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Quantifying the contribution of shallow subsurface processes to (sub)surface movement in the Groningen gas field area

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Surface and shallow subsurface deformation

Land subsidence, leading to surface and shallow subsurface deformation, is due to natural and human-induced processes occurring on different time-scales and depth-intervals. The negative impacts of land subsidence are manifold and the design of efficient measures mitigating land subsidence requires the **quantification of the individual processes** that contribute to total (sub)surface movement and reliable techniques for monitoring surface elevation changes at high resolution, spatial and temporal scales.

The ultimate aim of this research is to quantify shallow subsurface processes such as **oxidation** and **compression** occurring in the Holocene sequence (surface level up to 8 m depth). Additionally, the contribution of intermediate depth processes, induced by the extraction of groundwater from Pleistocene aquifers (8 m – 100 m depth), to total subsidence will be modelled. Within the overall DeepNL project this research will contribute to a surface elevation dynamics model, combined with reservoir models and InSAR observations.

Causes of shallow (sub)surface deformation

Shallow (sub)surface deformation rates are strongly influenced by (phreatic) groundwater level, loading, subsurface lithology and other parameters. Variations and fluctuations in these parameters lead to (Fig.1):

- primary and secondary (creep) compression
- oxidation of organic matter
- shrinkage and swelling of clay and peat

These processes cause cm-scale fluctuations in (sub)surface deformation, resulting in net subsidence rates of several mm/yr.

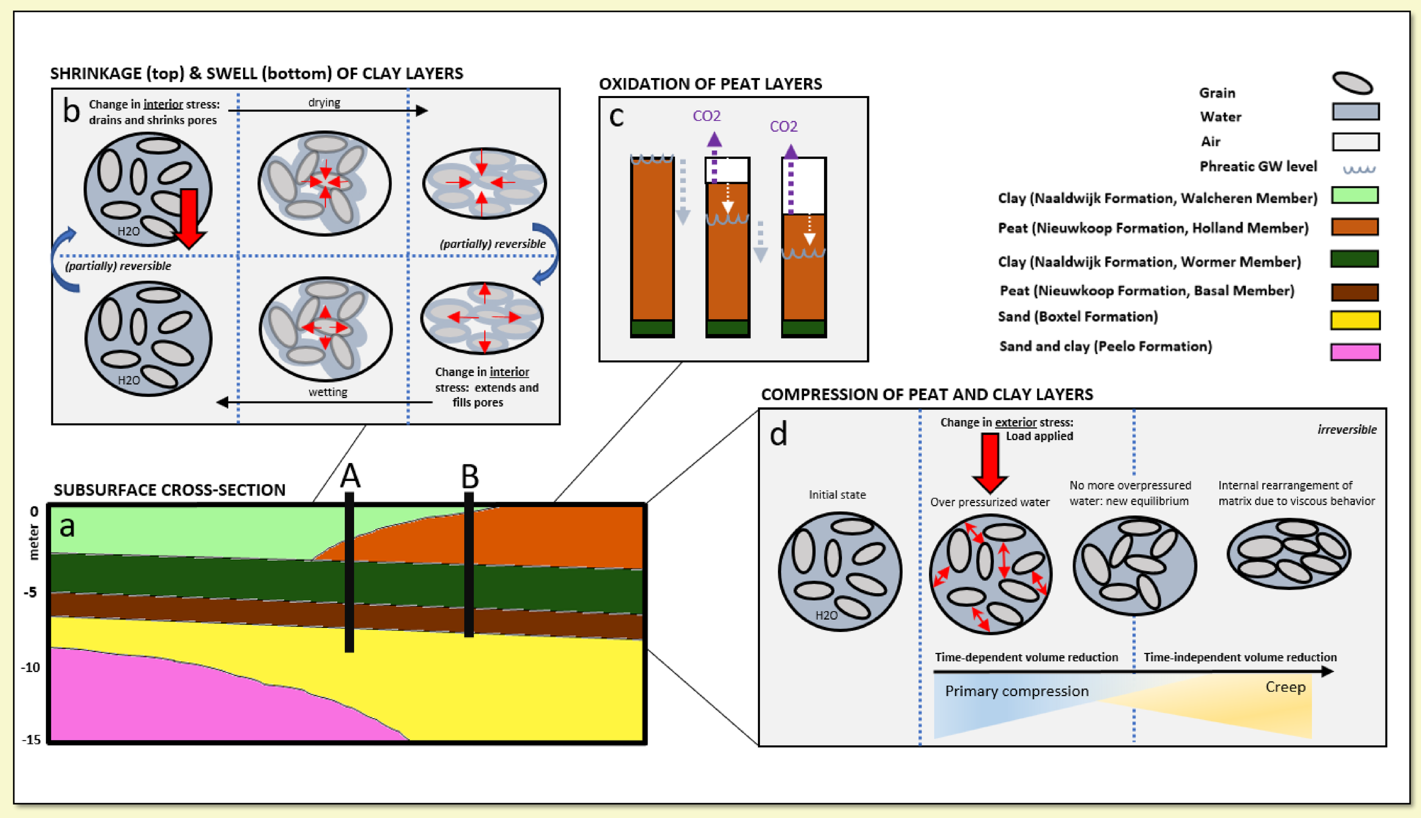

Figure 1 *Subsurface processes inducing vertical (sub)surface movement in the upper 15 m. a) Schematic shallow subsurface build-up consisting of Holocene and late-Pleistocene deposits (representative of N-S Groningen gas field area). b) Schematic overview of shrinkage and swelling in surficial clay layers induced by changes in interior stresses. c) Schematic overview of lowering of the phreatic groundwater level inducing decomposition of peat layers and subsequent subsidence and CO_2 release. d) Schematic overview of compression in peat and clay layers induced by changes in exterior stresses.*

Monitoring sites Nieuwolda

Two monitoring sites are developed in Nieuwolda (Fig. 2), for measuring and monitoring the shallow subsurface processes. One site is focused on surficial clay (A) governing mainly shrinkage and swelling and overall compression, whereas the other site (B) is focused on surficial peat governing mostly oxidation and overall compression (Fig. 3). Monitoring instruments include groundwater monitoring wells, extensometers with anchors positioned at different geohydrological boundaries for measuring relative deformation of different layers, a transponder for InSAR observations, and further meteostation devices such as moisture content devices, thermometers, and precipitation and evapotranspiration monitors. Both sites are currently used for agriculture which differs from the standard grassland monitoring sites. These are the first shallow monitoring sites in the Groningen gas field area. The first preliminary results over a 3-month period are shown in figure 4.

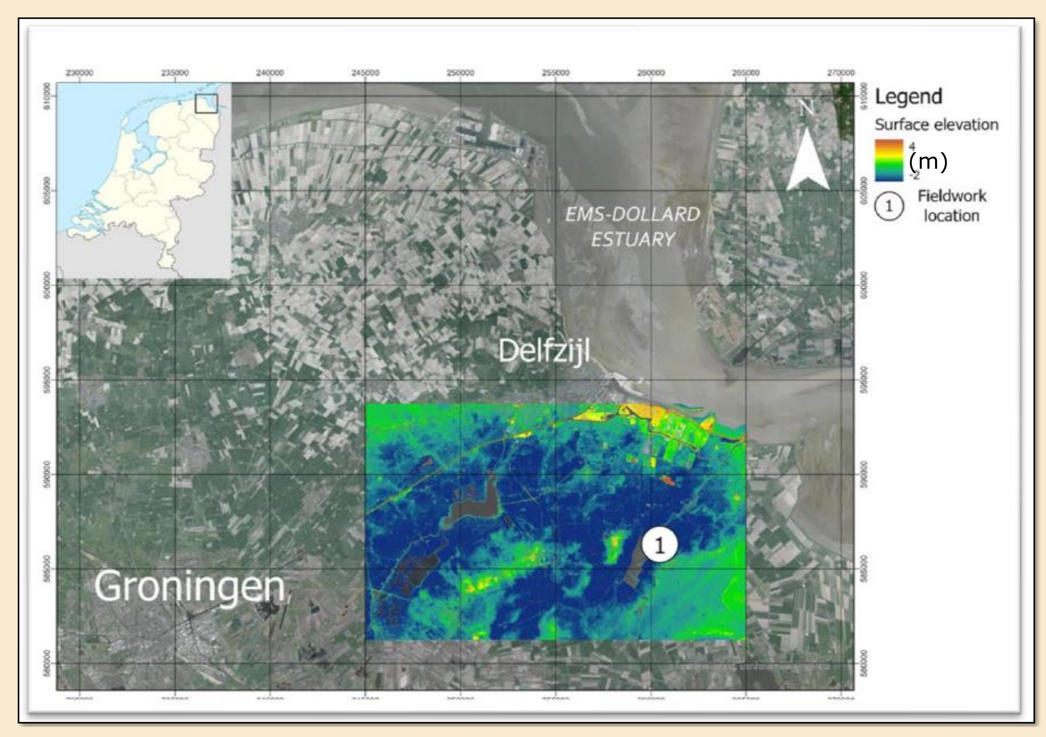

Figure 2 *Location of monitoring sites Nieuwolda, province of Groningen.*

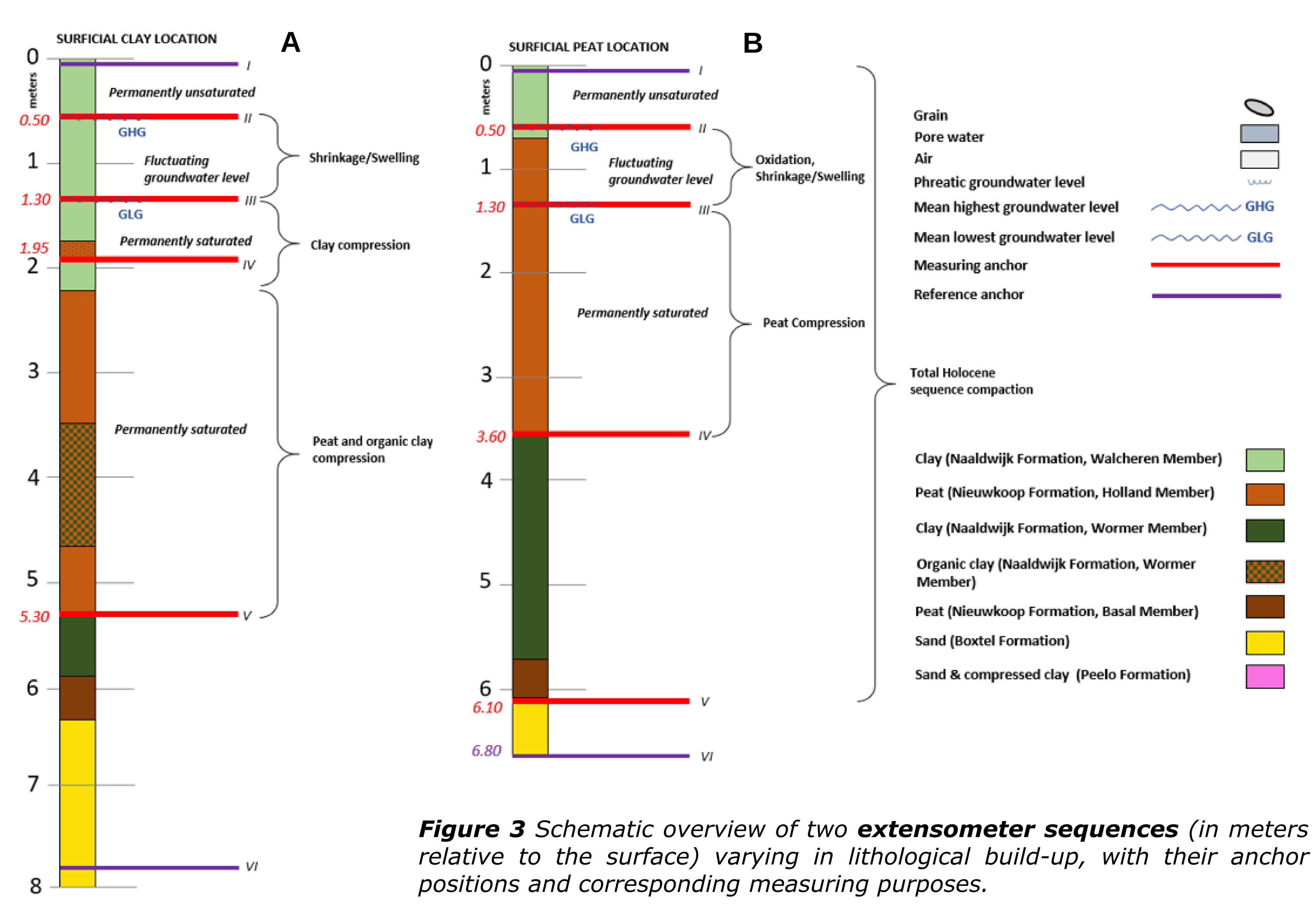

Figure 3 *Schematic overview of two **extensometer sequences** (in meters relative to the surface) varying in lithological build-up, with their anchor positions and corresponding measuring purposes.*

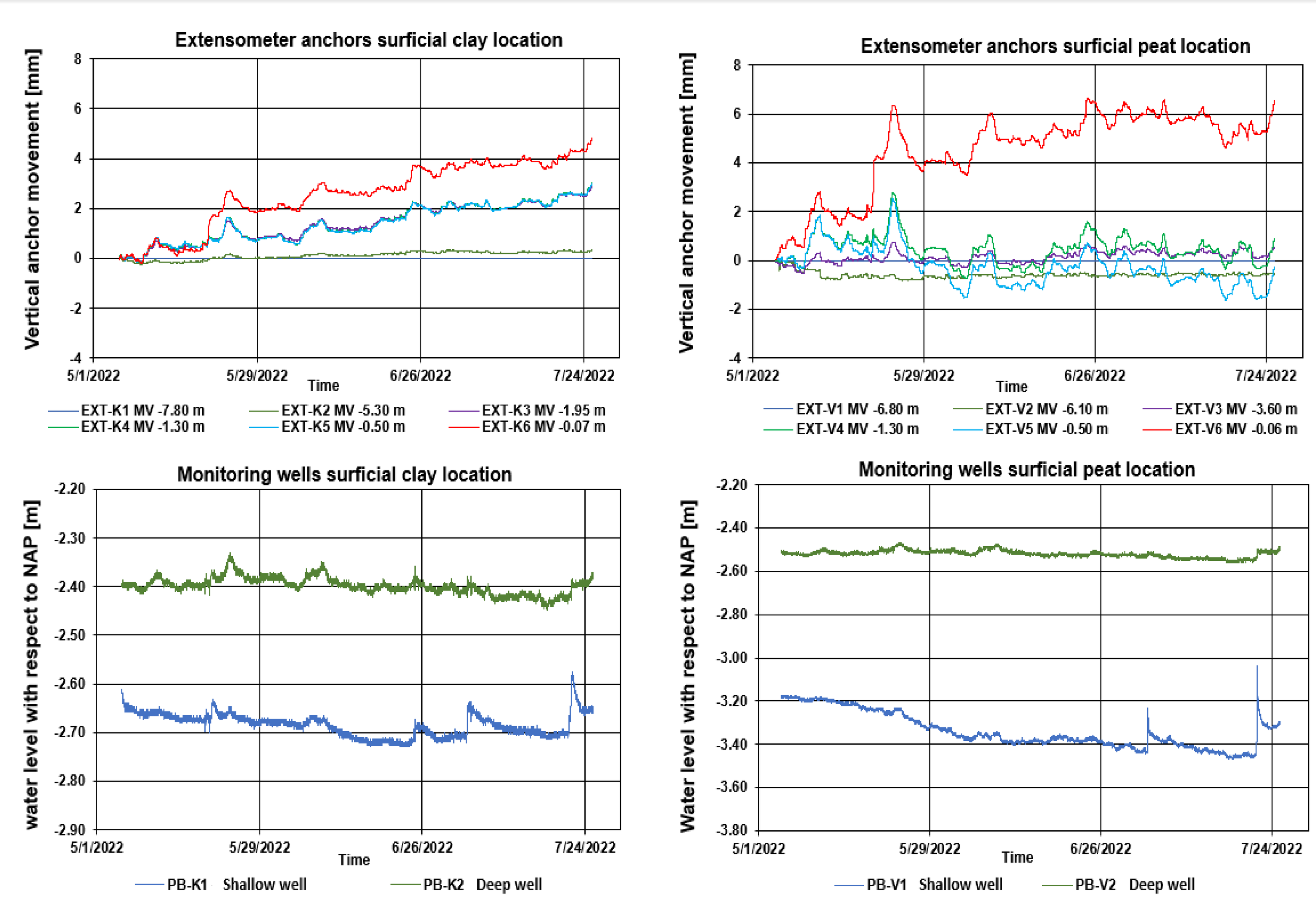

Figure 4 *First extensometer and groundwater level **results**. Vertical anchor movements in meters are relative to the installation depth. Anchor positions are relative to the surface level which is respectively 2.40 m below mean sea level for the surficial peat location and 1.48 m below mean sea level for the surficial clay location.*

Future monitoring and modelling

To quantify shallow subsurface processes over time on a **regional scale**, modelling is essential. Compression modelling based on the a,b,c-isotache method (Den Haan, 1994) and oxidation modeling (based on organic versus mineral content) will be performed over a period from 1959 until present. Measurements will serve as validation for these models and quantification on a local scale (Fig. 4). In addition, the contribution of groundwater extraction from Pleistocene aquifers to (sub)surface movement will be modelled using iMOD coupled to SubCR. These model outputs will give new insights in the contribution of shallow and intermediate depth processes to subsurface movement in the Groningen gas field area.

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https://youtu.be/hPG-7DYDZJg *Shallow subsurface monitoring sites video*