NATUR
WISSENSCHAFTEN REVIEW ARTICLES

Lake Formation and Catastrophic Dam Burst during the Late Pleistocene Laacher See Eruption (Germany)

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Instantaneous overloading of the Rhine River with tephra during the eruption of Laacher See Volcano c. 12 900 aBP led to the formation of a major dam at the bottleneck oulet of the morphological Neuwied Basin. A temporary lake formed upstream between Andernach and Koblenz, extending for some 140 km^2 and rising more than 15 m above the pre-eruptive land surface. Collapse of the unstable dam prior to the final phase of the eruption resulted in sudden drainage of the lake. Deposits laid down by the catastrophic floodwaves occur at least as far north as Bonn, more than 50 km downstream from Andernach.

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In many disastrous Plinian eruptions most of the economic damage and major losses of life are caused by the sudden overloading of rivers in the foreland, the eruptions of Nevado del Ruiz (1985) and Pinatubo (1991) being two major recent examples (Scott et al. 1996). The overloading of the drainage systems is caused by the instantaneous deposition and fast erosion of large amounts of fallout tephra and by pyroclastic flows entering rivers, thereby transforming into mud and debris flows further downstream. The hazards of explosive volcanoes and the environmental impact of historic or prehistoric eruptions are evaluated by analyzing their tephra deposits.

We are currently studying the environmental impact of the Plinian eruption of Laacher See Volcano (LSV) c. 12,900 aBP (Bogaard 1995) – the largest explosive eruption in Central and Western Europe during the late Quaternary. We have followed up earlier suggestions that rivers in Neuwied Basin had been dammed up during the Laacher See eruption (LSE) (Schmincke et al. 1990), studying outcrops of primary and reworked Laacher See tephra (LST) on both sides of the Rhine River by petrographic, geochemical, sedimentological, and volcanological methods. Our preliminary findings suggest that the deposition of c. 0.43 km^3 primary fallout tephra in the lower Neuwied Basin (c. 115 km^2 <100 m asl.) between c. 9 and 24 km east of LSV and abundant pyroclastic flows entering tributary valleys led to the complete disruption of the Rhine River traversing the basin.

A temporary lake was dammed up, extending over c. 140 km^2 in Neuwied Basin and the adjacent valleys up to c. 80 m asl. and reaching more than 15 m above the preeruptive land surface (Figs. 1, 2). Its sudden drainage probably caused one or several catastrophic floodwaves downstream. Damming and drainage of the c. 0.9 km^3 water occurred within several

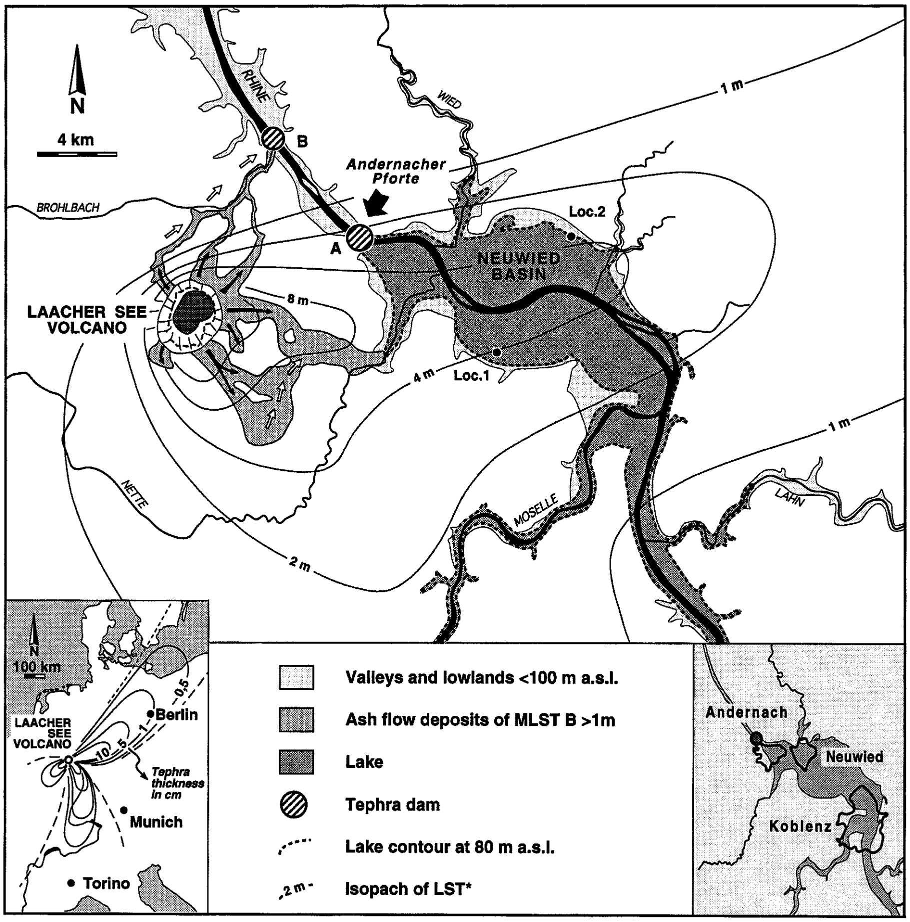

Fig. 1. Area devastated by the LSE 12,900 aBP. *Dashed line*, approximate extent of the lake dammed up in Neuwied Basin during the LSE. *A*, major tephra dam at bottleneck outlet of Neuwied Basin; *B*, dam caused by ash flows entering the Rhine River at the mouth of Brohl valley. Isopachs of total LST* (ash flow deposits excluded) and areal distribution of major ash flow deposits (MLST-B) after Bogaard and Schmincke 1984 and Freundt and Schmincke 1986. *Black arrows*, radial flow and surge fans; *white arrows*, flow directions in tangential paleovalleys to the N and SE of LSV, where ash flow deposits reach their maximum cumulative thickness (>60 m). *Bottom left*, isopachs of distal LST fallout deposits; *bottom right*, larger present-day cities in Neuwied Basin

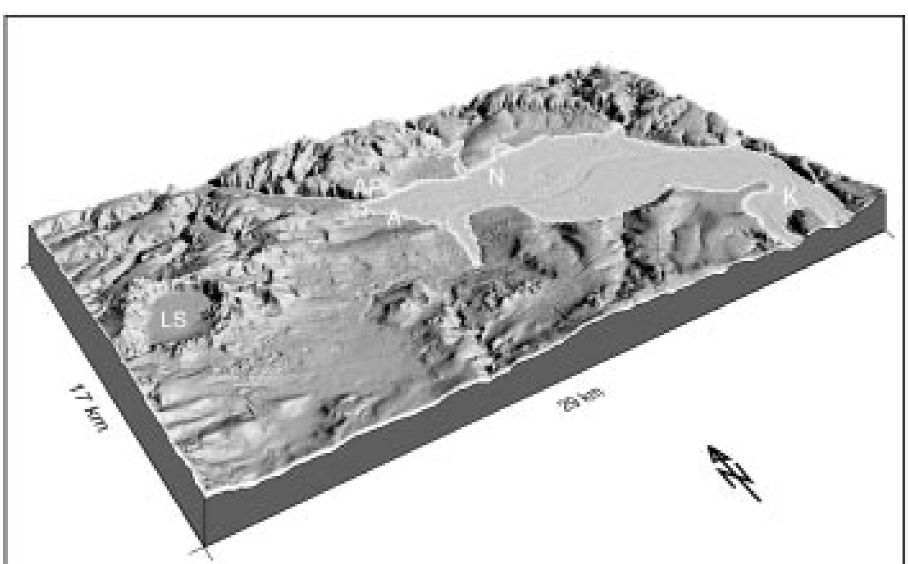

Fig. 2. Three-dimensional view of the temporary lake dammed up in Neuwied Basin during LSE resulting from the extensive congestion of the Rhine River with tephra and the formation of a major dam at the narrow, bottleneck outlet of Neuwied Basin. *AP*, Andernacher Pforte; *LS*, Laacher See. The lake (0.9 km^3 water) probably extended over 140 km^2 and reached more than 15 m above the preeruptive land surface. Sudden collapse of major parts of the tephra dam probably caused one or several gigantic floodwaves downsteam. Larger present-day cities in Neuwied Basin: *K*, Koblenz; *A*, Andernach; *N*, Neuwied. View from the SW; vertical exaggeration ×3. (Digital data with permission by the Landesvermessungsamt Rheinland-Pfalz: Az 23668–6/97

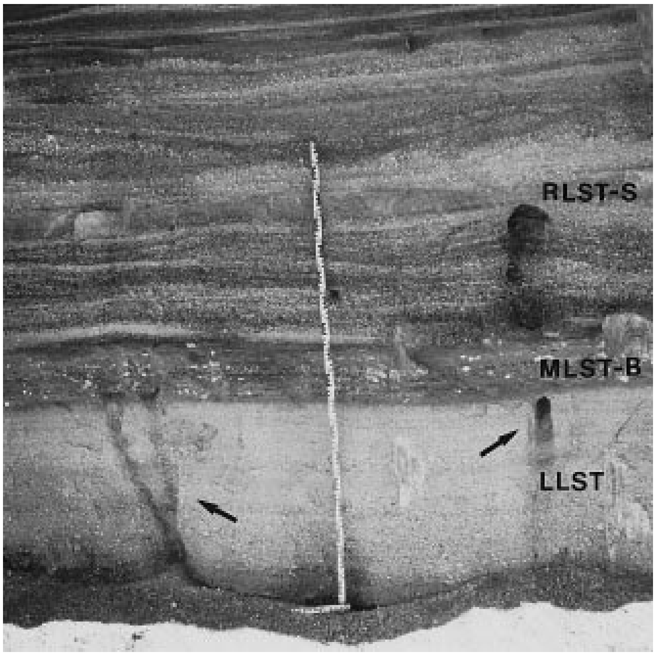

Fig. 3. Thick tephra deposits (RLST-S) clearly reworked by fast-flowing water overlying areas occupied by dry land prior to LSE, as indicated by molds of rooted trees and shrubs (*arrows*) and primary LLST and MLST-B deposits – excellent evidence that the Rhine River was dammed up as a result of the LSE. MLST-C and ULST fallout deposits and deposits of the ascending flood stage are eroded. The xenolith-rich reworked deposits were sedimented during the catastrophic drainage of the lake. Loc. 1; scale in centimeters

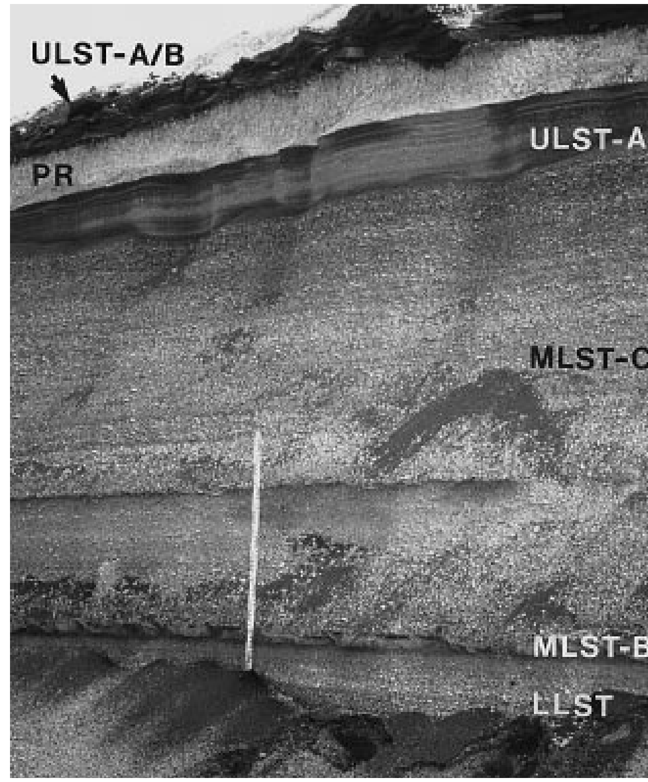

Fig. 4. Significant contrast between stranded pumice raft (*PR*, close to lake shore at 80 m asl.) consisting entirely of white LLST pumice and underlying primary MLST-C fallout deposits composed of a mixture of pumice and xenoliths. Note change from white to gray pumice in top section of MLST-C. The pumice raft is overlain by primary tephra sedimented during the final hydroclastic stage of the LSE (ULST-A/B), good evidence that the lake was dammed up and drained again while LSE was still in progress. *MLST-B*, Britzbank interval. Primary LLST is only partly exposed. Loc. 2; scale in centimeters

days while the eruption was still in progress. Here we present a preliminary account of some of the new results. A more detailed discussion will be published elsewhere.

LSV is located on the higher western shoulder of the tectonic Neuwied Basin that interrupts the steep Middle Rhine Valley between Koblenz and Andernach (Fig. 1). The terrain drops from 290–300 m asl. in the vicinity of LSV to c. 55 m asl. in the basin. The Rhine River traverses the broad basin floor in an east-west direction over a distance of c. 20 km.

LSV erupted c. 16 km^3 of tephra (c. 5.3 km^3 DRE of phonolitic magma) and c. 0.7 km^3 xenoliths in probably less than 24 h. The pumice and ash deposits have been subdivided into a Lower (LLST), a Middle (MLST-A/B/C), and an Upper LST sequence (ULST-A/B; Bogaard and Schmincke, 1984, 1985; Bogaard et al. 1990; Schmincke et al. 1990). The eruptive products are strongly zoned compositionally from highly vesicular, phenocryst-poor white pumice erupted during LLST to vesicle-poor, crystal-rich gray pumice erupted during MLST-C and ULST (Wörner and Schmincke 1984). A major break that may have lasted days to weeks occurred at the end of the upper main hydroclastic stage (ULST-A) prior to the eruption of characteristic green tuff of the terminal phreatomagmatic phase (ULST-B; Bogaard et al. 1990; Schmincke et al. 1990). The dispersal axes of the major fallout fans cross Neuwied Basin, tephra thickness decreasing from >10 m at Laacher See to 2–4 m within the basin (Fig. 1). Quickly reworked tephra deposits (RLST) reach a thickness of up to 12 m between the eruptive center and the Rhine. We here distinguish syneruptive (RLST-S) from posteruptive reworked deposits (RLST-P).

We were able to establish a correlation between primary LST deposits as well as most of the reworked deposits throughout Neuwied Basin and adjacent areas on both sides of the Rhine, allowing a detailed reconstruction of the volcanic events and major flood phases. Thick tephra deposits clearly reworked by fast-flowing water overlie areas occupied by dry land prior to LSE – excellent evidence that the Rhine River was dammed up as a result of the eruption

Fig. 5. Reworked LST (white pumice, dark xenoliths/gray pumice) mixed with Rhine sand (*light-gray*) deposited by the braided river system established in Neuwied Basin after the total drainage of the lake. Admixture of sand is indicative of the reincision of the Rhine River through more than 4 m of primary and reworked LST even into the preeruptive valley fill during lake drainage and braided river phase. The heigh of the photograph is 75 cm

(Fig. 3). We think that the first major congestion of the Rhine occurred after pyroclastic flows of MLST-B had entered the Rhine valley at the mouth of the Brohlbach 6.5 km downstream of the outlet of Neuwied Basin (Fig. 1). Flooding must have immediately affected large parts of the lower Neuwied Basin due to the low relief and the extensive overloading of stream channels by fallout tephra. Thick deposits in the basal part of the fluvially reworked section showing a very incomplete separation of pumice and xenoliths indicate that the rising flood almost choked in its own sediment during the early stage of flooding, when the water level was only slightly higher than the primary tephra thickness. Huge quantities of tephra were transported towards the narrow, bottleneck outlet of Neuwied Basin north of Andernach (Andernacher Pforte) leading to total congestion of the Rhine and formation of a major dam (Figs. 1, 2).

We found gray pumice clasts in the very base of the fluvially reworked LST throughout the lower Neuwied Basin. This suggests that major dam formation and associated increased flooding occurred after the onset of the fallout of gray pumice clasts. Damming therefore probably coincided with the maximum mass eruption rates near the end of the major Plinian phase (MLST-C) of LSE characterized by the coarsest fallout deposits.

At many localities, especially in the eastern Neuwied Basin, we found a characteristic bed entirely free of xenoliths and consisting only of highly buoyant white pumice clasts of unequivocal LLST composition (Fig. 4). We interpret these deposits overlying either primary ULST-A or fluvially reworked LST deposits as stranded pumice rafts originally floating on top of an extensive water body – clear evidence that a temporary lake had formed in Neuwied Basin as a result of rapid tephra sedimentation and dam formation. Judging from the fact that the deposits show similar thicknesses (up to c. 40 cm) and sedimentary characteristics irrespective of the depositional environment and topographic elevation, large areas of the lake surface probably were covered by a thick continuous sheet of floating pumice. The pumice rafts were stranded when the lake was catastrophically drained. We found pumice raft deposits at 80 m asl., indicating that the water level of the lake was at least as high. At places the lake must therefore have reached more than 15 m above the preeruptive land surface, filling the entire lower Neuwied Basin and reaching far into tributary valleys – probably also upstream into the Upper Middle Rhine and Moselle Valleys (Fig. 1). The dammed up water volume must have amounted to at least 0.9 km^3 and could have been accumulated by the Rhine River and its tributaries in c. 4.5 days given the recent discharge for late spring, the likely season of the eruption (Schweitzer 1958; Bittmann personal communication). The actual damming of the lake may have lasted up to twice as long because the dam was likely not completely sealed.

We interpret pronounced channel erosion on the lower basin floor cutting through more than 4 m of primary and reworked LST even into pre-LST valley fill as indicating a catastrophic drainage of the lake. This may have resulted from the sudden collapse of major parts of the dam perhaps triggered by earthquakes and air shocks accompanying the powerful late stage phreatomagmatic explosions (ULST-A) which, according to Schmincke et al. (1973), were caused by ground water influx into the partly collapsed magma reservoir. One or several surge-like floodwaves charged with large amounts of LST must have abruptly passed from Neuwied Basin into the narrow Lower Middle Rhine Valley. We found several outcrops of fluvially reworked LST more than 50 km downstream of Andernach as far north as Bonn that we interpret as floodwave deposits resulting from catastrophic lake drainage.

The erosional channels in Neuwied Basin were refilled with deposits that indicate high flow velocities and most probably were laid down during the waning phase of drainage (Fig. 3). In the lower section the channel fill consists entirely of reworked LST, extremely enriched in xenoliths. Admixture of alluvial components (pebbles and Rhine sand) appears only in the upper section, indicating complete drainage of the lake and channel incision into pre-LST valley fill.

The xenolith-rich channel-fill and the pumice raft deposits of the drainage phase are directly overlain in some places by primary LST deposits (Fig. 4) sedimented at the end of the upper main hydroclastic stage (ULST-A) and during the terminal phreatomagmatic phase (ULST-B). This is clear evidence that the accumulation and catastrophic drainage of the ca. 0.9 km^3 of lake water must have occurred while the eruption was still in progress – prior to the break in eruptive history between ULST-A and ULST-B. According to mass eruption rate estimates, the LS Plinian phases probably lasted about 7–11 h (Schmincke et al. 1990). The duration of the intermediate (MLST-B/C) and especially the final hydroclastic stages (ULST-A/B) is difficult to estimate. The time span calculated for the accumulation of the lake indicates that the major eruptive activity of LSV (LLST until ULST-A) prior to the significant break shortly before the end of the eruption most probably lasted at least 4–5 days.

After the end of LSE a braided-river system was established in Neuwied Basin and may have persisted up to several years until the barren landscape was sealed again by vegetation. Its deposits were still significantly dominated by reworked LST (RLST-P) (Fig. 5).

Judging from the eruptive history of two older phonolitic volcanoes in the East Eifel volcanic field, LSV might erupt again (Schmincke et al. 1990). Given the prevalance of westerly winds, the fallout distribution pattern of a future eruption is likely to resemble that of the Alleroed eruption. The Laacher See crater is now filled by a large lake. Recurrence of a major eruption of LSV would no doubt generate phreatomagmatic explosions more powerful than those 12,900 years ago and would pose a major hazard and risk to the densely populated and highly industrialized lowland of Neuwied Basin.

We thank R. Gaupp, E. Gölz, A. Ikinger, and W. Schirmer for discussions during field trips and E.W. Hildreth for valuable comments on the manuscript. Our studies were supported by grants (Schm 250/59, 47-1) from the Deutsche Forschungsgemeinschaft in the priority research program “Wandel der Geo-Biosphäre.”

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