

Characterization of the Libna Fault and Tectonic Activity in the Krško Basin

Project Overview and Status

26 April 2013

Engineering & Construction Management
Hydro-Nuclear-Fossil
Geotechnical Engineering
Seismic & Structural Engineering
Hydrological & Hydraulic Engineering
Tunnel Engineering
Environmental Engineering & Permitting

Background

- Alternative interpretations exist for the displacement in Libna Hill Trench
 - Incipient karst and sinkhole development
 - Mass wasting and fluvial processes
- Amount and age of offset observed in trench is questionable
- Position based on
 - 70+ years combined experience in paleoseismicity
 - Ongoing geomorphological investigations
 - Ongoing HRS investigations

Background

- Not professionally responsible to base conclusions on one trench
- Investigators must consider
 - Geologic and tectonic processes
 - Other explanations/interpretations
 - Other investigation techniques
- Additional field investigations are underway
- All work performed under the RIZZO Quality Assurance Program (NRC NQA-1)

Objectives – Field Investigations

- Specific investigations:
 - Characterize the Libna Fault
 - Evidence for Plio-Quaternary displacement
 - Fault length
 - Assess presence and activity of other nearby faults
 - Assess level and character of tectonic activity within the Krško Basin
- Activities commenced in October 2012
- Final Report is scheduled for September 2013

Scope of Work – 3 Major Tasks

- **Tectonic geomorphology:** Analyze surface processes and features to identify Plio-Quaternary tectonic deformation
- **High resolution seismic survey:** Identify and locate the presence and extension of the Libna and Stara Vas features
- **Geochronology:** Utilize various dating methods to constrain the age of Plio-Quaternary stratigraphic units and most recent fault displacement

Tectonic Geomorphology Investigations

- Use existing Light Detection and Ranging (LiDAR) data and apply multiple processing techniques
- LiDAR data processed to produce 5m & 1m digital elevation models (DEMs)
- DEM resolution is excellent for techniques such as:
 - Hill shading to enhance linear surface features (lineaments)
 - Slope gradient enhancement
 - Slope Aspect (slope direction) enhancement
 - Surface roughness anomalies
 - Surface curvature anomalies

High Resolution Seismic Survey

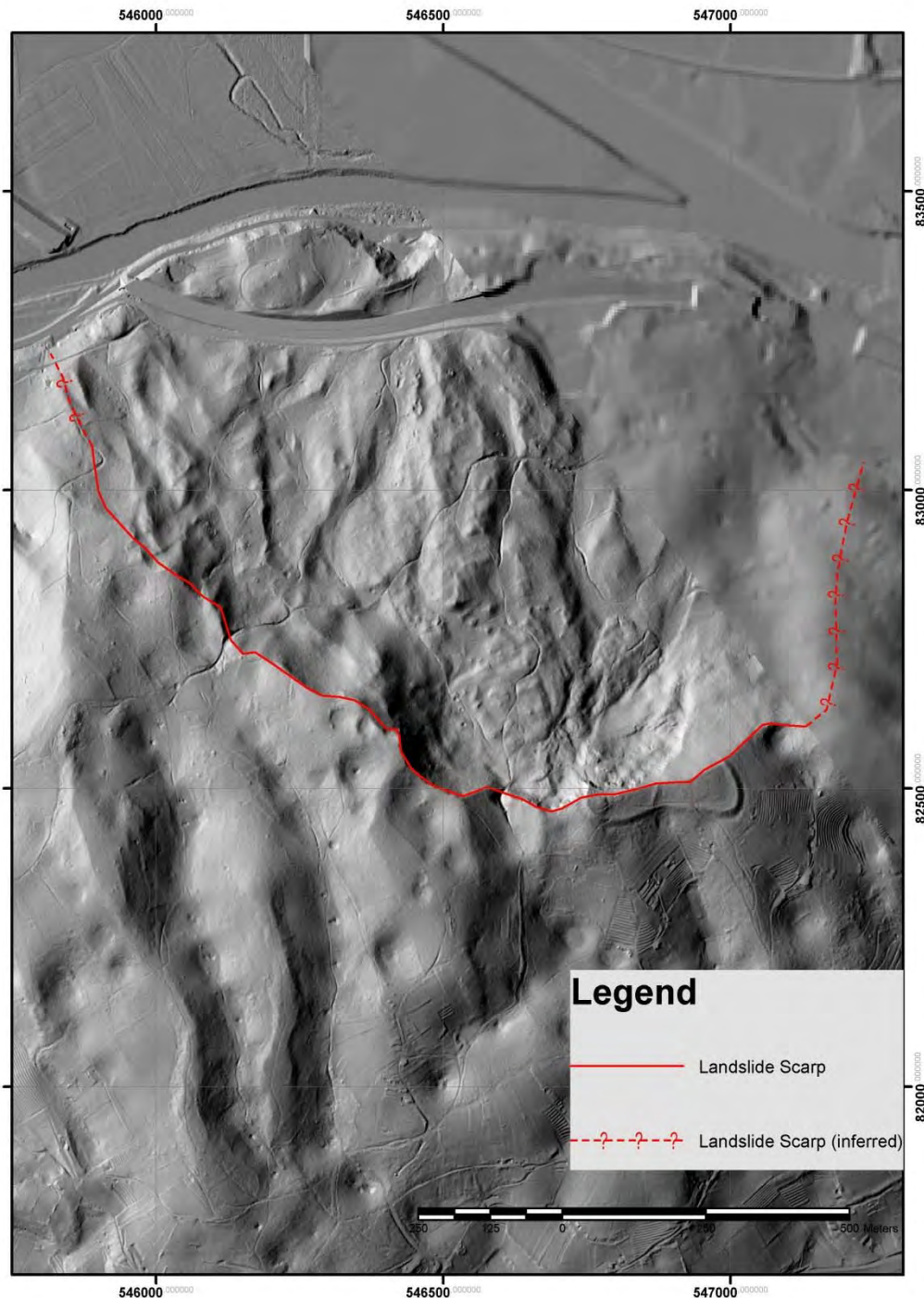
- Conducted 17.25 km of seismic reflection surveys
 - Surveys conducted by GeoExpert
 - Post processing performed by Sterling Seismic
 - Interpretation being performed by Geological Associates with input from GeoZS and RIZZO
- HRS data were dominated by environmental noise limiting signal/noise in post processing
- Interpretations identified inferred and possible faults in the Miocene within the Krško Basin
- Interpretations are continuing

Age Dating

- Samples for geochronology collected during field investigations
- Geochronology techniques:
 - Optical Stimulated Luminescence (OSL)
 - Cosmogenic Radionuclide (CRN)
 - Uranium-Thorium (GeoZS)
- Samples submitted to
 - University of Bern OSL laboratory
 - Prime (Purdue University) Laboratory for CRN

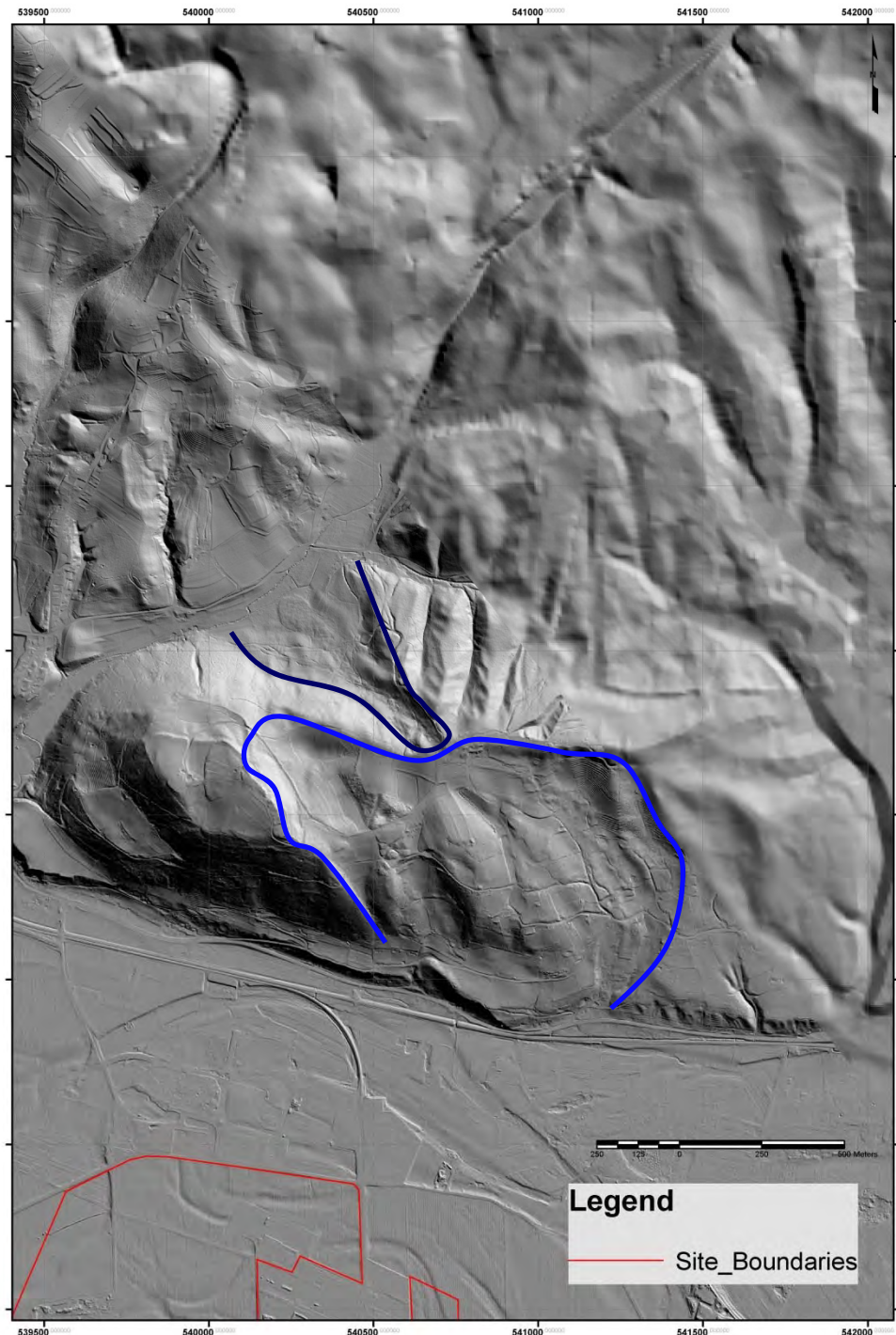
Early Findings

- Processing of LiDAR strips away all vegetation
- DEM of Krsko Basin
 - Bedrock surface dominated by landsliding and karst
 - Allowed for immediate recognition of the landslide at Catez, Krka and Sava Rivers
 - Immediate confirmation of geologic mapping

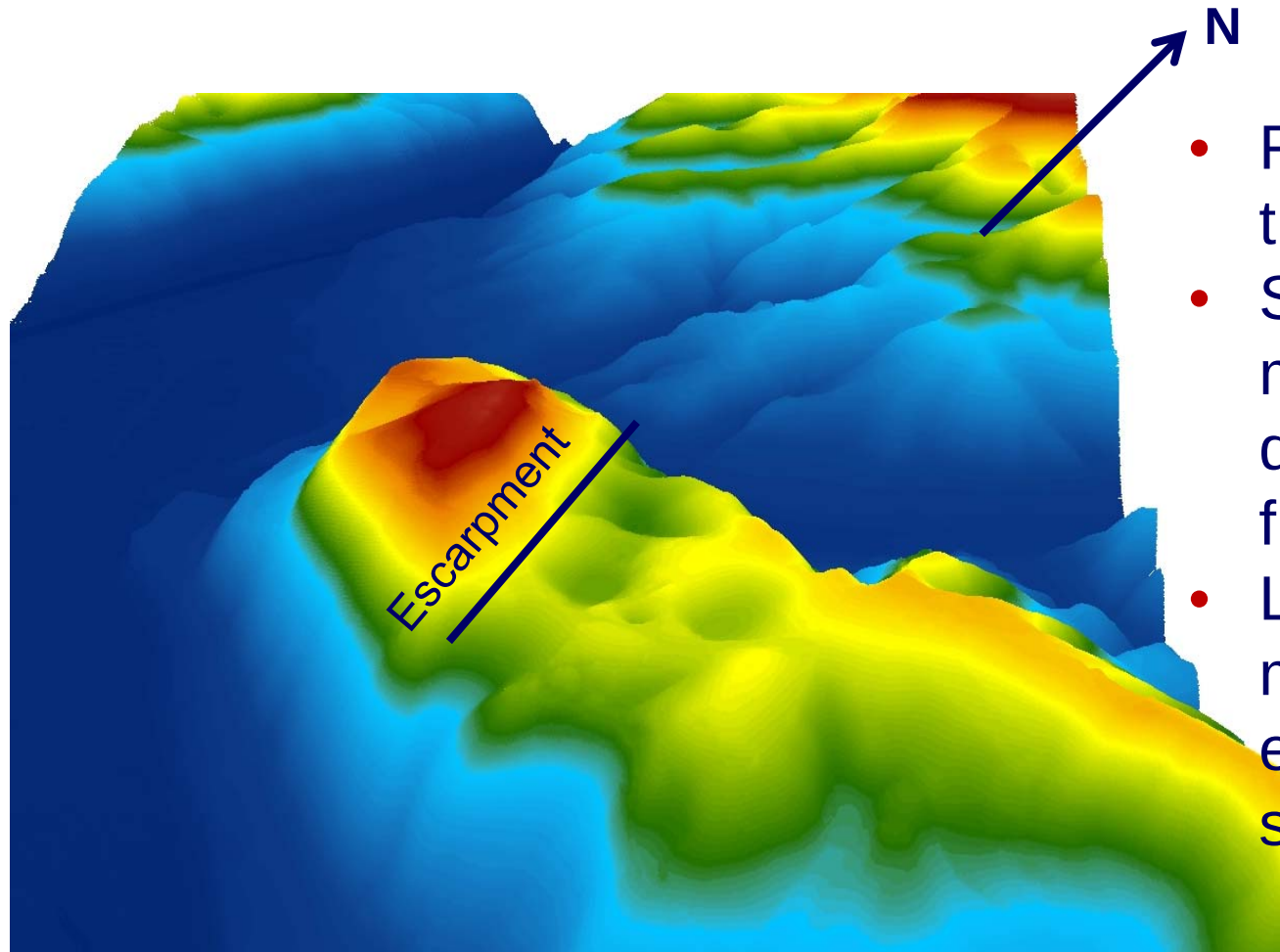


Early Findings

- Two large landslides are present on Libna Hill
- Landslide on south slope of Libna Hill has prominent E facing head scarp coincidental with trace of Libna Fault
- Landsliding exaggerates the apparent offset of the Libna Fault.
- No geomorphic evidence of the fault trace north of the landslide



Early Findings

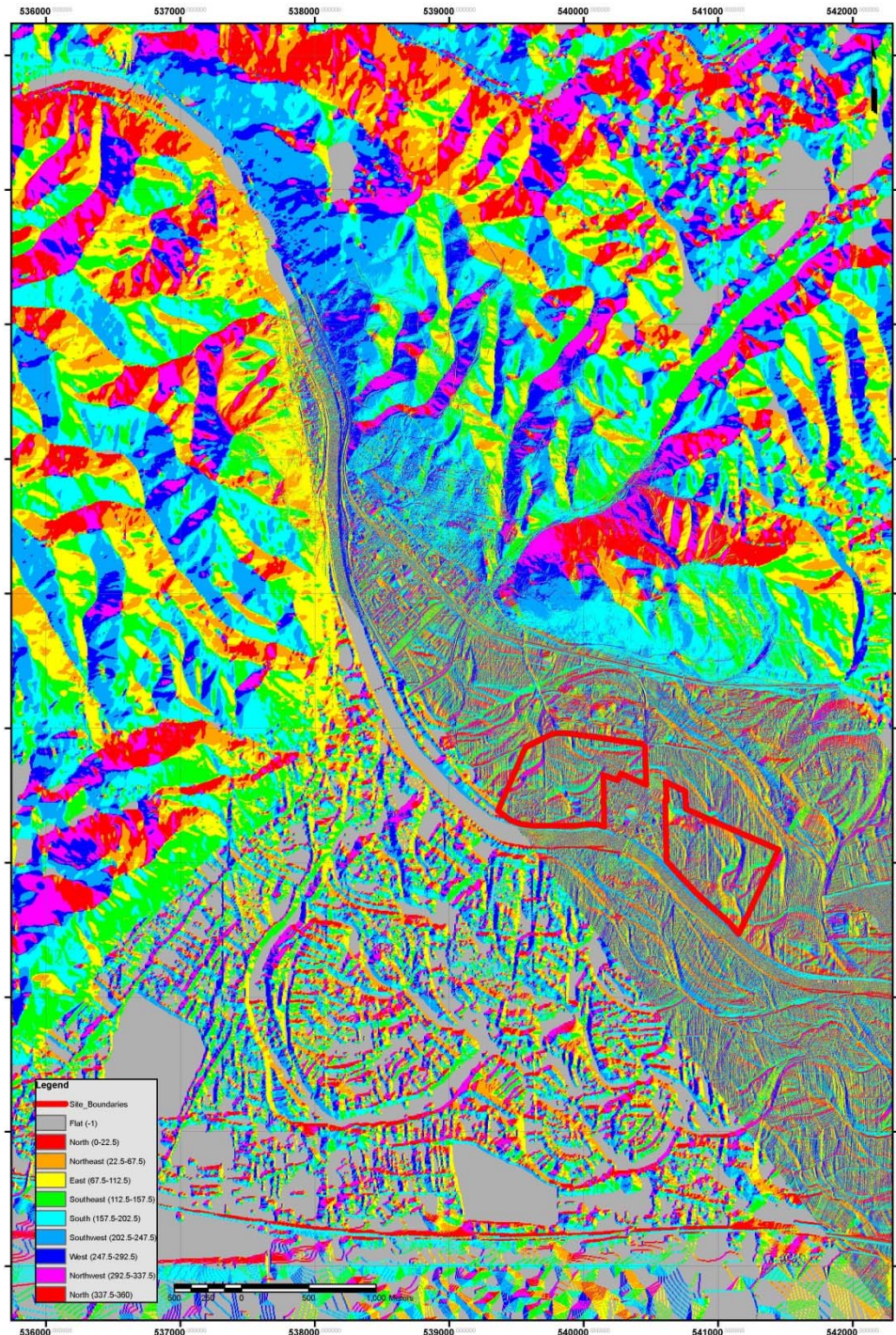


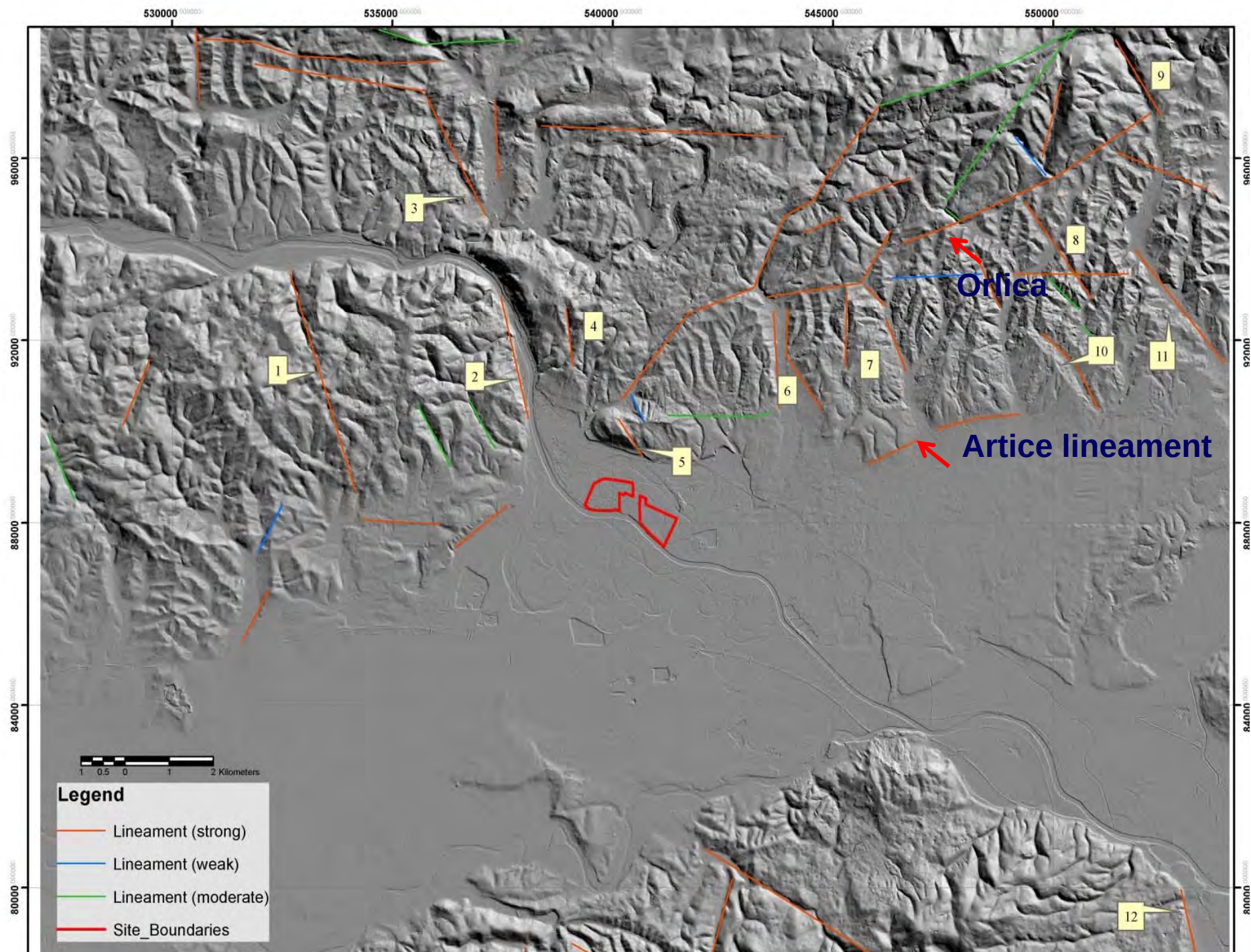
- Four sinkholes along trace of fault
- Southern sinkhole may be breached due to landsliding & fluvial processes
- Libna Hill Trench may have been excavated within southern sinkhole

Early Findings

- Orlica Fault Zone
 - Slope aspect shows dominant geomorphic expression
 - Evidence for a linear continuation of the Orlica Fault Zone, SW of the Sava River.
- Sava River
 - Unknown erosion/denudation rates relative to tectonic activity
 - Erosion rates: 0.1 – 1.4 mm/yr with peaks of 10 -60 mm/yr

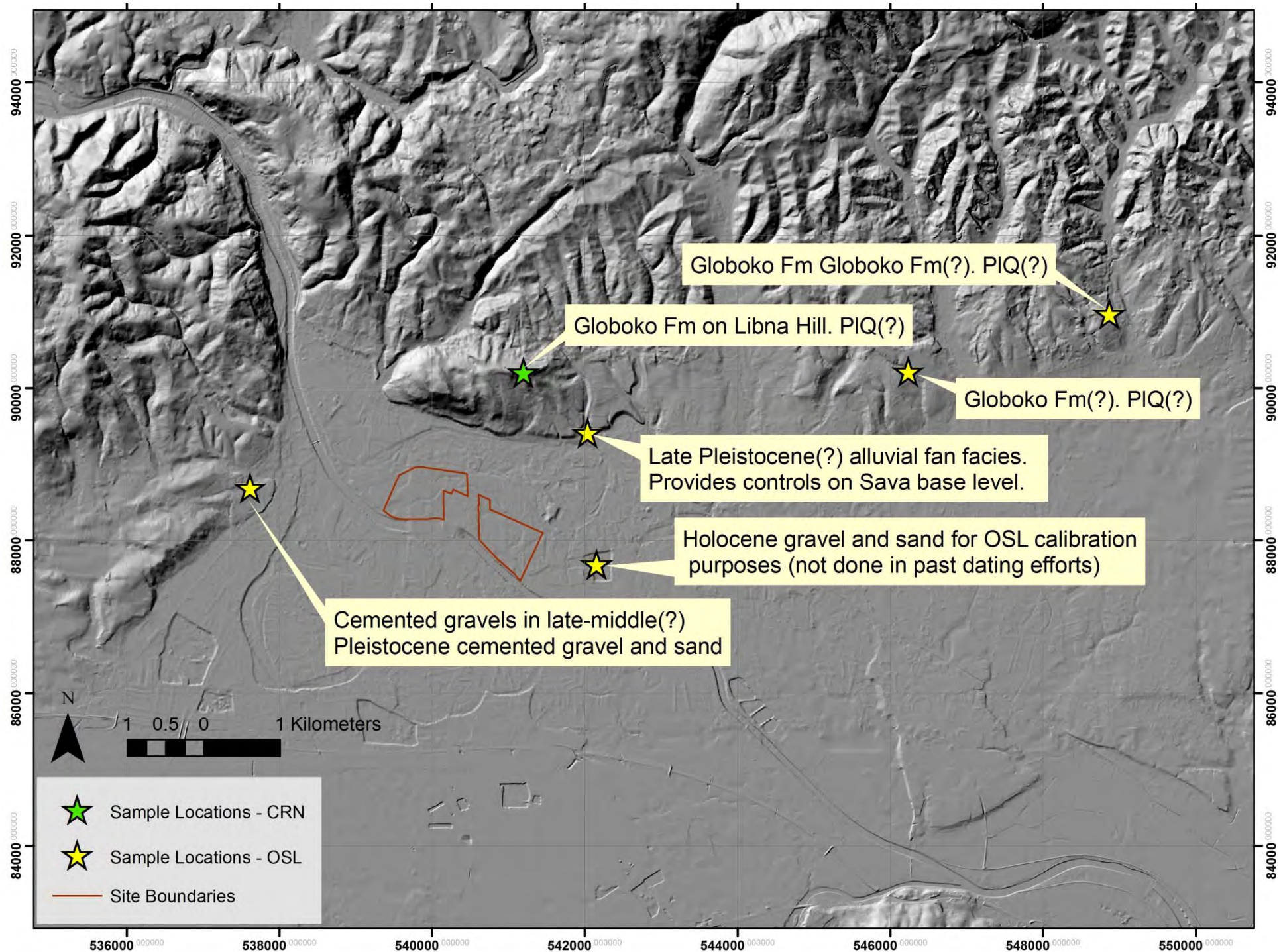
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Early HRS Findings

- Identified both inferred and possible faults
 - Many faults that have apparent normal dip-slip component – Likely Miocene
 - Faults observed within the projection of the Libna Fault but with possible inconsistent fault dip direction suggesting different faults
- Continuation of the Libna Fault across the Krško Basin has not been observed
- Upper reflector identified in 2010 RIZZO survey is not the Plio-Quaternary boundary
 - Likely Miocene or artificial or multiple



Early Conclusions

- Landsliding and karst features dominate the Krško and Orlica Hills
- Libna Fault is dominated by landslide and karst features bringing into question age and amount of tectonic displacement
- Evidence for the extension of the Libna Fault across the Krško Basin is inconclusive
- Apparent normal dip-slip faults (Miocene?) identified with some frequency in the Krško Basin

Early Conclusions

- Orlica fault has segmented dominant geomorphic features suggesting late Quaternary faulting
- Artice fault has short dominant lineament along its mapped trace but it terminates east of Krško
- No evidence for Stara Vas fault
- Geochronology may provide more conclusive evidence for constraining the age of
 - Plio-Quaternary (?) sediments and Libna Fault
 - Tectonic activity in the Krško Basin

Early Conclusions

- Relationship of Libna Fault to 2004 Model
 - Alternative interpretations of the Libna Fault displacement are viable given new information
 - No basis for the extension of Libna Fault beyond 5 kms
 - **IF** it has had Plio-Quaternary displacement, it is likely secondary displacement
 - Libna is not a separate seismogenic source
- Based on our current understanding the seismotectonic model from 2004 PSHA is valid