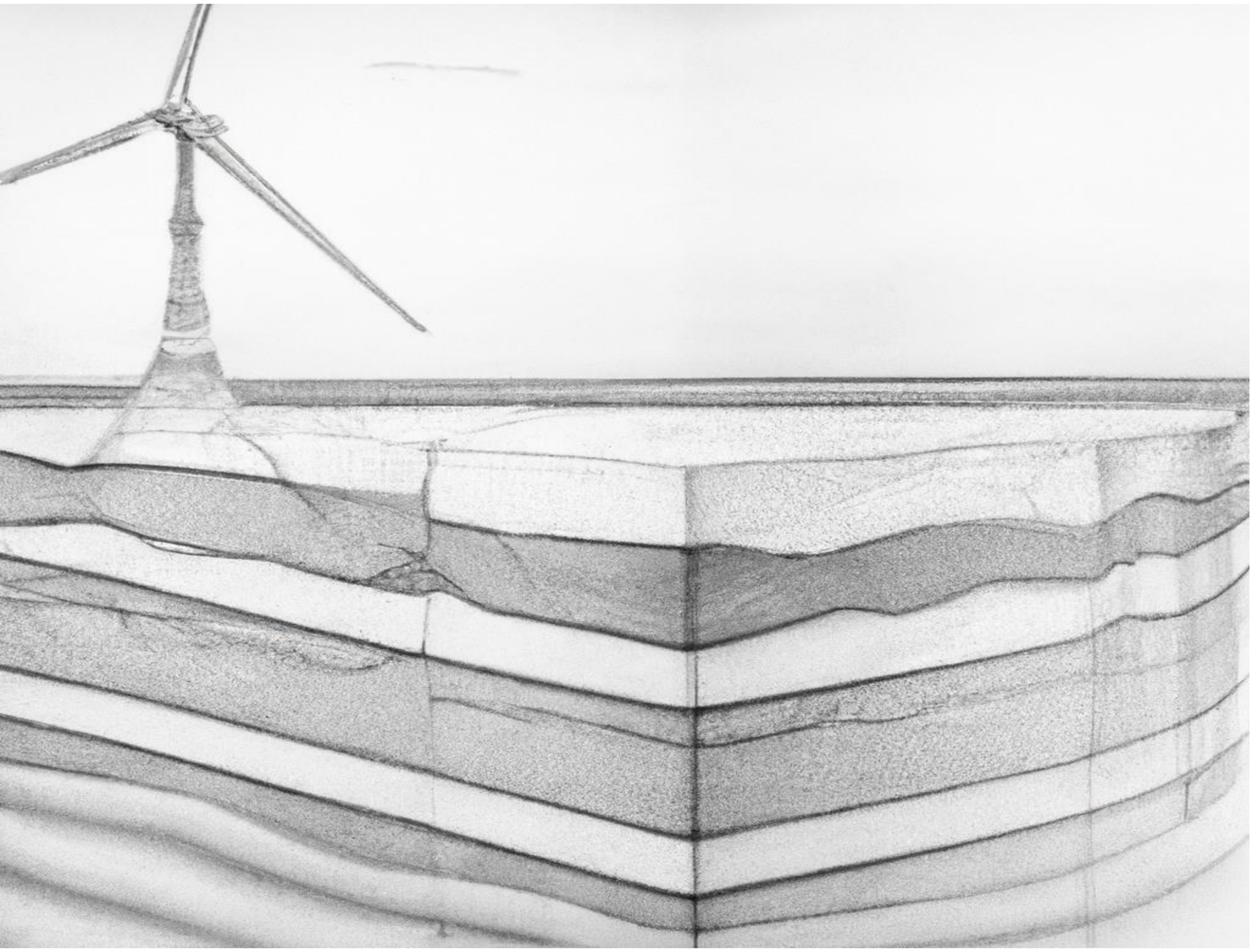

Clay Tectonics Project – short note

Diffraction hyperbolae on seismic profiles in the Kortrijk Formation (Princess Elisabeth zone, Belgian part of the North Sea) - preliminary findings

Details

Concerns: Diffraction hyperbolae on seismic profiles in the Kortrijk Formation (Princess Elisabeth zone, Belgian part of the North Sea) - preliminary findings

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Preface – Clay Tectonics project

The Clay Tectonics project is a cSBO-project funded by Flanders Innovation and Entrepreneurship (VLAIO) through the Blue Cluster (DBC) (2023-2025). The project investigates the influence of clay tectonic features in the Kortrijk Formation in the North Sea on offshore wind foundation design and installation. In this context, the project partners (VLIZ, UGent, VUB - OWI-Lab) apply a multidisciplinary strategy, combining geophysical, geological and geotechnical methods.

In the Industrial Advisory Board (IAB) of the Clay Tectonics project of 15 February 2023, several stakeholders indicated an explicit interest in the diffraction hyperbolae that are present on seismic profiles of the Kortrijk Formation acquired in the Princess Elisabeth-zone (Belgian part of the North Sea, BPNS). This note provides an overview of the preliminary findings related to the observed diffraction hyperbolae.

1. Diffraction hyperbolae in the Kortrijk Formation (BPNS)

In the context of the Clay Tectonics project, several (ultra-)high-resolution seimic reflection surveys have been conducted (2022-2023) in the area of the Princess Elisabeth-zone (BPNS) in order to visualize the deformation features that occur within the Kortrijk Formation. Especially on the data that were acquired with parametric echosounders (PES), a considerable number of diffraction hyperbolae were observed throughout the Kortrijk Formation. In time sections, these diffraction hyperbolae arise from subsurface discontinuities which radially scatter (rather than reflect) incident acoustic energy. They can be related to steeply dipping interfaces, structural complexities, or isolated (small-scale) features representing a significant and abrupt contrast in acoustic properties. The latter features may be denser (e.g. due to the presence of clay stones) or less dense (e.g. due to the presence of gas/fluid pockets) than the surrounding sediments. At this stage, without a dedicated mapping of the diffraction hyperbolas, areas with higher or lower concentrations of occurrences cannot readily be delineated, although it cannot be excluded that regional variations in the abundance of diffraction hyperbolae in the Kortrijk Formation exist.

The following section focuses on examples of PES-profiles within the Princess Elisabeth Zone, acquired with the Innomar SES Quattro on RV Simon Stevin (Fig. 1 and 2) and Kongsberg TOPAS on RV Belgica (Fig. 3). The main acquisition parameters for these data are summarized in Table 1. Apart from bandpass filtering and a spherical divergence correction, no further (amplitude) processing was applied.

Table 1. *Summary of the main acquisition parameters used for the PES-profiles shown in this document.*

	System	**Center frequency**	**Ping rate**
Fig. 1	Innomar SES Quattro	6 kHz	~15 pings/s
Fig. 2	Innomar SES Quattro	8 kHz	~15 pings/s
Fig. 3	Kongsberg TOPAS	4 kHz	~5 pings/s

All three examples reveal the abundant presence of diffraction hyperbolae (Fig. 1a, 2a and 3a), with the used system, frequency or ping rate seemingly having little to no influence on how they are imaged. Their vertical distribution through the profiles appears rather random, although two categories can be distinguished: (i) diffraction hyperbolae linked to reflection horizons, and (ii) isolated diffraction hyperbolae (Fig. 1a, 2a and 3a)). For both categories, the signal polarity of the diffractions is identical to the polarity of the seabed reflection. This observation holds true for both the Innomar profiles (Fig. 1b/1c and 2b/2c) and TOPAS profile (Fig. 3b/3c). This indicates that, at least for the examples analyzed in this document, the diffraction hyperbolae arise from a positive reflection coefficient, meaning that whatever feature causes the diffraction has a higher acoustic impedance than the overlying/surrounding sediment (hinting towards dense features in the clay sediment). The high relative amplitudes on some of the diffraction hyperbolae (Fig. 1d, 2d and 3d) furthermore indicate that the impedance contrast must be quite significant, although it should be noted that other factors (e.g. incidence angle) may play a role as well.

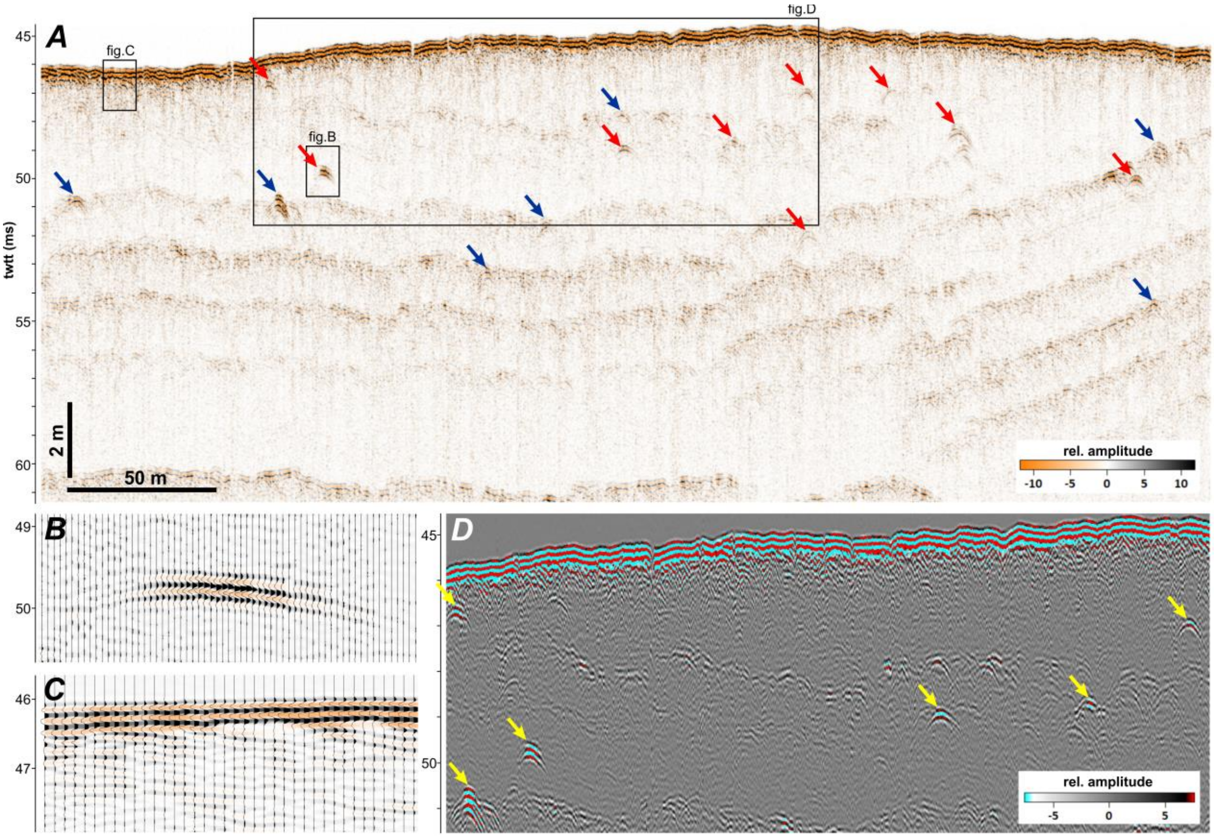

Figure 1. ***(A)*** *Innomar SES Quattro profile of the Kortrijk Formation within the Princess Elisabeth-zone, illustrating the abundant presence of isolated diffraction hyperbolae (red arrows) and diffraction hyperbolae associated with reflection horizons (blue arrows).* ***(B)*** *-* ***(C)*** *Details of a diffraction hyperbola and the seabed reflection respectively, demonstrating an identical signal polarity.* ***(D)*** *Detail of (A) with alternative amplitude scale, indicating the high relative amplitude of some of the diffraction hyperbolae (yellow arrows).*

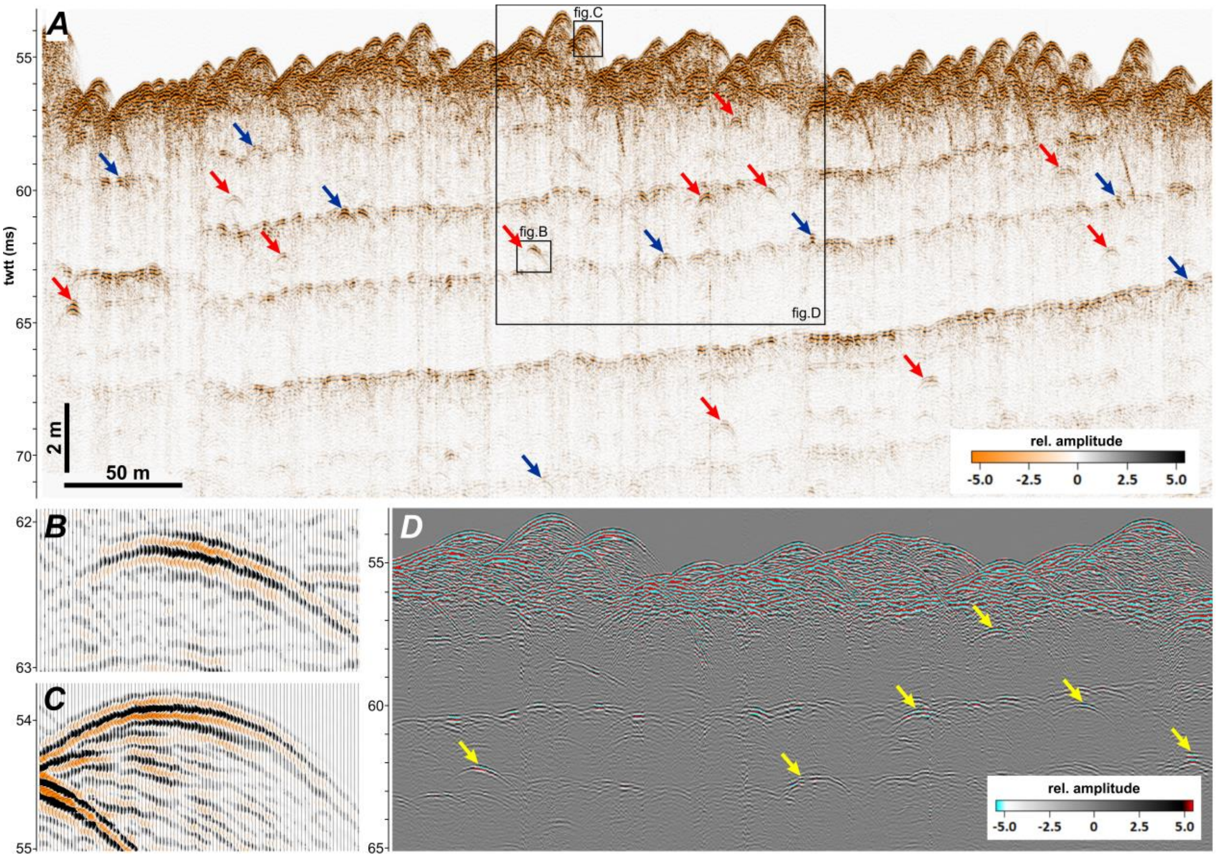

Figure 2. (A) *Innomar SES Quattro profile of the Kortrijk Formation within the Princess Elisabeth-zone, illustrating the abundant presence of isolated diffraction hyperbolae (red arrows) and diffraction hyperbolae associated with reflection horizons (blue arrows).* ***(B)*** *-* ***(C)*** *Details of a diffraction hyperbola and the seabed reflection respectively, demonstrating an identical signal polarity.* ***(D)*** *Detail of (A) with alternative amplitude scale, indicating the high relative amplitude of some of the diffraction hyperbolae (yellow arrows).*

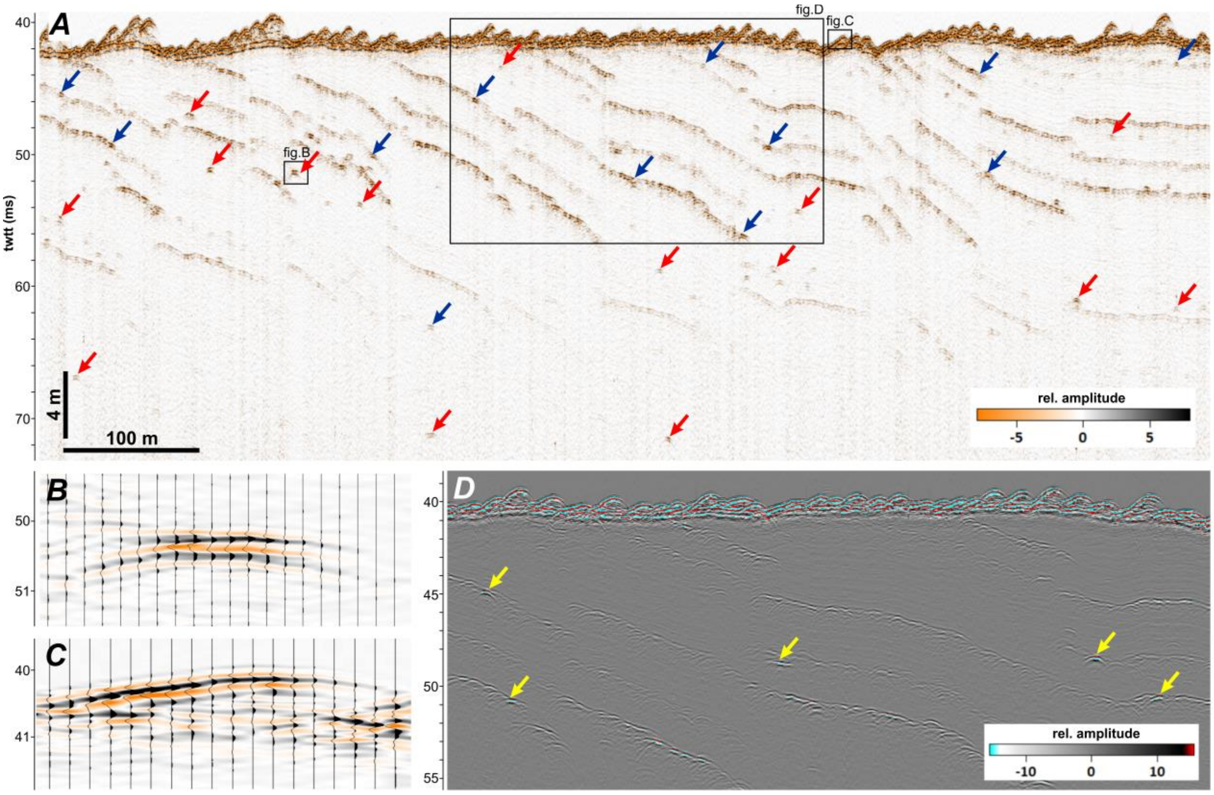

Figure 3. (A) *Kongsberg TOPAS PES profile of the Kortrijk Formation within the Princess Elisabeth-zone, illustrating the abundant presence of isolated diffraction hyperbolae (red arrows) and diffraction hyperbolae associated with reflection horizons (blue arrows).* ***(B) - (C)*** *Details of a diffraction hyperbola and the seabed reflection respectively, demonstrating an identical signal polarity.* ***(D)*** *Detail of (A) with alternative amplitude scale, indicating the high relative amplitude of some of the diffraction hyperbolae (yellow arrows).*

2. Land-based observations of concretions in the Kortrijk Formation

In the literature the Kortrijk Formation is described as a rather homogeneous deposit of up to 180 m thick, consisting of neritic marine clay sediments that were deposited in the North Sea basin during the Early Eocene (e.g. Geets 1988 and Steurbaut 1998, Steurbaut 2006, Borremans 2015). This clay layer is present in the subsoil of the entire northern part of Belgium and crops out in the western and southern part of Flanders where it is excavated in several clay pits.

In contrast to the Boom Formation, a clay layer of more than 100 m that was deposited during the Oligocene and in which well described horizons with hard concretions (so-called septaria) are present, the literature makes little reference of (sizeable) nodules in the Kortrijk Formation. However, concretions have been reported on a more anecdotical basis in a limited number of locations in the Members of Aalbeke, Moen and Saint-Maur (e.g Steurbaut and Nolf, 1986, Notebaert, 1980 and Steurbaut and King, 2017). Recently, more detailed observations of nodules have been made in a clay quarry in the Member of Aalbeke (Fig. 4, Reyniers 2020 and Croenen 2022). It was reported that the nodules (with diameters of several decimeters) were not confined to a specific horizon but appeared scattered throughout the entire clay layer. A mineralogical analysis revealed that it concerned siderite- and phosphate-bearing carbonate nodules with a comparable mineralogical composition as the concretions in layer S60 and S80 from the Boom Formation (Reyniers 2020). The concretions, found in the Member of Aalbeke have a rather fine and soft texture with no internal fissures (septae).

In contrast to the septaria of the Boom Formation, not much research is available on the occurrence and formation of the concretions in the Kortrijk Formation. Based on mineralogical and geochemical analyses of the nodules as well as the clay surrounding the concretions (Fig. 5), Croenen (2022) hypothesized that the genetic model of the nodules in the Kortrijk Formation may be comparable to the ones in the Boom Formation (see for example De Craen et al. 1999). As such, it is put forward that shortly after deposition, the bacterial degradation of organic material may have lowered the pH of the porewater leading to the dissolution of certain ions. In turn, these ions reprecipitated once the saturation state had been reached, forming concretions in the sediment. Reyniers (2020) hypothesized that the observation that the nodules in the Kortrijk Formation are not confined to a certain horizon may be related to the lack of zonation of the phosphate concentration in this layer, in contrast to the Boom Formation.

Figure 4. *Pictures of concretions that were observed in the Member of Aalbeke (Kortrijk Formation) in a clay quarry of Wienerberger nv (Reyniers 2020).*

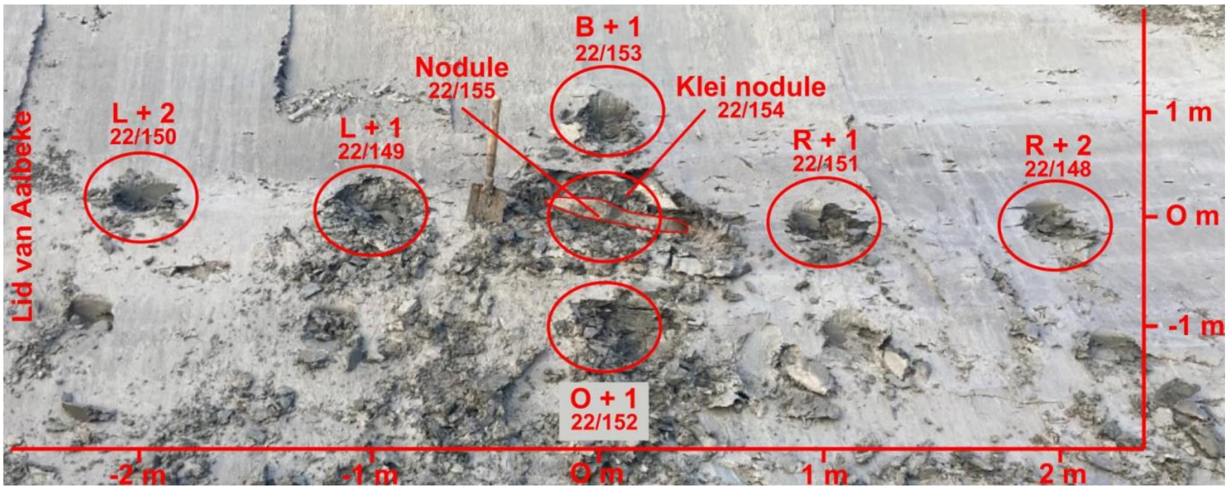

Figure 5. *Picture of the sampling strategy that was applied in the vicinity of a clay nodule in the Kortrijk Formation by Croenen (2022).*

3. Preliminary conclusions

An initial analysis of diffraction hyperbolae on seismic profiles of the Kortrijk Formation that were acquired in the Princess Elisabeth-zone (BPNS), indicate that on specific locations dense features may be (abundantly) present in the clay sediment. Recent land-based observations in a clay pit in the Member of Aalbeke (Kortrijk Formation) may reveal a potentional candidate for these dense objects, as siderite- and phosphate-bearing carbonate nodules have been reported, scattered throughout the entire clay layer.

Claystone layers within the Ieper Clay Group were also included as a geohazard for the installation of offshore wind farms in the Geological Desk Study of the Princess Elisabeth Zone that was conducted on behalf of the FPS Economy SMEs, Self-Employed and Energy (O'Leary et al. 2022). In this respect the following was mentioned: *no information is available for the depth of the claystone and therefore until a site-specific geotechnical campaign is completed, the depth of occurrence and likelihood of encountering within 100 m cannot be confirmed*.

It should be emphasized that the current note only provides **preliminary findings** and that the topic of the diffraction hyperbolae in the seismic profiles of the Kortrijk Formation will be further investigated in the context of the Clay Tectonics project in order to come to fully underpinned conclusions.

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