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Was Lake Messel a short-lived lake?

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ABSTRACT

The fossil-bearing sediments of Grube Messel in west-central Germany are thought by mainstream geologists to have been laid down as seasonal lake deposits over a period of one million years. However, the sediments are better understood as the products of turbidity currents and debris flows in a small basin with high relief. The sediments of Grube Messel probably represent a short-lived lake that filled up within only tens or hundreds of years.

INTRODUCTION

The fossil site of Grube Messel ('Messel Pit') is well known not only in professional circles but since 1995, at the request of the state of Hesse, it has been a UNESCO World Heritage Site and open to the public. The lake sediments that contain the fossils are said to have formed over a period of one million years – as seasonal deposits built up annually (Figure 1). However, it is not easy to see how this time duration is derived from the geological record – on the contrary.

Figure 1. *In situ* oil shale in Messel Pit. Height of picture approximately 50 cm. Photograph by Michael Kotulla.

Figure 2. World Natural Heritage site, Grube Messel, an abandoned open-cast oil shale pit. The Messel 2001 exploration well (433 m depth) was drilled in the centre of the former sixth working level. Above this level about 55 m of oil shale have been mined. Photograph by Michael Kotulla.

FORMATION AND FILLING OF EOCENE LAKE MESSEL

With the sufficiently deep research borehole Messel 2001 (final depth 433 m) in the centre of the Messel Pit (Figure 2) it could be demonstrated that the Messel basin was volcanic and not – as was thought for a long time – tectonic in origin. The sequence of events can now be reconstructed as far as possible using the rocks extracted from the borehole (partly after Felder and Harms 2004; see Table 1 and Figure 3):

Intrusive molten rock made contact with groundwater near the Earth's surface. Violent magma-steam explosions caused the development of a funnel-shaped hollow (*diatreme*). This was partially filled during or immediately after the eruption with broken fragments (*diatreme breccia*, 373–433 m). Immediately afterwards, erupted and falling or collapsing material (ashes, lapilli, tuffs) mixed with surrounding rocks, leading to further backfilling of the explosion funnel (the so-called pyroclastics, mainly *lapilli tuffs*, 228–373 m). The remaining hollow, a basin with a maximum diameter of 1500 m and a maximum depth of 300 m, was quickly flooded with groundwater and possibly also surface water. The first stratified lake sediments were mainly formed by major reworkings of material from the crater walls and the tuff walls, the so-called *resediments* (143–228 m) [*see Glossary*].

The black pelites that followed in the centre of the basin (also known by the older name of the Messel *oil shale*, 0–143 m), disrupted at the base by strong resedimentation, provide evidence of the accumulation of finer-grained and organic-rich material. To estimate the total thickness of the black pelites, the *oil shale* of the pit with a thickness of about 55 metres must be added. It is from this last section that the very well preserved faunal and floral elements[1] have been recovered.

Thus, the crater-like Lake Messel became a small-scale

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sediment and organism trap until it was silted up. The final phase of the lake is not known; the upper part of the crater rim and the tuff wall have been removed. And the few metres of thick, colourful clays formerly overlying the oil shale have largely been cleared away by the mining.

THE OIL SHALE – DEPOSITS WITH A SEASONAL IMPRINT?

The Messel oil shale is a partially laminated or finely laminated, organic-rich claystone (black pelite). In the wet state it contains about 35% by weight clay minerals, about 25% by weight organic material (mainly algal residues) and about 40% by weight water.

The fine stratification of the oil shale is primarily attributed to alternations between algae-rich layers and algae-poor layers, or layers of algae and layers of clay; the change is attributed to a seasonal, annual control (Matthes 1966, Irion 1977, Goth 1990, Lenz et al. 2010).

Goth (1990, p.84) explains the formation of the laminated oil shale, which he also refers to as algal-laminite, as follows:

> The fine lamination of the oil shale is caused by the accumulation of algal remains[2] as a result of seasonal water blooms. The horizons between the algae-rich layers represent the background sedimentation [*see Glossary*] of almost a whole year between two algal blooms. This sedimentation pattern is verifiable throughout the thickness of the oil shale. The environmental conditions must have remained constant for the entire duration of the existence of Lake Messel.

Therefore, each pair of layers (or couplet) represents one 'annual layer' or one 'oil shale varve'.

By counting couplets ('annual layers') in a few thin-sections, Goth (1990, p.84) determined an average sedimentation rate of 0.1 to 0.2 mm per [varve-] year, which he extrapolated to the whole succession. Based on an estimated total thickness of the oil shale of 190 m, with deductions made for the accumulation of sediment by means of landslides, he calculated an 'existence time for the Messel Lake [...] of almost one million years.' Taking an average of Goth's sedimentation rate of 0.15 mm per [varve-] year and a total thickness of about 155 m (Felder and Harms 2004, middle Messel Formation), yields 1,033,333 [varve-] years. One million years – this is the formation time for the oil shale deposits reported in the Visitor Centre at Grube Messel (opened in 2010) (Figure 4).[3]

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However, Goth (1990) offered no proof of seasonal deposition. Rather, his 'sedimentation pattern' was derived from a theory-laden sedimentation model. He has imposed his idea of a seasonal, yearly control ('oil shale

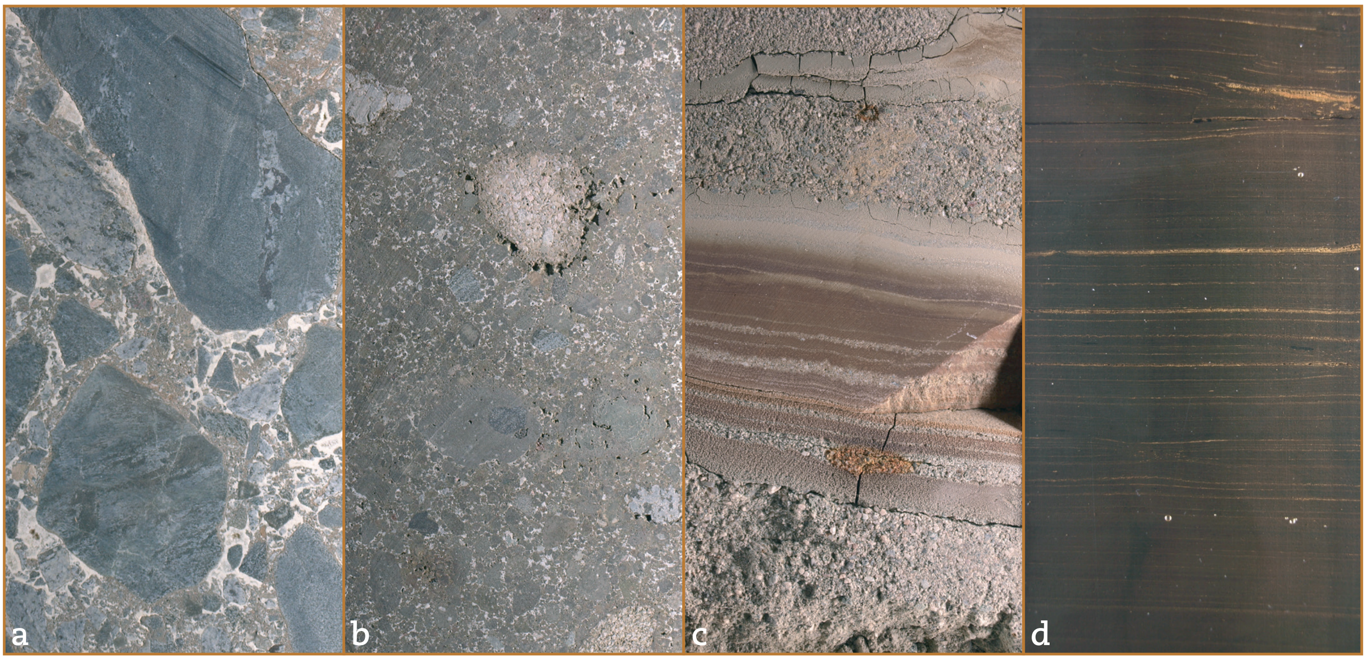

Figure 3. Drill cores of the research borehole Messel 2001 on display in the Messel Visitor Centre. Selection of typical rocks, in each case showing the surface of a vertical cut section with an image width of approximately 10 cm. **a.** Diatreme breccia, presumably amphibolite and granodiorite clasts in a sandy calcitic matrix; extracted from a depth of 384–385 m. **b.** Lapilli tuff with fragments from surrounding rocks; extracted from a depth of 305–385 m. **c.** Resediment: sandstone (predominantly massive) alternating with silts and clays (finely laminated); extracted from a depth of 164–165 m. **d.** Oil shale: finely laminated black pelite with sandy-coloured siderite and reddish-brown laminae. Airtight sealing of the surface; extracted from a depth of 32–33 m. Photographs by Michael Kotulla.

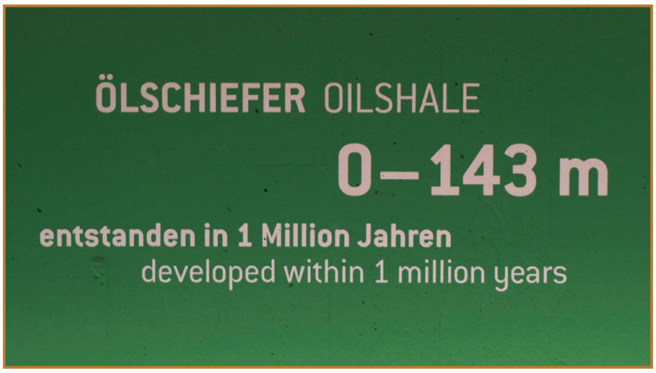

Figure 4. Short description of the drill core of the research borehole Messel 2001, oil shale section; Visitor Centre, Messel Pit. Photograph by Michael Kotulla.

varve') on the whole oil shale succession. This procedure of assigning years to recurrent changes of light and dark, finely laminated layers – without providing evidence of a seasonal imprint – is a common geochronological practice (Kotulla 2014, sheet 3-01 and following).

EVENT-INDUCED SEDIMENTATION

Characteristics of the black pelite

According to Irion (1977) the thin oil shale laminae are about 0.1 mm thick on average. Microscopic observation of thin-sections often shows that the lamination is indistinctly developed (for example, see the figures in Irion 1977, Goth 1990 and Lenz et al. 2010); the laminae are blurred, wavy or flaser-like. The particle accumulations appear cloud-like, agglutinated and lenticular, and even over the narrow width of only 1 cm the 'laminae' often thin out or even disappear. Weber (1988, p.59) therefore uses the expression 'pseudo-lamination'.

The detailed macroscopic description of the 101 m-long core section of the 2001 research borehole (black pelite of the middle Messel Formation) after Felder and Harms (2004; Appendix 2) comprises about 2,000 individual positions, often in the cm-range. Besides the finely laminated black pelite (over 800 mentions), a flaser-like type is just as common; in addition, the black pelite forms some massive (homogenous) sections (about 100 mentions). Also, a coarser clastic, sandy type often occurs (over 700 mentions). Macroscopically visible clasts (rock fragments) are reported more than 500 times, the grain size 'gravel/gravelly', often in connection with the clasts, more than 400 times. It is noteworthy that the term 'graded' (significant increase or decrease in grain size) is used over 1,000 times. Reddish-brown laminae, presumably algal laminites, are only mentioned (mostly in the plural) just over 80 times.

Likewise, from the individual descriptions of Goth (1990), which refer to shorter sections from the abandoned former open-cast mine, it can be concluded in summary that the black pelitic sediment succession is heterogeneous in detail. A distinct fine lamination does not seem to predominate; in his defined ordinary facies ('Normal-Fazies') of the oil shale, the inorganic sediment gets its lamination (only) from 'rhythmic deposition of algal cysts', whereas the discrete (definable) formation of an algae layer is rare (p.42).

Interpretation

Goth (1990) has already interpreted sections of the black pelitic succession in the Messel Pit as turbidites, (rapid) event deposits of turbidity currents [*see Glossary*]. But a clear differentiation as well as quantification seems problematic. He describes, among other things, 'graded layers', 'dissolved/disrupted fine layering' and 'resedimented oil shale shreds' and classifies these phenomena as 'turbiditic oil shale layers' or 'clastic turbidites'.

Felder and Harms (2004), on the other hand, do not use the term *turbidites* in their interpretation of the black pelitic succession. They do not comment on the 1000-fold described grading, an indication of turbiditic deposits, nor on the irregular sediment changes observed at intervals of less than one to about 20 cm. However, the flaser-like black pelite laminae are interpreted as within-basin reworkings (p.173), i.e. also as (micro-) resediments.

In addition, it is noteworthy that Pirrung (1998, p.15) interprets the 'indistinctly layered, e.g. flaser-like, lenticular or homogeneous clays and silts' of the Döttinger Maar (Eifel) as distal (far distant from the place of origin) turbidites.

Thus far, for the greater part of the black pelite – due to its sedimentological characteristics – (rapid) sedimentation or resedimentation events can (and must) be assumed: the transport of the material to the central basin was mainly carried out by turbidity currents and subordinate debris flows [*see Glossary*], both of varying dimensions.

Furthermore, turbidity currents can also cause primary lamination, which can range from fine and regular, through fine and irregular to indistinct (Shanmugam 2000; classic turbidite sequences according to Bouma 1962 and fine-grained turbidite sequences according to Stow and Shanmugam 1980). That means (when transferred to the Messel basin): Not only can the coarser layers, graded sequences and the homogeneous (massive) and flaser-like laminated sections (micro- as well as macroscopic) be understood as current-deposited formations but also the various distinctly laminated sections of pelite as well. Namely, they can be referred to as distal turbidites, and as horizontal or vertical basinward-terminating end members of a turbidite sequence. As such, the distinctly laminated parts complete the overall picture in that sedimentation was likely to be primarily event-driven throughout.

The laminated sediments of the Eckfelder Maar (Eifel) are also interpreted in a similar way; Bullwinkel (2003) and Nickel (1996) both rule out an annual rhythmic formation of the analysed laminites – in contrast to Mingram (e.g. 1994), who postulates that they are varves. Nickel (1996, p.102) interprets the Eckfeld laminites as the highest part of a Bouma sequence (see also Kotulla 2014, sheet 3–40).

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The events

It can be assumed that the development of Lake Messel was mainly influenced by the post-eruption circumstances, among other things the nature of the basin (instability, high relief), surrounding topography, tectonics and climate (subtropical/tropical).

A high level of persistent clastic sediment input could have been triggered by high precipitation or heavy rainfall events (erosion of the crater rim and tephra walls, influx from all sides), smaller-scale landslide events (continual but comparatively smaller collapses of the bank) due to crater instability (or tectonically induced), and possibly a temporary (?) connection to a water network. In-basin events such as gravitational processes (landslides, multi-level slope failure), subsidence and softening (fluidization) are directly or indirectly related to the nature and condition of the basin itself.

Under such climatic and also possibly post-eruptive conditions, mass propagation of algae may have occurred several times a year or quasi-continuously. The die-off events may have taken place on an ongoing basis, so that even quasi-continuous precipitation of algal remains is conceivable.

With regard to the frequency of the different events, it can be assumed that there would have been between a dozen or even hundreds in one year.

SUMMARY AND CONCLUSIONS

The oil shale of Lake Messel consists of a series of event-induced deposits; the events causing sedimentation were not subject to a seasonal rhythm. The different characteristics of the black pelitic sediments in the basin centre, which are described or interpreted as laminites, turbidites and resediments, can be explained by bedload transport (turbidity currents and debris flows) with different hydrodynamic energy and transport in suspension (precipitation) as well as from their interactions and interferences. It represents a complex, irregular sedimentary occurrence in a (limited) quasi-circular (lake) basin with high relief.

The post-eruptive Lake Messel may have been a short-lived lake that was already filled and silted up after tens or hundreds of years. The presentation of a time duration for the formation of the oil shale of one million years, almost as a matter of fact, as is the case at the Visitor Centre at Grube Messel, is misleading.

ENDNOTES

1. The fossils of the Messel Pit are not the subject of this article. However, their excellent preservation, in some organisms complete with 'skin and hair', suggests

<table>
<tr><th colspan="3">Lithology and stratigraphy after Felder and Harms 2004</th><th colspan="3">Presentation at the Visitor Centre, as of 2014</th></tr>
<tr><th>Depth (m)</th><th>Lithology (short description)</th><th>Stratigraphic units</th><th>Depth (m)</th><th>Structure (lithology)</th><th>Formation time</th></tr>
<tr><td>0–94</td><td>black pelite, laminated</td><td rowspan="2">middle Messel Formation (0–101 m)</td><td rowspan="3">0–143</td><td rowspan="3">oil shale</td><td rowspan="3">1 million years</td></tr>
<tr><td>94–111</td><td>resediments (products of debris flows)</td></tr>
<tr><td>111–143</td><td>black pelite + resediments</td><td rowspan="2">lower Messel Formation (101–240 m)</td></tr>
<tr><td>143–228</td><td>resediments, stratified</td><td>143–228</td><td>resediments</td><td>100s of years</td></tr>
<tr><td>228–373</td><td>pyroclastics (lapilli tuff)</td><td rowspan="2"></td><td>228–373</td><td>lapilli tuff</td><td>days</td></tr>
<tr><td>373–433</td><td>diatreme breccia</td><td>373–433</td><td>diatreme breccia</td><td>seconds</td></tr>
</table>

Table 1. Outline of the succession of layers in the research borehole Messel 2001. On the right is the presentation from the Visitor Centre at Messel Pit with formation times (as of 2014). For explanation see the text and also Figures 3 and 4.

that rapid sedimentation led to their preservation. The common assumption that the deeper waters of the lake bottom must have been free or low in oxygen, and that this is the only reason for their being so well preserved, does not seem adequate.

2. Mainly the green algae *Tetraedron* and *Botryococcus*.
3. The formation time of one million years for the oil shale deposits given in the Visitor Centre at Grube Messel refers on the one hand (only) to the drilled part up to a depth of 143 m (Figure 4), but on the other hand the description of the oil shale core is assumed to refer to the entire oil shale sedimentation (including the open-cast pit, a further 55 m): 'For the following 1 million years, until its silting, the crater-lake would support the life forms of the Eocene' (as of 2014).

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GLOSSARY

Background sedimentation: Concept of quasi-continual, but extremely slow, (vertical) particle-by-particle sedimentation, predominantly of fine-grained material (clay).

Resediment: Sediment that has been formed by the reworking of existing sediment (e.g. by slumping) and its re-deposition, sometimes with further additional (new) components. Felder and Harms (2004) differentiate between resedimentation caused by turbidity currents and resedimentation caused by debris flows (see below).

Turbidity current: Event-induced, ground-hugging turbulent current with a defined sediment concentration of 1–23% by volume. Sediment, sedimentary rock: turbidite.

Debris flow: Event-induced, elastic or plastic mass-transport current with a defined sediment concentration of more than 25% by volume. Sediment, sedimentary rock: debrite.

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Michael Kotulla is a geologist and business economist. For many years he was engaged in the banking industry. Since 2012 he has been a full-time researcher for Studiengemeinschaft Wort und Wissen e. V. (Germany). His main interests are stratigraphy, sedimentology, volcanology, tectonics and geochronology, as well as geoscience theory. He is familiar with both the sciences and economics. His research also includes the communication path from the primary scientific literature to the public.