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A window into development of a complex ice-marginal lake prior to the Late Glacial Maximum (LGM) in Austria

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ABSTRACT

Although the retreat process of glaciers from the Late Glacial Maximum (LGM) is well documented, high-resolution insight into conditions prior to the maximum is lacking in the eastern European Alps, resulting in a gap in our understanding about the processes associated with this important climatic tipping point. We describe an outstanding sand and gravel outcrop at Gröbming in the Enns Valley (Ennstal), Austria, that represents the development of a delta complex that debouched into a large body of water that we name paleo-Lake Gröbming, fed by a major valley glacier. The succession consists of sands bearing climbing ripples, parallel laminations, and supercritical bed forms (bottomsets) overlain by meter-scale gravelly foresets. Topsets comprise gravels. We argue that sustained accumulation of supercritical bed forms required a jet efflux feeder mechanism best explained by a direct glacial meltwater source. Complex vertical and lateral repetition of this tripartite succession is observed, with sequence stratigraphic analysis permitting us to argue that stratal complexity is attributable to base-level changes in paleo-Lake Gröbming resulting from dam breaches of the lake. Thus, application of well-established sequence stratigraphic approaches to Quaternary ice-marginal successions in the Alps has significant potential to yield unprecedented insights into conditions prior to the LGM.

INTRODUCTION

In the European Alps, intensive work has been undertaken over the past two decades on the timing and character of deglaciation from the Late Glacial Maximum (LGM) (van Husen, 2000; Reitner, 2007; Ivy-Ochs et al., 2008, 2023), but not on the processes involved in ice-sheet growth to the LGM position. Glacially shaped lake basins often preserve an excellent record of deglaciation from the LGM (Daxer et al., 2018), but the record of ice buildup from lakes is far less clear. The explanation for this is that clastic sediments recording glacial advance ("Vorstoßschotter" in the sense of proglacial fluvial gravel; van Husen and Reitner, 2022) are typically poorly preserved in trunk valleys as a result of subglacial cannibalization. Inner-alpine deltaic deposits from the onset of LGM glaciation are only found in tributary valleys, where their preservation is best explained by ice-flow changes during the course of the LGM (Menzies and Reitner, 2016) or by the formation of epigenetic valleys after the LGM (Sanders et al., 2014). The last major phase of ice buildup commenced ca. 30,000 yr B.P. (Barrett et al., 2017).

In this article, we provide high-resolution sedimentologic data and the first sequence stratigraphic analysis of a lake succession lying below LGM deposits in the eastern European Alps (Fig. 1). We reveal a succession in the Enns Valley (Ennstal), Austria, that was fed by a stable jet efflux, for which we interpret an ice-marginal lake scenario to explain the sediment delivery and supercritical flow deposits. We term this major body of water paleo-Lake Gröbming. By deriving a chronostratigraphic diagram from stratal geometries, significant lake-level changes were recognized that possibly resulted from episodic dam breaching. Based on the context and elevation of the outcrop in relation to its host valley, we demonstrate that the lake was a significant feature.

GEOLOGIC BACKGROUND AND STUDY AREA

The Gröbminger Mitterberg is a SW-NE–oriented hill in the Enns Valley, Styria, east of the village of Gröbming, with its highest point at 235 m above the modern valley floor. The Enns Valley is a typical longitudinal valley of the eastern European Alps. It sits along a major strike-slip fault with the Northern Calcareous Alps (dolostone, limestone) to the north and crystalline rocks of the Niedere Tauern range to the south. The Mitterberg hill is composed of Pleistocene sands and gravels resting on phyllite and greenschist that are capped by a very poorly exposed diamicton long since interpreted to be subglacial in origin (Griesmeier et al., 2021; van Husen, 1968, 1987). The till together with the streamlined surface indicate final shaping by the Enns Glacier during the Alpine LGM (ca. 27–19 ka; Supplemental Material[1]: glaciological maps). After a rapid phase of ice decay (Reitner, 2007), large valleys became ice free around 18.5 ka, according to calibrated ^{14}C data from peat base layers in the Enns river catchment and other sites in the eastern European Alps (van Husen, 1997; Reitner, 2007). Previous research regarded the gravels and sand as (glacio-)fluvial remnants of a pre-penultimate glaciation resting on a preglacial valley floor (van Husen, 1968). The presented outcrop at Frankenbichl gravel pit was discovered by Kellerer-Pirklbauer et al. (2004), but no sedimentological interpretation has yet been attempted.

METHODS

Fieldwork was undertaken in June 2020 in Frankenbichl gravel pit at the eastern part of the Mitterberg (Fig. 1) and included photogrammetry and sedimentary facies description. The studied quarry face is vertical and largely inaccessible, so we deployed a DJI Mavic

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[1]Supplemental Material. Supplemental material part 1: palaeo-glaciological maps; supplemental material part 2: high-resolution orthophoto. Please visit https://doi.org/10.1130/GEOL.S.23669283 to access the supplemental material, and contact editing@geosociety.org with any questions.

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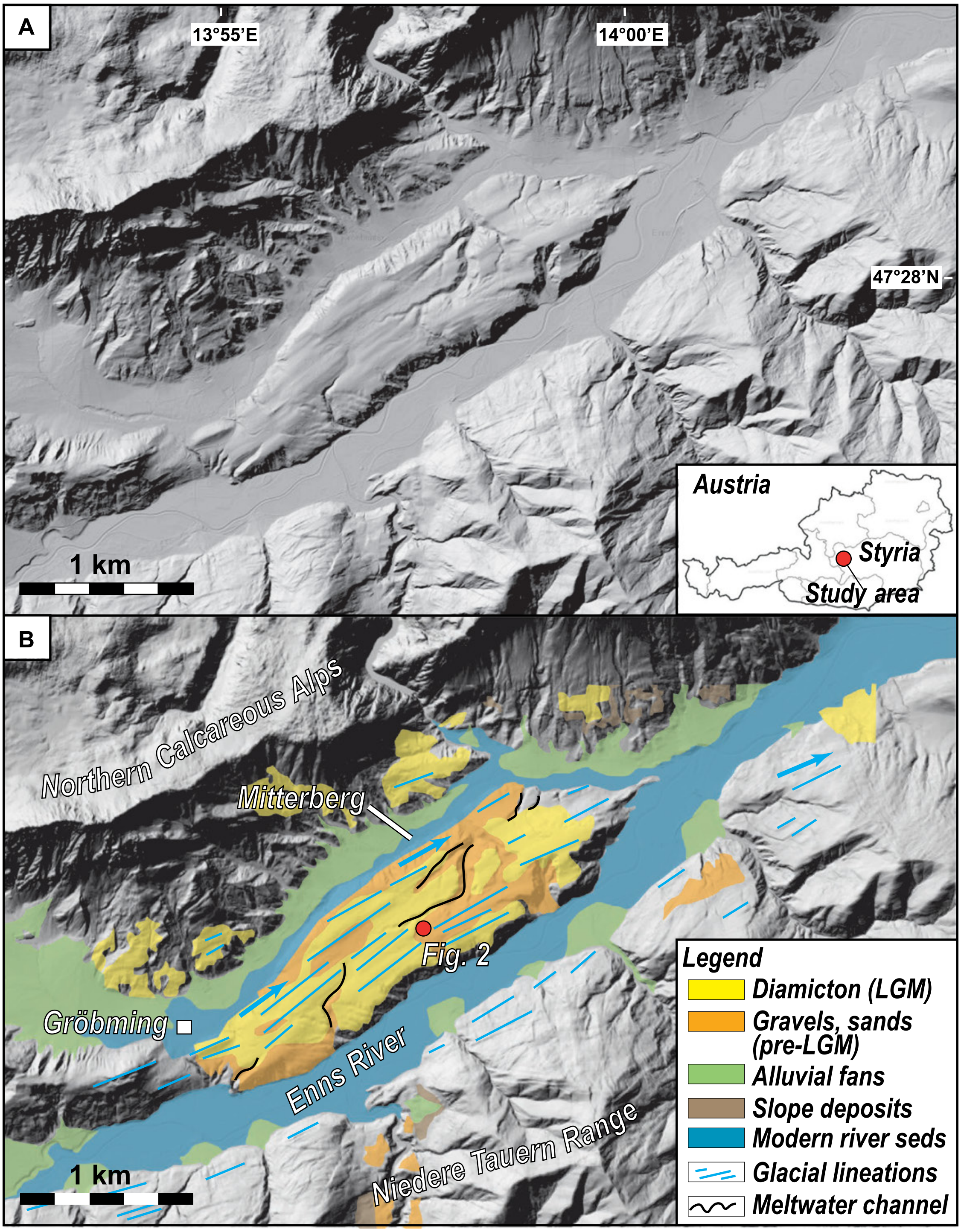

Figure 1. (A) Light detection and ranging (LiDAR) image of Mitterberg hill outcrop in Ennstal, Styria, Austria (1 m resolution, free access at https://gis.stmk.gv.at/wgportal/atlasmobile). Present structure of Enns Valley (Ennstal) is defined by major slopes to south and north. (B) Geological map of Quaternary section of Mitterberg and surrounding Ennstal simplified after Kreuss (2020), showing location of Frankenbichl quarry. Interpretations of glacial lineations from LiDAR data are authors' own. LGM—Last Glacial Maximum.

Mini uncrewed aerial vehicle (UAV), flying in manual mode, to capture the quarry face. The UAV was flown at 2–5 m from the cliff face, with overlap of at least 60% between a total of 131 photographs. These were processed in Agisoft Metashape following a standard workflow, with high-quality point cloud generation and high-quality mesh generation selected. The sheer vertical face of the 6 m cliff was treated as a flat surface, and an orthophoto mosaic was produced. The resulting image was a high-resolution photograph (locally to 0.2 cm) of the outcrop (Fig. 2A; see also Supplemental Material for orthophoto download), which allowed the lithology in the inaccessible (upper) part of the section to be accurately recorded. The photograph was then interpreted using a sequence stratigraphic approach (Martini and Brookfield, 2005). The vertical and lateral organization of stratal geometries was determined, and hiatuses were recognized to construct a chronostratigraphic chart (Wheeler, 1958, 1964). This concept is scale-independent, from outcrop to seismic scale (Qayyum et al., 2017). In Quaternary studies, sequence stratigraphy is often applied (Boyd et al., 1989), but its use in Quaternary glacial sedimentology is rare (for exceptions, see Brookfield and Martini, 1999; Powell and Cooper, 2002). To our knowledge, no previous attempt has been made to do this for the Quaternary of the eastern European Alps.

RESULTS

The Frankenbichl gravel pit exposes an ~6-m-thick succession (Fig. 2A) in which three facies can be recognized, namely, (1) sandy

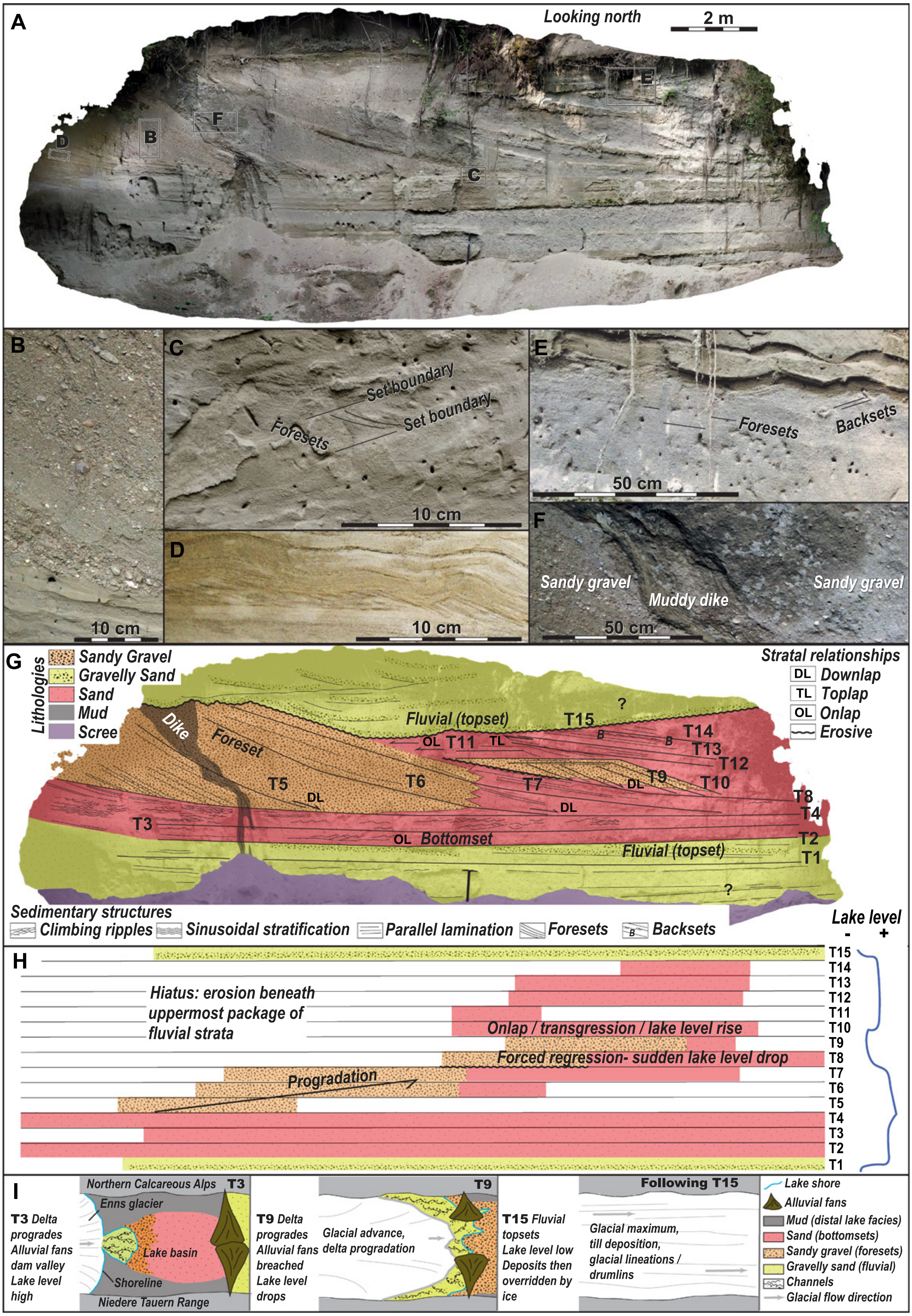

Figure 2. Sedimentologic and stratigraphic data from Frankenbichl quarry, Mitterberg. (A) Composite orthomosaic derived from 131 photographs taken with a DJI Mavic Mini uncrewed aerial vehicle (see Supplemental Material [text footnote 1]). (B) Transition from parallel laminated to sinusoidally stratified sand (bottom) to sandy gravel foresets (top). (C) Climbing ripple stratification in sand, apparent paleoflow from left to right. (D) Current ripple set (apparent paleoflow left to right) draped by undulose and sinusoidal lamination. (E) Backset stratification. The gently sloping (∼12° toward right) structures are distal delta foresets; backset structures are superimposed and well exposed immediately beneath small shaded overhang. They are recognized as ripple foresets dipping in opposing orientation to foresets (i.e., toward left). (F) Detail of sedimentary dike composed of mud, intruded into sandy gravel deposits. (G) Detailed interpretation of orthomosaic, showing stratal relationships and facies, plus arbitrary time lines (T1–15) as basis for chronostratigraphic interpretation. (H) Chronostratigraphic chart (Wheeler diagram) of outcrop based on stratal extent and relationships, together with lake-level curve derived from analysis. (I) Map-view sketches for three time slices from H showing evolution of sedimentary system. No scale implied.

gravel, (2) sand, and (3) gravelly sand. Sandy gravels comprise moderately sorted deposits that show both internal fining upward within layers and a subtle alternation in clast size between layers. These layers dip up to 35° to the east and exhibit an asymptotic contact on underlying deposits (Fig. 2B). Tabular clasts show alignment of the A-B axis parallel to the dipping host strata. The sand facies exhibits well-expressed climbing ripple sets, some of which have well-preserved stoss side–lee side transitions (Fig. 2C). In other cases, current ripple sets are draped by undulose laminations and sinusoidal stratification (Fig. 2D). Ripple-scale backsets, in which the stoss and lee slopes are oriented in the opposite direction to the host foresets, are also observed. The sand facies association is represented both as subhorizontal packages beneath sandy gravels, but also as a lateral facies transition away from the sandy gravels (Fig. 2E). Both the sandy gravels and sand deposits are dissected by a sedimentary dike at the westernmost part of the outcrop (Figs. 2A and 2F). This sedimentary dike is composed of mud, and it crosscuts both sands and gravels (Fig. 2F). The third facies association, a gravelly sand, is characterized by diffuse cross-stratification and an irregular basal contact where the contact is exposed (Fig. 2G). This contact dissects occurrences of both the sandy gravel and sand facies (Fig. 2G). In terms of stratal architecture, we recognized examples of downlapping, toplapping, and onlapping contacts, with associated abrupt changes in facies across these contacts. These contacts, together with 15 arbitrary time lines, were used to construct a chronostratigraphic chart (Wheeler diagram) for the succession (Fig. 2H).

The Frankenbichl succession is interpreted to represent the deposits of an ice-marginal delta in which the architecture was influenced by fluctuating lake levels. The individual graded layers in the foresets are interpreted as the deposits of sustained or surge-type density flows, compatible with this slope setting (Dietrich et al., 2016; Lang et al., 2017; Winsemann et al., 2018). The sands are interpreted as bottomsets transitional to basal foresets on account of their geometry (Figs. 2A and 2E), rather than the unconfined sheetflood deposits seen in many large sandy alluvial-fan deposits (e.g., Winsemann et al., 2022). Although coarsening-upward successions are well known from neighboring valleys (the so-called Vorstoßschotter deposits), these are typically poorly sorted, boulder-bearing, and locally cross-stratified deposits, allowing those to be interpreted as braided river deposits (Reitner, 2022). Instead, the architecture of the Frankenbichl succession closely resembles that predicted for stratified jet-fed, coarse-grained sediment deltas (Winsemann et al., 2022). In that model, derived from laboratory experiments and field observations, gravelly foresets (grain-flow deposits) pass basinward via backset cross-stratification to sinusoidal stratification (including stable antidunes and ripples) and to climbing ripple cross-stratification at the transition to bottomset deposits. At Frankenbichl, the backset stratification is also observed in some of the upper sand layers, which can be interpreted as cyclic step deposits (Dietrich et al., 2016; Lang et al., 2017).

The various downlapping, toplapping, and onlapping relationships in the interpreted section (Fig. 2F) are proposed to reveal complex delta development in multiple cycles, rather than the simple buildout of a sediment wedge into a body of water. This, together with the derived Wheeler diagram (Fig. 2G), illustrates that progradation (illustrated by time lines T7 and T8) was punctuated by a basinward shift in facies (time lines T9 and T10), and then succeeded by renewed onlap (time lines T11–T14). This was followed by a phase of downcutting, where fluvial strata of T15 and above rest unconformably on the underlying strata. Together, these apparently complex changes can be explained as (1) a phase of steady-state base-level (lake-level) fall typical of normal progradation, (2) a phase of forced regression associated with relatively sudden lake-level drop, (3) a renewed lake-level rise, and (4) renewed, sudden lake-level fall. The evolution of the lake basin is shown in simple map-orientation cartoons for three arbitrary time intervals at T5, T9, and following T15, where progradation occurred in tandem with advance of the Enns glacier, ultimately terminating with subglacial deposition of till and the generation of drumlins on the Mitterberg (Fig. 2I). To explain the sedimentary dike, we envisage upward injection into the delta deposits, with distal muddy lake sediments providing a possible source. In the present day, these probably correspond to deposits concealed by scree (Fig. 2G).

DISCUSSION AND CONCLUSIONS

The evolution of the delta system at Frankenbichl provides high-resolution insight into highly dynamic conditions immediately prior to the LGM in Enns Valley. We contend that (1) the facies provide unequivocal evidence for the presence of a lake, which we name paleo-Lake Gröbming, (2) the geometry and evolution of the delta require the presence of a glacier that fed it, and, therefore, (3) dramatic lake-level oscillations were allied to fluctuating meltwater input into paleo-Lake Gröbming in concert with bursting of a dam. These interpretations stand in contrast to previous interpretations of the Quaternary section of the Enns Valley. Van Husen (1987) proposed that the upper part of the Enns Valley recorded a three-phase development, including (1) valley floor formation to glacial excavation, (2) a phase of interglacial siliciclastic sedimentation, and (3) the LGM glaciation (glacial lineations crosscutting the outcrop; Fig. 1). Together, our evidence provides clues about the way in which the Enns glacier behaved prior to its advance to its LGM position. Although absolute geochronology is lacking, two lines of evidence underpin the view that paleo-Lake Gröbming was in existence prior to the LGM, namely (1) the presence of a subglacial till capping the delta deposits, and (2) the well-preserved glacial lineations crossing the Mitterberg hill and transecting both delta deposits and tills. Because the till is interpreted as LGM in age, it follows that the glacial lineations along the Mitterberg hill correspond to the same cycle.

We argue that the delta deposits record deposition in a major body of standing water fed by a glacier that is hypothesized to have filled the entire valley. The Frankenbichl section occupies a significantly elevated position with respect to the present-day Enns Valley (~840 m compared to ~650 m on the modern valley floor). Only part of the reason for this elevation difference can lie in subglacial erosion of the valley following delta deposition. The modern elevation of these deposits collectively points to a lake that would have covered the Mitterberg completely when base levels were highest.

How was the lake dammed? Based on current geomorphology, large alluvial fans have been mapped throughout the Enns Valley (Fig. 1A; Kellerer-Pirklbauer et al., 2004; van Husen, 1987; Kreuss, 2020). Such fans represent a simple mechanism to dam paleo-Lake Gröbming, like the model suggested for other longitudinal valleys (e.g., Inn Valley; van Husen 1983, 2000). Their reorganization via slope collapse would likewise provide a simple mechanism for dam collapse and breaching. Such a dam collapse event may explain the rapid base-level falls inferred from offlapping geometries (T9–10; Figs. 2F and 2I). The base-level reconstruction from the chronostratigraphic analysis (Fig. 2G) points to punctuated but clear evidence for base-level fall throughout the sequence. We interpret this as progressive infill of the lake by glacial meltwater–sourced siliciclastic sediments. Once the lake was filled with sediments, the Enns glacier overrode the sediment package, depositing a subglacial till (van Husen, 1968, 1987; Griesmeier et al., 2021). In this same phase, at the acme of the LGM, large subglacial bed forms developed over the crest of the Mitterberg. These structures, including megascale glacial lineations, formed through the local remolding of the delta deposits and till as a soft, deformable subglacial bed. This process is also considered to be a plausible mechanism for the injection of sedimentary dikes into the delta deposits. Elsewhere, the injection of subglacial dikes is well recorded and also occurred beneath subglacial tills (Ravier et al., 2015).

Beyond paleogeographic interpretations, our analysis highlights the value of a detailed sequence stratigraphic approach applied to Quaternary sediments of the Alps, an approach previously unattempted. This is surprising, given that deployment of this approach in a wide variety of settings, including the Quaternary of Ontario (Brookfield and Martini, 1999), has yielded significant insights into complex ice-margin behavior, even allowing generic models for temperate glaciated shelves to be proposed (Powell and Cooper, 2002). This approach has a significant role to play in paleogeographic investigation of the eastern European Alps, facilitating rigorous interpretation of evolving depositional environments.

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REFERENCES CITED

Barrett, S., Starnberger, R., Tjallingii, R., Brauer, A., and Spötl, C., 2017, The sedimentary history of the inner-alpine Inn Valley, Austria: Extending the Baumkirchen type section further back in time with new drilling: Journal of Quaternary Science, v. 32, p. 63–79, https://doi.org/10.1002/jqs.2924.

Boyd, R., Suter, J., and Penland, S., 1989, Relation of sequence stratigraphy to modern sedimentary environments: Geology, v. 17, p. 926–929, https://doi.org/10.1130/0091-7613(1989)017<0926:ROSSTM>2.3.CO;2.

Brookfield, M.E., and Martini, I.P., 1999, Facies architecture and sequence stratigraphy in glacially influenced basins: Basic problems and water-level/glacier input-point controls (with an example from the Quaternary of Ontario, Canada): Sedimentary Geology, v. 123, p. 183–197, https://doi.org/10.1016/S0037-0738(98)00088-8.

Daxer, C., Moernaut, J., Taylor, T., Haas, J.N., and Strasser, M., 2018, Late Glacial and Holocene sedimentary infill of Lake Mondsee (Eastern Alps, Austria) and historical rockfall activity revealed by reflection seismics and sediment core analysis: Mitteilungen der Österreichischen Geologischen Gesellschaft, v. 111, p. 111–134, https://doi.org/10.17738/ajes.2018.0008.

Dietrich, P., Ghienne, J.-F., Normandeau, A., and Lajeunesse, P., 2016, Upslope-migrating bedforms in a proglacial sandur delta: Cyclic steps from river-derived underflows?: Journal of Sedimentary Research, v. 86, p. 113–123, https://doi.org/10.2110/jsr.2016.4.

Gani, M.R., 2017, Mismatch between time surface and stratal surface in stratigraphy: Journal of Sedimentary Research, v. 87, p. 1226–1234, https://doi.org/10.2110/jsr.2017.67.

Griesmeier, G.E.U., Reitner, J.M., and Le Heron, D.P., 2021, The Gröbminger Mitterberg (Austria): A time machine to the pre-LGM?: European Geosciences Union General Assembly conference abstract 7104, https://doi.org/10.5194/egusphere-egu21-7104.

Ivy-Ochs, S., Kerschner, H., Reuther, A., Preusser, F., Heine, K., Maisch, M., Kubik, P.W., and Schlüchter, C., 2008, Chronology of the last glacial cycle in the European Alps: Journal of Quaternary Science, v. 23, p. 559–573, https://doi.org/10.1002/jqs.1202.

Ivy-Ochs, S., Monegato, G., and Reitner, J.M., 2023, The Alps: Glacial landforms during the deglaciation (18.9–14.6 ka), *in* Palacios, D., et al., eds., European Glacial Landscapes—The Last Deglaciation: Amsterdam, Netherlands, Elsevier, p. 175–183, https://doi.org/10.1016/B978-0-323-91899-2.00005-X.

Kellerer-Pirklbauer, A., Proske, H., and Untersweg, T., 2004, Darstellung der Talbodenbereiche des steirischen Ennstales, Bericht: Graz, Austria, Joanneum Research, 50 p.

Kreuss, O., 2020, Geofast 1:50.000–Zusammenstellung ausgewählter Archivunterlagen der Geologischen Bundesanstalt—128 Gröbming: Vienna, Austria, Geologische Bundesanstalt, scale 1:50,000.

Lang, J., Sievers, J., Loewer, M., Igel, J., and Winsemann, J., 2017, 3D architecture of cyclic-step and antidune deposits in glacigenic subaqueous fan and delta settings: Integrating outcrop and ground-penetrating radar data: Sedimentary Geology, v. 362, p. 83–100, https://doi.org/10.1016/j.sedgeo.2017.10.011.

Mandl, G.W., Hejl, E., and van Husen, D., 2014, Geologische Karte der Republik Österreich 1:50.000: Erläuterung zu Blatt 17 Schladming: Vienna, Austria, Geologische Bundesanstalt, 191 p.

Martini, I.P., and Brookfield, M.E., 2005, Sequence analysis of Upper Pleistocene (Wisconsian) glaciolacustrine deposits of the North-Shore Bluffs of Lake Ontario, Canada: Journal of Sedimentary Research, v. 65, p. 388–400, https://doi.org/10.1306/D426825C-2B26-11D7-8648000102C1865D.

Menzies, J., and Reitner, J.M., 2016, Microsedimentology of ice stream tills from the Eastern Alps, Austria—A new perspective on till microstructures: Boreas, v. 45, p. 804–827, https://doi.org/10.1111/bor.12189.

Powell, R.D., and Cooper, J.M., 2002, A glacial sequence stratigraphic model for temperate, glaciated continental shelves, *in* Dowdeswell, J.A., and O'Cofaigh, C., eds., Glacier-Influenced Sedimentation on High-Latitude Continental Margins: Geological Society, London, Special Publication 203, p. 215–244, https://doi.org/10.1144/GSL.SP.2002.203.01.12.

Qayyum, F., Betzler, C., and Catuneanu, O., 2017, The Wheeler diagram, flattening theory, and time: Marine and Petroleum Geology, v. 86, p. 1417–1430, https://doi.org/10.1016/j.marpetgeo.2017.07.034.

Ravier, E., Buoncristiani, J.-F., Menzies, J., Guiraud, M., and Portier, E., 2015, Clastic injection dynamics during ice front oscillations: A case example from Sólheimajökull (Iceland): Sedimentary Geology, v. 323, p. 92–109, https://doi.org/10.1016/j.sedgeo.2015.04.013.

Reitner, J.M., 2007, Glacial dynamics at the beginning of Termination I in the Eastern Alps and their stratigraphic implications: Quaternary International, v. 164–165, p. 64–84, https://doi.org/10.1016/j.quaint.2006.12.016.

Reitner, J.M., 2022, The imprint of Quaternary processes on the Austrian landscape, *in* Embleton-Hamann, C., ed., Landscapes and Landforms of Austria: Cham, Switzerland, Springer, World Geomorphological Landscapes, https://doi.org/10.1007/978-3-030-92815-5_3.

Sanders, D., Wischounig, L., Gruber, A., and Ostermann, M., 2014, Inner gorge–slot canyon system produced by repeated stream incision (Eastern Alps): Significance for development of bedrock canyons: Geomorphology, v. 214, p. 465–484, https://doi.org/10.1016/j.geomorph.2014.03.007.

van Husen, D., 1968, Ein Beitrag zur Talgeschichte des Ennstales im Quartär: Mitteilungen der Gesellschaft der Geologie- und Bergbaustudenten in Österreich, v. 18, p. 249–286.

van Husen, D., 1983, A model of valley bottom sedimentation during climatic changes in a humid alpine environment, *in* Evenson, E., et al., eds., Tills and Related Deposits: Rotterdam, Netherlands, Balkema, p. 345–349.

van Husen, D., 1987, Zur Entwicklung des Oberen Ennstales im Pleistozän: Tagungsband der Arbeitstagung der Geologischen Bundesanstalt 1987 Blatt 127 Schladming, p. 86–93.

van Husen, D., 1997, LGM and Late-Glacial fluctuations in the Eastern Alps: Quaternary International, v. 38–39, p. 109–118, https://doi.org/10.1016/S1040-6182(96)00017-1.

van Husen, D., 2000, Geological processes during the Quaternary: Mitteilungen der Österreichischen Geologischen Gesellschaft, v. 92, p. 135–156.

van Husen, D., and Reitner, J.M., 2022, Quaternary System, *in* Piller, W.E., ed., The Lithostratigraphic Units of Austria: Cenozoic Era(them): Abhandlungen der Geologische Bundesanstalt 76, p. 240–267.

Wheeler, H.E., 1958, Time-stratigraphy: American Association of Petroleum Geologists Bulletin, v. 42, p. 1047–1063.

Wheeler, H.E., 1964, Baselevel, lithosphere surface, and time-stratigraphy: Geological Society of America Bulletin, v. 75, p. 599–610, https://doi.org/10.1130/0016-7606(1964)75[599:BLSAT]2.0.CO;2.

Winsemann, J., Lang, J., Polom, U., Loewer, M., Igel, J., Pollok, L., and Brandes, C., 2018, Ice-marginal forced regressive deltas in glacial lake basins: Geomorphology, facies variability and large-scale depositional architecture: Boreas, v. 47, p. 973–1002, https://doi.org/10.1111/bor.12317.

Winsemann, J., Hartmann, T., Lang, J., Fälber, R., and Lauer, T., 2022, Depositional architecture and aggradation rates of sand-rich, supercritical alluvial fans: Control by autogenic processes or high-frequency climatic oscillations?: Sedimentary Geology, v. 440, https://doi.org/10.1016/j.sedgeo.2022.106238.

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