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Geological Structure and History of Southwestern Germany

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With 2 figures

The southwestern part of Germany can be divided into the following geological units by using criteria of their geological history as well as of their recent geological and structural status (fig. 1).

1. Pre-Upper Carboniferous (to Permian) basement formed by several geotectonic processes of metamorphism and magmatism, the latest one being the Variscan (Hercynian) orogeny. This basement is exposed in the Black Forest (Schwarzwald), the Odenwald, and on the opposite (western) side of the Upper Rhine Graben in the Vosges mountains (Fig. 2). It consists of two major units:

1.1 Pre-Variscan (-Hercynian) Gneiss series of complex history. Metamorphosis led to the formation of gneisses, mostly paragneisses even before the Variscan orogeny. If there has ever been a depth zone with phyllitic metamorphites or mica shists. such rocks must have been eroded or destroyed otherwise already before sedimentation of the permo-mesozoic cover series. The gneisses of the Black Forest were partly altered by migmatisation (Anatexis) which occured during the Variscan orogeny. Such gneissanatexites are outcropping mainly in the southern parts of the Black Forest which have been elevated highest und thus were exposed to a deep level.

1.2 Variscan magmatites intruded during the later Devonian up to the Upper Carboniferous. Granites of different composition are most abundant, whereas basic rocks are rather rare. The magmatism of the Variscan era continued into Permian times, when, as in many other parts of Europe, also in SW-Germany Rhyolites and Porphyrites were deposited by volcanic outflows and interfingered with the contemporaneous clastic sediments. These effusive rocks occupy a position between basement and sedimentary cover.

1.3 Pre-Permian paleozoic sediments are outcropping only at a few minor areas in the Black Forest and the Odenwald. They are of Devonian to Carboniferous age. By deep drilling it could be detected that beneath the mesozoic cover instead of gneisses or magmatites paleozoic shists of possibly Silurian or Ordovician age are present at some places.

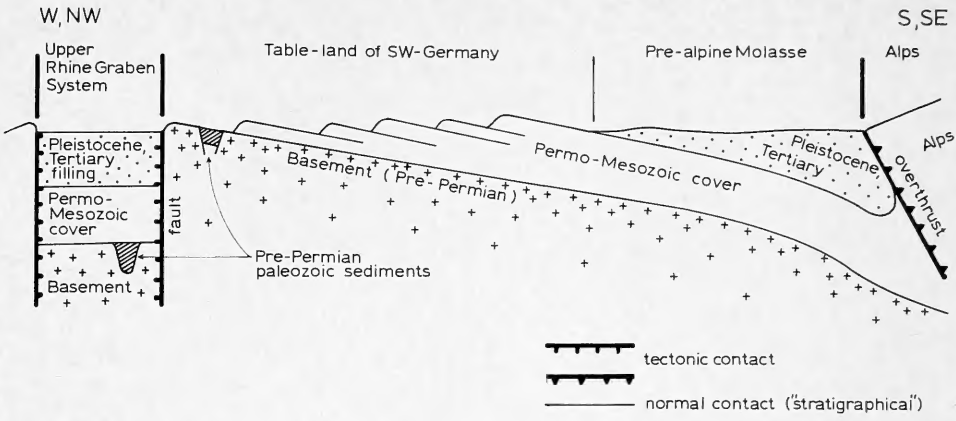

Fig. 1 Schematic profile section of Southwestern Germany.

2. Permo-Mesozoic and Cenozoic sedimentary cover. The mesozoic cover is outcropping now in the table-land of SW-Germany and remains buried beneath the tertiary and pleistocene sediments of the Upper Rhine Graben and the prealpine Molasse basin. The area of SW-Germany was covered by sediments of Permian to Upper Jurassic age. Although Triassic and Jurassic are very rich in rock and facies types, it may be stated that the paleogeological evolution during these periods as a whole was very uniform everywhere. Only the Permian was not deposited over the entire area. During the Cretaceous this part of Europe emerged above sea level. During the older Tertiary the region was finally divided into units with different geological histories since that time.

2.1 Permo-Mesozoic cover. Briefly, the geological history during the Permian and the Mesozoic may be described as follows: During the Permian (and locally starting already in the uppermost Carboniferous) the relief generated during the Variscan orogeny consisted of intramountain basins, mostly striking WSW-ENE. These basins were filled with red bed arkoses and fanglomerates („Rotliegendes"). Only the larger basins show a distinguishable facies differentiation with clayey sediments or even calcareous beds in the central parts. Some of the basins subsided considerably during sedimentation. The thickness of the „Rotliegend" series is differing within a wide range from a few meters to over 1000 m. Towards the end of the Permian the sea spread from northern and middle Germany well into SW-Germany to an extreme shore-line running from the Palatinate via Pforzheim-Heilbronn into northern Franconia. This marginal part of the „Zechstein" formation is not salt-bearing as the central basin in the north. Limestones, dolomites and clayey sediments do not exceed 60 m in thickness.

The Triassic is divided into the classic „germanic" sequence of Buntsandstein, Muschelkalk and Keuper. The Buntsandstein of SW-Germany was deposited in an appendage basin to the main basin located between what is now the North Sea and Poland. The basin of southern Germany expanded during the Buntsandstein period, younger members are spreading outwards, whereas the older ones are thinning out even in the northern and middle part of the Black Forest. Buntsandstein is also missing partly or totally underneath the Swabian Jurassic and the prealpine Molasse region. Buntsandstein is considered to have been deposited under continental conditions, running water being the prevalent medium of transport.

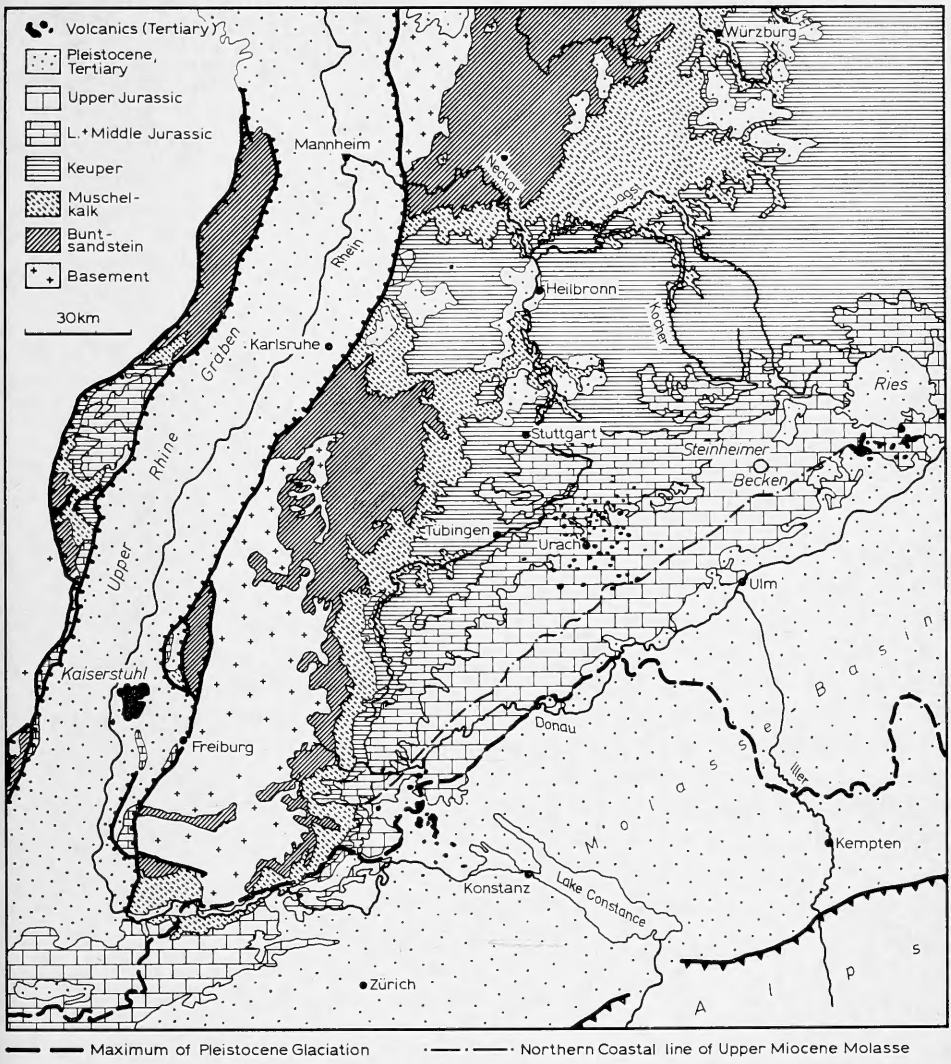

Fig. 2 Geological map of Southwest Germany.

The climate conditions are pointed out by the dominating red rock colours and the occurence of feldspar within the sandstones. Sedimentation went on within several cycles ranging from coarse to fine grained beds, believed to be caused by epirogenetic uplift in the marginal areas and subsidence of the basins.

This clastic way of sedimentation was ended by the invasion of the Muschelkalk sea, which covered great parts of Germany and adjacent countries. This sea had connections to the alpine and carpathian Tethys as well as towards the Arctic Ocean. Water circulation between this mostly shallow Muschelkalk sea and the open oceans was for most of the time sufficient to warrant the supplies for the sedimentation of up to 200 m of limestones and dolomites, partly micritic, partly bioclastic. On the other hand circulation was restricted in such a way that salt concentration and water temperature were high, resulting in a very characteristic

endemic fauna, and salt precipitation during the Middle Muschelkalk. Profiles of the Lower as well as the Upper Muschelkalk are very uniform in the area where these formations are outcropping now and can be correlated by bed-to-bed connection over lateral distances up to 100 km. This leads to the assumption that the Muschelkalk sea within this region was of a very uniform depth, without any accentuated relief. Synchronous change of sedimentation from bioclastic to micritic or even to clays was controlled by some superior agent(s).

The Lower Keuper („Lettenkeuper") is a continuation of the Muschelkalk only in some respects that vanished during the Middle Keuper. This latter sequence is up to 400 m thick. It is difficult to characterize this formation with a few words. The German Keuper basin still was a platform-like sedimentation area which was covered most of the time by water, considering for example the very regular and uniform distribution of thickness. However, the sediments were no longer carbonates, they changed to terrigeneous matter. Clays and marls were deposited together with gypsum and several carbonate beds in the central Keuper basin. They are interfingering with arkose sandstones of the marginal areas in Southern Germany. These sandstones originated from a land mass called the „Vindelician Land" (after the ancient tribe of the Vindelicians living in the area of Augsburg). This source area expanded from the Bohemian Massif in the East towards the Central Massifs of the Helvetic realm of the Swiss Alps. It existed during the Triassic and disappeared in the early and middle Jurassic. This region was exposed to its granitic basement, as is well established by drilling in the Molasse basin of Bavaria and Swabia. The Keuper sedimentation was complicated further by the expansion of deltaic sandstones from the Baltic area towards the South (Lettenkeuper-Sandstein and Schilfsandstein). The climate of the Keuper period ist marked by the red bed character as well as the occurence of gypsum and arkoses.

The change to the marine and stable shelf environment of the Jurassic took place already during the Upper Keuper (Rhetian). The Lower Jurassic (Liassic) or „Black Jurassic" as a whole is a sequence of greyish to black clays and marls, almost 100 m thick, rich in cephalopods, brachiopods and pelecypods. During the Hettangian several offshore sandstone bodies were deposited. The beginning of the Sinemurian is marked by the overall occurence of a sequence of bioclastic limestone beds with *Gryphaea arcuata*. Another outstanding member of the Liassic is the euxinic bituminous „Posidonien-Schiefer" (Toarcian), deposited when water circulation was obviously restricted and large areas of the sea-floor were left without oxygen, as it was the case already locally during the early Sinemurian. The anaerobic conditions are one reason for the excellent conservation of the famous Holzmaden and Boll fishes and saurians.

Epicontinental environment extended well onto the Middle Jurassic. Richness in ferruginous oolites led to the local name „Brown Jurassic". Clayey sediments with occasional interfingering sandstone lenses are still predominant. Calcareous matter is often concentrated in concretions.

During the Middle Jurassic an important change in the paleogeographic pattern of Central Europe took place. The connection between the basins of Northern and Southern Germany via the „Hessian strait" (Hessische Straße) became less important.

When the Upper Jurassic began, Southern Germany was an appendage of the Jurassic Tethys sea of the alps. Mediterranean ammonites were joining the fauna of northern European provenance. Also sedimentation changed to limestones

and marls, being decisive for the denomination as „White Jurassic". During this period the Jurassic sea reached its greatest depth of more than 100 m. An outstanding attribute of the White Jurassic are bioherms built up mainly by siliceous sponges und very probably algae. This facies type is situated heterochronously within the sequence of micritic limestones and marls and is followed towards the uppermost beds by sporadic coralligene and oolitic limestones, pointing to a shallowing of the sea. As a matter of fact, the Jurassic sea retreated from Southern Germany towards the Tethys before the end of the Jurassic period.

Cretaceous sediments both marine or terrestrial were not deposited in SW-Germany.

2.2 Upper Rhine Graben system. Beginning with the Eocene the rift system of the Upper Rhine Graben came to function, separating the South German bloc or „plate" from the opposite regions of France (Vosges mountains and table-land of Lorraine a. s. o.). The Graben structure developed from south to north, situated above what is now believed to be an upper mantle diapir. In the same way the graben was filled with thick sedimentary series during the Tertiary (marine, limnic, fluviatile) and the Pleistocene (fluviatile, glaciofluviatile, aeolian). Tectonic movements along some faults of the Graben are active even now. Altogether the filling of the Graben exceeds 3000 m.

2.3 Table-land of SW-Germany. Between the Upper Rhine-Graben in the West and the Bohemian Massif in the East the mesozoic described above (2.1) is outcropping without younger cover. In connection with the subsidence of the Rhine Graben, the bloc of SW-Germany was uplifted and tilted so that the strata are now dipping generally towards SE. The mesozoic sequence was exposed to erosion by river systems flowing with the dip towards S and SE in consequent direction to the Molasse basin and later on to the Danube river. With the subsidence of the Rhine Graben a second river system developed with an inclination to the opposite direction, obsequent or partly subsequent. These competing systems modelled the table-land. Resistant, water-permeable strata are forming the cuestas and terraces. Clayey beds of less resistance against the agents of erosion are found at the slopes of the table-land.

As the stratigraphic sequence of the Triassic and Jurassic of Southern Germany contains a great variety of rocks also concerning their resistance against erosion, the sculpture of the landscape shows much variety. The outcrop areas of the several formations are spreading from the SW to the NE (fig. 2), due to the decrease of dip which has its maximum near the southern parts of the Black Forest and diminishes towards the North and Northeast.

Major and all the way continuous terraces and cuestas of this table-land are formed by the Buntsandstein, the Upper Muschelkalk, sandstones within the Keuper (mainly in NE-Württemberg and Franconia), bioclastic limestones of the lower Liassic (Sinemurian), the bituminous shales of the Toarcian, and finally the limestone members of the Upper Jurassic. There are more terraces of more local importance not listed here.

2.4 Pre-alpine Molasse. The southernmost part of the bloc or plate of Southern Germany was forced downward during the final stages of alpine orogeny. Beginning with the Oligocene and ending during the Upper Miocene in this subsiding trough the clastic Molasse sediments were accumulated. They originated from the Alps being folded and uplifted, and, at a lower rate, also from the tilted mesozoic foreland bloc of Southern Germany. As the subsidence did not continue

at a constant speed, the sedimentation of the Molasse took place partly at an emerged level with fluviatile conglomerates, sandstones and clays (so-called „Fresh Water Molasse"), sometimes below sea-level (so-called „Marine Molasse"). Thickness of the Molasse is maximal near the alpine border and reaches more than 5000 m. It decreases continuously outwards the Alps. The recent border line between Molasse and the adjacent table-land is the northern erosional margin of the Molasse and not a structural line. The southernmost parts of the Molasse basin themselves were folded and thus incorporated within the structural cmplex of the Alps („Subalpine Molasse"). Almost the entire area of the Molasse in southern Swabia was covered by the glaciers of the Pleistocene glaciation, or at least by the glaciofluviatile outwash. In this region the classic subdivision of the pleistocene period was established. As the recent Rhine river on his course between Basle and Mainz developed from the Rhine-Graben rift system, the Danube river ist the final heir of the Molasse subsidence system.

3. Young volcanics. In some areas of Southern Germany volcanism was active during the Tertiary. The volcanoes situated within the table-land are handed down to the present only as the conveying pipes. Volcanic surface forms have been eroded. There are about 300 diatremes in the vicinity of Urach (Swabian Alb). The magmatic components are of foid character. Other diatremes are situated in the Kraichgau (Steinsberg) and the southern part of Odenwald (Katzenbuckel). Their significance lies in the fact that the filling of these pipes contains Jurassic sediments that had been existent in these northern areas still in the Tertiary, far outside their recent occurrences.

Near the border line of the Molasse basin the Hegau volcanic district is situated with both Melilitites and Phonolites. Finally, in the Upper Rhine Graben, the volcanic complex of the „Kaiserstuhl", active during Miocene, was buried by the Graben filling, but still arises above the recent sediment level for about 300 m. This volcano is considered to be the direct outlet of the mantle diapir underneath the Upper Rhine Graben.

4. Ries and Steinheimer Becken (Steinheim basin). These two phenomena are outstanding in Europe. Almost roundly shaped basins are embedded in the plateau of the Upper Jurassic of the Swabian and Franconian Alb. The diameter of the „Ries" amounts to 22 km, the Steinheim basin is much smaller (2,5 km). Both basins are filled with sediments of Neogene age and surrounded by brecciated masses originating from the basins. Their origin was controversial for a long time. Now there is little doubt that they were caused by the impact of extratelluric masses.

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