# Towards a glacial-interglacial sequence concept for mountain ranges, in comparison with glacio-eustatic marine sequences.

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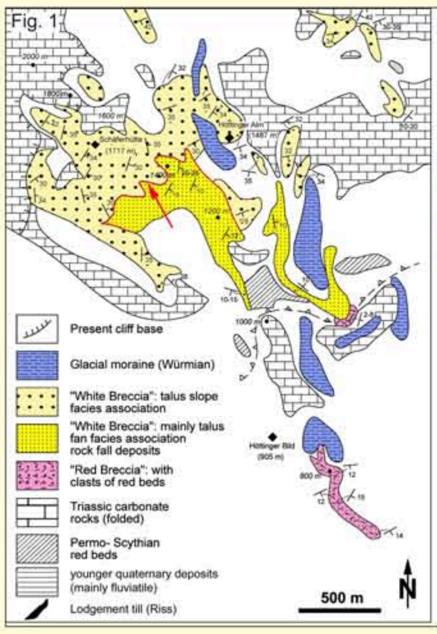
The establishment of models for marine deposition is among the oldest goals of stratigraphic research. The marine, glacio-eustatic depositional sequence became the paradigm of present stratigraphy. By contrast, for glacial-interglacial "montane" Quaternary successions, to date few attempts at a comprehensive concept of stratigraphic development were made. For the present contribution, in addition to data and results from literature, observations from six major outcrop areas of Quaternary successions, from more than 30 recent talus slopes, and from several Holocene alluvial fans are integrated. The main similarity of glacio-eustatic marine and glacial-interglacial montane sequences, respectively, is that the shift in space and time of depocenters is steered by glacial to interglacial/interstadial climatic rhythms. In montane sequences, however, deposition and erosion are mainly controlled by comparatively ephemeral processes of limited areal extent, and that are strongly influenced by both climate and/or by local relief and base-levels. In marine sequences, deposition and erosion are controlled by longer-lived processes of comparatively large areal extent, and by sea-level approximating the single most important base-level surface (in the shelf environment). On a very large scale, the development of both marine and montane sequences follows a grossly similar canon. Lowstand deposits accumulate during glacials, transgressive and highstand deposits accumulate during deglaciation and interglacials. Except under marked sediment starvation, however, marine sequence development is characterized by deposition throughout and at nearly all locations below base-level. This allows for a distinction of lowstand, transgressive, and highstand systems tract by their relative physical position within the sequence. In glacial-interglacial montane sequences, such a distinction of systems tracts is only possible for deposystems (such as alluvial fan-talus systems) characterized by net base-level rise over at least most of their development.



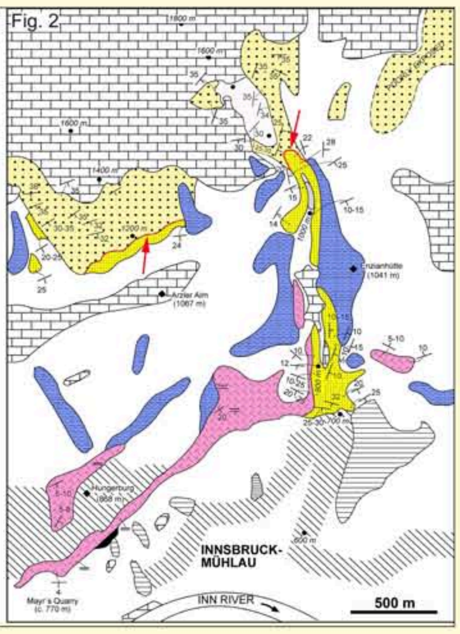




**Fig. 3:** Quarry cut into deposits of ephemeral streams and debris flows ("Red breccia" variety of Höttinger Brekzie). The distinct bedding surfaces represent thin intercalations of loess (Obojes, 2003). The outcrop shows the lower, low-dipping part of the "fossilized" alluvial fan and talus succession (cf. Fig. 2). Persons for scale.

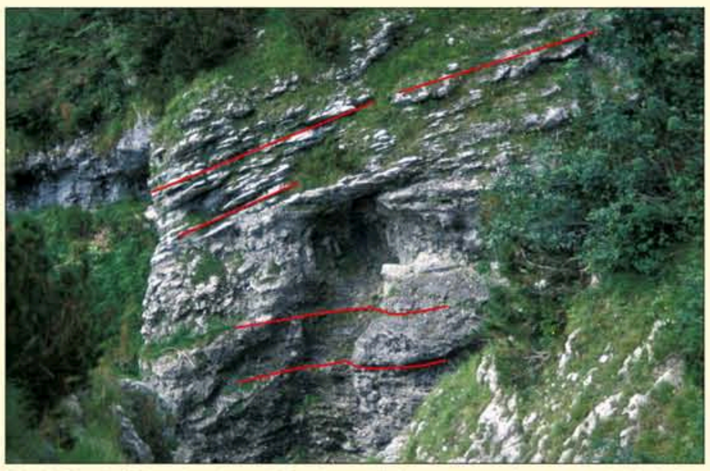
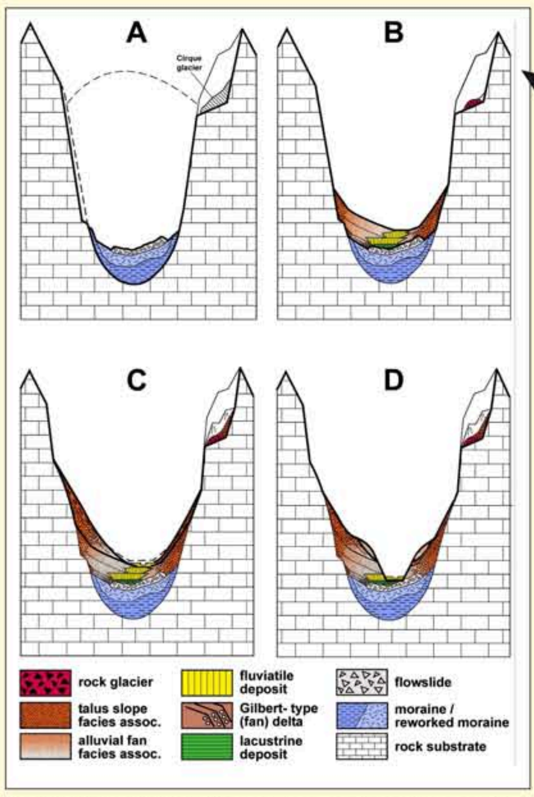


**Fig. 4:** Detail of "downlap interval" from lower-dipping ephemeral stream and debris flow deposits below to steeper-dipping (about 25°) debris flow breccias above. Within an altitudinal range of 1100-1350 m, this changeover of both prevalent deposits and bedding dip can be identified in the entire Höttinger Brekzie (cf. Figs. 1, 2).

**Fig. 1:** Map of western part of Höttinger Brekzie near Innsbruck, a "fossil" alluvial fan and talus succession. The Höttinger Brekzie overlies carbonate rocks and red beds. In its lower part ("Red breccia", lower part of figure), in this area, the Höttinger Brekzie consists mainly of low-dipping deposits of both debris flows and of ephemeral streams. Higher up ("White breccia", upper part of figure), bedding dips steepen. The middle part of the succession is dominated by rudites deposited from rockfalls and from ephemeral streams and debris flows. The upper part consists mainly of grain flow breccias dipping with 30-35°; these breccias constituted the middle and upper part of mature talus slopes. The thick red line indicates a "downlap interval" between the grain flow breccias and the underlying succession.

**Fig. 2:** Map of eastern part of Höttinger Brekzie. There, the lower part of the succession consists of a low-dipping succession of deposits from ephemeral streams and from debris flows ("Red breccia", see Fig. 3). Farther east, a succession mainly of coarse-grained, proximal stream/ephemeral stream deposits of "White breccia" type represents the lower part of the Höttinger Brekzie. Higher upslope, these deposits are overlain, along a "downlap interval" (thick red line), by a steep-dipping (25-30°) package of breccias deposited mainly by cohesive debris flows and by grain flows (see Fig. 4). The steep-dipping breccias extend up to highest preserved part of the fossil talus slopes, where they onlap ancient cliffs (cf. Fig. 2).



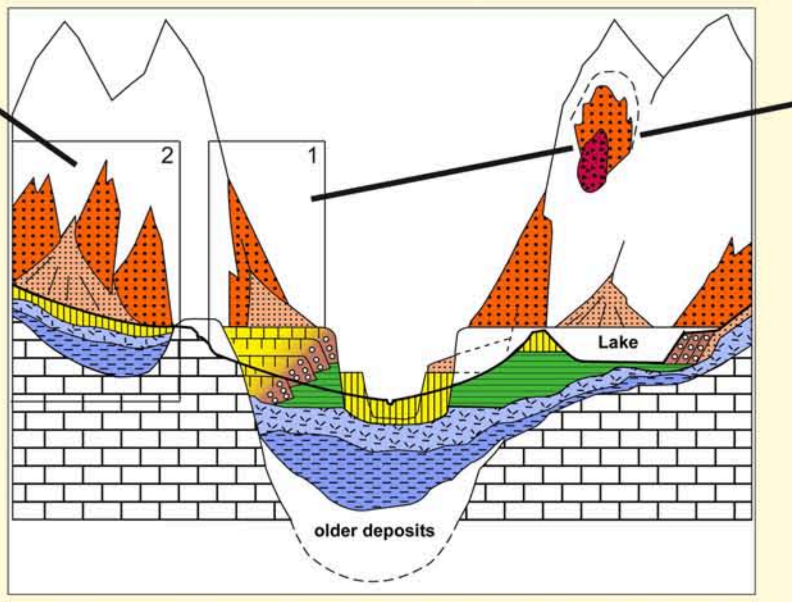




**Fig. 6:** Scheme of glacial-interglacial succession in a larger mountain valley and side valleys (valley overdeepening facultative). Deposits of the glacial phase (mainly moraines) are overlain by deposits of interstadial and/or of deglacial to early interglacial origin (mainly fluviatile and lacustrine sediments). Closely after deglaciation, along mountain flanks, alluvial fans and talus slopes built up rapidly, while fluvial incision started in the main valley. Except episodes of minor deposition and erosion, both along the main valley and along the flanks of side valleys, the "mature" interglacial stage is characterized by prevalent sediment by-pass and slow incision, and by low rates of physical erosion.

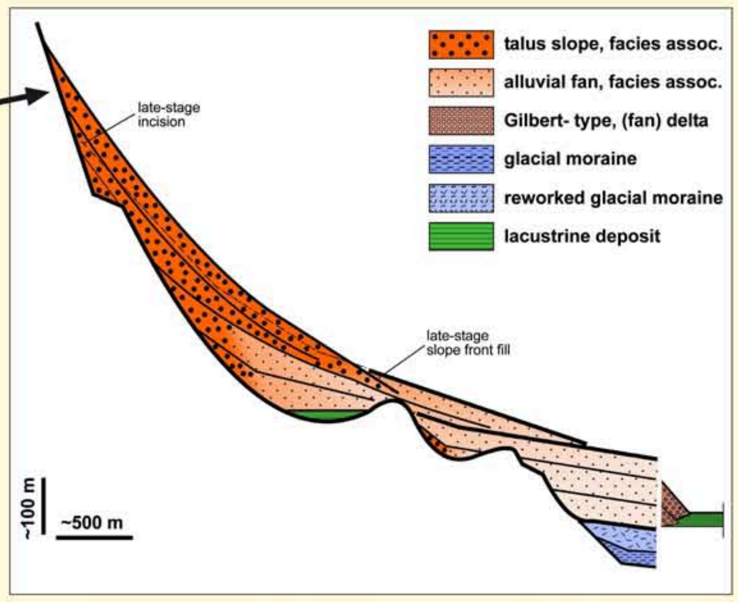


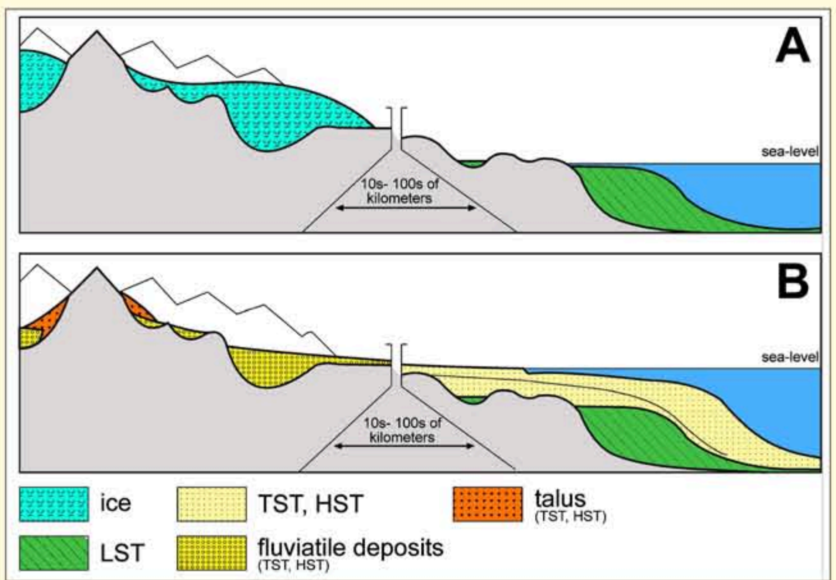

**Fig. 7:** Deposits and depositional geometries of alluvial fan-talus slope systems, deduced from Quaternary successions in the Northern Calcareous Alps (e. g. Figs. 1 to 4). The substrate is, either, country rock with a differentiated relief cut mainly by glacial erosion, or glacial-"paraglacial" deposits. Above, an alluvial fan succession is present. The alluvial fan succession provides the foundation for aggradation and progradation of talus slopes. During a late stage of development (corresponding to stage D in Fig. 6), the talus slopes are linearly incised, and deposition along the slope front prevails (slope front fill).

**Fig. 5:** Scheme of glacial-interglacial succession in tributary valley (cf. Fig. 6). A: During glaciation, the valley is filled by ice (dashed line), and moraines accumulate locally. During deglaciation, paraglacial deposition (reworking of moraines) and flowslides preferentially occur. B: Thereafter, in the valley, aggradation mainly of fluvial deposits starts while along mountain flanks, significant aggradation of alluvial fans and talus proceeds. C: Under interglacial conditions, slope erosion is lowered by vegetation. Both in valleys and on alluvial fans, aggradation is slowed. In cirques, rock glaciers become juxtaposed or downlapped by talus. D: In a "mature" stage, under persistent interglacial conditions, because of progressive or lasting hillslope stabilization, talus slopes are characterized by incision and redeposition. Alluvial fans and fluvial systems are dominated by by-pass or incision. In stages C and D, minor climatic fluctuations can trigger increase or decrease of hillslope erosion, and resulting minor pulses of deposition and erosion on fans and along rivers. Overall, however, the rate of change is very slow relative to glacial to "paraglacial" conditions (stage A and B).

**Fig. 8:** Hypothetical, simplified correlation of glacio-eustatic marine sequence with montane, glacial-interglacial sequence.

A: During glaciation and sea-level lowstand, in marine sequences, an unconformity and a lowstand systems tract form. In the mountains, except local accumulation of moraines, glacial erosion prevails; major deposition occurs on sandur ahead of glaciers (potential interstadial deposits not shown).

B: During deglaciation and interglacial sea-level highstand, in marine sequences, the transgressive and highstand systems tracts (TST, HST) accumulate. In the mountains, corresponding to the TST and HST, valleys become filled mainly by fluviatile deposits while mountain flanks become onlapped by talus slopes (but note that fluvial incision, fanhead trenching, and incision of talus slopes may commence early after maximum aggradation; see Figs. 5 to7).




| GLACIO-EUSTATIC MARINE SEQUENCE | GLACIAL-INTERGLACIAL MONTANE SEQUENCE |
|---|---|
| Sea-level fall, sequence boundary formation. Turbidite deposition on basin floor and slope front | Buildup of major glaciation. Deposition of fluvial deposits ahead advancing glaciers. |
| Sea-level lowstand: Lowstand prograding wedge | Glacial: Deposition of glacial diamicton. Major "lowstand" sedimentation in the foreland of glaciers. |
| Sea-level rise: Transgressive systems tract. | Deglaciation: Redeposition of glacial deposits, rapid accumulation of alluvial fans and talus. |
| Sea-level highstand: Highstand systems tract. | Interglacial: Fluvial incision or sediment by-pass, incision or by-pass on alluvial fans, slow aggradation to incision on talus slopes. |
| Major erosion typically confined to subaerial portion of sequence boundary, and to the interval of sea-level lowstand. | Deep erosion (glacial, fluvial, mass-wasting) can be active during any stage of sequence development. |
| Common, distinct erosional surfaces: (1) Unconformity, (2) Ravinement surfaces. | Numerous erosional surfaces within a single glacial-interglacial succession. |
| Processes of sediment dispersal active over large areas and long intervals of time. | Distinct sets of processes of sediment dispersal active over small areas and over short intervals of time. |
| Systems tracts distinguished by both consistent physical position and superposition within a sequence. | Systems tracts distinction by physical position and superposition hardly possible (only in some deposystems). |

Simplified comparison of glacio-eusatic marine sequence with glacial-interglacial montane sequence

**Reference:**
Obojes, U., 2003, Quartärgeologische Untersuchungen an den Hängen der Innsbrucker Nordkette (Höttinger Breccie). Unpubl. Diploma thesis, University of Innsbruck, 89 pp., 1 map.

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