3-D Forward Modeling and Simulation of Sediment Flow: Distribution and Deposition, Ormen Lange Gas Field *

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Methods and Geologic Setting

The deterministic process-based software MassFLOW-3D™ has been developed and successfully used to construct a process-based, 3D model for the simulation of turbidity currents. All principal hydraulic properties of the flow and its responses to topography can be continuously monitored in 3D. Computational fluid dynamics (CFD) is a tool for numerical solutions of the physical equations describing fluid flow and sediment transport. The method has been widely applied in the engineering branches of fluid mechanics but has been little used in sedimentological research. Currently MassFLOW-3D™ is being developed to fill the gap between small laboratory experimental scale and large field scale, integrating data from theory, nature, and experiments. It can also shed light on flow parameters which are so far impossible to deduce from experimental and field studies.

The present study is aimed to evaluate, with deterministic process-based modeling, the sediment flow behavior and distribution of sand in the Ormen Lange field. This gigantic gas field, located 120 km northwest of Møre coast, Mid-Norway (Figure 1) was discovered in 1997 at a depth between 800 and 1100 m. (3280 feet) below sea level, where the gas-bearing layers of sand are about 50 meters thick; they were deposited by turbiditic currents onto the basin floor. The reservoir is 40 km long and 8 km wide, covering an area of 350 km^2 (217 mi^2) The Ormen Lange Field provides an ideal topography to test, validate, and evaluate the potential of MassFLOW-3D^{TM} software results. The subtle variation of the palaeo bathymetry with some interesting features, such as two depressions and a "bypass channel" (see Figure 3) connecting them, are an ideal "playground" for our study. Particular attention is given to the evaluation of a possibility that the sediments, coming from a single source point located in the southeastern side of the basin, could fill the two existing depocenters and to the understanding of how subtle changes in topographic relief could affect the sediment flow.

Analysis and Results

In order to run a process-based forward, fully 3D, numerical simulation, the bathymetry at the time of deposition by turbidity currents had to be reconstructed (the palaeo-bathymetry). This was performed from the available seismic data by back-stripping (removing sequentially and de-compacting (removing the overburden)) and flattening (removing possible tectonic effects) the sediment layers present above the desired surface.

After generating the desired surface (in our case, the "Base" surface of Figure 2), a number of different runs was performed. Multiple grain sizes, as observed in the cores, were represented, showing how the presence of fine sand modifies the flow deposition. Different realizations, having realistic conditions (position of the flow inlet, flow size and velocity, grain distribution, single-sustained flow vs multiple flows) were analyzed, observing different possible scenarios aimed at reproducing the stratigraphy observed from the core samples (Figure 4).

One significant achievement is the verification that the flow coming from one single source point was capable of filling both depocenters, reproducing realistically what was mapped in the available well cores. The sediment transport directions are considered to be mainly to the north, due to subtle topographic confinement to the east and west (Figure 3).

In the experiment(s) coeval sedimentation occurs in the depocenters with the areas in between possibly acting as a bypass zone, dominated by erosion and sediment re-suspension. As the primary topographic relief was gradually smoothed out by sediment accumulation, the whole area began to act increasingly as a bypass zone (Figure 5).

Fine sediments travel farther within the simulated area, whereas the coarser ones settle in a more proximal region. By increasing the percentage of coarser sediments, the particles deposit at first in the proximal depression rather than flowing towards the second depocenter. Nevertheless, even a small percentage of fine sediments enhances the "run-out" of the flow, allowing it to reach the distal pond and to begin deposition there at the same time as in the proximal pond.

A single, sustained flow creates a sediment layer which covers simultaneously both the proximal and the distal depocenters, uniformly draping the topographic relief; on the other hand, a system of subsequent surges have the tendency to "fill-up-and-level" the first depression before spilling into the distal basin.

More information from the cores could give more indication about the nature of the flows (i.e., if they are erosional or depositional, grain size, flow direction, single surge or multiple), reducing the number of plausible scenarios. erosional or depositional, grain size, flow direction, single surge or multiple), reducing the number of plausible scenarios. In fact, several different boundary conditions may lead to similar depositional basins. Nevertheless only the finer structure observed in the cores can give indications for narrowing the possibilities from several plausible flows to a specific one capable of creating the different layers observed.

Reference

Moeller, N.K., J.G. Gjelberg, L.J. Martinsen, M.A. Charnock, R.B. Faerseth, S. Sperrevik, and J.A. Cartwright, 2004, Geological model for the Ormen Lange reservoir: Norwegian Journal of Geology, p. 169-190.

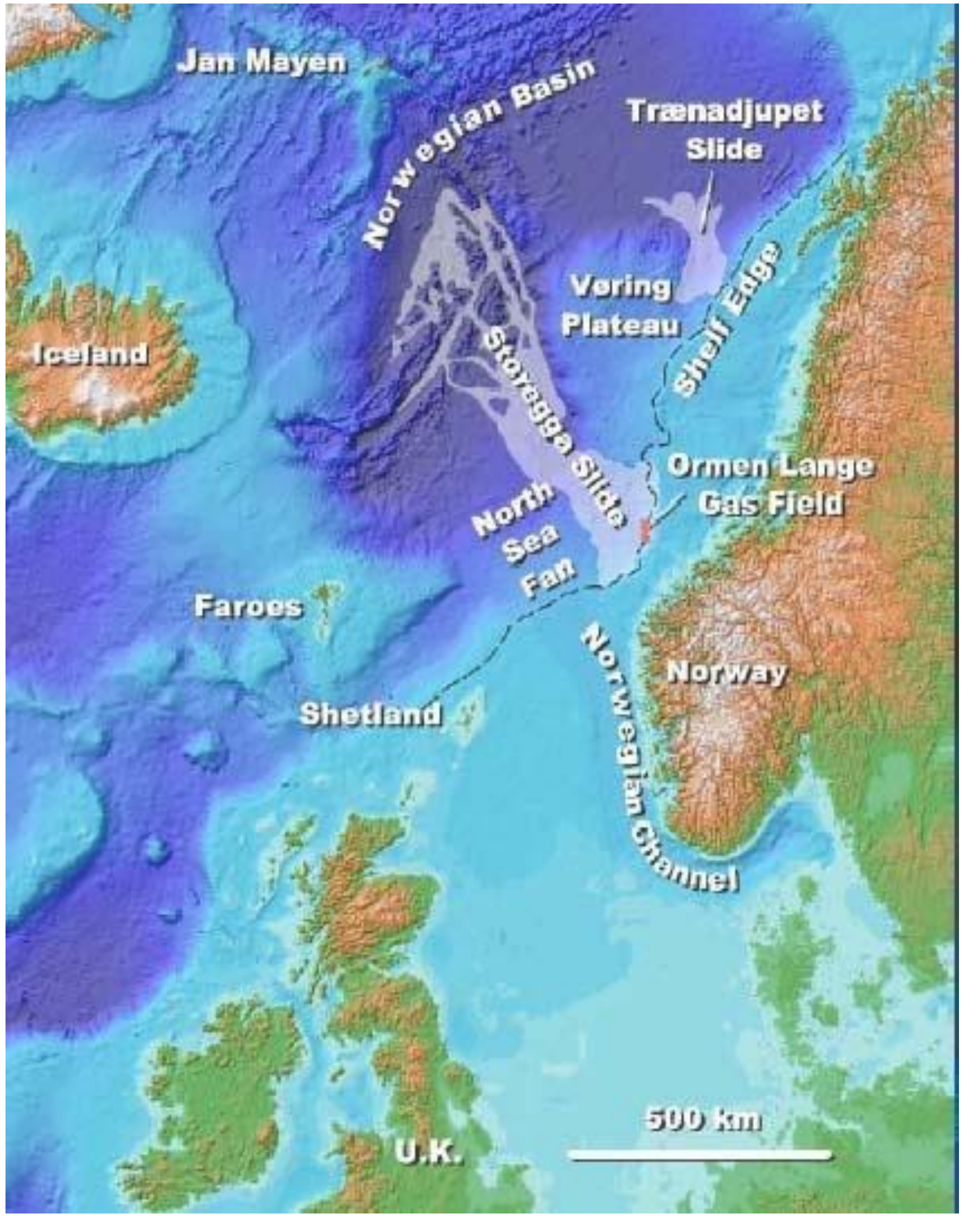

Figure 1. Location of Ormen Lange Field, 120 km northwest of Møre coast, Mid-Norway.

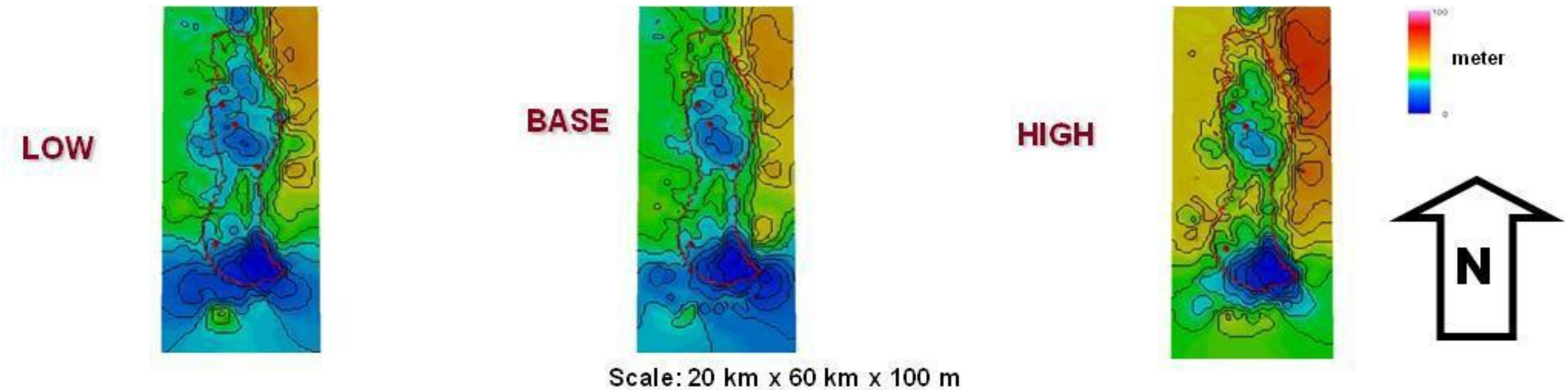

Figure 2. Back-stripping and de-compacting, from seismic data; three different possible surfaces.

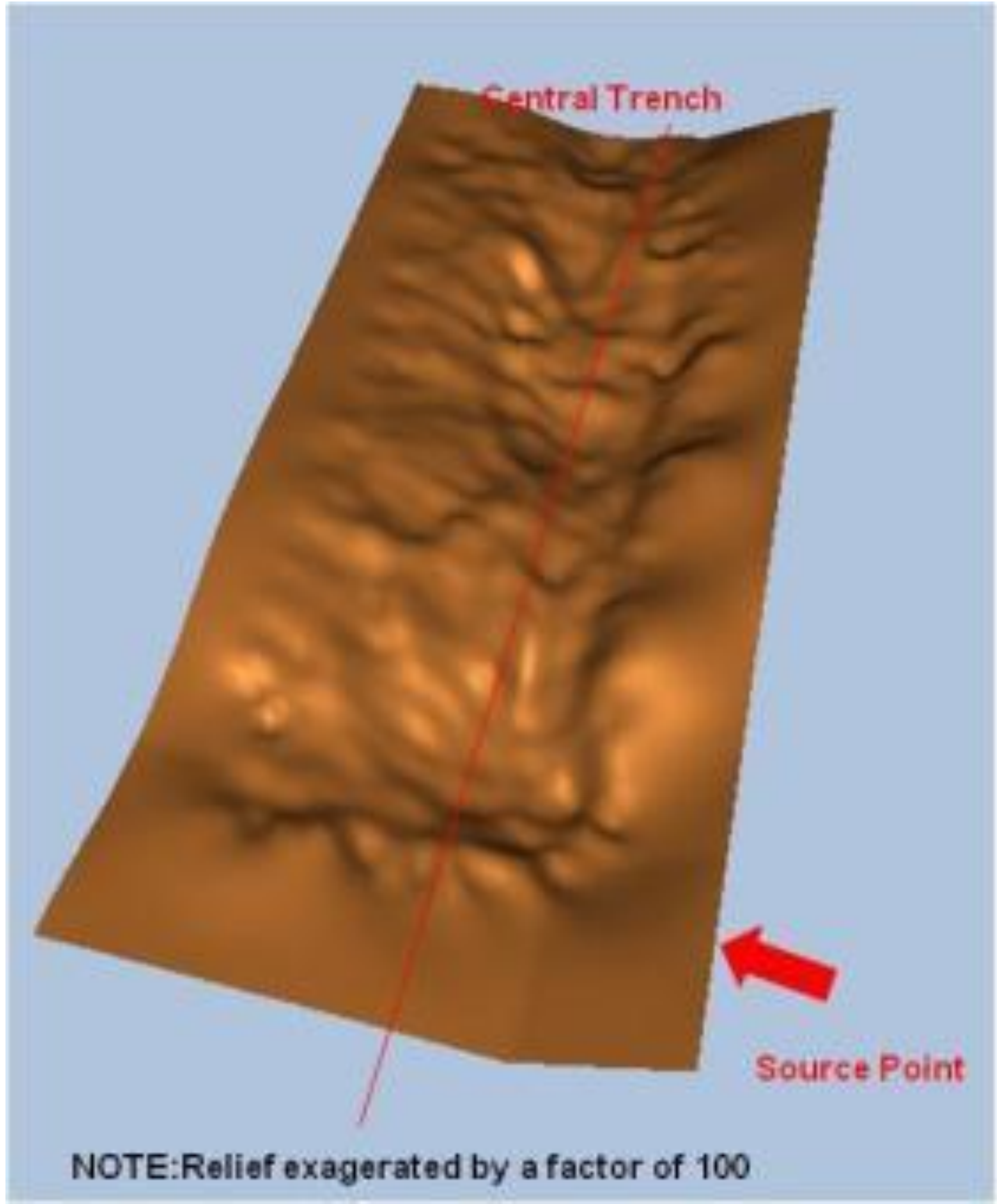

Figure 3. 3-dimensional reconstruction of the Ormen Lange paleo bathymetry

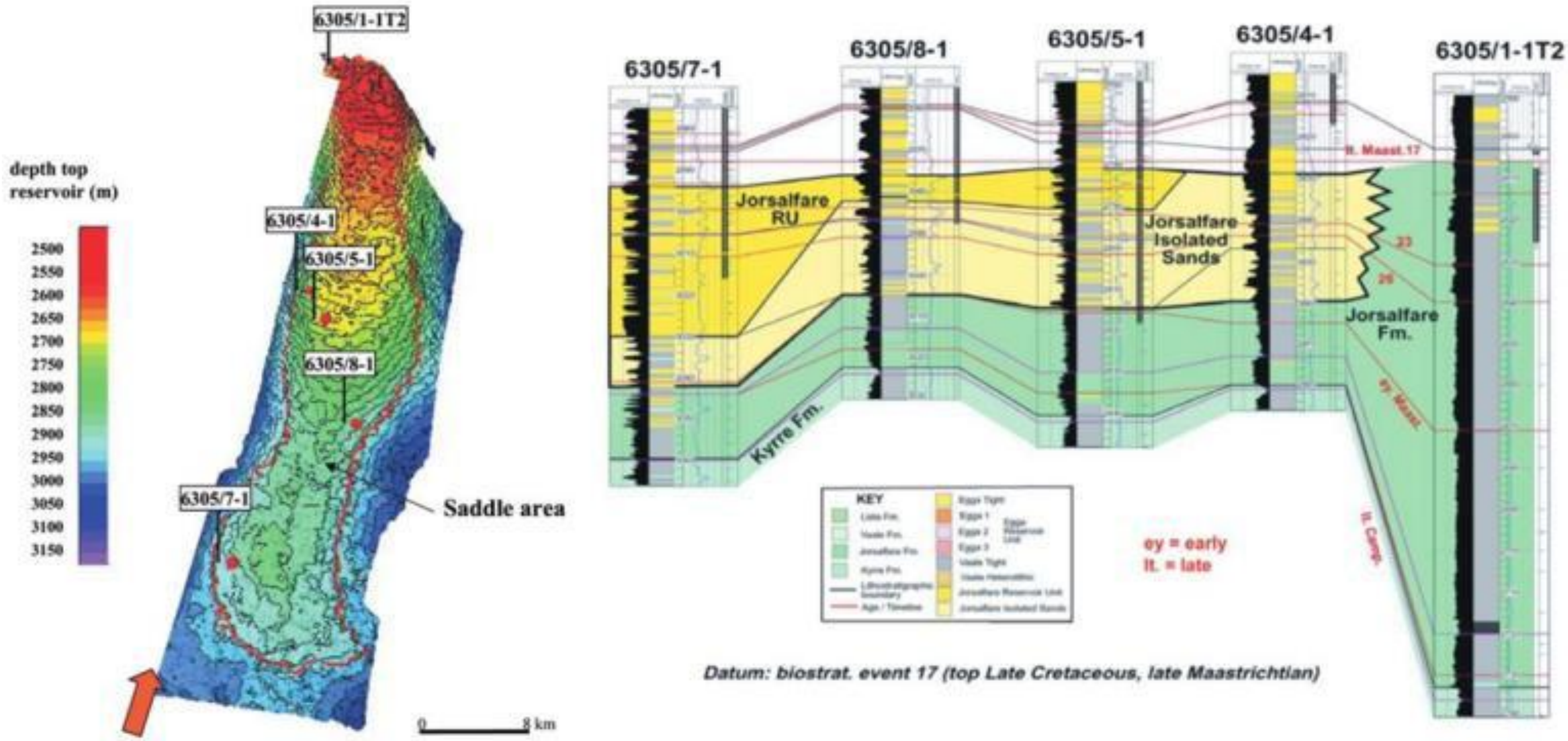

Figure 4. Location of the exploration wells and correlation of the core samples (Moeller et al., 2004), Geological model for the Ormen Lange reservoir, Norwegian Journal of Geology, 169-190)

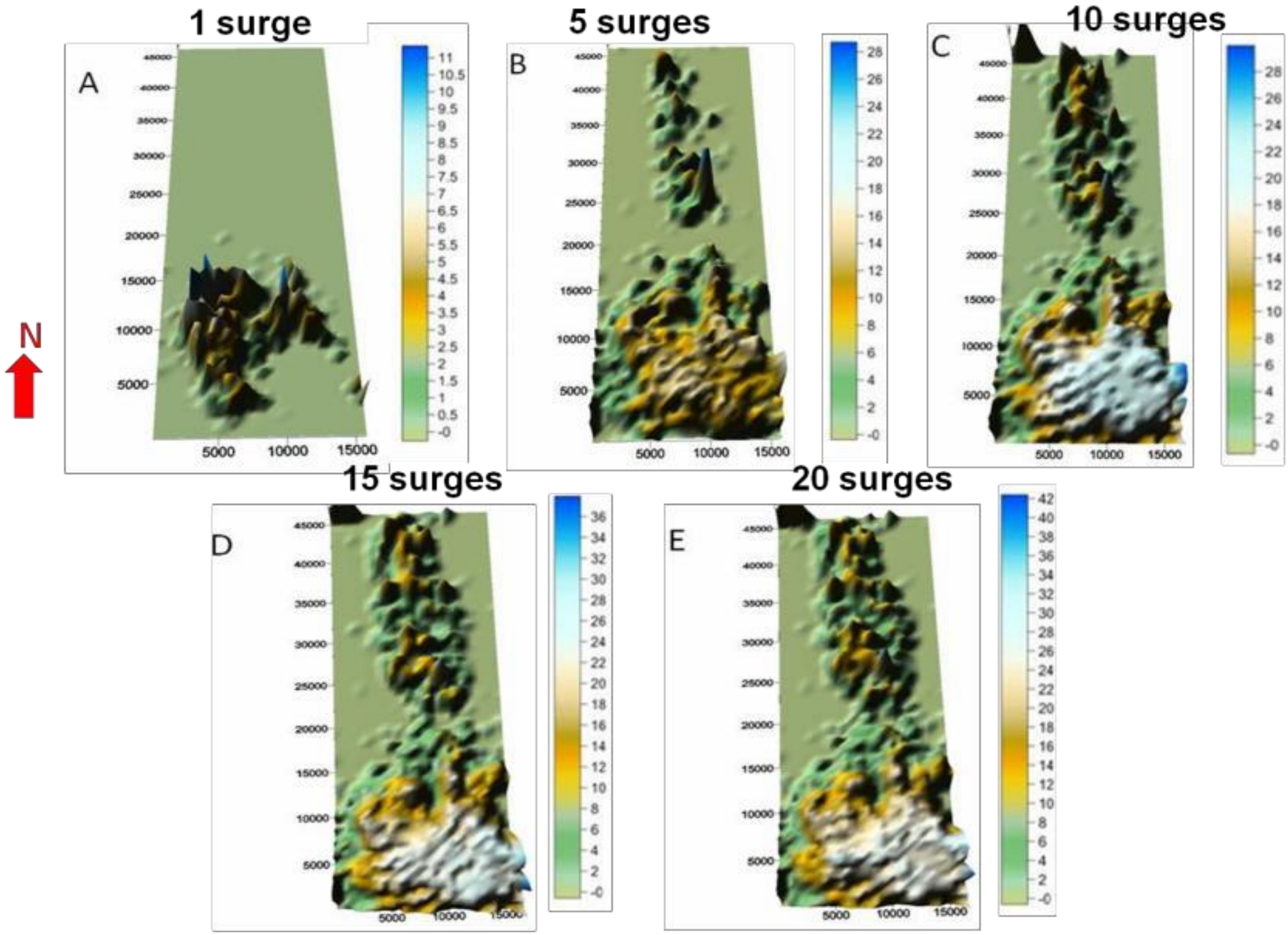

Figure 5. Sediment- thickness evolution for one of the possible scenarios in the Ormen Lange field, after 1, 5, 10, 15 and 20 surges.