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Prehistoric and Roman gullying in the European loess belt: a case study from central Belgium

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Abstract: In contrast with the understanding of present-day soil erosion processes, knowledge on past soil erosion phenomena is still rather limited. Although some studies report on severe gully erosion phases during the fourteenth and eighteenth centuries, almost no evidence is available that documents earlier gully erosion phases. This study investigates the development and age of two old, permanent gullies that are conserved in the ancient Meerdaal forest in central Belgium. The development history of both gullies is very similar. In the first gully, archaeological evidence was found indicating an erosion phase during Roman times, followed by a partial infilling of the gully. In the second gully, radiocarbon dating provided evidence of the same Roman activity phase (cal. yr 46 BC–AD 78), but also of an earlier incision phase during the Middle Bronze Age (cal. yr 1743–1602, 1568–1533 BC). Also here, the erosion phase was followed by a partial infilling. This limited infilling indicates that the catchment of the gullies was reforested quite rapidly, hereby cutting off all runoff and sediment production. This has led to a unique situation in the Meerdaal forest, with the conservation of about 43 similar, large gullies in an area of about 17 km^2. This area has a high geovalue, as the studied gullies are among the oldest and best conserved gullies in northwestern Europe.

Key words: Gully erosion, ancient forest, land use, landscape evolution, Prehistoric, Roman, Belgian loess belt.

Introduction

In recent decades, public awareness and concern about the irreversible effect of certain human-induced environmental changes on the ecosystem has grown rapidly. Soil degradation is one of the most important irreversible changes to the non-biotic part of the ecosystem. Soil erosion is generally recognized as a key soil degradation process. Various studies have already demonstrated that gully erosion is not only the most visible and obvious soil erosion process, but that it is also very important in a wide range of environments (Poesen *et al.*, 2003). Not surprisingly, in many European countries, detailed studies investigating different aspects of gully erosion were set up over the last decades (Poesen *et al.*, 2003).

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In contrast with this extensive assessment and relatively good understanding of actual gully erosion phenomena, documentation of earlier gully erosion phases is very limited. Figure 1 and Table 1 give an overview of reported gully erosion phases in central and northwestern Europe. Time steps of 100 years were chosen for Figure 1, given the often coarse dating that is reported for historical gully erosion phases. Although Figure 1 is only indicative, since many studies that were published in local journals could not be accessed, it illustrates clearly that most gullies studied formed during the last century. Regarding older gully erosion phases, several authors seem to agree that two phases with increased erosion activity occurred during the historical period: a first phase during the fourteenth century and a second phase during the eighteenth century (Table 1). However, evidence for gullies forming before the fourteenth century is quite rare. Only a few cases of such gullies have been documented in the literature. In Germany,

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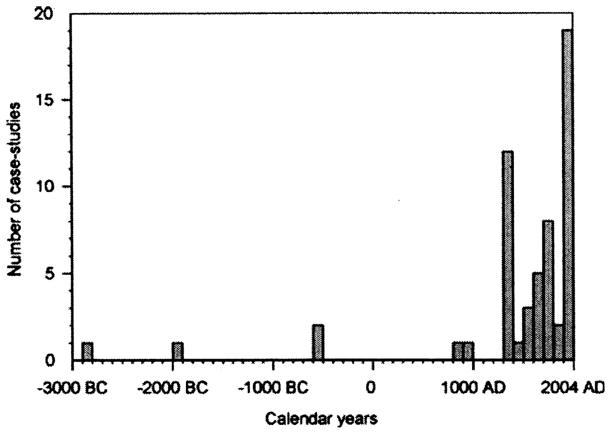

Figure 1 Reported gully erosion phases in northwest and central Europe. Each case study can report on one or more gullies. Details are given in Table 1

Schmidtchen and Bork (2003) dated charcoal at the bottom of an infilled gully in Biesdorfer Kehlen in the Final Neolithic and Dotterweich (2005) found evidence of gully initiation between the eighth and tenth centuries AD. Also in Germany, Semmel (1995) described a Neolithic fossilized gully, however without chronometric dating. Schmitt *et al.* (2003b) described a small Bronze Age gully in Poland. Harvey (1996) investigated a fossilized gully system in the Howgill Fells, NW England, which – on the basis of several radiocarbon dates – he situated in the tenth century AD. Larue (2005) reported ravine-like incisions in the dry valleys of the Pays de Thelle (Paris Basin, France), most probably formed around 500 BC. Whether or not this implies that farmers were less confronted with the problem of gully erosion before historical times is far from certain. Every study on past soil erosion phenomena is limited by the absence of adequate written archives (Bell, 1992). Additionally, the soil archive is less well-conserved for these older erosion phases because the probability is higher that it has been destroyed by subsequent erosion phases.

In this respect, the ancient Meerdaal forest offers a unique setting to study older gully erosion phases. In this 17 km^2, ancient forest area in the central Belgian loess belt (Figure 2a), Gullentops (1992) first reported the presence of 'fossilized badlands'. A recent, systematic survey by Vanwalleghem *et al.* (2003) described the presence of 43 large gullies in this forest. From historical documents it is clear that this forest has been continuously forested since the fourteenth century, yet Vanwalleghem *et al.* (2003, 2005a) found the spatial distribution and morphology of these gullies to be indicative for small, local clearings of the forest cover. Such gullies forming under cropland are, however, characterized by a rapid cycle of incision and infilling and, if their catchment remains under cropland, they are usually completely filled in (Vanwalleghem *et al.*, 2005b). This renders the situation in Meerdaal forest even more unique since reforestation of the gully catchment area stabilized the old gully channels. It is, however, not known to what extent these gullies filled in and conserved their original shape. In the Meerdaal forest, there is thus a unique geomorphic archive of old gullies, which are most probably human-induced. To date, however, no dating of the gully activity phases has been done. Given that the forest has existed already for more than 700 years, such a dating could possibly rank these gullies among the oldest gullies known in Europe so far. Moreover, dating of the associated gully sediment bodies would confirm or deny the arguments for their anthropogenic origin.

The objectives of this study are therefore to reconstruct the erosion and infilling phases of old, permanent gullies in an ancient forest and to provide a time frame for these phases.

Materials and methods

The Meerdaal forest is located in the Belgian loess belt (Figure 2a). For this study, two gullies, representative in terms of dimension and location, were selected from the 43 permanent gullies mapped in the Meerdaal forest (Figure 2b, Vanwalleghem *et al.*, 2003). Detailed information on this study area can be found in Vanwalleghem *et al.* (2003, 2005a). The selected gullies are located in the central part of the forest as some areas at the forest edges were cultivated during historical times, which could possibly disturb the old gully channels and associated sediments (Bossuyt, 2001). The two gullies selected were also chosen because they have a clearly visible, undisturbed colluvial fan. This increases the odds of finding datable material because, for the dating of the gully activity phases, it is only possible to date the deposition of the associated sediments. The position of the two selected gullies (gully G14 and G19) is indicated in Figure 2b. In each gully, a first trench was dug at the transition zone between the downslope end of the present-day gully channel and the beginning of the colluvial fan. A sketch of the first gully (G14) and its colluvial fan is shown in Figure 2c. In addition to the first trench (transect G14-TR1), a second, smaller pit was excavated more upslope, in the gully thalweg (transect G14-TR2). Transect G14-TR1 is about 10 m long, 1.2 m wide and 3 m deep. The second transect, G14-TR2 is 1.25 m long, 0.75 m wide and 1.80 m deep. Figure 2d shows a sketch of the second gully (G19), its colluvial fan and the location of the third excavation, G19-TR1. Here, no second trench upslope was dug since soil augerings indicated no important sediment deposits upslope of the first trench. During the field survey, a preliminary stratigraphy with relative ages was made and detailed drawings of the vertical walls of each trench were made. Sediment units were characterized in the field (based on colour, field texture and structure) and by additional laboratory analysis on some selected samples (texture, dry bulk density, pH, carbon, nitrogen and phosphorus content). Radiocarbon dates were established with the AMS method by the Leibniz Labor für Altersbestimmung und Isotopenforschung, Kiel. Large artefacts were dated by archaeologists (see Acknowledgements for details).

Results

Both selected gullies, G14 and G19, are located only a few hundred metres apart and dissect the southeast-oriented slope of one of the main valleys in the Meerdaal forest (Figure 2c and d). The present-day gully channel G14 has a length of 60 m, a mean top width of 7.96 m, a mean depth of 1.21 m and a volume of 388 m^3. Gully G19 is 68 m long, 13.11 m wide, 3.39 m deep and has a volume of 2257 m^3. An overview of the first transect through gully G14 (G14-TR1) is shown in Figure 3a. The detailed stratigraphy of transect G14-TR1 is shown in Figure 4a. In this study, only the sedimentary structures observed in the infill of the southeast-facing (head wall) are presented.

Transect G14-TR1 shows that the original incision at this point was about 1.6 m deeper than the present-day soil surface. The gully incised down to the top of the Tertiary sands (Figure 4a, 1), most probably because these are covered by an erosion-resistant, stony layer (2). The gully channel formed thus

Table 1 Reported gully erosion phases in northwest and central Europe

Country	Study area	Timing of gully erosion phase(s)	Dating method	Reference(s)
Germany	Biesdorfer Kehlen	(1) After 2857–2495 BC; (2) AD 1600–1800	C	Schmidtchen and Bork (2003)
Poland	Kazimierz Dolny	(1) 2000–1750 BC; (2) AD 1700–1800	A, C	Schmitt *et al.* (2003b)
Germany	Taunus and crystalline Odenwald mountains	(1) Before 540 BC (Neolithic?); (2) From AD 1600 on	H, C	Semmel (1995)
France	Paris Basin	Before 540 BC	A, C	Larue (2005)
Germany	Hainbach	(1) AD 800–1100; (2) AD 1300–1350; (3) AD 1500–1900	C	Dotterweich *et al.* (2003); Dotterweich (2005)
UK	Howgill Fells	AD 900–1000	C	Harvey *et al.* (1996), Harvey *et al.* (1981)
Germany	Rüdershausen	(1) AD 1200–1450; (2) AD 1650–1800	A, C	Bork *et al.* (1998)
Germany	Wolfsschlucht	(1) AD 1300–1400; (2) AD 1700–1800	A, C	Bork *et al.* (1998); Schmitt *et al.* (2003a)
Germany	Coppengrave	AD 1300–1350	A, C	Bork *et al.* (1998)
Germany	Drudevenshusen	(1) AD 1300–1350; (2) AD 1400–1500	A, C	Bork *et al.* (1998)
Germany	Lützellinden-Zechbach	AD 1300–1600	A, C	Bork *et al.* (1998)
Germany	Neuenkirchen	AD 1200–1500	A, C	Bork *et al.* (1998)
Germany	Antreff	AD 1200–1500	A, C	Bork *et al.* (1998)
Germany	Sälgebach	AD 1200–1500	A, C	Bork *et al.* (1998)
Germany	Thiershausen	AD 1200–1500	A, C	Bork *et al.* (1998)
Germany	Welschbach	AD 1200–1500	A, C	Bork *et al.* (1998)
Germany	Mörsbach	AD 1500–1600	A, C	Bork *et al.* (1998)
Germany	Adelshofen	AD 1500–1800	A, C	Bork *et al.* (1998)
Germany	Bottenbach	AD 1500–1800	A, C	Bork *et al.* (1998)
Germany	Hinterreit	AD 1600–1900	A, C	Bork *et al.* (1998)
Germany	–	AD 1600–1800	H	Hempel (1976)
Slovakia	Myjava hill land	(1) AD 1550–1730; (2) AD 1780–1850	H	Stankoviansky (2003)
Germany	Nienwohlde	(1) AD 1700–1800; (2) AD 1974–1988	A, C	Bork *et al.* (1998)
Belgium	Kinderveld	AD 1700–1900	A, C	Vanwalleghem *et al.* (2005b)
France, Germany	E France, SW Germany	AD 1700–1800	H	Vogt (1953)
Germany	SW Germany	AD 1750–1850	H	Hard (1976)
Hungary	Szekszárd Hill country	AD 1780–1860	H	Zámbó (1972)
Hungary	Csérhat hill country	*c.* AD 1820	H	Zámbó and Gábris (1977)
Hungary	NE Hungary	*c.* AD 1850	H	Gábris *et al.* (2003)
Belgium	Central Belgium	*c.* AD 1900	–	Grégoire and Halet (1906)
Belgium	Central Belgium	AD 1970–2004	F	De Ploey (1990); Poesen and Govers (1990); Vandaele *et al.* (1996); Steegen *et al.* (2000); Nachtergaele *et al.* (2001), Vanwalleghem *et al.* (2005b)
France	Northern France; Normandy	AD 1970–2004	F	Auzet *et al.* (1995); Cerdan *et al.* (2002)
Norway	Southern Norway	AD 1970–2004	F	Oygarden (2003)
Romania	Moldavia	AD 1970–2004	F	Radoane *et al.* (1995)
Russia	Kursk region; Stavropol region	AD 1970–2004	F	Roshkov *et al.* (1993); Belyaev *et al.* (2004)
Sweden	Southern Sweden	AD 1970–2004	F	Alstrom and Akerman *et al.* (1992)
UK	South Downs; Howgill Fells; Scotland; Oxfordshire and Berkshire	AD 1970–2004	F	Evans and Cook (1987); Boardman (1992); Harvey (1992); Grieve *et al.* (1995); Boardman *et al.* (1996)

A, archaeological dating of artefact; C, chronometric dating (^{14}C, OSL); H, dating based on manuscripts or maps; F, field observations.

entirely in the Quaternary loess deposits. Part of the original, calcareous loess (3) can still be found in the northeastern part of the transect. On top is decalcified loess (4), in which a clay illuviation horizon (or Bt horizon) formed. In the gully infill, five different sediment units could be distinguished (5, 6, 7, 8, 9). The largest part of the gully infill (5) consists of silty to sandy loam, with some fine layering and intercalated with several bands of coarser material (6, 7, 8). Weakly developed clay illuviation bands run through the entire gully infill. At several depths in sediment unit 5, charcoal, Roman brick fragments (roof tiles or tegulae) and late Roman pottery were found (Table 2). On top of the previous layers and over the

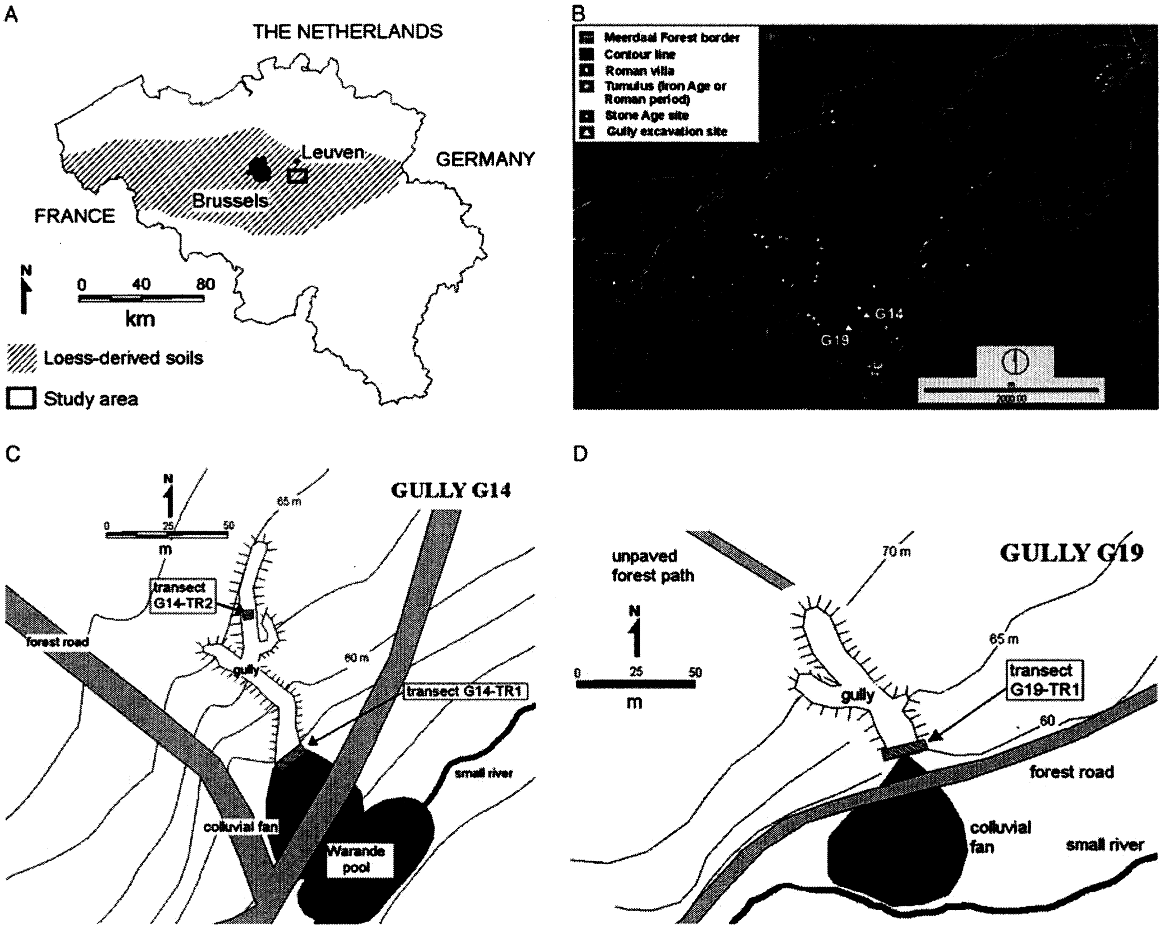

Figure 2 (a) Location of the study area in Belgium. (b) Map of Meerdaal forest (adapted from AWZ – Afdeling Waterbouwkundig Laboratorium and AMINAL – Afdeling Water, 2004) with the position of the two permanent gullies G14 and G19 studied. The position of archaeological sites (Martens, 1981) is also indicated. (c) Schematic representation of gully G14 with its colluvial fan and the location of the two transects G14-TR1 and G14-TR2. (d) Schematic representation of gully G19 with its colluvial fan and the location of transect G19-TR1

entire width of the transect, a sandy loamy colluvium layer (9) is found. This sediment unit is much less dense than the rest of the profile. It is not clear whether this is the result of the homogenizing action of roots and faunal activity or if it is younger colluvium that was deposited over the entire footslope.

An overview of the topographical location of the second transect in gully G14 (G14-TR2) is shown in Figure 3b. For this transect, the head wall (perpendicular to the flow direction in the gully) and the side wall (parallel to the flow direction, from north to south) are shown in Figure 4b.

Comparable with the situation in the downslope transect G14-TR1, the original gully incised until the level of the Tertiary sands (Figure 4b, 1), after which it filled in partly with about 1.45–1.75 m of sediment. In this second transect through gully G14, eight different sediment units were distinguished in the infill. The first sediment unit (2) above the Tertiary sand is reworked gully floor material. On top of (2) lies a thick, homogeneous sediment unit (3), in which most of the artefacts were found. Two sediment units (4 and 5) are intercalated between (3). Sediment unit (4) is quite homogeneous, while (5) is characterized by a clear, fine layering typical for water-deposited sediments. In between the layers, a small brick fragment was found (not included in Table 2). The upper sediment units (6 and 7) are homogeneous. On top of these, a thick humus horizon has formed (8). These upper three sediment units are, as in the first transect, less compact compared with the sediment units below.

An overview of the location of transect G19-TR1 is shown in Figure 2d. In Figure 4c, the detailed stratigraphy of the south-southeast facing wall of G19-TR1 is shown.

As in the previous gully, the original incision of gully 19 was considerably deeper (1.80 m) than the present surface (Figure 4c). The original soil profile is still visible at both extremities (ie, on the west-southwest and east-northeast borders) of the transect. There, the Tertiary sands (Figure 4c, 1) are covered by reworked Tertiary sand (2) and a layer with very coarse debris (3). In the colluvial gully infill, evidence was found of minimally five cut and fill cycles, each of which characterized by the deposition of a coarse gravel layer (5, 7, 9, 10, 12) and a more sandy layer (6, 8, 11, 15). At the bottom of the first channel a piece of pottery was found, which was, however, too small to be dated. Other sediment units, probably resulting from gully wall failure since they are quite similar to the material in which the gully incised, fill up the remainder of the gully (4, 13, 14). A small, isolated sand lens (16) on top of (14) is probably part of sediment unit (15).

A charcoal fragment (g in Figure 4c) from sediment unit (14) (1.20 m below the soil surface) was dated to the Middle Bronze Age (Table 2: 1743–1602 cal. yr. BC 1568–1533 cal. yr. BC). Another charcoal fragment (h in Figure 4c) from sediment unit (15) (0.88 m below the soil surface) was significantly younger, and was dated to Roman times (Table 2: 46 cal. yr BC – AD 78). Other charcoal fragments (see Figure 4c) were unfortunately destroyed during the dating procedure.

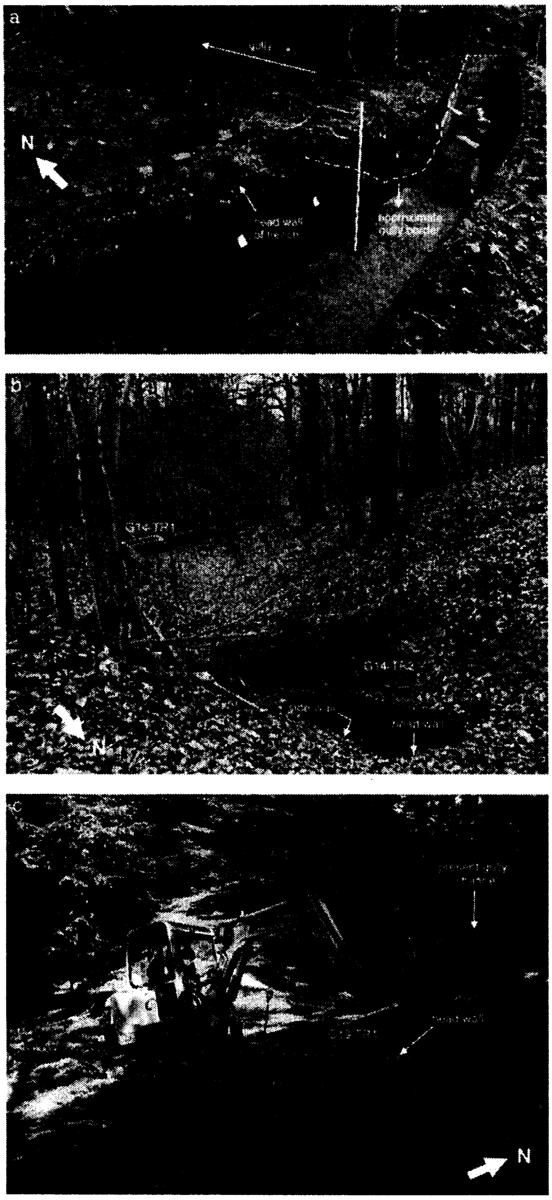

Figure 3 (a) Overview of transect G14-TR1 through the lower end of permanent gully channel G14 (see Figure 2c), with indication of the approximate gully wall and bottom. Measuring stick is 2 m high. The original incision was about 1.60 m deeper than the actual gully channel with a depth of 1.21 m. (b) Overview of transect G14-TR2 (see Figure 2c) in the thalweg of the same gully. At this location, the depth of the gully infill amounts to 1.75 m. The location of transect G14-TR1, further downslope, is also indicated. (c) Overview of transect G19-TR1 (see Figure 2d) through permanent gully G19. The actual gully channel, visible in the background, has a depth of 3.4 m. At the location of the transect, the gully is filled in with about 1.7 m of sediments

These sediment units are overlain by more silty sediment units (17, 18 and 19), in which a Luvisol profile has formed. Charcoal found at the west-southwest side of the transect shows that these three soil horizons are formed in colluvium and not in *in situ* loess.

In the vicinity of the main gully (about 10 m from transect G19-TR1, at the southern border of the colluvial fan, at a depth of 0.10 m below the soil surface), a Bronze coin was found that was dated to the first half of the first century AD (Table 2).

Discussion

The development history of both gullies is to a large extent similar and is therefore presented together. Figure 5 gives a schematic representation of the development of a typical gully under forest, based on the detailed stratigraphy observed in the gully transect G19-TR1.

Phase A: soil formation

After deposition of glauconite-rich sands by the Tertiary seas, these sands were covered by a sandy layer that appears to be a solifluxion layer during subsequent cold periods. During the Pleistocene, most of the area was covered with loess, which is very thin or sometimes even absent on south-facing slopes (Goossens, 1988), such as the slope on which gully G19 is located. On this slope, the loess layer is absent at the gully end but is a few metres thick on the plateau near the gully head. At the site where gully G14 incised, the loess thickness varies between 1.5 and 2.5 m. After deposition, the upper layer of the originally calcareous loess was decalcified, after which clay could migrate to form a clay illuviation horizon (Bt). In G14, this Bt was continuous, while in G19, where the parent material is more sandy, the Bt was formed in bands. Although there is still discussion in the literature about the exact timing of the main phase of clay illuviation either being Lateglacial or Holocene, most authors agree that by the time of the first gully incision, at the earliest during the Middle Bronze Age, this Bt horizon was already fully developed (Kühn, 2003).

Phase B–C: gully incision and partial infilling

From the transects through both gullies, several indications were found that support the hypothesis by Vanwalleghem *et al.* (2003, 2005a) that these gullies were caused by a human-induced land use change from forest to cropland in the gully catchment area.The fact that no undisturbed, loess-derived soil profile (eg, Albeluvisol or Haplic Luvisol) is found on top of the Tertiary sands in the thalweg of the gully is the first evidence that this gully is not of periglacial origin. Moreover, the shape of the present gully is not visible in the Tertiary sands, but is cut entirely in the loess cover (Figure 4a and c). Further evidence for the anthropogenic origin of the gully is given by the various artefacts found in the transects (Table 2) and the dating of the charcoal fragments.

The C-14 datings in gully G19 originate from two different periods, which could possibly be associated with two phases of gully activity and agriculture in the catchment: a first one during the Bronze Age and a second one at the end of the Roman period. Silty layers slid in from the gully walls just after the first incision of the gully, when these walls were still very unstable. The second incision cleared out part of these sediments again. Based on the artefacts found in the infill of gully G14 (Table 2), indications were found only for a Roman gully incision phase.

In both gullies, the infilling must have been a rather rapid process since no indications of a stable phase with humic horizon development within the sediment deposited was found. This is further supported by the relatively steep gully walls that can be seen in both infills (around 0.54 m/m in G14 and 3.4m/m to overhanging in G19). Field observations at the nearby Kinderveld site (Vanwalleghem *et al.*, 2005b) confirm that the infilling of a gully of several metres deep can occur within a few decades when its catchment is continuously under cropland.

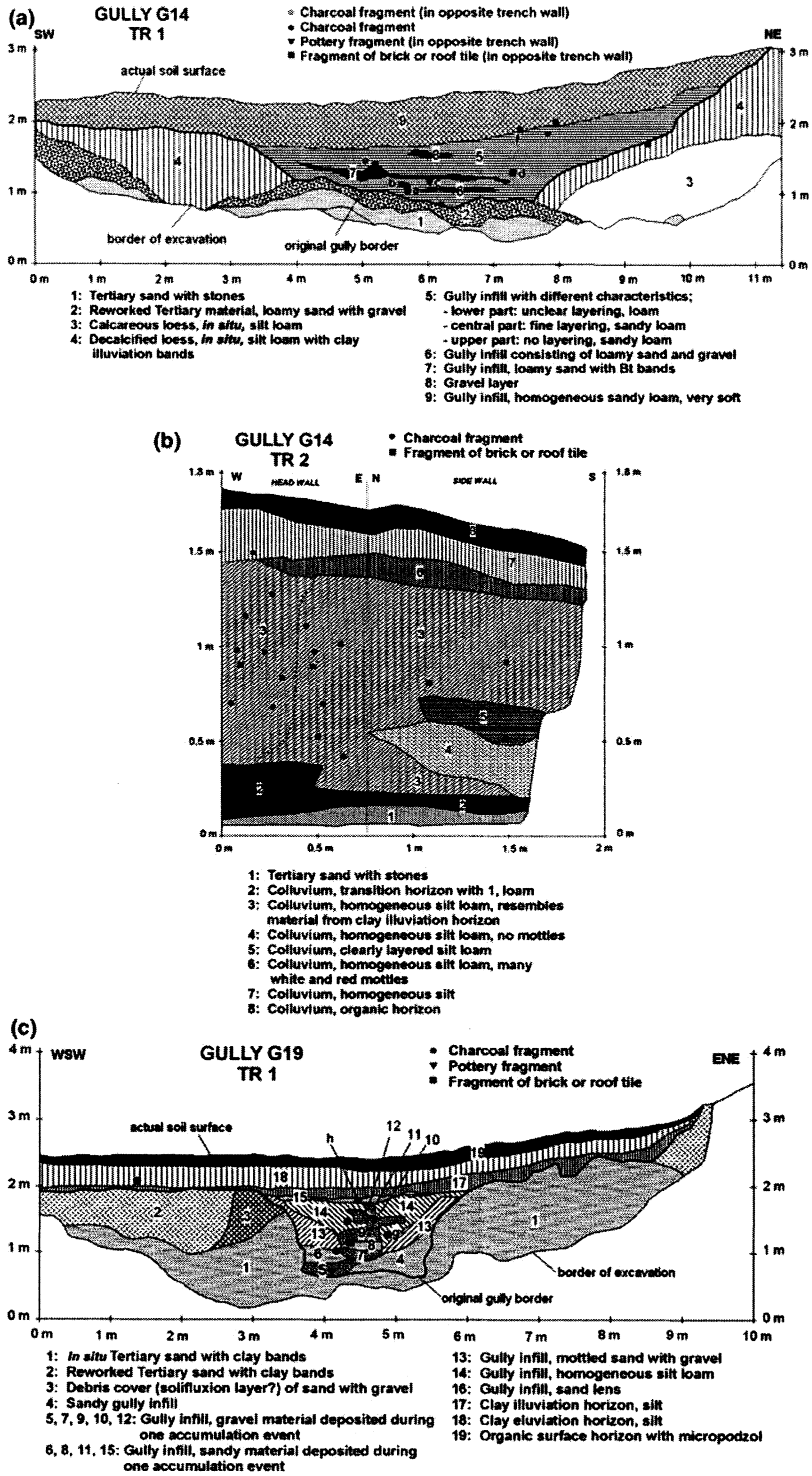

Figure 4 (a) Detailed stratigraphy of trench wall G14-TR1 (see Figure 2c). For a description and approximate age of the artefacts found in this trench that could be dated (indicated by letters), see Table 2. Most of the datable material was found in the opposite trench wall, and their position in the drawn transect wall is therefore only indicative. (b) Detailed stratigraphy of trench wall G14-TR2 (see Figure 2c). For a description and approximate age of the artefacts found within this transect, see Table 2. No sample codes are indicated here since these artefacts were not found directly in the trench walls. (c) Detailed stratigraphy of transect G19-TR1 (see Figure 2d). For a description and age of the artefacts and charcoal fragments (indicated by letters) found in this transect, see Table 2

Lang and Hönscheidt (1999) point to the fact that charcoal fragments they found in colluvium were reworked from an upslope sink. Moreover, it is possible that artefacts and charcoal fragments were at the soil surface for a long time before the gullies incised. Therefore, the age of the datable material found in the gully infills, strictly speaking, only provides a maximum estimate of the age of the gully (*terminus post quem*). Nevertheless, the land-use history of the Meerdaal forest suggests that the gullies are not younger. Although archaeological data are scarce and the existing sites cannot be linked directly to the land use and erosion phase that is suggested by the dating of the gully infills, all archaeological sites in Meerdaal forest are from the Roman period or earlier (see Figure 2b and Vanwalleghem *et al.* 2003, 2005a). At a horizontal distance of only 500 m to the south of gully G14, on the plateau of Saint Nicaise, the oldest known traces of human

Table 2 Relevant datable material (archaeological artefacts and charcoal fragments) found in transects G14-TR1, G14-TR2 and G19-TR1

Excavation code	Sample code	Depth below soil surface (m)	Type of material	Dating method	Laboratory code	Age and/or detailed description
G14-TR1	a	1.26	brick fragment	ARCH	–	Piece of Roman tile
	b	1.22	brick fragment	ARCH	–	Piece of Roman tile
	c	1.19	pottery	ARCH	–	Not dated
	d	1.32	brick fragment	ARCH	–	Piece of Roman tile
	e	0.70	brick fragment	ARCH	–	Piece of Roman tile
	f	1.35	brick fragment	ARCH	–	Piece of Roman tile
G14-TR2	–	0.50	iron artefact	ARCH	–	Clamp, probably Roman
	–	0.98	pottery	ARCH	–	Pottery with metal glaze, from the Argonne, wine beaker, showing evidence of secondary burning, AD 210–270
	–	0.52	ceramic, large piece	ARCH	–	Fragment of mortarium, from Tienen, Roman
	–	0	ceramic	ARCH	–	Fragment of Roman dolium, AD 50–300
	–	0.80	ceramic	ARCH	–	Fragment of Roman dolium, AD 50–300
	–	1.27	ceramic	ARCH	–	Pink ceramic with motive (glazed), Tiens smoked pottery, from beaker, AD 160–170
	–	0.48	brick fragment, large	ARCH	–	Piece of Roman tile
	–	0.29	brick fragment, large	ARCH	–	Piece of Roman tile
	–	0.48	brick fragment	ARCH	–	Piece of Roman tile
	–	0.73	intact brick tile	ARCH	–	Roman tile
	–	0.89	brick fragment	ARCH	–	Piece of Roman tile
G19-TR1	g	1.2	charcoal fragment	C-14	KIA15410	BP 3380 +/– 22 (cal. 1743–1602; 1568–1533 BC)*
	h	0.88	charcoal fragment	C–14	KIA15409	BP 1988+/–30 (cal. 46 BC–cal. AD 78)*
	–	0.1	metal coin	ARCH	–	AD 0–50, showing image of emperor Claudius

For location of sample codes, see Figure 4a, b and c. ARCH, dating by archaeologists; C-14, radiocarbon dating.
*two σ-range.

occupation in Meerdaal forest are found, with several Iron Age or Bronze Age tumuli and an earthen wall (see Figure 2b). Three Roman tumuli are at a distance of only 500 m to the west. Gully G19 is even located somewhat closer (350 m) to the three Roman tumuli. Although *in situ* traces have not been found so far, brick fragments found at the soil surface suggest the presence of three Roman villa sites in Meerdaal forest, of which one is located in the drainage area of gully G14 (Figure 2b). Younger archaeological sites are not present in the forest and definitely after the fourteenth century, when the Meerdaal forest received a special protective status, it can be expected that written documents would exist of any agricultural land use phase.

Phase D: deposition of colluvium

Next, a silty colluvial layer was deposited over the entire length of the transect in both gullies. This layer was most probably deposited simultaneously or shortly after deposition of the previous sediment units since in gully G14, artefacts of Roman Age were found inside this layer.

Phase E: soil formation

The archaeological evidence in Meerdaal forest and its surroundings suggest that the area was abandoned after the Roman period, most probably after the invasion of German and Frank tribes at the end of the third century (Faider-Feytmans, 1977). Cropland and/or settlements in the Meerdaal forest were also abandoned probably somewhere around this period and no more runoff or sediments could be produced in the drainage area of the gullies. The infilling of these gullies stopped abruptly after the forest recovered and the gullies remained stable for almost two millennia. During this period, further soil formation took place. In gully G19, a clay illuviation horizon in bands (band Bt horizon) developed through the entire profile and a micropodzol developed in the upper centimetres of the soil, which further stress this stability phase. Also in gully G14, such Bt bands developed in the gully infill. Additionally, in this gully, decalcification continued after the gully incision (see Figure 4a). Assuming that the original decalcification border was orientated horizontally, such as between $10 < X < 11$ m, it can be seen in Figure 4a that the current decalcification border between 8 m $< X < 10$ m is orientated parallel to the gully wall and about 0.2 m lower. This is consistent with values given by Vormezeele (1999) and Aerts (2003), who found a post-Roman decalcification between 0.2 and 0.5 m, associated with a grave pit and a sunken lane, respectively, near Tienen (about 25 km east of Meerdaal forest).

Conclusions

Previous studies have shown that gully erosion phases in past times were sometimes even more catastrophic compared with present-day gully erosion, for example during the first half of the fourteenth century (Bork *et al.*, 1998). However, while information on gully erosion during the historical period is already scarce, information on gully erosion before this period is nearly absent.

This study has shown that gully formation is definitely not a new problem and that already during Bronze Age and Roman times, farmers were confronted with the development of large gullies. The gullies that were studied are among the oldest gullies that have been dated in Europe. More important than these two studied gullies, however, is that the entire study area of Meerdaal forest encompasses a total of 43 similar gullies, mapped during a recent study (Vanwalleghem *et al.*, 2003). Although only two of these gullies have now been analysed in detail, it is reasonable to assume that the development history of the other gullies is similar given their

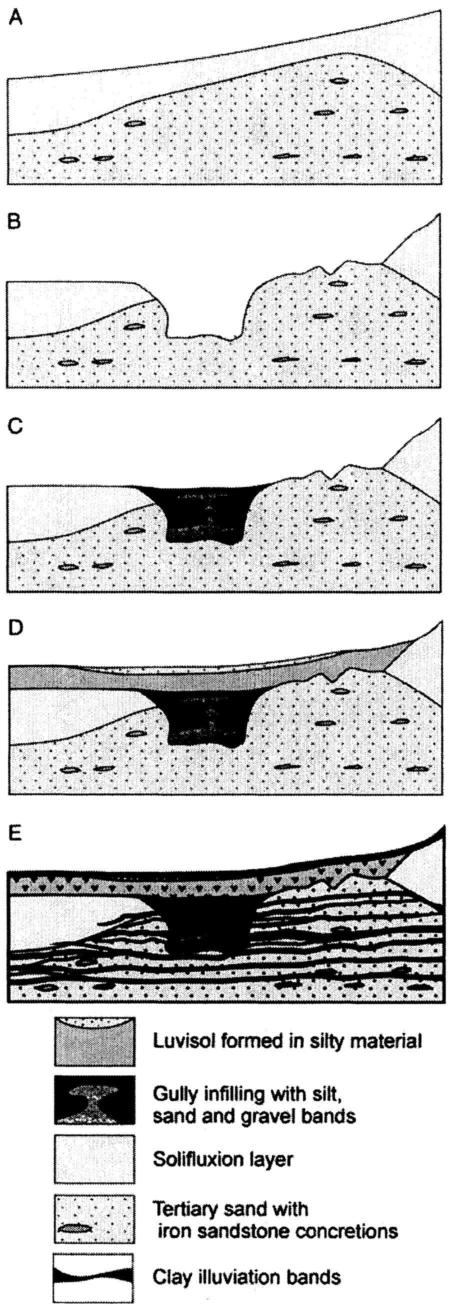

Figure 5 Schematic development history of a typical gully in Meerdaal forest

location. This makes the Meerdaal forest a unique area in Europe, with a well-conserved late-Roman topography. When looking at the landscape in this ancient forest, it becomes clear that gully erosion must have been a significant process for landscape development. Outside the forest border, under cropland, similar gullies were probably also present but centuries of water and tillage erosion have erased them from the present-day surface. This stresses the importance of the Meerdaal forest as a unique area and calls for its protection as a geosite.

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