ASPECTS OF QUATERNARY STRATIGRAPHY ON THE GEOLOGICAL MAP OF THE WESTERN DOLOMITES: PROBLEMS AND APPLICATIONS.

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The geological mapping of the Western Dolomites was mainly carried out within the framework of the project Geological Base Map South Tyrol, Sedimentary Part in the years 1995 to 2003. The main focus of the project was on the bedrock and structural geology, less on the quaternary geological mapping. The mapping of quaternary deposits was therefore carried out partly according to lithofacial, partly according to lithogenetic, and often according to geomorphological criteria using aerial photography interpretations. This applies in particular to the widespread landslides, which in the main valleys have frequently reworked the sediments and altered the morphology of the Würmian Late Glacial Maximum (LGM) and the Würmian Lateglacial. For the 2nd edition of the Geological Map of the Western Dolomites, the quarternary deposits and the landforms were revised by the interpretation of aerial photographs and laser scan images, field observations and consultation of new research results. The stratigraphic subdivision of the quarternary deposits follows the guidelines of the Italian national geological map programme CARG for terrestrial quarternary deposits (Guida al rilevamento della Carta Geologica d'Italia 1:50.000 - Quaderno 1 serie III, 1992, with additions 2001 and 2003). This provides for a subdivision according to allostratigraphic aspects into so-called "UBSU" (= unconformity-bounded stratigraphic units, Salvador, 1994). These are units which are limited by discordances. The basic unit of the UBSU is the synthem, subunits are called subsynthems, superordinate units are called supersynthems. In the lithostratigraphic subdivision, the synthem roughly corresponds to the rank of a Group. The synthems are represented on the geological map with different colors. In turn, they are composed of different deposits, lithofacies types and lithogenetic units that can be mapped at a scale of 1:10.000, such as glacial and glaciofluvial deposits, ice-marginal deposits, talus breccias, etc. However, these are always provided with the same oversignatures. For the 2nd edition, the German nomenclature of the Quaternary legend was revised and adapted to the modern international standards and terms used by the CARG. The newly developed terminology catalogue for Quaternary and landslides of the Geological Survey of Austria (Steinbichler et al., submitted) was also taken into account. Following this, the term moraine, which in German is traditionally used to refer to sediments as well as morphology, is replaced by till (e.g. basal till of a laterofrontal moraine) and moraine ridges (moraine). Also in the case of landslides, the rock bodies detached from the original rock units and gravitatively moved by falling, sliding, creeping and flow processes are regarded as deposits. In the Dolomites, due to the special lithological succession characterised by significant dolomite cliffs and underlying weak marly strata, many rockfall deposits, rapid landslide deposits, debris flow deposits and earth flow deposits can usually be well delimited according to these criteria. The lithogenetic units are summarized on the present geological map as in the CARG under the term lithofacies, the geomorphological units and quaternary phenomena under the term landforms. The chronostratigraphic classification is done by assigning the lithofacies and landforms to the respective synthems and subsynthemes.

The age-related classification of the Quaternary and landslide deposits and forms on the map sheet is based almost exclusively on stratigraphic evidences and analogies to better investigated areas of the nearer and wider surroundings (Brixen/Bressanone Basin, Überetsch/Oltradige, Etsch/Adige Valley, Venetian-Friulan Foreland, Inn Valley) and on the most recently published absolute dates from the Dolomites. In the last decades, quaternary geologists and geomorphologists of the University of Modena dated numerous organic remains in different quaternary deposits in the upper Gader/Badia Valley by means of a large number of radiocarbon-datings (also taken from drill cores). For the first time they could prove pre-LGM- (46-38 ka BP) and early Lateglacial (about 16 ka BP) ages of deposits on the Pralongià plateau. In addition, numerous radiocarbon-datings of organic remains (woods) in landslide deposits or their underlying or backwater deposits allow a good cronological delimitation of the numerous landslides of this area. The data show clusters of landslide activities from the Early Holocene (10 ka BP) until the present day, triggered probably by climate variations or induced by earthquakes (Corsini et al. 2001; Soldati et al., 2004; Borgatti et al., 2007; Soldati & Borgatti, 2009; Panizza et al., 2011; cf. also Brandner & Keim 2011). Numerous historical landslide events are also documented in reports.

The Synthem classification applied to the Geological Map of the Western Dolomites had to be modified as compared to adjacent new CARG map sheets (e.g., Toblach/Dobbiaco, Cortina) due to lacking field evidence or contexts which are difficult to interpret.

TIERS/TIRES SYNTHEM

One of the main discordances of alpine quarternary deposits is the contact of non-glacial deposits with glacial deposits (till deposits). For example, in the Tiers/Tires Valley, in the area of Völs am Schlern/Fiè allo Sciliar and in the Gröden/Gardena Valley, there are slope, debris flow and torrent deposits as well as lacustrine deposits overlain by till (especially basal till) of the LGM. These "pre-LGM"? deposits have been grouped under the name "Tiers/Tires-Synthem". Referring to the common synthem-structure of the CARG project, this synthem is part of the Monte Spinale Supersynthem.

DOLOMITES SYNTHEM

The glacial deposits of the Last Glacial Maximum are named after the catchment areas of the individual large ice streams of the ice flow network, which mostly also followed the valleys of today's main rivers and bear their names. The "Garda-Synthem" comprises the catchment area of the former Etsch/Adige glacier. Its name derives from its main glacial tongue in the Lake Garda basin with its wellknown amphitheatre-shaped terminal moraines (Ravazzi et al., 2014). The delimitation of the Garda-Synthem causes great difficulties in the western Dolomites. In their central areas, the flow directions of the LGM ice streams are still largely unclear. The main reason for this is primarily the special topography with the plateau-like mountain ranges, which are separated by wide, low passes. This results in the absence of large contiguous glacier accumulation areas. Ice transfluences are possible in all directions. Furthermore, the glaciers of the Dolomites were significantly backlogged and deflected by the thick central alpine ice streams of the Rienz/Rienza and Eisack/Isarco glaciers. Mutschlechner (1933), Klebelsberg (1956), Panizza et al. (2011) and Marchetti et al. (2017) all postulate the penetration of the Rienz/Rienza glacier from north to south into the uppermost Gader/Badia Valley and a transfluence to the south into the Cordevole Valley, based on sparse isolated finds of crystalline clasts in till. They presume the advance of the Eisack/Isarco glacier into the upper Gröden/Gardena Valley with a transfluence to the East over the Gröden/Gardena pass. This assumption has to be questioned, however, as important erratic blocks such as amphibolite and quartz porphyry are missing. In addition, the subglacial striations on the Seiser Alpe/Alpe di Siusi and on the Puflatsch/Bullaccia plateau, which are approximately E-W-oriented in the laser scan image, indicate ice transports out of the valley for most of the Gröden/Gardena Valley. Only in the lower Gröden/Gardena Valley an ice flow in NE-SW direction is clearly visible. The general lack of ice flow direction indicators and informative erratic blocks from the Dolomite region do not allow a clear delineation of the Garda synthema or any sub-synthema for the central part of the map sheet area. For this reason, the term "Dolomites Synthem" was introduced, which applies to all areas with LGM glacial deposits consisting of debris from the upper Permian to Cretaceous strata (Bellerophon Fm to Puez Fm) of the Dolomites.

EISACK/ISARCO SUBSYNTHEM

The till deposits of the LGM with frequent clasts of crystalline and Permian quartz porphyry are distributed throughout the entire Tiers/Tires Valley and partly in the Villnöß/Funes and outer Gröden/Gardena valleys. They are evidence of the dominance of the Eisack glacier in these valley sections and show its advance to the slopes of the Rosengarten/Catinaccio, as for example in the Tiers/Tires Valley. Here the term "Eisack/Isarco subsynthem" was used, which is a subsynthem of the Garda synthem. On the other hand, neither a separate Rienz/Rienza subsynthem and Avisio subsynthem as parts of the Garda synthem nor a Cordevole subsynthem as spart of the Piave synthem have been identified. This is because the few finds of crystalline clasts in the quaternary deposits of the upper Gader/Badia Valley (Mutschlechner, 1933; Klebelsberg, 1956) do not imply the southward advance of the Rienz/Rienza glacier during the LGM and its overflow to Buchenstein/Livinallongo Valley. In addition, the crystalline clasts could also derive from older glaciations and be reworked. Similarly, ice flow directions and potential transfluences over the Sella Pass or Pordoi Pass in the upper Fassa Valley have not yet been clarified. For these reasons, the LGM sediments in the entire Gader/Badia Valley, Fassa Valley and Buchenstein/Livinallongo Valle have been subsumed under the Dolomites synthem (cf. Geological Map Sheet 029 Cortina d'Ampezzo, 2007; Panizza et al., 2011; Marchetti et al., 2017).

LATEGLACIAL SYNTHEM

The conditions of the Lateglacial deposition history are very complex. They are characterized by the early Lateglacial deglaciation and subsequent pulses of glacier advances remaining in upper valleys (valley glaciers). The advances occured during distinct climate deteriorations in the Oldest and Younger Dryas (stadials). The cold phases were interrupted by warmer periods (Bølling/Allerød interstadial) Each of these valleys is to be regarded as a separate deposition system with corresponding till, ice-marginal deposits, talus breccias, debris flood deposits, etc. The correlation of these sediment bodies, limited by unconformities, from one valley to the next is therefore extremely difficult, especially in the absence of absolute age dating. To prevent the introduction of new names (subsynthems), the informal name "Lateglacial Synthem" was used for all glacial and non-glacial deposits of the Lateglacial. The Lateglacial moraine stratigraphy was established in the Central Alps and is named after stabilised terminal moraines of glacier advances in the valleys of the Stubai Alps (Tyrol, Austria) (Gschnitz, Daun and Egesen stadial moraines). Meanwhile, the exposure ages of a number of these terminal moraines have been dated (cf. Ivy-Ochs et al., 2008; Reitner et al., 2016). For the Dolomites there are no absolute dates available so far. The Lateglacial moraine stratigraphy, transferred from the Central Alps to the Dolomites, has been applied by some autors until the recent past (cf. Klebelsberg, 1927; Castiglioni, 1964; Ghinoi & Soldati, 2017). The previous data on the Gschnitz, Daun and Egesen stadial moraines in the Dolomites, which are based exclusively on calculating the equilibrium line altitudes (ELA) in relation to the 1850s moraines of the Little Ice Age, are, however, no longer valid according to modern scientific knowledge. This is because the topographical and climatic conditions of the Dolomites deviate fundamentally from the Central Alps and moraines of the 1850s are scarce. Absolute age dating of stabilised glacier moraines or rock glacier deposits is still lacking. Therefore, only temporally undifferentiated Würmian Lateglacial moraines and till are identified on the geological map. Due to the lack of age dating information, there are also overlaps between the Lateglacial and the Alpine Postglacial Synthem with regard to the age classification of, e.g., landslide deposits, rock glacier deposits, alluvial and debris fan deposits.

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