

HALFGRABEN FORMATION PERPENDICULAR TO EXTRUSION: THE NEOGENE WALDHEIMAT BASIN IN THE EASTERN ALPS

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The Neogene Waldheimat basin (Early-Middle Miocene) is characterized by an asymmetric basin fill along a major, ENE-trending normal fault which is oriented subparallel to the northern boundary of the Neogene extrusional wedge in the Eastern Alps. The Waldheimat basin include the St. Kathrein (W) and Kogl (NE) subbasins. Considering all available surface and subsurface (former mining) information, we subdivide several lithofacies. These include from the base to the top: (1) **Basal breccia/sand lithofacies**: A thin veneer of fine breccia and grits covers the basement. These lithotypes were mainly found during mining in the St. Kathrein subbasin. (2) **Sand/coal facies**: Mica-rich sands and silts are intercalated by three coal seams. The coal seams are together ca. 10.5 meters thick and include some whitish vitric and phenocrystic tuffs. (3) **Sand/clay lithofacies**: The section above the sand/coal lithofacies is composed of bituminous, often laminated clay which yield plant fossils, brown and gray clay followed by well-bedded coarse sand. Basal portions of the sand/clay lithofacies within the St. Kathrein subbasin comprise some tuffaceous material mostly within the bituminous clay. (4) **Gravel facies**: A thick sequence of well-rounded gravels within a yellowish, clayey matrix represents the most prominent formation exposed at the surface. The thickness of these gravels reaches 170 meters within wells. The clasts have a diameter of 10 to 40 cm in average, with a maximum diameter of ca. one meter suggesting a very short transport distance. A broad range of clasts have been observed which include the following sources: (a) Light greenish quartzite, deformed metaconglomerates and paraconglomerates within a foliated, sericite-rich matrix are most likely derived from the Alpine Verrucano Fm. which is exposed

to the east within the upper part of the Wechsel window. These comprise major portions of the entire boulder spectrum. (b) Augen orthogneiss, paragneiss are exposed within the Stuhleck-Kirchberg nappe in the surroundings of the basin. (c) Vein quartz is common, micaschist clasts are rare. (5) **Unsorted gravel facies**: At the north-eastern corner of the Kathrein subbasin, unsorted gravels with blocks and boulders of a diameter of ca. one meter are exposed. All clasts are angular to subangular. The clasts are mostly quartzphyllite, augen gneiss and quartzitic micaschist to light-brownish quartzite which all strongly resemble to rocks of the Stuhleck-Kirchberg nappe as exposed at the ridge to the north of the Waldheimat basin.

The basin fill displays a uniform, coarsening upward depositional cycle. The lower lithofacies types (1-3) are interpreted to represent a marsh and lake environment which is later replaced by fluvial and alluvial deposits. Sections based on mining data display that basal formations are thick along northern sectors and thin towards south. The presence of a normal fault with a minimum vertical displacement of 300 meters along the northern margin and the internal discordance between sand/clay and gravel lithofacies suggest a rollover structure. The near-base coal seams are folded according to published sections from the mining period.

The ENE-trending master normal fault suggests ca. NNW-SSE extension. This fault is overprinted by N-trending sinistral strike-slip faults and NE-trending reverse faults. Slickenside and striation data were collected at 33 sites between Alpl and Retenegg in order to evaluate fault kinematics. In many outcrops, superimposed sets of slickensides and striations indicate a polyphase reactivation of these faults. Note that along fault

traces outcrop conditions are poor and therefore only a few reasonably large exposures have been found along major faults. We observed four sets of paleostress tensor groups deduced from fault patterns.

(1) **Deformation stage D₁**: The dominant pattern, including more than 70 percent of all measured mesoscale faults, records N-S to NNW-SSE extension. The pattern includes predominantly S- to SE-dipping normal faults with dip-slip sense of displacement.

(2) **Deformation stage D₂**: The normal faults are overprinted by E-W (to subordinate NE-SW) extension patterns which include ca. N-trending normal faults. The basement high separating the St. Kathrein and Kogl basin was initially delimited by such faults.

(3) **Deformation stage D₃**: Extensional patterns are overprinted by N-S to NNW-SSE oriented compressional structures. The pattern is obviously related to compressional structures, folds and reverse faults as found in the subsurface.

(4) **Deformation stage D₄**: The final event is ca. E-W to NE-SW strike-slip compression which formed a conjugate set of strike-slip faults.

The data presented above show that formation of the Waldheimat basin was initiated by a major normal fault along northern margin of the basin. Both map-scale fault geometry and paleostress orientations consistently argue for a predominantly normal sense of movement which resulted in at least 300 meters vertical offset after map data. Both the missing faults along the southern margin of the St. Kathrein subbasin and the internal structure argue for an essentially half-graben-type structure in the St. Kathrein subbasin which was later modified by minor reverse faults and some internal folding forming ca. ENE-trending folds. We interpret these structures to record two stages of basin evolution: (1) Basin formation during a tensional stage of faulting with a top to the SSE dip-slip throw leading to NNW-SSE extension (D₁) and subsequent E-W extension (D₂); (2) basin inversion during a late-stage N-S to NNW-SSE (D₃) and subsequent E-W (D₄) contractional stages.

The basin fill records the structural evolution. In a first step fine breccias and grits were deposited. The relative fine grain size and sediment composition indicate an only minor relief, short

distances of transport and a local source. Deposition of these clastics was followed by sedimentation of organic material within a calm aquatic environment in a lake without a major relief in the surroundings. A later increasing amount of coarse clastic material came into the depocenter with a river from the northeast (Wechsel window area). The relief rapidly increased with deposition of rocks comprising the gravel lithofacies. The composition of clastics within the gravel lithofacies argues for an eastern source within the Wechsel window which was uplifted during the Miocene. This argues for a longitudinal sediment transport parallel to the basin axis typical for rift settings. Finally, supply of sediments from the eastern source stopped and lateral sediment supply along the northern basin flank with mass flows replaced it. This resulted in the deposition of unsorted gravel lithofacies along the northern basin margin.

The extensional nature of the Waldheimat basin contrasts with other intramontane basins of the Eastern Alps which are generally interpreted to represent pull-apart- and transcurrent basins along major strike-slip faults. In this sense, the Waldheimat basin belongs to a group of basins which formed internal to the northern lateral margin of the extrusional wedge. The basin is obviously not controlled by strike-slip faults but by normal faults which indicate extension perpendicular to the motion direction of the escaping block. The Waldheimat basin is, therefore, an example of an extensional basin that formed in response to the widening of the escaping block during progressive eastward extrusion. The succession of deformation events is similar to those found to the north along the Mur-Mürz wrench corridor.

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