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Synmetamorphic uranium mineralization from Tiraun, Graubünden, Switzerland

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ABSTRACT. Petrographic, microscopic, and X-ray investigations of a uranium occurrence near Tiraun, Graubünden, Switzerland, are described. The uranium mineralization occurs in greenschist facies metamorphic rocks of the Tavetsch massif and consists essentially of uraninite of various habits with minor chalcopyrite, linnaeite, millerite, galena, marcasite, pyrite, hematite, magnetite, and skutterudite. The ore structure, characterized by concentrations along foliation planes, boudinage, and rotated (helicitic) textures of uraninite porphyroblasts, is indicative of a synmetamorphic (Alpine) remobilization, recrystallization and enrichment of the ore, which was probably derived from an original 'protore' in psephites and psammites (? sandstone-type mineralization) of at least Variscan age. The synmetamorphic emplacement of the ore took place under medium- to high-temperature conditions (approx. 350-400 °C), as demonstrated by the lattice constants of the uraninite phases and by the ore paragenesis. Late to postmetamorphic tectonism resulted in a partial remobilization (over cm distances) and redistribution of the ore along veinlets that cut the foliation planes. The characteristics of the ore from Tiraun are similar to those from the synmetamorphic ore from Preit, northern Italy, as described by Cevales (1961).

URANIUM-mineralized blocks occur in detritus in the locality of Tiraun at the foot of the slope south of the village of Schlans in the Anterior Rhine Valley, Graubünden, Switzerland (fig. 1). The occurrence was discovered in 1962 and investigated by three shallow drill holes put down by the Swiss 'Studiengesellschaft für die Nutzbarmachung Schweizerischer Lagerstätten mineralischer Rohstoffe'.

This paper presents results of petrographic, mineralogical and X-ray investigations of a suite of samples from Tiraun and of comparative samples from the similar occurrence of Trun, some 1.5 km to the south-west. The latter occurs *in situ*, in metamorphic rocks of the Tavetsch massif, and was investigated by Kramers (1973). Kramers determined the primary age of the mineralization as being between 303 and 329 Ma and suggested that the ore formed under high-temperature hydrothermal conditions by mobilization of metal contents from the adjoining host rock during the Variscan metamorphism.

Geological setting

The area of interest lies at the eastern end of the three massifs of the Swiss Central Alps (i.e. the Aar massif, Tavetsch massif, and Gotthard massif), consisting of basement rocks of pre-Pennsylvanian age and their respective sediment covers, here consisting of Permocarboniferous ('Verrucano') and Mesozoic rocks (fig. 1).

The uranium occurrence of Tiraun lies at the eastern end of the Tavetsch massif, very close to the contact with the overlying Verrucano of Ilanz. The contact itself is covered by slope debris. Rocks of the Tavetsch massif in the Tiraun area comprise mainly muscovite schists and muscovite gneisses, and subordinate amphibolites, biotite gneisses, 'streifen' gneisses, and biotite granite (Niggli, 1967). The Verrucano of Ilanz consists primarily of psephitic and psammitic rocks which were metamorphosed during the Alpine orogeny and now occur as partly brecciated metaconglomerates with a greenish-grey sericitic matrix and greenish, greenish-grey to purple sericite quartzites. The Alpine metamorphism overprinted also the rocks of the Tavetsch massif, so that they are now in a polymetamorphic state. The Alpine metamorphism in the Tiraun area reached conditions of the lower greenschist facies: Tiraun lies almost exactly at the boundary of two Alpine metamorphic mineral zones, characterized by the disappearance of stilpnomelane and the appearance of chloritoid (Frey *et al.*, 1980).

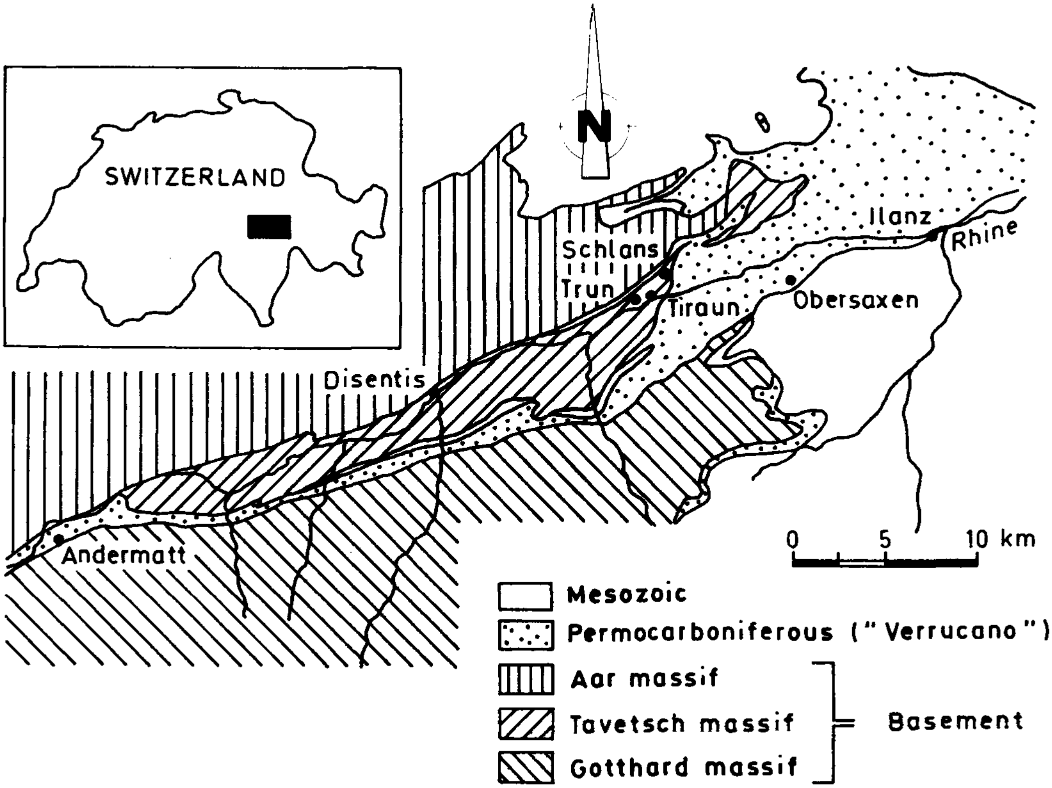


FIG. 1. Geological-tectonic sketch map of the Anterior Rhine Valley (after Kramers, 1973).

Petrography of the host rocks

The uranium mineralization occurs in two rock types of the Tavetsch massif: (*a*) in orthoclase-plagioclase-quartz-muscovite schists, partly carbonate-rich, and (*b*) in feldspar-quartz-chlorite-muscovite gneisses.

The light green, phyllitic schists consist of parallel-oriented muscovite layers, 0.02 to 0.8 mm thick, alternating with up to 2 mm thick aggregates of quartz, carbonate, and muscovite (grain size 0.02 to 0.04 mm), and of orthoclase and plagioclase (grain size up to 0.2 mm), with lenticular or boudinage structures; lenticular granitic fragments occur locally. Helicitic structures in partly perthitic feldspars demonstrate their metamorphic recrystallization.

The light greenish gneisses consist of abundant (40 vol. %), almost monomineralic quartz lenses, up to 0.25 mm wide and 5 mm long, minor augen of perthitic feldspar, and rare carbonate aggregates in a sericitic-chloritic matrix. The fabric is characterized by a regular parallel orientation of the lenses and the matrix.

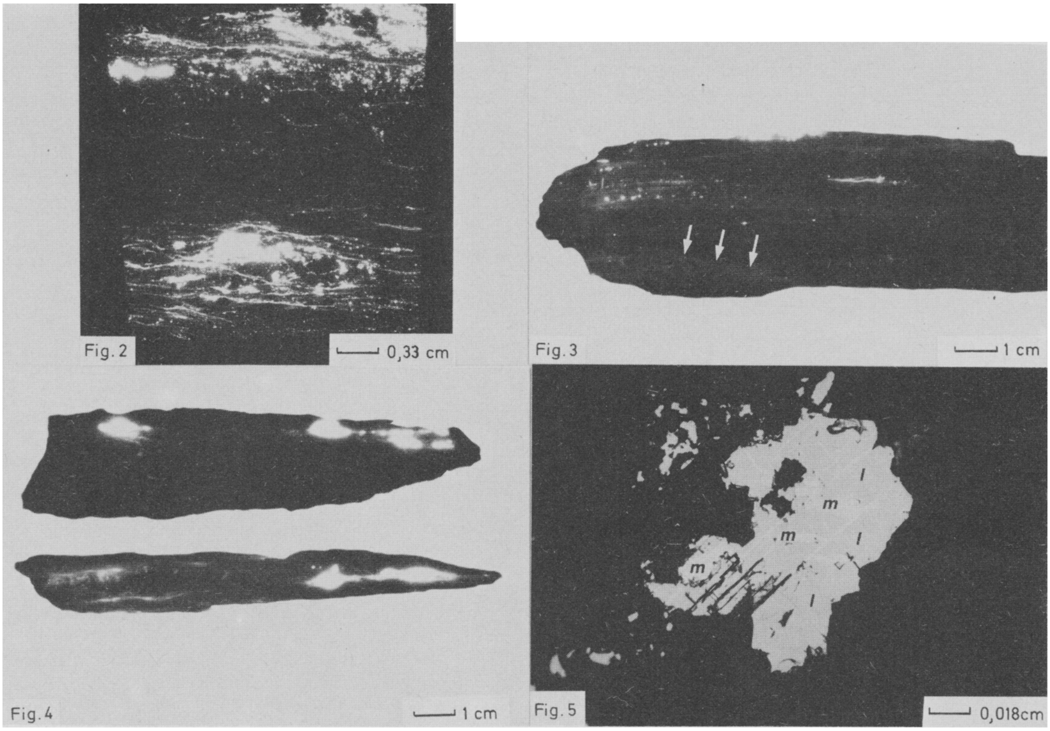
The schists and gneisses of the Tavetsch massif are very similar in composition and appearance to the rocks of the Verrucano of Ilanz (cf. Kramers, 1973, pp. 19 ff.).

Ore mineralogy

The ore consists essentially of uraninite accompanied by minor amounts of chalcopyrite (partly with spindle anisotropy), linnaeite with exsolution bodies of millerite (fig. 5), galena, marcasite, pyrite, hematite, often intimately intergrown with magnetite (fig. 12), and skutterudite. Iron oxides and hydroxides occur locally as joint coatings.

The presence of two essentially different types of uranium mineralization is apparent on the macroscopic scale: (*a*) mineralization cross-cutting the foliation plane, and (*b*) mineralization parallel to the foliation plane of the host rock. The second type forms the main topic of this paper.

Uranium mineralization parallel to foliation planes. Except for local enrichment around quartz-feldspar-mica-carbonate aggregates, the



FIGS. 2–5. FIG. 2. Sample CH 650 (Tiraun); autoradiograph of a thin section. S-parallel distribution of radioactivity (white) with local stronger enrichments in crests of small folds. FIG. 3. Sample CH 651 (Tiraun); autoradiograph of a hand specimen. S-parallel distribution of radioactivity (white) and postmetamorphic redistribution in a fracture cutting the foliation at a low angle (arrows). FIG. 4. Sample CH 650 (Tiraun); autoradiographs of hand specimens. S-parallel radioactivity and nodular enrichment (white) in a gneiss (top) and a mica schist (bottom). FIG. 5. Sample CH 660 (Tiraun). Photomicrograph of a polished section; nic. //; obj. 50 × imm. Network-like exsolution of millerite (m) in linnaeite (l).

uranium mineralization is not related to any particular compositional layers, such as micaceous or feldspathic.

The main characteristic of the uranium mineralization is its orientation, which is strictly parallel to the foliation planes (s-parallel) of the host rock (figs. 2 and 3). The ore concentrations form mm-thick interlayers and spots that locally grow into aggregates of up to 3 cm size (figs. 2 and 4), particularly in the crests of small-scale folds or in the pressure-shadows of larger lenticular quartz boudins.

In other cases, the uranium mineralization forms s-parallel boudin-like concentrations, in which the individual uraninite porphyroblasts are elongated perpendicular to the foliation plane (fig. 6). A similar feature is displayed by large mica flakes. Some of the porphyroblasts are clearly rotated (helicitic texture, fig. 7), similar to the feldspars of the host rocks.

The features described above clearly indicate that uraninite recrystallized during metamorphism (Spry, 1974, p. 255), simultaneously with and showing the same growth features as some silicate minerals (micas, feldspars).

The s-parallel uranium mineralization consists essentially of uraninite, which occurs in various morphological varieties: (*a*) nebulous fine-grained material concentrated along the cleavage planes of minute sheet silicates (figs. 8 and 9), (*b*) botryoidal pitchblende aggregates (fig. 9), and (*c*) euhedral uraninite grains (figs. 8 and 9). The three varieties can occur separately or, more commonly, mutually intergrown (figs. 8 and 9). The most abundant variety is the botryoidal pitchblende, which often shows concentric layers of varying reflectivity (fig. 10).

The colloform uraninite grains are often strongly fragmented (fig. 11) and the fractures are healed essentially by quartz, locally euhedral, and by minor chalcopyrite and rare galena or hematite–magnetite intergrowths. Kramers (1973, p. 40) reports intergrowths of pitchblende and (?) doiomite from Trun.

The uraninite is locally altered to 'gummite', i.e. hydrated, as shown by reddish rims visible in thin section.

Pitchblende, especially from comparative samples from Trun, shows distinct anisotropy (fig. 13); however, the X-ray diffractogram does not contain twin peaks like, for example, the tetragonal α-U_3O_7 from Key Lake (Voultsidis *et al.*, 1982). Therefore, it is concluded that the cubic pitchblende from Trun–Tiraun has a slight lattice defect, probably due to the influence of late metamorphic stress (Klemm, 1962). The lattice constant *a* of the pitchblende varies between 5.439 Å and 5.454 Å.

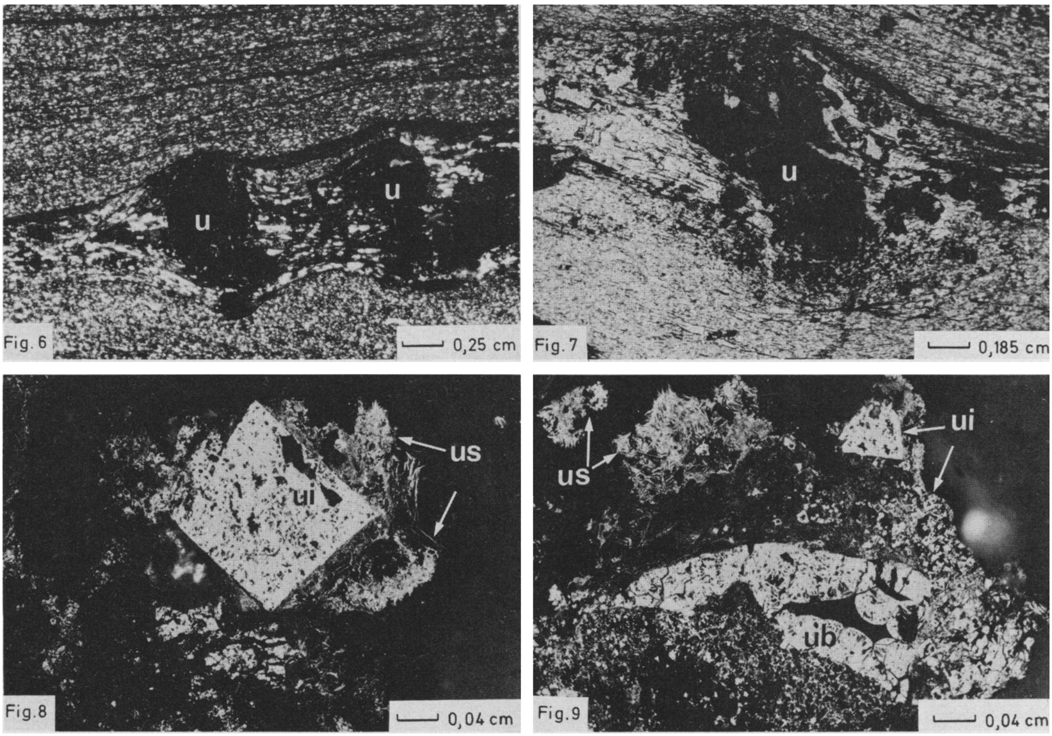
Late to postmetamorphic features. Late to postmetamorphic mineralization occurs in veinlets of up to 2 mm width that cross-cut the foliation. They consist essentially of uraninite. In some cases, uranium concentrations cut the foliation plane at a very low angle (fig. 3), which suggests mineralization along late metamorphic cleavage planes.

The latest event, probably Quaternary, is represented by the surface alteration which resulted in the formation of yellow, or more rarely, greenish- or orange-coloured secondary minerals. Kramers (1973, p. 51) determined autunite, $Ca(UO_2)_2 . 10\text{–}12\ H_2O$; kasolite, $Pb(UO_2)(SiO_3)(OH)_2$; and vandendriesscheite, $PbO_7O_{22} . 12H_2O$. During the present investigation, the occurrence of billietite, $BaU_6O_{18}(OH)_2 . 8H_2O$, has been determined by X-ray diffractometry.

Conclusions

The observations described above are interpreted as follows.

The uranium mineralization was formed under moderate to high temperature conditions. It is generally accepted that the lattice constant of

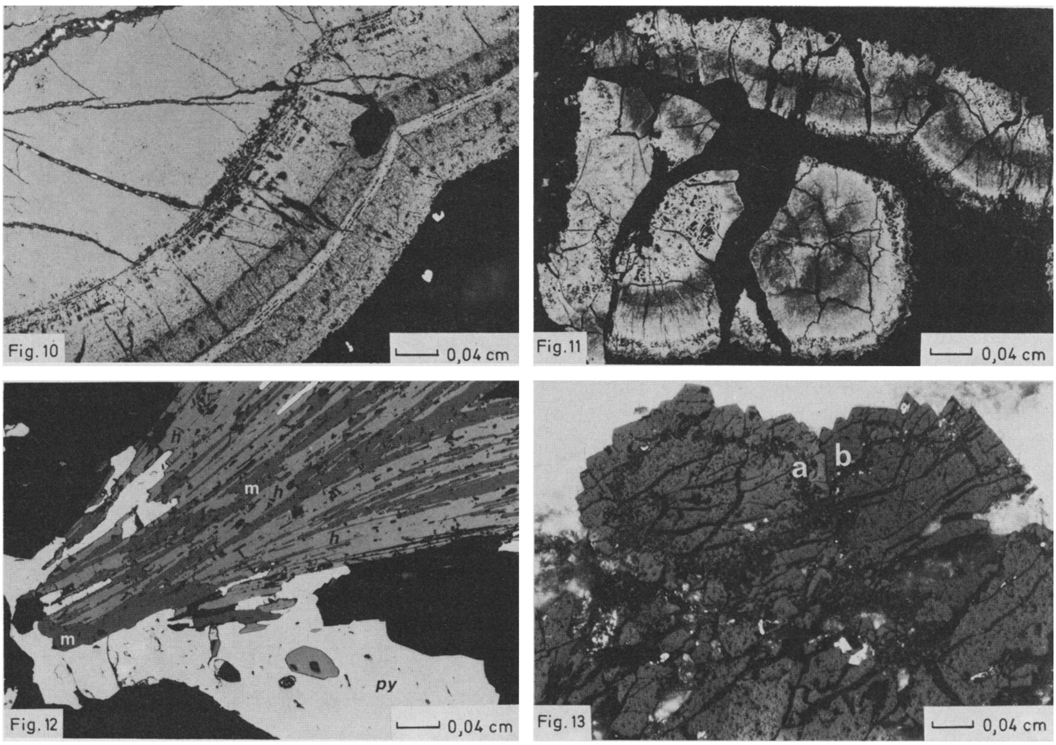


FIGS. 6–9. Photomicrographs: FIG. 6. Sample CH 651 (Tiraun). Thin section; nic. //. S-parallel boudinage of (? rotated) uraninite in mica schist; the larger uraninite porphyroblasts (u) are elongated perpendicular to the foliation. FIG. 7. Sample CH 651 (Tiraun). Thin section; nic. //. Rotated porphyroblast of uraninite (u) in mica schist. FIG. 8. Sample CH 652 (Trun). Polished section; nic. //; obj. 20 × imm. Idiomorphic uraninite (ui) surrounded by sheaf-like uraninite (us) grown after sheet silicates. FIG. 9. Sample CH 652 (Trun). Polished section; nic. //; obj. 20 × imm. Sheaf-like uraninite (us) grown after sheet silicates and around botryoidal (ub) and idiomorphic (ui) uraninite.

uraninite shows a linear increase proportional to the temperature of formation, from low (5.39 Å, sedimentary) to high (5.46 Å, pegmatitic) (Brooker and Nuffield, 1952), although deviations from this rule may be caused by varying contents of trace elements (e.g. Makarov *et al.*, 1960; Cathelineau *et al.*, 1979) and by the age of the uraninite (Cathelineau *et al.*, 1979). The lattice constant of the uraninite from Tiraun and Trun (5.439 to 5.454 Å) indicates a moderate to high temperature of formation, around 350 to 400 °C. This compares well with the conditions of the Alpine regional metamorphic grade of host rocks of the area, i.e. lower greenschist facies, with temperatures around 400 °C and pressures of about 3 (?) kbar (Frey *et al.*, 1980).

The occurrence of spindle-like anisotropy in chalcopyrite and the presence of linnaeite may be further indications for a higher temperature of formation of the ore (Ramdohr, 1975, pp. 568 and 754).

The ore was remobilized, recrystallized, and enriched synmetamorphically from a pre-existing 'protore'. This main conclusion is supported by several observations. First, the host rocks do not show any signs of alteration phenomena that would be expected if the mineralization were the product of hydrothermal-magmatic ore-forming processes. Secondly, the macroscopic structure and the microscopic features of the ore are typical for a synmetamorphic ore, i.e. boudinage, rotated porphyroblasts (helicitic texture), and the presence of ore in pressure-shadows of silicate porphyroblasts. Similar features are described from the uranium mineralization at Preit, Italy (Cevales, 1961, p. 118). Finally, the synmetamorphic formation is also indicated by the simultaneous occurrence of two to three uraninite varieties: nebulous, colloform, and idiomorphic. Cevales (1961, p. 116) reports similar features from Preit and postulates that synmetamorphic remobilization resulted in



FIGS. 10-13. Photomicrographs of polished sections: FIG. 10. Sample CH 660 (Tiraun); nic. //; obj. 20 × imm. Botryoidal uraninite (grey) with concentric structure and reflectivity variations; chalcopyrite (white, top left) as fracture infilling. FIG. 11. Sample CH 651 (Tiraun); nic. //; obj. 20 × imm. Strongly fractured, botryoidal uraninite (grey) in matrix (black). FIG. 12. Sample CH 658 (Trun); nic. //: obj. 20 × imm. Leaf-like intergrowth of hematite (h) with magnetite (m) in pyrite (py). FIG. 13. Sample CH 656 (Trun); nic. × (−8°); obj. 20 × imm. Aggregate of uraninite (grey) with anisotropy visible at the boundary of grains (*a*) and (*b*); matrix: dolomite.

the presence of a more oxidized nebulous variety and one or two less oxidized varieties (i.e. idiomorphic and botryoidal) that have lost oxygen during metamorphism.

The coexistence of the three varieties is possibly also an indication that the mobilization was spatially limited (perhaps over cm-dm distances; cf. Ramdohr, 1953).

Since the mineralization is in rocks from the Tavetsch massif, that is in polymetamorphic rocks, the question arises whether the synmetamorphic mineralization is related to the Alpine metamorphic event or represents a relict from the Variscan (or an older) metamorphism. It appears reasonable to assume that a Variscan (or older) mineralization could not have suffered the lower greenschist-facies Alpine metamorphism without being remobilized and recrystallized. The microscopic ore features, such as boudinage, porphyroblasts elongated perpendicular to the foliation, and rotated porphyroblasts, are identical with those typical from low- to medium-grade metamorphic rocks derived from Mesozoic rocks from the same area and to the west (e.g. chloritoid, margarite, staurolite, garnet; cf. Frey *et al.*, 1980, pp. 215 ff.); that is, from rocks that suffered only the Alpine metamorphism. The authors therefore conclude that the Tiraun-Trun mineralizations represent the remobilized and recrystallized Alpine metamorphic products of an older (cf. Kramers, 1973: 303-329 Ma) mineralization, which was possibly in the form of 'protore', i.e. as a low-grade metal concentration. Since the host rocks are derived from clastic sediments (ranging from psephites to pelites), it might be speculated that the original uranium concentration was of sandstone-type origin. If this is true, then the Alpine metamorphism resulted in a substantial enrichment rather than a dilution of the premetamorphic protore; in fact, grab samples from the Tiraun occurrence contain up to several per cent U_3O_8.

Late to postmetamorphic events resulted in a partial, spatially very limited, redistribution of the ore as shown by the uraninite veinlets cross-cutting the rock foliation, and in the local formation of secondary uranium minerals.

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