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Structural Studies of the Valser Rhine Valley and Lukmanier Region and their Importance for the Nappe Structure of the Central Swiss Alps

By *Gerhard Voll*, Bonn *)

Abstract

These studies were carried out from 1963–1967. Outcrops at the Lukmanier road gallery yielding important evidence have been partly covered since. The study is concerned with fabric development and related metamorphism, conclusions concern relations between basement and cover, Gotthard massif and Lepontine Nappes, nappe movement and structural development. There is disagreement in important points with work done later in the same region (CHADWICK 1968; THAKUR 1973). There is no space here to discuss this in detail but comparison will make the differences obvious.

THE LUKMANIER REGION: BOUNDARY BETWEEN AUTOCHTHONOUS BASEMENT + COVER AND LEPONTINE NAPPES

Aar- and Gotthard-massifs are parts of the variscan basement underlying the alpine chain. They are deformed by a first slaty cleavage (s_1) forming a fan and strong stretching upward (str_1). str_1 fans along the strike, lying down the dip of s_1 in the strike culminations of both massifs. Urseren-Curaglia- and Disentis-synclines are pinched between these massifs and include a further basement slice – the Tavetsch massif.

The Lukmanier region is the most southerly part of the Gotthard massif and the S margin of the autochthonous basement. Its rocks consist of variscan granite- (Streifengneis, Riesenaugengneis) and para-gneisses (e.g.: Tremola series) + posttectonic variscan intrusions (e.g.: granite: Medelser granite; diorite: Cristallina diorite). Granite gneisses were strongly flattened, stretched and partly refolded before the posttectonic intrusions arrived. This is seen clearly N

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of Platta where granite gneiss feldspars are strongly flattened, stretched and recrystallized, then cut by variscan pegmatites. These have suffered alpine deformation only but no recrystallization of feldspars. Prealpine str plunges gently NE, superimposed alpine str_1 is down the dip of alpine s_1.

Near the S-end of the Gotthard massif the Scopi syncline is faulted and folded into the basement. Its S-limb is bounded against the basement by a large zone of movement, affecting sediments and basement aswell. It continues W into the basement where the plunging syncline lifts out. The movement zone uses s_1 and str_1 for deformation. W of the Scopi syncline basement rocks continue S to near Frodalera, underlying the mesozoic cover rocks which form the mountains E of Lukmanier Pass. Towards the N-margin of the Scopi syncline Medelser granite and Cristallina diorite are increasingly deformed. This shearing is inhomogeneous. It uses s_1 and str_1, found throughout Aar and Gotthard massifs. Xenolith-deformation in the diorite indicates strong flattening in s_1, extension parallel str_1 which plunges steeply SW in s_1. Towards Scopi syncline strongly sheared zones increase in width and number. Less deformed slabs in between contain tension-gashes normal to str_1. In Medelser granite of normal deformation K-feldspar and plagioclase form rigid, unrecrystallized inclusions and quartz flow round them, strongly deformed and recrystallized. Within zones of strong shearing, however, feldspars are changed into micas. Within such slabs of micaschist, formed from Medelser granite, magmatic quartzes form augen, lying little deformed and recrystallized between the micas. This shows: the shear zones have started early in deformation. They allowed water to enter and early formation of micas from feldspars. Quartz was then still less deformed and escaped further deformation between micas. Therefore the quartz augen are less recrystallized. Biotite and garnet grew at maximum T cutting the resulting s_1-planes.

The most southerly parts of the granite are totally silicified. The boundary to the basal quartz conglomerate and a narrow dolomite-layer is largely obscured. The resulting quartzites show static annealing.

Stratigraphy in the N-limb of the Scopi syncline is reduced. Strata, however, show first folds overfolding towards the main syncline, s_1 crosses bedding (ss). s_1, str_1 continue from the granite into the sediments. There is no trace of an older deformation related to gliding of sediments across the cover and cutting out of strata (FREY, 1967). I conclude: such an earlier deformation does not exist – s_1, str_1 have formed with the first deformation affecting basement and cover. Axes of minor folds related to the main syncline curve in s_1 from parallel to the main axis (35 NE) to down the dip. str_1, however, maintains a constant attitude in s_1. As everywhere in mesozoic sediments of (calcareous, psammo-) pelitic character a simple method can be used to recognize s_1 and refolding of it (VOLL, 1960, 1968): quartz (– carbonate – sulfide) – veins are formed during and parallel to s_1. Formation of second folds refolds ss, folds the veins and s_1. No new veins are formed parallel to $s_{2,3...}$. Where the main syncline bends round numerous minor folds with limbs of equal length and strongly curving axes occur. Within marls of upper liassic age just S of the main axis minor first folds are largely sheared. s_1 is indicated by quartz-carbonate-sulfide – veins indicating an intersection ss/s_1 related to the main syncline. These rocks have suffered intense refolding with mm- to 10-m-amplitudes and corresponding recleaving. I call resulting features B_4, s_4, str_4 within the Lukmanier region – for reasons becoming clear furtheron. s_4 is nearly penetrative, intersects ss in the same sense as s_1 on horizontal and with opposite sense on vertical sections across ss. B_4 is parallel $str_{1,4}$. str_4 coveres s_4 and now maintains the attitude of the former str_1. Veins following s_1 are minutely plicated between s_4-planes. The same is true for s_1 itself, but this may only be seen in thin section. Resulting minute B_4-folds are included by numerous zoisite-blasts which overgrew B_4 in a still less compressed state. Outside the blasts the matrix has sagged together by further compression, due to pressure solution-folding and without rotation of the blasts. There B_4-hinges between s_4-planes are largely obliterated. Crinoid beds are repeated 3 times above the gallery by B_4-folding. Going S along the gallery B_4, s_4 die away on entering more sandy beds of lower liassic age. There B_1, s_1, str_1 again dominate. A major 1st fold repeats characteristic garnetiferous beds 3 times along 300 m. Veins are not plicated any more, Quartzite-ss-surfaces carry flexure-gliding-slickensides normal to B_1 of the main syncline. Garnets grew while s_1 was still active: they fix an earlier thickness of thin shaly layers which suffered further thinning outside garnet or are rotated indicating upward movement of more southerly parts under rotational deformation.

Short limbs of minor B_1-folds in the Quartenschiefer following S are intensely sheared. s_1 is kinked into third folds. I call them 3rd because they seem earlier with respect to porphyroblast growth than B_4. The kink-band morphology is caused by the strong planar anisotropy acquired by mica orientation during s_1-movements. s_1 is kinked from normal steep N-dip into S-dip within short B_3-limbs. There s_1 is plicated between s_3 on a sub-mm scale. s_3-planes – and kink-boundaries – dip 30° N. s_3 again is covered by str_3, lying in the great circle normal to the strike and containing $str_{1,\,4,\,2}$. B_3 curves strongly in s_3 to attitudes similar to the ones of B_1. B_4- and B_3-refolding are restricted to narrow zones within the Scopi syncline. They have escaped observation by other workers and do not occur further S.

Larger folds complicating the S-limb of the Scopi syncline and the large Campo anticline following to the S (where gypsum and carbonate rocks reach the surface) are all 1st folds. At the S-margin of this Campo anticline a new narrowly spaced cleavage develops. I call this s_2 of Lukmanier region as it developed earlier than $s_{3,\,4}$ with respect to garnet growth. At the S-slopes of Piz Cadreghe, i.e. at the N-margin of its area of distribution it starts forming at high angles to s_1. Going S s_2 is rotated quickly with increased deformation (in clockwise sense looking W). s_1 and veins are finely plicated between s_2-planes. Towards the S larger folds with amplitudes up to 100 m develop. They are all isoclinal with N-vergency. s_2 and axial planes of B_2 are flat. s_2 is covered by str_2, normal to the strike, B_2 curves to all positions within s_2. Veins are folded into isoclinal B_2-folds.

Gotthard massiv cover-rocks refolded this way are bent into a broad open synform; I call this B_5 of this area as its folds are late with respect to growth of garnet, staurolite and kyanaite, and later than all others. Numerous minor folds plicate $s_{1,\ 2,}$, related to this synform. They are open, their axial planes and correlated s_5 fan, being vertical in the center. B_5 does not curve and plunges gently NE. s_5 is more widely spaced (1–15 mm), micas are not reoriented thoroughly in B_5-hinges. No stretching fibre develops but there is strong metamorphic differentiation by solution and redistribution. Quartz and carbonate migrate into B_5-hinges, limbs are enriched relatively in micas. Hornblendes of liassic rocks frequently depict this by preferentially growing in hinges. At the S-margin of the Dötra-synform a 5th antiform bends s_{1+2} down towards the old road to Olivone. Near Frodalera axial planes of 1st synclines are steep again. These folds are penetrated and refolded by s_2, B_2 and plicated by B_5. Further E the same folds lie flat N of the Lucomagno nappe and are plicated by open B_5-folds. Hornblende-, oligoclase- and even biotite-blasts are largely posttectonic with respect to B_5, garnet is largely pretectonic with respect to B_5, posttectonic with respect to B_2 and staurolite, kyanite maintain intermediate positions, being post-B_2 but in parts still syn-B_5.

The Dötra-synform preserved a higher nappe resting directly upon liassic rocks of the Gotthard massif cover. This nappe starts with triassic Quartenschiefer and continues upward with a pile of liassic Lugnez schists. These are equivalent to Sosto schists and Grava Series further E and belong to a higher Pennine nappe, rooted underneath the Tambo nappe. The importance of this fact will become clear after description of structures from the Valser Rhine valley. Here the Lugnez schists are deformed in the same manner as autochthonous sediments underneath. There is no doubt that this fabric (isoclinal flat B_2) developed during immigration of this (and higher) nappe(s). It caused rotation of s_1 and refolding in autochthonous sediments thereafter, dragging these rocks by friction. This effect fades downward (or N in the S-slopes of Piz Cadreghe) and where Medelser granite and Cristallina diorite reappear at Selva Secca to the W of and underneath the B_5 antiform they only display the same steep s_1 and str_1 as further N. Relations of garnets still affected by s_1-movements in the S-limb of the Scopi syncline and of garnets having grown post-s_2 in the Dötra synform and S of it show that at a lower level s_1 and str_1 were still active while they had died long ago at a higher level containing the Lugnez schist nappe and sediments below it. This provides an excellent example of different deformation in lower and higher levels. It should be kept in mind that stages of folding and refolding do not represent episodes bounded by rigid time limits and may cover different time sections at different places. This is commonly found where softer layers occur between more rigid ones. There commonly the softer rocks are folded more often than harder ones at the same time.

The Lucomagno paragneiss nappe S of Frodalera to Olivone displays the same deformation as liassic rocks N of it, but B_2, s_2 become less important. Rocks of this nappe contain the same s_1, str_1 refolded by B_2, s_2, str_2. At the N-margin of the nappe these elements and B_5, s_5 have the same attitude as in mesozoic rocks N of the front. An open major B_5-synform bends s_{1+2} back into flat attitudes further S. There the Molare synform is folded into the back of the Lucomagno nappe. Bündner schists filling it are a southerly continuation of the Lugnez schists. These are wrapped round Adula and Simano nappes and draw back underneath them. Going S from the Dötra synform the Lugnez schist nappe leaves contact with the autochthonous cover and does not continue underneath the Lucomagno nappe. The Molare synform is a second fold with respect to alpine folding of the Lucomagno gneisses. Lugnez schists filling it, however are folded at least 5 times. Though ss is largely lost this may still be inferred from quartz-carbonate veins. These rocks were complicatedly folded by wrapping round the Adula front and captured by the Molare synform in this state, folded again during formation of the Molare synform. Furthermore, it shall be pointed out that the front of the Lucomagno unit has not suffered the same refolding as the Leventina- and Antigorio-fronts, a refolding which indicates braking effects at the lower side near the frontal parts.

STRUCTURES AT LUNSCHANIA, VALSER RHINE VALLEY

The structures of the Peiden Schuppenzone and Schuppen N of it has been described by NABHOLZ and VOLL (1963). To the S Lugnez schists rest upon these Schuppen. My studies have shown that they are determined by the same structural elements: B_2 isoclinal, N-vergent, s_2 flat, str_2 lying in s_2, normal to the strike, B_2 curving strongly in s_2. S of St. Martin, however, s_{1+2} are bent upward to the S round a synform (B_3 of this area) and back again round a corresponding B_3-antiform S of Pala de Tgiern. I.e.: the Lugnez schists are bent round these major folds into the Grava-Series with which they are identical. This is contrary to NABHOLZ (1945), who regards the Lugnez schists as rooted underneath the Adula nappe and the Grava Series as a different nappe unit as rooted underneath the Tambo nappe. This large fold continues far to the W and to the E where it splits up towards the Praettigau. I have shown all this to Prof. Nabholz many years ago and mentioned all the important consequences of stratigraphical and structural kind. There are numerous minor folds overfolding towards the hinge of the large ones, plicating s_{1+2} and isoclinal B_2-folds of quartz-carbonate veins. Corresponding s_3-planes are narrowly spaced, dipping steeply S. Micas are partly reoriented in B_3-hinges. A distinct str_3 is produced dipping steeply W on s_3. Therefore I do not correlate this syn- and antiform with the Dötra-synform, which is less penetrative. B_3 here, however, plunges constantly gently NE, curving only little. The S-limb of the Lunschania-Antiform is strongly refolded and recleaved by a rotational continuation of B_3-folding producing B_4, s_4 and B_5, s_5. These fold marbles and ophiolites of the Aul-Lappen.

CONSEQUENCES OF INVESTIGATIONS IN BOTH AREAS

Lugnez schists and Grava series are identical. Consequently they must be wrapped underneath the Adula front and be ironed out underneath Adula and Simano nappes back to Torre and the Molare synform. Complications of this wrapping in are seen at Sosto mountain N of Olivone. Lugnez schists there are folded 2 times before and 3 times during wrapping round the Adula front. Further S Lugnez schists contain the same complications, ironed out but still recognizable from veins. Folding in the Molare syncline adds at least one refolding.

Lugnez schists reached the Dötra synform with B_2, s_2 only, i.e. with the deformation N of the Lunschania-B_3-fold. In the Dötra syncline this nappe reached rocks of the Gotthard massif cover without being wrapped round the Adula front. As in the Valser Rhine valley, $s_{1,2}$ were produced during nappe movement, before porphyroblast growth. I conclude: no Lepontine nappe from Antigorio to Adula nappes has reached that far N in this cross section. The Lugnez schist nappe has travelled N and lefts its basement behind and these nappes aswell, even in this westerly cross section.

Lucomagno-, Leventina- and Antigorio-nappes cannot be regarded as parautochthonous basement, similar to that of the Gotthard massif either. For mesozoic cover rocks disappearing S underneath them show features of friction produced by overriding nappes. These Lepontine nappes themselves have all features of nappe gliding inside: flat s_1 and str_1 over their flat main parts; strong extension (str) normal to the strike. s_1 may be joint by flat s_2 in softer rocks (paragneiss of the Lucomagno). These nappes left their root areas simply deformed (s_1, str_1) and remained simple during main transport (or acquired second folds as the Molare synform in softer parts). They became complicated by refolding in the steepened roots and by braking effects at the lower side near the front. This caused strong increase of rotational deformation for Antigorio and Leventina, producing recleaving and refolding, formation of a str_2 on

s_2-planes – again normal to the strike. Cover sediments were wrapped in or refolded where they had been overrolled already. The Lucomagno nappe does not show this braking – it has moved freely into its present position. Such braking effects too indicate free gliding before they became effective. Even the lowest Verampio unit shows the flat s_1, str_1 of nappe gliding and soft schists on top of it are folded 4 times, the folds being ironed out to become isocinal. In the Lukmanier region pressures necessary for formation of kyanite must have been produced by nappes higher than the Adula, resting on top of the Dötra synform at the time of kyanite formation. There is no fabric equivalent to a later gliding off of such nappes and it seems more likely that they were removed by erosion.

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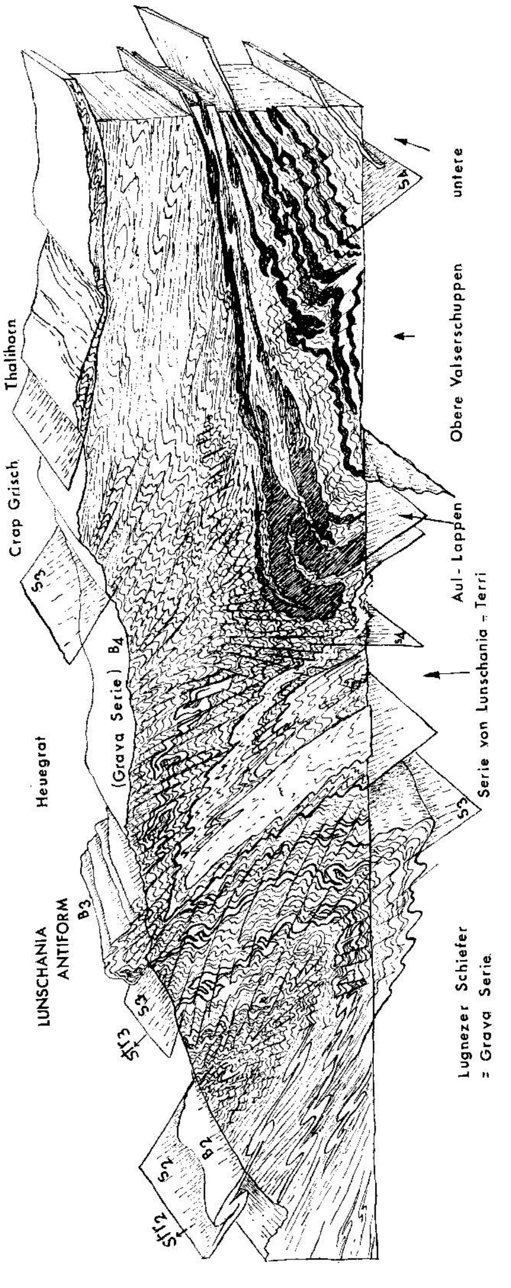
DIE DECKENFALTE VON LUNSCHANIA IM VALSER RHEINTAL, eine dritte Falte



DECKENPROFIL VOM MISOX INS PRÄTIGAU W. Nabholz (1951)

VOLL

Lu Lugnezer Schiefer, M Molare Mulde
Sc Scopi Mulde, Sa Soja Decke

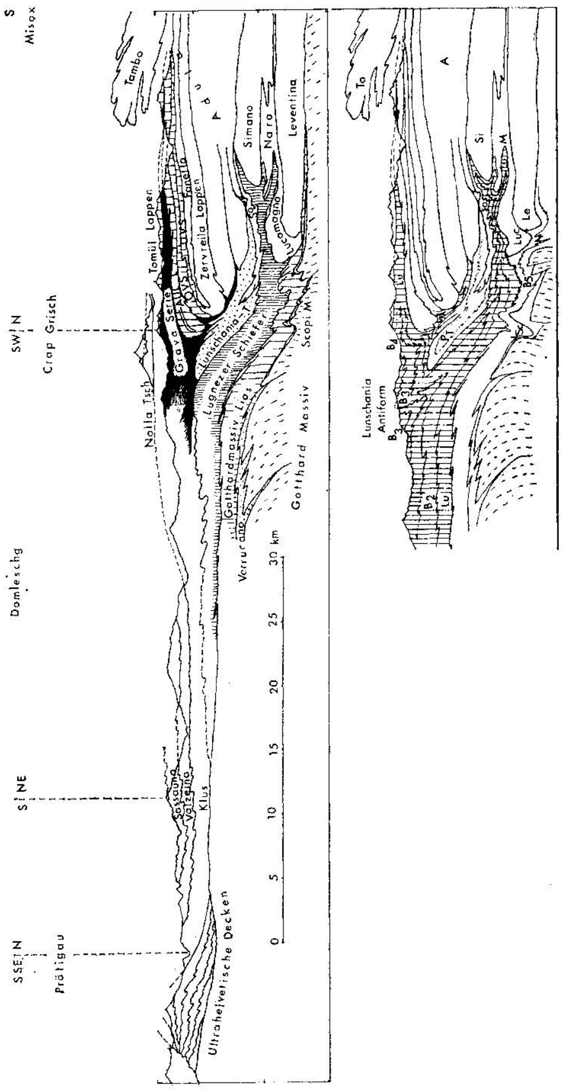


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PLATE I

GERHARD VOLL: Structural Studies of the Valser Rhine Valley and Lukmanier Region and their Importance for the Nappe Structure of the Central Swiss Alps