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Herausgegeben von Claus von Carnap-Bornheim, Falko Daim, Peter Ettel und Ursula Warnke

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HARBOURS AS OBJECTS OF INTERDISCIPLINARY RESEARCH – ARCHAEOLOGY + HISTORY + GEOSCIENCES

International Conference »Harbours as objects of interdisciplinary research – Archaeology + History + Geosciences« at the Christian-Albrechts-University in Kiel, 30.9.-3.10.2015, within the framework of the Special Research Programme (DFG-SPP 1630) »Harbours from the Roman Period to the Middle Ages«

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FOREWORD

The Priority Programme 1630 »Harbours from the Roman Period to the Middle Ages« funded by the German Research Foundation (Deutsche Forschungsgemeinschaft) in the years 2011-2018 has made it its priority to unite and connect multidimensional approaches to harbour research within the vast research area of the North Atlantic to the Mediterranean. Modern research of the last three to four decades has particularly shown how the integration of geophysical and geoarchaeological methods has brought new insights into interdisciplinary and interpretational approaches. Thus the logical consequence was to dedicate the first international conference on the framework of the Priority Programme to this approach and its wide discussion. It took place from 30 September to 3 October 2015 with the title »Harbours as objects of interdisciplinary research – Archaeology + History + Geosciences«. About 130 participants from 15 nations with 70 lectures presented their work approaches and results within the five sections of the conference: »Plenum keynote-lectures«, »Geophysics and Field Research: Developing methods«, »Geoarchaeology: Changing Harbour Environments«, »Archaeological Features: Harbour Facilities and Infrastructure«, »Written and Iconographic Sources: Complementing the Material Evidence«. The ceremonial address of the evening was given by Sabine Ladstätter (Vienna) on the harbour of Ephesos. On the last day of the conference the participants visited the Viking Museum Haithabu as well as exhibitions at the Schleswig-Holsteinisches Landesmuseum Schloss Gottorf in Schleswig.

Subsequent to the conference in Kiel, the initiators of the Priority Programme decided on what at first glance appears to be an unusual publication strategy in which the predominantly archaeologically and historically oriented papers are being published in the present volume, whereas some mainly geophysical and geoarchaeological papers will be published in Quaternary International Special Issue »Integrated geophysical and (geo)archaeological explorations in wetlands« (guest editors: Christoph Zielhofer, Wolfgang Rabbel, Stefanie Berg-Hobohm, Tina Wunderlich), thereby reaching different milieus, which are, however, interconnected by their interdisciplinary research on harbours. Consequently, the thematic structure of the present volume will differ from the actual conference and the submitted contributions are arranged regionally as well as topically.

Our thanks go especially to Ilka E. Rau, who was both responsible for organising the conference as well as for the editorial responsibilities of this volume. Moreover, our thanks go to the editorial team of the RGZM in Mainz.

The initiators of the SPP 1630 »Harbours from the Roman Period to the Middle Ages«
Claus von Carnap-Bornheim
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EVA LEITHOLDT · MICHAEL SCHNEIDER · SVEN LINZEN
STEFANIE BERG-HOBOHM · PETER ETTEL

FOSSATA MAGNA – A CANAL CONTRIBUTION TO HARBOUR CONSTRUCTION IN THE 1ST MILLENNIUM AD

NAVIGABLE CANALS IN THE 1ST MILLENNIUM AD – AN INTRODUCTION

Navigable canals are an exception in the 1st millennium AD in central Europe – but not as rare as often thought (**fig. 1**)[1]. Although they form key elements of the European harbour network, only a few prominent examples have so far been the subject of considerable (geo)archaeological research, first and foremost the Kanhave Canal (Denmark)[2], the Fossa Carolina (Germany)[3], the Glastonbury Canal (Great Britain)[4], the harbour canals in Ostia/Portus (Italy)[5], the Fossa Corbulonis (Netherlands)[6], a canal near Spangereid (Norway)[7], in Avenche (Switzerland)[8], in Tendu (France)[9], and in Ephesus (Turkey)[10]. Many more are poorly documented/published or have only been proven in written sources, some of them only as planned projects which have never been realised. Furthermore, in many cases the navigability is not confirmed and the original purpose and *de facto* use is unknown[11].
By means of canals, transition zones of the transportation network have been artificially modified[12]. The construction of canals, especially their water depths and fairway width, reflects the specific requirements regarding the usability of inland harbours and waterways. These requirements result from the interplay between local to regional site conditions and vessel characteristics[13]. In our paper, we present three case studies to discuss this topic for different types of canals, different transport zones[14] and different periods. The pivotal point of our interdisciplinary team in the Priority Programme 1630 is the Fossa Carolina or *fossatum magnum*[15].

CANAL LOCATIONS IN HARBOUR NETWORKS

Irrespective of their individual configuration, we classified three general types of navigable canals regarding their location and connectivity in the harbour network (**fig. 2**)[16].
1. Dead-end canals (**fig. 2, 1**), which effectuate a local enlargement of a certain transport zone in the hinterland. Usually they are harbour entrances at the same time and connect a production site or a consumer center in the hinterland to a navigable waterway[17]. Important examples are the canals in Avenche, Ephesus and Tendu (Roman) as well as in Glastonbury, Sawtry and Bruges (medieval)[18].
2. Shortcut or parallel canals (**fig. 2, 2**), which are used to bypass an obstacle or simply reduce the travel distance between harbours within a certain transport zone[19]. Important examples are the Iron Gate canal and the Canale Romano (Roman) as well as the Kanhave Canal and canals in Bampton, Abingdon and Calbe (medieval)[20]. An especially vivid description of the construction of this type of canal comes from early 11th-century London: in 1016 a Danish fleet dug a big ditch to bypass London Bridge during a military operation, because the bridge blocked the waterway for their ships[21].

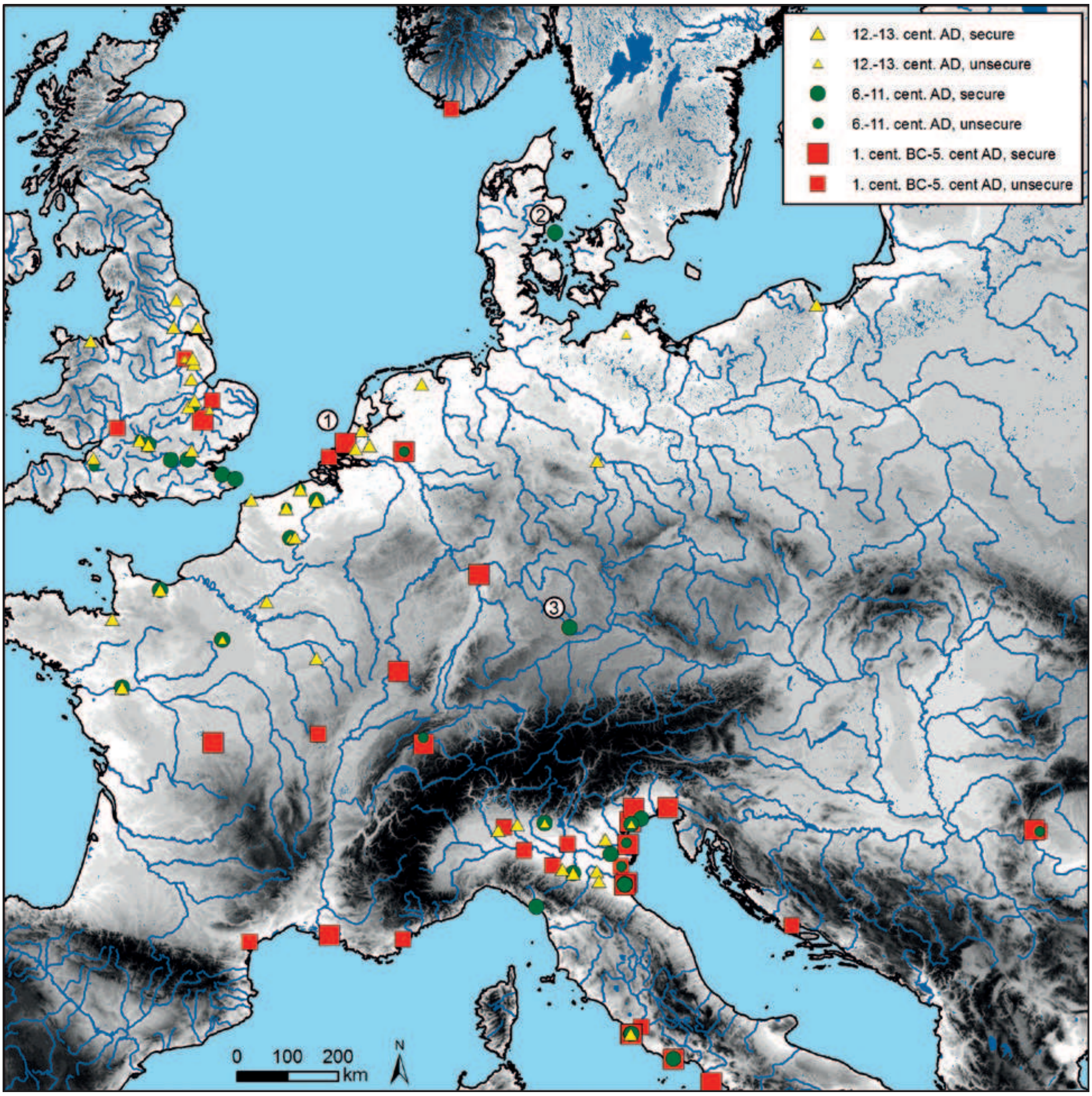


Fig. 1 Distribution of selected navigable and probably navigable canals (1st century BC to the 11th century AD, planed as well as constructed, with information concerning the security of the record/interpretation) in Central Europe based on written sources and (geo-) archaeological data. – (Basemap SRTM-GDEM © NASA 2009, CCM River and Catchment Database © European Commission 2007; cartography and data collection L. Werther).

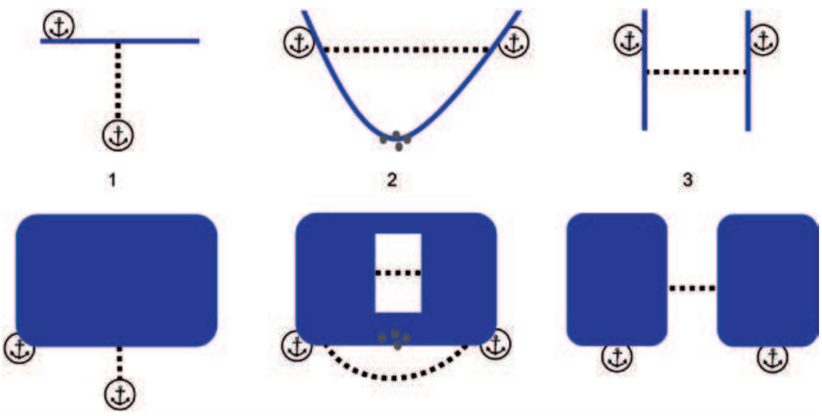
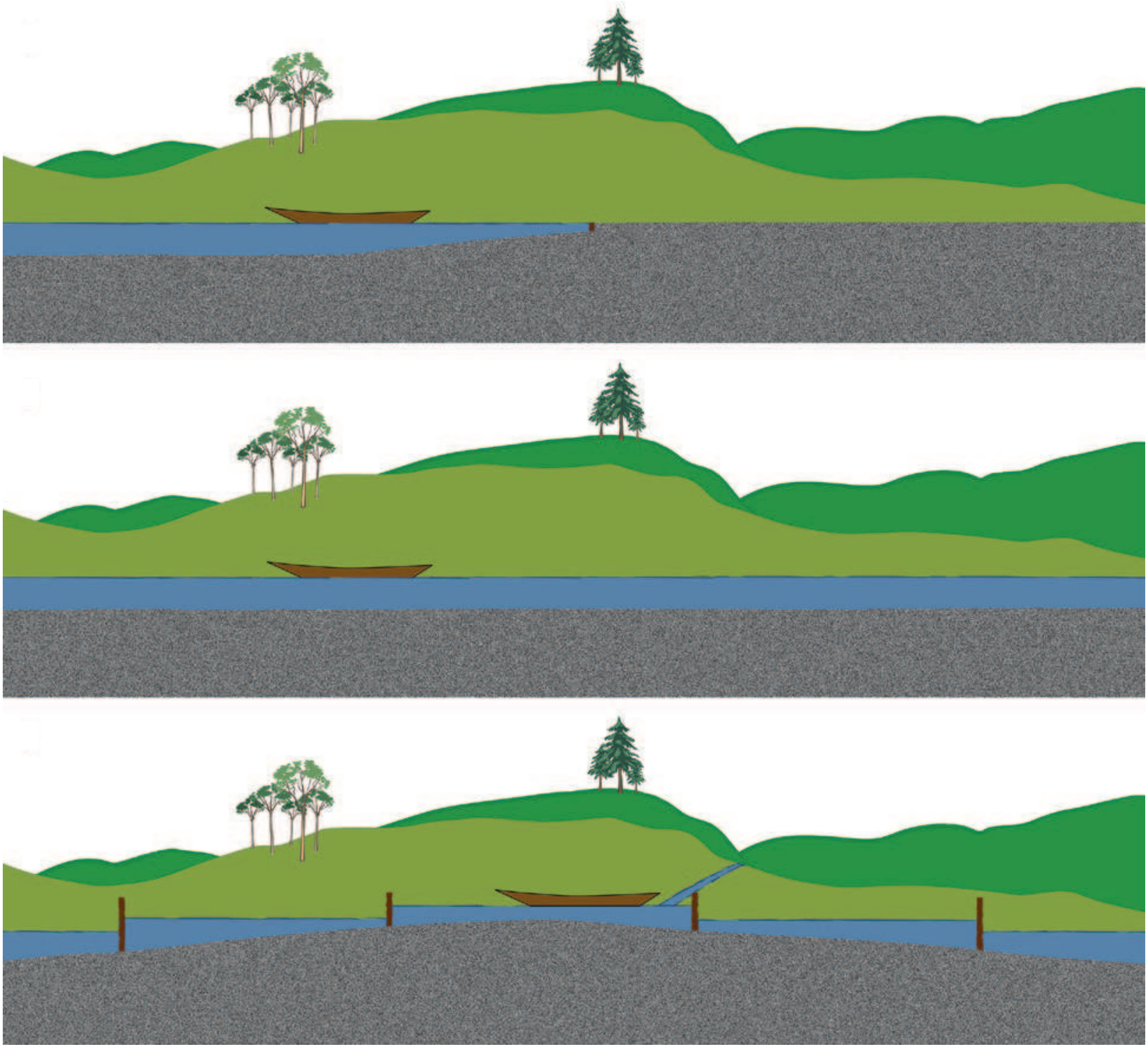


Fig. 2 Types of navigable canals regarding their location and connectivity in the harbour network. Top: inland; bottom: coast; dashed line: canal; anchor symbol: harbour; grey dots: obstacles. – **1** dead-end canal. – **2** shortcut or parallel canal. – **3** connection or watershed canal. – (Graphics L. Werther).



1
2
3

Fig. 3 Classification of canals concerning their hydrological concept and longitudinal profile. – (Graphics L. Werther, after Bockius 2014, fig. 3).

3. Only the last type, **connection or watershed canals** (**fig. 2, 3**), connect two separate harbour networks, drainage systems and transport zones. Important examples are the canals between the Moselle and Saône (Roman) as well as the Fossa Carolina and the Stecknitzfahrt (medieval)[22].

CONSTRUCTION AND LONGITUDINAL PROFILE

The technical construction and longitudinal profile offers a second method of canal classification (**fig. 3**).
1. Technically, the least complex is a **dead-end canal** with a **homogenous water level**, only connected to one hydrological system (**fig. 3, 1**). The canals in Avenche and Tendu offer vivid examples of this type of canal, only the water level of Lake Morat and the River Bouzanne respectively are relevant for the canal hydrology[23].

2. A bit more complex is a canal connecting **two waterbodies** on a more or less **homogeneous water level** (**fig. 3, 2**). The Kanhave Canal, dependent on the sea level on both sides of Samsø island, is a well-known maritime example[24]. The Canale Romano at Portus, bypassing the Tiber, belongs to the fluvial system[25].
3. The most complex solution is a canal with a summit level, which connects **two waterbodies with different water levels** and therefore two different hydrological systems (**fig. 3, 3**). Important representatives of this type are the Fossa Carolina, bridging the watershed between Danube and Rhine, and the Fossa Corbulonis, bridging the watershed between Meuse and Rhine[26]. Several other ambitious canals of this type were planned but never realised in the 1st millennium AD, such as a canal between the Moselle and the Saône projected in 55/56 AD according to Tacitus or a canal from Lake Sapanca to the sea described by Pliny the Younger in 111 AD[27].

CANAL FAIRWAYS AND VESSELS

Naturally, the cross section of canal fairways is mainly influenced by the size of vessels they are made for. Therefore, the fairway dimension could help us to evaluate the usability for different types of ships. Wrecks or parts of wrecks conserved *in situ* in canal fairways are almost inexistent except for one example: in the canal of Avenche, a Gallo-Roman naval building yard of the 2nd century AD, several planks, frames and other pieces for the construction of barges have been excavated[28].
Reliable data about canal dimensions are crucial for a comparison with vessel sizes, but especially reliable information concerning the actual fairway width can only be given by (geo)archaeological investigations. This is stressed by the example of the Fossa Carolina with an assumed canal width of 20 m to 30 m in older publications[29], whereas new on-site data gave proof for a fairway width of not more than 5-6 m[30]. In general, the range of vessels used in the 1st millennium AD covers small riverboats, but also huge seagoing ships[31]. The fairway dimension might answer the question which vessels and which type of cargo a specific canal was made for and to which and from which transport zone vessels may have shipped by using a canal. The interplay between canal fairway and vessels might also shed light on the question how neighbouring harbours were constructed and for which vessels they would have been appropriate. Nevertheless, this is a dynamic field as the usability of a canal is all but stable because fairway dimensions change due to factors like sedimentation and insufficient maintenance[32]. The following case studies, which are ordered chronologically, will discuss these general issues in greater detail.

CASE STUDY 1: THE FOSSA CORBULONIS

Our oldest example of a canal with a summit level is a Roman canal in the Netherlands, the Fossa Corbulonis (**fig. 1, 1**)[33]. It is common knowledge that Roman engineers and especially the Roman army realized large-scale transport infrastructure frequently. The construction of roads, storehouses and also harbours is well known, but there are also lesser-known components such as a certain number of artificial waterways from this period.
In the 1st century AD Roman military built a shore-parallel canal between the Rivers Meuse and the (Old) Rhine (**fig. 4**). Tacitus offers a vivid description of the construction circumstances in the year 50 AD: »*Ut tamen miles otium exueret, inter Mosam Rhenumque trium et viginti milium spatio fossam perduxit, qua incerta Oceani vitarentur.*«[34] After an aborted military operation east of the Rhine the general Corbulo or-

Fig. 4 Topographic position of the Fossa Corbulonis (red). – (Basemap SRTM-GDEM © NASA 2009, CCM River and Catchment Database © European Commission 2007; cartography L. Werther).

dered the construction of the canal, amongst other things to keep the soldiers busy[35]. According to Tacitus, the main motivation of the project was to avoid the dangerous detour – *incerta Oceani* – on the open sea between the two river systems. The dating is perfectly confirmed by dendrochronology[36].

The total length of the canal is more than 30 km, although natural watercourses were integrated into the construction in some sections[37]. In the north-east, the canal is connected to the Rhine close to the Roman fort of Matilo, which was built a short time after the canal[38]. The south-eastern connection to the Meuse is uncertain, but it is most likely located close to the 2nd-century fleet base at Naaldwijk[39]. In Leidschendam, close to the later Roman city of Forum Hadriani, the canal bridges the local watershed between the two catchments. The level difference of the canal bottom seems to be no more than 2 m[40]. On both sides of an assumed portage with earthen dams, the canal bottom reaches the highest levels which have been documented, forming some kind of a flat ramp[41].

As the excavations indicate two different trench bottom levels east and west of the watershed, one must assume a canal with a summit level divided by locks or two disconnected dead-end canals (**fig. 3, 1. 3**)[42]. Regarding the position within the entire harbour network, the Fossa Corbulonis is a hybrid with elements of all types: a connection canal bridging a local watershed (**fig. 2, 3**), a shore-parallel canal bypassing an obstacle (**fig. 2, 2**) and a combination of two dead-end canals (**fig. 2, 1**), which enlarge the transport zones of the Rivers Rhine and Meuse in the hinterland. It connects two riverine transport zones bypassing an open sea passage which is impassable for riverboats due to the *incerta Oceani* described by Tacitus[43].

The assumption that the canal was mainly made for riverine vessels is supported by the excavated cross sections[44]. Between the timbering, the fairway reveals a maximum width of 15 m, but the crucial bottlenecks are no wider than 4.5 m[45]. The fairway depth was not more than 1.3 m from the Roman surface at the shallowest point and therefore the water depth must have been even lower[46]. This corresponds to the maximum water depth of 1.5 m in the basin of the inland harbour in Voorburg-Arentsburg, which was constructed

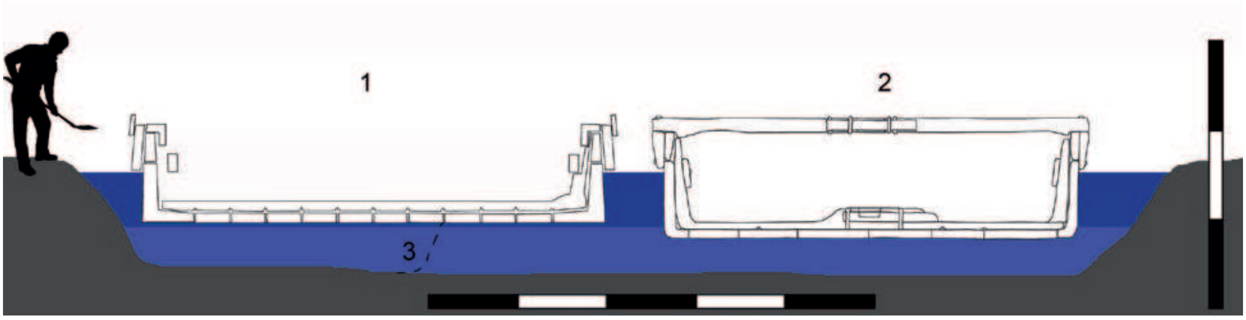


Fig. 5 Idealized cross-section of the Fossa Corbulonis with cross-sections of contemporary vessels. – **1** Woerden 7. – **2** Zwammerdam 4. – **3** projection of the crucial bottleneck of the canal with a fairway width of only 4.5 m. – Dark blue: estimated maximum water level; light blue: estimated minimum water level. – (Graphics L. Werther / L. Kröger; based on de Kort / Raczynski-Henk 2014).

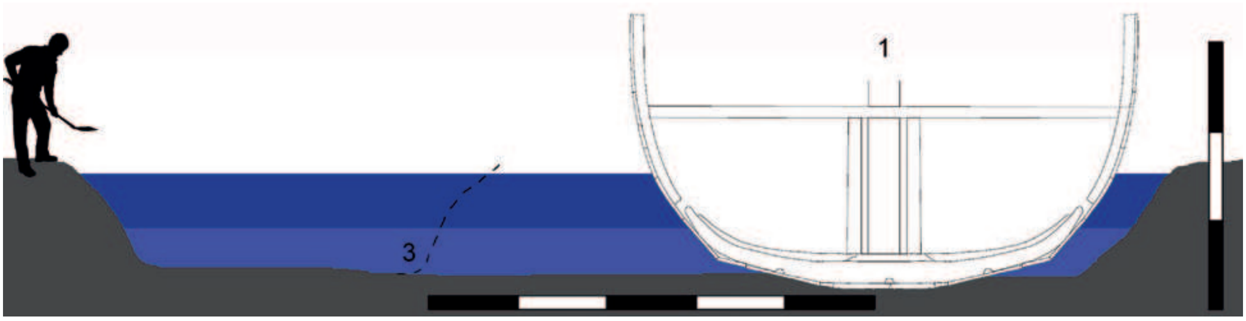
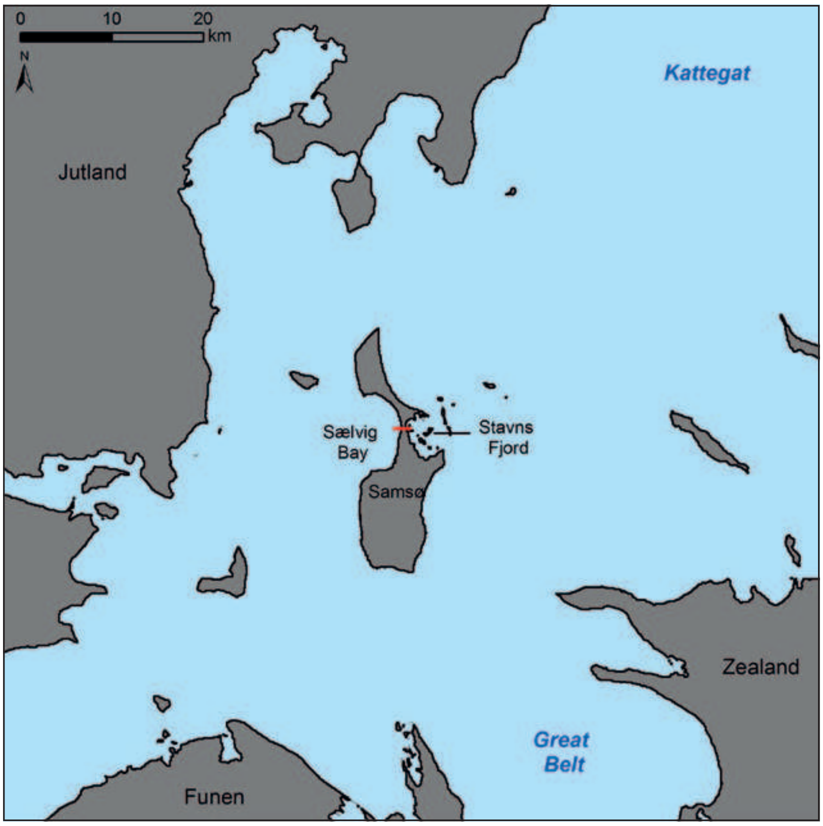


Fig. 6 Idealized cross-section of the Fossa Corbulonis, with cross-section of a contemporary seagoing vessel. **1** Blackfriars 1. – **3** projection of the crucial bottleneck of the canal with a fairway width of only 4.5 m. – Dark blue: estimated maximum water level; light blue: estimated minimum water level. – (Graphics L. Werther / L. Kröger; based on de Kort / Raczynski-Henk 2014).

around 160 AD close to the canal summit[47]. The minimum water depth has been reconstructed at around 0.5 m, so there have been significant fluctuations due to seasonal and long-term hydrological changes[48]. A connection of this harbour to the Fossa Corbulonis is most likely[49]. However, similar changes must also have affected the Fossa Corbulonis. Therefore, the maximum water depth of 1.3 m was obviously no long-term condition and the mean level has to be calculated as lower. Further fluctuations and regional differences concerning the navigability are indicated by excavations, which showed that the northern part of the canal to Matilo was probably already out of use when the Voorburg-Arentsburg harbour was constructed – but the southern branch to the Meuse was still in use, perhaps until the first decade of the 3rd century AD[50]. Large-scale dredging operations in the harbour basin point to another source of fluctuations in water depth, which may also have affected the canal fairway of the Fossa Corbulonis – at least it makes clear that the technology was available during its maintenance[51].
Irrespective of the shifting layout, a correlation of the canal cross section with excavated vessels of the 1st to 2nd century AD in the surrounding area highlights the specific usability of the canal and the harbour of Voorburg-Arentsburg (**fig. 5**). Even huge flat-bottomed boats for inland navigation such as Zwammerdam 4, De Meern 1 or Woerden 7 could have passed the fairway due to their minimum draught and overall width between 2.5 and 5.2 m[52]. Nevertheless, big vessels such as Zwammerdam 4 with an overall width around 5 m would have had problems at the crucial bottlenecks of the canal, which are no wider than 4.5 m according to published excavation data[53]. While big flat-bottomed boats were able to carry up to 170 tons, the reduction to a width of less than 4.5 m minimises the cargo that could have been carried, if, at the same time, the draught was not increased[54]. To move these vessels, a nearby towpath accompanying the fairway was used[55].

Fig. 7 Topographic position of the Kanhave Canal (red). – (Basemap SRTM-GDEM © NASA 2009, CCM River and Catchment Database © European Commission 2007; cartography L. Werther).



However, it is evident in our opinion that the cross section is not constructed for bigger seagoing keelboats, like the 2nd-century vessel Blackfriars 1 from England, which were too wide (over 6 m) and too deep (about 1.5 m) to cross the narrow and shallow sections of the canal (**fig. 6**)[56]. Therefore, it is obvious that the canal was targeted to the riverine transport zone and not to the maritime network. According to the material culture in Forum Hadriani, the canal facilitated long-distance contacts on the waterway far away from the big rivers – and the harbour of Voorburg-Arentsburg worked as a port of transhipment, among other things, to supply the Roman military of the surrounding hinterland[57].

CASE STUDY 2: THE KANHAVE CANAL

In contrast, our second case study is exclusively integrated in a maritime network: the Kanhave Canal (**fig. 1, 2**) is located on Samsø, a Danish island between Jutland, Funen and Zealand in the southern part of the Kattegat without any contact to inland waterways (**fig. 7**)[58]. The oldest part of the construction is dated by dendrochronology to the year 726 AD. It was in use at least around 750 AD (tree-ring dated repairs between 741 and 759) and abandoned around 800 AD according to ^{14}C datings of the canal fill[59].

The canal cuts an isthmus west of the Stavns Fjord, which, due to sedimentation, has not been passable since the 1st century AD[60]. Therefore, the canal offers a shortcut between Sælvig Bay in the west and the Stavns Fjord in the east, which is one of the safest natural harbours in the region. Wooden constructions from the 4th century AD and written sources from the 11th century onwards give proof of a long tradition of anchorage in the Stavns Fjord[61]. Place names (for instance the term *Snekke* connected with navigation and warships) as well as early medieval finds pointing to the production of iron components for ships on Samsø close to the canal underline the naval character of the island[62].

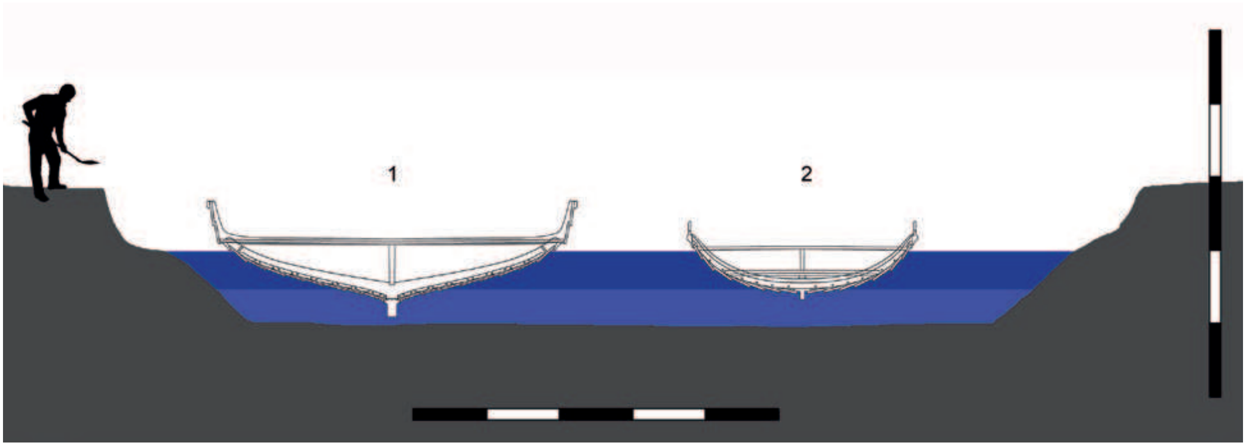


Fig. 8 Idealized cross-section of the Kanhave Canal, with cross-sections of contemporary vessels. – **1** Oseberg. – **2** Kvalsund. – Dark blue: estimated maximum water level; light blue: estimated minimum water level. – (Based on Nørgård Jørgensen 2002a; graphics L. Werther / L. Kröger).

The only weakness of the Stavns Fjord was the missing harbour entrance and exit to the west, which resulted in long detours around the island for ships and fleets which wanted to navigate between Sælvig Bay and the harbour[63]. This time loss must have been so considerable that an artificial entrance to the harbour was built – the Kanhave Canal. Therefore, a cut through the isthmus was realized in a straight line with a total length of about 500 m[64]. In the east and in the west, the canal and the wooden timbering do not reach the modern shoreline, but several indications from the excavations point to an early medieval water level 40-90 cm above the modern sea level[65]. Consequently, the shoreline in the 8th century would have been further inland, offering direct access to the canal without an overland transport[66]. The published data (early medieval surface: 1.75 m above NN; trench bottom: 10-20 cm below NN) points to an excavation depth of *c.* 2 m below the 8th-century surface and a consistent level of the trench bottom[67].

Regarding its location, the Kanhave Canal is a shortcut canal (**fig. 2, 2**), which optimizes the transport zone around Samsø in the southern Kattegat, but causes no far-reaching changes in the entire harbour network, as there are nearby alternative waterways. Furthermore, the canal connects two waterbodies on a homogeneous level (**fig. 3, 2**). Practical use and motivation for the construction are not documented in the sources[68]. Nevertheless, there seems to be a consensus that the canal and the Stavns Fjord had a military purpose as an early naval base to control the southern part of the Kattegat. The canal is undoubtedly part of a group of previously unknown large-scale infrastructures connected to the control of navigation – among them the sea defences of the harbour Gudsø Vig and the Schlei fjord close to Haithabu – which were built in the early 8th century around the southern Kattegat[69]. Nørgård Jørgensen associates this tremendous effort with the »introduction of the ›modern‹ ship type (the sailing ship) [which] led to a revolution for both commerce and navy«[70].

Based on the excavated cross sections, we once more considered the question of the types of vessels which could have used the Kanhave Canal (**fig. 8**). The excavations show a total fairway width of about 11 m at the top[71]. Due to sloping banks on both sides with massive timbering, the inner part with the maximum water depth is about 9 m wide[72]. As the canal bottom of the 1995 excavation has been documented 10-20 cm below NN and the early medieval water level »was 60-90 cm above present-day level«, the actual water level in the canal fairway in the 8th century must have been *c.* 70-110 cm[73]. Due to the connection to the Kattegat, the canal was influenced by the tides. Even if the tide is of secondary importance in Skagerrak and Kattegat in general, for a canal with a minimum water level of 70 cm, 20 cm less water under the keel may have been critical for navigability of the fairway[74]. Therefore, during low tide the canal may have worked like a mixture between waterway and portage to move big seagoing ships like the Oseberg ship,

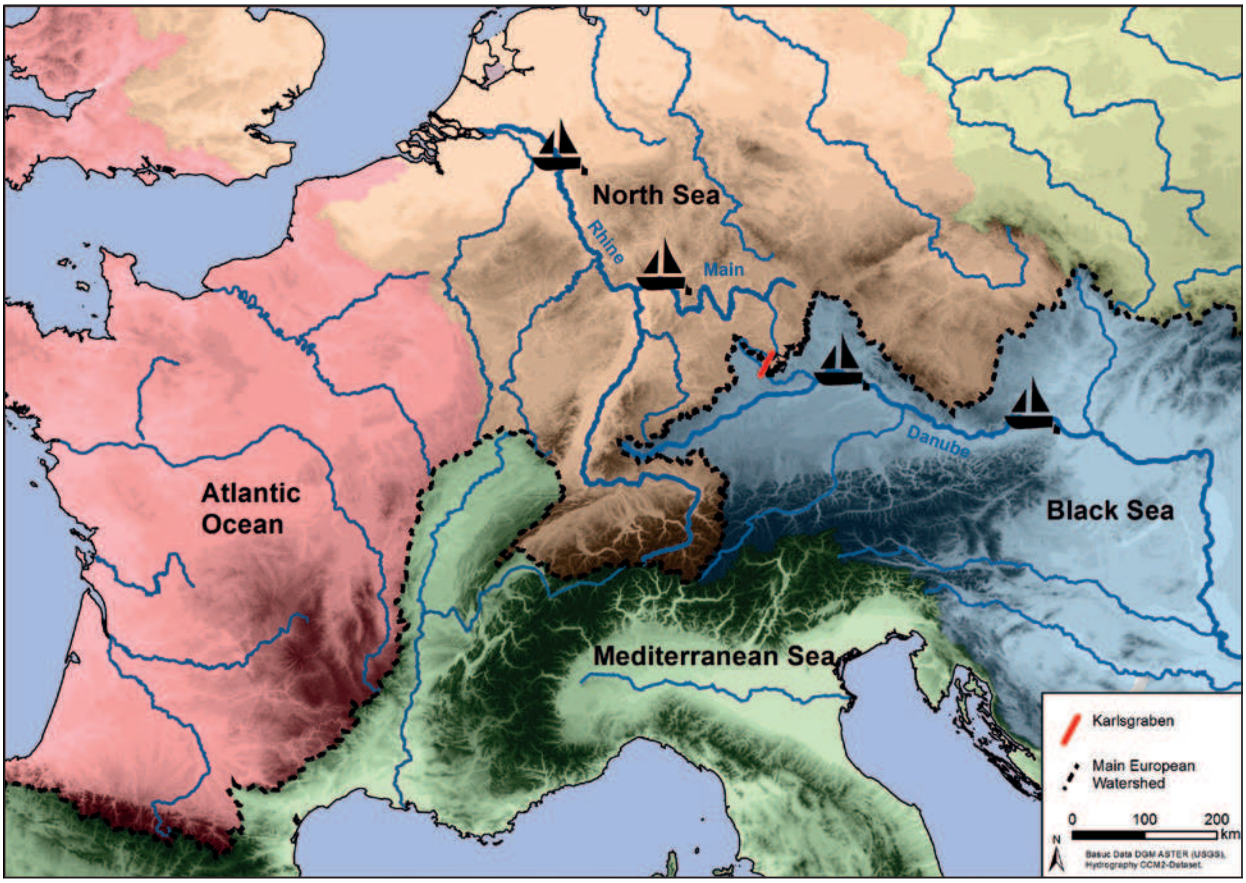


Fig. 9 Topographic position of the Fossa Carolina (red) with the Main European Watershed. – (Basemap SRTM-GDEM © NASA 2009, CCM River and Catchment Database © European Commission 2007; cartography L. Werther).

dated *c.* 820 AD with a draught of *c.* 80 cm, from one side to the other, half swimming and half slipping[75]. Smaller vessels with a minimum draught like the Kvalsund boat may have navigated the canal also during low tide with a water level of around 50 cm. It is uncertain when the sail was introduced as a permanent feature into the region of Jutland[76]. The vessel of Gredstedbro, dated after 630 AD, is not preserved well enough to show traces of a mast step[77]. Also the find of the Kvalsund boat, dated to around 700 AD, has been reconstructed without a sail[78]. On the other hand, the well-preserved grave ship of Oseberg, dated to 820 AD, has a strong mast and was prepared for long-distance sailing[79]. Therefore, the canal was constructed in a period of far-reaching innovation in northern shipbuilding. Although the design of the cross section of the early rowing vessel is close to the later boats fit for sailing, the draught can differ on a great scale. On the other hand, even for later sailed vessels of the 11th century, the channel size would still have been sufficient without any problems[80].

CASE STUDY 3: THE FOSSA CAROLINA

Our last case study will highlight a watershed or connection canal, which is the most influential type of artificial waterway and the pivotal point of our project: the Fossa Carolina or *fossatum magnum* (**fig. 1, 3**)[81]. In 793, Charlemagne initialized a large-scale hydro-engineering project to bridge the European watershed between the Rhine and Danube by means of a canal (**fig. 9**). Written sources describe the building process in

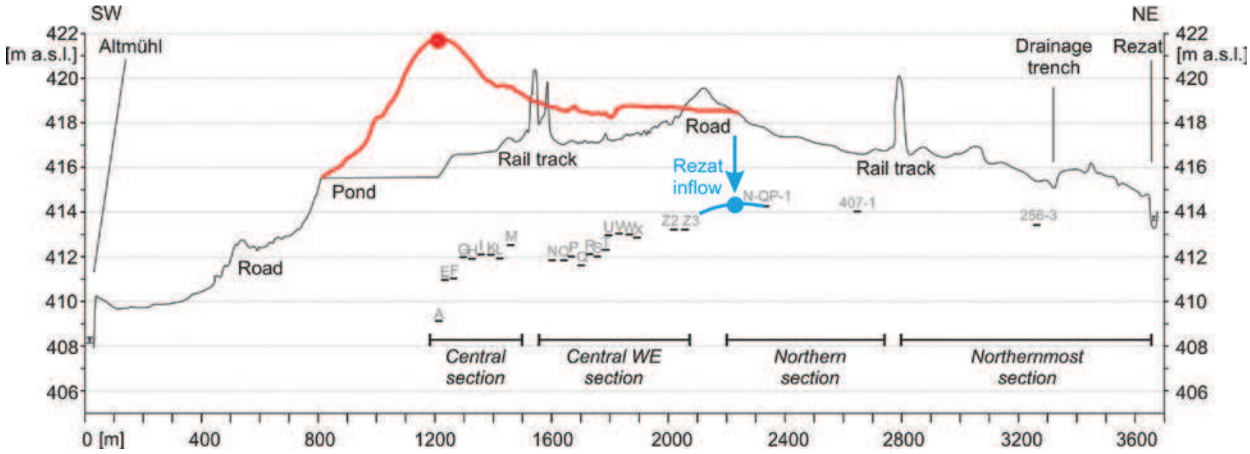


Fig. 10 Synthetic longitudinal profile of the Fossa Carolina from Graben to Rezat River. The red line shows the Pre-Carolingian surface and watershed, the red dot indicates the summit of the natural watershed. The short horizontal bars feature the Carolingian levels of excavation deduced from the drilling stratigraphies, while the blue dot indicates the artificial summit of the Carolingian trench bottom. The solid black line represents the level of the recent trench surface following the course of the canal. – (After Zielhofer et al. 2014, fig. 15).

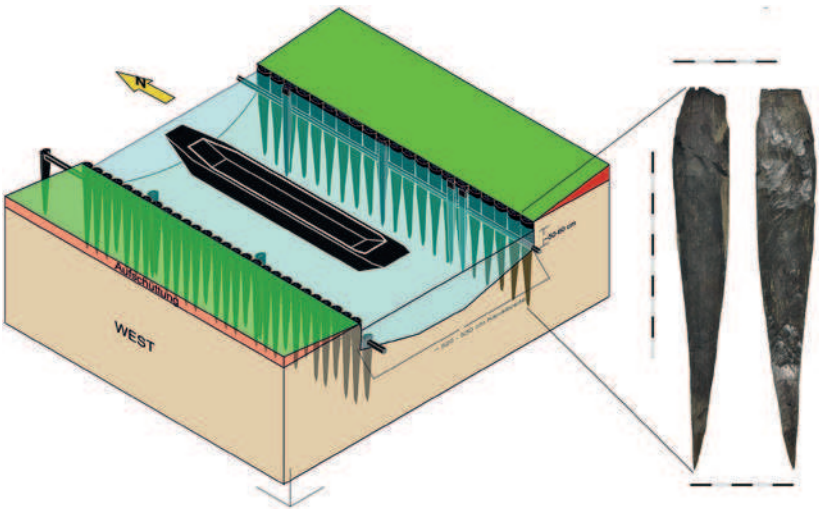


Fig. 11 Reconstruction of the wooden construction of the Fossa Carolina based on the excavation in 2013 with original timber. – (Graphics L. Werther / F. Herzig).

Fig. 12 Timbering of the canal fairway of the Fossa Carolina during the excavation 2013, dated to 793 AD. – (Photo L. Werther).

great detail and the dating is precisely confirmed by dendrochronology[82]. The archaeological remains of this attempt are still visible between the Rivers Altmühl and Rezat south of the modern town of Nuremberg[83]. Similarly to the Kanhave Canal, we do not know the essential motivation to build this canal – but the royal initiative is unquestionable in this case[84]. The early 9th-century *Annales qui dicuntur Einhardi* describe the incompletion of the construction and, due to heavy rain and unstable sediment, the abandonment of the project[85]. Nevertheless, the stage of completion in different sections of the canal is unclear and the subject of our current research – at least for some parts of the fairway there is (geo)archaeological and geophysical evidence that the construction was ready for use[86].

The total length of the canal is about 3 km, but the northern and the southern ends are not verified yet[87]. The altitude difference between the River Altmühl and the watershed lies at *c.* 13 m – demonstrating a completely different scale and challenge compared to the other case studies[88]. This resulted in an extraordinary excavation depth of more than 10 m in unstable sandy and loamy sediments, which seem to have caused severe static problems in the construction pit – as described in the written sources[89]. Numerous drillings indicate that the canal was constructed as a stepped chain of ponds with a summit level (**fig. 10**) which was supplied by the nearby River Rezat (**fig. 3, 3**)[90]. Therefore, the Fossa Carolina is a connection canal (**fig. 2, 3**) bridging a watershed between two independent riverine transport zones. As there is no alternative waterway, this canal would have changed the entire network of inland harbours in the catchments of the Rhine and Danube profoundly[91].

Only one other such attempt to bridge the main European watershed in the 1st millennium AD in central Europe can be found: according to Tacitus, there had been planning for a canal to connect the Moselle and Sâone in 55/56 AD, but the project was never realized[92]. This canal would have connected the entire Roman harbour network of the Rhine with the harbour network of the Rhône[93]. Therefore, it would have solved the difficulties of a discontinuous waterway or as Tacitus describes it, the *itineris difficultatibus navigabilia* between the Mediterranean Sea on the one hand and the North Sea on the other hand[94]. The enormous impact of such a cross-watershed connection between the Rhône and Rhine in the Roman period as well as between the Rhine and Danube in Carolingian times is more than evident.

As for the other case studies, we also tried to answer the question which vessel types the Fossa Carolina was suitable and constructed for. In 2013, an archaeological excavation in the northern part of the Fossa Carolina resulted in numerous details about the fairway construction, which were complemented by drillings and geophysical measurements (**fig. 11**)[95]. Both banks of the fairway were stabilized by wooden timbering which had been hammered down in two parallel lines side by side (**fig. 12**)[96]. In the excavated section, the fairway has a clear diameter of 5.2-5.3 m[97]. The good preservation of the wooden construction allowed for a reconstruction of the minimum water depth between 0.5 and 0.6 m[98].

The dendroarchaeological analysis of a sample of construction timber demonstrates that the whole woodworking process for the excavated section was carried out between the summer and autumn of 793 in the surroundings of the construction site[99]. If this is representative for the entire construction, a huge force of workers operated in a very short period to realize this ambitious task before winter came. Nevertheless, if the written sources are reliable in this point, the work started too late in the year and bad weather washed away Charlemagne's dreams of a connection canal[100].

Nevertheless, the excavated ready-to-use section highlights the usability of the canal compared to contemporary vessels (**fig. 13**). In the regional surroundings, there are almost no early medieval shipwrecks except for isolated logboats on the River Main further north[101]. Even for the biggest logboats such as the Stettfeld vessel (9th century AD, width 68 cm), navigation in the fairway of the Fossa Carolina would have been trouble-free[102]. Concerning the navigability for bigger vessels, we compared the fairway with Carolingian boats excavated on the Rivers Rhine and Weser, although it is uncertain if they are in fact characteristic of

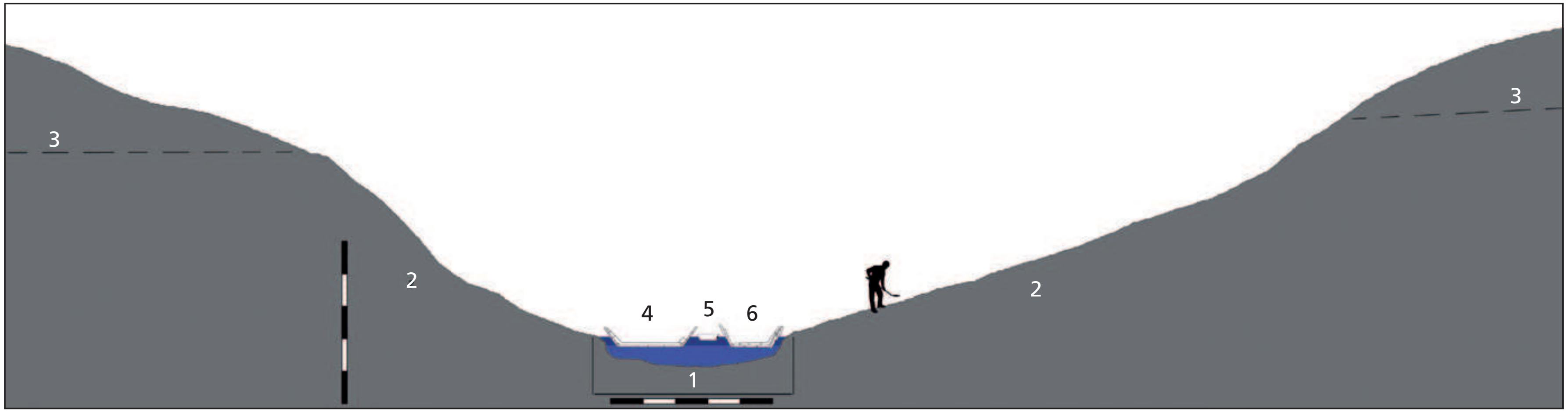


Fig. 13 Idealized cross-section of different parts of the *Fossa Carolina*. – **1** canal fairway, based on the excavation 2013. – **2** idealised trench with earthen walls based on a drilling cross-section in the central West-East section and not yet verified in detail. – (After Zielhofer et al. 2014, fig. 9). – **3** level of the pre-Carolingian surface. – Cross-sections of contemporary vessels: **4** Krefeld-Gellep III; **5** Stettfeld logboat; **6** Karl von Bremen. – (Graphics L. Werther / L. Kröger).

the riverine transport further south. Medium-sized flat-bottomed boats of the 8th/9th centuries AD like the examples found in Krefeld-Gellep (width 2.8 m), Kalkar-Niedermörmter (width 2.5 m, height 0.6 m) and Bremen (width 1.9 m, height 0.8 m) with a shallow draught were able to navigate the Fossa Carolina fully loaded without any restrictions[103]. This is confirmed by excavations of early medieval harbour installations and the associated river course (width 6-7 m, medium depth 0.7 m) in Großhöbing, some 30 km east of the Fossa Carolina and close to the watershed[104].

NAVIGABLE CANALS IN THE 1ST MILLENNIUM AD – SYNTHESIS AND OUTLOOK

The case studies represent a big range of canal types which modified the affected harbour networks in different ways. Regardless of the individual motivation and purpose, every canal documents the essential technical needs which have been crucial in a specific transport zone concerning fairways, vessels – and also harbours. We find it striking that in antiquity as well as in the Middle Ages engineers tried to modify conditions and connectivity inside and between certain transport zones with such an immense effort. Nevertheless, the intended benefit of canals was all but permanent and often very short-lived, if they were finished at all. The enormous effort to build and maintain canals and also changing natural conditions favoured a fast abandonment in many cases[105].

Notes

1) Cf. Bedon 1997. – Bockius 2014b. – Bond 2007. – Grewe 2008. – Salomon et al. 2014b. – Wawrzinek 2014, 34-39. – Werther 2014. – Wikander 2000.
2) Cf. Nørgård Jørgensen 2002a.
3) Cf. Zielhofer et al. 2014. – Werther et al. 2015.
4) Cf. Hollinrake / Hollinrake 2007.
5) Cf. Keay / Millet / Strutt 2014. – Salomon et al. 2014a; 2012.
6) Cf. de Kort / Raczynski-Henk 2014.
7) Cf. Grimm 2011.
8) Cf. Arnold 2009. – Bonnet 1982. – Pury-Gysel 2015.
9) Pichon 2002.
10) Cf. Stock et al. 2016.
11) The classification between canals for navigation, drainage, water power or other purposes is a big challenge. As there are many multi-functional examples, a clear differentiation is often not possible. Cf. Bond 2007, 155-157. – Bütow 2011, 86. – Elmshäuser 1992. – Magnusson / Squatriti 2000, 222-265. – Wikander 2000.
12) Blair 2007a. – Bond 2007, 155-157. – Ellmers 2007. – Sherratt 2006. – Westerdahl 2006b, 35; 2000.
13) Cf. Blair 2007a, 4. 7, who combined canal cross-sections with vessel cross-sections. See also Salomon et al. 2014a, 44.
14) Concerning the concept of transport zones cf. Westerdahl 2000.
15) The other case studies have been researched and published by colleagues from Denmark and the Netherlands, whom we are grateful for their excellent work.
16) Canalization of existing rivers has not been included here. Of course there are also several hybrid forms between these general types.
17) Similar to the »closed-end« canal of Blair 2007a, 6.
18) Avenche (Swiss): Pury-Gysel 2015. Tendu (France): Pichon 2002. Ephesus (Turkey): Stock et al. 2016. Glastonbury (Great Britain): Hollinrake / Hollinrake 2007. Sawtry (Great Britain): Bond 2007, 187 f. Bruges (Belgium): de Witte 1999.
19) Similar to the »bypass canal« of Blair 2007a, 6. The obstacle may be physical or also economical, for example a water toll.
20) Iron Gate (Romania): Wawrzinek 2014, 36. Canale Romano (Italy): Salomon et al. 2014a; 2016a. Kanhave (Denmark): Nørgård Jørgensen 2002a. Bampton (Great Britain): Blair 2007b, 272-283. Abingdon (Great Britain): Blair 2007a, 5. – Hooke 2007, 42. Calbe / Saale (Germany): Elmshäuser 1992, 4.
21) Blair 2007a, 5. – Anglo-Saxon Chronicle to the year 1016 AD.
22) Moselle-Saône (France): Eckoldt 1980. Fossa Carolina (Germany): Ettel et al. 2014. – Werther et al. 2015. Stecknitzfahrt (Germany): Wellbrock 2009.
23) Pichon 2002. – Bonnet 1982.
24) Nørgård Jørgensen 2002a, 135-145.
25) Salomon et al. 2014a, 36-49. – Salomon et al. 2016a; 2016b.
26) Zielhofer et al. 2014. – de Kort / Raczynski-Henk 2014.
27) Eckoldt 1980. – Bockius 2014b, 90 ff.

28) Arnold 2009.

29) For example »over 27 m wide« in Bond 2007, 171.

30) Werther et al. 2015. – Zielhofer et al. 2014, 17.

31) Kröger 2014. – Pomey / Rieth 2005. – Crumlin-Pedersen 2010.

32) For impressive examples in Ephesus see Stock et al. 2016. In Portus see Salomon et al. 2014a; 2016b.

33) Driessen / Besselsen 2014, 201-225. – de Kort 2013. – de Kort / Raczynski-Henk 2014.

34) Heller 1992, Tac. Ann. 11, 20.

35) de Kort / Raczynski-Henk 2014, 53; Heller 1992, Tac. Ann. 11, 18-20.

36) de Kort / Raczynski-Henk 2014, 63 ff.

37) de Kort / Raczynski-Henk 2014, 52-65.

38) de Bruin 2015, 186 f.

39) Driessen / Besselsen 2014, 203-208.

40) de Kort / Raczynski-Henk 2014, 63. 68.

41) de Kort / Raczynski-Henk 2014, 63.

42) de Kort / Raczynski-Henk 2014, 63. 67.

43) Heller 1992, Tac. Ann. 11, 20.

44) de Kort / Raczynski-Henk 2014, 59-65. – de Kort 2013, 239.

45) de Kort / Raczynski-Henk 2014, 68.

46) de Kort / Raczynski-Henk 2014, 61.

47) Driessen / Besselsen 2014, 201. – Domínguez-Delmás et al. 2014.

48) Driessen / Besselsen 2014, 209.

49) Driessen / Besselsen 2014, 201.

50) de Kort / Raczynski-Henk 2014, 60 f. – Driessen / Besselsen 2014, 207. – Jansma / Haneca / Kosian 2014, 493.

51) Driessen / Besselsen 2014, 199-202.

52) Jansma / Morel 2007. – Mees / Pferdehirt 2002, 40-49. – Vos et al. 2011, 101-118. – Weerd 1988.

53) de Kort / Raczynski-Henk 2014, 68.

54) Bockius 2003, 479 f.

55) de Kort / Raczynski-Henk 2014, 59-65.

56) Mardsen 1994, 33-95. – With a different conclusion Driessen 2014, 224.

57) van Lanen et al. 2016, 133. – Driessen / Besselsen 2014, 207 f.

58) Christensen 1995. – Nørgård Jørgensen 2002a, 126. 135 ff. 143 ff.; 2000. – Englert 2015, 64 f. – Asingh 2006b.

59) Nørgård Jørgensen 2002a, 137. – Daly 2002, 155 f.

60) Nørgård Jørgensen 2002a, 144.

61) Nørgård Jørgensen 2002a, 135 f.

62) Asingh 2006b, 114. – Skov 2011, 334. For the *Snekke* names cf. Westerdahl 2002, 173 ff.

63) Nørgård Jørgensen 2002a, 135-138. – Skov 2011, 336.

64) Nørgård Jørgensen 2002a, 144.

65) Nørgård Jørgensen 2002a, 136 f. 144.

66) Nevertheless according to Nørgård Jørgensen 2002a, 137. 144 the connection or disconnection of the canal seems unclear. On the one hand she discusses a higher water level which offered a connection between shoreline and canal, on the other hand she describes that the canal was »presumably closed at the western end«. Forthcoming publications will hopefully clarify this.

67) Nørgård Jørgensen 2002a, 136 fig. 13.

68) Christensen 1995. –Nørgård Jørgensen 2002, 126-145; 2000. – Asingh 2006b.

69) Cf. Kramer 1999. – Nørgård Jørgensen 2002a; 2002b, 319 f. – Dobat 2008.

70) Nørgård Jørgensen 200b2, 320. – Concerning ship technology in this period of transformation in Danish waters cf. Crumlin-Pedersen 1999. – McGrail 1990.

71) Nørgård Jørgensen 2002a, 135 f.

72) Nørgård Jørgensen 2002a, fig. 13. – Crumlin-Pedersen 1991, 69-82.

73) Nørgård Jørgensen 2002a, 136.

74) According to www.dmi.dk/hav/maalinger/tidevand/ (28.10.2016) low tide at Ballen on Samsø may be 10-20 cm below NN. – According to Englert 2015, 55 »astronomiske tidevand (ebbe og flod) havde derimod kun underordnet betydning for strøm- og vandstandsændringer i Skagerrak og Kattegat«.

75) For the draught see Kalmring 2010, 352. – Concerning this mode of transportation in early medieval Scandinavia cf. Stylegar 2006. – Vinner 2006. – Westerdahl 2006b. – Asingh 2006a, 112 f. – Skov 2011.

76) Crumlin-Pedersen 2010, 97 ff.

77) Ejstrud et al. 2008, 63 ff.

78) Crumlin-Pedersen 2010, 66.

79) Sjøvold 1971, 32. – Bischoff 2012, 337-342.

80) Crumlin-Pedersen 1991, 69-82.

81) Cf. Ettel et al. 2014. – Leitholdt / Krüger / Zielhofer 2014. – Leitholdt et al. 2012. – Werther et al. 2015. – Zielhofer et al. 2014. – For previous research cf. Koch 2008.

82) Concerning the written sources cf. Hack 2014 and Nelson 2015, 221-229. Concerning dendrochronology cf. Werther / Herzig 2014a. – Werther et al. 2015, 162-176. – Werther 2016.

83) Berg-Hobohm / Werther 2014.

84) Hack 2014, 54. 58-61.

85) Hack 2014, 54 f. – Rau 1993, 60-63.

86) Werther et al. 2015. – Zielhofer et al. 2014. – In addition to this, based on the results of drillings, sedimentological analysis and geophysical measurements of some model-based estimations, that predict the cross-section appearance and give a direct support for locally applied invasive investigations, were performed and finally validated by excavations in the meantime (cf. S. Linzen / M. Schneider / S. Berg-Hobohm et al., Magnetic prospection with SQUIDs – A basis for interdisciplinary [geo] archaeological-geophysical research, Paper given

at the conference »Harbours as objects of interdisciplinary research« Kiel, 1.10.2015).

87) Cf. Werther et al. 2015, 155 ff. – Linzen/Schneider 2014.

88) Werther et al. 2015, 154. – Zielhofer/Kirchner 2014, 6 ff.

89) Werther et al. 2015, 158 f. 167 f.

90) Zielhofer et al. 2014.

91) Concerning the function within the harbour network cf. Preiser-Kapeller/Werther in this volume p. 7-31.

92) Tac. ann. 13, 53 in Heller 1992. Cf. Bockius 2014b, 90 f. – Campbell 2012, 223 f. – Eckoldt 1980.

93) Concerning the function within the harbour network cf. Preiser-Kapeller/Werther in this volume p. 7-31.

94) Tac. ann. 13, 53 in Heller 1992.

95) Werther et al. 2015, 162-176. – Zielhofer et al. 2014.

96) Werther 2016.

97) Werther et al. 2015, 171.

98) Werther et al. 2015, 171.

99) Werther 2016. – Werther et al. 2015, 169-176. – Werther/Herzig 2014a; 2014b.

100) Hack 2014, 55-58.

101) Cf. Werther/Kröger 2017. – Kröger 2014.

102) Kröger 2014, 102 ff.

103) Cf. Kröger 2014, tab. 1. – Bockius 2014a.

104) Liebert 2015, 67-75.

105) This will be subject of future publications.

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Summary

Big navigable canals – *fossata magna* – are crucial parts of the European harbour network in the 1st millennium AD. By means of canals, site conditions at transition zones of the transportation network were artificially modified. Water depths and fairway widths of canals reflect specific requirements regarding the accessibility of inland harbours and waterways in the adjacent transport zones. These requirements significantly depend on the size of ships. In our study we present a supraregional and diachronic comparative approach, integrating canal parameters and ship findings. Our pivotal point is the Fossa Carolina or *fossatum magnum* (Germany), constructed in 793 AD to bridge the main European watershed. The 8th-century Kanhave Canal was cut through an isthmus on Samsø island (Denmark) to avoid a lengthy detour and to offer direct access to a safe natural harbour. The Fossa Corbulonis, built around 50 AD by Roman military, bridged the watershed between the Rivers Waal and Maas (Netherlands) to avoid a dangerous coastal route.

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Häfen im 1. Millennium AD

Bauliche Konzepte, herrschaftliche und religiöse Einflüsse

Interdisziplinäre Forschungen zu den Häfen von der Römischen Kaiserzeit bis zum Mittelalter in Europa, Band 1

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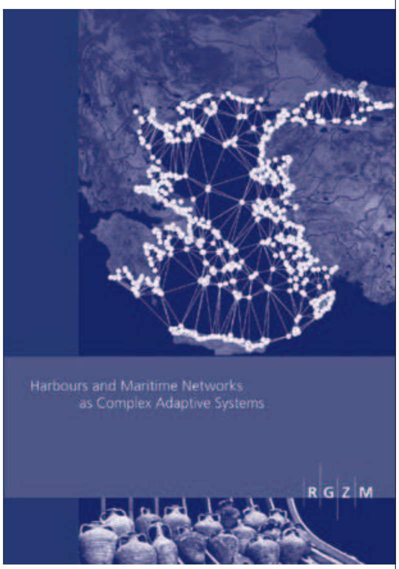
19 Beiträge, die auf einer Plenartagung 2014 gehalten wurden, füllen einen geographisch weit gespannten Rahmen, der vom Nordatlantik bis in den östlichen Mittelmeerraum reicht. Breiten Raum nehmen dabei Ergebnisse der häufig in enger Zusammenarbeit mit naturwissenschaftlichen Disziplinen angelegten Feldforschungen ein. Eine Besonderheit liegt in der Zusammenschau von Arbeiten aus unterschiedlichen historischen, archäologischen und naturwissenschaftlichen Disziplinen.



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The concept of complex systems allows for a better understanding of the interplay between social and environmental factors for the emergence and maintenance of maritime infrastructure and route systems in the ancient and medieval period.
Complexity theory and network analysis provide an analytical framework to describe social configurations (cities, maritime communities, polities) and environmental phenomena (hydrosphere, climate) as complex systems, entangled via mechanisms of feedbacks, adaptation or disruption. In this volume, this approach is applied on various phenomena of maritime history as discussed within the DFG-funded Special Research Programme (SPP 1630) »Harbours from the Roman Period to the Middle Ages« (www.spp-haefen.de).

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Häfen im 1. Millennium AD

Standortbedingungen, Entwicklungsmodelle und ökonomische Vernetzung

Interdisziplinäre Forschungen zu den Häfen von der Römischen Kaiserzeit bis zum Mittelalter in Europa, Band 3

Das DFG-Schwerpunktprogramm »Häfen der Römischen Kaiserzeit bis zum Mittelalter – Zur Archäologie und Geschichte regionaler und überregionaler Verkehrssysteme« (SPP 1630) widmet sich der Erforschung von Häfen als Schnittstellen zwischen dem Wasser- und Landweg unter verschiedensten Aspekten.
Der Band versammelt 13 Beiträge, die 2015 im Rahmen einer Plenartagung gehalten wurden. Der geographisch weit gespannte Rahmen reicht vom Nordatlantik bis in den östlichen Mittelmeerraum. Thematisiert werden See- und Binnenhäfen sowie künstliche Wasserstraßen. Der Band vereint Ergebnisse interdisziplinärer (geo-)archäologischer und geophysikalischer Feldforschungen, schriftquellenbasierter Untersuchungen und überregionaler Studien.