Soft-sediment deformation structures
and palaeoseismic phenomena
in the South-eastern Baltic Region

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Injection structures and load casts in lagoon sediments (Sārnate outcrop, W Latvia)

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Highlights

- A high frequency of layers with injection structures and load casts
- Liquefaction is a main process responsible for soft-sediment deformation structures (abbr. SSDS) development
- Two primary phases of SSDS development occurred with an erosional-event interruption

Study area

The Sārnate study site is located on the Ventava Plain of the Piejūra Lowland of western Latvia, 37 km SSW of the town of Ventspils (Figs 1 and 2). The outcrop is located in the southern part of a ~ 3 km long stretch of an ancient lagoon of the Litorina Sea, which has since been eroded by contemporary coastal erosion. This area was completely covered by Late Weichselian glacial ice, becoming ice-free only after its retreat from the Valdemārpils ice-marginal zone position at ~ 14 ka (Zelčs et al., 2011). After deglaciation, this area was completely submerged under various stages of the Baltic Ice Lake. The Ancilus Lake shoreline is not traceable today in the vicinity of this site, as it has been eroded during subsequent Litorina Sea stages (Grīnbergs, 1957). Plant macroremain and pollen analysis indicate isolated lake (freshwater) conditions during the Ancilus Lake time (Saulīte et al., 2007). Whether the site was covered or not by Ancilus Lake waters is still not fully settled. Litorina Sea's shoreline (stage Lita according to Grīnbergs, 1957) was then located approximately 600 m to the SE. During the Litorina Sea time this site was located in a bay that was eventually cut-off from open sea by the fall of the relative water level, which was accompanied by the formation of a spit due to longshore sediment transport (Saulīte et al. 2007). Lagoonal organic deposits have been dated with 14C samples, providing ages from top to bottom of 3450–3560, 5990–6130, and 7580–7730 cal. years BP (Saulīte et al., 2007).

At the ancient seaside – above lagoonal sediments – are located dunes with a relative elevation of ≤ 10 m above the plain. Dune morphology indicates that their formation is caused by a reactivation of wind-action on older sediments, which is a typical response to human-activity induced aeolian processes noted along large portions of Latvia's coastal area. The whole expanse has been – and still is – experiencing land-uplift since the time of deglaciation due to glacio-isostatic adjustment.

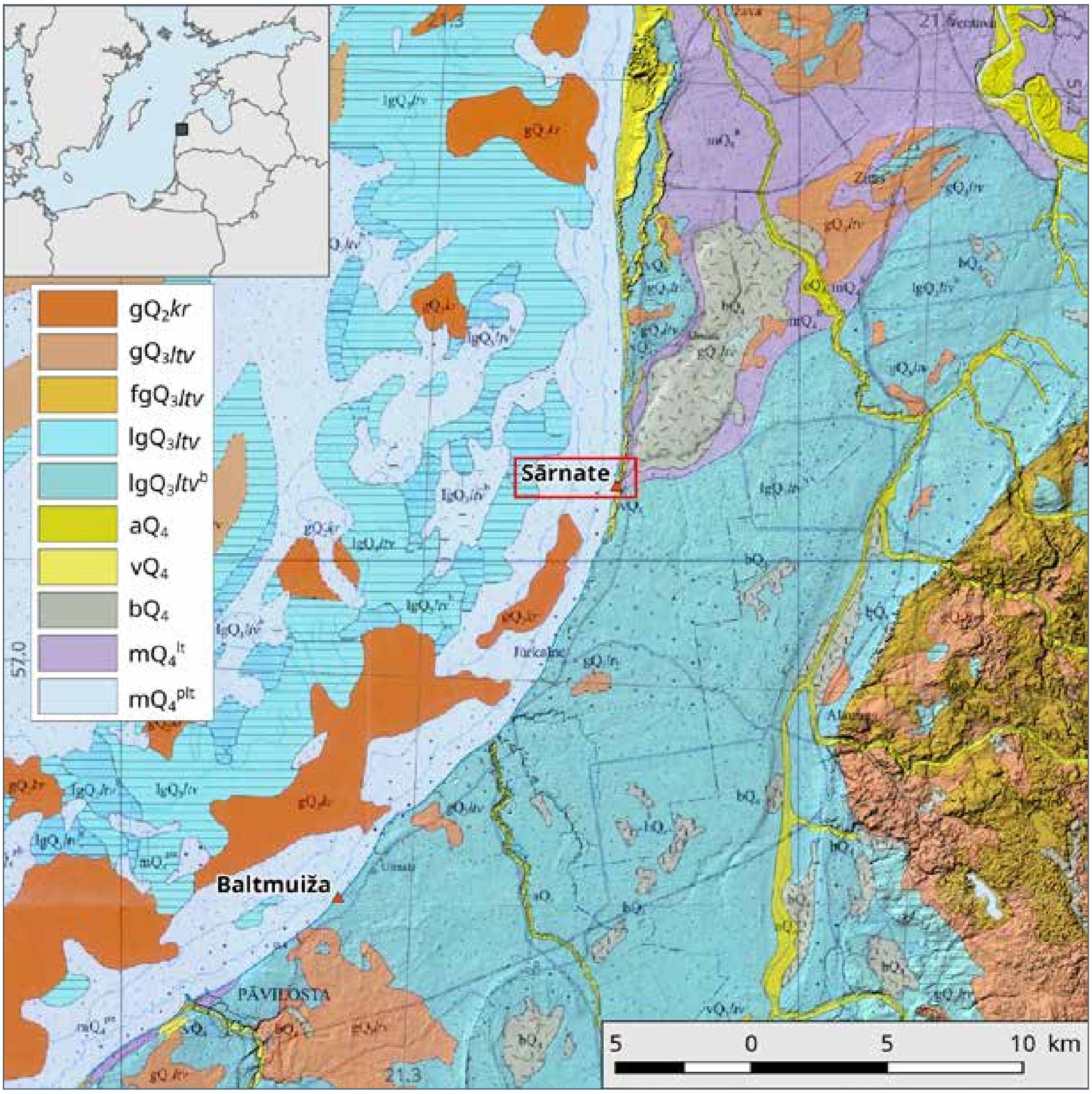

Fig. 1. Quaternary sediment map of the Sārnate outcrop and its surroundings (Juškevičs et al., 1998)

AGE AND GENESIS OF SEDIMENTS: gQ2kr – glacigenic sediments (till) of Kurzeme (Saalian) glaciation, gQ3ltv – glacigenic sediments (till) of the Latvija (Weichselian) glaciation, fgQ3ltv – glaciofluvial sediments, lgQ3ltv – glaciolacustrine sediments, lgQ3ltvb – glaciolacustrine (Baltic Ice Lake) sediments, aQ4 – Holocene river (alluvium) sediments, vQ4 –Holocene aeolian sediments, bQ4 – Holocene peat (bog) sediments, mQ4lt – Holocene marine (Litorina Sea) sediments, mQ4plt – Holocene marine (post-Litorina Sea) sediments.

Quaternary sediment cover at the study site is 127 m thick. That cover sediments is underlain by Middle Devonian sandstones of the Aruküla Regional Stage. Crystalline bedrock is located at a depth of 1.2 km. There are no known crystalline bedrock or sedimentary cover faults within a radius of 10 km around the site.

Sedimentological description and interpretation

The clay, silty clay, and fine-grained sand in sedimentary succession was observed at a 3.5 m high and ~20 m wide outcropping of the Sārnate outcrop in the Latvian Baltic Sea coast (Fig. 3A). Two sedimentary units (A and B lithofacies associations) were recognised in the Sārnate outcrop. The upper unit B was covered by a fine-grained sandy dune (0.7 metre thick) with organic matter.

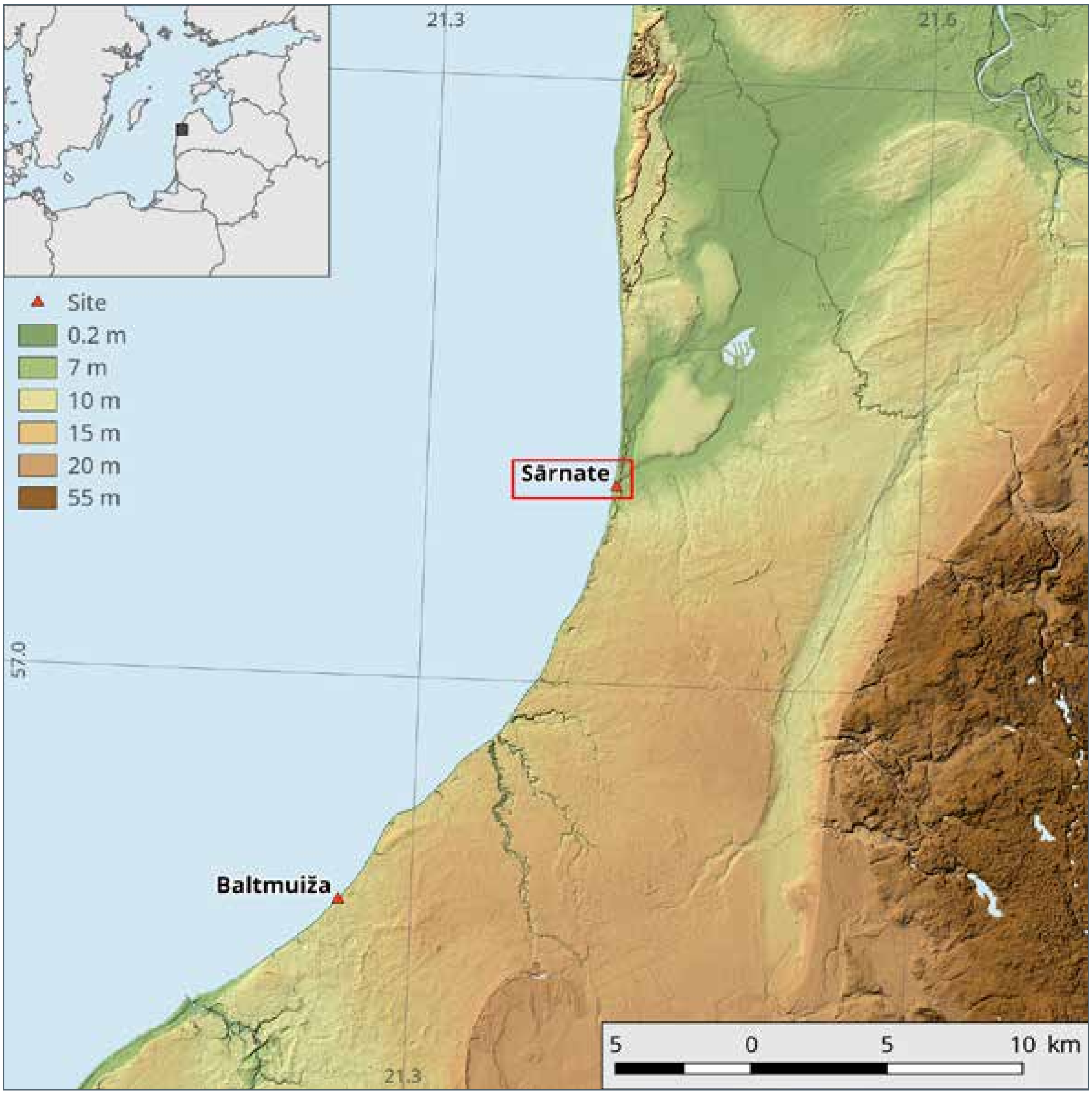

Fig. 2. **Terrain of the W Latvia coastal area between Sārnate and Pavilsota. Based on LiDAR data of Latvian Geospatial Information Agency** (2016)

The lower unit A has a thickness at least 1.05 m, mainly containing silt, silty clay, and clay deposits with massive and horizontally-laminated structures (lithofacies Fm and Fh). Also in association was a silty clay deposit interbedded by a thin layer of clay. The thickness of these lithofacies vary between a few centimetres and a few millimetres. SSDS, frequently occurred in unit A, are described in the chapter below. Between unit A, and the overlying unit B – being transitional to unit A/B – there is a locally sharp erosional boundary, accommodating a few recognizable channels (Fig. 3A-C). In channel bottoms are clayey clasts of 1–2 cm diameter.

The upper unit B, 1.85 m thick, contain horizontally-laminated sand (lithofacies Sh), which are interbedded by thin layers of massive clay or clayey silt (lithofacies Fm). The thicknesses of the sandy lithofacies vary from 1–20 cm and the clayey lithofacies are from 1–5 cm thick. Furthermore, a rhythmic sedimentary sequence was recognized – Sh→Fm – interpolated between two different thickness types. The first type consists of very thin sand and silty clay laminae (each 2–3 mm thick). The second type has thick sandy laminae (~ 10–20 cm thick) as well as very thin clayey laminae (2–3 mm thick). Clayey clasts (rafts) of a few millimetres diameter were recognised within the horizontally-laminated sandy lithofacies. SSDS features occurred in unit B are described in the chapter below.

Since the silty lower unit A's, grain size was very fine, that sediment could have been deposited in a very calm lake or lagoon environment that formed due to sea level rise. Deposition could have been driven by a hiatus in sea-level rise or by sediment suspension in association with a static lagoonal water-level. That suspension load was significant; suggesting that the present section represents deposition derived from the central part of a lake/lagoon since no current features were found in lower unit A. Deposition from unit A suspension was interrupted locally by an erosional channel-building event – a **transitional unit for A/B**. Eroded channels, mostly shallow, were first infilled in their lower portions by eroded silty clasts that were derived from unit A, then afterwards filled by sand or silty sand from above. This erosion-fill event was caused by a significant increase of sea level, accompanied by erosion in unit B channels, which supplied lagoonal water and sediments to the sedimentary system.

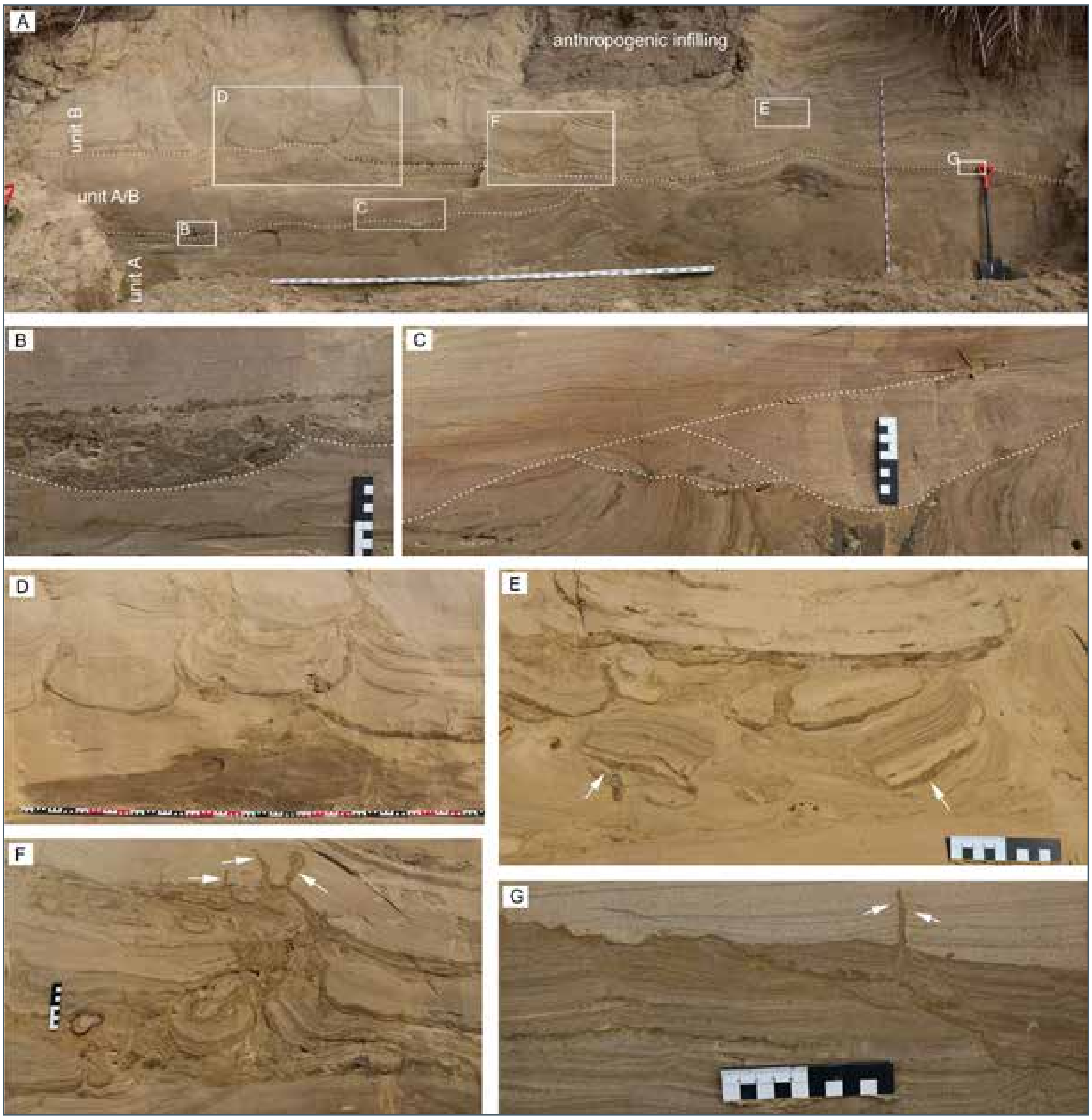

Fig. 3. Sedimentary succession at the Sārnate site

A: Sedimentary units involved in soft-sediment deformation structures; **B and C:** Channels occurred between units A and B. **D:** Load casts in fine-grained sediments. **E:** Broken and defragmented layers – white arrows. **F:** Injection structures infilled by silty sediments present between load casts. **G:** Injection structure developed from lower silty sediments into the horizontally-laminated sands above (note that laminae around the injection structure are curved upwards – white arrows).

SSDS features

Strongly deformed layers occur in units A and B, which are stacked atop each other. However, in some cases corresponding primary sedimentary structures are also visible. **Lower unit A** contains load casts in its bottom portion in association with injection structures like fluid-escape structures. Also present are symmetrical standing folds with injection structures in their centre portion. In many instances, the top of layer involved in SSDS is truncated and pointing at erosion of its sedimentary surface.

Unit B has large-scale load casts (~1.30 m high) that occur among chaotically distributed smaller-scale load casts. A few generations of load casts are recognised – each generation is smaller than the previous one. Furthermore, inside these load casts lay thin massive clayey laminae (lithofacies Fm) and horizontally-laminated sands (lithofacies Sh) with small-scale (0.5–15 cm diameter) injection structures. The largest load casts in unit B reach to the bottom portion of unit B. In the interstitial space between the large load casts there are huge injection structures reaching to the top of load casting. The injection structures displayed strong internal deformation signs generated during load cast formation. Unit B load casts attenuate upwards, their tops are smaller than the bottoms; their frequency increases from bottom to top.

SSDS origin

Two phases of SSDS development were recognised in the Sārnate outcrop. **The first phase** is connected to unit A, it was a single deformation event caused by the liquefaction process of fluidized (perhaps water-lain) silt and silty sand deposits. After this deformation event, an erosional event occurred, which incised previously formed SSDS.

The second phase is associated with a deformational event that occurred after the accumulation of unit B. During unit B's liquefaction and fluidization event the thin uppermost layer of horizontally-laminated sand (lithofacies Sh) became mobilized, being overlain by thin layers of clay deposits. The highest water pressure occurred in the layers directly below the clay layers. Each of the clay laminae produced an impermeable layer. Upward-migrating water reached the top of lithofacies Sh. It is likely that these injected structures were created during a single deformation event concerning the whole of unit B. High water pressure in the upper layer of the Sh lithofacies is attributed to the incision noted to clay laminae, which caused the deposition of clayey and silty clasts. A rhythmic sedimentary sequence – Fh→Fm – includes very thin sand laminae and silty clay. All of these sediments were mobilised when the large-scale injection structures were created. Then, the large-scale injection structures incised the entire mass of B unit deposits – in process forming large load casts.

Possible trigger mechanisms:

- Ground-water level fluctuations
- Hydrostatic pressure changes related to progressive water-wave or tsunami passage
- Palaeoseismic event

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References

Grinbergs, E., 1957. The late glacial and postglacial history of the coast of the Latvian SSR. The Publishing House of the Academy of Sciences of the Latvian SSSR, Riga, 122 (In Russian).

Juškevičs, V., Kondratjeva, S., Mūrnieks, A., Mūrniece, S., 1998. Geological map of Latvia. Scale 1:200,000. In: Āboltiņš, O. P., Kuršs, V. (Eds), Explanatory note and map, Sheet 41-Ventspils, 48 pp. State Geological Survey, Rīga (In Latvian).

Saulīte, A., Kalniņa, L., Stinkulis, Ģ., Ceriņa, A., 2007. A new data from the outcrop at the coastal cliff of the Baltic sea near to Sārnate. In: Guobytė, R., Stančikaitė, M. (Eds), The Quaternary of Western Lithuania: from the Pleistocene glaciations to the evolution of the Baltic Sea: Proceedings: The INQUA Peribaltic Group Field Symposium, May 27–June 02, 2007, Plateliai, Lithuania, Lithuanian Geological Survey, Institute of Geology and Geography, Vilnius, 73–74.

Zelčs, V., Markots, A., Nartišs, M., Saks, T., 2011. Pleistocene Glaciations in Latvia. In: Ehlers, J., Gibbard, P.L., Hughes, P.D. (Eds), Quaternary Glaciations – Extent and Chronology: A Closer Look, Developments in Quaternary Science 15, Amsterdam, 221–229.

Notes