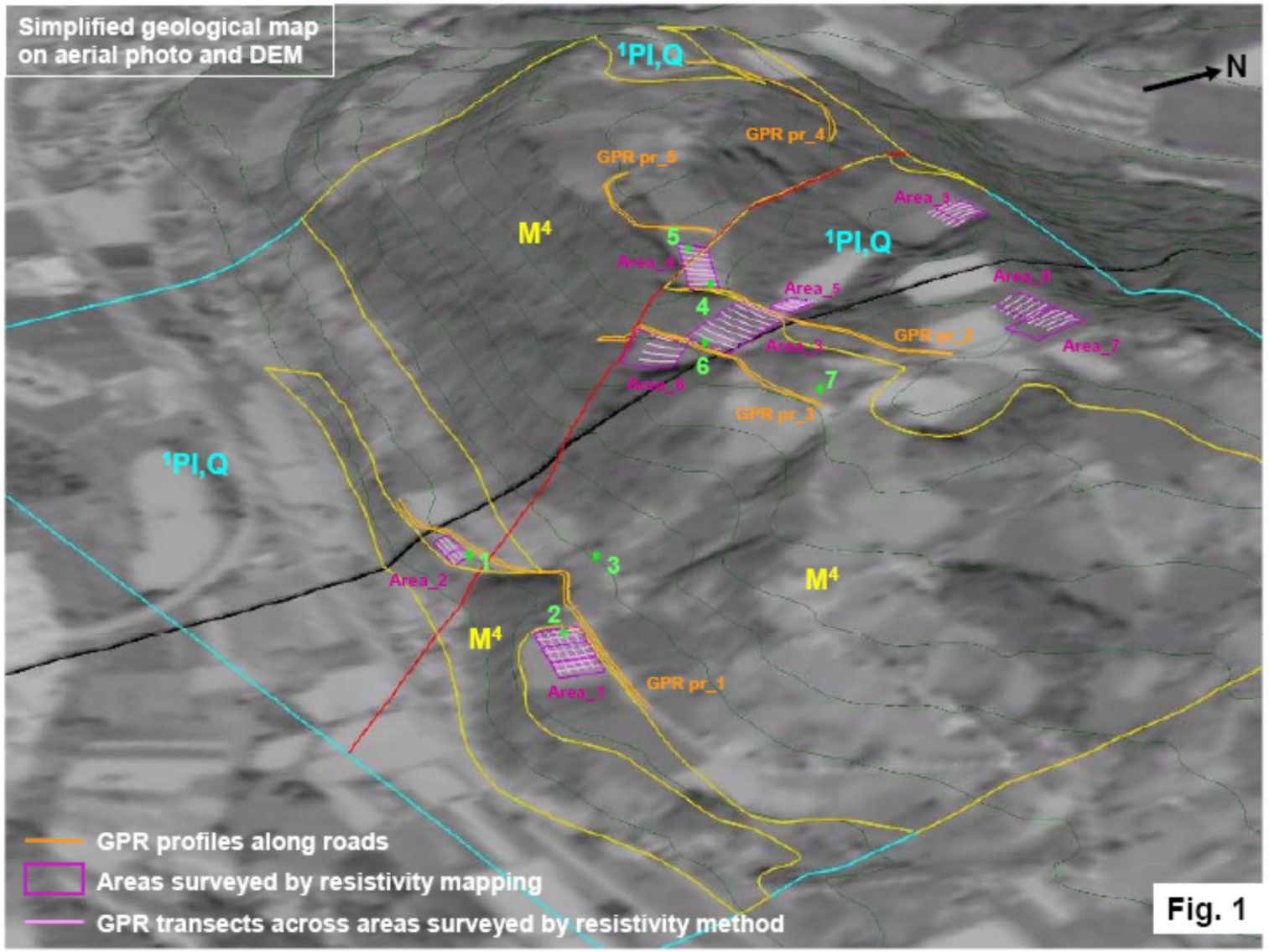
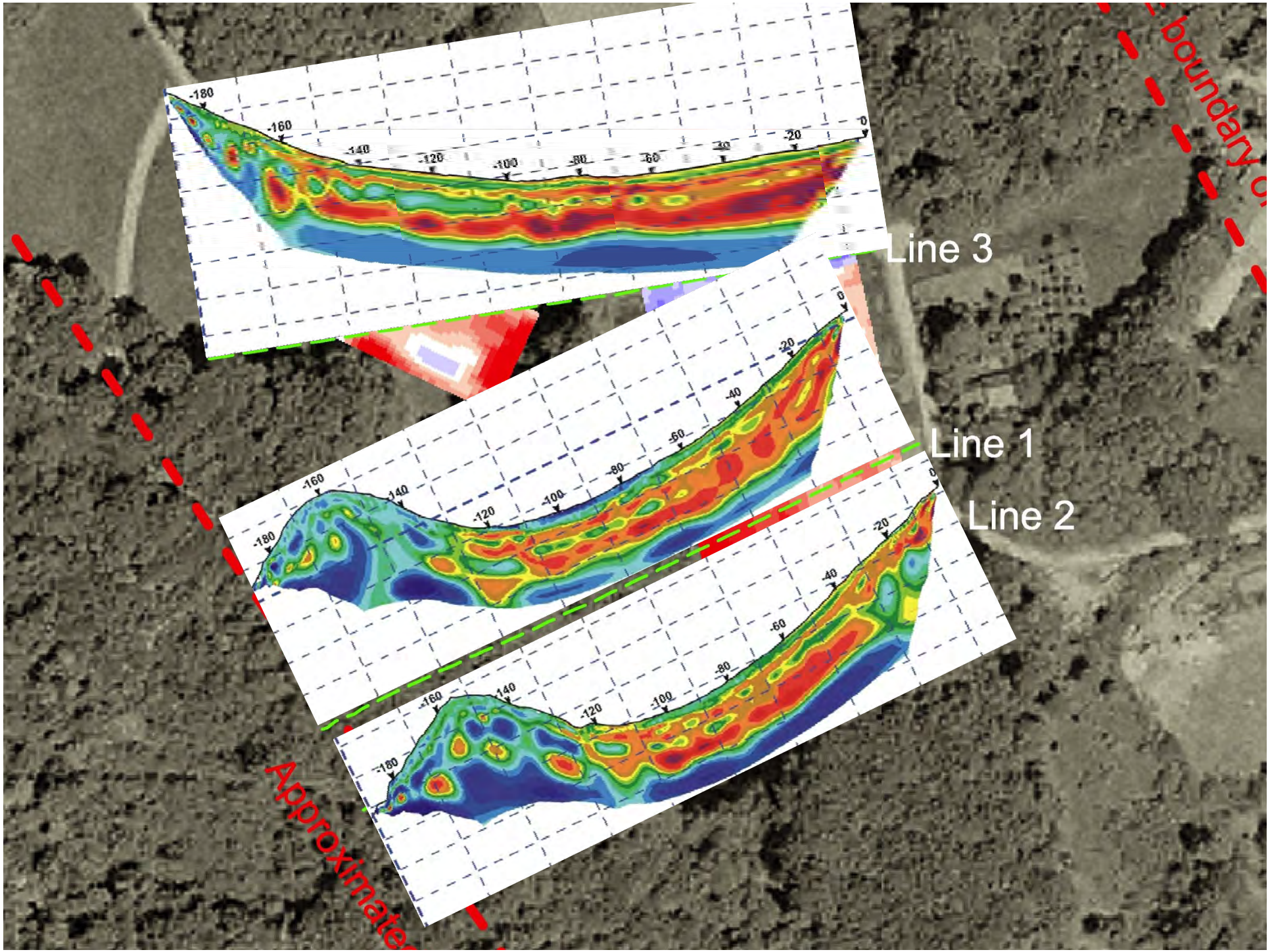

Simplified geological map on aerial photo and DEM
N
^{1}Pl,Q
GPR pr_4
GPR pr_5
Area_3
M^4
5
Area_4
^{1}Pl,Q
Area_5
Area_8
4
GPR pr_2
Area_7
Area_6
6
7
GPR pr_3
^{1}Pl,Q
1
Area_2
3
M^4
2
M^4
Area_1
GPR pr_1
GPR profiles along roads
Areas surveyed by resistivity mapping
GPR transects across areas surveyed by resistivity method

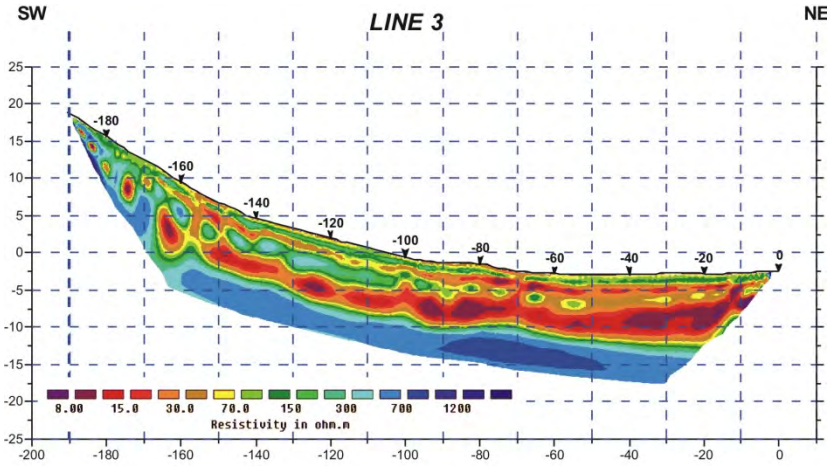
Fig. 1

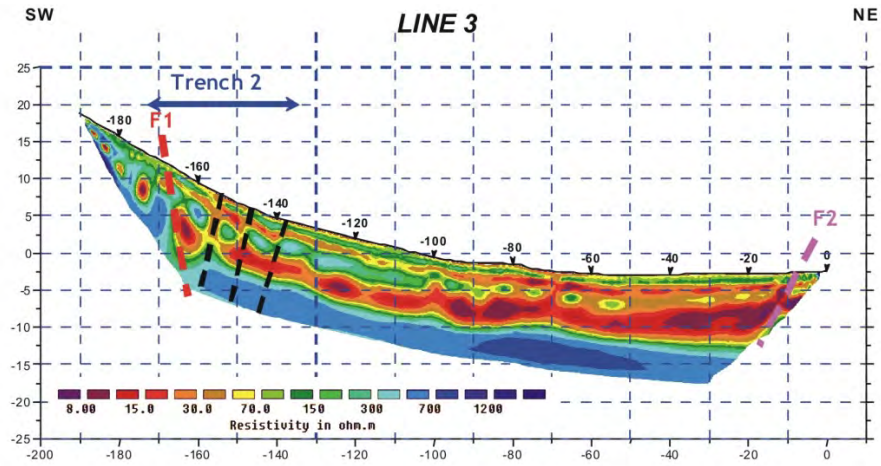
Northern part of the zone was selected for tomography because:

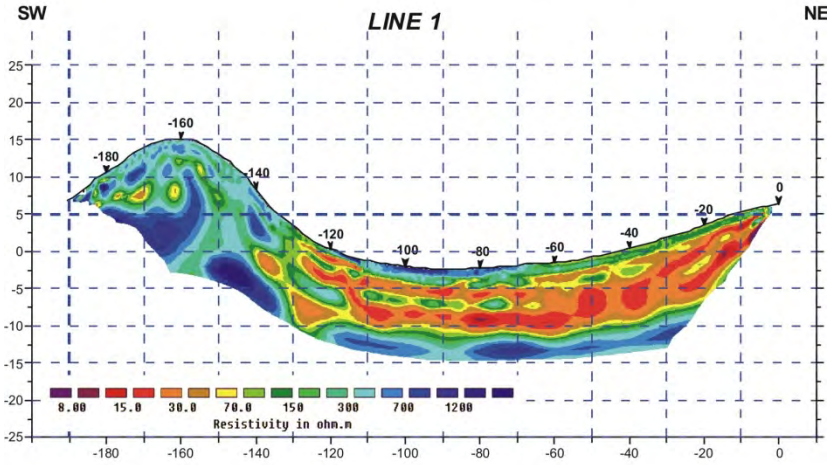
- more evident irregularities in sed. succession (resistivity and GPR)
- sediments appropriate for trenching (layering)
- relief and vegetation for potential trenching

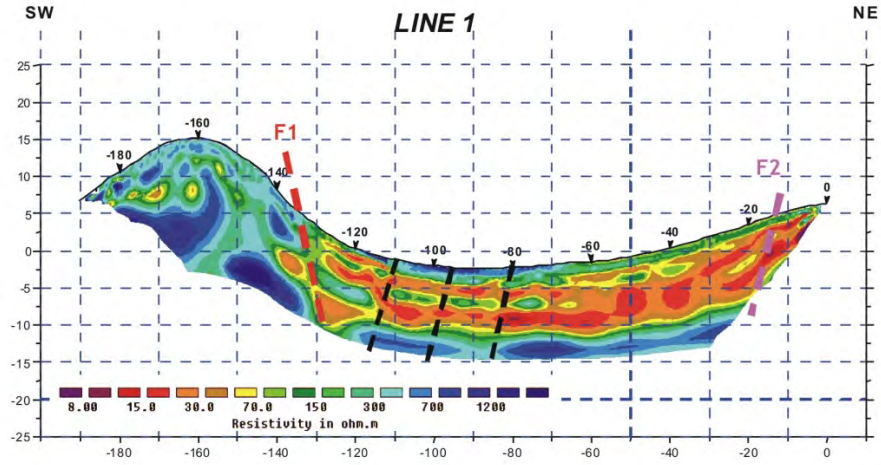

Approximated NE boundary of the Libna fault zone
Approximated SW boundary of the Libna fault zone
GPR Profile 2b
GPR Profile 2a
GPR Profile 4b
GPR Profile 4a
GPR Profile 3b
GPR Profile 3a

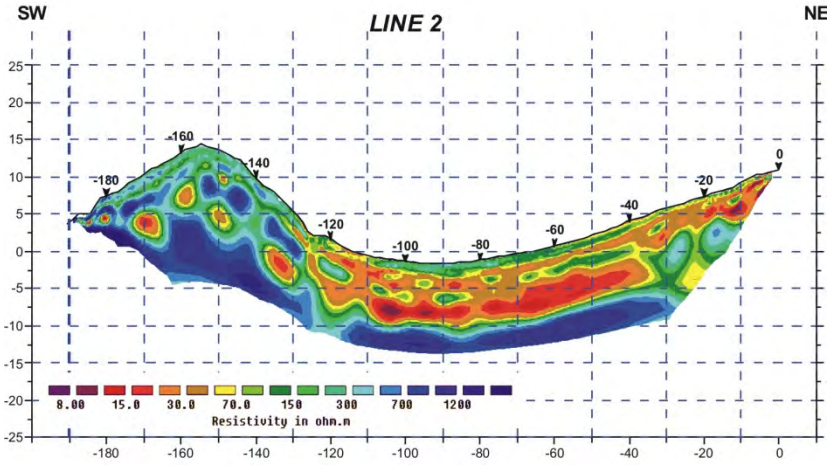

Line 3
Line 1
Line 2
Approximate
boundary

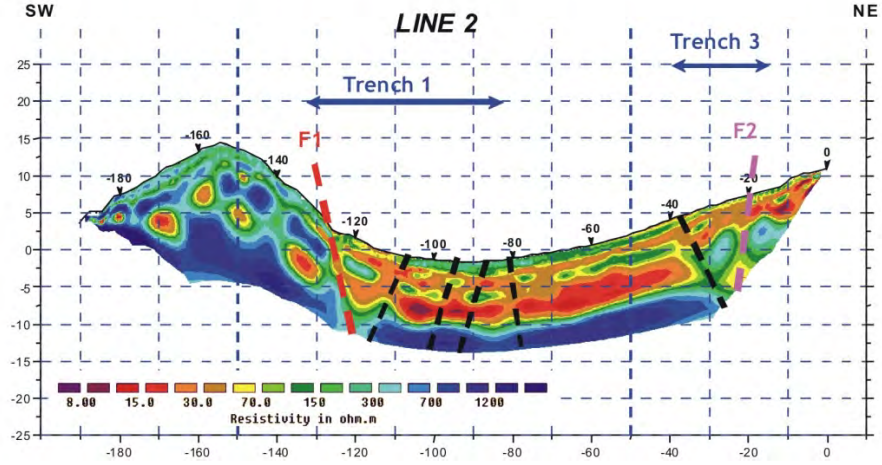

SW
LINE 3
NE
8.00 15.0 30.0 70.0 150 300 700 1200
Resistivity in ohm.m

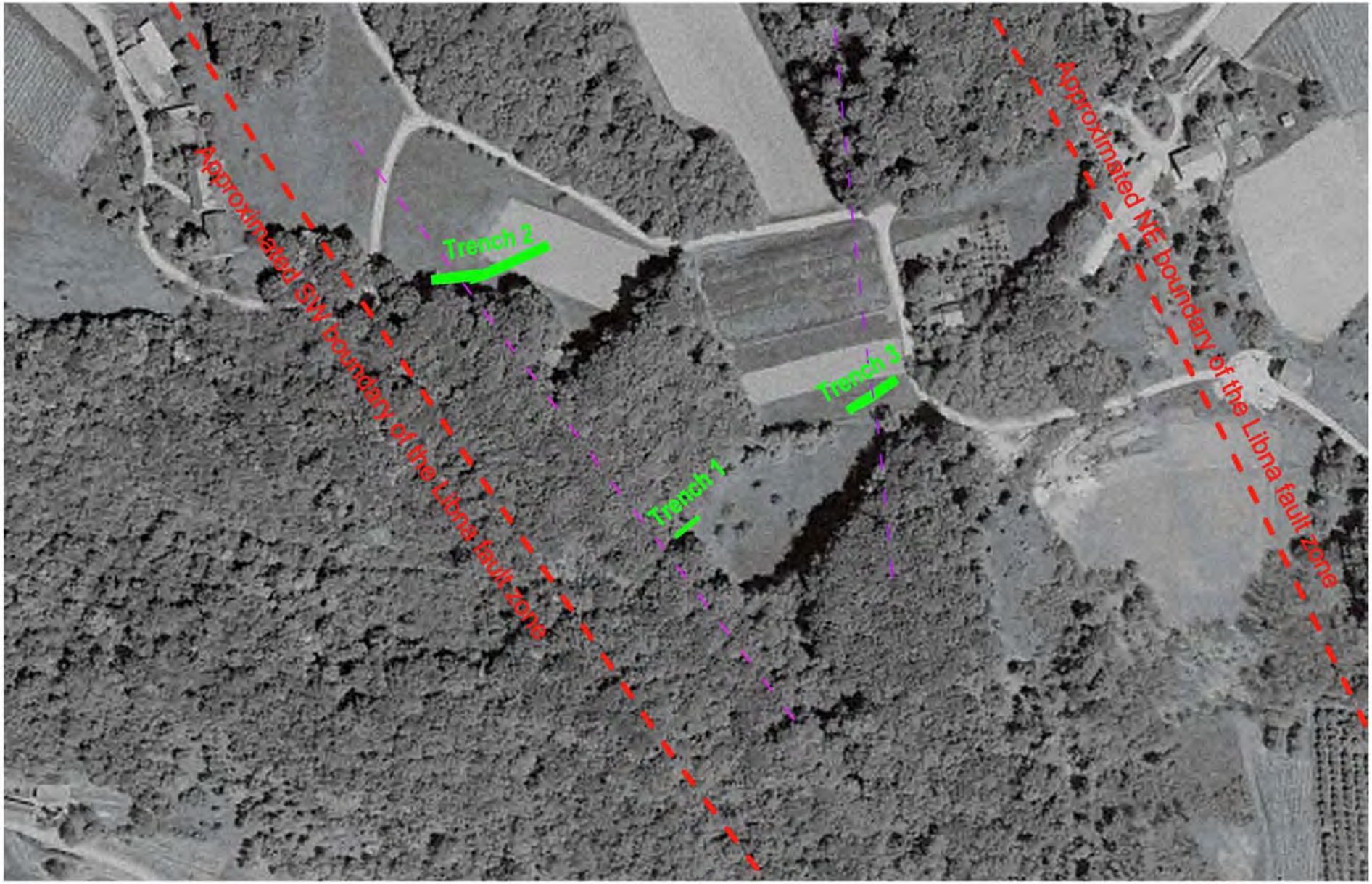

SW
LINE 3
NE
Trench 2
F1
F2
8.00 15.0 30.0 70.0 150 300 700 1200
Resistivity in ohm.m


SW
LINE 1
NE
8.00 15.0 30.0 70.0 150 300 700 1200
Resistivity in ohm.m


SW
LINE 1
NE
F1
F2
8.00 15.0 30.0 70.0 150 300 700 1200
Resistivity in ohm.m

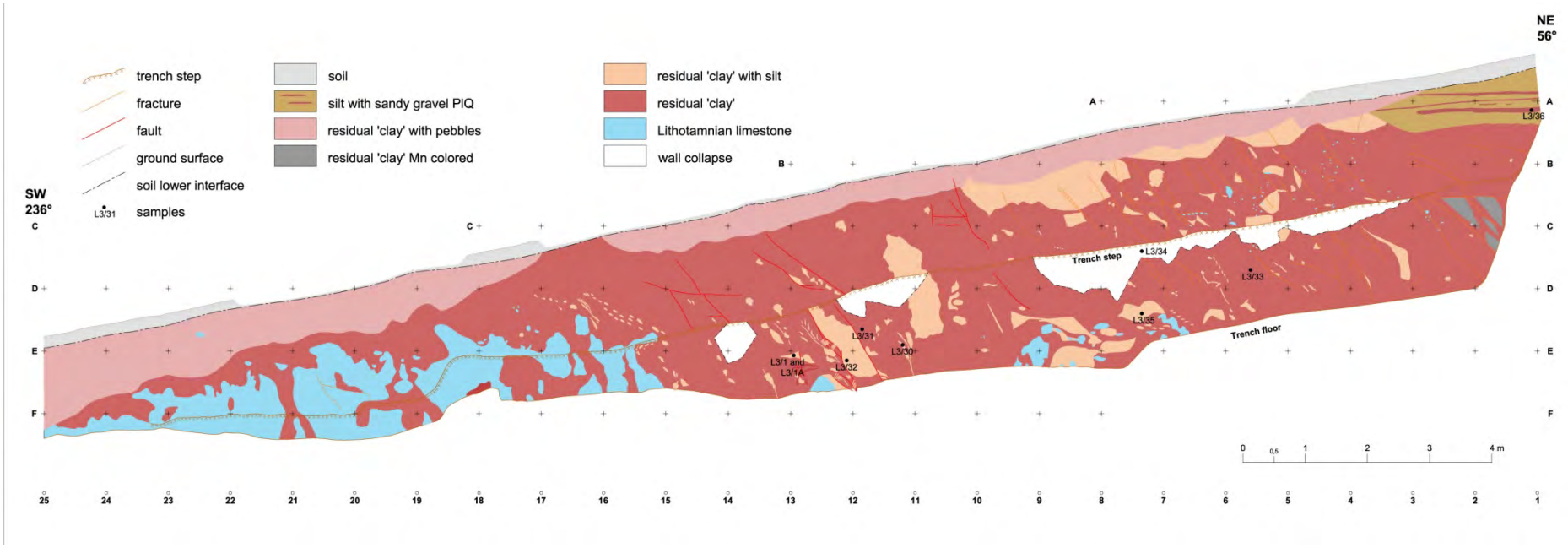

SW
LINE 2
NE
8.00 15.0 30.0 70.0 150 300 700 1200
Resistivity in ohm.m


SW
LINE 2
NE
Trench 1
Trench 3
F1
F2
8.00 15.0 30.0 70.0 150 300 700 1200
Resistivity in ohm.m

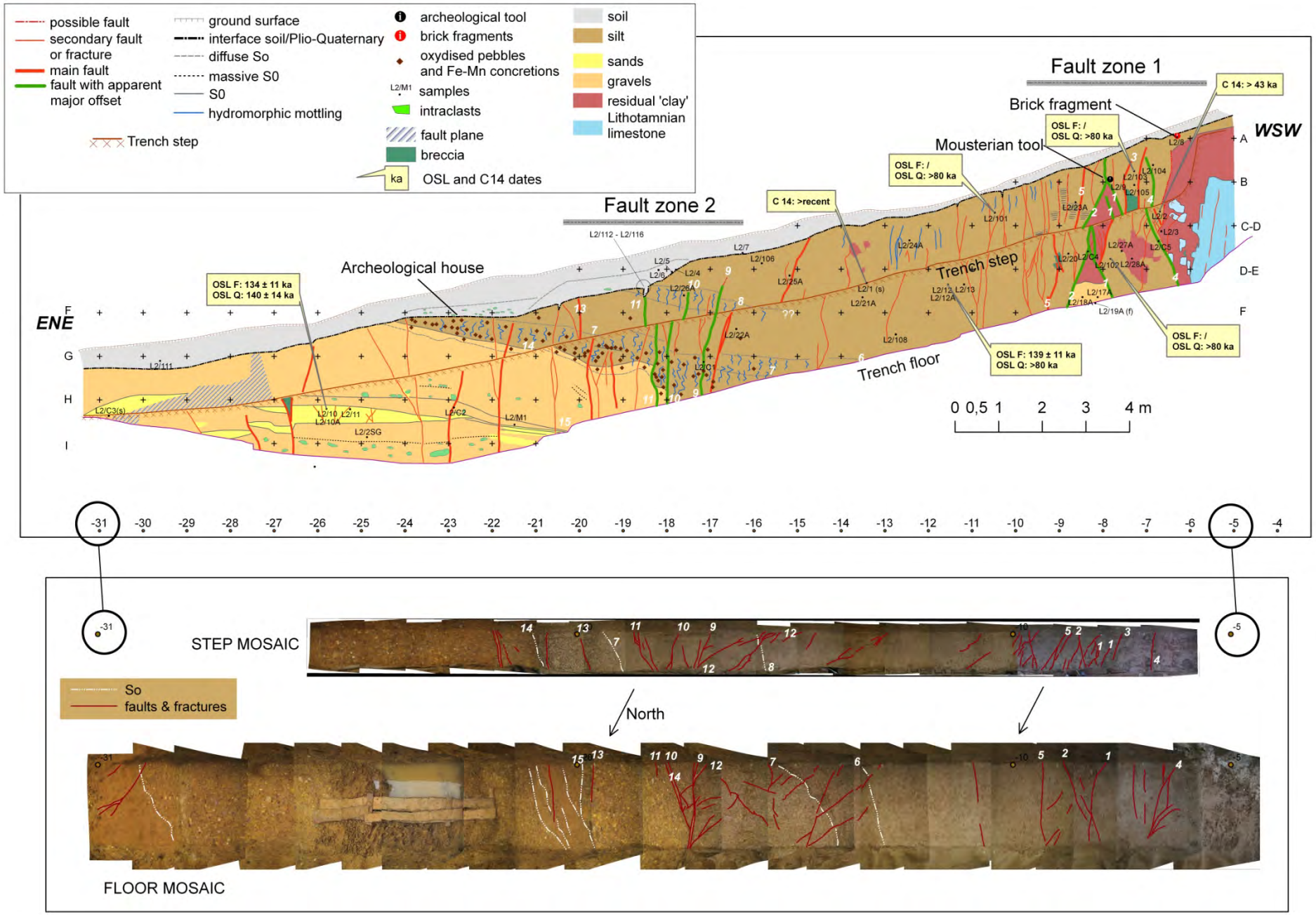

Approximated SW boundary of the Libna fault zone
Approximated NE boundary of the Libna fault zone
Trench 1
Trench 2
Trench 3

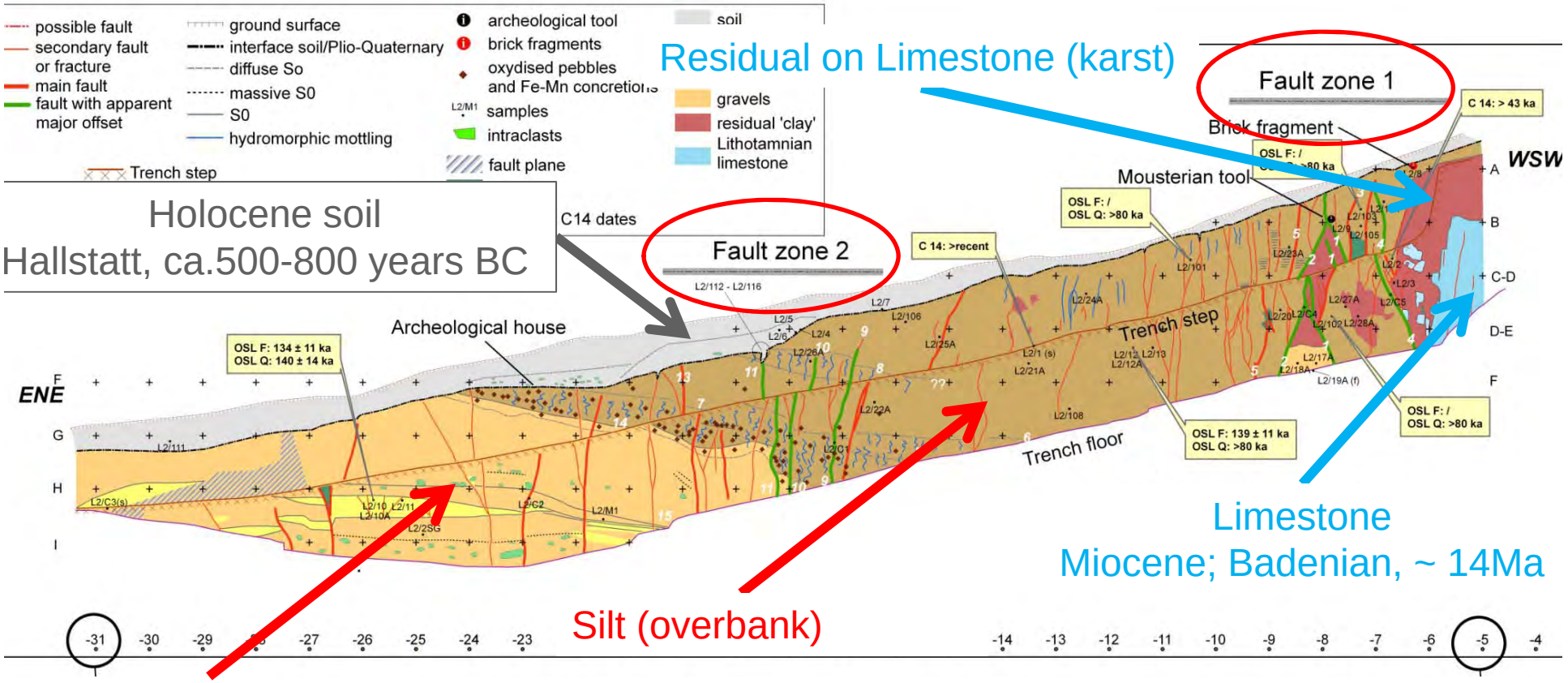
Trench 1

Trench 3

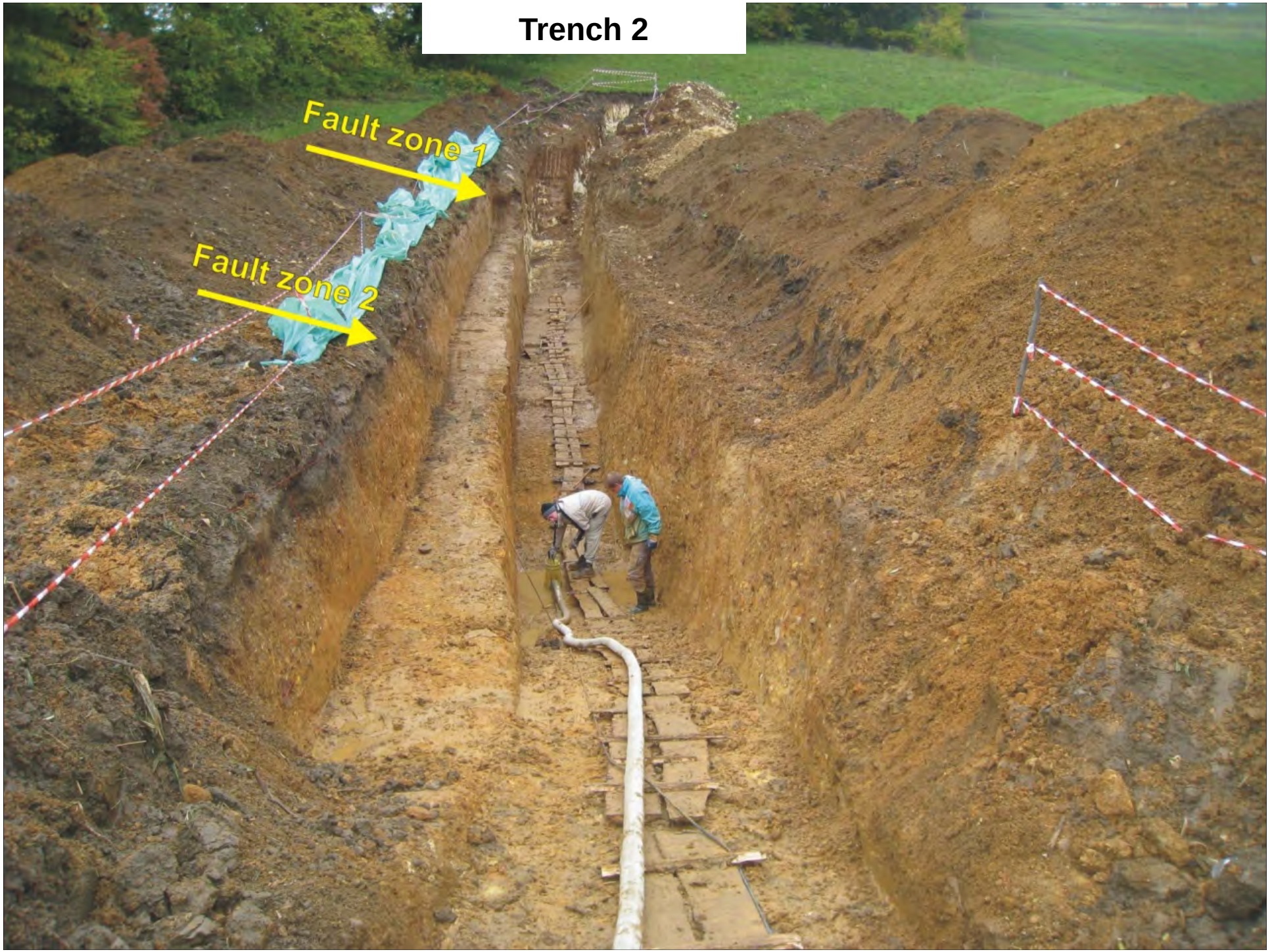

trench step
fracture
fault
ground surface
soil lower interface
samples
L3/31
soil
silt with sandy gravel PlQ
residual 'clay' with pebbles
residual 'clay' Mn colored
residual 'clay' with silt
residual 'clay'
Lithotamnian limestone
wall collapse
SW
236°
NE
56°
Trench step
Trench floor
L3/34
L3/33
L3/35
L3/36
L3/31
L3/30
L3/1 and
L3/1A
L3/32
0
0,5
1
2
3
4 m
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1

Trench 2


possible fault
secondary fault or fracture
main fault
fault with apparent major offset
Trench step
ground surface
interface soil/Plio-Quaternary
diffuse So
massive S0
S0
hydromorphic mottling
archeological tool
brick fragments
oxydised pebbles and Fe-Mn concretions
L2/M1 samples
intraclasts
fault plane
breccia
ka OSL and C14 dates
soil
silt
sands
gravels
residual 'clay'
Lithotamnian limestone
Fault zone 1
Fault zone 2
Brick fragment
Mousterian tool
Archeological house
Trench step
Trench floor
C 14: > 43 ka
C 14: >recent
OSL F: / OSL Q: >80 ka
OSL F: 134 ± 11 ka OSL Q: 140 ± 14 ka
OSL F: 139 ± 11 ka OSL Q: >80 ka
ENE
WSW
0 0,5 1 2 3 4 m
STEP MOSAIC
So
faults & fractures
North
FLOOR MOSAIC

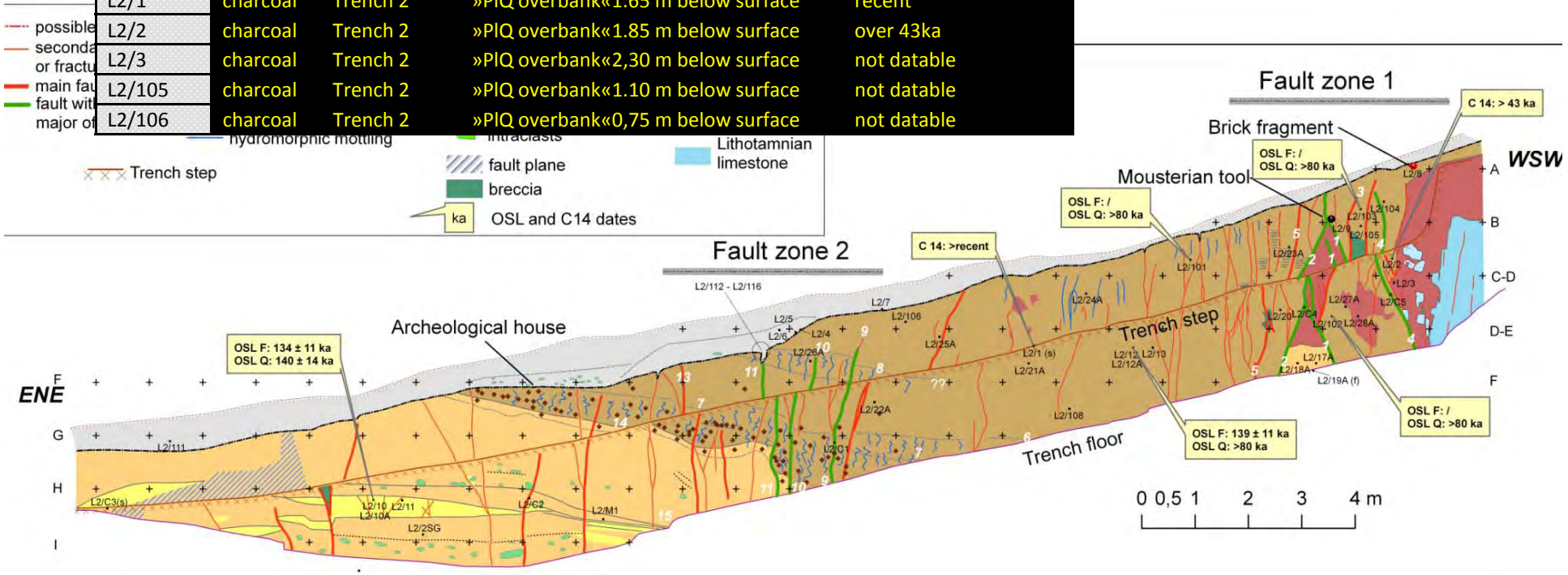

possible fault
secondary fault or fracture
main fault
fault with apparent major offset
Trench step
ground surface
interface soil/Plio-Quaternary
diffuse So
massive S0
S0
hydromorphic mottling
archeological tool
brick fragments
oxydised pebbles and Fe-Mn concretions
L2/M1 samples
intraclasts
fault plane
soil
gravels
residual 'clay'
Lithotamnian limestone
Holocene soil
Hallstatt, ca.500-800 years BC
C14 dates
Residual on Limestone (karst)
Fault zone 1
Fault zone 2
L2/112 - L2/116
Brick fragment
Mousterian tool
C 14: > 43 ka
C 14: >recent
OSL F: / OSL Q: >80 ka
OSL F: 134 ± 11 ka OSL Q: 140 ± 14 ka
OSL F: 139 ± 11 ka OSL Q: >80 ka
Archeological house
Trench step
Trench floor
ENE
WSW
Limestone
Miocene; Badenian, ~ 14Ma
Silt (overbank)
Gravel and sand
Globoko aloformation –
„ Plio-Quaternary “

Trench 2



Fault zones 1 and 2

Sample	material	site	location of sample	^{14}C age (ka b.p.)
L2/1	charcoal	Trench 2	»PlQ overbank«1.65 m below surface	recent
L2/2	charcoal	Trench 2	»PlQ overbank«1.85 m below surface	over 43ka
L2/3	charcoal	Trench 2	»PlQ overbank«2,30 m below surface	not datable
L2/105	charcoal	Trench 2	»PlQ overbank«1.10 m below surface	not datable
L2/106	charcoal	Trench 2	»PlQ overbank«0,75 m below surface	not datable



Sample	material	site	location of sample	OSL age (ka b.p.)	
				Quartz	Feldspar
L2/10	sand	Trench 2	PlQ sand layer; 2 m below surface	140 ± 14	134 ± 11
L2/12	silt	Trench 2	»PlQ overbank«; 1,7 m below surface	> 80	139 ± 11
L2/101	silt	Trench 2	»PlQ overbank«; 60 cm below surface	> 80	--
L2/102	silt	Trench 2	»PlQ overbank«; 2,7 m below surface	> 80	--
L2/103	silt	Trench 2	»PlQ overbank«; 70 cm below surface	> 80	--

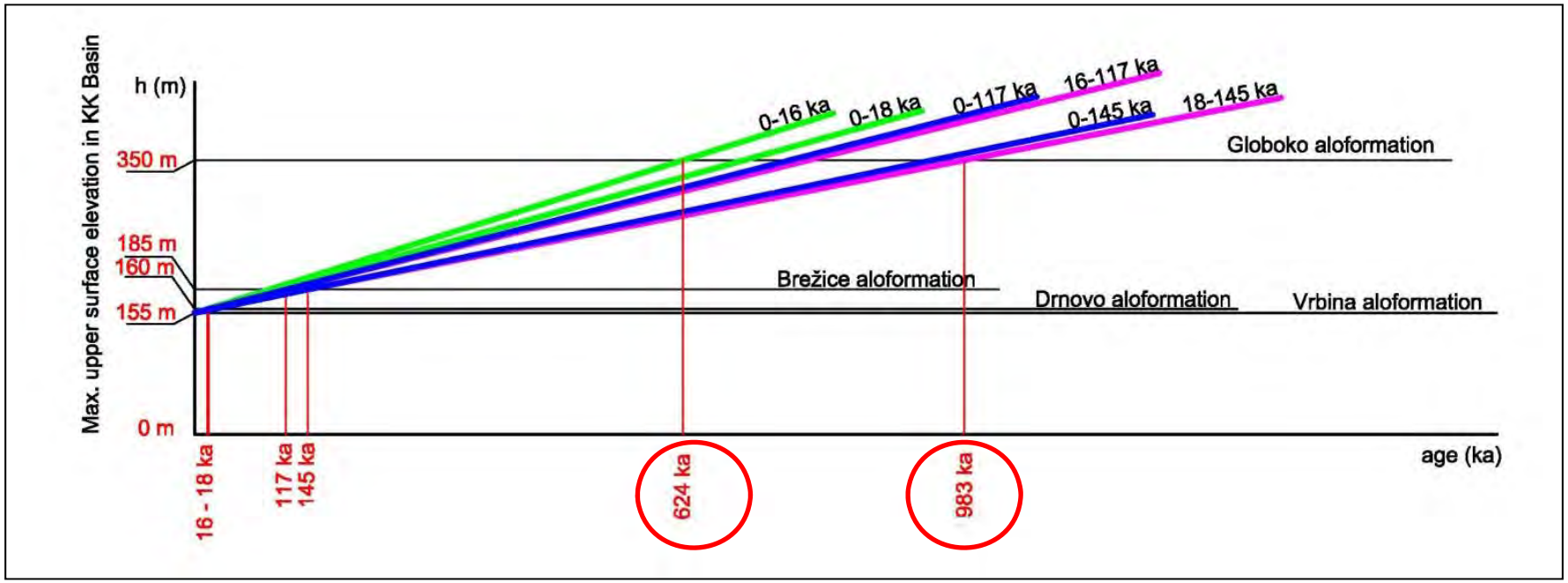
Sample	material	site	location of sample	ESR age (ka b.p.)
G 4-2	silty sand	Globoko pit	»PlQ overbank«11 m below surface	190 ± 28
ES 1-3	sand	ES-1 borehole	»PlQ overbank«1.85 m below surface	204 ± 31
G 11	silty sand	Globoko pit	»PlQ overbank«5 m below surface	540 ± 81 *
G 8-2	sand	Globoko pit	»PlQ sand«7 m below surface	211 ± 32

ESR and OSL dates showing that the age of the deformed sediments is between 130 ka and 230 ka. Wrong?

Published and "published" alternatives:

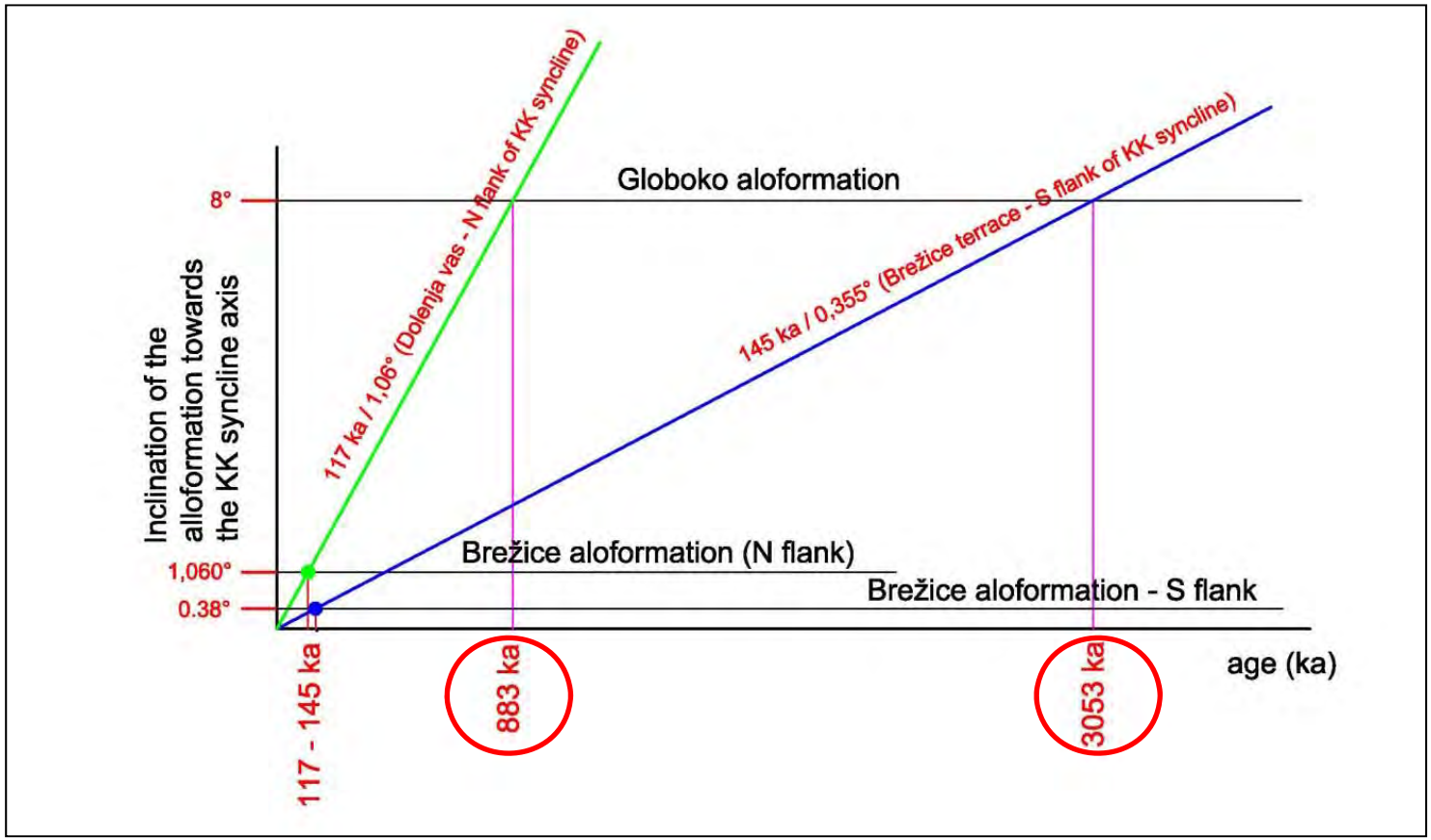
- *Estimated by previous authors expert estimates to 1 – 2 Ma*
- *Bracketed by footwall (Upper Pannonian; 5.5* Ma b.p.) and the oldest overlying fluvial aloformation (dated by OSL at 117 and 145 ka)
- Synchronous with the "Upper Paludina Beds" (more than 2 Ma)
- Estimated in Globoko at more than 300 ka (OSL, year 2003)

ESR and OSL dates showing that the age of the deformed sediments is between 130 ka and 230 ka. Wrong?



Age estimation of the Globoko aloformation (Pl,Q gravel) based on extrapolation of the max. elevation of the Q and Pl,Q gravels. Input age dates are a rough estimate of various absolute age dates as approximated by Verbič (2004

ESR and OSL dates showing that the age of the deformed sediments is between 130 ka and 230 ka. Wrong?



Age estimation of the Pl,Q based on extrapolation of the max. inclination of the Q and Pl,Q gravels

conclusions

LIBNA FAULT AS A CAPABLE FAULT

*Recent findings in the trench #2 at the Libna Hill indicate that the Libna fault **may be also described** as capable because:*

- *The geologic buildup of the Libna hill is affected by strike-slip faulting, including deformation of the Globoko PlQ gravels and the overlying silts. Deformation is significant.*

- *Alternative interpretations (slope mass wasting, karstic collapse) **can not be ruled out***

- *The trench survey revealed a structural pattern in PlQ sediments (multiple fault traces close to the surface, complex branching pattern leading to an anastomosing geometry) that **may be** indicative of coseismic and recurrent displacements.*

- According to IAEA and NRC guidelines and according to the Consortium decision about the appropriate period for defining capability, the age of deformed sediments **(if absolute ages are taken as relevant)** is sufficient to state that Libna fault is capable.

The potential deformation is concentrated mostly to differential folding along the Libna anticline and most deformation should be taken up there (on the Libna anticline).

LIBNA FAULT AS A SECONDARY STRUCTURE, ACTIVATED BY A NEARBY SEISMIC SOURCE ?

- *Can not be conclusively excluded*

- *No known direct relationship with Orlica or Artiče faults.*

LIBNA FAULT AS A SOURCE IN SEISMIC MOTION CALCULATION?

- *Faults of such geometry are already included into the background seismicity zone of 2004 PSHA*

- *Length of up to 5 km is completely consistent with the available data,*

- *The highly speculative (and structurally nearly impossible) option with a 10 km long fault (continuation into the Gorjanci mts.) is being further investigated by additional geophysics*

Mousterien - historic deformation?

Infiltration of the Late Holocene (500 – 800 years b.c.) soil into the underying silt. Tectonic? Coseismic?

Alternative interpretations:

•Opening of cracks due to mass movement (the modern surface is inclined at about 10°)

•Desiccation is the controlling process.

•Bioturbation (??)

Mousterien artifact (silex tool, either 300.000 to 20.000 years b.c. or 2.500 b.c.) **infiltrated down into the faulted Plioquaternatry silt. Tectonic? Coseismic?**

Alternative interpretations:

- the human activity that produced the silex artefact is isochronous with the silt (either this formation is colluvial or fluvial)
- bioturbation may be the cause of a deep infiltration
- infiltration into desiccation or slope movement-related cracks,
- artifact was dragged down from surface by excavator during trenching.


Modern dessication cracks (after 1 month drought)

Modern dessication cracks

(after 1 month drought)

GeoZS response to the IRSN Letter

IRSN states that the Consortium agrees on the capability of the Libna fault. Given the Report, this statement is not concise and should be placed into its appropriate context, as we state in the Report the following ***(Quote)***:

Libna fault is not an important structural element *of the Krško basin. Moreover, from its geomorphic expression and its mapped length, it seems unlikely that it is a fault that is capable of generating earthquakes large enough to produce surface fault rupture.*

However, recent findings in the trench #2 at the Libna Hill indicate that the Libna fault ***may be described as capable if*** *capability is defined in line with Safety guide SSG-9 (IAEA, 2010; where capability is not necessarily related to earthquakes on the fault of concern) and if the lower age-estimates of Pl,Q formation are taken as relevant.*
Results were ***not conclusive*** *regarding two topics:*

- *The data does not allow distinguishing between the two alternative interpretations of the observed features in the trenches: the aseismic and the coseismic one.*
- *Comparison of various age dates of the Plio-Quaternary sediments in the area gives inconsistent results, which sheds doubts about the age of displacement along the Libna fault.*

GeoZS response to the IRSN Letter

According to the current tectonic model, the potential displacement is not distributed evenly along the whole length of the Libna fault. It is concentrated mostly to differential folding along the Libna anticline and most deformation should be taken up there (on the Libna anticline).

Base on these ambiguities we (the Consortium) conclude regarding the capability of the Libna fault in section 4.4. of the Report as follows **(*Quote):***

- *The Libna fault may also be described as a capable fault and additional data and/or analysis are required because some important issues for the assessment of the potential impacts of the fault are still open.*

Moreover, to address the many ambiguities left unanswered, In the report, we proposed that the Client addresses these ambiguities with a series of new investigations such as:

- *Investigating nature and amount of displacement*
- *Re-addressing the location and geometry of fault along with the details of the spatial pattern of the fault zone including its length*
- *Determining age of sediments. An extensive and multi-method campaign of datings is required to conclude as there is no known single absolute dating method that would guarantee reliable age dating of the deformed sediments in trench on Libna and consequently the age of deformation.*

GeoZS response to the IRSN Letter

Thus, it is opinion of GeoZS that the current state of knowledge on the issue of the Libna fault:

- does not meet the criteria to unequivocaly define it as a capable fault (given the IAEA SSG-9)