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Depositional setting of the sedimentary rocks containing the "warm-interglacial" fossil flora of the Höttinger Brekzie (Pleistocene, Northern Calcareous Alps, Austria): a reconstruction

Diethard Sanders & Marc Ostermann

Ablagerungsraum der Sedimentgesteine mit der „warm-interglazialen" Flora der Höttinger Brekzie (Pleistozän, Nördliche Kalkalpen, Österreich): eine Rekonstruktion

Abstract

Most of the plants fossils of a reputed, "warm-interglacial" flora of the Höttinger Brekzie near Innsbruck (Pleistocene, Northern Calcareous Alps) were deposited in a shallow pond, or ephemeral ponds, that were affected by episodic debris flows and mudflows.

The fossiliferous section at about 1110–1130 m a.s.l. at "Rossfall-Lahner" is traditionally assigned to the Höttinger Brekzie, a lithified succession deposited mainly from stream-dominated alluvial fans and from talus slopes. The Höttinger Brekzie accumulated after the Riss Glacial and lithified well-before the Last Glacial Maximum. At Rossfall-Lahner, the rock substrate is represented by Triassic red beds and carbonates. At present, the fossiliferous interval is largely covered by vegetation, hence its depositional setting was reconstructed from fossil collections, field mapping, and from a tailing. The fossiliferous succession is reconstructed as (1) a basal interval with fluvial breccias and conglomerates, (2) the main plant-fossiliferous interval mainly of calcisiltites, calcilutites and calcilithic arenites, and (3) an upper interval with fluvial conglomerates. Up-section, above a gap in outcrop, the reconstructed succession is overlain by a well-exposed package of breccias (Höttinger Brekzie) deposited mainly from rockfall, talus fans and talus slopes.

The intervals containing most of the plant fossils include (a) parallel-laminated calcilutites (lime mudstones), (b) graded laminae to very thin beds of lithic calcisiltite (more rarely calcarenite) to calcilutite, (c) a bed or beds of lithic calciwacke, (d) breccias with clasts supported by a matrix of calcilutite to lithic calcisiltite, and (e) parallel-laminated or ripple drift cross-laminated, lithic calcisiltite or calcarenite. Within stacked, graded laminae of calcarenite to calcilutite, softground burrow mottles are present. Whereas the calcilutites are interpreted as a lacustrine background sediment, at least most of the graded beds probably originated by suspension fallout from waning density flows. The parallel- or ripple drift cross-laminated beds of calcarenite accumulated under episodic fluid flows and/or density flows. The bed(s) of calciwacke are rich in plant leaves (*Rhododendron*), and accumulated from mud flows. Similarly, the matrix-supported breccias may contain twisted leaves and larger phytoclasts such as branch fragments that are embedded randomly relative to bedding; these breccias accumulated from muddy, cohesive debris flows. The facies and their association indicate deposition in a shallow pond, or in ephemeral ponds, under influence of episodic mud flows and debris flows. The mappable intersection of the basal unconformity of the Höttinger Brekzie with the present topography underscores that a pond may have existed at the location.

The accumulation of the main fossiliferous package proceeded during a climatic phase wherein the adjacent mountain slopes were covered by a diversified vegetation of shrubs (Pteridophyta, Gramineae), ever-green bushes (*Rhododendron*), deciduous trees and conifers. Leaves of *Rhododendron ponticum* var. *sebinense* (formerly designated as *R. "sordellii"*) and *Vitis vinifera* subsp. *sylvestris* suggest but not strictly indicate an overall warmer climate than today at site, and their former presence may equally well result from more humid and/or more equable conditions. The environmental characteristics indicated by the flora seem incompatible with the thick lithified talus slopes above, which most probably were nourished from periglacial environments higher up (rock cliffs in higher altitude), or that accumulated under periglacial conditions. The fossiliferous interval of Rossfall-Lahner may in fact represent the only vestige of a warmer phase of the Riss-Würm Interglacial.

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Zusammenfassung

Die meisten der fossilen Pflanzen der altbekannten „warm-interglazialen" Flora der Höttinger Brekzie bei Innsbruck (Pleistozän, Nördliche Kalkalpen) gelangten in einem flachen See oder ephemeralen Seen bis Teichen zum Absatz, die unter gelegentlichen Einbrüchen von kiesführenden Muren und Schlammströmen standen.

Das fossilführende Profil auf etwa 1110–1130 m ü.d.M. im „Rossfall-Lahner" wird traditionsgemäss der Höttinger Brekzie zugeordnet, einer lithifizierten Abfolge die vorwiegend von bach-dominierten Schuttfächern und, höher hangaufwärts, von Talus-Hängen abgelagert wurde. Die Höttinger Brekzie lagerte sich nach der Riss-Vereisung ab und lithifizierte deutlich vor dem Letzten Glazialen Maximum. Am Rossfall-Lahner wird der ältere Gesteinsuntergrund von Alpinem Buntsandstein und unter- bis mitteltriassischen Karbonatgesteinen (Reichenhaller Formation, Alpine Muschelkalk Gruppe) gebildet. Da derzeit das fossilienführende Intervall völlig von Vegetation bedeckt ist, wurde sein Ablagerungsraum aufgrund von Fossiliensammlungen, einer Kartierung, und Aufsammlungen einer Abraumhalde im Feld rekonstruiert. Die fossilienführende Folge wurde wie folgt rekonstruiert, (1) ein basales Intervall mit fluviatilen Brekzien, Konglomeraten, lithischen Kalzisiltiten und Kalklutiten, (2) der Abschnitt, dem die meisten Pflanzenfossilien entstammen, vorwiegend aus lithischen Kalksiltiten, Kalklutiten und lithischen Kalkareniten, und (3) ein oberes Intervall mit fluviatilen Konglomeraten. Höher aufwärts wird die Abfolge über einer Aufschlusslück von einer dicken, gut aufgeschlossenen Folge von Brekzien (Höttinger Brekzie) überlagert, die hauptsächlich von Felsstürzen, auf alluvialen Schuttfächern, und auf Talus-Hängen abgelagert wurde.

Die wichtigsten fossilführenden Intervalle bestehen aus (a) parallel-laminierten Kalklutiten, (b) gradierten Laminae bis sehr dünnen Bänken von lithischem Kalksiltit (seltener lithischer Kalkarenit) bis Kalklutit, (c) eine Bank oder Bänke von lithischer Kalziwacke, (d) Brekzien, deren Klasten von einer Matrix von Kalklutit bis Kalksiltit gestützt werden, und (e) parallel-laminierte oder rippel-kreuzlaminierte Kalksiltite bis Kalkarenite. In Stössen von gradierten Laminae bis dünnen Bänken von Kalkarenit bis Kalklutit finden sich Spuren von Weichgrund-Bioturbation. Während die Kalklutite als Hintergrund-Sediment des Teiches (oder der Teiche) gedeutet werden, bildeten sich zumindest die meisten der gradierten Bänke durch Aussaigern aus Suspension von Dichteströmen. Die parallel- oder rippel-kreuzlaminierten Bänke von Kalkarenit bildeten sich unter gelegentlichen Flüssigkeitströmen und/oder von Dichteströmen. Die Bank (Bänke) von Kalziwacke ist reich an Blättern (*Rhododendron*), und wurde von einem Schlammstrom abgelagert. Die matrix-gestützten Brekzien enthalten verbogene Blätter und grössere Phytoklasten, die in unterschiedlichen Orientierungen relativ zur Bankung eingebettet wurden; diese Brekzien wurden ebenfalls von schlammigen, kohäsiven Trümmerströmen abgelagert. Insgesamt zeigen die Fazies und ihre Vergesellschaftung Ablagerung in einem Teich oder in ephemeralen Teichen an, die unter dem Einfluss gelegentlicher Schlammströme und Trümmerströme standen. Die kartierbare Verschneidung der Diskordanz am Fuss der Höttinger Brekzie mit der Topographie legt ebenfalls nahe, dass sich ein Teich im genannten Bereich durchaus hätte bilden können.

Die Bildung des hauptsächlich fossilführenden Intervalles erfolgte in einem klimatischen Zeitabschnitt, während dessen auf den umliegenden Berghängen eine diversifizierte Flora aus krautigen Pflanzen (Pteridophyta, Gramineae), immergrünen Büschen (*Rhododendron*), Laubbäumen und Nadelbäumen stockte. Blätter von *Rhododendron ponticum* var. *sebinense* (früher als *R. „sordellii"* bezeichnet) und *Vitis vinifera* subsp. *sylvestris* legen ein wärmeres Klima als heute an dieser Stelle nahe, doch könnte deren frühere Gegenwart ebensogut auf ein feuchteres und/oder gleichmässigeres Klima zurückzuführen sein. Die Milieu-Charakteristik der fossilen Flora scheint in jedem Fall im Widerspruch zu den darüberliegenden dicken, lithifizierten Talus-Abfolgen zu stehen, deren Versorgung mit klastischem Material und vielleicht auch Bildung wahrscheinlich in einem periglazialen Klima erfolgte. Das fossilhältige Profil am Rossfall-Lahner könnte möglicherweise der einzige Rest eines wärmeren Abschnitts des Riss-Würm Interglaziales sein.

Key words: Quaternary, Alps, Hötting, Höttinger Brekzie, sedimentology, Riss-Würm Interglacial, flora, *Rhododendron*

Introduction

The Höttinger Brekzie, a lithified Pleistocene alluvial fan to talus succession near Innsbruck (Fig. 1) (PASCHINGER 1950; SANDERS et al. 2001), since long is reputed for its plant fossils. Today, the Höttinger

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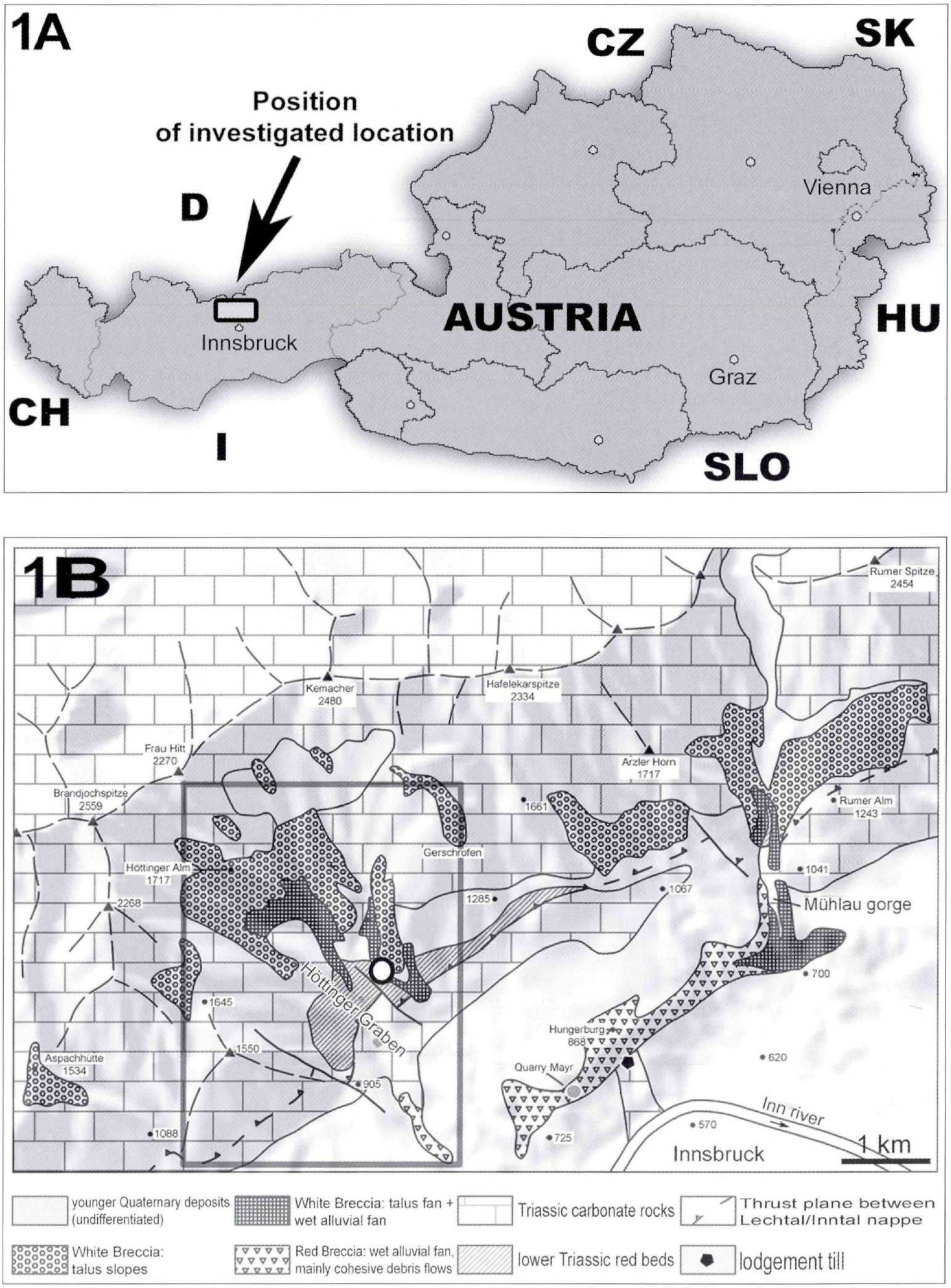

Fig. 1A: Geographic position of the Höttinger Brekzie in Austria. 1B: Simplified map of Höttinger Brekzie, with Red Breccia and White Breccia distinguished (see text). The White Breccia comprises deposits of a stream-dominated alluvial fan to proximal fluvial system (Mühlau gorge) and of talus slopes. Black-lined dot marks the location of the plant-fossiliferous succession at Rossfall-Lahner. Outlined rectangle shows area shown in figure 3.

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Brekzie is preserved along the southern slopes of Nordkette, a mountain chain built mainly by Triassic carbonate rocks (Fig. 1). The plant fossils first were mentioned by Arnold Escher (ESCHER 1845), and then subject to a series of taxonomic investigations, re-investigations, and partial revisions (UNGER 1852; UNGER IN: PICHLER 1859; ETTINGSHAUSEN 1885; STUR 1886; WETTSTEIN 1892; MURR 1926; GAMS 1936, 1954; HANTKE 1983). The fossil flora, originally considered as late Tertiary in age (UNGER 1852; STUR 1886), excavated at Rossfall-Lahner became reputed both for its high total diversity and because it contains species that might indicate a warmer climate than today (WETTSTEIN 1892; MURR 1926; GAMS 1936). Because the Höttinger Brekzie locally overlies a lodgement till and, in turn, is overlain by the basal till of the Last Glacial Maximum, the fossil flora of Rossfall-Lahner became a key argument for a warmer climate, presumably during the Riss-Würm Interglacial. With respect to taxonomic composition, much has been perseverated over more than 100 years, yet the sedimentology of the fossiliferous rocks was never described and interpreted with due care, although outcrop conditions were much better in the past (see photos in WETTSTEIN 1892, and in PENCK 1921). The location had been exposed by blasting since at least the 1880s for fossil collecting, and plant fossils had been traded to private collectors and museums (cf. WETTSTEIN 1892). Except highly vague and in part contradictious descriptions of the succession (WETTSTEIN 1892; GAMS 1936), however, no care was given to the rocks. The last sampling campaign by blasting, conducted by military regulars, was done in 1930 (GAMS 1936). Since then, the location became covered by dense forest with very scattered, limited outcrops, and this is the unfortunate state of exposure the site is in nowadays.

The fossiliferous succession at Rossfall-Lahner consists of a facies association unique within the Höttinger Brekzie. This calls for closer investigation, since it is not granted that this succession formed during the same depositional episode than the rest of the Höttinger Brekzie. Moreover, better understanding of the sedimentology of the fossiliferous rocks also bears on the palaeoclimatic interpretation of the flora. Today, because of progressive forestation, except a few small outcrops the location is covered nearly completely. Fortunately, fossiliferous rock samples stored in museums and institutes, and short descriptions in WETTSTEIN (1892) and GAMS (1936), our own field mapping on a scale of 1/10.000, and sampling of the still-preserved tailing of the 1930 campaign provided data to allow for a general reconstruction of the succession and to deduce the depositional setting of the fossiliferous rocks. The following descriptions are based on samples stored at the Institute of Geology and Palaeontology (University of Innsbruck), the Institute of Botany (University of Innsbruck), and the collection of the Tiroler Landesmuseum Ferdinandeum, Innsbruck. In total, about 600 fossiliferous rock samples were inspected. In addition, polished slabs and thin sections of rock samples from fossil collections and from the field provided documentation of lithologies. The results indicate that the succession with plant fossils accumulated from proximal-fluvial and shallow lacustrine (pond or ephemeral pond) environments, under influence of debris flows and mud flows. During deposition of the fossiliferous succession, a similar or slightly warmer/more humid climate than today prevailed that appears inconsistent with an overlying, thick succession of fossil talus that comprises the upper part of the Höttinger Brekzie. The fossiliferous succession most probably accumulated during a distinct depositional episode unrelated to the overlying Höttinger Brekzie, but perhaps represents a last vestige of the Riss-Würm Interglacial preceeding the accumulation of thick talus slopes above.

Geological Setting

The Höttinger Brekzie is preserved near the southern limit of the Northern Calcareous Alps (NCA), along the southern slope of the Nordkette mountain chain. The Nordkette consists of Lower Triassic red beds and, mainly, of Middle to Upper Triassic shallow-water carbonates (Fig. 1). The Nordkette consists of two superposed cover thrust nappes that, internally, are more-or-less intensely folded and faulted. In its topmost portion, the structurally subjacent thrust nappe (Lechtal nappe) consists of shear slices including the Reichenhaller Formation up to the Hauptdolomit Formation (see Tab. 1). In the overlying Inntal nappe, the succession ranges from the Alpiner Buntsandstein Formation (Lower Triassic *pro par-*

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Formation local original thickness	Range	Characteristic lithologies	Interpretation
Alpiner Buntsandstein (lower Triassic red beds in Fig. 1)	?lower Scythian to ?uppermost Scythian	dark red clayst, quartz siltst, fine- to medium-grained quartzites with diagenetic haematite	deposits of distal alluvial plain to marginal-marine settings within semi-arid climate (STINGL 1989)
Reichenhall Fm	?uppermost Scythian to lower Anisian p.p.	cellular dolost, organic-rich dolost/limest, marly limest/dolost, marls	marine, restricted shallow subtidal to supratidal deposition in arid to semi-arid climate.
Virgloria Fm	lower Anisian p.p. to upper Anisian	stylo-nodular, burrow-mottled lime mudst to wkst, bioclastic wkst to pkst	subtidal deposition on the inner to middle part of a wide carbonate shelf
Steinalm Fm	upper Anisian p.p.	floatst-rudst (locally dolomitized) of bioclasts of dasycladaleans and crinoids	bioclastic sand bodies colonized by and built mainly of fragments of dasycladalean algae and crinoids
Reifling Fm	base Ladinian to upper Ladinian p.p.	nodular to evenly-bedded, locally cherty lime mudsts to bioclastic pksts	neritic deposition on a carbonate shelf undergoing differentiation into platforms and basins
Partnach Schichten	lower Ladinian p.p. to lower Carnian p.p.	shales with intercalated beds and bedsets of marly to pure lime mudsts to bioclastic pksts	terrigenous basinal clastics and limestones Partnach Schichten are basinal equivalent to Reifling Fm and to Wettersteinkalk
Wettersteinkalk	lower Ladinian to top lower Carnian	(1) shallow-water bioclastic limest, litho-bioclastic rudst, microbialite-cement boundst (2) lime mudsts, fenestral lst, dolost, tepee structures	(1) deposition from fore-reef via reef to back-reef (2) deposition in lagoonal to arid tidal flat environments
Nordalpine Raibler Schichten	base middle Carnian to top Carnian	mixed siliciclastic-carbonate succession of shales, bioclastic and fenestral limest and dolost	mixed siliciclastic-carbonate deposition in neritic to peritidal environments
Hauptdolomit	Norian	coarsely crystalline, thick-bedded, brown-weathering dolost and fenestral dolost	deposition in lagoonal to peritidal sector of a huge carbonate platform

Table 1: Lithostratigraphic units of the Triassic rock substrate of the Höttinger Brekzie. Abbreviations: Fm = formation; st = stone, stones (ending of names of lithologies); wkst = wackestone; pkst = packstone; grst = grainstone. Formal status of stratigraphic units according to Stratigraphische Tabelle von Österreich 2004.

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Unit	Age	Characteristic lithologies	Interpretation, reference, remarks
Till 1 („Liegendmoräne“)	Riss Glacial (?)	Diamicton of calcisiltite to calcilutite with floating, faceted/polished/striated clasts from NCA and of metamorphic rocks	Lodgement till (AMPFERER 1914; PENCK 1921)
Höttinger Brekzie	Terminal Riss-Würmian interglacial to early Würmian (supported by Th-U ages)	Mainly clast-supported breccias and conglomerates	Deposits of alluvial fans and talus slopes (PASCHINGER 1950; SANDERS ET AL. 2001)
Till 2 („Sockelmoräne“)	Würmian (?early Würmian)	Gravelly to bouldery diamicton, locally rich in lithoclasts of Höttinger Brekzie; diamicton locally associated with glacio-fluviatile and glacio-lacustrine deposits	Glacial till of uncertain position relative to LGM (PENCK 1921; KATSCHTHALER 1930)
Fluvial deposits („Terrassenschotter“, „Vorstoss-Schotter“)	Würmian	Cross-laminated sands, stratified sandy gravels and gravels composed of clasts of crystalline rocks (including garnet amphibolite, „Julier“ granite) and clasts derived from the local NCA Triassic and from the Höttinger Brekzie (Red breccia, White br.). Locally associated with intervals of laminated fine-grained lacustrine deposits and/or with clinostratified delta front gravel beds dipping with 25–30°	Deposits of braided rivers ahead of advancing Inn glacier (cf. KATSCHTHALER 1930), derivation of clasts from local sources (Triassic, Hötting Breccia) and from distant sources (metamorphic rocks)
Till 3 („Hangendmoräne“), tills of local glaciers	till 3: late Würmian local till: Late-Glacial	till 3: Diamicton of clayey calcisiltite to calcilutite rich in clasts of metamorphic rocks (index clast: garnet amphibolite)	till 3: Lodgement till of Inn valley glacier (AMPFERER 1914; PENCK 1921)
Topmost deposits (typically unlithified)	Late-Glacial to Holocene	fluvial sands and gravels, gravelly hillslope colluvium, soil and soil colluvium, talus slopes, spring tufas	obvious from depositional system

Table 2: Major Quaternary depositional units north of Innsbruck, arranged according to relative age. Abbreviations: NCA = Northern Calcareous Alps.

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te) up to the Middle Triassic Wettersteinkalk (Tab. 1). In the area considered herein, the Alpiner Buntsandstein is well-exposed in a belt between about 1040–1120 m altitude (Fig. 1). In a few outcrops at 660–740 m altitude, the Höttinger Brekzie overlies a glacial lodgement till (Fig. 1, Tab. 2). In a key exposure near Weiherburg, a mould of an upright tree trunk embedded by the basal portion of the Höttinger Brekzie indicates that the area was forested, or at least partly so, during deposition of the oldest preserved portions of the Höttinger Brekzie (AMPFERER 1914). The Höttinger Brekzie, in turn, is overlain by a glacial and glacio-fluvial succession of Würmian age (Fig. 1, Tab. 2) (AMPFERER 1914; KATSCHTHALER 1930). Because the underlying till was assigned to the Riss Glacial, the Höttinger Brekzie had been bracket-dated into the Riss-Würm Interglacial (AMPFERER 1914). Lithification of the Höttinger Brekzie well-before the Last Glacial Maximum is recorded by an unconformity between the breccia and the overlying till interval 2 ("Sockelmoräne") (Tab. 2). Both till 2 and its associated glacio-fluvial deposits contain clasts of Höttinger Brekzie (KATSCHTHALER 1930).

The Höttinger Brekzie is traditionally subdivided into two main lithotypes (PENCK 1921; PASCHINGER 1950). The *"Red Breccia"* is rich in dark red to pink-coloured clasts (arenites, siltstones, claystones) of the Alpiner Buntsandstein, and contains a primary matrix of pink to red, argillaceous calcilutite to carbonate-lithic siltite. The red colour results from diagenetic haematite from the Alpiner Buntsandstein in the source area (cf. STINGL 1989). The Red Breccia accumulated mainly from stream-dominated alluvial fans nourished by erosion of the rocky slopes of Nordkette. The fans were characterized by deposition of breccias from cohesive debris flows, and by conglomerates to breccias from ephemeral stream floods. The Red Breccia comprises the major portion of the western, lower part of the Höttinger Brekzie and, towards the east, interfingers with White Breccia (Fig. 1, Fig. 2) (SANDERS & SPÖTL 2001). In its lower part, the Red Breccia contains a few intercalated layers up to a few decimeters thick of yellow silt composed of quartz, feldspar, micas and carbonate-lithic grains. These layers were interpreted as loess-like deposits (LADURNER 1956; OBOJES 2003). The other variety of Höttinger Brekzie, the *"White Breccia"*, in turn, consists of prevalently grey-coloured clasts of Triassic carbonates of Nordkette and, in some facies, of a matrix of white to light-grey calcilutite to carbonate-lithic siltite. In its lower part, the White Breccia accumulated from stream-dominated alluvial fans to proximal fluvial systems (Fig. 1); the upper part of the White Breccia accumulated from talus slopes (Fig. 1, Fig. 2). In the western sector of outcrops, the distinction Red Breccia/White Breccia largely corresponds to a physical stratigraphic division, with the Red Breccia present in the topographically lower belt (Fig. 2). In addition to the described lithologic varieties, at Rossfall-Lahner in about 1100–1120 m altitude, an interval is present that stands unique within the succession of Höttinger Brekzie. This interval delivered the famed fossil flora with *Rhododendron ponticum* var. *sebinense* (formerly designated as *R. sordellii*; see article of Thomas Denk, this volume) and *Vitis vinifera* subsp. *sylvestris* (Fig. 1, Fig. 2, Fig. 3). The Rossfall-Lahner interval consists mainly of conglomerates, breccias, lithic arenites, and lithic siltites to calcilutites that contain plant fossils in highly different abundance and states of preservation (see below for further descriptions).

Plant fossil locations of the Höttinger Brekzie

In the Höttinger Brekzie, three main locations with plant fossils may be distinguished (MURR 1926), (1) location 1, in the Red Breccia, represented by quarry "Mayr" covering the interval from 740 m to 780 m altitude, (2) location 2, in the Red Breccia, including three small abandoned quarries between 840 to 890 m altitude, and stratigraphically above location 1, and (3) location 3 situated in Rossfall-Lahner at about 1100–1110 m altitude (Fig. 1). The plant fossils of locations 1 and 2 record a climate that was of similar character or more cooler that presently at site (MURR 1926). At both locations, the plant fossil assemblages are characterized by *Pinus* and *Salix* (MURR 1926; GAMS 1936). The plant remains typically are preserved as imprints or as moulds within fine-grained deposits. Such fine-grained deposits include laterally limited laminae and very thin lenses of calcisiltite to calcilutite that accumulated upon episodic surface runoff within puddles (Fig. 4), and the mentioned loess-like layers with micas. In debris

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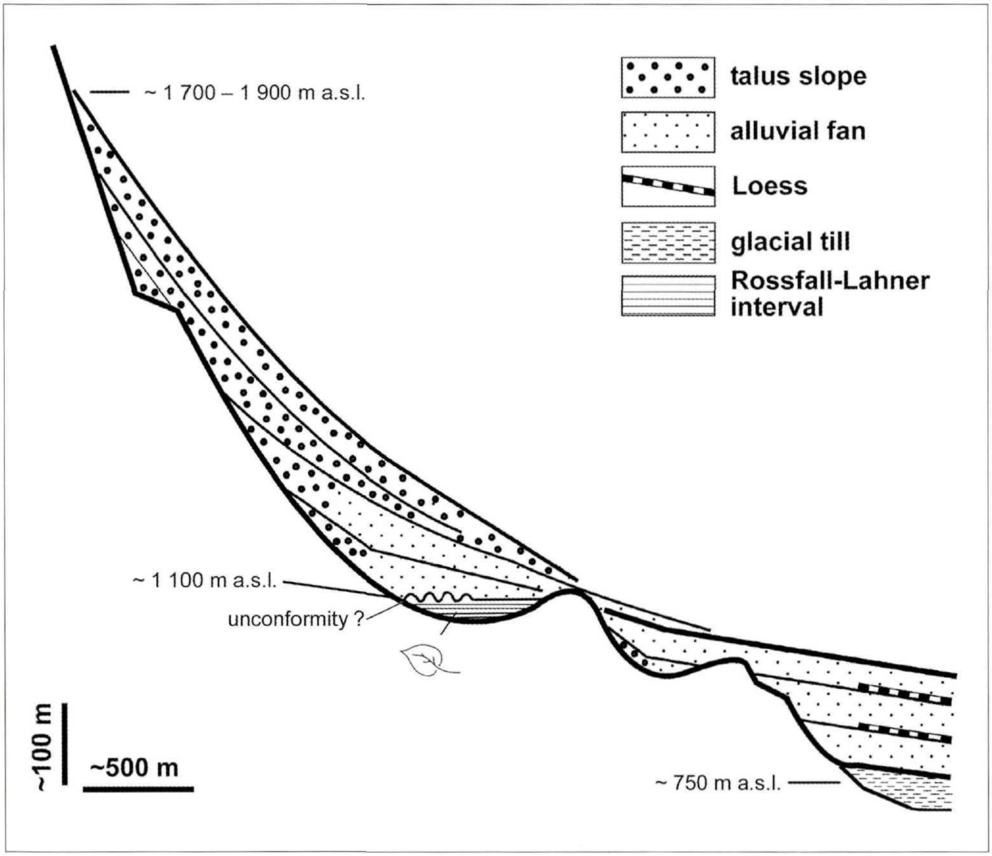

Fig. 2: Depositional scheme of Höttinger Brekzie, roughly to scale (modified from SANDERS et al. 2001). The Höttinger Brekzie overlies Triassic rocks or, in the lower part of the succession, a lodgement till. With respect to both depositional geometries and facies associations, the Höttinger Brekzie can be subdivided into two major stratal packages. The topographically lower package is dominated by breccias to conglomerates deposited from alluvial fans, and contains intercalated layers of loess-like material. The topographically upper part consists mainly of breccias deposited from talus fans and talus slopes. The fossiliferous Rossfall-Lahner interval is sandwiched, at about 1100-1130 m altitude, between the Triassic rock substrate below and the overlying alluvial fan-to-talus slope package of Höttinger Brekzie. The boundary between the Rossfall-Lahner interval and the overlying deposits may be an unconformity. The lithified talus slopes that comprise the upper part of the Höttinger Brekzie pinch out between 1700 – 1900 m altitude.

Fig. 3: Map of western outcrop sector of Höttinger Brekzie (white areas = no outcrop). In the topographically lower part, Red Breccia overlies a substrate of Triassic carbonate rocks. Higher up, within a belt along 1000-1100 m altitude, along the base of the Inntal thrust nappe, a package of Lower Triassic red beds is present. The red beds are overlain by the fossiliferous Rossfall-Lahner interval. The red beds or, locally, the Rossfall-Lahner interval are overlain by the succession of the White Breccia that here comprises talus fans, rockfall deposits and talus slopes. In the area of Höttinger Graben, between about 1150-1400 m altitude, the succession of White Breccia is up to about 150–200 m in preserved thickness, and fills a subcircular depression in the older rock substrate.

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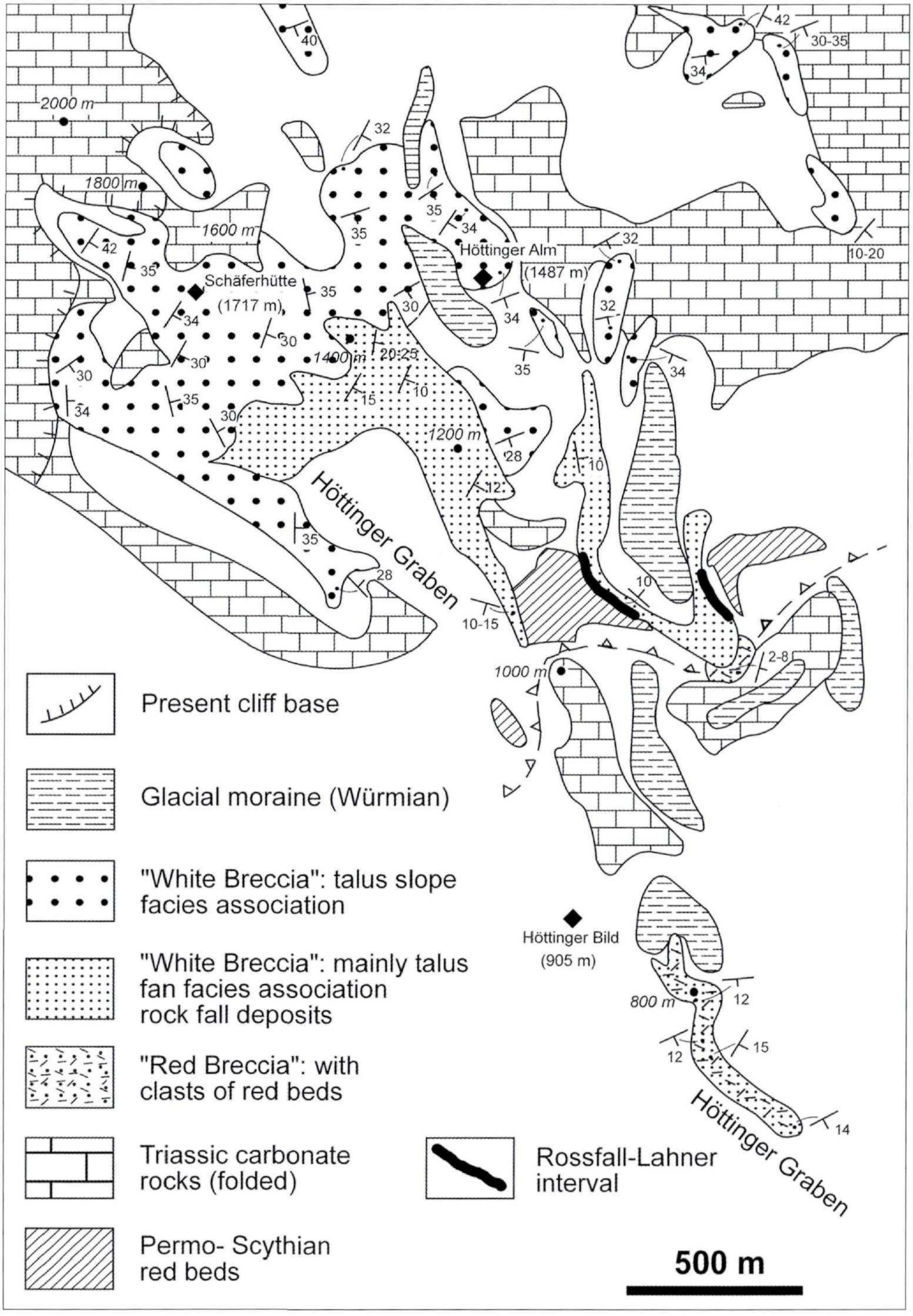

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flow breccias with a calcilutitic matrix, twisted leaves (e. g. of *Acer*) were rarely found. For location 1 and 2, however, needles of *Pinus* are the most common plant remains (MURR 1926), and are particularly common at the boundary from fine-grained deposits below to debris flow deposits above. By contrast, a part of the fossil assemblages at Rossfall-Lahner (location 3) is suggestive of a slightly warmer and/or more humid/more equable climate than today (MURR 1926). The deposits and some elements of the flora of Rossfall-Lahner are described and discussed in more detail below.

Radiometric age data

In the White Breccia near Höttinger Alm, at 1490 m altitude, in grain flow breccias deposited from a fossil talus slope, isopachous fringes of skalenohaidral calcite cement are present. These cements indicate a Th-U isochron minimum cementation age of 109 ± 6.6 ka (marine isotope stage 5d), i. e. an early Würmian age (OSTERMANN 2006). The Th-U age data reported herein will be described and discussed in more detail in a separate publication. In quarry Mayr (740–780 m altitude) in the Red Breccia, SPÖTL & MANGINI (2005) age-dated with the Th-U single age method a flowstone crust along a subvertical joint to a maximum of 101 ka (marine isotope stage 5c). These ages are consistent with the geological evidence for lithification of the Höttinger Brekzie before it became covered by Würmian ice streams. Preliminary luminescence ages of the loess-like layers within the Red Breccia indicate that the major portion of the Red Breccia accumulated during the latest Eemian or early Würmian, preferrably upon the climatic deterioration at the onset of marine isotope stage 5d (SPÖTL & GEMMELL 2005). This might suggest that the White Breccia higher up-slope is older than the Red Breccia farther down. As shown in the eastern part of outcrop, however, such a chronostratigraphic relation is precluded by an interfingering of White and Red breccia, and by downlap of White Breccia (Fig. 1B, Fig. 2) (SANDERS et al. 2001). As discussed below, however, the fossiliferous succession at Rossfall-Lahner, containing the "warm-interglacial" flora, may represent a vestige of an older generation of Pleistocene deposits. In the following, the succession, sedimentary facies and facies association of the interval at Rossfall-Lahner are described and interpreted.

Succession

<u>WETTSTEIN (1892) versus GAMS (1936)</u>:
In literature, despite the very good former outcrop conditions, partly contradictious statements on the succession and the vertical distribution of plant assemblages were made (Fig. 5). According to WETTSTEIN (1892, p. 7), the succession is underlain by a "Rother Sandstein in bedeutender Mächtigkeit" (red sandstone of significant thickness) that was stated to be completely devoid of plant fossils. Nowhere in the rest of that work, this sandstone is characterized in more detail. In view of the relative care exerted by WETTSTEIN (1892) to characterize the fossiliferous succession, to us, this indicates that this sandstone represents the Alpiner Buntsandstein. In figure 5A, we thus indicate this sandstone as the Alpiner Buntsandstein. WETTSTEIN (1892, p. 7) points out that the best-preserved plant fossils are present in fine-grained beds in the basal part of his investigated succession (see Fig. 5A) where, among other forms, *Potentilla micrantha* and *Prunella grandiflora* are present. Today, *P. micrantha* is present in the same area, up to about 1960 m altitude (WETTSTEIN 1892, p. 34). *Prunella grandiflora* is indicated to be present, today, all over Middle Europe and in the Caucasus up to more than 1200 m in altitude (WETTSTEIN 1892, p. 35). Above the basal interval, plant fossils were found both in breccia layers and in thin, fine-grained intercalations; the latter were not separately sorted out but only mentioned by WETTSTEIN (1892). According to GAMS (1936), the lower 13 m of the succession at Rossfall-Lahner are characterized by a "cool-loving" flora with conifers and *Salix*, an assemblage that was compared by that author to the "cool-loving" flora of the Red Breccia (Fig. 5B). Above, the "warm-loving" fossil flora with *Rhododendron* and *Vitis* is present, but only up to 20 m above the top of the Alpiner Buntsandstein (GAMS 1936); this would confine the presence of the warm-loving flora to an interval 7 m in thickness. In the tailing of the

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Fig. 4: View onto bedding surface of Red Breccia (Höttinger Brekzie) used as building stone for masonry (Waltherpark, Innsbruck). Two terminal parts of branches of *Pinus*, embedded within a lamina of pink lime mudstone. Coin is 25 mm in diameter.

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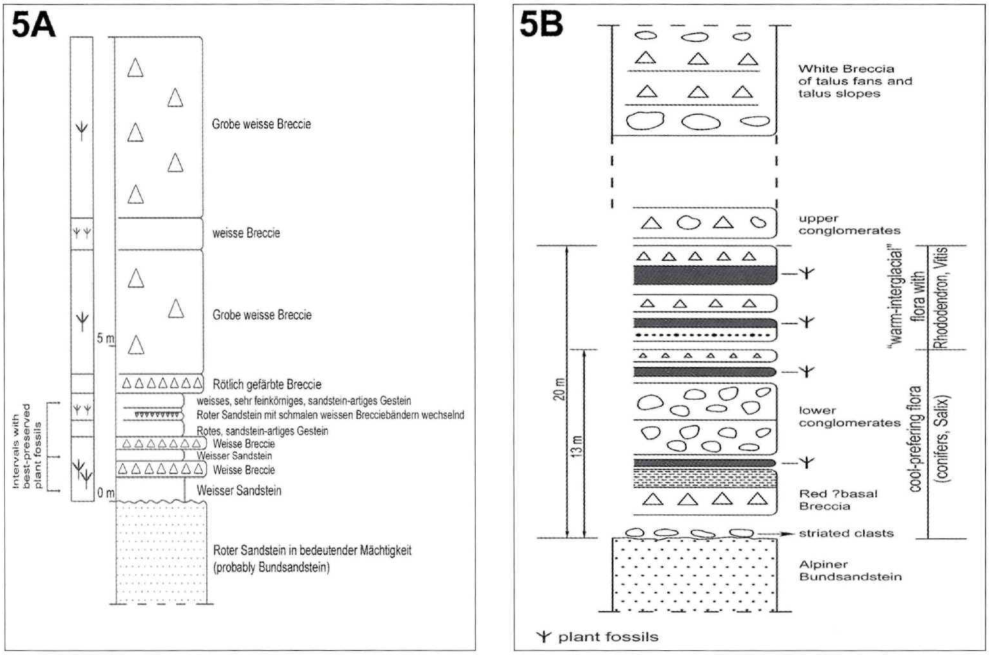

Fig. 5A: Section of Rossfall-Lahner interval drawn and labelled in German according to WETTSTEIN (1892). 5B: Conceptual section according to a short description in GAMS (1936) and our own observations. Note that in section B the vertical succession of lithologies and their relative thickness is not to scale.

1930 sampling campaign, we found distinctive lithologies (such as a Red Breccia composed of clasts of Alpine Buntsandstein, and beds of calcilutite; see below) not mentioned in the description of the succession by WETTSTEIN (1892, p. 7). In the following, the succession is described according to GAMS (1936) and our field observations (Fig. 5B).

Description of succession:

According to GAMS (1936, p. 72), during the excavation of the section in 1930, the Buntsandstein was found overlain by a few striated clasts at the base of the overlying succession *(... "über dem liegenden Buntsandstein, auf dem sich einige gekritzte Geschiebe fanden,"...)*. The entire excavated succession, perhaps some 20 meters thick (cf. GAMS, 1936, p. 67), is characterized by GAMS (1936, p. 72) as a repetitive interlayering of breccias, lacustrine limestones, "clay" and clasts and sand grains derived from the Alpiner Buntsandstein (... *"mehrfache Wechsellagerung von Breccie, Süßwasserkalk, Ton und umgelagertem Buntsandstein."*). We are not sure about the meaning of *"Ton"* (clay) in that description, i. e. whether it refers to claystones s. str. or to marly deposits of "clay s. l." grain size. Considering the montane depositional setting on a substrate strongly dominated by carbonate rocks, to us, the presence of claystones within the section seems quite improbable.

Today, at the fossil location of Rossfall-Lahner, the boundary between the Alpiner Buntsandstein and the Höttinger Brekzie is covered. The local rock substrate is provided by partly exposed, white to pink quartz arenites of the Buntsandstein. A few meters downslope of the tailing of the 1930 sampling campaign, we found a few pieces of clast-supported conglomeratic breccia and a vertically associated, quartz-rich arenite; both breccia and arenite are composed practically exclusively of clasts from the Buntsandstein and the Reichenhall Formation ("Red ?basal breccia"; see Fig. 5B, Tab. 3). The breccia consists of angular to subrounded, poorly sorted fine-grained to coarse gravels that locally are arranged into imbrica-

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Designation	Characteristics	Presence/Preservation of plant fossils	Interpretation of facies
Calcilutite	Intervals up to at least a few cm thick, homogeneous or parallel-laminated.	well-preserved, unfolded plant leaves parallel to bedding	Parallel-laminated calcilutite: suspension fallout Homogeneous calcilutite: mudflow, or indistinct lamination, or rapid suspension fallout
Calcisiltites to calcarenites (pkst, grst)	(1) Intervals up to a few cm thick, carbonate-lithic silt to coarse sand, may show (stacked) 3D-ripple drift cross-laminasets. (2) Ripple drift cross-laminasets, separated by laminae of calcisiltite to calcilutite	plant leaves and other small phytoclasts rare	(1) Traction current deposits (2) Traction currents within slow-flowing or standing body of water
Calciwacke	Up to at least 16 cm thick, homogeneous carbonate-lithic wkst with matrix of slighty micaceous calcilutite	Rich in leaves and other phytoclasts. Many large, twisted and unfolded leaves of Rhododendron ponticum embedded randomly relative to bedding	Mudflow
Matrix-supported breccias	Up to at least 15 cm thick, medium-to fine-gravelly breccias of angular to subrounded clasts of Triassic carbonates, matrix is micaceous-argillaceous calcisiltite to calcilutite	Leaves, grass shoots, branch fragments. Many leaves embedded twisted or torqued, phytoclasts without preferred orientation	Mudflow
Graded layers of breccia into calcisiltite	Intervals up to at least 16 cm thick. Fine-gravelly clast- supported (some with imbrication) or matrix-supported breccias, subangular to subrounded clasts of Triassic carbonates, matrix is winnowed calcarenite. Upward-fining into calcarenite to calcilutite	Common, typically unfolded leaves in calcisiltite and calcilutite near top of beds	Suspension fallout from density flow
Graded, very thin beds and laminae	Graded from fine-grained calcarenite (grst, pkst) in lower part to calcisilite to calcilutite in upper part. Beds/laminae separated along surfaces with microscours. Some samples with softground burrows	Lower part of beds: plant fossils very rare. Upper part to top of beds may contain leaves	Suspension fallout from density flow
„Two-layer" samples	(1) Two-layer graded, very thin beds of calcarenite/calcisiltite->calcilutite (2) Two-layer graded, very thin beds to laminae of calcisiltite/calcilutite	(1) Leaves uncommon in two-layer beds. (2) Twisted and unfolded leaves in calcisiltite; prevalently unfolded leaves in calcilutite	(1) and (2) Suspension fallout from density flow

Table 3: Main fossiliferous lithologies at Rossfall-Lahner, between about 1110-1120 m altitude, that yielded most plant fossils of the „warm-interglacial" flora (see text). Description based on field inspection and rock sampling of the tailing of the 1930 collection campaign, and on rock samples stored in institutes and museums (see text). Abbreviations for texture: wkst = wackestone; pkst = packstone; grst = grainstone.

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ted fabrics. Matrix is scarce, and is represented by an arenite mainly of quartz grains and rock fragments (quarzite, claystone) from the Buntsandstein. Partial to complete lithomoulds of argillaceous dolostones of the Reichenhaller Formation are common both in the matrix arenite and in the coarse-grained sediment fraction (Fig. 6). A few meters above the highest present outcrop of Buntsandstein, a partly exposed package of well-indurated, clast-supported conglomerates is present ("lower conglomerates"). The conglomerates consist of very poorly to moderately sorted, subangular to well-rounded fine to coarse gravels that are derived from the Triassic carbonate rocks of the local substrate. Imbricated clast fabrics are locally present, but mostly the conglomerates display an orientation of clast [a, b]-planes subparallel to bedding. The matrix is a light-yellow to light-grey weathered calcilutite to carbonate-lithic wakkestone. Stratification of the conglomerates is subhorizontal, at least on the limited scale of outcrops. Because the tailing of the 1930 campaign tapers out at about the same altitude than the "lower" conglomerates, we assume that the conglomerates are positioned below the interval with the lithologies rich in plant fossils. Above, within an interval covered by vegetation, the tailing of the 1930 sampling campaign is present. The tailing consists of diverse unfossiliferous and fossiliferous lithologies that, with respect to either their presence or their abundance and thickness, are unique to the location at Rossfall-Lahner (see section 6. below). Higher up, perhaps near the top or in the upper part of the fossiliferous interval, again conglomeratic breccias composed of Triassic carbonate rock fragments are present, but are poorly exposed below a few fallen trees only. These deposits are overlain, still higher up, by a continuously exposed, thick cliff-building succession of White Breccia (Fig. 7).
About 400 meters ESE of Rossfall-Lahner, along a road cut at 1120 m altitude, deposits of overall similar character than at Rossfall-Lahner are exposed over about 20 meters (Fig. 3). There, an interval about 3 meters (between outcrop limits) thick of clast- to matrix-supported, extremely poorly sorted, fine-gravelly to small-bouldery breccias is present. The clast spectrum is dominated by clasts of Virgloria Formation and Wettersteinkalk, whereas clasts of Reichenhaller Formation are subordinate in abundance; clasts of Alpiner Buntsandstein are rare. The clasts typically are subangular to subrounded, whereas a few are well-rounded. The matrix is a yellow weathering, slightly micaceous calcilutite to lithic calcisiltite. Mapping indicates that in this area, the rock substrate of Alpiner Buntsandstein is present a few meters below this outcrop. Up-section, at Rossfall-Lahner and at the location ESE thereof, the described fossiliferous succession is unconformably overlain by a thick package of breccias pertaining to the White Breccia (Fig. 2, Fig. 3). Closely above the Rossfall-Lahner interval, bedding of the White Breccia dips with 5–10° south to southeast. The succession of White Breccia overall is very well-exposed, and clearly accumulated from depositional systems markedly different from that of the underlying fossiliferous interval, i. e. from rockfalls, stream-dominated talus fans and, higher up, from talus slopes (SANDERS et al. 2001).

Interpretation :
Although both GAMS (1936) and ourselves identified conglomerates within the Rossfall-Lahner interval, WETTSTEIN (1892) wrote exclusively of breccias to characterize the coarse-clastic lithologies. Such apparent contradictions perhaps result from a less rigid or different application of the termini conglomerate and breccia in earlier days. For instance, in his description of the Höttinger Brekzie, PICHLER (1859, p. 167) characterizes it as a conglomerate that consists of angular (*sic!*) to subangular clasts ("*Das Conglomerat besteht aus eckigen oder an den Kanten etwas abgerundeten Trümmern der älteren Formation der nördlichen Kalkkette, . . .*"). In the investigated section, with respect to the striated clasts above the Buntsandstein, mentioned by GAMS (1936, p. 72), we assume that this might imply that the Buntsandstein is overlain by reworked glacial till. Higher up, for the described "red ?basal breccia", because of its composition exclusively of clasts of Buntsandstein and Reichenhall Formation, we infer that this breccia and its overlying, quartz-rich arenite accumulated in the basal or the lower part of the succession, when larger areas of the two source lithologies were still exposed. The scarcity of the matrix of winnowed lithic arenite, the imbricated clast fabrics, and the overlying parallel-laminated arenite indicate that the breccia/arenite-ensemble accumulated from a waning flow of decreasing capacity, either a den-

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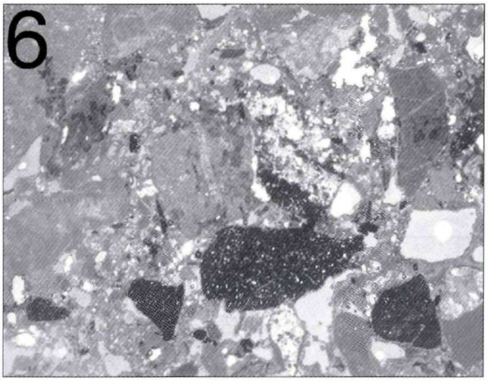

Fig. 6: Red ?basal breccia from tailing at Rossfall-Lahner. The breccia consists of clasts derived from the Alpiner Buntsandstein (dark claystones, quartz arenites) and from the shallow-water carbonates of the Reichenhall Formation and the Virgloria Formation. Note dissolution pores that mainly represent lithomoulds. Width of view 17 mm.

Fig. 7: Extremely poorly sorted megabreccia exposed along the left flank of Rossfall-Lahner, about 1160 m altitude. The breccia consists of clasts of carbonate rocks derived from the local Triassic rock substrate. Note absence of both bedding and of organized clast fabrics. Width of view about 25 meters.

sity flow or a fluid flow (cf. ALLEN 1997). Similarly, the described "lower conglomerates" probably accumulated from fluid flows (surface runoff). For the conglomerates, deposition from debris flows seems less probable because of the clast-supported, matrix-poor fabric and by the common orientation of clast [a, b]-planes subparallel to bedding, by the imbricated fabrics, and by absence of unorganized clast fabric (COLLINSON & THOMPSON 1989). The rounding of most of the clasts indicates abrasion by bedload transport before final deposition. Because the clasts are derived from the local rock substrate, this strongly suggests that the clastic material was transported within and attained its shape characteristics by flowing water, probably creeks or ephemeral creeks on a stream-dominated, fan-like accumulation of coarse clastic material. Below cliffs of the recent Northern Calcareous Alps, stream-dominated "talus fans" are fairly common.

As mentioned, the succession excavated in 1930 had been characterized by GAMS (1936, p. 72) as a repetitive interlayering of breccias, lacustrine limestones, clay and reworked Buntsandstein. As underscored by the inspection of the samples of the main fossiliferous interval (see below), we concur with this rough characterization. According to GAMS (1936, p. 72), in the lower 13 meters of the excavated succession only plant fossils of "cool" climates are present (Fig. 5B). The plant association of the lower part of the succession has been compared by GAMS (1936) with the plant assemblage of the "Hungerburg Brekzie", i. e. of the Red Breccia between about 740 – 880 m altitude that contains plants apparently indicative of an overall "cooler" (micro)climate (cf. MURR 1926). At Rossfall-Lahner, the diversified fossil flora rich in leaves of deciduous trees and in shrubs would start only beyond 13 meters above base. Because the total fossiliferous interval was indicated by GAMS (1936, p. 67) with 20 meters in thickness, this suggests that the rocks with the deciduous fossil flora are present within an interval about 7 meters thick. We assume that the lower part of the succession with fossils of conifers and *Salix* corresponds roughly to the interval with the "red? basal breccia" and the "lower conglomerates" described herein. An overall low thickness of a few meters of the richly fossiliferous interval with the deciduous flora is also suggested by our field observations. The mentioned outcrop about 400 m ESE indicates that, there, the Alpiner Buntsandstein is overlain by deposits of a character similar to the Rossfall-Lahner. The clast- to matrix-supported, extremely poorly sorted breccias are interpreted as deposits of cohesive debris flows with a matrix of carbonate silt to mud. Again, however, the presence of subangular to well-rounded clasts of the local rock substrate indicates fluvial bedload transport and rounding before final deposition. In summary, the general characteristics of the section indicate that most of the Rossfall-Lah-

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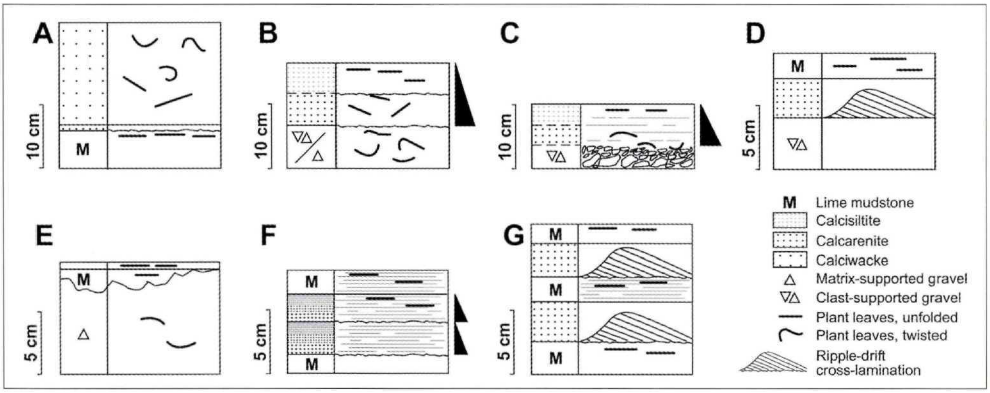

Fig. 8: Main fossiliferous lithologies at Rossfall-Lahner (compiled from inspection of about 600 samples from diverse collections).

ner succession accumulated in association with a stream-dominated alluvial fan that probably was characterized by marked fluctuations in runoff. In the following, the common sedimentary facies of the "main" fossiliferous intervals at Rossfall-Lahner are described and interpreted (Fig. 8, Tab. 3).

Facies of fossil-bearing sediments

Calcilutite (lime mudstone):
This lithology is present in intervals a few millimeters to at least a few centimeters thick of ocre to white, more-or-less chalky, parallel-laminated or homogeneous calcilutite (Fig. 8F). The maximum thickness of this facies is not known, because of the formatting of plant-fossiliferous rock samples. These calcilutites typically contain very well-preserved plant leaves or stacks of leaves, most commonly preserved unfolded and embedded parallel to bedding.

Interpretation: The deposition of parallel-laminated lime mud requires settling from suspension, either from slow flow or from a standing body of water. Deposition of the parallel-laminated beds of calcilutite from suspension is also underscored by the preservation of plant leaves in an unfolded fashion. At present, on stream-dominated alluvial fans of the NCA, accumulation of laminae to very thin beds of laterally limited extent (decimeters to a few meters) of carbonate-lithic siltite to carbonate mud is observed during the waning stage of floods in spring to summer; these fine-grained deposits typically accumulate in side-bays with slow flow, alongside channels characterized by swift flow. Alternatively, as also observed on stream-dominated fans of the NCA, during rainstorms and/or during ephemeral floods, very thin to thin beds of lithic silt to carbonate mud may also accumulate in puddles to very small ephemeral ponds, i. e. in standing water bodies. Conversely, the samples of homogeneous calcilutite may have been deposited from mud flows (i. e. from flows with debris flow rheology) or from suspension fallout. Indeed, evidence for mud flow deposition is present, but within different facies (see below). If the homogeneous calcilutites had been deposited from mud flows, the plant leaves should be embedded randomly relative to bedding, and be twisted and torqued (see below). The observation that, in this facies, the leaves are embedded unfolded and subparallel to bedding, thus, suggests that also the homogeneous calcilutite is a suspension fallout deposit.

Calcisiltites to calcarenites:
This facies comprises intervals up to a few centimeters thick of light grey to light brown, homogeneous, well-sorted, fine-grained winnowed calcarenites to calcisiltites. In some samples, a single level or vertically repeated levels with 3D-ripple drift cross-lamination are present (Fig. 8D, 8G; Fig. 9). Ripple drift

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lamination is visible because in some foreset laminae, diagenetically unstable sand grains were dissolved, leaving arrays of small lithomoulds. The levels with ripple drift cross-laminasets are vertically separated by very thin beds or laminae of homogeneous calcisiltite or calcilutite that may show parallel lamination (Fig. 8G; Fig. 10A, Fig. 10B). The calcarenites are commonly devoid of fossils, but are vertically associated with breccias of debris flows (Fig. 8B) or sheet flows (Fig. 8C) and/or with lithologies (such as the calcilutites) that contain plant fossils (Fig. 8D). In the tailing of the 1930 campaign, clasts that consist of ripple-drift cross-laminated, coarse to fine-grained carbonate-lithic arenite are common, in intervals at least up to 5 cm in thickness (thickest clast observed). Because they are unfossiliferous, these arenites are not represented in the fossil collections. In the tailing, also clasts were found that consist of (parallel-laminated) calcilutites with sharply intercalated, single or stacked 3D-ripple drift cross-laminasets (Fig. 9).

Fig. 9: Cut bed of calcilithic arenite to –siltite, showing stacke three-dimensional ripple-drift cross-laminasets. Sample from tailing of 1930 excavation campaign. Width of view 4 cm.

Interpretation: The build-up and migration of "three-dimensional" (3D) current ripples requires a tractive flow persistent, at least, over minutes to hours (cf. ALLEN 1982; ALLEN & FRIEND 1976). The good sorting and the well-preserved, complete laminasets of the arenites and the absence of outsize clasts suggest that, during migration and deposition of the cross-laminated sand, flow was fairly steady and constant. The good preservation of the laminasets and their interbedding with calcisiltite to (parallel-laminated) calcilutite, in turn, indicates that the tractive flows that shaped the ripples waned geologically rapidly, and deposition returned to suspension fallout. Intervals a few centimeters thick and up to a few meters in length of 3D-ripple-drift cross-laminated sand were observed on the surface of recent alluvial fans (own obs.), and within both the Red and the White Breccia of the Höttinger Brekzie (SANDERS et al. 2001). On both the recent fans and in the Höttinger Brekzie, however, the levels of cross-laminated sand are vertically directly associated with breccias deposited from debris flow or from sheet flows. In the investigated samples from Rossfall-Lahner, this is not the case. The repetitive intercalations of ripple drift cross-laminated sand with parallel-laminated or homogeneous calcilutite, however, suggests that at least these laminasets formed by flow within a standing body of water. The vertical association of cross-laminated arenite with debris flow breccias, by contrast, may have formed in either a subaerial or a subaquatic setting.

Calciwacke:

This facies is present in intervals up to at least 16 cm thick (thickest sample observed) of light grey to white, homogeneous, well-indurated, fine-grained calcilithic wacke with a matrix of slighty phyllosilicate-bearing (micaceous/argillaceous) calcilutite (Fig. 8A; Fig. 11). The calciwacke contains well-preserved, isolated phytoclasts (leaves, branch fragments) or small accumulations of phytoclasts. In the calciwacke samples, leaves are preserved in all orientations relative to bedding (but often, on the scale of samples, subparallel to each other and vertical to bedding), and/or are folded and twisted (Fig. 12; Fig. 13). Immediately below and within this interval of calciwacke, most of the large, well-known leaves of *Rhododendron ponticum* var. *sebinense* are present. In the collections, a suite of plant-bearing rock sam-

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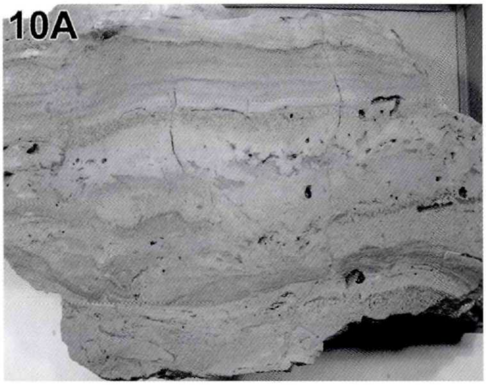

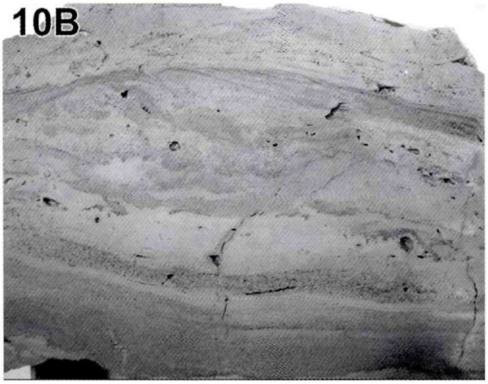

Fig. 10A: Cut bed of parallel- and ripple-drift cross-laminated, lithic calcarenite, interlaminated with calcisiltite to lime mudstone. In the lower part of the bed, a set of parallel laminae is present that each consists of calcarenite graded into lime mudstone. The middle part of the bed consists of chips of lime mudstone and of deformed, small lenses and laminae of arenite. The upper part of the bed contains 3D ripple drift-cross-laminasets of arenite. Sample donated by Landesmuseum Ferdinandeum. Width of view about 21 cm. 10B: Detail of same bed than shown in Fig. 10A, but opposite side of cut. Shows the lower, parallel-laminated part of the bed, the middle deformed part, and the upper part with ripple-drift cross-lamination. Width of view 14 cm.

ples all of identical character is common that strongly suggests that these are from a single bed. At their base, these samples consist of a lamina of calcilutite with well-preserved, unfolded plant leaves (Fig. 14). The top of the calcilutite layer shows arrays of subcircular, convex-downward marks similar in size and shape to drop impact marks (Fig. 15). The calcilutite layer is sharply overlain by a discrete layer about 6–8 mm thick of calcarenite with a matrix of calcilutite. Above, an interval up to at least 16 cm thick of calciwacke is present. Within the wacke, leaves of *Rhododendron ponticum* var. *sebinense* and other plants are common. The leaves of *R. ponticum* are preserved mostly unfolded, but twisted and torqued leaves are present, too. In addition, the plant leaves are preserved in all orientations relative to bedding.

Interpretation: The single bed or, less probably, the beds of calciwacke accumulated from a mudflow, i. e. from a slurry with debris flow rheology (cf. Allen 1997). If the bed were deposited from suspension, it should be graded (Shanmugam 1996), which is not observed. Deposition from a mud flow is supported by the preservation of large leaves of *R. ponticum* and other plants in all orientations relative to bedding. Leaves of *Rhododendron* are quite stiff and may also attain a twisted and torqued shape when withered. Thus, if the calciwacke represented a suspension fallout, the unfolded leaves and ?withered, twisted leaves should be embedded subparallel to bedding; this is not the case. Because no burrowing was identified in the calciwacke, this supports the interpretation in terms of a thicker event bed. The described vertical association of calcilutite – calcarenite – calciwacke represents a succession of different processes. After deposition of the basal lamina of calcilutite (see facies description for possible interpretations), the mud partly desiccated, to enable preservation of the potential drop impact marks. Subsequently, the lamina of calcarenite was deposited, perhaps from suspension fallout. Closely thereafter, the mud flow giving rise to the highly fossiliferous calciwacke accumulated.

Matrix-supported breccias:

At plant location 3, poorly sorted, matrix-supported, medium- to fine-gravelly breccias composed of angular to subrounded clasts of Triassic rocks appear to be fairly common. The thickness of this facies is not known; it is at least up to about 15 cm thick (thickest sample observed) (Fig. 8B, 8E). In these breccias, plant leaves are commonly preserved twisted and torqued, or subparallel to bedding, or normal to bedding but subparallel to each other. This facies may contain larger phytoclasts such as branch fragments disoriented relative to bedding. In addition, isolated grass leaves and grass shoots may be oriented parallel to each other. The breccia layer may be topped by a sharp surface with a relief (in hand sam-

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ple scale) of up to a few centimeters. This relief is levelled and overlain by calcisiltite or, in other samples, by calcilutite that contain plant leaves embedded parallel to bedding.

Interpretation: The matrix-supported breccias are interpreted as deposits of mud flows (cohesive debris flows) with admixed lithoclasts. The orientation of tree/bush leaves and grass leaves and grass shoots subparallel to each other, but either subparallel of subvertical to bedding suggests an orientation of the phytoclasts according to the internal shear within the mud flow. Before their ultimate deposition within these parabreccias, the lithoclasts were subject to limited (short-distance) fluvial bedlodad transport, resulting in their subangular to subrounded shapes. Because, in the samples inspected, the underlying lithologies are absent and only a very limited portion of the overlying lithology is preserved, it is difficult to assess whether these breccias accumulated in a subaerial or a subaquatic setting. The sharp contact, with a small-scale relief, of the parabreccia to overlying calcisiltite or calcilutite, however, probably was produced by at least intermittent subaerial exposure of the flow, followed by deposition of the fine-grained lithologies above. As mentioned, on recent stream-dominated alluvial fans, drapes of very thin beds or laminae of carbonate-lithic siltite to carbonate mud do accumulate in ephemeral puddles laterally along the main channels, or in "side-way bays" of the creek bed that are covered only by a thin sheet of water during floods.

Fig. 11: Thin section image of homogeneous, carbonate-lithic wackestone (calciwacke). Width of view 12 mm.

Graded layers of breccia into calcisiltite:

This facies comprises normally graded layers a few centimeters to at least about 16 cm thick of fine-grained clast- or matrix-supported breccias (the latter with a matrix of winnowed calcarenite) at the base to calcarenite to calcisiltite to, more rarely, calcilutite at the top (Fig. 8C). No distinct, sharp boundary was observed between the calcarenite-calcisiltite and the overlying calcilutite. In the calcisiltite or calcilutite, plant leaves may be embedded slightly oblique to parallel to bedding, but most commonly are preserved unfolded. The fine-grained upper portion of a layer of this type yielded many of the well-preserved plant fossils from Rossfall-Lahner. More rarely, plant leaves also are present in the medium to coarse sand portion of graded beds. Intervals of this facies type may also start from their base by a clast-supported, fine-gravelly breccia or coarse sandy calcarenite with imbricated clasts, and fine upward as described. In both the breccias and the calcarenites of this facies type, clasts of Buntsandstein are absent or extremely rare.

Interpretation: Normally graded layers of breccia into parallel-laminated sand may accumulate in subaerial settings, typically from sheet flows during waning flood stage. A *continuous* upward fining from breccia into arenite and, significantly, into lithic siltite and calcilutite, however, were quite unusual for subaerial sheet flow deposition on an alluvial fan; to date, such a deposit was not observed by us on recent stream-dominated fans of the NCA. Moreover, if the calcilutite is part of the same depositional event than the interval of breccia to calcisiltite, it is even more improbable for waning/falling sheet flows in subaerial settings to produce such beds. These beds thus are interpreted as gravity flow deposits into a body of standing water.

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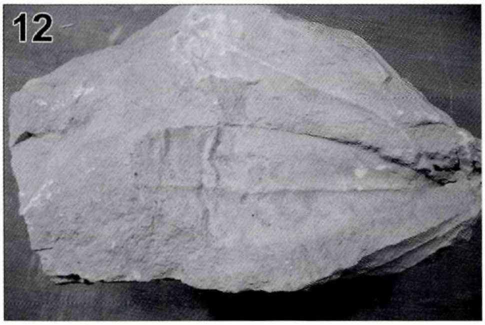

Fig. 12: Leaf of *Rhododendron ponticum* within a bed of calciwacke, embedded disoriented relative to bedding. This type (or this bed?) of calciwacke yielded many of the celebrated *ponticum*-leaves from Rossfall-Lahner. Note the poor preservation. Sample of Institute of Geology and Palaeontology, University of Innsbruck. Width of view 24 cm.

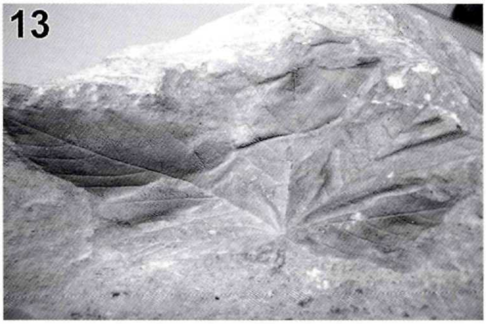

Fig. 13: Detail of same bed than shown for the *Rhododendron* leaf in Fig. 12. Photo shows a leaf of *Acer*, positioned subvertical to the bedding of the calciwacke bed. The sharp, subparallel folds within the leaf may have resulted from compaction and dewatering of the mud flow from which the bed accumulated. Width of view 10 cm.

<u>Graded beds and laminae</u>:
This facies includes very thin beds to laminae that show an upward-fining from fine-grained calcarenite in their basal part to calcisiltite or calcilutite in their upper part (Fig. 8F; Fig. 16A, Fig. 16B). These beds may be vertically separated from each other along sharp, plane, microscoured surfaces (Fig. 16A, Fig. 16B), and/or are sharply separated from intercalated laminae of white, chalky calcilutite with plant leaves. Together, the described graded beds-laminae and intervals of calcilutites were observed in samples up to about 5 cm in thickness. In thin section, softground burrow mottles are present within this lithology (Fig. 17A, Fig. 17B). In a few cases, the layers of calcilutite intercalated between the graded beds show parallel-horizontal laminae up to about one millimetre thick. These laminated calcilutites may contain well-preserved, unfolded plant leaves.

<u>Interpretation</u>: The graded beds to laminae record waning competence of a turbulent flow with suspended material (cf. STOW & SHANMUGAM 1980; SHANMUGAM 1996). The laminae thus may be interpreted as, either, density flow deposits into a standing body of water, or as deposits of waning sheet flows in a subaerial setting. In a very small area and for a single event, the occurrence of such a style of sheet flow deposition is possible in a subaerial setting (see above). Even the repeated occurrence of such a type of deposition at the very same location perhaps might be explained by episodic crevassing of water over mud flats laterally adjacent to a channel. In this case, however, features of desiccation may be expected, such as desiccation cracks and mud chips, as were observed by us in recent comparable deposits on alluvial fans of the NCA. In all of the samples of this facies, however, the absence of both clear-cut features of desiccation (vertical desiccation cracks, sheet cracks, polygonal nets of cracks on bed surfaces) and of mud chips is distinct. In addition, if the stacked graded laminae had accumulated in a subaerial setting, aside of desiccation features, features of subaerial erosion due to rainfall and surface runoff are to be expected; in this case, the boundary between successive beds should not be plane as observed in all these samples, but should show a distinct relief recognizable also in hand samples. Finally, at least some of the layers of calcilutite between the graded beds/laminae show subparallel millimetre-lamination. As mentioned, to date, no depositional process is known for subaerial settings to result in calcilutites composed of plane millimetre-laminae parallel to bedding, and devoid of fenestral pores or other pore types. Thus, taken all evidence together, it is most probable that the graded beds/laminae were deposited from density flows in a subaquatic setting.

<u>"Two-layer" samples of calcarenite/calcisiltite, and of calcisiltite/calcilutite</u>:
A few samples of "two-layer" graded beds were observed in two varieties. (1) Beds a few centimeters

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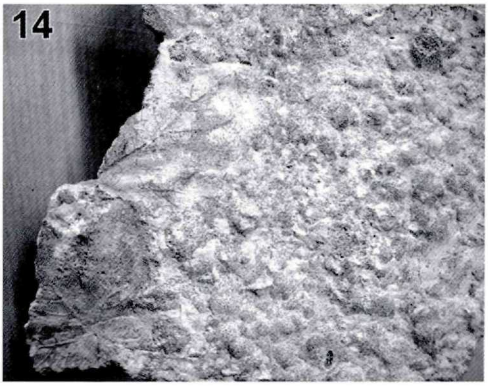

Fig. 14: Leaf of *Rhododendron ponticum* imprinted into lamina of lime mudstone. View onto the underside of a bed of calciwakke that contains leaves of *R. ponticum*. This is the bed that is at least 16 cm in thickness (see text). Note mammillary protrusions from bed underside that may represent raindrop marks. Width of view about 15 cm.

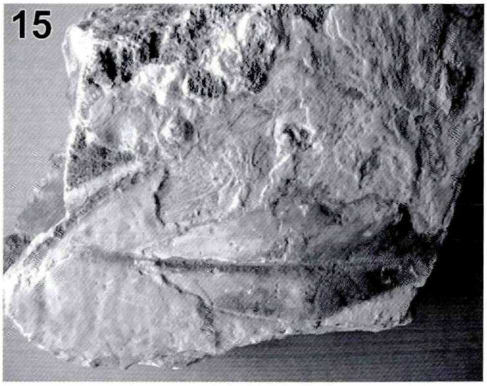

Fig. 15: View onto underside of „*Rhododendron*-leaf bed" of calciwacke. Note (a) imprints of plant leaves into lamina of light grey lime mudstone (only partly preserved), and (b) the numerous mammillary protrusions of the bed underside, suggestive of drop-impact marks. Width of view about 8 cm.

thick that consist of medium to fine-grained calcarenite in their lower part, and a layer of light brown calcisiltite into calcilutite in their upper part. These intervals may be overlain along a sharp, plane boundary by very thin beds to laminae of white, slightly phyllosilicate-bearing (micaceous/argillaceous) calcilutite with unfolded plant leaves. (2) A bed, or beds, at least 10 cm thick of homogeneous calcisiltite in the lower part and calcilutite in the upper part, with unfolded plant leaves atop the calcilutite. In addition, a few samples of an interval at least up to 6 cm thick of calcisiltite were observed that contain torqued leaves and chaotically arranged phytoclasts (leaves, branch fragments). It is not certain whether this latter interval pertains to the described samples of two-layer calcisiltite/calcilutite, or represents a distinct level.

Interpretation: Because of the formatting of rock samples for fossil collections, it cannot be decided whether the "two-layer" samples represented beds of their own and/or just the upper part of thikker beds with the same or another lithology below (e. g. facies P 5). In any case, for the samples of variety (1) as described above, an origin from event beds in a subaquatic setting seems probable. Two-layer grading is widespread in calciclastic gravity flows (COLACHICCHI & BALDANZA 1986). In some samples the superposition, along a sharp and plane surface, of the calcisiltites to calcilutites by white calcilutite also seems to favour a subaquatic origin of these event beds. The style of deposition of samples of variety (2) can hardly be assessed unequivocally. Apparently homogeneous calcisiltite may be deposited from either mud flows (or, in case of hyperconcentrated suspensions, from rheological debris flows) or from gravity flows. As mentioned, a few samples up to 6 cm thick of calcisiltite with twisted and torqued leaves and chaotically arranged phytoclasts (leaves, branch fragments) were observed in the collections. This style of plant fossil embedding is characteristic for mud flows, or rheological debris flows at least. In any case, for the samples with preserved transition into calcilutite, the plane sharp boundary to fossiliferous calcilutite above again seems to favour a subaquatic origin of these samples.

Integrated facies interpretation

For the samples of "red ?basal breccia", their abundance in clasts of Buntsandstein and, less commonly, of Reichenhall Fm indicate a very close relation to the rock substrate at site. Thus, this breccia probably formed directly or very closely above the local substrate. Higher up, for the "lower conglomerates" (cf. Tab. 3), their composition of subrounded to well-rounded clasts of local Triassic carbonate rocks

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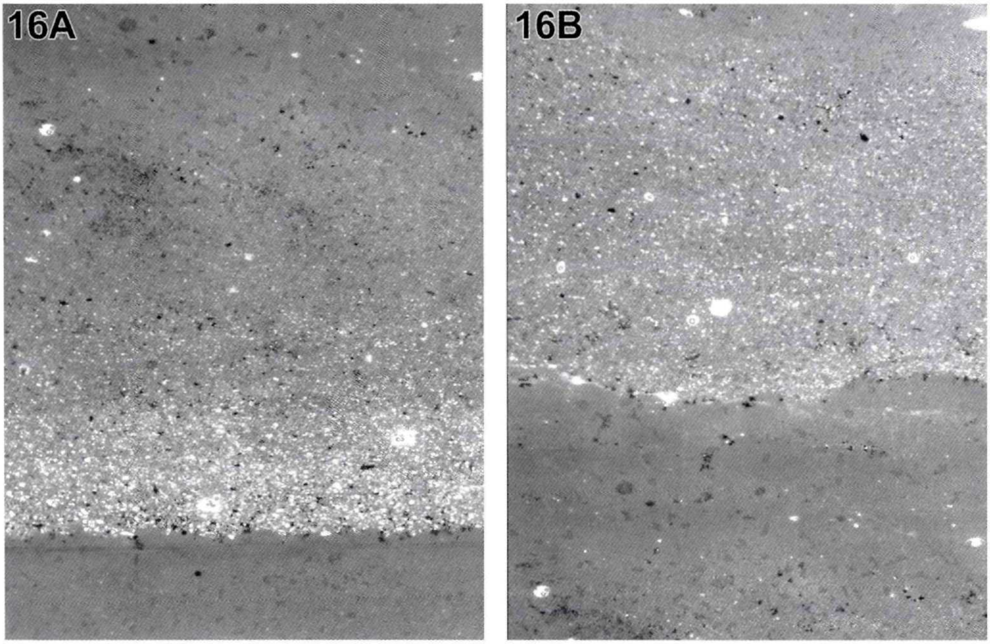

Fig. 16A Fig. 16B: Section through two very thin, sharp-based beds. Each bed shows a normal grading from carbonate-lithic fine sand to coarse silt at the base to lime mudstone in the upper part. Width of each image 17 mm.

records clast shaping by surface runoff persistent/frequent and intense enough to lead to rounding of clasts of medium to coarse gravel size. Stratigraphically above plant location 3, the sheer thickness of Höttinger Brekzie and its mappable intersection with the older rock substrate record a very steep to vertical rocky slope in the subcrop (Fig. 3). Thus, during accumulation of the lower conglomerates, ephemeral to perennial water falls may have debouched from the cliffs and over talus material accumulated below, leading to rounding of clasts in a short-headed creek system.

Above, the fossiliferous lithologies of plant location 3 probably accumulated from a pond or ephemeral pond, perhaps in its marginal part strongly influenced by alluvial processes. Because of limitations of outcrop, the potential former size of that postulated pond(s) can not be assessed. For the calcilutites, their parallel lamination combined with absence of features of desiccation suggests a standing body of water. In particular, the repeated vertical association of (parallel-laminated) calcilutites with levels of ripple-drift cross-laminated calcarenites and with graded beds of calcarenite into calcilutite indicates that the standing body of water was repeatedly affected by tractive currents. Today, very thin beds or laminae of carbonate-lithic silt to carbonate mud may accumulate in ephemeral puddles along, both, stream-dominated fans or braided creeks with strongly fluctuating discharge. To all our knowledge, however, such laminae drape underlying beds of gravel or sand along an highly irregular relief and, in turn, become sharply overlain for instance by fluvial gravels and sand, or by debris flows, or become largely or completely eroded during the subsequent flood. In the main fossiliferous interval of Rossfall-Lahner, thus, the repeated vertical association of calcilutites with ripple-drift cross laminated sand thus implies a local environmental stability hardly provided by a puddle falling dry within a few days. Graded beds of breccia supported by clasts or by winnowed sand may originate during waning floods, in a subaerial setting. Again, however, the continuous grading of beds into calcisiltite to calcilutite is highly unusual for the proximal portion of stream-dominated fans in subaerial settings. Similarly, the formation and preservation of stacks of graded, very thin beds to laminae of arenite to siltite, and with intercalated layers

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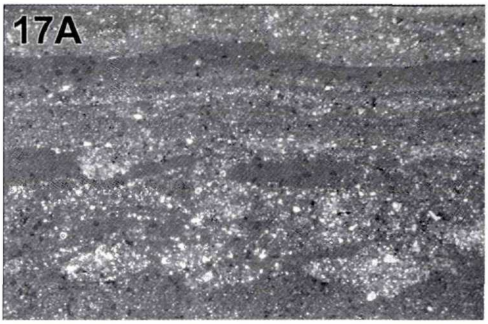

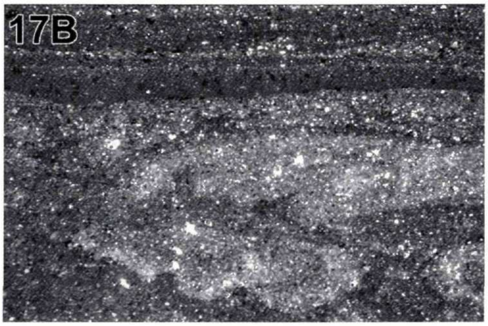

Fig. 17A, Fig. 17B: Different motifs from bed that consists of calcilithic packstone to wackestone interlaminated with lime mudstone. Note distinct softground burrow mottles in this lithology. Width of each view is 17 mm.

of calcilutite, seems highly unusual for a purely subaerial setting. Moreover, if the depositional environment of the calcilutitic to calcisiltitic lithologies fell dry over longer periods, desiccation cracks, intraclast chips of calcilutite, and distinctly scoured erosive boundaries between successive intervals of fine-grained lithologies were to expect; as far as obvious from the inventory of the samples checked by us, this is not the case. Mudflows producing the matrix-supported breccias and the calciwacke bed(s) can form both in subaerial and aquatic settings. At least the graded beds and the ripple drift cross-laminated arenites and, perhaps, also the graded beds of breccia to calcisiltite, however, indicate that the postulated standing water body was subject to episodic current events. If the water body was closed (pond or very small lake), the graded beds and the cross-laminated arenites may be interpreted in terms of density flows. If the water body was hit by floods of a creek, these facies might also represent fluid flow events (e. g. episodic events of slow flow across the pond). Because of limited outcrops, the potential origin of the postulated pond can not be assessed. Ephemeral ponds may form in inactive, episodically flooded side arms of braided creeks or wet fans.

The formation of a pond, or ponds, may have been favoured by the local morphology of the bedrock. Between about 1070–1140 m altitude in Höttinger Graben, the trace of the intersection of the boundary between the local rock substrate (Buntsandstein, Reichenhall Formation) with the Höttinger Brekzie indicates a slope of overall low gradient. Quantitative estimates of the slope amount to 14° (NE-SW 200 m across Höttinger Graben, based on field-measured altitudes of outcrops, maximum estimate) to less than 1° (N-S at plant location to 400 m eastward thereof, projected from outcrops aside, based on the field-measured altitudes of good outcrops), on a lateral scale of hundreds of meters. Thus, steep to vertical cliffs at the mountain side faced a low-dipping substrate or a gentle swell on the valley side. Ponds and small lakes that become filled by fine-grained carbonate-lithic material and by event beds shed from adjacent talus fans are fairly common at higher altitudes in the present NCA. Today, such ponds are present at local relief inversions produced, either, by subglacial erosion, and/or by terminal moraines of glaciers, and/or by karstification. Thus, the interpretation of the plant-bearing lithologies as deposits of a pond seem consistent both with present-day facies distributions and with the facies types and their distribution within the Höttinger Brekzie. Finally, it is recalled that the fossiliferous rock samples most probably stem from a few beds only, and from a narrow stratigraphic interval a few decimeters to, at most, a few meters in thickness. The palaeoclimatic significance of the plant fossils is discussed farther below. The interpretation as a pond, or ponds, is supported by an exposure of the contact Buntsandstein/Höttinger Brekzie along a road cut at 1080 m alt. There, the substrate shows an upward-convex curvature, oblique to subperpendicular to regional downhill dip, with a positive relief of at least about 2 meters. Such local slope inversions of a few meters may have sufficed to bar up surface runoff to an ephemeral pond, or ponds.

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Flora

Based on the known geographic distribution of the living relatives of several species of the fossil flora, on the growth patterns of leaves and their features, and on a comparison of the entire fossil flora with the present flora from the Pontic mountain chain, WETTSTEIN (1892, p. 36–38) discusses the evidence for an overall warmer climate than presently at site. He concluded that a sensibly warmer and/or more equable climate with attenuated seasonal temperature gauge that presently pertained. WETTSTEIN (1892, p. 42–47) also provides evidence from recent plant geography that the warm-loving "pontic" flora of Rossfall-Lahner may well have co-existed with loess steppes in the Alpine foreland. Although all fossil plants of the Höttinger Brekzie would need a timely taxonomic revision, the two most prominent elements of Rossfall-Lahner and of the entire Höttinger Brekzie, for that matter, here are shortly re-considered, i. e. *Rhododendron ponticum* var. *sebinense* and *Vitis vinifera* subsp. *sylvestris*. These two species are present in the richly fossiliferous, upper part of the excavated section at Rossfall-Lahner (GAMS 1936). The following discussion refers only to the upper part. The fossil flora recovered from there is characterized by a mix of warm- and/or wet-preferring taxa (e. g. *Rhododendron ponticum, Vitis vinifera* subsp. *sylvestris, Taxus baccata, Carex, Populus, Fagus, Acer*) with cool-preferring and subalpine taxa (e. g. *Abies alba, Poa hybrida, Salix glabra, Ribes alpinum, Alnus, Carex flacca, Convallaria majalis*) (MURR 1926). With respect to diversity, the major part of the flora is represented by taxa of environmental preference "intermediate" between the former two groups of plants (e. g. *Pinus silvestris, Picea abies, Salix incana, Alnus incana, Rubus caesius, Prunella vulgaris*). Of the warm- and/or wet-preferring taxa, since MURR (1926), *Rhododendron ponticum* and *Vitis vinifera* subsp. *sylvestris* were perservated as evidence of a warmer Riss-Würm Interglacial climate than today at this location.
MURR (1926, p. 166) concluded that to derive a "White-Breccia" flora including *R. ponticum*, a mean annual temperature about 3° higher than at well-lit locations (village Trins) of comparable altitude in the present Tyrol may be needed; on the other hand, an annual mean of 8.5–9° must not be exceeded because of the simultaneous presence of subalpine taxa (Trins: 5.3° annual mean). Already MURR (1926, p. 166–167) cautioned that an increase in air moisture and annual precipitation can lower the temperature requirement for plants, and states that an annual precipitation comparable to that of the city of Bregenz (1537 mm) may have been sufficient, where a similar natural spectrum of species is present today, and where *R. ponticum* grows without protection in houseyards (MURR (1926, p. 167). MURR (1926) conceded that to enable *R. ponticum* and *V. vinifera* subsp. *sylvestris* to have grown near Rossfall-Lahner may thus have needed little, if any, modification of mean annual temperature relative to present.
Today, *R. ponticum* spread from gardens became a problematic bioinvader in England, although the January temperatures are 5–10°C lower than in its area of origin (MILNE & ABBOTT 2000). For the forms of *R. ponticum* in the Höttinger Brekzie the ecoclimatic requirements are not well-known. Widespread recent occurrences of *R. ponticum* indeed characterize an "insubric" climate, i. e. a warmer and more humid climate than presently at site. Because of microclimatic conditions (gauge and amplitude of mean annual temperature, air humidity, winter/summer illumination), however, smaller-scale stocks of such plants may thrive in morphological depressions, chutes and gorges (MURR 1926; K. PAGITZ written comm. 2005). This holds particularly for ever-greens such as *R. ponticum*, which is resistant down to about -20°C (K. PAGITZ written comm. 2005). Finally, WETTSTEIN (1892, p. 45) points out that the southern slopes of the Solstein-Brandjochspitz massif are long-known as stands of "southern plants" and lists a few of these species. In summary, the presence of fossil *R. ponticum* var. *sebinense* suggests but not indicates warmer winters and more precipitation than today, but not necessarily indicates a higher mean annual temperature (K. PAGITZ written comm. 2005; cf. also MURR 1926). An overall similar conclusion applies to *Vitis vinifera* subsp. *sylvestris* (K. PAGITZ written comm. 2005).

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Discussion

During deposition of the main fossiliferous interval of Rossfall-Lahner, the facies and facies association of the fossiliferous rocks record a pond, or ephemeral ponds, associated with a stream-dominated alluvial fan or a braided creek with fluctuating discharge, and that was flanked by soil-covered, vegetated mountain slopes with a diversified, deciduous vegetation. The fossil location at Rossfall-Lahner, however, is overlain by a succession more than 100 meters thick that accumulated from stream-dominated talus fans and, higher up, from large mature talus slopes (SANDERS et al. 2001). All available evidence indicates that effective production of talus proceeds only in cool and sufficiently wet ("periglacial" s. l.) climates (CHURCH et al. 1979; HALES & ROERING 2005). As WETTSTEIN (1892) indicated (see also MURR 1926; GAMS 1936), about 70% of the species of the fossil flora also today thrive in this area. Today, except for rock cliffs, the environs of Rossfall-Lahner practically throughout is covered by dense vegetation composed of conifers, deciduous bushes and trees (e. g. *Fagus*), and shrubs. Higher up, the talus slopes between about 1400–1900 m altitude today are nearly completely relict, and are largely and progressively covered by soil, grass, and stands of *Pinus mugo*. The present climatic conditions thus are incompatible with formation of thick talus wedges at site. Together, this strongly suggests that the deposition of the fossiliferous rocks of Rossfall-Lahner is incompatible with the thick fossil talus successions of the White Breccia above. Unfortunately, the stratigraphical transition from the fossiliferous rocks into the overlying White Breccia is covered by forest, and also had not been described by previous geologists.

We may propose two hypotheses to explain the relation of the Rossfall-Lahner flora to the White Breccia. (1) The Rossfall interval represents an erosional vestige of an older generation of Quaternary deposits, i. e. the boundary to the overlying White Breccia is an unconformity. In this interpretation, the depositional setting of the Rossfall flora were irrelevant to the Höttinger Brekzie. (2) The richly fossiliferous portion of the Rossfall interval accumulated during a phase of warmer climatic conditions, after deposition of the main volume of Red Breccia, but before a climatic cooling that started the formation of the fan to talus succession of the White Breccia. This latter hypothesis is supported by the observation that the lower part of the fossiliferous Rossfall succession is characterized by a plant assemblage typical of a cool climate (GAMS 1936). The Rossfall-Lahner succession thus may have started to accumulate during post-glacial climatic warming, records a phase of climatic optimum with soil-covered slopes and a diversified, deciduous vegeation, and was followed by climatic cooling and formation of thick talus wedges during climatic deterioration in the late Riss-Würm interglacial to early Würm.

Within the entire Höttinger Brekzie, except perhaps the fossiliferous interval at Rossfall-Lahner (if this interval is considered as part of the Höttinger Brekzie), no clear-cut evidence for a climate even of similar mean annual temperature and temperature gauge is found. Thick talus slopes develop best in high-latitude or high-altitude locations with sparse vegetation and sparse soil, within a climatic "window" with frequent freeze/thaw cycles, to propel physical erosion (CHURCH et al. 1979; FRANCOU 1990; VAN STEIJN et al. 1995; HARRIS & PRICK 2000; HALES & ROERING 2005). This is also indicated by widespread presence of coarse-grained slope deposits in Pleistocene periglacial settings of the Mediterranean and peri-Mediterranean area (GERSON 1982; COLTORTI & DRAMIS, 1988; FRANCOU 1990; HÉTU et al. 1995; VAN STEIJN et al. 1995), of Central and Western Europe (FRANCOU 1990), and of North America (GARDNER et al. 1991; MASON & KNOX 1997). In the Quaternary of the Eastern Alps, deposition of coarse-grained alluvium proceeded mainly under "periglacial" (cf. French, 2000) climatic conditions, as a result of intensified physical weathering of rocky slopes (VAN HUSEN 1997, 1999). In the NCA, Late-Glacial to Holocene alluvial fans and/or talus slopes quarried for gravel, and sections of ground-penetrating radar and reflexion seismics indicate that many scree slopes are underlain by successions a few tens of meters to more than 100 m in thickness (BRÜCKL et al. 1974; SASS & WOLLNY 2001; SCHROTT et al. 2004). The present accumulation rates of alluvial fans and talus slopes are far below Late-Glacial to early Holocene rates (e. g. PATZELT 1987). For a typical valley of the western NCA, SCHROTT et al. (2004) conclude that Holocene talus slopes represent the most significant sediment volume, but that more than two-

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thirds of them are relict, paraglacial landforms. This accords with our field observations on talus slopes of the NCA. In general, most of the recent talus slopes of the NCA below about 2000–2400 m altitude are of low activity to relict, and many talus slopes below about 2000–1700 m now are subject to linear erosion rather than accumulation (leading to parasitic alluvial fans farther down slope, or to shedding of reworked talus material into perennial creeks). It is probable that the major phase of accumulation of the recent fans and talus slopes in the NCA was a few thousands of years between the start of the Late-Glacial (17–14 ka bp.) and widespread reforestation and rise of the timber line between about 13–10 ka ago (PATZELT 1980). For the Höttinger Brekzie, this implies that thick packages of coarse-grained deposits may accumulate within a few thousands of years near the base of and along mountain flanks, but that little activity may take place during persistently warm interglacial conditions.
In the area of the Höttinger Brekzie, Holocene scree is present only as pavement of chutes incised into the substrate (Triassic rocks, or Höttinger Brekzie). Overall, along the southern slope of Nordkette near Innsbruck, the Holocene scree slopes do not significantly modify surface morphology, as occurred during deposition of the Höttinger Brekzie. Moreover, there is a clear-cut disparity between the large volume of Höttinger Brekzie and the comparatively small volume of Holocene scree. Thus, talus production and accumulation were more efficient or prolonged, or both, during the depositional phase(s) of the Höttinger Brekzie. In fact, the fossiliferous succession at Rossfall-Lahner may represent the only vestige of the "warm" Riss-Würm Interglacial ascribed by most previous authors to the entire Höttinger Brekzie (or to the White Breccia). Only further investigations into the absolute age of the Rossfall-Lahner interval (e. g. by optically-stimulated luminescence dating) and, perhaps, an increased Th-U age resolution of cements within the Höttinger Brekzie may decide whether the Rossfall-Lahner is part of the same depositional cycle, or is an older vestige.

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