DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE **RAPPORT 2021/37**

A basic geological complexity map for use in the implementation of the MapField concept

Peter B. E. Sandersen

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
DANISH MINISTRY OF CLIMATE, ENERGY AND UTILITIES

G E U S

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Contents

1. Summary

The ‘Geological Complexity Map’ subdivides the Danish onshore area in four classes of expected geological complexity. The map is a basic, low-resolution map based on existing maps with added general and specific geological knowledge. The map is exclusively intended as input to a prioritization tool for implementation of the MapField concept and only for assessments of the expected geological complexity in and around selected ID15 catchments (approximately 1500 hectares each).

The different landscape types in Denmark are indicative of the geology that can be expected to be found beneath the surface in the way that they represent a volume with its own formation history, dominant lithologies, and related structures. Thus, for each landscape type and corresponding underlying volume, the lithology and the expected structural complexity can be described in general terms based on geological background knowledge. Basically, the geology at a given location consists of ‘stacked’ landscapes and associated geological layers, and therefore the geological complexity of the subsurface should be considered as a combination of the complexity of the individual, stacked landscape types. For simplicity, only the two uppermost landscape types are included in the map. This interval – c. the uppermost 30 m - is considered most important, because this is the interval in which most nitrate retention takes place.

Just as the geological complexity map is a basic map, it should also be seen as a preliminary map in the sense that with time and with an increasing number of areas covered with detailed mapping in the coming years, the geological complexity map can be updated and refined.

2. Introduction

A targeted nitrogen (N) regulation in agriculture requires detailed knowledge of both the geological and geochemical setting and the nitrate transport paths and reduction processes (Hansen et al., 2021). In the MapField project, a new concept and technologies integrating interpretation of data from high-resolution geophysical mapping, borehole information, sediment colour, geochemistry, and groundwater chemistry are developed in order to generate N-retention maps at field level for use in an anticipated future more targeted N-regulation. The generated knowledge in MapField is important for implementation of the political vision of more targeted N-regulation of Danish agriculture (Hansen et al., 2021).

Complex redox structures are often found in heterogenous geological settings because of complicated water flow paths, varying mineral content and reactivity of reductants in the geological layers (e.g. Hansen and Thorling, 2008) and new MapField results stresses the importance of detailed mapping of the spatial relationships between geology and geochemistry (Kim et al., 2019, 2021; Hansen et al., 2021).

However, for future implementation of the MapField concept at a national scale, an initial prioritization tool is required for ranking agricultural areas in classes from low to high priority in relation to implementing the MapField concept. An initial prioritization tool will have to include a number of different parameters, and because of the importance of the geological architecture in relation to redox conditions, the tool should therefore include an assessment of the geological complexity.

Several 2D maps covering themes such as surface geology, pre-Quaternary geology, geomorphology, and topography, are available for the Danish area, but a national scale assessment of geological complexity does not exist. Earlier work has focused specifically on mapping glaciotectonic deformation of the subsurface as interpreted from borehole data, outcrops, seismic data, geomorphological maps, and topography (Jakobsen, 2003). This work enabled correlation of glaciotectonic features with specific ice advances related to the two latest glaciations (Figure 2.1). Another map, using the so called ‘Poly Morphological (PM) concept’ was constructed to assess geological heterogeneity in glacial sediments - especially tills (Figure 2.2; Klint et al., 2013). The PM concept identifies areas in the glacial terrain that in terms of fracture and sand lens distribution can be considered as having a characteristic geological heterogeneity. Because this map has only been made for Zealand and surrounding islands, and because it focuses on tills, the applicability in the MapField project is at this point considered as low, but the concept of evaluating superimposed landscapes is considered to be highly relevant. The glacial processes that form glacial landscapes are highly dynamic and typically younger landforms are superimposed on older landforms. The sedimentary succession of the Danish subsurface therefore represents stacked landforms and thereby a stacked representation of erosive, depositional, and deformational events.

A rather new 3D hydrostratigraphic model with a nation-wide coverage is constructed as a layer model of the uppermost 200-300 m focusing on aquifers and aquitards (the ‘FOHM’ model; Arvidsen et al., 2020). The model is based on existing models and data from the national groundwater mapping program and is intended for management of groundwater resources. Because of this, and because it does not include high-resolution data such as tTEM, the resolution of the uppermost tens of meters is fairly low. The model is therefore not considered as a first choice for construction of a geological complexity map.

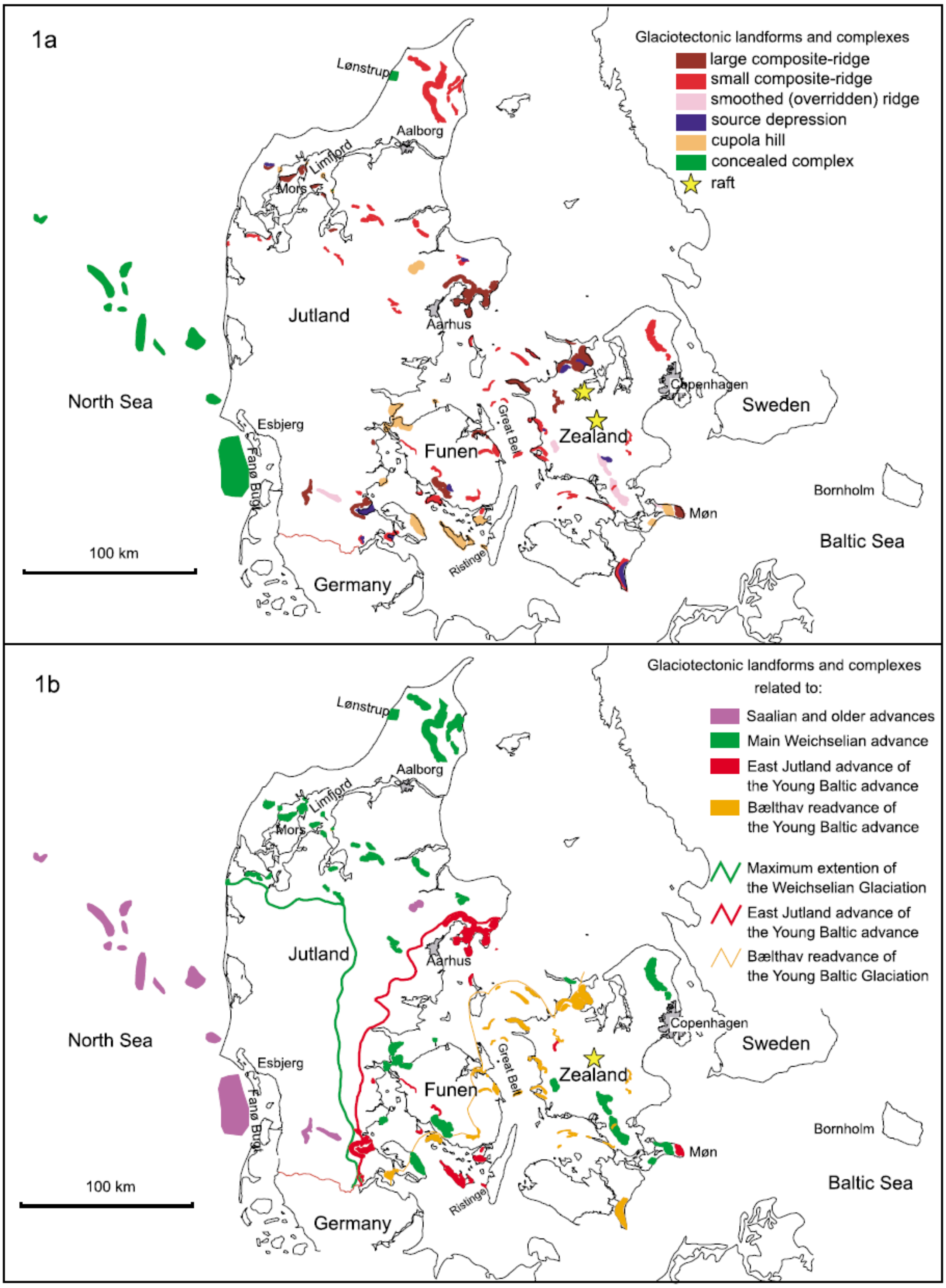

Figure 2.1: 1a — Glaciotectonic Map of Denmark, showing the distribution of glaciotectonic landforms and features; 1b — Event stratigraphic map showing the distribution of glaciotectonic features related to ice advances of Saalian (and older) and Weichselian ice advances. From Jakobsen (2003).

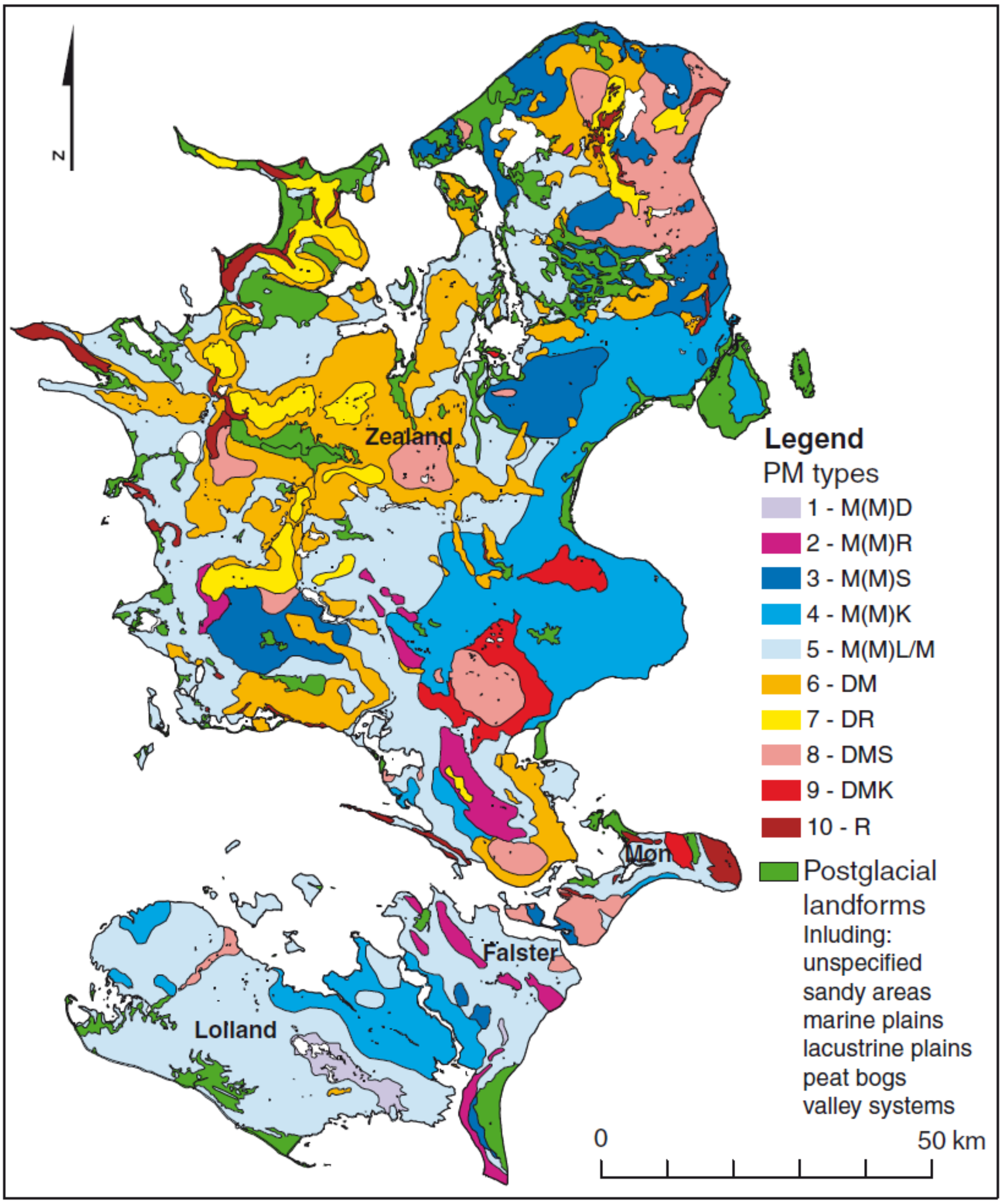

Figure 2.2: Poly Morphological map of Zealand and surrounding islands. PM units: M undulating till plain, D hummocky moraine, S outwash plain, R marginal moraine, K basement limestone, L basement marine clay. From Klint et al. (2013).

Construction of a detailed geological complexity map for the uppermost part of the Danish area will require a dense, nation-wide grid of highly detailed data and a detailed national 3D geological model in which all data are integrated, and as of now, this is not available. Therefore, a national map of geological complexity will have to be generated by synthesizing existing national maps and adding general geological knowledge. As no specific map of geological complexity exists, the maps used for construction of a geological complexity map will encompass themes such as geomorphology, topography, and surface lithology.

The ‘Geological Complexity Map’ presented in this report is a basic, low-resolution map exclusively intended as input for the MapField prioritization tool and only for preliminary assessments of the expected geological complexity in and around selected catchments. Based on existing maps and general and specific geological knowledge, the map subdivides the Danish onshore area in four classes of expected geological complexity. Due to the scale of the existing maps, the geological complexity map is not intended to be used at scales finer than these maps (ca. 1:300.000). The geological complexity map aims to cover the upper 30 m of the subsurface because this is the interval in which most nitrate retention takes place.

A national geological complexity map will only be able to give an overall picture of the expected geological complexity based on existing maps and general geological knowledge. But considering the intended use of such a map, this is considered acceptable. The goal of the map is to provide a general picture of the level of expected geological complexity to be used in the MapField prioritization process.

3. Data and methods

3.1 Geological complexity: Definitions and contributors

In the context of the MapField project we define *'geological complexity'* as the sum of lithological variations, erosion, and deformation of the original geological layers/formations in an area.

Contributors to geological complexity can be:

- Lithological changes in the sedimentary environment (facies changes)
- Aeolian erosion and sedimentation
- Fluvial erosion and sedimentation
- Glacial erosion and deposition
- Glaciofluvial erosion and sedimentation
- Glaciotectonic deformation
- Deformation related to movement of salt structures
- Deformation not related to salt structures (Pre-Quaternary and Quaternary tectonics)

The degree of geological complexity is highly dependent on the scale at which we observe. Complexity in geology is present at all scales, but not all of this complexity is relevant in MapField where focus is on the uppermost tens of meters of the subsurface. Within the areas mapped with tTEM, the horizontal spacing between survey lines is at best around 20 to 30 m and the vertical resolution of the individual tTEM models is up to a few meters. The voxel models constructed in the MapField study areas have a voxel grid discretization of 25 x 25 x 2 m (Madsen et al., 2021) matching the resolution provided by the tTEM data, meaning that smaller sized facies variations and structures will not be represented.

3.2 Geological setting

The Danish landscape and the near-surface geology are to a large degree formed by the action of glaciers and their meltwater during the Pleistocene. The geological setting of the uppermost 200-300 m comprises Cretaceous limestone and chalk at depth, overlain by Paleogene and Neogene sandy and clayey sediments, and on top of that, Quaternary deposits of varying thickness.

The landscape shows a variety of landforms and landscape types. The map in Figure 3.1 subdivides Denmark into 9 different landscape types (Aarhus University, 2005). The landscape in West Jutland represents the old glacial landscape (Saalian) of the hill-islands surrounded by the flat, sandy, outwash plains ('meltwater plains'; Lateglacial) and marsh-areas close to the coast (Postglacial). This contrasts with the younger glacial landscape ('Weichselian moraine') that can be found in most of the remainder part of the country. This young, hilly glacial landscape is furrowed by tunnel valleys and meltwater valleys now partly filled with Lateglacial sand/clay and Postglacial freshwater or marine sediments. Surrounding the hilly young glacial landscape in predominantly North Jutland and Himmerland are Lateglacial marine (‘Yoldia’) and Postglacial marine sediments (‘Littorina’). Spread across primarily West Jutland and along the coastlines of Thy/North Jutland are patches of aeolian dunes covering older landscapes and sediment types. The crystalline basement can only be found exposed in small areas on the island of Bornholm.

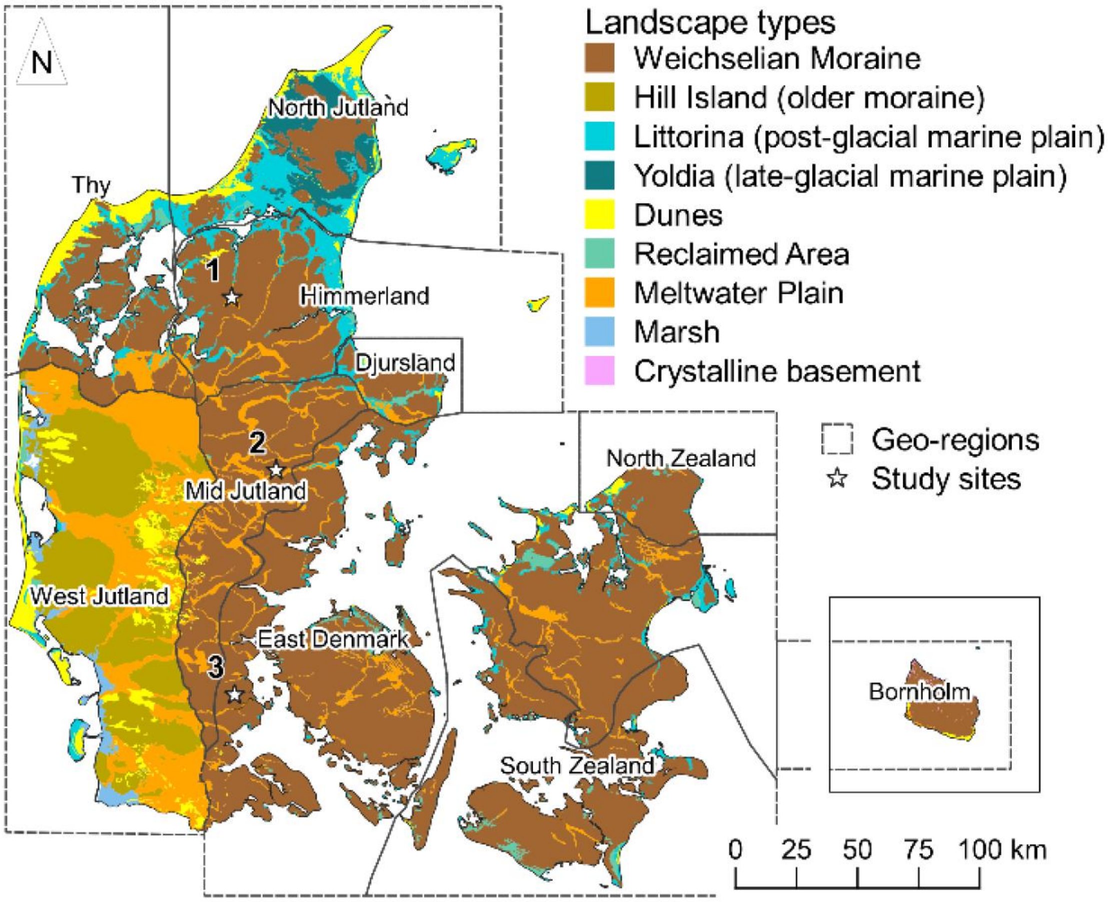

Figure 3.1: Simplified map of Danish landscape types (Figure from Hansen et al. 2021). Map from Aarhus University, 2005. The annotated study sites are not relevant to the present work.

3.3 Geological complexity of the landscape types

The different landscape types are indicative of the geology that can be expected beneath the surface, and therefore each of the landscape types used in the map described above (Figure 3.1), can be considered to represent the surface of a volume with its own geological formation history, dominant lithologies, and related structures. Thus, for each landscape type and corresponding volume, the lithology and the expected structural complexity can be described in general terms based on geological background knowledge:

A) **Aeolian dunes ('Dunes'):** The aeolian dunes represent sand which has been eroded by wind and subsequently deposited close to the sea or on inland flats. The lithology is predominantly fine-grained and well-sorted sand with occurrences of peaty layers. The internal erosional and depositional structures can be complex, but this is not relevant in the present case. The aeolian dunes are Postglacial.

   Structural complexity: Low

   Examples: Lodbjerg (Clemmensen et al., 2001), Skovbjerg hill-island (Larsen & Kronborg, 1994), Frøslev (Kolstrup & Jørgensen, 1982), Vejers (Clemmensen & Murray, 2006).

B) **Reclaimed areas:** The reclaimed areas represent low-lying areas that have been artificially drained. The areas are former fiords, marine foreland, or lakes, and the lithology therefore encompass clayey and sandy marine or freshwater sediments. The sediments are most likely undeformed and typically horizontally layered. The reclaimed areas are Postglacial.

   Structural complexity: Low

   Example: Bøtø (Mogensen et al., 2000).

C) **Marsh:** The marsh represents low-lying areas close to present-day tidal coasts where frequent marine inundations occur. The marsh is flat with shallow run-off gullies and with low, halophile vegetation. The sediments of the marsh are typically clayey with a high organic content and dominated by horizontal layering.

   Structural complexity: Low

   Example: Skallingen (Bartholdy et al., 2018).

D) **Young marine flats ('Littorina; Postglacial marine plain'):** The young marine flats represent marine sediments from the Littorina Sea that inundated low-lying areas around 7000 years ago. The lithology is dominated by clayey and sandy marine sediments. The sediments are predominantly undeformed and typically horizontally layered except for near-shore environments where erosional structures can be present. Post-depositional erosion of the marine flats is common. The young marine flats are Postglacial.

   Structural complexity: Low

   Examples: Varde (Pedersen et al., 2009), Skagen Spit (Knudsen et al., 2009).

E) **Old marine flats ('Yoldia; Lateglacial marine plain'):** The old marine flats represent marine sediments from the Yoldia Sea that inundated low-lying areas around 18000 to 12000 years ago. The lithology is dominated by clayey and sandy marine sediments. The sediments are predominantly undeformed and typically horizontally layered except for near-shore environments where erosional structures can be present. Lateglacial tectonic deformation of the marine sediments has been described in North Jutland (e.g. Brandes et al., 2018). Although faults and depressions have been described, they are of a size that does not require an inclusion in the geological complexity map given the scale used. Post-depositional erosion of the marine flats is common. The young marine flats are Lateglacial.

Structural complexity: Low

Example: Sønder Rubjerg (Pedersen, 2005).

F) **Outwash plain ('Meltwater plain'):** The outwash plains represent gently sloping plains of meltwater sediments deposited in front of the Late Weichselian ice sheet. The sediments are dominated by sand and gravel, with the coarsest material being deposited close to the ice margin and the finest material at greater distances. The sediments are generally undeformed and typically show an overall horizontal layering, but due to the dynamic sedimentary environment, the outwash plain sediments typically show a complex internal architecture. Postglacial tectonic deformations of outwash plain sediments have been described at some locations in Jutland (e.g. Sandersen & Jørgensen, 2015). Although these deformations are interpreted to have created topographic depressions filled with Postglacial lake sediments and peat, they have not been included in the complexity map – primarily because of the map scale. The outwash plains are Lateglacial.

Structural complexity: Low

Examples: Karup outwash plain (Møller & Vosgerau, 2005).

G) **Young glacial landscape ('Weichselian moraine'):** The young glacial landscape is formed by the latest ice advances that reached the Danish area. The landforms that can be observed in the landscape today is therefore predominantly a result of the action of glaciers and their meltwater. The sediments consist of sandy and clayey tills, and meltwater clay, silt, sand, and gravel. The forces exerted by the moving glacier ice have typically resulted in deformations of the underlying sediments, and generally it should be expected that the sediments of the young glacial landscape are heavily deformed – especially in and around hills representing temporary ice-marginal standstills. Glaciotectonic complexes in Denmark often show deformations down to 200 to 300 meters below the surface. Adding to the subsurface complexity of the young glacial landscape is the occurrence of buried tunnel-valley structures (Sandersen & Jørgensen, 2017) and fractures in tills. However, for the sake of simplicity we only take large-scale deformations into consideration in the present complexity map. The young glacial landscape is primarily formed during the Weichselian glaciation, but when looking at the 'volume' of this landscape, it is not possible to properly distinguish Weichselian sediments from glacial sediments related to older glaciations because of very sparse dating of sediments. However, in the context of MapField, the important thing is whether the sediments have a complex build or not.

Structural complexity:
- *Ice margins: High*
- *Hilly glacial landscape: Moderate to high*
- *Smooth glacial landscape: Low to moderate*

Examples: Rubjerg Knude (Pedersen, 2005), Javngyde (Kim et al. 2019), Stokkemarke (Pedersen et al., 2015).

H) **Old glacial landscape ('Hill-island; older moraine'):** The old glacial landscape is only found exposed on the hill-islands of West Jutland. The landscape is smooth and formed by the action of the glaciers of the Saalian glaciation, but particularly by erosion by wind and water during the long period since the Saalian ice left the area around 130000 years ago. The sediments consist of sandy and clayey tills, meltwater clay, silt, sand, and gravel from the Saalian and older glaciations, and occasionally sediments from the intervening interglacials. Just as for the young glacial landscape, the glacier ice has typically caused deformation of the underlying sediments, and generally it should be expected that the sediments of the old glacial landscape are highly deformed. Adding to the subsurface complexity of the old glacial landscape is the occurrence of buried tunnel-valley structures (Sandersen & Jørgensen, 2017). The old glacial landscape is underlain by marine and continental Miocene sediments.

Structural complexity: Moderate to high

Example: Ølgod (Høyer et al., 2013).

I) **Precambrian basement ('Crystalline basement'):** The Precambrian basement represent the oldest rocks found in the Danish area. They consist of granite and gneiss and is only found in the near-surface domain on Bornholm and is only exposed along the coast and in smaller areas in-land. The basement is fractured.

Structural complexity: Low

Example: Bornholm (Gravesen et al., 2014).

3.4 Geological complexity map concept

As mentioned earlier, the geology at a given location consists of 'stacked' landscape types and therefore the total geological complexity should be considered as a combination of the complexity of the individual, stacked landscape types.

An example of stacked landscapes can be seen in Figure 3.2. The cross-section shows a highly deformed lower part with steeply inclined layers of tills and meltwater sand and gravel glaciotectonically deformed at an ice margin. This sequence is overlain by an almost horizontally layered succession of till and meltwater sand representing a succession deposited by the advancing glacier. Even though the example shows two superimposed, young glacial landscapes, it illustrates the shifting complexity of the subsurface – even within the uppermost parts.

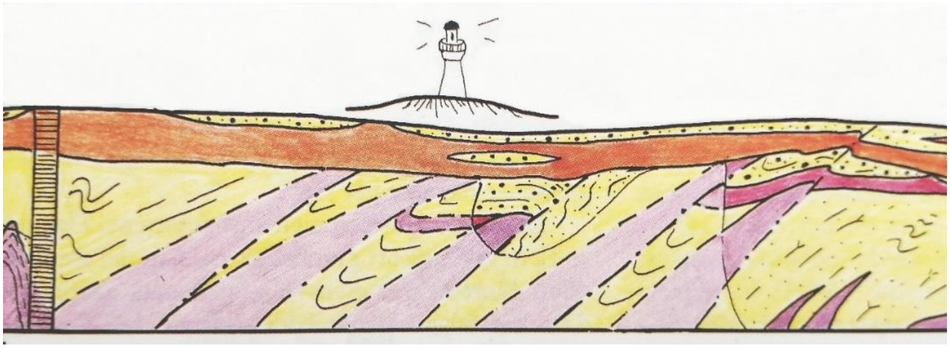

Figure 3.2: Sketch of the cliff-section at Bovbjerg Lighthouse, Northwest Jutland. (Ca. 500 m long, ca. 35 m high; ca. 3,5 x vertical exaggeration). Brown and purple: tills; yellow: meltwater sand/gravel. Modified from Larsen & Kronborg (1994).

For the geological complexity map, we therefore wish to combine the inferred complexity of the uppermost landscape type as seen on the map in Figure 3.1 with the complexity of the older landscape type just below. However, the landscape type below is not covered by any national map, so the landscape type and inferred complexity must therefore rely on general geological knowledge, either regional or local.

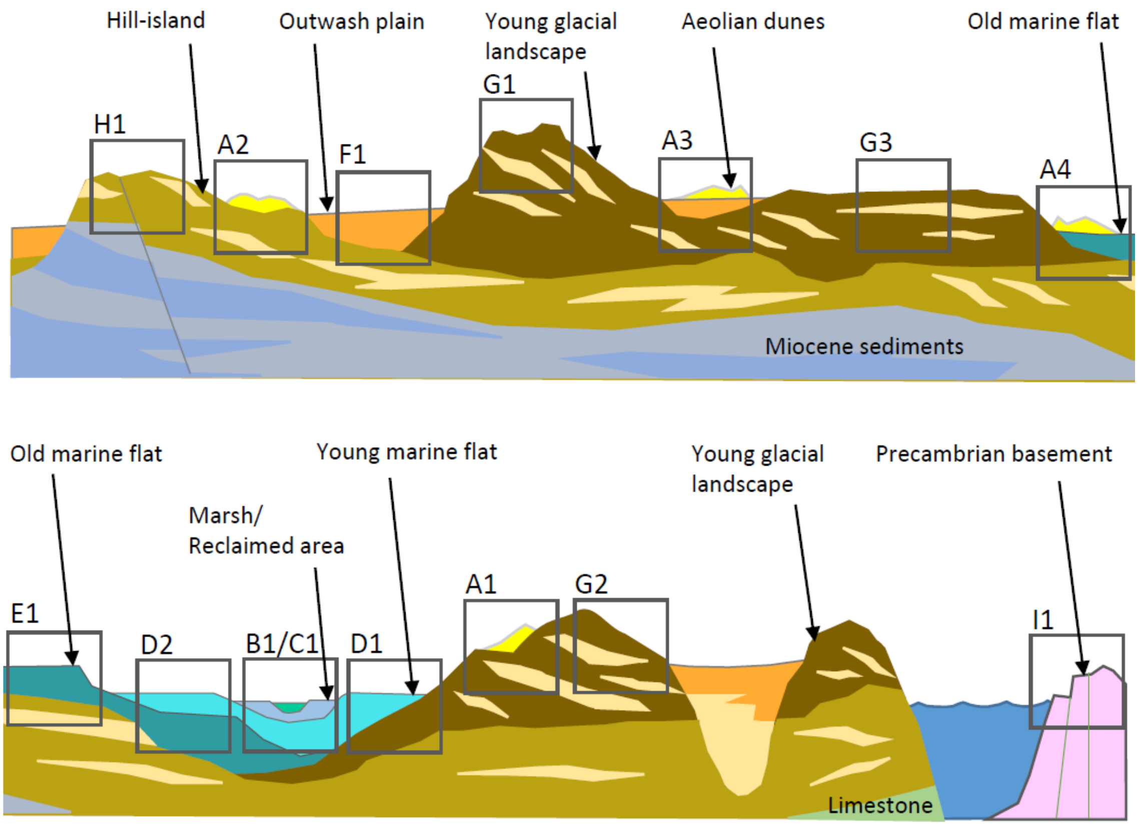

Figure 3.3: Sketch of superimposed landscape types. Colours follow the legend in Figure 3.1, except for the Miocene sediments (sand: blue-gray; clay: blue), Paleocene limestone/Cretaceous chalk (green) and Quaternary meltwater sand (pale yellow). The rectangles and signatures refer to the landscape types shown in Figure 3.4.

Unit	Sub-unit	Landscape type - Upper	Landscape type - Lower	Complexity			C-index
				Upper part	Lower part	Combined	1-3
A	1	Aeolian dune	on young glacial landscape	Low	Low to high	Low to high	2
	2	Aeolian dune	on hill-island	Low	Moderate to high	Low to high	2
	3	Aeolian dune	on outwash plain	Low	Low	Low	4
	4	Aeolian dune	on Lateglacial or Postglacial marine flat	Low	Low	Low	4
B	1	Reclaimed area	former lake or marine fiord	Low	Low to high	Low to moderate	3
C	1	Marsh	on older flats (marine/non-marine)	Low	Low to high	Low to moderate	3
D	1	Young marine flat (Littorina)	on older sediments (glacial/non-glacial)	Low	Low to high	Low to moderate	3
	2	Young marine flat (Littorina)	on older marine flat (Yoldia)	Low	Low	Low	4
E	1	Old marine flat (Yoldia)	on older sediments	Low	Low to moderate	Low to moderate	3
F	1	Outwash plain	on older sediments	Low	Low to high	Low to moderate	3
G	1	Young glacial landscape, ice-margins	on older landscape/sediments	High	Low to high	High	1
	2	Young glacial landscape, hilly	on older landscape/sediments	Moderate to high	Low to high	Moderate to high	2
	3	Young glacial landscape, smooth	on older landscape/sediments	Low to moderate	Low to high	Low to moderate	3
H	1	Old glacial landscape (Hill-island)	on older landscape/sediments	Moderate to high	Moderate to high	Moderate to high	2
I	1	Precambrian basement	-	Low	-	Low	4

High	1
Moderate to high	2
Low to high	
Moderate	3
Low to moderate	
Low	4

Figure 3.4: Geological complexity of upper and lower landscape types respectively, and in combination. The combined complexity is expressed as a 'C-index' ranging from High (1) to Low (4).

Figure 3.4 shows the combination of an ‘Upper landscape’ and a ‘Lower landscape’ using the 9 landscape types of the map in Figure 3.1. The figure shows that when combining two landscape types, the number of possible combinations increase. For example, aeolian dunes can be found deposited on four different landscape types resulting in four different combinations (A1 to A4). This is illustrated in Figure 3.3, where the possible combinations of two superimposed landscapes are highlighted with gray squares.

The inferred complexity of the landscape types of the upper part is described in Section 3.3, and this is also used as a template for the lower part. The combined complexity is a qualitative combination of the complexity of the upper and the lower parts, for instance with added existing knowledge of layer thickness. The combined geological complexity is expressed as a ‘C-index’ ranging from High (1) to Low (4) (see Figure 3.4).

3.5 Data used

The primary data used for the geological complexity map is the landscape type map in Figure 3.1 as it delineates the present-day landscape types. The map is available in ArcGIS and MapInfo-formats, and is based on topographical maps in 1:100.000, and information from geomorphological maps, geological maps, and soil maps, generally using coarser scales (https://dca.au.dk/forskning/den-danske-jordklassificering).

The secondary data used as support are

- Topography (Digital Elevation Models based on LiDAR data: www.kortforsyningen.dk)
- Surface geology maps (Jakobsen & Touborg, 2020; Jakobsen 2003)
- Geomorphological maps (Smed, 1978)
- Borehole data (Jupiter database; www.geus.dk)
- Geological publications on Danish near-surface geology (i.e. see section 3.3)

3.6 Procedure for collating and interpreting data

The polygons of the individual landscape types of the Aarhus University map were extracted. Based on knowledge of the landscape type underneath (see Section 3.4), the individual polygon themes of the landscape types were then split into separate files using the Clip function in QGIS. The result of this was the 15 theme maps shown in Table 1.

A – Aeolian dunes: The aeolian dunes can be found superimposed on the young glacial landscape (A1), the old glacial landscape (hill-islands) (A2), the outwash plains (A3) and on marine flats (A4), and therefore a subdivision of the aeolian dunes GIS theme in four subthemes was necessary. For this purpose, temporary polygons were used. Along the coastline of Jutland, a subdivision (on the young glacial landscape and on marine flats) was made using general knowledge, local mapping, and the Jupiter database. Dunes on the outwash plain and the old glacial landscape was done by clipping the overlap between the GIS themes ‘Dunes’ and the ‘hill-island’ and ‘Meltwater plain’ respectively (the Aarhus University map; Figure 3.1).

Table 1: MapInfo TAB-files for each of the combined landscape types (see Figure 3.4).

A1_aeolian_on_young_gl.tab
A2_aeolian_on_hill_island.tab
A3_aeolian_on_outwash_plain.tab
A4_aeolian_on_marine_flats.tab
B1_reclaimed_on_old flat.tab
C1_marsh_on_old flat.tab
D1_young_marine_on_old_sedim_2.tab
D2_young_marine_on_old_marine_2.tab
E1_old_marine_on_old sedim.tab
F1_outwash_on_old_sedim.tab
G1_ice-marg_young_gl_on_old_sedim.tab
G2_gentle_young_gl_on_old_sedim.tab
G3_smooth_young_gl_on_old_sedim.tab
H1_old_gl_on_old_sedim.tab
I1_precambrian_basement.tab

B – Reclaimed areas and C – Marsh: The outlines of the 'Reclaimed area' and the 'Marsh' themes of the Aarhus University map was used directly.

D – Young marine flats: The young marine flats represent Littorina Sea sediments. In Northern Jutland these sediments are generally superimposed on the older marine flats representing the Yoldia Sea (E). The southern limit of the Yoldia Sea was supposedly along a line going from northwest from Jammerbugt and to the southeast to Randers Fjord (Larsen et al., 2009). The 'Littorina' theme of the Aarhus University map was therefore split along this line, resulting in D1 south of the line (Littorina sediments on sediments older than the Yoldia sediments) and D2 north of the line (Littorina sediments on older Yoldia sediments).

E – Old marine flats: The outline of the 'Yoldia' theme of the Aarhus University map was used directly.

F – Outwash plain: The outline of the 'Meltwater plain' theme of the Aarhus University map was used directly.

G – Young glacial landscape: The young glacial landscape represents a landscape that has been formed by the different ice-advances during the Weichselian glaciation. The youngest geological events therefore have a high chance of being visible in the present-day landscape. Thus, the morphology of the young glacial landscape can be used to point out ice-marginal standstills where glaciotectonic deformations are expected to be especially intense (G1), hilly areas presumably with some glaciotectonic deformation (G2), and more smooth glacial landscapes, where deformations are considered less intense (G3).

The map of glaciotectonic deformations of Jakobsen (2003), Figure 2.1, shows areas of known glaciotectonic deformation, and together with the geomorphological maps of Smed (1979), it is possible to sketch areas, where the degree of deformation is expected to be especially intense. This has resulted in the G1-areas (young glacial landscape, ice-margins). However, it should be noted, that these areas are not precise delineations of deformed areas, but merely areas of hills in which the sedimentary succession is expected to be intensely deformed. On the other hand, some parts of the glacial landscape appear very smooth and thus expected to be less deformed. These areas are labelled G3. The areas in-between these two landscape types are hilly glacial areas without pronounced ice-marginal hills. These areas are labelled G2. The G1 areas were subtracted from the G2 areas in QGIS.

H – Old glacial landscape: The outline of the 'Hill-island' theme of the Aarhus University map was used directly.

I – Precambrian basement: The outline of the 'Crystalline basement' theme of the Aarhus University map was used directly.

3.7 Combined geological complexity

The combined geological complexity index 'C' (Figure 3.4) was then applied to each of the 15 polygon themes (Table 1) using a colour code as shown in Table 2.

Table 2: The combined geological complexity index 'C' and related colour code.

Geological complexity	C-index	RGB-colours
High	1	R: 255, G: 127, B: 0
Moderate to high	2	R: 255, G: 255, B: 0
Low to high		
Moderate	3	R: 100, G: 215, B: 238
Low to moderate		
Low	4	R: 0, G: 250, B: 50

4. Results and discussion

4.1 The geological complexity map

The final geological complexity map is shown in Figure 4.1. The colours refer to Table 2.

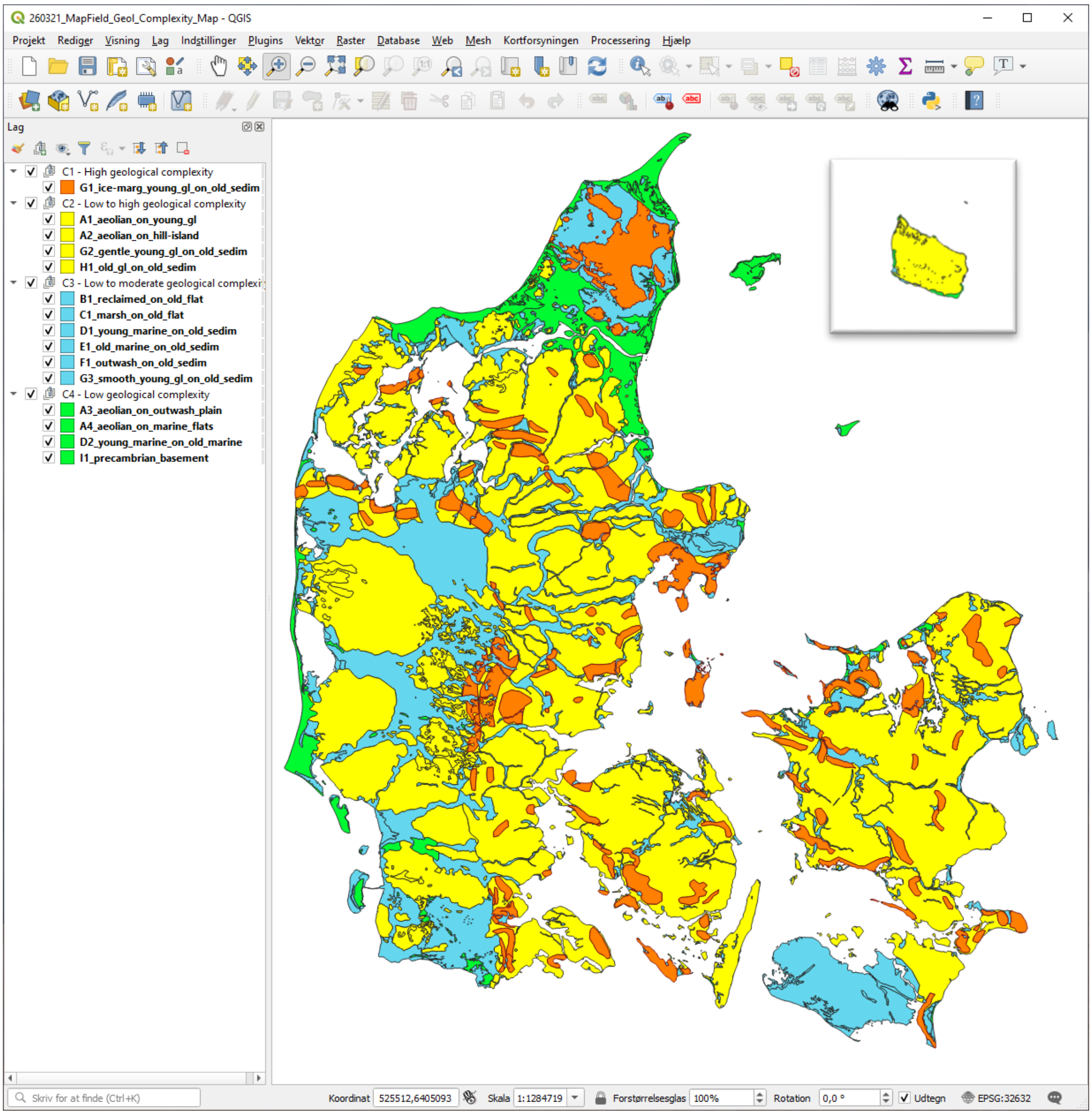

Figure 4.1: The geological complexity map showing the C-index (Figure 3.4 and Table 2) for each of the combined landscape types shown to the left. NB: Bornholm has been inserted onto this screen-capture.

The map is available as a QGIS project (260321_MapField_Geol_Complexity_Map.qgz). Supplementary information is available in an Excel spreadsheet (100221_MapField_Geol-_Complexity_Map_Suppl.xlsx).

4.2 Discussion

As mentioned earlier, the map is a basic, low-resolution map exclusively intended as input for the MapField prioritization tool and only for assessments of the expected geological complexity in and around selected catchments. The basis for the geological complexity map is the existing map of landscape types from Aarhus University (2005), whereas other types of data and background knowledge have only been used as support for making the map. Other data types such as mapped buried tunnel valleys, detailed geomorphological maps, local and regional geological models, and maps etc. have - for the sake of simplicity - not been used.

The map therefore has limitations that the user should be aware of:

- The map illustrates the expected level of geological complexity of the upper c. 30 meter of the subsurface only.
- The individual landscape types on the Aarhus University map are delineated based on topographical maps, geomorphological maps, geological maps, and soil maps. The topographical map is in 1:100.000 whereas the other maps use different scales. This means that there can be inconsistencies between the delineation of the individual landscape types in the geological complexity map when compared to other maps. This is especially the case for the geomorphological map by Smed (1978) which is in 1:360.000 and not available digitally, and the surface geology map by Jakobsen & Touborg (2020) available in 1:25.000.
- As seen on Figure 3.2 from Bovbjerg, a smooth young glacial landscape covers slightly older and very intensely deformed sediments. It should be noted, therefore, that, the sub-categorisation used for the G-areas can be deceptive; even beneath a smooth glacial landscape, intense deformation can be present.

Just as the geological complexity map is a basic map, it should also be seen as a preliminary map in the sense that with time and with an increasing number of areas covered with detailed mapping in the coming years, the geological complexity map can be updated and refined.

5. Conclusion

The ‘Geological Complexity Map’ is a basic, low-resolution map exclusively intended as input for the MapField prioritization tool and only for assessments of the expected geological complexity in and around selected catchments. Based on existing maps and general and specific geological knowledge, the map subdivides the Danish onshore area in four classes of expected geological complexity. The map is available as a collection of MapInfo tables in a QGIS project.

Just as the geological complexity map is a basic map, it should also be seen as a preliminary map in the sense that with time and with an increasing number of areas covered with detailed mapping in the coming years, the geological complexity map can be updated and refined.

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