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Historical earthquakes in Lower Silesian Block (Poland) - an archeoseismological approach

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Abstract: *We present here the results of a comprehensive archeoseismological study of 55 churches located in the Lower Silesian Block adjacent to the SMF. We report several structures with unusual buttresses, tilted inward/outward walls, dropped keystones, displaced masonry, shifted blocks and/or columns, etc. Based on the history of deformations and repairs, our results suggest that some sites experienced more than one moderate to destructive earthquake. For ten of the studied sites, the assigned archeo-intensity exceeds VIII. Further studies are needed to date the recorded seismic events and establish their potential sources.*

Key words*: archaeoseismology, historical earthquake, Lower Silesia, deformation, buttress.*

INTRODUCTION

Archeoseismology, due to the common lack of written testimonies and incompleteness of seismic catalogs, might play a crucial role in filling the gaps in historical earthquake records and, therefore, in improving the seismic hazard assessments. This is particularly true for regions opulent in archeological sites and/or medieval structures (especially churches). This task is even more relevant and challenging in intraplate regions characterized by the low deformation rate and associated low to moderate seismicity with an usually long recurrence period.

STUDY AREA

Lower Silesian Block in the NE Bohemian Massif has abundant medieval to modern buildings presenting a rich history of damage/repair/renovation suitable for archeoseismological studies (Gaidzik and Kázmér, 2021). The unit is cut by the 200-km long Sudetic Marginal Fault (SMF), i.e., one of the most prominent tectonic zones in central Europe that exhibits the pronounced morphotectonic escarpment of the Sudetic Mountains front.

Its Quaternary activity, mainly late Pleistocene, with a prehistoric earthquake of minimum moment magnitude M 6.3 and the inferred slip rate of about 0.03 mm/year (late Pleistocene slip rate of ~1.1 mm/yr) have been corroborated by paleoseismological trenching (Štěpančíková et al., 2010, 2022) and damaged speleothems (Szczygieł et al., 2021). Moreover, several historical earthquakes since the XV century have been reported (e.g., Guterch and Kozák, 2015; Sana et al., 2021).

METHODS

We applied the archeoseismological analysis to 55 churches located in the Lower Silesian Block adjacent to the SMF, as these are the best to recognize past damaging seismic events (e.g., Kázmér, 2015). During fieldwork, any deviation from the architectural traditions and norms was recorded, either related to deformation, e.g., bent (folded), bulging, torn, or collapsed walls, dropped, shifted, rotated, extruded blocks, dropped keystones, fracture across blocks, walls, an entire building, etc. or associated with restoration, e.g., repair, support, reconstruction, reuse of spoiled masonry, unnecessary, exaggerated buttresses, etc. (Kázmér, 2018). Survey and documentation were carried out by photography together with structure-from-motion 3D modeling, drawings, and by handheld instruments (GPS, compass, vertical and horizontal distances were measured by laser range finder Nikon Forestry Pro II, and wall tilting, if possible, by a digital compass-clinometer FieldMove Clino. Construction and repair history is based on observations and published archaeological results. A succession of recognized events is correlated to historical data, if available. Earthquake intensity was assessed based on the Earthquake Archaeological Effect (EAE13) scale (Rodríguez-Pascua et al., 2013).

Table 1. Main historical earthquakes in the studied area (based on Guterch and Kozák, 2015).

Date	Local magnitude	Intensity	Date	Local magnitude	Intensity
1443.06.05	6.0	8-9	1751.06.31	>4.3	6-7
1496.06.23	3.5	5	1778.05.10	>3.5	5-6
1562.02.10	5.2	7	1829.06.02/03	3.5	5
1594.09.15	3.5	5	1877.11.25	3.5	5
1615.02.13	3.5	5	1895.06.11	>4.4	6-7

Figure 1. Examples of observed deformation/restoration suggesting seismic origin. A – Leaning Tower in Ząbkowice Śląskie presenting >2 m deviation from the vertical; B & C – Castle in Ząbkowice Śląskie with folded wall (fold with subvertical axis); D-H – Church of the Assumption of the Blessed Virgin Mary in Kłodzko; D – general view on the exaggerated buttresses supporting two uneven towers and NW wall; E – tilted inward NW wall; F – dropped keystone above the portal on the NW wall; G – dropped and shifted keystone above window in SW wall; H – deformed arch below N tower.

RESULTS AND DISCUSSION

Conducted fieldwork revealed numerous churches in the Lower Silesia region in Poland and partly in the Czech Republic that show different types of anomalies in their construction/reconstruction (Fig. 1). The most common features include:

- unusual or oversized buttresses (almost all of the studied buildings)
- tilted inward/outward walls (e.g., Kłodzko, Karszów, Prusy, Ząbkowice Śląskie, Złotoryja, Dziwiszów, Ścinawa Mała, Lwówek Śląski)
- dropped keystones (e.g., Kłodzko, Złotoryja, Dziwiszów, Świerzawa, Pogwizdów, Lwówek Śląski, Środa Śląska)
- displaced masonry (e.g., Kłodzko, Prusy, Złotoryja, Lwówek Śląski, Środa Śląska)
- shifted blocks and/or columns (e.g., Kłodzko, Złotoryja)
- deformed arches (e.g., Kłodzko, Lwówek Śląski, Złotoryja, Środa Śląska)
- folded wall (e.g., Ząbkowice Śląskie, Lwówek Śląski)

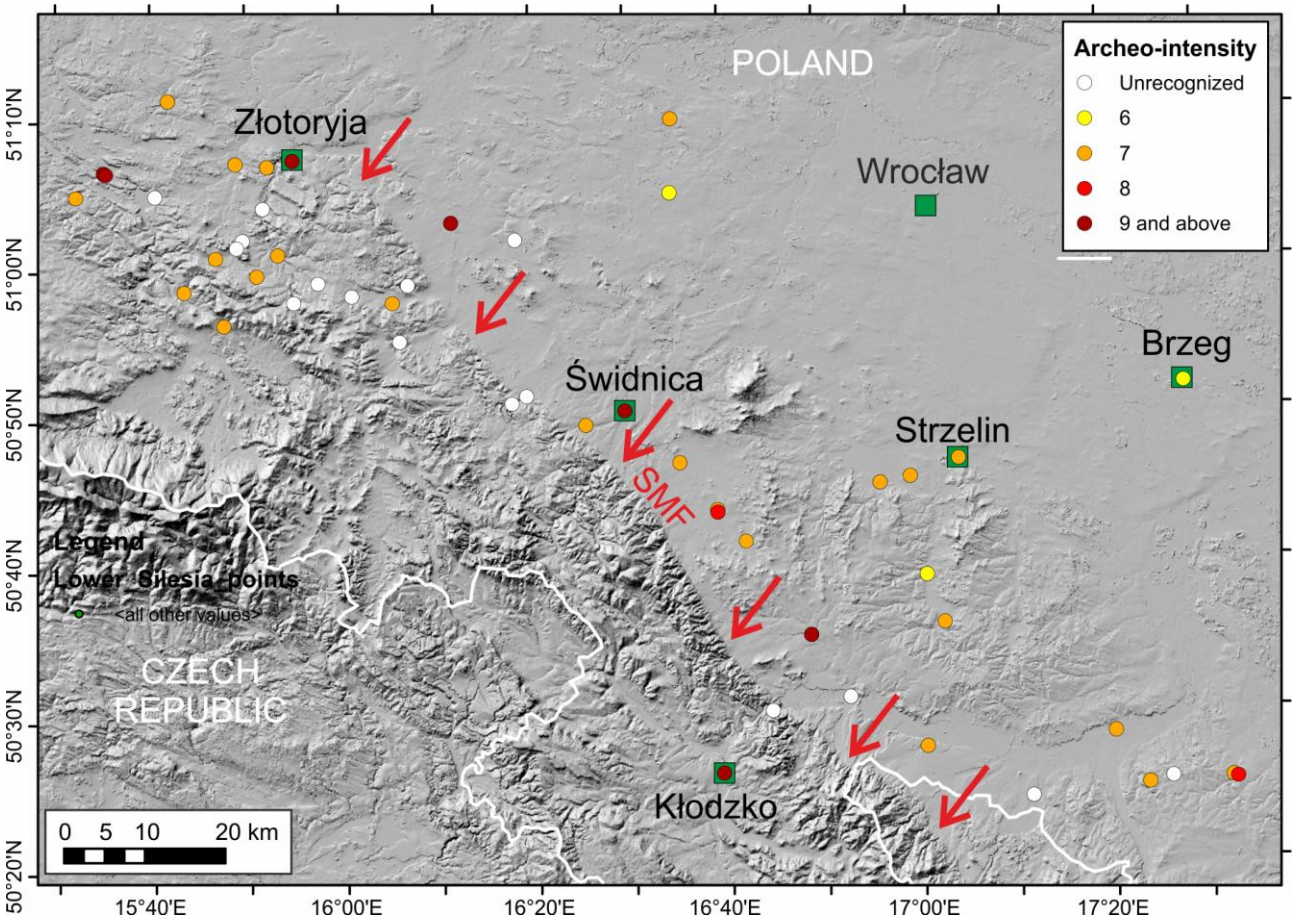

Figure 2. Maximum archeo-intensities for studied churches in the Lower Silesia region based on our field observations and measurements. Red arrows present the SMF – Sudetic Marginal Fault.

Based on the history of deformations and repairs, our results suggest that some sites experienced more than one moderate to destructive earthquake. For ten of the studied sites (i.e., St. George Church in Dzierżoniów, Church of the Visitation of the Blessed Virgin Mary in Ścinawa Mała, Church of the Assumption of the Blessed Virgin Mary and Church of Saint Francis of Assisi in Lwówek Śląski, St. Martin Church in Jawor, Cathedral of St. Stanislaus and St. Vaclav in Świdnica, St. Anna Church and Leaning Tower in Ząbkowice Śląskie, Church of the Nativity of the Virgin Mary in Złotoryja, Church of the Assumption of the Blessed Virgin Mary in Kłodzko), the assigned archeo-intensity exceeds VIII based on the Earthquake Archaeological Effect (EAE13) scale (Rodríguez-Pascua et al., 2013) (Fig. 2). However, for many sites, the exact archeo-intensity was not possible to assess and/or requires further detailed studies.

Preliminary results of dating using historical records, known earthquakes (Guterch and Kozák, 2015), and history of construction/destruction/restoration of each specific church suggest that at least some of the recorded deformations, e.g., Leaning Tower in Ząbkowice Śląskie and Church of the Assumption of the Blessed Virgin Mary

in Kłodzko, could be related to known historical events. On the other hand, deformations observed in the Church of the Assumption of the Blessed Virgin Mary and Church of Saint Francis of Assisi in Lwówek Śląski, St. Martin Church in Jawor for example, suggest additional events, not included in the seismic catalogs. However, further studies to date these more precisely and establish their potential sources.

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