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The morphological units between the end moraines of the Pomeranian phase and the Eberswalde ice-marginal valley (Urstromtal), Germany – a critical examination by means of a high-resolution DEM

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Abstract: The area between the Pomeranian end moraine and the town of Eberswalde, located in the Torun-Eberswalde ice marginal valley (IMV), has long been considered to represent a sequence of proglacial landforms in good agreement with the model of the glacial series of Penck & Brückner (1901–1909). The most prominent geomorphological feature in the area is the Pomeranian end moraine which was formed at about 20 ka. However, the meltwater deposits in the research area were not only formed by meltwaters from the Pomeranian ice margin but also by those draining the Parstein and the Angermünde subphases of the retreating Scandinavian Ice Sheet (SIS). The main meltwater discharge was assumed to have followed a major valley structure, which today forms a gap in the end moraine ridge. The analysis of the landforms, their altitudes as well as the surface features, by means of a high-resolution digital elevation model (DEM) based on light detection and ranging (LiDAR) data now allow a new interpretation. The newly reconstructed relative chronology of meltwater drainage in the area shows a much more complex picture: The Britz Forest, the highest glaciofluvial landform which was formerly considered to be a sandur of a recessional subphase, is now interpreted as a pre-Pomeranian meltwater deposit, because of its altitude and its smoothened surface. The Ragöse Sandur, the Stadtforst and the Mönchsheide, as well as the Amtsweg Sandur were previously considered to be either sandurs of the Pomeranian phase, partly underlain by dead ice, or to represent sandur of a recessional subphases. However, DEM analysis clearly shows that Ragöse sandur lacks any fluvial pattern and consists of sedimentary lobes perpendicular to the front of the end moraine. A similar structure can be identified on the Amtsweg sandur. Both are therefore attributed to several small meltwater outlets at the Pomeranian end moraine. The Klosterbrücke Sandur was formed by different successional processes but its initial formation is also now attributed to the Pomeranian phase of the SIS. In contrast, the Stadtforst and the Mönchsheide show a distinct east-west directed fluvial pattern, and are therefore not sandur deposits of the Pomeranian phase. The Stadtseerinne and Neuhütter Rinne can be traced across the IMV and their origin can therefore be attributed to a pre-Pomeranian ice advance and subsequent conservation by dead ice during the Pomeranian phase and the following subphases. According to the DEM based landform analysis, a lower meltwater discharge than that derived from previous reconstructions is very likely. In addition, the landforms are likely to have experienced a longer and more complex genesis then previously assumed. The DEM analyses also support the assumption that at least in parts, transformation of the landscape by periglacial processes also played a significant role.

Die geomorphologischen Einheiten zwischen der Endmoräne des Pommerschen Stadiums und dem Eberswalder Urstromtal (Deutschland) – eine kritische Überprüfung mittels eines hochaufgelösten Digitalen Geländemodells

Kurzfassung: Die Geländeformen im Gebiet zwischen der Pommerschen Endmoräne und der Stadt Eberswalde, die im Thorn-Eberswalder Urstromtal (IMV) liegt, sind lange Zeit als eine typische proglaziale Abfolge im Sinne der Glazialen Serie von Penck & Brückner (1901–1909) gedeutet worden. Die deutlichste morphologische Erscheinung ist die Pommersche Endmoräne, die um 20 ka gebildet wurde. Die Schmelzwasserablagerungen gehören jedoch nicht nur zur Pommerschen Eisrandlage sondern wurden auch durch die Abflüsse der jüngeren Parsteiner und Angermünder Staffeln während des Abschmelzens des Skandinavischen Inlandeises gebildet. Es wurde davon ausgegangen, dass der Hauptabfluss durch einen Taldurchbruch, der heute eine Lücke in dem Endmoränenrücken bildet, erfolgte. Die Analyse der Geländeformen hinsichtlich ihrer Höhenlagen und ihrer Oberflächenformen mittels eines LiDAR-gestützten Höhenmodells (DGM) erlaubt nun eine neue Interpretation. Die neue, relative Chronologie der Schmelzwasserabflüsse in dem Gebiet zeigt ein deutlich komplexeres Bild: Der Britzer Forst, die am höchsten gelegene glazifluviale Geländeform, wurde bisher als ein Sander einer Rückzugsstaffel angesehen; nun wird das Gebiet als eine prä-Pommersche Schmelzwasserablagerung gedeutet. Diese Interpretation basiert auf der Höhe und der geglätteten Oberfläche. Der Ragöse Sander, der Stadtforst, die Mönchsheide und auch der Amtsweg Sander wurden entweder als Sander des Pommerschen Stadiums, die teilweise von Toteis unterlagert waren, oder als Sander von Rückzugsstaffeln beschrieben. Aber in dem DGM wird deutlich, dass die Oberfläche des Ragöse Sanders keine fluvialen Muster aufweist, sondern aus sedimentären Loben besteht, die von der Endmoräne ausgehen. Ein ähnlicher Aufbau kennzeichnet auch den Amtsweg Sander. Beide werden daher auf viele kleine Schmelzwasser-Ausflüsse an der Endmoräne zurückgeführt. Der Klosterbrücke Sander ist durch mehrere aufeinander folgende Prozesse gebildet worden, aber seine Anlage wird auf Schmelzwässer der Pommmerschen Eisrandlage zurückgeführt. Im Gegensatz dazu zeigen der Stadtforst und die Mönchsheide eine deutlich ost-west ausgerichtete fluviale Oberflächenstruktur und sind daher keine Sanderablagerungen vor der Pommerschen Eisrandlage. Die Stadtseerinne und die Neuhütter Rinne können quer durch das Urstromtal verfolgt werden, ihre Entstehung wird daher auf einen prä-Pommerschen Eisvorstoß zurückgeführt mit anschließender Konservierung durch Toteis während des Pommerschen Stadiums und der folgenden Rückzugsstaffeln. Aufgrund der Reliefanalyse auf der Basis des DGM wird nunmehr davon ausgegangen, dass die Schmelzwasserabflüsse geringer waren als bisher angenommen. Außerdem haben die Geländeformen offensichtlich eine längere und komplexere Entstehungsgeschichte. Die Reliefinterpretation auf der Basis des DGM stützt auch die Annahme, dass die Veränderung der Landschaft durch periglaziale Prozesse eine bedeutende Rolle gespielt habt.

Keywords: Pomeranian phase, meltwater deposits, ice-marginal valley, glacial geomorphology, Germany

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1 Introduction

The end moraines northeast of Eberswalde are prominent landforms of the Weichselian glaciation. They belong to the Pomeranian phase (qw2) (Terms according to Symbolschlüssel Geologie 2015), which is considered to be a glacial re-advance from the Baltic Sea depression. The Pomeranian phase followed the down-wasting of the of the Brandenburg phase ice lobe (qw1), the latter representing the maximum Weichselian ice advance (Lippstreu 1995, Lüthgens & Böse 2011).

After their first description by Berendt (1888), these end moraines and the areas surrounding them played major roles in establishing and discussing theories concerning the glaciation history of northern Central Europe. The research area itself focusses on the morphological units adjacent to the end moraines between the Pomeranian ice-marginal position and the Toruń-Eberswalde IMV (see Fig.1). The research area has been considered as a classical model for the glacial series landform concept of Penck & Brückner (1901–1909), extending beyond the glacier's front. Nevertheless it has been under controversial discussion concerning sedimentary and drainage patterns. In addition, there are different opinions on the development and the timing of the meltwater flow in the IMV in relation to the Oder valley. Liedtke (1956/57; 2001) postulates that the continuous east-west flow in the IMV was only possible from the Angermünder subphase onwards, as dead ice in the Oder basin (Oderbruch) blocked it during the Pomeranian phase and the meltwater streams flowed to the Warsaw-Berlin IMV. According to Liedtke (1956/57) the lower lying Oder valley was preserved by dead ice whereas Brose (1978) attributes the distinct lower valley bottom to Late Glacial-Early Holocene fluvial erosion. Börner (2007, Fig. 64) postulates an east-west flow through the IMV during the Angermünde subphase. All theories imply the formation of a pre-Pomeranian IMV which has been transformed during the Pomeranian phase. The research area was also influenced by meltwater streams from more northerly ice margins of the qw2 Parstein and Angermünde (qw2AN) subphases.

The main end moraine is a defining part of the Pomeranian phase and has been dated to about 20 ka by means of Optically Stimulated Lumincescence (OSL) (Lüthgens et al. 2011). In addition, Heine et al. (2009) dated the main end moraine by Surface Exposure Dating (SED) with ^{10}Be of erratic

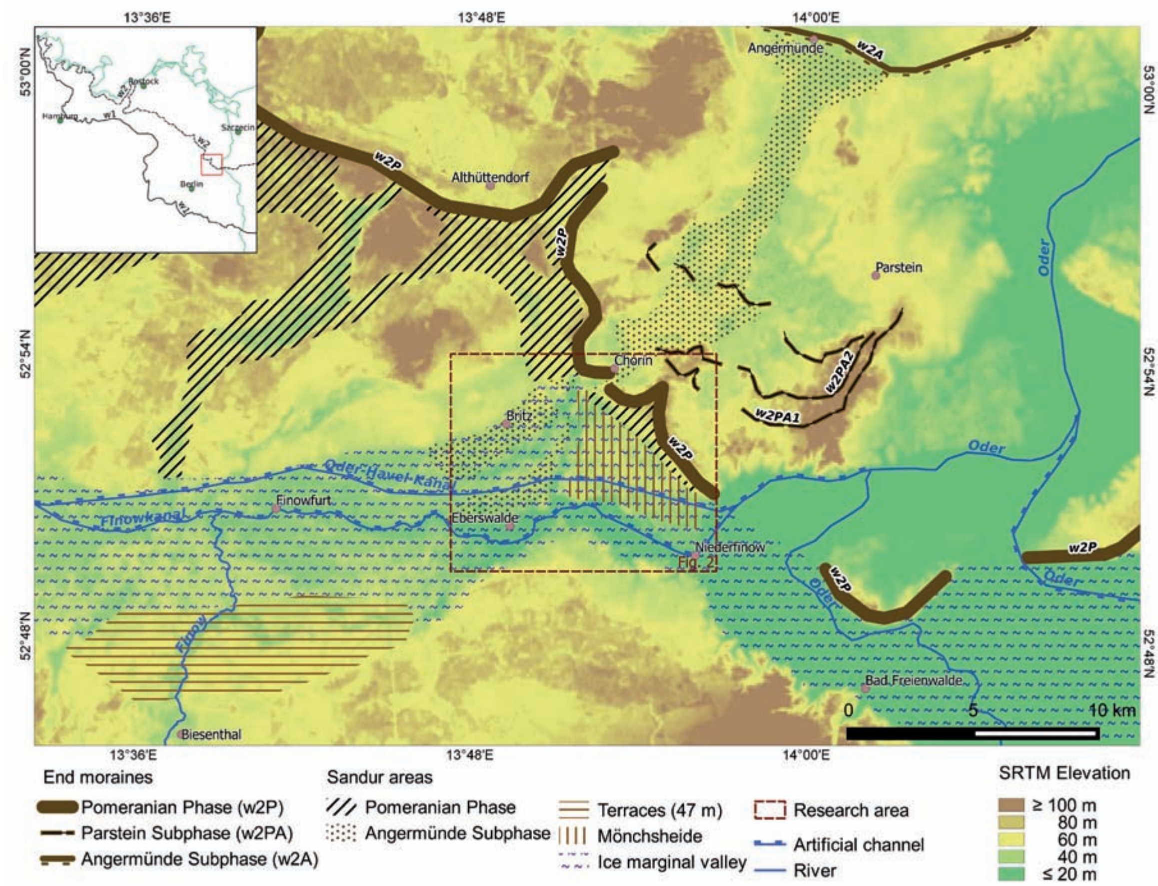

Fig. 1: The location of the research area and the geomorphological units according to the classification of Liedtke (1956/57) and Brose (1978) (simplified).

Fig. 1: -Die Lage des Untersuchungsgebietes und der geomorphologischen Einheiten nach Liedtke (1956/57) und Brose (1978) (vereinfacht).

boulders. The results gave a wide range of ages, mainly in the Weichselian Late Glacial (15.6 ±0.7, 17.1±0.9 and 14.7±0.5 ka). Recently the surface exposure data published by Heine et al. (2009) have been recalculated by Hardt & Böse (2016), giving slightly older ages and therefore confirm the OSL results.

The area has been studied by Berendt 1888, Liedtke (1956/ 57), Brose (1978), Gärtner et al. (1995), Börner (2007), Lüthgens et al. (2011) and Pisarska-Jamroży (2013). The numerical dating work by means of OSL and SED of the Pomeranian main advance and the Angermünde retreat phase by Lüthgens et al. (2011), Heine et al. (2009), and Hardt & Böse (2016) provides the above-mentioned temporal framework.

The inconsistencies between the recent numerical data and the older geomorphological interpretations led to the present study, for which a geomorphological approach has been adopted. Using newly available data, which promise better insights on the surface in combination with an interpretation of sediment archives known from literature, new aspects of the relative chronology of the processes involved are revealed.

2 Methods

The DEM consists of data acquired and preprocessed by the *Landesvermessung und Geobasisinformation Brandenburg* (LGB) via airborne LiDAR in March 2011. The horizontal resolution is set at 5 m, the vertical accuracy is estimated at ± 0.3m. Data outside the research area were obtained from the topographical map 1:25.000.

The DEM was then processed to reveal slope, surface flow and hillshade, which were afterwards analysed visually with the help of profiles taken from the DEM. The main regional focus of the work lies in densely forested areas that were only scantily surveyed in the past.

The DEM results were compared with lithological properties given in literature, and the genesis of the landforms was then interpreted in a relative chronology.

3 The research area

The research area is almost triangular in form and lies between the Chorin village to the north and the part of the IMV west of the Oderbruch depression and east of the city of Eberswalde (Fig. 2).

The end moraine of the Pomeranian phase, marking the northeastern edge of the area, is a very distinct ridge with relative altitudes reaching 60 to 70 m a.s.l. A well visible gap in the end moraine ridge as part of a glaciofluvial channel system is caused by repeated locally concentrated meltwater flows from northerly directions. In this gap, the ruins of the Chorin monastery are located, therefore this morphological distinct interruption in the end moraine will be named the Chorin gap in the following text. The possible sandurs have been attributed to different phases of meltwater activities belonging the Pomeranian phase, the Parstein subphase and

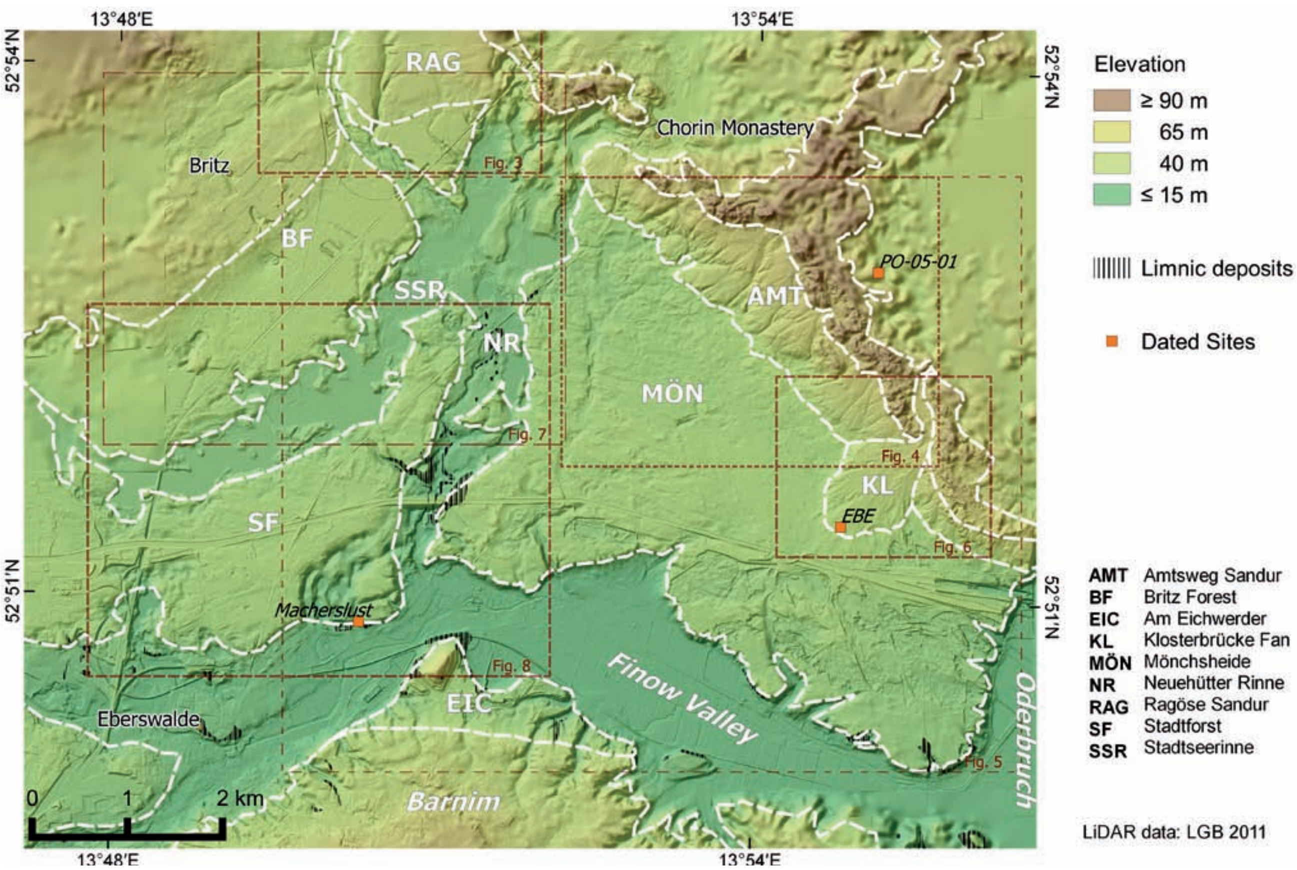

Fig. 2: Elevation model with hillshade (5-fold exaggerated), names of the main geomorphological units and sites of geochronological samples (PO-05-01 (Heine et al. 2009), EBE (Lüthgens et al. 2011), Macherslust (Schirrmeister 2004, Lüthgens et al. 2011, Pisarska-Jamroży 2013).

Fig. 2: Höhenmodell mit Schummerung (5fach überhöht), Namen der wichtigsten geomorphologische Einheiten und Lage der Probenentnahmestellen für geochronologische Datierungen (PO-05-01 (Heine et al. 2009), EBE (Lüthgens et al. 2011), Macherslust (Schirrmeister 2004, Lüthgens et al. 2011, Pisarska-Jamroży 2013).

the Angermünde subphase (Liedtke 1956/57, Brose 1978, Marcinek & Brose 1987, Brose 1995, Börner 2007).

It is thought that the IMV was not active as a continuous stream when the glacier formed the Pomeranian end moraine (Liedtke 1956/57, Kozarski 1966). The main discharge of the IMV has been rerouted through southern overflows, because the Oderbruch depression was blocked by dead ice at this time (Liedtke 1956/57). The occurrence of this is barrier is controversial (cf. the discussion by Liedtke (2001) vs. Brose et al. (2003)). The latter authors consider the Oderbruch as a fluvial erosional feature formed after deglaciation, having a higher valley bottom at the time of the IMV.

For the research area itself the main qw2 glaciofluvial sediments were thought to be represented by the Ragöse Sandur, derived from the north, described as a sandur valley originating at Althüttendorf, north of the research area (Liedtke 1956/57:11; Fig.1). The Amtsweg Sandur links directly to the terminal moraines and is of similar age; this phase corresponds to accumulation of terrace deposits at 47 m a.s.l. southwest of Eberswalde (Liedtke 1956/57) (Fig.1).

Following the glacial retreat from the Pomeranian ice-marginal position, the IMV became active in an east-west direction, albeit for a short period. The glaciofluvial breakthrough at the terminal moraines east of Oderberg, east of the research area, marks the end of the IMV activity. The meltwaters then followed the modern Oder valley towards the Noteć-Randow IMV further north (Marcinek & Brose 1987, Börner 2007).

Therefore, the Eberswalde IMV should have been occupied during the Angermünde subphase (qw2AN) (Liedtke 1956/57, Kozarski 1966). At that time, meltwaters from the north-northeast followed a channel through the Chorin gap, a transverse valley in the end moraine of Pomeranian phase. To the south, the alluvial fan merges with the main terraces of the IMV at Eberswalde at about 37.5 m a.s.l.,i.e. the “main terrace” level of Liedtke (1956/57).

Brose (1978) and Marcinek & Brose (1987) introduced an additional subphase between the Pomeranian phase and the Angermünde subphase, the Parstein subphase (qw2PA). The meltwater deposits related to this still stand correspond to terrace surfaces at 40–42 m a.s.l. (Marcinek & Brose 1987) in the IMV. The waters passed through the gap at the Chorin monastery and another gap at Klosterbrücke to merge with the main terraces at an unspecified location.

In addition, banded lake deposits, documented and dated in terrace outcrops east of Eberswalde gave ages of Late Glacial time and represent the youngest Weichselian deposits in this area.

According to the high-resolution DEM showing the relief in detail and permitting altitudinal profiles, the following questions arise:

1. Do the Ragöse Sandur, the Stadtforst and the Mönchsheide really represent the deposits of a meltwater stream from the Althüttendorf area according to Liedtke (1956/57)?

2. What is the relative age of the the Britz Forest terrace in relation to the other landforms located in the northern part of the IMV?

3. What could be the origin of the Amtsweg Sandur and the Klosterbrücke Sandur just in front of the Pomeranian end moraine?

4. What is the relative age of the formation and conservation of the Stadtseerinne and Neuhütter Rinne?

5. What is the relation of Late Glacial lake deposits in the IMV to the other landforms?

4 The morphological units in the research area – description on based on the DEM

Despite the previous research, differences emerge in the genetic interpretation and chronological positioning of landscape units in the foreland of the Pomeranian end moraine. Surface structures and differences in altitudes can be evaluated. The landscape units are represented by distinct landforms with local names cited in the above mentioned literature (Fig. 2).

The DEM derived from LiDAR data offers new possibilities to reveal the detailed morphology in a spatial context. This is particularly so in forested areas, as recently shown on the Barnim till plain, where a succession of ice-marginal fans has been detected using a LiDAR DEM (Hardt et al. 2015).

4.1 The Ragöse Sandur

The name of this sandur was derived from a Holocene stream incised into the glaciofluvial deposits. In all previous publications, the Ragöse Sandur is linked to the glaciofluvial activities of the Pomeranian phase at Althüttendorf, to the northwest of the research area. It is considered by Liedtke (1956/57) to be of the same age as the Amtsweg Sandur east of the Chorin gap. However, there is no direct continuation of these two units. At its southern margin, the Ragöse San-

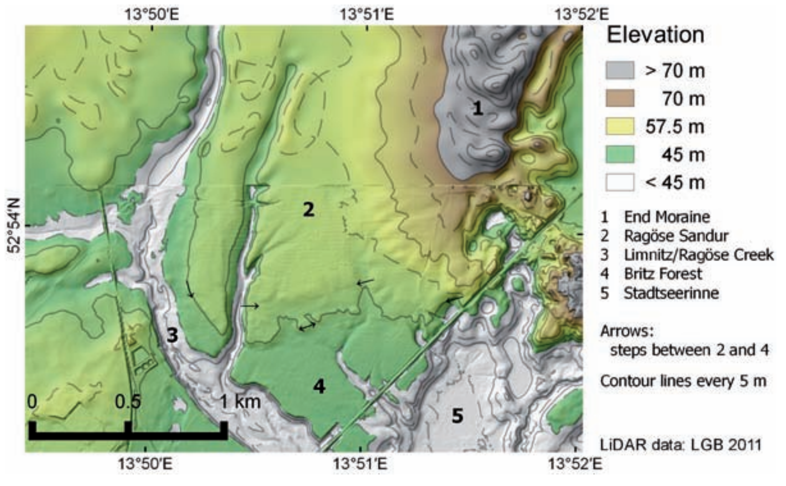

Fig. 3: The Ragöse Sandur (2), lying at the northwestern edge of the research area (northern part DEM based on topographic map 1:25000, southern part DEM based on LiDAR data; hillshade with 5-fold exaggeration). The end moraines of Pomeranian phase are clearly visible to the east (1). The steps to the Britz Forest (4) are marked with arrows. The present-day Limnitz-Ragöse valley (3) is incised into Ragöse Sandur and Britz Forest.

Fig. 3: Der im Nordwesten des Untersuchungsgebietes liegende Ragöse- Sander (nördlicher Teil DGM aus der topographischen Karte 1:25000, südlicher Teil DGM auf der Basis von LiDAR Daten, Schummerung mit 5facher Überhöhung). Deutlich erkennbar ist die östlich anschließende Pommersche Endmoräne (1) und der stufenartige Übergang zum Britzer Wald im Süden (4). Die Stufen sind mit Pfeilen markiert. Das heutige Limnitz-Ragöse-Tal (3) ist sowohl in Ragösesander als auch in den Britzer Wald eingeschnitten.

dur is separated by a step from the lower lying Britz Forest plain and the northernmost part of the Stadtseerinne, a glaciofluvial channel to the east of the former (Fig. 3).

The sandur is dissected by the present-day Ragöse-Limnitz valley system, which will be described below.

4.2 The Amtsweg Sandur

The Amtsweg Sandur is a fringe of glaciofluvial sediments in front of the end moraine, southeast of the Chorin gap. It is separated by a distinct change in the inclination from the end moraine and a step from the Mönchsheide, a forested area stretching to the southwest.

Taking into account the whole area between the end moraine slope and the Mönchsheide, several topographical units can be differentiated (Fig. 4).

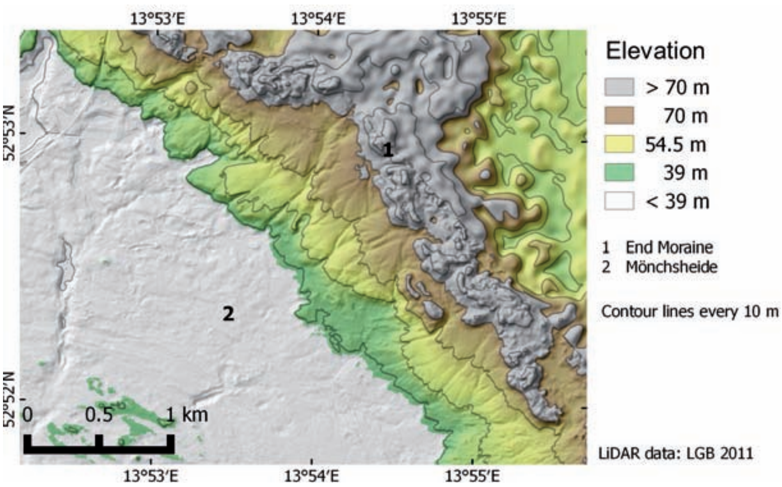

Fig. 4: Morphology of the Amtsweg Sandur. This sandur has a distinct gradient towards the southwest and a step in the profile. This morphological unit in total has a sharp border to the Mönchsheide (2).

Fig. 4: Morphologie des Amtswegsanders. Der Sander hat eine deutliche Neigung nach Südwesten und eine Stufe in seinem Längsprofil. Die Mönchsheide (2) ist deutlich gegen diese morphologische Einheit abgegrenzt.

The upper area represents a sandur formed by merged sedimentary fans. It can be clearly separated from the end moraine in terms of slope and elevation. The end moraine has slope angles of 10° to 30°, whereas the sandur shows a gradient of less than 5°. The dividing line between end moraine and sandur is at about 70 m a.s.l., and the sandur gently declines to about 55 m a.s.l. This upper part is separated by a step, running in a straight line from southeast to northwest, from the lower area. This lower area consists of four overlapping sedimentary fans, of which the proximal parts are indistinct. The lower limit to the Mönchsheide is very clearly visible as an irregularly curved margin formed by a distinct step at 42 m a.s.l. Nevertheless, the step is formed by the depositional front of the fans and doesn't show any erosional undercutting.

Brose (1978) classified the Amtsweg sandur as a sandur belonging to the end moraine. Liedtke (1956/57) described two different genetic phases involved in its' formation: the upper part from the end moraine itself to the step at about 60 m a.s.l. is a sandur, the lower part between the sandur *sensu stricto* and the Mönchsheide, consisting of fans, is interpreted by Liedtke (1956/57) as periglacial fan deposits.

4.3 Mönchsheide

The adjacent area to the southwest is the Mönchsheide which has an apparently irregular surface; the altitudes vary between 32–42 m a.s.l. and can be separated into the "37.5 m" or into the "40–42 m" levels when discussing terraces of the IMV.

According to Liedtke (1956/57), the Mönchsheide forms part of the Pomeranian sandur complex, which was deposited onto dead ice. According to his interpretation, late melting of the dead ice potentially explains the slope change observed towards the Amtsweg sandur and the irregular surface of the Mönchsheide.

Following Brose (1978), the Mönchsheide is classified as a sandur of a later subphase that originated at the breakthrough at the Chroin gap. It is attributed to the Angermünde (Brose 1978) or Parstein subphases (Marcinek & Brose 1987).

Scamoni (1975) questions the interpretation of the area as originating as a sandur, and points out that the Mönchsheide rather resembles gravelly fluvial valley sediments. That corresponds to the signatures of the 1:25000 geological map (Berendt & Schröder 1899).

The DEM provides some new insights for the interpretation. The area shows a surface that reflects a fluvial shallow channel pattern that discharged from southeast to west-northwest as part of a bend in a braided river system. It follows the mean direction of the IMV with a slope of about 0.6‰. The discharge used several channels with ridges between them, reaching from several centimetres to two meters in altitude. Excluding local dead-ice kettle holes the fluvial pattern is continuous through the Mönchsheide (Fig. 5).

There is no indication of an inclination from north to south, as would be expected in the case of a sandur fan (Fig. 5), nor is there evidence of a gradient towards the southwest as a prolongation of the Amtsweg Sandur (Fig 5c). The northern part of the Mönchsheide is even lies somewhat lower, at about 33–36 m a.s.l., than the southern part. The main area of the Mönchsheide is structured by west-trending depression lines. Some minor elevations up to 41.5 m a.s.l. are preserved, thus 3 m higher than the bottom of the nearby depression. The southern part of the Mönchsheide around the Kahlenberg, at the margin of the deepest section of the valley, the present-day Finow valley, reaches up to 42 m a.s.l. The Kahlenberg has been considered as an erosional residual of a former higher landscape (Scamoni 1975).

The Mönchsheide is dissected by a small north-south trending channel that cuts the fluvial structures, with an irregular floor and a blind end to the south. A second channel is directed from north-east to south-west, but it is not continuous and is only partly visible in its northern part.

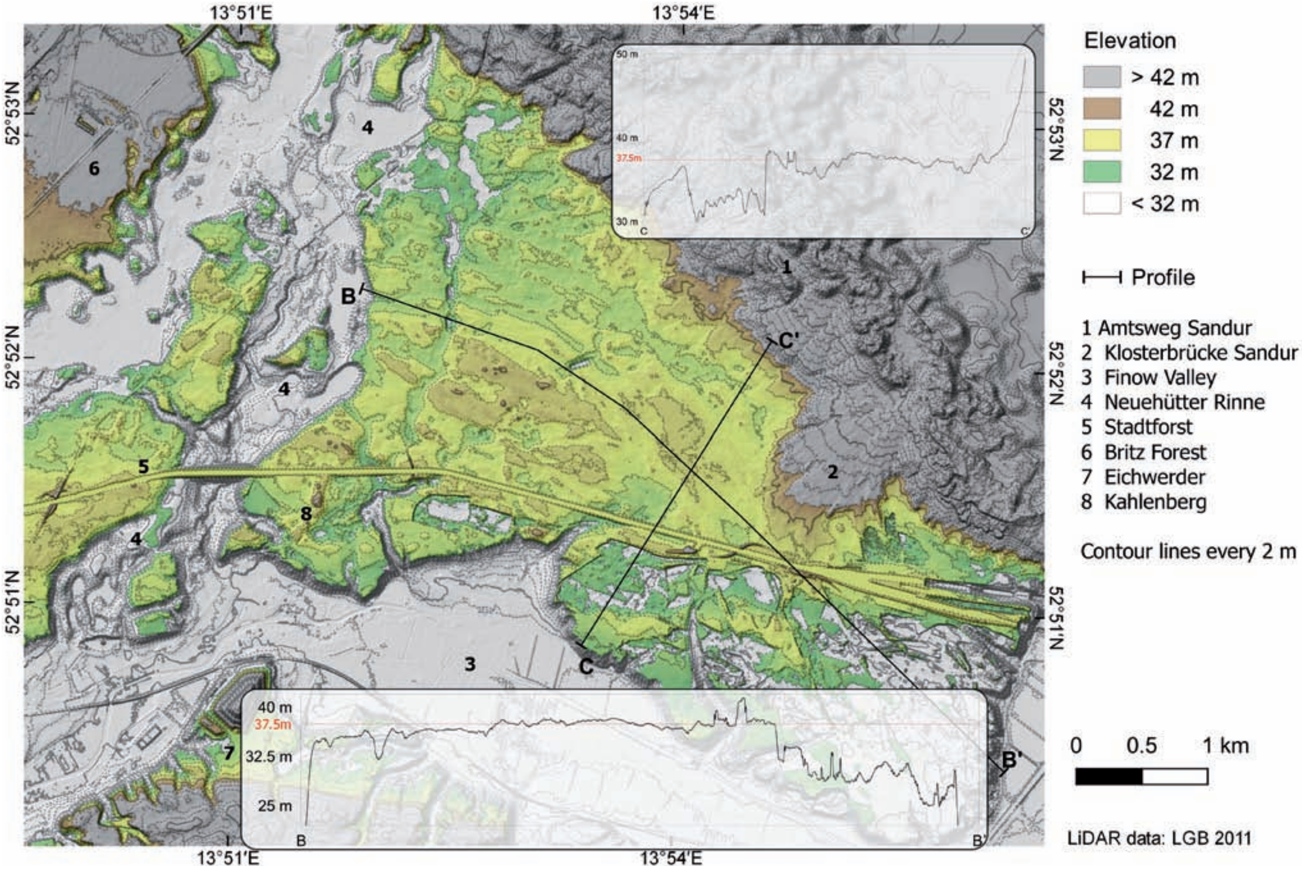

Fig. 5: Morphology of the Mönchsheide, sharply separated from the Amtsweg- Sandur (1), the Finow valley (3) and the Neuehütter Rinne (4). – B: The WNW-ESE orientated profile is the longitudinal profile according to the supposed fluvial pattern. – C: A profile perpendicular to the supposed fluvial pattern, showing that the Mönchsheide has no gradient from the end moraine to the central part of the meltwater valley. Dashed line indicates the 37.5 m level, the main terrace level according to Liedtke (1956/57).

Fig. 5: Die Morphologie der Mönchsheide, deutlich abgesetzt gegen Amtswegsander (1), Finowtal (3) und Neuehütter Rinne (4) – B: Das WNW-OSO ausgerichtete Profil entspricht dem Längsprofil des als fluvial interpretierten Oberflächenmusters. – C: Ein Querprofil über das als fluvial interpretierte Oberflächenmuster, das zeigt, dass die Mönchsheide keine Neigung von der Endmoräne zum zentralen Teil des Urstromtales aufweist. Die gestrichelte Linie markiert das 37,5 m – Niveau, nach Liedtke (1956/57) die Höhe der Haupterrasse.

4.4 Klosterbrücke Fan

The prominent fan at Klosterbrücke (Fig. 6) has been described as a sandur deposited during the Parstein subphase (Brose 1978) or was formed as periglacial formation (Scamoni 1975). Its position is linked with a small breakthrough in the end moraines, a valley which abruptly ends at the hinterland of the end moraine (Fig. 2; Fig.6: A). There is no connection to any landscape feature north of the end moraine. Conflicting opinions concerning whether this sedimentary fan is younger or older than the adjacent Mönchsheide have been voiced by Liedtke (1956/57) and Brose (1978).

OSL data from a sand pit in the distal part of the Klosterbrücke fan provided an average age of three very consistent determinations of 19.4 ± 2.4 ka, while four samples collected from the sandur deposits in front of the end moraine of Pomeranian phase close to Althüttendorf gave an average OSL age of 20.1 ± 1.6 ka (Lüthgens et al. 2011). Therefore the formation of the main ice margin and that of the Klosterbrücke sandur fan can be considered contemporaneous. The sediments of the Klosterbrücke fan are classified as well sorted fine to medium sand at the OSL sampling site (Dörschner 2008, cited in Lüthgens 2011), nevertheless the fan is covered by "Geschiebedecksand", a cover sediment characterised by clasts (including ventifacts) in a sandy matrix, also described by Liedtke (1956/57).

The fan at Klosterbrücke shows several steps in its topography. On the western and eastern sides, a definite step separates the fan from the lower lying Mönchsheide, whereas in the southwest a gentle transition to the Mönchsheide occurs. Four fan generations can be deduced from these steps:

The first generation was undercut at about 55 m a.s.l. (Fig. 6: U). This corresponds to the step in the Amtsweg Sandur, stretching in a northwesterly direction. This step is only partly preserved in the Klosterbrücke fan, mainly in the northwestern part.

1) The second generation, with a broader extent, is separated from the Mönchsheide at about 42 m a.s.l. (Fig. 6: L) and has apparently almost concealed the first step.

2) The most distal part, stretching in southwesterly direction, does not show the distinct step (L) to the Mönchsheide.

3) A younger incision, probably of periglacial origin, dissects the northern part of the Klosterbrücke fan.

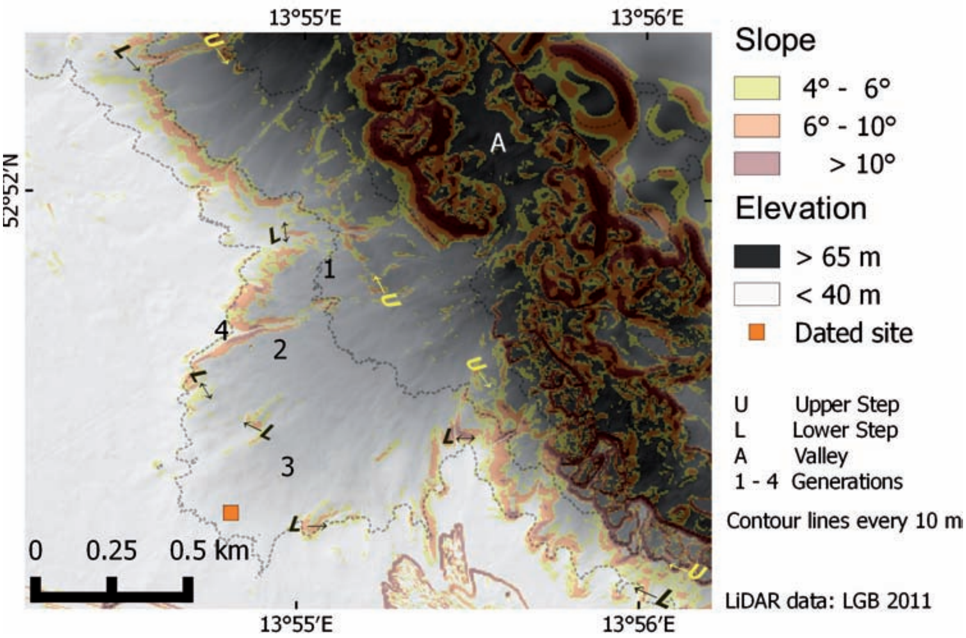

Fig. 6: Depositional generations of the Klosterbrücke Sandur and the dating site of Lüthgens *et al. (2011). Combined elevation and slope; arrows marking distinct steps.*

Fig. 6: Ablagerungsgenerationen des Klosterbrückesanders und Lage des datierten Profils von Lüthgens *et al. (2011). Kombination aus Höhen- und Hangneigungsdarstellung, Pfeile markieren deutliche Stufen.*

4.5 The Britz Forest

The Britz Forest is a flat, slightly inclined area in the western part of the research area (Fig.7). The plain, at present showing no distinct natural structure at its surface, is separated by steps (up to 8 m high) from the till plain in the west, the Ragöse Sandur in the north, and the Stadtseerinne in the east. It is considered to be the part of a meltwater stream related to the Angermünde subphase (Liedtke 1956/57:25). The plain is inclined to the southwest, the elevation is about 48 m in the north and about 37.5 m in the south; the gradient is slightly steeper than at the rest of the Angermünde valley sandur (Liedtke 1956/57).

The NE-SW inclination is indeed exceptionally regular and steeper than typical IMV terraces (2.3‰).

The hypothetical prolongation of the Britz Forest plain to the northeast shows no direct connection to the Chorin gap. The Britz Forest plain is definitely higher than Mönchsheide and Stadtforst on the other side of the Stadtseerinne.

4.6 Stadtforst

Another prominent plain is that at Stadtforst, between the Britz Forest and the Mönchsheide, separated from them by channel landforms. The Stadtforst has a similar altitude as the southern part of the Britz Forest, but with a less regular surface. Altitudes here vary between 35 m and 40 m. Whether the surface in the smaller northern part represents the continuation of the fluvial pattern at the surface of the Mönchsheide is not clear but likely (a in Fig. 8). The southern part, separated from the northern part by a small valley, shows two east-west extending elevations, but the rest of the plain is strongly influenced by artificial constructions, including the Oder-Havel-channel. Nevertheless the southernmost part (b in Fig. 8) is a somewhat lower (about 2 m), corresponding to a small isolated remnant further east in the Neuehütter Rinne (c in Fig. 8). The latter areas may be attributed to the IMV terrace system. On the opposite side of the IMV, a terrace remnant (Eichwerder), has a similar altitude and has been mapped as "*Talsand*" (fluvio-glaciofluvial deposit) already by Berendt & Schröder (1899).

4.7 Stadtseerinne and Neuehütter Rinne

The Stadtseerinne and Neuehütter Rinne are deeper lying, elongated, channel-like landforms, separating the before described landforms Britz Forest, Stadtforst and Mönchsheide from each other. Both channels are broad, irregular and interfere with each other (Fig. 9).

4.7.1 Stadtseerinne

The Stadtseerinne is a northeast-southwest trending elongate landform at about 24.5–25 m a.s.l.. The steep but irregular margins to the neighbouring plains, the Britz Forest plain and the Stadtforst are striking. Spurs at the edge of the Britz Forest protrude into the Stadtseerinne. The floor itself is full of depressions, some of which are filled by lakes.

This landform can be traced to the north beyond the Chorin gap, while further to the south it is following parallel to the IMV in a westerly direction. In this area it can be traced by depressions and marshy areas at least as far as Finowfurt.

4.7.2 Neuehütter Rinne

The Neuehütter Rinne occurs at an even lower elevation and is also characterized by an irregular topography and several branches. Some depressions are infilled by lakes. The Ragöse stream crosses the Stadtseerinne and then follows the western branch of the Neuehütter Rinne, having formed terraces at several levels between 15–26m a.s.l.

The depression itself has a different origin. It begins further north at the Chorin gap, in the end moraine. Further south, in the area of the IMV terrace, the channel subdivides into two parts. The Neuehütter Rinne can be traced southwards across the IMV and the Finow valley to the Barnim till plain. Its name here is the Schwärzerinne.

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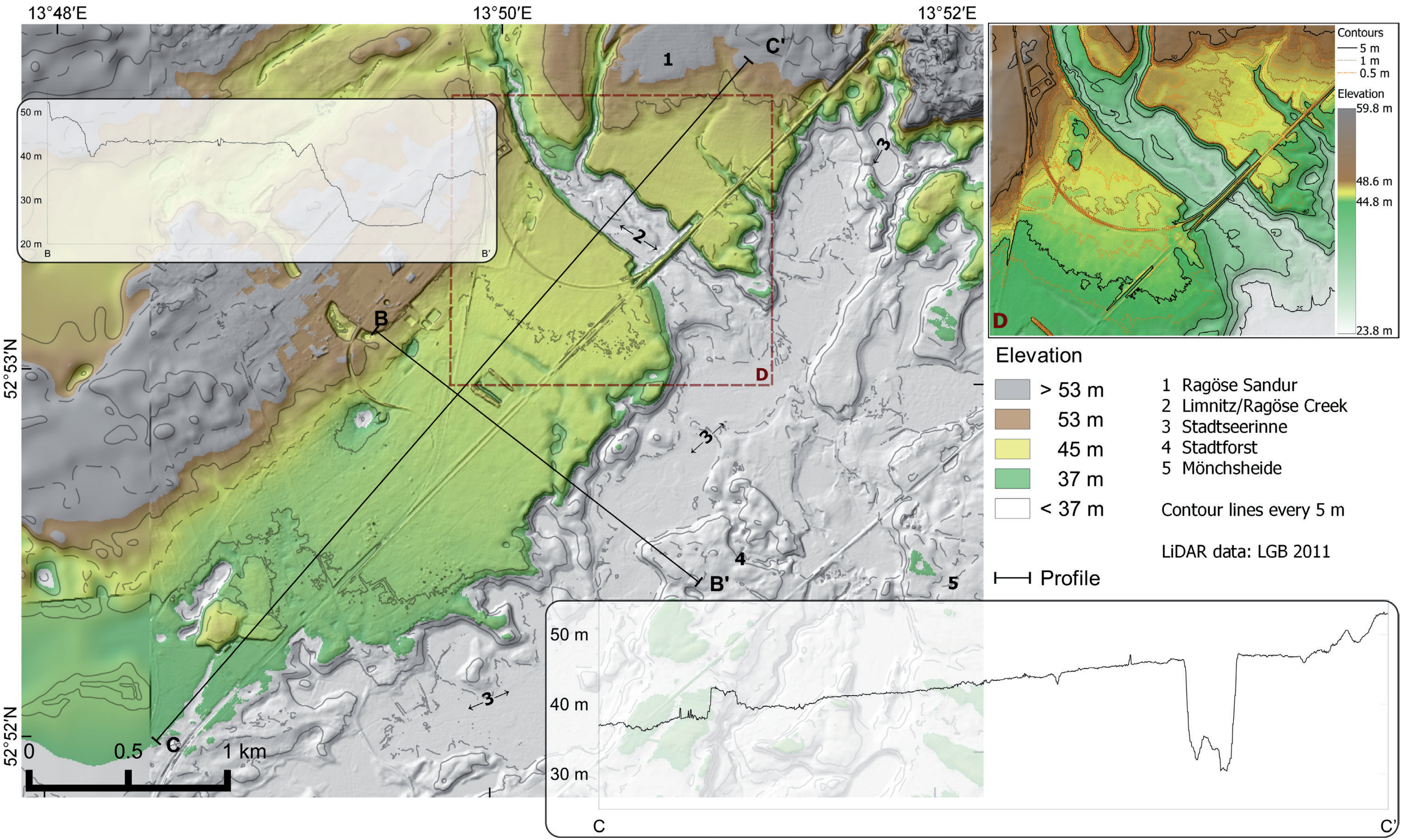

Fig. 7: Morphology of the Britz Forest. – B: WNW-ESE cross profile of the Britz Forest, the Stadtseerinne (3) and into the Stadtforst (4), showing the distinctiveness of the units and their height differences. – C: NNE-SSW longitudinal profile of the Britz Forest showing the gentle gradient (2.3‰) towards the Eberwalde IMV. – D: Detail view of the small alluvial fan on top of the Britz forest.

Fig. 7: a: Morphologie des Britzer Forsts. – B: WNW-OSO-Querprofil über den Britzer Forst, durch die östlich angrenzende Stadtseerinne und in den Stadtforst. Die scharfen Grenzen und klaren Höhenunterschiede zwischen den Einheiten werden hier verdeutlicht. – C: NNO-SSW-Längsprofil des Britzer Forsts, das die schwache Neigung (2,3‰) Richtung SSW hin zum Eberswalder Urstromtal zeigt. – D: Detailansicht des kleinen Schwemmfächers auf dem Britzer Wald.

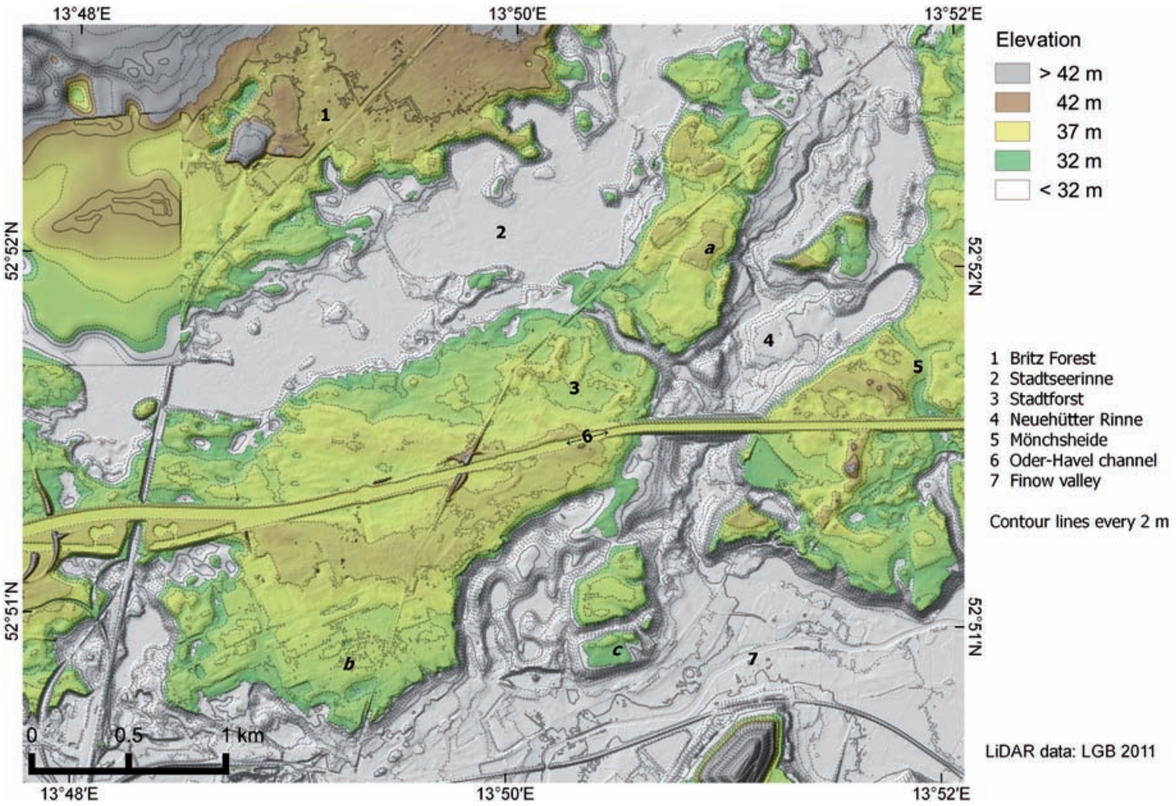

Fig. 8: The Stadtforst area with morphology similar to that of the Mönchsheide. It is more heavily transformed by human activities such as the Oder-Havel-channel (6) and the outskirts of Eberswalde (around b).

Fig. 8: Der Stadtforst hat eine der Mönchsheide ähnelnde Oberflächenstruktur. Sie ist jedoch stark verändert durch menschlische Eingriffe, wie den Oder-Havel-Kanal (6) und die Außenbezirke von Eberswalde (bei b).

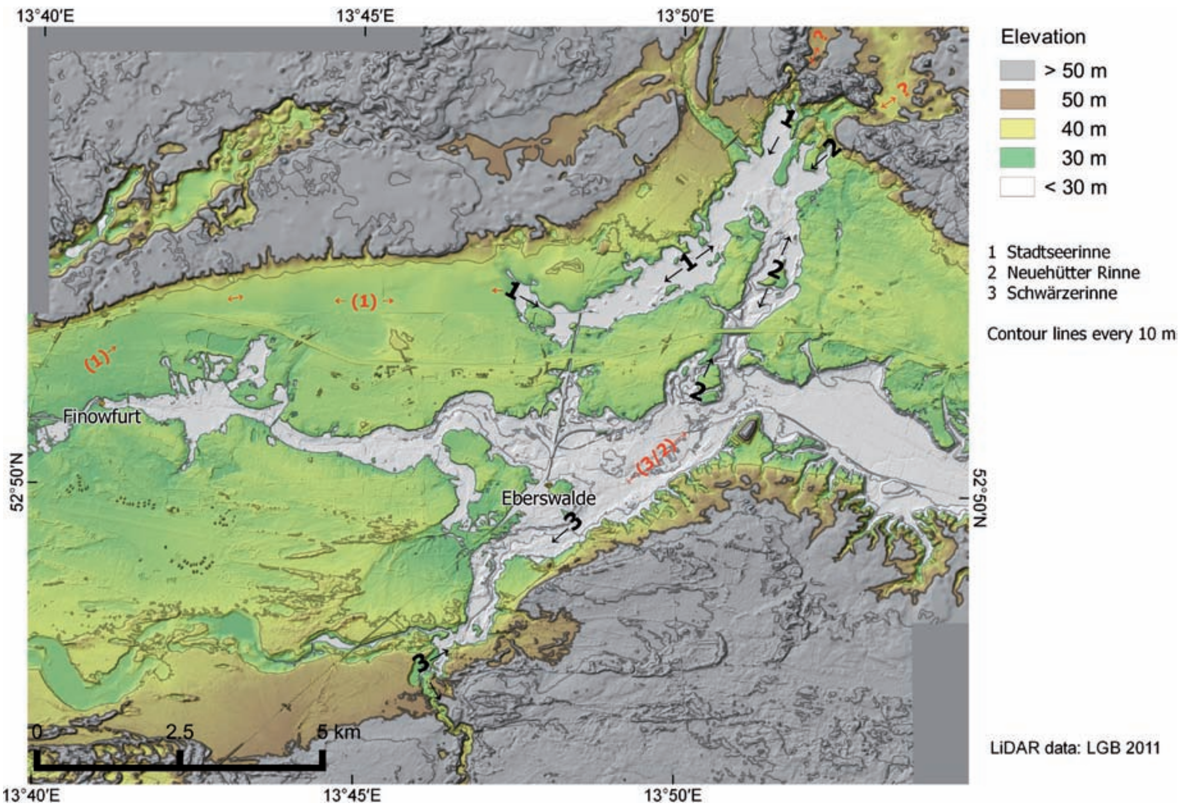

Fig. 9: Pre-Pomeranian channels of subglacial origin in the foreland of the end moraine of the Pomeranian phase and their interpreted connection to the south across the IMV.

Fig. 9: Vor-pommernzeitliche subglazial angelegte Rinnen im Vorland der Pommerschen Eisrandlage und die vermutliche Verbindung nach Süden quer durch das Urstromtal.

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4.8 The terraces of the IMV

The "main terraces" of the IMV represent a vague description of fluvial terraces at about 37.5 m a.s.l.; they have never been clearly defined. Liedtke (1956/57) classified the southern part of the Mönchsheide as "main terraces", whereas this separation is justified by the artificial Oder-Havel channel. Marcinek & Brose (1987) placed these "main terraces" at 36–37 m a.s.l. and considered them as representing the discharge level related to the Angermünde subphase.

All areas from 32–40 m a.s.l. that have not been described as sandurs are attributed to "the main terrace". Areas at lower levels are seen either as dead ice topography or Holocene fluvial formations. Most of these areas, especially the Mönchsheide south of the Oder-Havel channel, have been transformed by the construction of the channel. A geomorphological interpretation of this area is therefore almost impossible.

South of the Finow valley, a spur at Eichwerder has the same elevation as the "the main terraces".

4.9 Laminated silts

In the area of Macherslust, outcrops of laminated silty deposits, as well as clay deposits, have repeatedly been described and were also exploited by mining (Berendt 1896, Berendt & Schröder 1899, Beschoren 1934, Liedtke 1956/57). They are located at the margins of the IMV and in the Neuehütter Rinne, but not in the Stadtseerinne.

Most of the sites (Fig. 2) are now inaccessible, but the remnant outcrop at Macherslust, east of Eberswalde, has been repeatedly studied over the last decades (Schirrmeister 2004, Lüthgens et al. 2011, Pisarska-Jamroży 2013). These glaciolacustrine laminated deposits include sliding and deformation structures and are located on the northern fringe of the Holocene Finow valley to the Stadtforst. The sediments have been dated by OSL to 14 ± 1 ka (Lüthgens et al. 2011), and by Infrared Stimulated Luminescence (IRSL) to 17 ± 4.4 ka (data from M. Krbetschek, Freiberg, published in: Schirrmeister 2004). Pisarska-Jamroży (2013) also presented two OSL ages of 14.6 ± 6.5 ka and 12.18 ± 4.5 ka from these deposits. These results show a high uncertainty, and the information about the applied methodology is sparse. Pisarska-Jamroży (2013) attributes the sedimentation to a hyperconcentrated meltwater flow of the Angermünde subphase. At any case, the statement by Schlaak (in: Gärtner et al. 1995:249) that laminated clays in the Eberswalde IMV belong in general to the Saalian glaciation, cannot be sustained at least in the case of the Macherslust outcrop and at the Kienwerder site in Eberswalde.

5 Interpretation of the landforms

The revised interpretation of the landforms is given according to their relative ages. The geomorphological results are bracketed by the existing geochronological data of the Pomeranian phase and the silty limnic sediments in the IMV terrace. The IMV itself is considered to be at least partly a pre-existing landform which was already occupied during the downwasting of the Brandenburg phase. It cannot be excluded that there was already a Saalian valley system as clays west of Eberswalde suggest even a pre-Weichselian depression that has been re-occupied by Weichselian meltwaters (Chrobok 1987).

The Britz Forest is the highest terrace remnant in the study area of the IMV. These deposits were sourced from northeasterly direction and their surface gradient was directed to the southwest. The surface of this area is very flat and shows no fluvial pattern at its surface, probably resulting from a relatively long and intense periglacial transformation smoothening the surface by gelifluction. Therefore the formation is considered to be older than the other accumulation landforms in the IMV, and is attributed to the down wasting of the Brandenburg phase. This interpretation is not in accordance with the interpretation of Liedtke (1956/57) who has seen the Britz forest as part of the youngest meltwater stream from the Angermünde subphase. He reconstructed a meltwater stream through the Chorin gap from northeasterly directions to the main terrace of the IMV.

The Mönchsheide, repeatedly classified as a sandur in front of the end moraine of Pomeranian phase (Liedtke 1956/57), shows a former fluvial surface with channels and bars. It was formed by a braided river in a bend with water flowing from easterly to westerly direction. Such braided rivers (Paola 2006), found in periglacial areas and typical for the IMVs in northern Germany, suggesting a high sediment supply. At an elevation of about 38–38.5 m a.s.l. the Mönchsheide forms a continuous braided river valley bed, roughly corresponding to the "main terrace" altitude, but about 2 m higher than the actual IMV terraces. The DEM-based surface contradicts the interpretation of being part of a sandur deposited from meltwaters from the Pomeranian end moraine. Furthermore, the area of Mönchsheide shows no indication of being a sandur related to the Parstein or Angermünde subphase. Its gradient neither slopes from the end moraines nor from the Chorin gap.

This fluvial pattern of the Mönchsheide is also found in the Stadtforst. Eichwerder at the southern fringe of the IMV is of similar altitude, but owing to the artificial constructions of Eberswalde, the surface is poorly preserved. Therefore it is suggested that during an early stage of the Pomeranian phase, water was flowing from an easterly direction through the IMV, incising older deposits and undercutting the Britz Forest. It is not clear whether this fluvial system also cut into the Amtsweg Sandur deposits, forming the upper step at 60 m. This part of the IMV must have been connected to a meltwater and fluvial system to the east and was a passage to the west.

During the formation of the Pomeranian end moraine the extent of fluvioglacial deposition was much more restricted than proposed by Liedtke (1956/57) and Börner (2007).

The Ragöse Sandur, as well as the Amtsweg Sandur, were formed as small fans along the end moraine by local, small meltwater outlets. On the Amtsweg Sandur this happened during two phases, the upper step likely being formed by a mudflow-type event. A second generation of fan deposits with steep frontal steps but without erosional forms at the distal parts was formed afterwards, but according to the geochronological data of the Klosterbrücke Sandur also belongs to the Pomeranian phase.

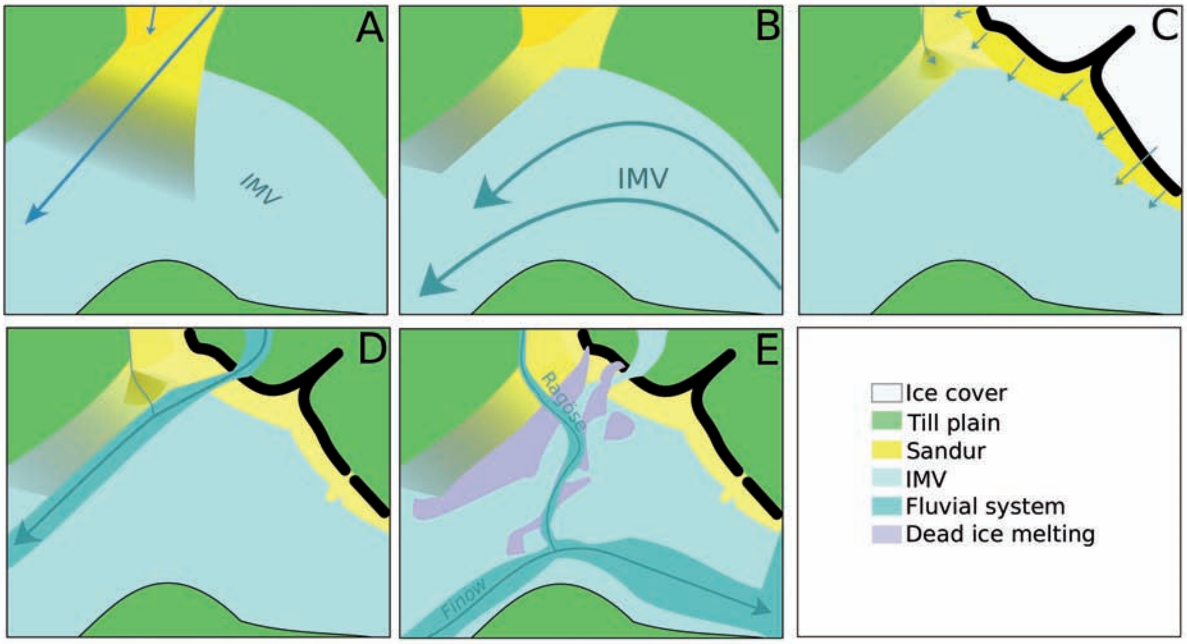

Fig. 10: Model of the formation of the landscape elements

A: An early stage of the IMV during the down melting following the Brandenburg ice advance. Deposition of the glaciofluvial deposits in the Britz Forest.

B: Fluvial to glaciofluvial discharge from east to west, incision into the eastern side of the Britz Forest, formation of the Mönchsheide and Stadtforst sediment structures.

C: Formation of the Pomeranian end moraine and the meltwater fans of the Amtsweg Sandur and the Ragöse Sandur; deposition of the alluvial fan on the Britz Forest sequence.

D: Meltwater flow from the northern Parstein and Angermünde subphases through the gap at Chorin Monastery.

E: Late-Glacial dead-ice melting inducing the appearance of the Stadtseerinne and the Neuehütter Rinne, as well as the initiation of the Late Glacial to Holocene fluvial system.

Fig. 10: Modell der Genese der Reliefformen

A: Ein Vorläufer des Urstromtales während des Abschmelzens des Eises des Brandenburger Stadiums. Glazifluviale Ablagerung des Sedimentkörpers des Britzer Forsts.

B: Fluvialer und glazifluvialer Abfluss von Ost nach West. Unterschneidung der Ostflanke des Britzer Forsts und Anlage der Oberflächenstrukturen der Mönchsheide und des Stadtforsts.

C: Bildung der Pommerschen Endmoräne und der Schmelzwasserkegel des Amtswegsanders und des Ragöse Sanders; Ausbildung des Schwemmfächers auf dem Britzer Forst.

D: Schmelzwasserabfluss der nördlich gelegenen Parsteiner und Angermünder Staffeln durch den Durchbruch beim Kloster Chorin.

E: Spätglaziales Toteistauen und Erscheinen von Stadtseerinne und Neuehütter Rinne sowie die Anlage des spätglazialen bis holozänen Flußsystems.

As a main result from this study, we propose that it is highly likely that no major meltwater stream reached this area. The main water stream from the Althüttendorf glacier mouth continued to the southwest along the Werbellin lake depression. The area of the Ragöse Sandur received some fluvioglacial deposits from the end moraine forming small fans, and the water was collected in a small stream, a predecessor of the Ragöse, which formed a flat fan on the Britzer Forst (Fig. 7D). At the same time the upper part of the Amtsweg Sandur was deposited.

The Klosterbrücke fan can partly be seen as a continuation of the Amtsweg Sandur, but it drained a far greater catchment area. Whereas for the Amtsweg Sandur possible sedimentation sources do not extend further than the terminal moraine itself, the Klosterbrücke fan must have had a connection to the end moraine's hinterland. Either it was an outburst from a meltwater pocket in the ice, or a small lake was dammed between the ice and the end moraine. The overflow can still be seen in the small, abruptly terminating valley (Fig. 6 A). The timing is provided by the dating results available for the Klosterbrücke fan, approximately dating to the Pomeranian phase, but later activity is well within the error margin of the dating.

No major meltwater activity is seen in the IMV at that time and therefore a rerouting of IMV waters (as discussed, for example, in Liedtke 1956/57, Kozarski 1966) is likely.

The glaciofluvial gap at the Chorin Monastery is related to the younger retreat subphases, such as the Parstein or Angermünde subphases, when the meltwaters eroded into the sediments of the Mönchsheide-Stadtforst. The continuation cannot be traced further because the area has been strongly remodelled by the melting of dead-ice and fluvial processes of the Finow.

According to this interpretation, the formation of the Neuehütter Rinne and the Stadtseerinne are attributed to a pre-Pomeranian ice advance as subglacial meltwater channels, which were filled with dead ice. The present day irregular geomorphological forms cannot be attributed to a proglacial meltwater stream of the Pomeranian phase or the subsequent subphases. Thus, they did not exist as landforms neither during the formation of the fluvial pattern with the east-west trending bars on the Mönchsheide and

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the northern Stadtforst, nor during the formation of the Pomeranian end moraine. The channels were inexistent probably until the substantial dead-ice melting phase. This process also induces the incision of the Ragöse-Limnitz valley down to the level of the Stadtseerinne.

The dated clays and silts of Macherslust occur in the depressions of the Neuehütter Rinne. The data obtained imply late deposition during the downmelting of dead ice, predominantly during the Weichselian Late-Glacial Bølling-Allerød interval. They are too young to follow the interpretation of Pisarska-Jamroży (2013). She attributed them to meltwater streams of the Pomeranian phase, but according to the OSL data of the landscape stabilisation during and after the melting of dead ice (Hardt 2017: 110), the surface deglaciation happened significantly earlier and the relief was only later on influenced by periglacial processes and the melting of buried dead ice.

6 Conclusions

- The Mönchsheide, as well as the Stadtforst, are not part of a sandur related to the Pomeranian end moraine position north of the area as postulated by Liedtke (1956/57), but are part of a fluvial or glaciofluvial system that flowed from east to west. It can be argued that the Mönchsheide, the Stadtforst and the remnants at Eichwerder all form parts of the same fluvial system.

- The Britz Forest is not directly linked to the glaciofluvial gap at the Chorin monastery but is considered to be older, representing only a remnant of a pre-Pomeranian meltwater deposit.

- The Neuhütter Rinne and the Stadtseerinne are also pre-Pomeranian by formation, but reappear as landforms only after the downmelting of buried dead ice.

- The main Pomeranian end moraine, deposited during the LGM at 20 ka in MIS 2 (Cohen et al. 2011), supplied little meltwater in the research area and only small fans accumulated at its margin. The meltwater from the glacier mouth at Althüttendorf did not pass through this area, and small local fans formed the Ragöse Sandur.

- The lacustrine deposits at Macherslust and Eichwerder predate the final Late-Glacial dead-ice melting as the banded silts show deformations, but are too young to be linked to the meltwater flow of the Parsteiner and Angermünder subphases. The final melting of dead ice not only led to the reappearance of the Neuehütter Rinne and Stadtseerinne as morphological features, but also terminates the paraglacial reorganisation of the landscape including the infill of small depressions with meltwater and sediments reworked by periglacial processes.

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