Conclusions

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amongst light-coloured acid tuffs. The tectonic structure and alteration of these rocks is largely Alpine; no definitely earlier structures have been observed other than a weakly developed bedding in some tufaceous conglomerates.

Two distinct cleavages are present in the basement rocks; the earlier one dips generally to the south at a low angle and is concentrated especially near the inverted limb of the fold. The second cleavage dips steeply to the south-east and lies in the axial planes of minor folds; it is especially well developed east of the Untere Furggeli, immediately north of a larger fold (100 m amplitude) which probably belongs to the same deformation phase (see stereograms, fig. 34).

The tectonic history of these basement rocks during the Alpine folding appears to have been (1) lateral transport of part of the Aar Massif as the core of the Windgällen recumbent fold, and (2) folding about steeply south-dipping axial planes. This corresponds to the structural development seen in the Mesozoic rocks of the N. Tödi area. The repeated deformations of the autochtonous massif produced movements on the same steeply south-dipping cleavage and gave no individual interfering structures.

CONCLUSIONS

The studies of the Tödi and Maderanertal areas show that the Upper Paleozoic formations contain a well-developed and varied volcanic suite of silicic to moderately silicic rocks which stretches for a distance of at least 20 km in an E–W direction. The estuarine and lacustrine beds that are seen in the eastern exposures were presumably laid down in small inland basins which formed in local areas of subsidence. Heavy rainfalls caused the rapid erosion of the volcanics and permitted the growth of a rich vegetation around the basins. Vegetation probably covered the greater part of the area and gave rise to the local carbonaceous beds found in the Maderanertal as well as to the thin anthracites of the NE Tödi area.

The older rocks below the volcanics formed a land surface during the early volcanic episode and had delivered components to the basal conglomerates of the Biferten inlier. During the main volcanic episode, lavas, lava débris, tuffs and explosive breccias formed an extensive blanket over the older rocks so that pebbles of gneisses, hornfelses and granites are not abundant; they are seen in the volcanics of the Klein Tödi and in one bed on W. Tscharren. In the Bifertengrätli Formation of the NE Tödi area the older rocks are again found as components in the Estuarine Member, as by this time rivers had worn through the volcanic blanket into the older rocks. Even during this period, however, volcanic explosions gave rise to crystal tuffs.

The acid volcanics of the Maderanertal area originated during violently explosive activity which is thought to be roughly coeval with the explosions of Klein Tödi and the Biferten inlier. The acid explosions gave rise to extensive ignimbritic flows which became rapidly eroded in more exposed areas. Crystal tuffs of more intermediate composition in the upper part of the Tscharren Formation support the correlation with the volcanic activity of the Bifertengrätli Formation, but no plants have been found in the former succession to make this correlation certain.

THE EXTENSION OF THE TÖDI-MADERANERTAL ZONE

The direct continuation of the Tödi-Windgällen-Bristenstäfeli zone of Upper Carboniferous formations to the west crosses the Reuss valley at Intschi and extends to the Sustenpass area, where it appears to enter the basement rocks below the Färnigen syncline (ALB. & ARN. HEIM 1916; MORGENTHALER 1920). Farther west this belt forms the so-called zone of envelope-schists of the Central Aar granite (E. HUGI 1934) which extends into the Lötschental and continues along the root zone of the Morcles nappe. Many of the rocks of this schist belt are older paragneisses with a complex history of intrusion of basic and acid rocks (LEDERMANN 1946), and hornfelses of possible Paleozoic age (MORGENTHALER 1920).

A narrow belt containing probable Carboniferous sediments is seen in the northern part of the central Aar Massif between the Gastern-Innertkirchen granites and the Erstfeld granite zone: this forms the frequently mentioned exposures of the Wendenjoch (HUEGGLY 1927; KOENIGSBERGER 1926; TH. HÜGI 1947, 1956) and was encountered in the Lötschberg tunnel (BRUECKNER 1943).

After a gap of some 50 km, dated Upper Carboniferous rocks reappear in the Salvan-Dorénaz syncline of the Aiguilles-Rouges Massif. The most marked contrasts of these sediments with those of the eastern Aar Massif are the predominance of locally derived older gneisses and granites in the conglomerates and the fact that they pass upwards into purple-coloured beds of supposed Permian age (OULIANOFF 1924; SUBLET 1962). Contemporaneous volcanic activity has not been described from the northern Aiguilles-Rouges Carboniferous (LAURENT 1965), although SUBLET (1962) describes rhyolites and quartz diorites from the Upper Carboniferous conglomerates which may indicate earlier volcanic activity. The lack of typical Mt-Blanc granites ("protogine") from these conglomerates is a suggestion of the post-Upper Carboniferous age of this granite, which may thus be of the same age as the similar Central Aar granite.

The Upper Paleozoic rocks of the Tödi-Maderanertal belt along the northern border of the eastern Aar Massif are the northernmost dated pre-Triassic sediments of the autochtonous units of the western Alps. To the south, Upper Paleozoic rocks are known from the internal areas of the Alps, but these lie in more complicated structural positions. The numerous and isolated outcrops of Upper Carboniferous sediments of the Swiss Alpine region are reviewed by RITTER (in JONGMANS 1960), and many further references are to be found in that work. The review of RITTER and a summary of the Verrucano (Permian) question by TRÜMPY (1966) make it clear that it is impossible to establish any detailed stratigraphical correlations between the widespread areas. The striking fact which emerges from the literature on the Upper Carboniferous and Permian sediments of the western, central, southern, and parts of the eastern Alpine regions is that during the whole of the later part of the Upper Paleozoic, continental conditions ruled over a large tract which was then to subside during the Mesozoic into a complicated geosynclinal area. Volcanic activity was widespread during the Upper Paleozoic, and to discuss the history and paleogeography one will have to clearly analyse the volcanic activity of the area which extends from the Massif Central (LETOURNER 1952), the French external massifs (LAMEYRE 1957, 1958; SARROT-REYNAULD 1964; TERMIER 1894; TOBI 1958, 1959), the Briançonnais area

(DEBELMAS et al. 1964), the Pennine nappes (SCHAER 1959), the Helvetic root zone (NIGGLI 1944) and the eastern Helvetic nappes (AMSTUTZ 1954) and into large areas of the southern Alps. At the moment only vague correlations invoking the use of hypothetical ancient structural lines are possible (STAUB 1956; TRÜMPY 1966).

VAL GLIEMS

The exposures of undated pre-Triassic sediments closest to the Biferten area lie directly south of Tödi in Val Gliems, near the eastern end of the Aar Massif. Metamorphic sediments from this area were described by EUGSTER (1951) as equivalents of the Bifertengrätli Formation; the metamorphic conglomerates of Val Gliems were correlated with the coarse breccias of WIDMER's Grünhorn Formation. The area was restudied to verify this correlation, but with negative results. Further results of this study will be published elsewhere (FRANKS 1968).

The rocks that make up Val Gliems and its extension to the west are metamorphic conglomerates, knotenschiefer and hornfelses with thin calc-silicate layers which form a distinct stratigraphical sequence. This sequence cannot be correlated with the Bifertengrätli Formation or any of the volcanic formations on the nothern border of the Aar Massif. Its older age is indicated by components of similar rock types in the conglomerates of the Bifertengrätli Formation. A Paleozoic age (possibly Lower Carboniferous) is probable for these sediments because of local graphitic horizons, the calc-silicate layers and the massive marbles that are found as components in the conglomerates. On the basis of the structural and metamorphic development of these rocks, we may assume that they were folded and metamorphosed at the same time as the Bifertenfirn metasediments; their higher grade of metamorphism is thought to be due to their proximity to the pre-Westphalian intrusive body (within the southern igneous complex of the Aar Massif?). The Bifertenfirn metasediments and the Val Gliems formations thus comprise, as proposed by WEBER (in HEIM 1922), a sequence of older "Carboniferous" sediments which are separated by a stratigraphical, structural and metamorphic break from the dated Upper Westphalian and Stephanian formations.

GENERAL AGE RELATIONSHIPS

The older rocks on which the Upper Paleozoic sediments were laid down consist in the eastern Aar Massif of two major units, (1) an older complex of gneisses, and (2) a younger series of metasediments (the Bifertenfirn and Val Gliems metasediments) and intrusives. The suggested relationships of the various areas are shown in fig. 65.

Age dating of rocks of the Aar Massif has not yet provided sufficient data to clarify the magmatic and metamorphic history that preceded the Upper Carboniferous sediments. Dates from the Aar Massif are concentrated in the Central Aar granite, and little is available for the older rocks. The late Hercynian age of the Central Aar granite, seen in the field to intrude the volcanics of the Tscharren Formation, is well established; the lead isotope ages (PASTEELS 1964) tend to give a slightly older average age – 230 to 300 million years – than the Rb/Sr ages of between 190 ± 21 and 250 ± 22 million years (JAEGER 1962; JAEGER & FAUL 1962; WÜTHRICH 1963, 1965).

The older history is not reflected in the dates available at present, but significance may be attached to the slightly older Rb/Sr dates from pegmatites in the Tödi granite (312 ± 12), the Etzlital (287 ± 12) and Lötschental (309 ± 30), from the Erstfeld gneiss (298 ± 12; 305 ± 12) and from the Gastern granite (271 ± 19). WÜTHRICH (1965) suggested that these slightly older dates may result from a "rejuvenation" of older minerals by heating just before the intrusion of the Central Aar granite; he rejects the possibility of distinguishing more than one orogenic phase.

The top of the Stephanian is generally accepted as ca. 280 million years (KULP 1961; SMITH 1964), but the base of the Stephanian and Westphalian stages are less well defined. FAUL & JAEGER (1963) suggest a revised age of 300 million years for the base of the Stephanian, but a somewhat younger age is more generally accepted (FRANCIS & WOODLAND 1964); an age of 300 million years would probably lie near the Namurian-Westphalian boundary. If this is correct, and if the ages of around 300 million years are significantly older than the ages of the Central Aar granite, the main Hercynian movements, metamorphism and intrusion took place after the Lower Carboniferous and before the Stephanian. The Central Aar granites would thus be unrelated to this episode, having intruded at a later date in the upper Stephanian or Permian. The Devonian and the lower part of the Carboniferous (Tournaisian to

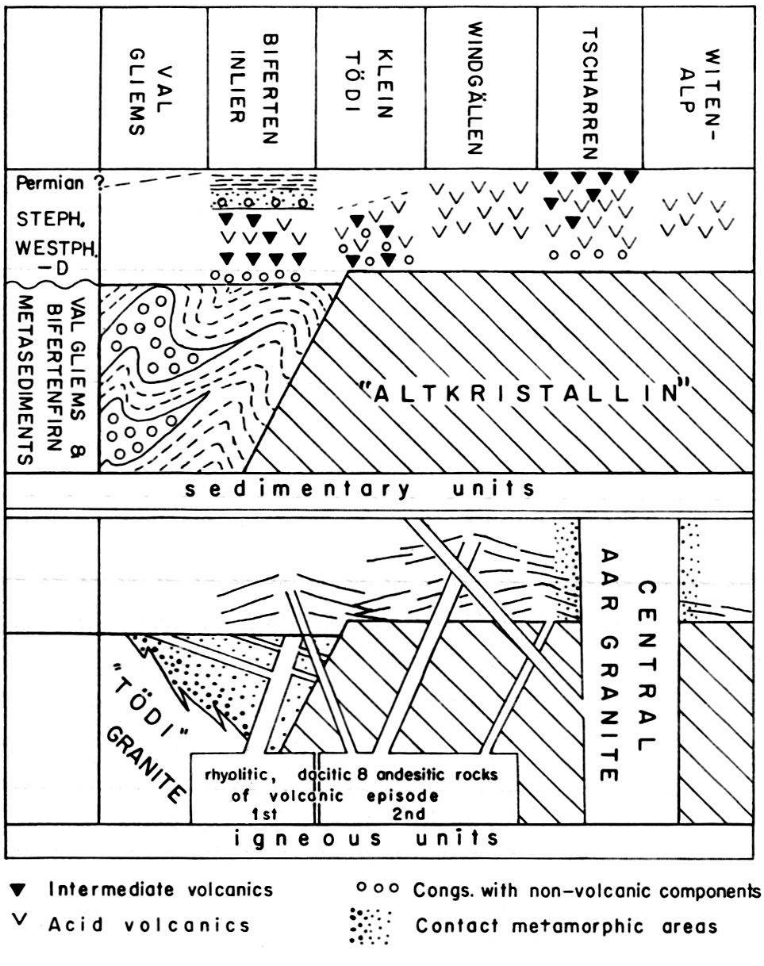

Fig. 36 Schematic reconstruction of the sedimentary and magmatic history of the eastern Aar Massif.

Namurian?) are open as a possible age for the Bifertenfirn and Val Gliems metasediments, but of course, a still older age cannot be excluded.

The pre-Westphalian-D movements and intrusions that are seen in the eastern Aar Massif are equivalent to the Segalunian phase of LUGEON (1911) in the western Alps, a term which is preferable to that of Asturian (STILLE 1924), as the former is imprecisely defined whilst the latter was intended by STILLE to mark a brief, sharply defined folding episode. The movements which preceded the deposition of the volcanic sediments of the eastern Aar Massif may prove to be the equivalent of the main Hercynian orogeny of this area.

ZUSAMMENFASSUNG

Die Zone der oberkarbonischen Sedimente, welche sich über eine Distanz von etwa 40 km vom Tödi im Osten zum Bristenstäfeli im Westen erstreckt, enthält eine Vielfalt an vulkanischen Gesteinen und damit assoziierten Sedimenten. Stratigraphie und Struktur dieser sedimentären und vulkanosedimentären Einheiten wurden einer Neuüberprüfung unterzogen, aus welcher eine Revision der Stratigraphie hervorgegangen ist. Folgende drei Gebiete stehen zur Diskussion:

1) Der NE-Abfall des Tödi,
2) Der Klein-Tödi,
3) Das Maderanertal.

Einzig der nordöstliche Tödi weist eine gut datierte Gesteinsfolge auf; die beiden westlicheren Gebiete wurden nur auf Grund ihrer Lithologie mit ersterem korreliert und damit als gleichaltrig angenommen.

Im NE-Tödi-Gebiet konnte nun eindeutig bestätigt werden, dass das Westphal-D und Stephan diskordant auf dem Tödigranit und älteren Hornfelsen liegt. Die Annahme WIDMERS (1949), wonach die Hornfelse ein metamorphosiertes Oberkarbon darstellen, musste aufgegeben und die frühere Auffassung WEBERS (1922) und HÜGIS (1941) gutgeheissen werden. Die Prä-Oberkarbon-Hornfelse zeigen eine leichte Kontaktmetamorphose (Albit-Epidot-Hornfels-Fazies erstreckt sich über den grössten Teil des Gebietes). Die Metamorphose wird als vom Tödigranit ausgehende Kontaktmetamorphose gedeutet. Die zahlreichen mikrogranodioritischen und mikroquarzdioritischen Lagergänge, die den gefalteten Hornfels durchschneiden, sind postmetamorphe Intrusionen, welche wohl viel eher mit einer späteren vulkanischen Tätigkeit als mit dem Tödigranit im Zusammenhang stehen.

Die aus oberkarbonischen Sedimenten bestehende *Bifertengrätli-Serie* besitzt lokal entwickelte Basiskonglomerate und -breccien aus Hornfels-, Granit- und Quarzitkomponenten. Es folgt ein rascher Übergang in vulkanische Breccien und Tuffe der unteren Abteilung, das «Volcanic Member». Diese klastische und pyroklastische Einheit wurde von WIDMER «Grünhorn-Serie» benannt und als jüngstes Glied aufgefasst; der Name «Grünhorn-Serie» soll aber nicht mehr verwendet werden. Die zwei oberen Abteilungen deuten auf die allmähliche Absenkung eines Beckens: Das «Estuarine Member» enthält kreuzgeschichtete Sandsteine und Arkosen, ferner Konglomerate mit sowohl älteren granitischen als auch vulkanischen Komponenten. Aus diesen Schichten stammen zudem die Pflanzenreste und die