

## Messel Pit UNESCO World Heritage Fossil Site in the UGGp Bergstraße-Odenwald, Germany– Challenges of Geoscience Popularization in a Complex Geoheritage Context

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### Abstract

Despite its paleontological importance, the Messel Pit was under threat to become a waste disposal site, and its eventual designation as the first Natural World Heritage UNESCO geosite in Germany followed an intense fight in which numerous principles of geoheritage and geoscience popularization were explored. The UNESCO agenda 2030 for sustainable development is the basis of current plans for the future of this extraordinary, unique geosite. The financial frame of the development and special support of the State of Hesse were crucial in establishing a visitor center. This provides a conceptual base for the Messel Pit WHS, through cooperation, exhibitions, guided tours, a variety of digital approaches in media use, leading to geotourism products and marketing activities. The challenge since March 2020 during the Sars-CoV-19 pandemic led to the development of web-based games. The new activities include a portrait series named “Deathly Paradise” and a project series of videos. Collaboration with the UNESCO Global Geopark Bergstrasse-Odenwald is realized in different projects. The importance of long-term collaboration between both UNESCO entities, the geosite and the geopark, provide an international best-practise example.

**Keywords:** Geoparks; World Heritage; Geoheritage; Eocene; Geoscience popularization; Geo-education; Geotourism; Paleontology.

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## Introduction

When the Messel Pit Lignite was discovered in 1884 (Harms 2011) local people noticed the potential for industrial development in this landscape mainly built from Variscan granitic rocks and basin fillings of Permian sandstones. The Messel Pit Lignite was seen as a miracle from the start because it was so soft, so extensive, and the outcrop was nearly circular, measuring about 1 km across

and with an area of 42 ha (Fig. 1). The fossils in the dark brown to black oil shales, dated as Eocene, raised many questions because of the completeness of the skeletons, the exceptional preservation of soft tissues, and similarities of many species to non-European groups of mammals and birds. At that time the oil shale deposit was identified as a sort of infilling in a granitic landscape.



Figure 1. View into the Messel Pit.

Commercial extraction of the oil shale operated from 1884 to 1971. The first fossils were found soon after commercial work began, pieces of a crocodile reported in the 1870s. Since the mid-1960s fossil collectors as well as the Hessian State Museum Darmstadt and since the middle of the 1970s the Senckenberg Research Institute and other institutions discovered an increasing number of extraordinary complete fossils. However, further industrial use was proposed, and the site could have been used as a landfill site. At once, an initiative to stop this was founded by Messel residents, municipality, scientists e.g. Dr. Heil, Hesse State Museum Darmstadt and others, and the fight lasted for nearly 20 years before the whole landfill

plan was abandoned at the end of 1989.

In the meantime, the residents of Messel had founded a small museum in the old municipality school, opened on 19<sup>th</sup> October 1980. In 1991, the State of Hesse bought the pit property and handed over management of the site to the Senckenberg Society for Nature Research in 1992. The signed contract identified the main task as proceeding with scientific investigations and digging for fossils. In parallel, an administrative company was founded in 1993 to take over the state's duty to safeguard this property.

After application to UNESCO in 1994, the Messel Pit was integrated into the list of UNESCO World

Natural Heritage Sites as an Eocene Fossil Site on 9<sup>th</sup> December 1995 as Germany's first natural WHS. The outstanding universal value (OUV) of Messel is defined as the only Eocene fossil site with a content of extraordinary mammal fossils and a high diversity of other organisms showing the development and evolution of organisms during the Eocene. It is not surprising that the exhibitions of Messel fossils in Messel, Darmstadt and Frankfurt focus on the paleontological aspects of this geosite.

In 2003, the state of Hesse, owner of the World Heritage Site, decided that new infrastructure was needed to give access to the Messel Pit and to transfer knowledge about its World Heritage status to the public. A new organization, a not-for-profit limited company, was established, the "Welterbe Grube Messel gGmbH", and this was the basis for a division between the scientific research and geoscience popularization. The main aim of the latter was to encourage the public to visit the Messel Pit World Heritage Site through education and geotourism activities. At that time, the close cooperation with UNESCO Global Geopark Bergstrasse-Odenwald started and includes a wide range of activities integrating the aims and needs of both organizations. After 2004, the numbers of visitors increased, and guided tours helped them to understand that the fossils of the Messel Pit are hidden inside a material called oil shale. When oil shale is excavated, it dries out, disintegrates, the layers split open and the fossils are destroyed.

Before the new company started, there were no regular daily offers to visit the World Heritage Site and very limited options to experience the fascination of the site. The challenge for the Messel Pit company was to implement a new approach for the site with the support and in cooperation with the UNESCO Global Geopark Bergstrasse-Odenwald. This includes activities that enable the visitor and scientific institutions to understand the world 48 million years ago, the landscape, climate, fauna and flora. By visiting a scientific excavation

site on a special tour or other formats visitors get a chance to experience the atmosphere and spirit of this unique site.

In this contribution, we describe our efforts in geoscience popularization, bearing in mind the complexity of topics and disciplines, including partner activities like geo-workshops and games, tourism activities as well as the challenges, including a short review of economic aspects. A special focus is laid on the partnerships of the Messel Pit World Heritage company with regional, national and global partners.

### **Geological Setting and Industrial Heritage**

The Messel Pit is situated about 14 km east of Darmstadt, in the northern part of the Bergstrasse-Odenwald UNESCO Global Geopark, on the Sprendlinger Horst (Fig. 2).

The oldest rocks of the area are pre-Paleozoic metamorphic shists (Weber and Bühn 2009). They are followed by Variscan crystalline rocks like granites, granodiorites and gabbros which are partly overlain by Lower Permian arkosic sandstones (Rotliegend) dating to 280 Ma. Both these formations were disrupted by volcanic activity, especially in the northern area of the Sprendlinger Horst, first from 70–65 Ma and then from 49–47 Ma (Reischmann *et al.* 2011). This volcanism was part of a wider phase of volcanic activity in the northern hemisphere (Ziegler 1988:134), termed the "Thulesian Volcanism", from 60-50 Ma, with explosive volcanism at the end. These volcanic activities were driven by the movement of the Upper Rhine Graben, starting from 50 Ma to the present day (Hinsken *et al.* 2007; Jacoby *et al.* 2000). Besides volcanism, horst structures such as the "Sprendlinger Horst" developed due to the rifting. The maar volcano of the Messel Pit is directly connected with the development of this horst structure.

For many years, geoscientific researchers have discussed the genesis of this location, especial-

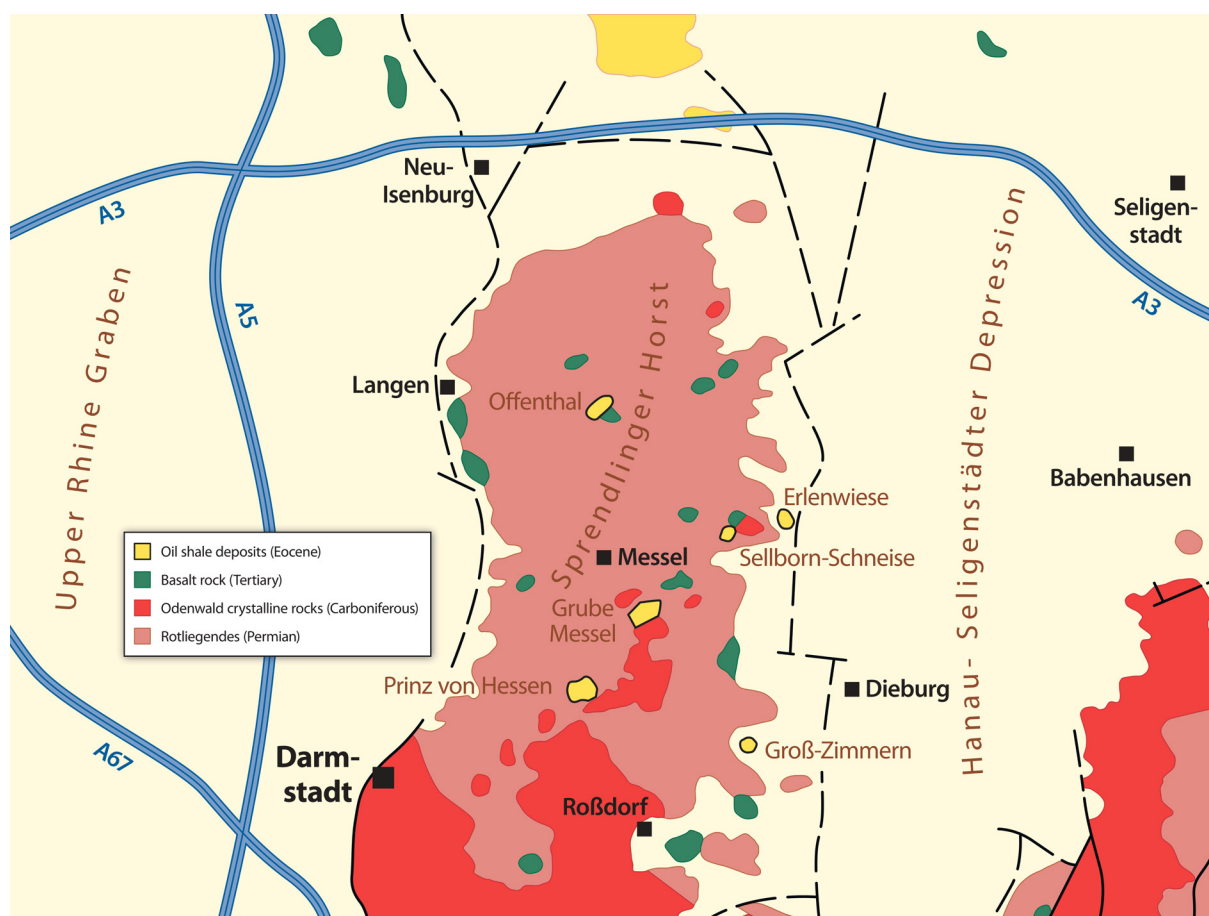


Figure 2. Simplified geological map of the Spremlinger Horst area and key locations.

ly as the number of extraordinary fossil findings increased during the digging campaigns. During the 1980s, scientific research on the formation of the Upper-Rhine-Graben as a geological structure started and delivered information on the wider geo-tectonic situation. Work was also done on the formation of the Messel Pit (Nix 2003; Reichmann *et al.* 2011; Büchel & Schaal 2018).

At the end of the 1990s, a scientific drilling project was agreed and implemented by several institutions in 2001, reaching the Variscan crystalline breccia at a depth of 433 m. It turned out that existing models for the formation of this structure were not confirmed. The only plausible model (Fig. 3) is that the Messel Pit formed through eruption of a maar volcano about 48.2 Ma, and the crater lake (Lorenz and Büchel 1980; Schulz *et al.* 2002) was then filled (Mertz and Renne 2005; Lenz *et al.*

2015), in the Eocene (middle Ypresian - lower Lutetian).

After the maar explosion, groundwater flushed into the crater and formed a lake in which sediments were deposited in the following ca. 1 Ma throughout the Eocene (Büchel and Schaal 2018; Lenz and Wilde 2018). Below this, the borehole penetrated a diatreme breccia (433–373 m), pyroclastic sediments (373–228 m) and lacustrine sediments, which make up the upper portion (228–0 m) (Felder *et al.* 2001; Felder and Harms 2004; Büchel and Schaal 2018). The diatreme breccia comprises amphibolite, granite, granodiorite, and Rotliegend sandstone, sampling the Variscan basement around the magma pipe of the Paleocene volcano. The pyroclastic sediments are primarily accretionary lapilli tuffs and lapilli representing airfall debris from the eruption.

The 229-m-thick maar lake filling comprises 90 m of the Lower Messel Formation, starting with mostly graded gravel to clay and some tuff, passing into a conglomerate with amphibolite blocks with sand and clay, then mostly graded fine gravel to clay and tuff, and a unit of oil shale (Lenz and Wilde 2018). The Lower Messel Formation ends with an event bed of redeposited blocks of oil shale, oil shale debris, and clay that extends across the whole deposit. The Middle Messel Formation in the upper 94 m of the borehole is entirely the

classical fossiliferous finely laminated oil shale, showing varve-like stratification. Above this, the Upper Messel Formation has been almost entirely removed by mining activity, leaving only traces in small areas in the eastern and south-eastern part of the Messel Pit today (Büchel and Schaal 2018). Radioisotopic age dating suggests an interval for deposition of the Lower and Middle Messel Formation of 700–900 kyr. The organisms and deposits document climate changes during this short time (Lenz and Wilde 2018) and confirm the

Erathem	System		Stages	Time					
Era	Period		Age	Ma					
				Numerical age					
<b>C E N O Z O I C  A R Y</b>	23 Foraminifera	<b>PALAEOGENE</b>	<b>OLIGOCENE</b>	Chattian	28,1	c. 51,4 - 57,9 Messel Formation			
	<b>T E R T I  A R Y</b>			<b>PALAEOGENE</b>	<b>EOCENE</b>		Rupelian	33,9	
			Priabonian				38,0		
			<b>EOCENE</b>		Bartonian		41,3		
					Lutetian		47,8		
			<b>PALAEOCENE</b>		<b>PALAEOCENE</b>		Ypresian	56,0	
							Thanetian	59,2	
								Seelandian	61,6
								Danian	66,0

After IUGS International Stratigraphic Chart 2021/10

[www.stratigraphy.org](http://www.stratigraphy.org)

Figure 3. Eocene stratigraphy at the UNESCO World Heritage Site Messel Pit, Germany.

greenhouse climate.

Within the oil shales, there are four marker horizons (Harms and Schaal 2002; Lenz *et al.* 2015:fig. 9), termed alpha, beta, gamma, and “M”, the final one being a “Messelit layer,” which are used by paleontologists to identify the position of fossil finds. Kubanek *et al.* (1988) identified these horizons as former palagonite ash layers. The only other comparable location is at Offenthal in Hesse Germany (Moshayedi *et al.* 2020).

In 1856 the first mining field was declared (Harms 2011). From 1864 to 1971, the oil shale was mined at a volume of about 25 million cubic meters in

total for the production of crude oil and other products. From 800 t per year in 1888 the production rose to 13.500 t per year in 1910 and in the 1930s reached a volume of about 20.000 t per year (Harms 2011). This was done first by the “Messel Union” company, founded in 1884 and worked up to 1923 extracting and processing the oil shale. From 1900 to 1924 the production of gasoline and diesel took place in furnaces. The company ownership changed in 1923 to the “A. Riebeck’sche Montanwerke AG” which was handed over to the “IG-Farben-Konzern” (IG-Colour-Concern). From 1929 onwards the “Deutsche Gasolin AG” worked on the distribution and sale of the products. After commercial activity ceased in 1971, an

open cast mine about 1 km in diameter and c. 65 m deep was left. Historically, the carbonaceous sediment was often mistakenly called the “Messel lignite.” It was described roughly as a black pelite with lignite seams and colorful pelites (Büchel and Schaal 2018).

### Importance of the Fossils from Messel

The importance of the site is underlined by abundant and mostly complete carcasses of animals and plants, with more than 40,000 finds in the Senckenberg Museum in Frankfurt am Main, the Hesse State Museum in Darmstadt, and the Museum in Messel. In addition, scientific results show considerable faunal innovation from the Eocene onwards, with for example reconstruction of the evolution of the horse by primitive horse finds of *Eurohippus* (Franzen 2018). Other primitive mammals with highly specialized adaptations, plant relicts and insect finds reflect environmental conditions of all ecosystems in and around the maar crater lake. All these fossils were preserved exceptionally by the special chemical conditions of the oil shales (Wuttke 1988; Wuttke 2012). More

than 75 plant families with more than 200 species have been identified (Bohaty and Zell 2021) and among the vertebrates about 75 taxa with more than 40 species from more than 30 genera of mammals. Numerous taxa found in the Messel Pit are holotypes of new genera and species. Since 2007 the Messel Pit WHS has been a National Geotop (Look & Quade 2007).

Bohatý and Zell (2021) summarize the history of these discoveries, including the cimolestan mammal *Kopidodon macrognathus*, the first mammal fossil to be described from Messel, in 1902. This was followed by the first primitive horse find around 1920, the first find of *Ailuravus macrurus*, a large rodent like a giant squirrel, described in 1949 and then a complete carcass found in 2013 (Fig. 4) by the Senckenberg Research Institute (Ruf and Lehmann 2018). Then in 1970 came *Lesmesodon behnkae*, a key specimen worldwide for understanding of early and middle Eocene hyaenodonts (“creodonts”) (Gruber & Micklich 2007).



Figure 4. Head and anterior torso of the skeleton of *Ailuravus macrurus* from the Messel Pit, Germany

The primitive tapir-like animal, *Hyrachyus* was the first Messel mammal to be studied and conserved by the newly developed “transfer method” in 1973 by Willi Ahrend (Gruber & Micklich 2007). The transfer method allows the fine detail of the fossil to be studied from both sides. After collection, the fossil and surrounding oil shale are kept moist with wet newspaper to prevent cracking, and the technician works to remove sediment from one side of the fossil. Once it is ready for transfer, the fossil is coated in lacquer and a frame is built to produce an epoxy mold on which the prepared face of the fossil sits. Then, the fossil is flipped over on its epoxy mold, and mechanical preparation is done from the other side, removing all oil shale and leaving simply the bones, viewed from behind and resting on the epoxy mold. The method has proved invaluable for close scientific study, but also for long-term conservation in museum collections without risk of the unstable oil shale around the fossil drying and cracking. The method cannot be used for insect and most plant fossils, which are instead archived in boxes with glycerine.

Additional well-preserved finds include the only complete fossil of an anteater-like pangolin, *Eurotamandua joresi* (first thought to be an anteater), hedgehog-like insectivores, and the first complete skeleton of *Buxolestes*, which is part of a primordial group of otter-like mammals, in 1977 by the Hesse State Museum. Fossils like those of *Eoglieravus*, a dormouse, give the oldest evidence of groups that exist today. Additional finds and investigations on insects have been done recently by Wedmann (2018) and Wappler *et al.* (2015). Their work has resulted in new, significant insights into the ecosystem and its functioning.

As most of the Messel Pit finds are complete carcasses in fantastic preservation conditions, the continuing scientific investigations have delivered a tremendous volume of information on a wide variety of animal groups, plant families and fungi of Eocene times; the living environments of these

organisms in and around the lake and tropical-type rainforest; paleoclimates; phylogenetics and paleobiogeography of key clades; food chains from their preserved gut contents; reproduction; and taphonomy.

The remarkable soft tissue preservation at Messel (Rose 2012) has enabled discoveries of such wonders as a pregnant horse with preserved uteroplacenta (Franzen 2019), the earliest and only known pollinating bird in the fossil record (Mayr & Wilde 2014), a coevolutionary relationship of a parasitoid fungi with ants (Hughes *et al.* 2010), fossils of mating turtles (Joyce *et al.* 2012), the first fossilized leaf insect (Wedmann *et al.* 2007), preserved uropygial gland lipids (O’Reilly *et al.* 2017), a new dragonfly family related to dragonflies extinct since the Early Cretaceous (Garrouste and Nel 2015), and a new spider species (Selden & Wappler 2019).

#### Geoheritage Values

After its designation as a World Heritage Site in 1995, the Messel Pit has received further geoconservation recognition. Through the UNESCO Global Geopark Bergstrasse-Odenwald it was designated Geotope of the year 2010 (Weber 2010) and National Geotope since 2006 of the Academy of Geosciences (Look & Quade 2007).

The Messel Pit has been protected as a “Geotop” under the Hesse Monument Law (HDSchG) since 1998 (Dietrich 1998). After designation as a World Heritage Site of UNESCO, the contribution of the finds from the Messel Pit to the UNESCO criteria viii was confirmed by the International Union of Conservation of Nature (IUCN) in the newly defined “Outstanding Universal Value” (OUV, Anonymous 2014): “Messel Pit Fossil Site is considered to be the single best site which contributes to the understanding of the Eocene, when mammals became firmly established in all principal land ecosystems. The state of preservation of its fossils is exceptional and the scientific work undertaken at the site is extensive and successful.”

The rich geodiversity and geoheritage of Messel have been used repeatedly in new models for geoscience popularization following the philosophy of the UNESCO Global Geoparks (Frey 1993; Kasig and Frey 1997; Frey 2000; Frey *et al.* 2002; Frey *et al.* 2006; Frey 2012; McKeever *et al.* 2012; Escher *et al.* 2015), in which today's storytelling is used as the main tool. In the following section, we explore examples of how the varied geodiversity of the Messel Pit can attract the public especially during the COVID-19 pandemic.

### **Challenges of Geoscience Popularization in a Complex Geoheritage Context**

The geodiversity of the Messel Pit WHS is not directly visible in the pit itself, as the fossils are hidden in the oil shale outcrops, which dry out under the sun (Fig. 5).

Following the geological and industrial history of Messel, different action fields and themes have led to a new concept for geoscience popularization according Agenda 2030 (Fig. 6). This was developed by close collaboration with the UNESCO Global Geoparks Bergstrasse-Odenwald, Vulkanneifel, Naturtejo, Hong Kong and Lesvos Island, which are all members of the International Geoscience and Geoparks Programme of UNESCO and the Global Geoparks Network. When regular visitor access started in 2004, it was clear that a new approach was needed to raise the interest of the wider public in the Messel Pit. Up to that time, only limited access by very engaged members of the local Messel Museum was available.

In this context, the main challenges were the geographically isolated situation of the Messel Pit in



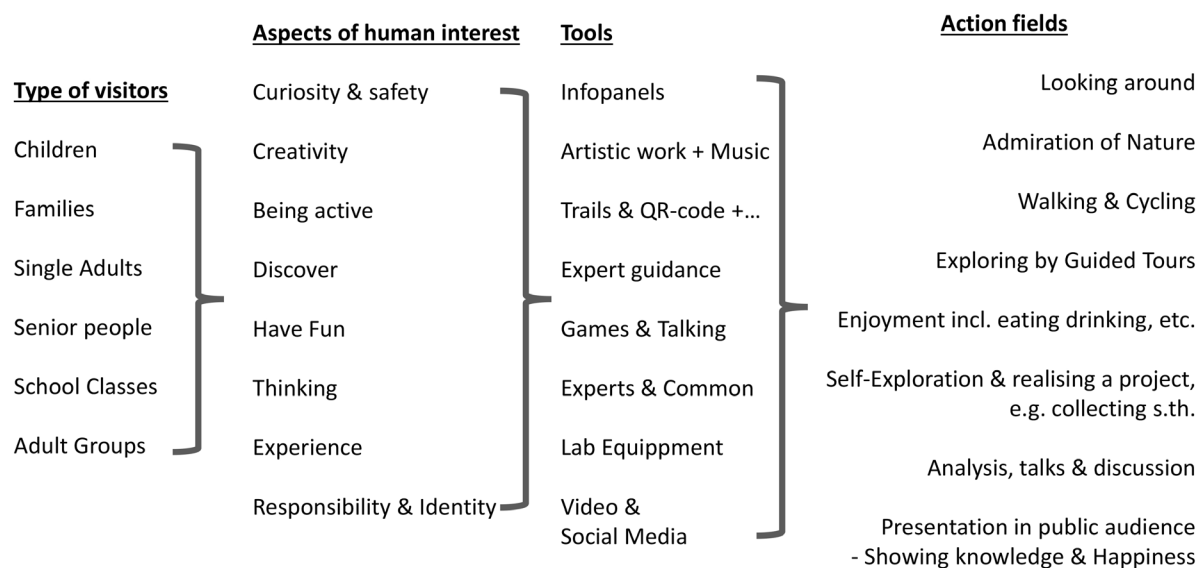
Figure 5. Example of exposed oil shale after drying under sunshine.



the middle of a forest; the absence of regular access to the Messel Pit WHS for visitors; the absence of infrastructure except for a viewing platform; no staff; access only by guided tours; no science information or transfer on-site; three other museums in the neighbourhood presenting Messel Pit

fossils; a small starting budget for administrative tasks; limited scientific results on the geodiversity of the site; and a division between site management (Senckenberg) and site access and science popularization (“Welterbe Grube Messel gGmbH”). From summer 2004, guided tours for visi-

### Scheme of Action fields within the concept for geoscience popularisation



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Figure 6. Scheme of action fields within the concept for geoscience popularization.

tors were developed first on an ad hoc basis. But the main question was how to transfer the spirit of this location and the importance of the Messel Pit in the new guided tour offers. The response was to tell the holistic story of the origins of the Messel Pit, and the big dream was to have a new visitor center at Messel.

### Geoscience Popularization Concept and Educational Programs

Geoscience popularization according to the many demands started in 2004 in close partnership with the UNESCO Global Geopark Bergstrasse Odenwald and with the headline “Dive into Time”. After two years, this approach was adopted based on visitor feedback (Frey & Wurche 2009). Since then, this approach has been checked continuously for its value in a changing society, with the sto-

rytelling prioritized on the “Formation-Degradation-Formation-Cycle”. Since 2018, storytelling themes of “fire, water, light and life” have been used as topics for activities (Fig. 7).

The guided tours start with a holistic central topic linked to “time”, looking at how the oil shale filled this unique location. But this cannot be the sole geoscience popularization concept for a program that also aims to attract a high number of visitors per year. Additional aspects have been developed in access, educational elements, raising awareness activities and tools: information for all residents and visitors is free of charge; visitors of all ages, provenances and educational backgrounds are included; regular access is offered; and also paid, service programs are offered.



Figure 7. Artist canopy in the outside garden of the Messel Pit visitor center with symbols on “Fire, water, light, life and forest” in Chinese writing – by the artist Barbara Beisinghoff

It was important also to consider that the site is “owned” by the citizens of the world. It was necessary to establish a new pride in the site for visitors as well as for the inhabitants of the region, making them willing to re-visit, as well as safeguarding this unique treasure. It became clear after some years that simply giving information on the World Heritage status of the Messel Pit and its international importance would not be enough in a rapidly changing society.

Luckily the investigations related with the drilling project and the borehole cores of 2001 brought new research results: a volcanic eruption as the source of the Messel crater; then it was filled with water; a lake was formed; then the lake was filled by algal mud that preserved animal bodies and plants. This opened up important educational topics about the site, as well as links from the climatic conditions of the organisms during a greenhouse time in the Eocene to the modern-day climate crisis. Diverse educational activities (Frey and Wurche 2009; Frey *et al.* 2006; Frey 2012, 2016, 2018) have been developed:

- a) **Self-explorer infrastructure** for single visitors or groups – outside the Messel Pit WHS: information and artistically designed interpretation panels
- b) **Transfer activities** across personal communication: guided tour offers with a variety of program durations into the Messel Pit WHS; special topic guided tours for people with special thematic interests, e.g., “Looking over the shoulder of the scientist by visiting a dig site” or “Bat tour evenings”
- c) **Transfer activities in the new visitor center** since 2010: thematic exhibition rooms to be discovered by visitors or by guided tours lasting one hour
- d) **Activities and events:** campaigns on Messel Pit related topics like “Summer Butterflies”; campaign on World Heritage Sites in Germany – “#shareourheritage”; special exhibitions e.g. Understanding climate change with Lesvos UGGp, Greece
- e) **Home working activities** through digital platforms, CD and printed materials, such as websites, QR-code trail as well as flyers, a yearly Messel Pit magazine, booklets, quiz formats, jigsaw puzzles and games
- g) **Special offers on:** scientific lectures; scientific exhibitions on old and new fossil discoveries (Fig. 8); film presentations “Film Summer Hesse” and / or “Junior WH-Officer” / “Welterbe Lotsen”.

Additionally, collaboration with the partner UNESCO Global Geopark was established and developed since 2004 onwards. Projects in the context of Agenda 2030 are:

- a) **Courses for young people** like “Geo-Workshop or Geo-Studio with the Geopark Rangers” for many years.
- b) **Transfer activities through art and nature themes:** exhibition “Zeitwert” / “Time value”; Land Art project Global Nomadic Arts Project – a collaboration with International Forest Art and UNESCO Global Geopark Bergstrasse-Odenwald (Fig. 9).
- c) **Partner activities and events:** Projects with UNESCO Global Geopark Bergstrasse-Odenwald include Quartett games and ABC game through EU funding project RURITAGE; participation activities on International Forest Art “Art-Nature-Identity” to create three sculptures for the Messel Pit Time garden areas, south of the Messel Pit WHS in 2020 and one new sculpture in 2021; COVID-19 campaign with games during lock down for home-based activities; virtual guided tour through the visitor center (six videos in cooperation with the Geopark); authors’ lectures with kids stories about the “Fiora Eozän – Fiora Eocene” time travel crew, a comic, exclusively developed for the WHS Messel Pit (five videos in cooperation with the Geopark).

In addition to the regular operation of the company, guided tours were the first offering to provide regular access to the Messel Pit WHS



Figure 8. Collection of flyers on special exhibitions at the visitor center on fossils.



Figure 9. New sculptures in the grounds of the visitor center at the Messel Pit by artist Waltraud Munz-Heiliger.



Figure 10. Geopark ranger “Geo-Studio” activity with children.

from spring 2004 onwards. Thanks to collaboration with the UNESCO Global Geopark, geopark-rangers (Fig. 10), were the first to offer tours of the Messel Pit.

Because of the scientific value of this geosite, special emphasis was laid on the qualifications of the guides, who were selected based on their academic degrees in geology, geography and/or biology. They also had to have an ability and will to improve their skills in education and on geoscientific topics related to the Messel Pit. It was necessary to define a fair payment for the guides, even though first there existed no experience on how to raise income across geotourism offers. These two points exemplify core challenges in developing all the activities: the mix of enthusiasm for the importance of this highly diverse geosite, and the economic demands that exist because of the organizational situation of this managing company

Through close collaboration with regional partners, marketing of the geosite started early. In 2007, the World Heritage Site was identified as the northern entrance to the UNESCO Global Geopark Bergstrasse-Odenwald. Public relations through the tourism platform and other communication channels were used, including tourism fairs like the International Tourism Bourse in Berlin from 2009 onwards (Fig. 11).

This promotion has been the third core challenge for the strategic geotourism concept. In this context, the Messel Pit has been developed as a high-profile attractor and lighthouse for the Odenwald-Bergstrasse tourism destination. The local and regional public and stakeholders also focus on the isolated location of the geosite in the middle of a forest- this has led to collaboration projects for example with the “Location Marketing”, Odenwald Tourism and also with the International For-



Figure 11. Messel Pit participation with UNESCO Global Geoparks Network at the ITB Fair, Germany.



Figure 12. Launch of newly created sculptures at Messel Pit.

est Art Association Darmstadt to attract visitors by art installations (Fig. 12).

This work goes hand in hand with high quality magazines and advertisements in appropriate magazines, such as “Erbe der Welt” (Matejka 2020). Interested visitors with a high-level educational background, mainly adults and seniors with academic degrees, are attracted by this type of quality promotion. Families and schools have been attracted since 2010 by events during the holidays and by popular posters accompanying exhibitions in the visitor center. With posters as handouts to visitors, knowledge of geological and natural topics was successfully disseminated. These kinds of events also attract coverage by newspapers, TV and radio. For a few years, digitization changed people’s behavior and activities (Moerstedt 2017). If Covid-19 had not have happened, the change would have taken longer, but now it dominates our

daily life.

### **Recent Geoscience Popularization Activities, “Deathly Paradise”**

Usually, scientists do not think of using games to engage people in geoh heritage themes, because the scientific community does not consider them to be serious. However, under the restrictions of the Covid-19 pandemic, there was pressure to develop programs for guided tours and quiz activities for visitors. By regular checking (Hogefeld and Frey 2021) it became clear that feedback on the new, unusual approaches is positive, as well as communication in an unpatronizing manner. Based on this experience, the Messel Pit WH team has developed new digital activities using games and knowledge about this geosite. One of the results was that users received positive energy through interesting quiz games and activities that took their minds off the Covid-19 situation.

One of the most successful offers has been the on-line portal “Deathly Paradise.” The first task was to inform users that not all fossils are dinosaurs, and some of the best-known fossils from the Messel Pit, Germany, the dawn horses or miniature horses were highlighted. The average first-time visitor tends to assume that there is only one spec-

imen, even though there are over 70 specimens of four species, *Propalaeotherium hassiacum*, *Propalaeotherium voighti*, *Eurohippus messelensis* and *Hallensia matthesi* (Fig. 13).

Other famous Messel fossils include the primate *Darwinius masillae*, named in 2009 and popularized as “Ida” and the giant bird *Gastornis geiselen-*

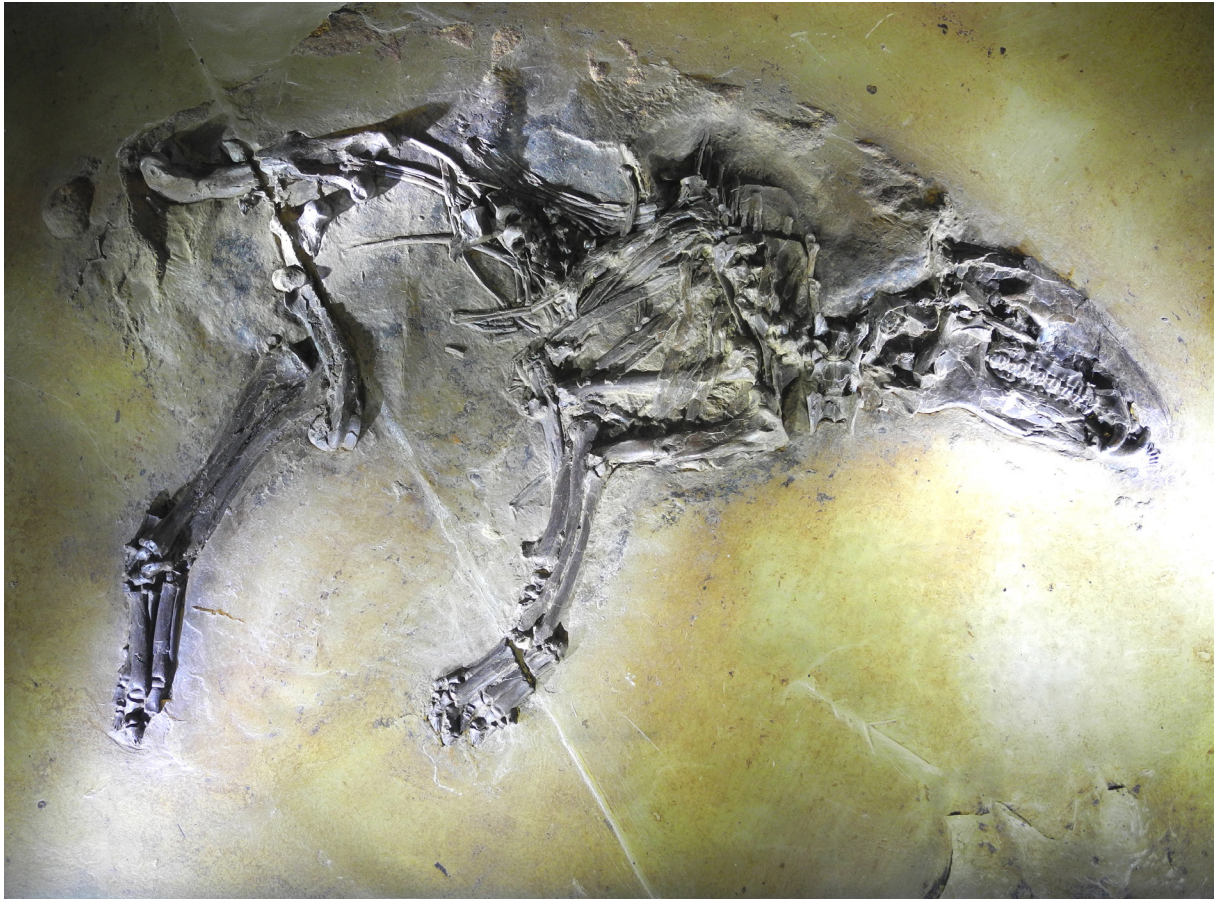


Figure 13. Messel fossil find: *Eurohippus messelensis* found in the year 2013, a complete skeleton prepared by the fossil transfer method and imaged against the epoxy base.

*sis*. Sometimes children know the mammal *Leptictidium* because it played a key role in a BBC TV documentary. Even children who are interested in paleontology do not know that this mammal was found in the Messel Pit and that there are three species (*L. auderiense*, *L. nasutum* and *L. tobieni*) or even that this documentary was set at the ancient Lake Messel.

During tours to the Messel Pit and in exhibitions at the visitor center, it became clear that people are

very interested in non-dinosaur fossils, especially fossils of a site like Messel Pit, which are miracles of preservation, as noted earlier. Their lack of knowledge is not their responsibility because it is not easy to find out which species of animals, plants or fungi lived 48 Ma ago in Messel. Scientific papers are in general too complex for the interested layman, hard to access and often hard to find. Newspaper articles are quickly forgotten. Books are important but can be expensive for the average visitor. Documentaries can reach a wid-



er audience, but are expensive to produce and can show, after a short time, outdated knowledge. This leaves the option of visiting a museum, a visitor center or the fossil key geosites itself. There is not yet an “Encyclopedia of Messel Organisms”. So, how can this problem be addressed? How can we give people the opportunity to inform themselves about the fossils of Messel Pit?

The answer has been the project “Deathly Paradise - Hesse in the Age of Dawn”. On the website of the Messel Pit – [www.grube-messel.de/projekte-aktivitaeten/toedliches-paradies.html](http://www.grube-messel.de/projekte-aktivitaeten/toedliches-paradies.html) – people can read about World Heritage topics. Here they find information about opening times, tour offers and a new option to book online tours was introduced in 2020. Every week or every month (depending on the season), a profile of one species is introduced. At the moment, these profiles are indexed as plants, insects, fishes, amphibians, mammals and sauropsids for easier navigation. A profile consists of a picture of a species with its scientific name below. The German name (if it exists), taxonomy, author, year of scientific description, age and geologic epoch complete the first page. On the following page, there are interesting facts about the species, like appearance, phylogenetic relationships, food, predators, paleogeographic implications, form of preservation, ecology or miscellaneous are presented. The categories are not always the same but depend on what is known of the species and seems interesting for the general public. The language used is easy for interested people, and important or useful scientific words and concepts are explained. So now everybody can be informed about the extraordinary adaptations of *Leptictidium* (Rose 2012; Maier *et al.* 1986), beetles with original colors (Chalumeau and Brochier 2001), the pit organs of the snake *Eoconstrictor fischeri* (Scanferla & Smith 2020) and what isolated feathers and feet can tell us about a hidden diversity of large birds (Mayr 2016). In addition, the Messel Pit is only one of two fossil geosites or “Fossil-Lagerstätten”, where a fossil with three trophic levels has been found, namely

a beetle within a lizard within a snake (Smith & Scanferla 2016; Kriwet *et al.* 2008).

To engage people more with the project, pictures of two fossils are presented on social media and everybody can vote for their favorite. After a certain amount of time, the winner is added to the website. Currently, an update of the website is planned, which integrates translations of the profiles into English. It is also intended to integrate the profiles into the physical exhibition, so people without access to the internet have an opportunity to browse the project. It can always be updated when new knowledge is gained, and it is certain that many new species will be added by further scientific excavations (Smith & Wedmann 2013).

The project “Deathly Paradise - Hesse in the Age of Dawn” will grow slowly and will help people to inform themselves about the significance of the Messel Pit and the Eocene, as well as paleontology in general. Currently it can be freely accessed without cost from anywhere in the world. The first visitors with print-outs of the project have already been spotted on tours. So “Deathly Paradise - Hesse in the Age of Dawn” can already be considered a success.

### **Geoscience Popularization: Interactions of Infrastructure, Collaboration, Visitor Offers as Tourism Products and Tourism Marketing**

A key question is how to finance activities such as these. The “Welterbe Grube Messel gGmbH was founded in 2003 to give regular access,” expand the activities and the knowledge about this unique geosite to a wider audience. Basic finances were decided for the “Welterbe Grube Messel gGmbH” with an internal two-part structure, a not-for-profit (charitable) part and an economic part. New management was recruited that gradually developed a new team to follow the goals given by this organizational structure and those given by the UNESCO Convention. Right from the beginning the political will of the board, responsible for official guidance and control of the management, was

declared to have an intensive collaboration not only with the scientific institutions working at the Messel Pit WHS but also with the Global Geopark Bergstrasse-Odenwald and other regional tourism organizations. This decision enabled the development of the activities already mentioned (Frey & Wurche 2009; Frey & Weber 2014).

With core funding from the shareholders, the new management and team developed a new range of guided offers to the Messel Pit Fossil Site. This raised additional income. During the first years, it was shown that a welcome point like a visitor center is needed to achieve a higher visitor stream, despite there being three natural history museums at a distance of 4–60 km. Visitors quickly made it clear that a visitor information point was missing at this unique location. Rising visitor numbers from nearly zero to 28,000 (Frey 2006) since 2004 provided evidence to invest in a new visitor center.

Fortunately, the State of Hesse showed their clear will to promote, safeguard and develop this first UNESCO Natural World Heritage Site in Germany by initiating progress with the planning and realization of a new visitor center (Frey 2012, 2016, 2018). The process started in 2004 and was successfully finished on 26<sup>th</sup> August 2010 when the handing over of the new visitor center to the public was celebrated by the former Minister President of the State of Hesse, Roland Koch. The visitor center was completely financed by the State of Hesse and a generous donation from a private bank in Frankfurt /Main. With this important step, visitor numbers jumped to 60,000 paying visitors in 2011. However, societal changes, technical advances and new demands led to declining visitor numbers, and this indicates that regular renewal and new attractions are required.

Tourism initiatives in the Bergstrasse-Odenwald territory paralleled progress around the Messel Pit WHS. An important step for both was enabled by the government of the Federal Republic of Germany after launching substantial funding through the

project in 2009 “National German World Heritage Sites” federal fund. As project partners, the Senckenberg Society for Nature Research, the Odenwald Tourism Company, and the Welterbe Gruppe Messel gGmbH came together. With support and coordination from the municipality of Messel, they succeeded in acquiring funding of about 2.1 Million Euro for restoration of main road access to the Messel Pit and about 700,000 Euro for tourism development of the Bergstrasse-Odenwald region and the Messel Pit WHS (Frey 2014; Rabenstein and Schaal 2012).

Over nearly ten years, the visitor center and geotourism activities described earlier cost a yearly budget of about 880,000–900,000 Euro. The marketing budget is about 5–7% of this. The main fixed costs are infrastructure maintenance plus staff at 70%. However, the income from geotourism activities, including products and services, plus the shop and bistro run by the company, generates nearly 50% of the budget, depending on visitor numbers and years without extreme restrictions such as the covid pandemic. Depending on seasonal changes, the core team works on guided tours or creates new ideas, as shown in 2020 and 2021 by the new virtual activities published on the website. It should be also emphasized that regional promotion of the WHS Messel Pit is enabled by regular and very constructive collaboration with the partner UNESCO Global Geopark Bergstrasse-Odenwald. As a follow up of this collaboration, other new funding options and projects were realized (Weber and Frey 2010). Thus, the WHS Messel Pit and the UNESCO Global Geopark Bergstrasse-Odenwald are best practice examples of collaboration between UNESCO entities in the long term (McKeever *et al.* 2012).

### **Summary and Conclusion**

For 18 years, a range of activities has been undertaken on geoscience popularization at the extraordinary, universal geosite Messel Pit WHS, a key geoheritage site Croft *et al.* (2020). After identi-

fyng the heart of the geosite or its “geo-identity”, a popularization concept could be developed that matched the challenge of scientific, world heritage and economic demands through the geosite management. The vision is based on the geodiversity of the Messel Pit, but this alone is not the core of successful development. Further, the quality of the activities and staff, as well as their creativity, the promotion strategy, and logistics of planning and carrying out guided tours, with quality control throughout, plus active collaboration with reliable partners are essential elements for a successful visitor experience and a successful economic result for the management.

As measured by visitor satisfaction, the key elements of our geo-education and geotourism activity include exciting impressions during a tour, an exciting story told about the formation of the site, an appropriate level of knowledge transfer, the special atmosphere on guided tours, and the self-directed experiences, games and quizzes, as well as competitions in social media. Long-term interest by visitors can only be achieved by continuing promotion of existing activities and new offers which allow new experiences, including events, special offers or new approaches by collaboration with partners like the UNESCO Global Geopark Bergstrasse-Odenwald, Vulkaneifel, Naturtejo, Hong Kong, Lesvos Island and specific projects. In this context, the Messel Pit as a single WHS has a limited potential for active experiences. Additional online activities will be important both to attract visitors to the site, and to allow them to feel the spirit of the location and its importance.

Following quality checks and visitor feedback it will be important to develop additional focal points or formats not exclusively inside the Messel Pit but around the geosite inside the tourism region and the geopark territory. A clear visible highlight is necessary at this geosite to give visitors a more obvious reason to visit this unique location or to explore its invisible treasures. New formats and their integration into a tourism struc-

ture will enable visitors to have an additional experience or give inhabitants a reason to re-visit the WHS Messel Pit. Collaboration in geoscience popularization plays an important role and raises high interest among the people living in the region and foreign visitors. Activities need to be communicated across media regularly to indicate that the geosite is alive and valuable. New infrastructure, regular collaboration and stable financial support, even in difficult periods such as the covid pandemic by the State of Hesse are core points for successful development as well as to generate income that enables and supports new development to adapt to new visitor demands.

Finally, a new pride in this treasure can grow step by step. According to Agenda 2030, the needs of future generations will be served by these activities, at least by handing over the knowledge and atmosphere at this location - that this is its “locus spiritus” – a key geoheritage site, a geosite of outstanding universal value worldwide and finally, a learning lab for our future on Earth.

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#### **Conflict of Interest**

The authors declare that they have no conflict of interest.

## References

- Anonymous 2014. UNESCO Outstanding Universal Value. <https://unesco.org>
- Bohaty J & Zell P (2021). Fossilagerstätte Grube Messel (UNESCO-Weltnaturerbe). In KuLaDig, Kultur.Landschaft.Digital. [www.kuladig.de/Objektansicht/KLD-315839](http://www.kuladig.de/Objektansicht/KLD-315839)
- Büchel GN & Schaal SFK (2018). The formation of the Messel maar. In Smith KT, Schaal S, Habersetzer J (eds) Messel – An Ancient Greenhouse Tropical Ecosystem. Senckenberg Buch 80 (pp. 7–13) Stuttgart: Schweizerbart'sche Verlagsgesellschaft.
- Chalumeau F & Brochier B (2001). Une forme fossile nouvelle de Chiasognathinae: *Protognathinus spielbergi* (Coleoptera, Lucanidae). *Lambillionea*. 101:593–595.
- Croft R, Gordon JE, Briha J, Gray M, Gunn J, Larwood J, Santucci FL, Tormey D, & Worboys GL (2020). (Groves C, Series Editor) Guidelines for geoconservation in protected and conserved areas. IUCN Publ. Best Practise Protected Areas Guidelines Series Nr. 31, Gland, Switzerland: IUCN.
- Dietrich R (1998). Geotopschutz der Grube Messel rechtlicher Rahmen und tatsächliche Gegebenheiten. *Natur und Museum*. 128:350–354.
- Escher HH, Frey ML & Krupetz M (2015). Fortentwicklung des Globalen Geopark Netzwerks (GGN) unter der Schirmherrschaft der UNESCO hin zu einer Kategorie UNESCO Global Geopark. Schriftenreihe der Deutschen Gesellschaft für Geowissenschaften. 86:16–25.
- Felder M & Harms FJ (2004). Lithologie und genetische Interpretation der vulkano-sedimentären Ablagerungen aus der Grube Messel anhand der Forschungsbohrung Messel 2001 und weiterer Bohrungen. *Courier Forschungsinstitut Senckenberg*, 252:151-203.
- Felder M, Harms FJ, Liebig V, Hottenrott M, Rolf C & Wonik T (2001). Lithologische Beschreibung der Forschungsbohrungen Groß-Zimmern, Prinz von Hessen und Offenthal sowie zweier Lagerstättenbohrungen bei Eppertshausen (Sprendlinger Horst, Eozän, Messel-Formation, Süd-Hessen). – *Geologische Jahrbuch von Hessen*. 128:29–82.
- Franzen JL (2018). Odd-toed ungulates – early horses and tapiromorphs. In Smith KT, Schaal S, Habersetzer J (eds) Messel – An Ancient Greenhouse Tropical Ecosystem. Senckenberg Buch 80 (pp. 293–301) Stuttgart: Schweizerbart'sche Verlagsgesellschaft.
- Franzen JL (2019). Report on the discovery of fossil mares with preserved uteroplacenta from the Eocene of Germany. *Fossil Imprint*. 73:67–75.
- Frey ML (1993). Der Geo-Park in der Verbandsgemeinde Gerolstein: Planung und Realisierung. In: Die schöne Eifel Gerolstein (pp. 106–113). Düren: Eifelverein.
- Frey ML (2000). Geotourism, a new perspective for public awareness on geology. Case study Geopark Gerolstein & Geo-Centre Vulkaneifel, Germany. 3<sup>rd</sup> Int. Conf. Geoscience Education, Sydney, 16-21th January 2000, Univ. NSW, Proceed., Poster, Abstract Volume, AGSO Record 1999/49: 156-157.
- Frey ML (2012). Vulkaneifel, a role model for the European and Global Geoparks Network. Proceed Contact Forum “Geoheritage, Geoconservation & Geotourism (15/11/2012), Royal Flemish Academy of Belgium for Science and the Arts, Museum, (pp. 31-44), Bruxelles: Geological Survey of Belgium.
- Frey ML (2014). Benefit chains at Messel Pit WHS – creating a Geotourism Highlight in the tourism destination Odenwald.Germany. 6th Internat. UNESCO Global Geoparks Conference, 19-22 September 2014, Stonehammer UGGp, Saint John, New Brunswick, Canada. <https://journals.lib.unb.ca/index.php/ag/article/view/atlgeol.2014.015/26306>
- Frey ML (2016). Geoscience Public Outreach at Messel Pit World Heritage (WHS, Germany) – Hand in Hand of World Heritage and Global Geoparks. In: Hess V, Rascher J, Zellmer H (Eds): Kultur. Wert. Stein. Verantwortung und Chancen für Geoparks.

- Schriftenreihe des Deutsche Geowissenschaftliche Gesellschaft, 88:37–44.
- Frey ML (2018). Visitor Centre at the Messel Pit World Heritage Site – Platform for the greater public, science and world heritage. In *Welterbe Vermitteln – ein UNESCO Auftrag*, Dornbusch R, Hansell F, Manz K. In *Industrie-Archäologie*, 19, Sächsisches Industriemuseum, IWTG/TU Bergakademie Freiberg, (pp. 98-107).
- Frey ML, Schäfer K & Büchel G (2002). Geologische Öffentlichkeitsarbeit eine Option für die Zukunft. 5. Int. Geotopschutztagung, Krefeld, Mai 2001, SCRIP-TUM, Nr. 9: 17–37, Krefeld: Geologischer Dienst.
- Frey ML, Schäfer K, Büchel G & Patzak M (2006). Geoparks – a regional, European and global policy in Geotourism. In Dowling RK, Newsome, D (eds), *Geotourism* (pp. 95-118). Elsevier: Amsterdam.
- Frey ML & Weber J (2014). Geo-education and geo-communication: cooperation experience of Global Geopark Bergstraße-Odenwald and WHS Messel Pit, Germany. *Schriftenreihe Deutsche Geowissenschaftliche Gesellschaft*, 85:643–656.
- Frey ML & Wurche B (2009). Wissenschaftliche Themenvielfalt und Erfahrungen in der Besucher-orientierten Kommunikation der UNESCO Grube Messel. In Dickel M, Glasze G (eds). *Vielperspektivität und Teilnehmerzentrierung – Richtungsweiser der Exkursionsdidaktik*. Praxis Neue Kulturgeographie, Bd. 6, Berlin: Lit-Verlag.
- Garrouste R & Nel A (2015). New Eocene damselflies and first Cenozoic damsel-dragonfly of the isophlebiopteran lineage (Insecta: Odonata). *Zootaxa*. 4028:354–366.
- Gruber G & Micklich N (2007). *Messel. Treasures of the Eocene*. Darmstadt: Hessisches Landesmuseum Darmstadt.
- Harms FJ & Schaal FSK (2000). Die Geologie der Grube Messel. In: *Fenster zur Urzeit – Weltnaturerbe Grube Messel*, 2nd edition (pp. 16–23). Hessisches Ministerium für Wissenschaft und Kunst, Wiesbaden, 72 p.
- Harms FJ (2011). Die Grube Messel auf Luftbildern von 1956/57. *Naturwiss. Ver. Darmstadt – Bericht N.F. 34*, Darmstadt, Special Print.
- Hinsken S, Ustaszewski K & Wetzel A (2007). Graben width controlling syn-rift sedimentation: the Palaeogene southern Upper Rhine Graben as an example. *International Journal of Earth Sciences*. 96:979–1002.
- Hogefeld C & Frey ML (2021). Visitor & product monitoring for sustainable geotourism at UNESCO World Heritage Site Messel Fossil Site: The “Geo”? visitor, his judgement and aspects on quality of service and products. *Schriftenreihe der Deutschen Gesellschaft für Geowissenschaften*. 95:93–107.
- Hughes DP, Wappler T & Labandeira CC (2010). Ancient death-grip leaf scars reveal ant-fungal parasitism. *Biology Letters*. 7:67–70.
- Jacoby W, Wallner H & Schmilde P (2000). Tektonik und Vulkanismus entlang der Messeler-Störungszone auf dem Sprendlinger Horst: geophysikalisch Ergebnisse. *Zeitschrift der Deutschen Gesellschaft für Geowissenschaften*. 151:493–510.
- Joyce WG, Micklich N, Schaal SFK & Scheyer T (2012). Caught in the act: the first record of copulating fossil vertebrates. *Biology Letters*. 8:846–848.
- Kasig W & Frey ML (1997). Geologische Öffentlichkeitsarbeit im Geotopschutz.- Hrsg. 2. Jahrestagung der Arbeitsgemeinschaft Geotopschutz in deutschsprachigen Ländern, 16.-19. März 1994, Gerolstein/Vulkaneifel, Aachener Geowissenschaftliche Beiträge, Aachen: Verlag der Augustinus Buchhandlung.
- Kriwet J, Witzmann F, Klug S & Heidtke UHJ (2008). First direct evidence of a vertebrate three-level trophic chain in the fossil record. *Proceedings of the Royal Society B*. 275:181–186.
- Kubaneck T, Nölter J, Weber J & Zimmerle W (1988). On the lithogenesis of the Messel Oil Shale. *Courier*

- der Forschungsinstitut Senckenberg. 107:13–28.
- Lenz KL, Wilde V, Mertz DF & Riegel W (2015). New palynology-based astronomical and revised  $^{40}\text{Ar}/^{39}\text{Ar}$  ages for the Eocene maar lake of Messel (Germany). *International Journal of Earth Sciences* 104:873–889.
- Lenz OK & Wilde V (2018). Changes in Eocene plant diversity and composition of vegetation: the lacustrine archive of Messel (Germany). *Paleobiology*. 44:709–735.
- Lorenz V & Büchel G (1980). Zur Vulkanologie der Maare und Schlackenkegel der Westeifel. *Mitteilungen Pollichia*. 68: 29–100.
- Look ER & Quade H (2007). *Faszination Geologie – Die bedeutendsten Geotope Deutschlands*. 2nd Ed. (Ed) Akademie der Geowissenschaften zu Hannover e.V., E. Schweizerbart'sche Verlagsbuchhandlung (Nägele u. Obermiller), 175 p.
- Maier W, Richter G & Storch G (1986). *Leptictidium nasutum* – ein archaisches Säugetier aus Messel mit außergewöhnlichen Anpassungen. *Natur und Museum*. 116:1–19.
- Matejka G (2020). Seit 25 Jahren UNESCO Weltnaturerbe. Das Erbe unserer Welt – Sammlerausgabe, Winter 2020 (pp. 102–108). London: Square Rock.
- Mayr G (2016). Avian feet, crocodylian food and the diversity of larger birds in the Early Eocene of Messel. *Palaeobiodiversity and Palaeoenvironments*. 96:601–609.
- Mayr G & Wilde V (2014). Eocene fossil is earliest evidence of flower-visiting by birds. *Biology Letters*. 10:20140223.
- McKeever PMC, Frey ML & Weber J (2012). Global geoparks and geological World Heritage. a case study from Germany. *World Heritage*. 70:36–42.
- Mertz DF & Renne PR (2005). A numerical age for the Messel fossil Deposit (UNESCO World Heritage Site) derived from  $^{40}\text{Ar}/^{39}\text{Ar}$  dating on a basaltic rock fragment. *Courier der Forschungsinstitut Senckenberg*. 255:67–76.
- Moerstedt B (2017). *Generation Z: Herausforderung für Unternehmen?* YouTube, <https://www.youtube.com/watch?v=B2JDEpKh9go> Access 16.12.2021
- Moshayedi M, Lenz OK, Wilde V & Hinderer M (2020). The recolonisation of volcanically disturbed Eocene habitats of Central Europe: the maar lakes of Messel and Offenthal (SW Germany) compared. *Palaeobiogeography and Palaeoenvironments*. 100:951–973.
- Nix T (2003). *Untersuchung der ingenieurgeologischen Verhältnisse der Grube Messel (Darmstadt) im Hinblick auf die Langzeitstabilität der Grubenböschungen*. Dissertation, Technischen Universität Darmstadt, Darmstadt.
- O'Reilly S, Summons R, Mayr G & Vinther J (2017). Preservation of uropygial gland lipids in a 48-million-year-old bird. *Proceedings of the Royal Society B*. 284:20171050.
- Rabenstein R & Schaal SMD (2012). *Erlebnisgestaltung Weltnaturerbe Grube Messel – Geologische Aspekt, SDGG Heft 79, GeoTop 2012, Landschaften und ihr Potential, Kirchheimbolanden, Hannover 2012, pp. 39–41.*
- Reischmann Th, Nesbor HD & Wimmenauer W (2011). *Tertiärer Vulkanismus*. In: Grimm KI et al. (Eds) *Tertiär, Teil 1: Oberrheingraben und benachbarte Tertiärgebiete*, SDGG, Heft 75: 16–30, Stuttgart: Schweizerbart Science Publishers.
- Rose KD (2012). The importance of Messel for interpreting Eocene Holarctic mammalian faunas. *Palaeobiodiversity and Palaeoenvironments*. 92:631–647.
- Ruf I & Lehmann T (2018). Rodents– gnawing their way to success. In: Smith KT, Schaal S, Habersetzer J (eds) *Messel – An Ancient Greenhouse Tropical Ecosystem*. Senckenberg Buch 80 (pp. 263–269) Stuttgart: Schweizerbart'sche Verlagsgesellschaft.
- Scanferla A & Smith KT (2020). *Exquisitely preserved*

- fossil snakes of Messel: insight into the evolution, biogeography, habitat preferences and sensory ecology of early boas. *Diversity*. 12:100.
- Schulz R, Harm FJ & Felder M (2002). Die Forschungsbohrung Messel 2001: Ein Beitrag zur Entschlüsselung der Genese einer Ölschieferlagerstätte. *Zeitschrift für angewandte Geologie*. 48:9–17.
- Selden PA & Wappler T (2019). A new spider (Arachnida: Araneae) from the Middle Eocene Messel Maar, Germany. *Palaeoentomology*. 2:596–601.
- Smith KT & Scanferla A (2016). Fossil snake preserving three trophic levels and evidence for an ontogenetic dietary shift. *Palaeobiodiversity and Palaeoenvironments*. 96:589–599.
- Smith KT & Wedmann J (2013). Unerforschte Vielfalt in der Grube Messel. *Das Senckenberg-Wissenschaftsmagazin*. 143:230–235.
- Weber J (2010). *Geotop 2010 – Grube Messel* (Flyertitel).
- Weber J & Böhn S (2009). Zwischen Granit und Sandstein. Eine Reise in die Erdgeschichte der Geo-Naturpark Region, 3. Aufl., Lorsch: Laurissa-Verlag, 39 p.
- Weber J & Frey ML (2010). *Geowissenschaften für die Öffentlichkeit – Erdgeschichte entdecken im Geo-Naturpark Bergstraße-Odenwald*. GeoDarmstadt 2010, Ann. Conf. Dt. Geol. Soc. (DGGV), Abstract-Volume, Hannover: DGGV (Ed.).
- Wappler T, Labandeira CC, Engel MS, Zetter R & Grimsson F (2015). Specialised and generalized pollen-collection strategies in an ancient bee lineage. *Current Biology*. 25:3092–3098.
- Wedmann J (2018). Jewels in the Oil Shale– insects and other invertebrates. In: Smith KT, Schaal S, Habersetzer J (eds) *Messel – An Ancient Greenhouse Tropical Ecosystem*. Senckenberg Buch 80 (pp. 63–103) Stuttgart: Schweizerbart’sche Verlagsgesellschaft.
- Wedmann S, Bradler S & Rust J (2007). The first fossil leaf insect: 47 million years of specialized cyptic morphology and behavior. *Proceedings of the National Academy of Sciences, U.S.A.* 104:565–569.
- Wuttke M (1988). Erhaltung – Lösung – Umbau. Zum Verhalten biogener Stoffe bei der Fossilisation. In: Schaal SFK, Ziegler W (Eds.). *Messel – ein Schaufenster in die Geschichte der Erde und des Lebens* (pp. 263–287). Frankfurt am Main: W. Kramer.
- Wuttke M (2012). Taphonomic processes in terrestrial and marine environment. *Palaeobiodiversity and Palaeoenvironments*. 92: 1-3.
- Ziegler P (1988). Evolution of the Arctic-North Atlantic and the Western Tethys. *American Association of Petroleum Geologists, Memoir* 43:99–100, 133–138.