Geological controls on formation of tufa-precipitating spring (Eastern Alps): what do the maps tell?

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A parameterized check of geological maps shows that most Eastern Alpine spring tufas are situated in till-veneered areas of the Rhenodanubian Flysch Zone and of the Molasse Zone, and on metamorphic rocks (phyllites, phyllonites) of the Penninic Unit. Presence and abundance of tufa is controlled by the underlying substrate and, in some cases at least, by deep-reaching faults supplying mineralized waters.

Spring tufa denotes calcium carbonate (calcite, aragonite) precipitated at and closely downstream of springs with cool to subthermal waters. $CaCO_3$ precipitation from spring waters is driven by CO_2-degassing, leading to or enhancing supersaturation for calcium carbonate. In the Alps, aside of speleothems and biogenic lacustrine carbonates, spring tufa is the third major type of presently-formed calcium carbonate. To better understand geological controls on the formation of tufa-precipitating spring, a top-down approach in scale is taken. To date of submission, a total of 125 maps was checked (2 in 1/500.000, 1 in 1/75.000, 82 in 1/50.000, 39 in 1/25.000, and 1 in 1/10.000). Main parameters recorded include tectonic unit, its major composition in map area, Tertiary and Quaternary deposits, the rock substrate a tufa is situated above, the immediate substrate a tufa rests on, and altitude and exposition of a tufa deposit. Only maps were used for which it was certain that spring tufas were mapped (post world-war 2 maps of the Geologische Bundesanstalt Wien and of the Bayerisches Geologisches Landesamt, and a few pre-1945 maps).

Spring tufas are most common in the Rhenodanubian Flysch Zone, and on marly successions of the Molasse Zone and of the inner-Alpine Tertiary. Next in abundance rank diverse types of phyllites and Bündnerschiefer of the Penninic Unit and, subordinately, of Austroalpine metamorphic units. Conversely, the Northern Calcareous Alps and the Drauzug are quite poor in tufas. The majority of spring tufas directly rests on glacial till or, much less commonly, on other deposits of Late-Glacial to Holocene age. Tufas are of roughly similar abundance on all slope expositions from north to south. Most Eastern Alpine tufas are present in 200–850 m a.s.l. Up from about 850 m, tufas overall are less common, but locally may be abundant up to 2500 m a.s.l. (highest recorded location: 2520 m a.s.l.). Topographic relief and relief roughness seem not to obviously control presence and abundance of tufa. The Alps show a „northern bias“ of both abundance and size of tufa deposits. Deposits kilometers in size are present in the undeformed northern Molasse from lake Constance to Munich. These tufas are situated where terraces built mainly by Pleistocene sandar break off into wide, north-draining valleys. In the foreland of the

Southern Alps, by contrast, tufa occurrences this size appear to be absent. On the Bohemian massif, in the inspected maps, no tufa occurrence was found, although large areas are veneered by loess.
A comparison of tufa locations with mineral springs and thermal springs indicates that many tufa deposits are present above or near deep-reaching fault zones that provide ascend to mineralized/thermal waters. Eastern Alpine spring tufas are present in three main types, (1) foreland-type, nourished by groundwaters percolating through veneers of till and sandar, typically including larger areas of paludine tufas, (2) perched-spring type on steep to vertical valley flanks, dominated by waterfall tufa, moss tufa and phytoclastic tufa, and (3) perched-seep tufa of paludine character situated on gentle slopes, and dominated by moss tufa and phytoclastic tufa.
The prevalence of tufas on flysch, on marl-dominated successions, and on glacial till indicates that tufa-precipitating spring is favoured by these substrata. Leaching experiments (by B. Rüf, Innsbruck) suggest that phyllites, too, are an effective source of dissolved calcium carbonate. In addition, oxidation of metal sulphides, common in phyllites, provides acid waters of high leaching potential. On carbonate rock terrains, rapid passage of karstic groundwaters typically results in springs that strongly fluctuate both in discharge and dissolved substances; in these areas, tufa-depositing spring is associated with thick mantles of till and/or with gypsiferous successions. Below the snowline, neither exposition nor altitude place obligate limits on tufa formation. The northern bias of tufas across the Alps may be related to large lobate sheets of lodgement till (mainly Riss and Würm) and associated sandar in the northern foreland. Extensive areas, underlain by molasse, of tills and sandar may favour the formation (till, molasse marls) and passage (sandar) of groundwaters rich in dissolved calcium carbonate. The Southern Alpine foreland is devoid of wide till-veneered areas, and late Pleistocene fluviatile gravels are largely buried by sandy-clayey deposits of the Po river. The scarcity or absence of spring tufas on the Bohemian massif is related to absence of till and/or to country rocks (gneiss, amphibolite, granulite, eclogite) unfavourable to formation of tufa-precipitating spring.