OIL EXPLORATION IN THE MOLASSE BASIN OF WESTERN AUSTRIA

BY

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ABSTRACT. The floor of the molasse basin in Western Austria consists of granites and gneisses of the Bohemian massif which in some areas are overlain by Upper Carboniferous and continental Triassic beds but more usually by Upper Jurassic and/or Upper Cretaceous beds. The oldest beds of the Tertiary basin sediments are of Upper Eocene age and the bulk of the four thousand to twelve thousand feet Tertiary sediments is formed by gray shales with sand, sandstone, and conglomerate layers ranging in age from Oligocene to Middle Miocene.

The molasse basin is asymmetric; the sediments being thickest in the immediate vicinity of the Alpine thrust front which now forms the southern margin of the exposed portion of the basin. Because of the greater strength of the Alpine movements during Upper Eocene and Oligocene time, the structural development within the basin sediments diminishes upward in the section and also towards the north. While the Upper Eocene and Lower Oligocene are more strongly disturbed and dip southwards under the Alpine front, the axis of the basin in Miocene time had shifted well to the north of the Alpine front. Therefore, as the southern margin is approached, the entire complex of Tertiary strata of the molasse basin shows a fan-like structure with the beds diverging towards the south. The development of structures within the basin shows the predominating influence of two basic factors; first the original structural pattern of the basement and overlying Mesozoic beds, associated with old fault lines and resulting in a pre-Tertiary surface of considerable relief, and second the effect of the northward movement of the Alpine ranges which becomes more and more evident to the south. This latter influence is expressed in the central part of the basin by numerous eastwest striking predominantly antithetic faults, while in the southernmost part of the basin the beds are isoclinally folded or broken up into imbricate structures (*schuppen*) in a belt of complex structures, which is over-ridden for several miles by the northward-thrust Helvetic and Flysch zone of the Alpine front. In spite of the large total thickness of sediments, the predominantly marine facies, and the varied structural development, only a few wells have encountered oil and up to now, no major oil or gas fields have been indicated. The question as to the origin of the oil remains unsolved.

RESUME. Le soubassement du bassin mollassique, en Autriche occidentale, consiste en granite et gneiss du massif de Bohème. Par endroits, ces roches sont recouvertes de couches du Carbonifère supérieur et du Triasique continental; mais plus généralement, elles sont recouvertes de couches du Jurassique supérieur, du Crétacé supérieur ou des deux à la fois. Les couches les plus anciennes des sédiments du bassin Tertiaire datent de l'Eocène supérieur; le gros des 4.000 à 8.000 pieds de sédiments Tertiaires est formé de marnes argileuses grises, alors que les couches de sable, de grès et de conglomérats se trouvent échelonnées de l'Oligocène au Miocène moyen.

Le bassin mollassique est asymétrique; les sédiments sont le plus épais dans la proximité immédiate du front de chevauchement des Alpes qui forme maintenant le bord méridional de la portion exposée du bassin. Du fait de la force supérieure des mouvements alpins au cours de l'Eocène supérieur et de l'Oligocène, la mollasse comporte une tectonique décroissante vers le haut et vers le Nord. Tandis que l'Oligocène inférieur et l'Eocène sont plus fortement tourmentés et plongent vers le Sud sous le front alpin, le Miocène forme un synclinal plat au Nord du front alpin. C'est pourquoi, au fur et à mesure que l'on approche du bord méridional, le complexe entier des strates

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Tertiaires du bassin mollassique présente une architecture en forme d'éventail à couches divergeant vers le Sud.

Deux tendances fondamentales dominent la tectonique: 1° la tectonique propre du soubassement cristallin et du Mésozoïque surmontant, avec failles plus anciennes et résultant en une surface pré-Tertiaire à relief très prononcé; 2° l'influence du charriage vers le Nord des chaînes alpines, de plus en plus prononcée vers le Sud. Elle se manifeste dans la partie centrale par de nombreuses failles en direction W-E essentiellement antithétiques. La partie la plus méridionale du bassin mollassique est plissée en isoclinal ou plusieurs fois imbriquée et chevauchée sur plusieurs kilomètres par l'Helvétique en direction Nord et par la Zone de Flysch. Malgré la grande épaisseur des sédiments, le faciès essentiellement marin et la tectonique variée, peu de sondages ont abouti à une découverte d'huile. Jusqu'à présent, aucun champ important de pétrole ou de gaz n'a été trouvé. L'origine de l'huile reste obscure.

Introduction

The rolling country of the Molasse basin in Austria, or Alpine foreland, lies between the Bohemian Massif on the north and the mountain ranges of the Alps on the south.

Rohoel-Gewinnungs A.G. (RAG), a subsidiary of Socony Mobil Oil Company, Inc. and Royal Dutch Shell, has done surface geological mapping, structure drilling, seismic reflection surveying, and deep drilling during the past twelve years in that part of the basin lying between the Inn and Salzach Rivers on the west and the Traun River on the east. The present status of this work forms the basis for the following discussion of stratigraphy, structure, and oil accumulation in the area shown in Figure 1.

Stratigraphy

Within that part of the molasse basin shown in Figure 1, the divisions in Stratigraphic Table, Figure 2, are recognized.

Basement and Pre-Tertiary

The floor of the molasse basin is formed, at least up to the overthrust front of the Alps, by granites and gneisses of the Bohemian Massif. Due to the wide extension and overlap of the Tertiary beds northwards, there are no outcrops within Austria of the Paleozoic and Mesozoic beds which, according to the evidence of deep wells, transgressively overlie the granites and gneisses in individual areas. Thus, Geretsberg 1 showed a section similar to wells drilled on the same structural unit in Germany and reached final depth of 8317 feet (2535 meters) in Upper Carboniferous beds directly below the Tertiary. Perwang 1, presently the deepest well in Austria, was abandoned at 11,578 feet (3,528.8 meters) in continental Triassic beds. Other wells penetrated, below the basal Tertiary unconformity, several hundred feet of Upper Jurassic and/or Cretaceous beds (both in Germanic facies) resting directly on the crystalline basement. Lower and Middle Jurassic as well as Lower Cretaceous have so far not been encountered in the deep wells drilled within the Austrian portion of the molasse basin. Only the Winetsham well, SSE of Passau (Fig. 1) penetrated Upper Dogger, immediately over the crystalline, in a thickness of few meters [3]. No wells so far have encountered beds of either the helvetic or flysch facies found in the northern foothills of the Alps.

Tertiary

The oldest member of the Tertiary molasse sediments, the Upper Eocene, lies unconformably on crystalline basement or on the Paleozoic/Mesozoic complex of strata.

The basal transgression is usually represented by a few feet of glauconitic pebbly sandstones. Above this the beds show much differentiation in facies, and in various parts of the area the following sequences have been observed, each in ascending order.

a) In the southwest (Perwang 1), dark gray marls with numerous *Discocyclinae* and grayish-green calcareous marls followed by Nullipore limestones and calcareous sandstones with *Nulliporae*.

b) In the central part of the basin (Geretsberg 1, Mühlleiten 1, and Puchkirchen 1 and 2), varicolored limnic clays with coal layers overlain by Cerithium beds in a facies of dark gray sandy shales with *Tympanotonos,* pectens, oysters and tubes of the worm *Rotularia,* which are followed by Nullipore limestones and calcareous sandstones.

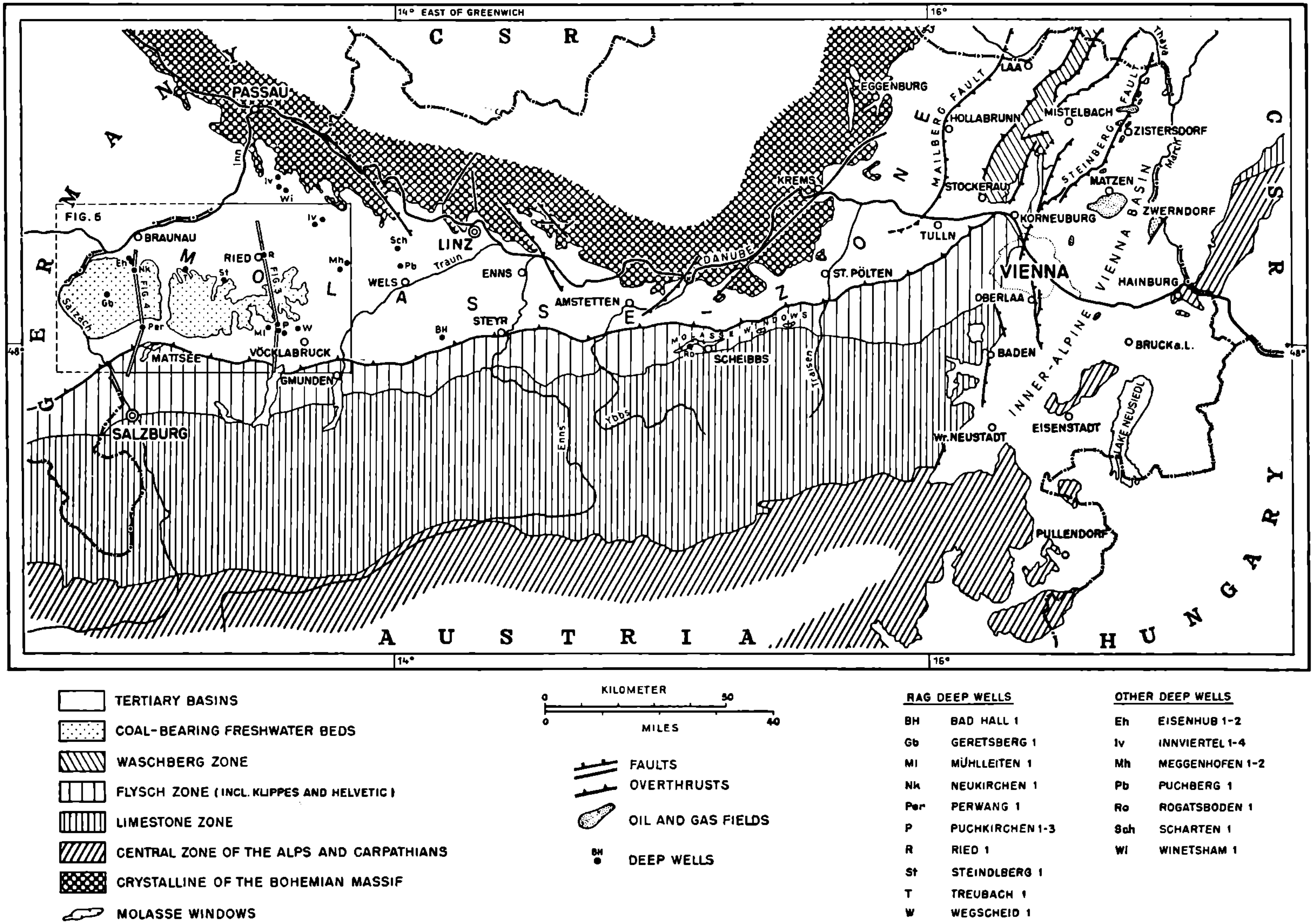

Fig. 1—General Geological Map of the Molasse Zone in Austria.

(By F. Aberer and R. Grill)

c) To the north (Neukirchen 1, Treubach 1, and Steindlberg 1), the limnic beds are directly overlain by the Nullipore limestones and calcareous sandstones.

In all these facies, sandstone intercalations ranging in thickness from one to thirty feet are often present. In the marine beds, particularly in the lower part of the Nullipore limestones and calcareous sandstones, *Nummulites* were found which according to A. Papp [4] establish an Upper Eocene age for this member.

The total thickness of the Upper Eocene ranges from 50 to 300 feet. The wells at Meggenhofen and Wels situated in the northern part of the basin did not encounter any Eocene, indicating the wedging out of these beds to the north.

Porous layers of the Nullipore limestones, and thin sandstone layers associated with the limestones, are oil-bearing in the crestal parts of the Puchkirchen, Wegscheid, Steindlberg, and Ried structures, and have yielded the recent production obtained by RAG.

The bulk of the Oligocene/Miocene sequence of strata in the molasse basin is made up of gray, well-bedded shales with sandy films, called Schlier. Intercalated with these are sand and sandstone layers of variable thickness. Due to the rather uniform petrology of these sediments, which are several thousand feet thick in the central part of the basin, the stratigraphic division is based chiefly on micropaleontology. Macrofaunae (molluscs and mammalian remains) have been found abundant in only a few localities. The individual members which are often called by their local names (see Fig. 2) are assigned on the basis of their fossil content to the Oligocene (Lattorfian, Rupelian, Chattian) or to the Lower and Middle Miocene (Aquitanian, Burdigalian, Helvetian). In the southern part of the basin the Chattian and Aquitanian contain intercalated gravel and conglomerate layers in which the pebbles are predominantly of dark dolomites and crystalline metamorphic rocks of central Alpine origin. These intercalations of coarse clastics increase in thickness towards the south [1]. As in the Upper Eocene beds, the Lattorfian and Rupelian wedge-cut to the north due to the progressive northward migration of the axis of the molasse basin. On the southern rim of the Bohemian Massif, the Chattian in the facies of the Linz sands, the Aquitanian and Burdigalian, or in places even the Helvetian, transgressively overlie the crystalline basement.

The predominantly marine sequence of strata discussed so far, is unconformably overlain in the western portion of the area by the upper freshwater molasse beds. These consist of a basal section with alternating gray to grayish-green sandy clays, shales, and sand and gravel layers in which there are intercalated coal seams of exploitable thickness. Above this there is a thick series of gravels with sand and clay layers. According to its fossil content (land snails and mammalian remains), the upper freshwater molasse is assigned to the Tortonian and Sarmatian stages of uppermost Miocene, and to Lower Pliocene ages. The youngest beds of the basin are the moraines, terrace gravels, and lake clays of Quaternary age.

Structure

The molasse basin is a young remnant of the Alpine geosyncline. During the movement of the Alpine folds northwards, the southern part of the Bohemian Massif gradually subsided, with increasing intensity to the south, under the increasing load. During Upper Eocene, Oligocene and Miocene time, the Bohemian Massif on the north and the rising Alpine ranges on the south were separated by this sedimentary basin, the axis of which gradually migrated northwards.

According to the classification of sedimentary basins by L. G. Weeks [6 and 7], the molasse basin belongs to the asymmetric group. In the north, the Tertiary sediments are only a few hundred feet thick, while in the south, in the vicinity of the Alpine overthrust front which forms the present south margin of the basin, they reach their maximum thickness of about 13,000 feet (4,000 meters).

Due to the greater strength of the Alpine movements during Upper Eocene and Oligocene time, the structures developed within the Tertiary beds of the basin are more pronounced in the lower part of the section. The Lower Oligocene and Upper Eocene are cut by many faults of pre-Aquitanian age, and there are well-marked unconformities at the base of the Aquitanian and of the Burdigalian.

The Aquitanian and succeeding stages of the Miocene show little disturbance except by the late faulting along the margin of the Bohemian Massif. The axis of the basin in post Aquitanian time lay north of the present overthrust front of the Alps, and the upper beds of the Miocene section dip north, at gradually diminishing angles, away from the overthrust front. In contrast,

Quaternary	Pleistocene	Alluvium	terrace gravels, lake-clays, peat
		Diluvium	Würm, Riß, Mindel, Günz } moraines; Low Terrace, High Terrace, Younger Deckenschotter, Older Deckenschotter } Gravels
Tertiary	Pliocene	Upper Pliocene	terrace gravels
		Lower Pliocene	Gravels of Hausruck and Kobernaußer Wald
	Miocene	Sarmatian Tortonian	} Coal-bearing Freshwater Beds (sands, clays, gravels)
		Helvetian	**West:** Oncophora Beds (brackish), sandy clay marls; Sand-Gravel Group **Center:** Oncophora Beds (brackish), sandy clay marls; { Treubach Sands, Braunau Schlier (=shales), Mehrnbach Sands } Glauconitic Series; Ried Beds (sandy shales) — Rotalia Schlier; Ottnang Schlier (= shales), Atzbach Sand, Vöckla Beds (very sandy shales) } Robulus Schlier **East:** -; -; Robulus Schlier (shales)
		Burdigalian	sand and sandstones / Upper Hall Schlier (sandy shales) shales with quartz pebbles / Lower Hall Schlier (shales) In the North of the basin: phosphorite bearing sands
		Aquitanian	N: grayish-brown clayey shales S: grayish-brown to brownish-gray shales partly with intercalations of gravels and conglomerates
	Oligocene	Chattian	N: Linz Sands S: gray shales, sands, sandstones, conglomerates (psammitic sediments mainly in the upper part)
		Rupelian	shales (Tonmergelstufe) Banded Marl (Bändermergel) Light Marly Limestone (Heller Mergelkalk)
		Lattorfian	Fish-bearing Shales (Fischschiefer)
	Eocene	Upper Eocene (Ledian + Wemmelian)	Upper and Lower Nulliporae Limestone (marine) **SW:** marls with Discocyclines (marine) and marly limestone **S:** Cerithium Beds (marine) varicoloured clays, sandstones, with coal layers (freshwater) **N:** varicoloured clays, sandstones, with coal layers (freshwater).
Mesozoic	Cretaceous	Upper Cretaceous: Santonian	dark gray to greenish-gray shales with few and thin intercalation of fine to medium-grained sandstone
		Upper Cretaceous: Coniacian	dark gray to greenish-gray shales and gray marly limestone
		Upper Cretaceous: Turonian	dark gray shales, with thin grained sandstone layers, dark gray shales and gray marly limestone
		Upper Cretaceous: Cenomanian	glauconitic sandstones
	Jurassic	Malm (Upper Jurassic)	grayish-yellow fine-oolithic limestone brownish-gray, porous dolomite brownish to yellowish-gray limestone glauconitic sandstone
	? Triassic	?	dark gray, green and reddish shales with sandstone layers (continental series without fossils)
Paleozoic	Carboniferous	Upper Carboniferous	gray sandstones with feldspar and plant remains conglomerates, dark gray slates
Crystalline of the Bohemian Massif: granites, gneisses			

(Cretaceous through Crystalline: } Basement of the Molasse Basin)

Fig. 2—Stratigraphy of the Molasse Zone in Western Austria.

the Oligocene and Upper Eocene dip south and below the overthrust front, thus causing the fan-like structure, divergent to the south, which is characteristic of both seismic profiles (Fig. 6) and geological cross sections (Fig. 3 and 4), across the southern margin of the molasse basin.

Structural Divisions of the Molasse Basin

From the seismic reflection surveys carried out by RAG, together with the surface geological mapping and some data from earlier refraction seismic surveys, information has been obtained on structural development in the Molasse basin.

Structural Relief of the Basement and the Pre-Tertiary Section

The structural relief of the crystalline basement is strongly marked. There are two particularly conspicuous basement swells, the northwest-southeast striking high zone of Burghausen-Geretsberg, which is the southeastern continuation of the Landshut-Neuötting ridge of Bavaria, and the east-west striking high zone of Mühlleiten-Puchkirchen-Wegscheid. In these high zones the Upper Cretaceous, and to some extent the Jurassic, was eroded away before the Upper Eocene transgression, and they appear as buried ridges below the Tertiary sediments.

In some areas where the crystalline basement still has a cover of Mesozoic strata, these latter are cut by several north northwest-south southeast striking faults with throws of up to several hundred feet which do not continue into the Tertiary cover. A few similar but minor faults at right angles to this trend have been detected.

Structures in the Tertiary Sediments of the Basin

In the seismic reflection surveys, particular attention was paid to the structure of the deepest Tertiary beds. Information on this was facilitated by the existence around the base of the Tertiary of a particularly clear-cut reflecting horizon which is traceable through almost the entire molasse basin. The seismic structure map (Fig. 5) was constructed on this horizon; on the basis of that map, and the supplementary surveys previously mentioned, structural divisions and their accompanying structural features may be outlined.

The Northern Rim of the Molasse Basin

Within this zone the structures are due to recent normal faulting. Narrow ridges of the crystalline basement, only a few miles wide, plunge to the southeast and are separated by Tertiary embayments bounded by northwest-southeast (Hercynian direction) striking faults (Fig. 1).

The Central Part of the Molasse Basin

In this area, the structures in the Upper Eocene and Lower Oligocene are chiefly due to east-west striking, predominantly antithetic, normal faults. Particularly conspicuous are the fault systems of Neukirchen-Aspach and St. Johann-Steindlberg-Lohnsburg. These faults sometimes show a vertical throw of 600 to 1000 feet, and can often be traced in seismic data for many miles; where their vertical throw dies out they are usually succeeded by other en echelon faults striking in similar directions. Closed structures against these faults form possible traps for oil accumulation.

In addition to the east-west striking fault structures, two major pre-Tertiary ridges exist in the central part of the basin. The first of these, the Burghausen-Geretsberg high zone, is the southeast plunging continuation of the northwest-southeast striking Landshut-Neuötting basement high. On the seismic structure map (Fig. 5), this high zone appears as an upwarp with several local highs, and is cut by normal faults. The deep well Geretsberg 1, located on the crest of one of these local highs, encountered plant-bearing Upper Carboniferous beds below the transgressive Upper Eocene. The Perwang 1 well, lying to the southeast on the continuation of the strike of this ridge, encountered under the autochthonous Upper Eocene, a series of non-fossiliferous continental, gray to greenish-gray and reddish-brown hard shales and sandstones of probable Triassic age. To the northeast and southwest, the Burghausen-Geretsberg high is flanked first by Upper Jurassic below the transgressive Upper Eocene and at greater distance by Upper Cretaceous beds.

The high zone of Mühlleiten-Puchkirchen-Wegscheid is formed by another old buried ridge which appears on the seismic structure map as several local highs separated by deeper saddle zones. The deep wells, Mühlleiten 1 and Puchkirchen 1, intersected Upper Jurassic limestones and dolomites immediately below the basal Tertiary transgression, whereas in Wegscheid 1, about 1,600 feet of Upper Cretaceous beds were found between the base of the Tertiary and the Upper Jurassic beds. Possibly due to its comparatively short distance from the northern front of the Alps, this high zone is cut by numerous faults, which have made the location of test wells very difficult.

The first oil production from the deeper part of the molasse basin in Austria was obtained in RAG's Puchkirchen 1, completed in May, 1956 for an initial flowing production of 200 b/d of 34° API oil from a six-foot-thick sand of the Upper Eocene at a depth of 8,467 feet. The well is now pumping about 100 b/d of clean oil and its cumulative production to the end of May 1959 was 100,000 barrels.

The Southern Margin of the Molasse Basin

Until recently, comparatively little has been known about the structure of the southernmost part of the molasse basin in the area covered by the map (Fig. 5). The seismic profiles, which extended into the zone of the overthrust of the flysch, showed the characteristic fan-like structure with southward divergence that has been mentioned. It was difficult, however, to find a satisfactory explanation for the apparent great increase in thickness of the Oligocene beds in the immediate vicinity of the Alpine overthrust, because no stratigraphic thickening was observed in the southernmost wells drilled in the basin. To the west of the area, the Oligocene and Miocene sediments immediately north of the Alpine front in Bavaria, are thrown into isoclinal folds and broken by steep south-dipping thrust faults to form the folded molasse zone. In the environs of Immenstadt and Murnau, reflection seismic surveys proved for the first time the occurrence at depth of schuppe and overthrust tectonics fading away to the north. To the east in the area south of Bad Hall, these beds are also strongly disturbed, and isoclinally folded to some extent, south of the fracture zone known as "Zehrmühlen line" [8]. Still further east in the area of Scheibbs, and several miles south of the Alpine overthrust front, folded beds of the molasse are exposed in fensters within the overthrusted flysch zone [5].

Hence, the possibility existed that the apparent thickening might be due to structural causes. This has now been verified by the deep well, Perwang 1, located by a detailed seismic reflection survey in the area north of Mattsee and with some of the seismic lines extending several miles southwards into the flysch zone. The seismic work in this area was difficult and very costly, since good reflections could only be obtained from shot holes penetrating below the moraines, which have thicknesses of up to 350 feet.

In the area north of Mattsee and covering a zone between 6 miles and 3.5 miles north of the overthrust, the deepest seismic marker horizon corresponding to the base of the Tertiary, at first dips rather steeply to the south. It then loses continuity and is evident only in individual shot holes. In this southern part of the area, some reflections in the upper part of the section were first interpreted as due to a buried hill bounded by faults. Such an interpretation might have brought up the base of the Tertiary by more than a thousand feet. The results of the Perwang 1 well, however, showed the structure to be very different. Beds of the Helvetian, Burdigalian and Aquitanian stages of the Miocene were penetrated down to 5,262 feet (1,604 meters) below which point, the well intersected beds of Rupelian age. The lower part of the Aquitanian and the Chattian beds were absent due to erosion below an unconformity within the Aquitanian. Underlying the thin Rupelian and Lattorfian section, the Upper Eocene showed a 60-degree dip. Its base was a fault contact below which the well again encountered Chattian, Rupelian, Lattorfian plus Upper Eocene, and then Upper Cretaceous. This Upper Cretaceous again showed a faulted base, and the well passed through two more thrust slices or "schuppen," with a sequence of beds ranging from Rupelian to Cretaceous, before passing out of the imbricated zone and entering Chattian beds of the normal molasse basin section at 8,730 feet (2,661 meters). Dips in this normal section ranged from one to ten degrees. After drilling a thick (1,150 feet) section of Rupelian shale and a Lattorfian-Upper Eocene section of about 370 feet, the well intersected pre-Tertiary beds (which in the absence of fossils were correlated as continental Triassic) at 10,830 feet (3,301.2 meters) and was abandoned in these at 11,578 feet (3,529 meters). The pre-Tertiary section showed south dips of up to 40 degrees. Determination of the Upper Cretaceous and of the boundaries within the Tertiary sections of the imbricated zone (schuppen) were made by precise micropaleontology. Within this zone there was no indication of a reversed sequence of strata. The dip meter survey within the zone showed generally south dips ranging from 10 to 50 degrees.

Particular reference should be made to the fact that within the imbricated zone, the Upper Eocene beds

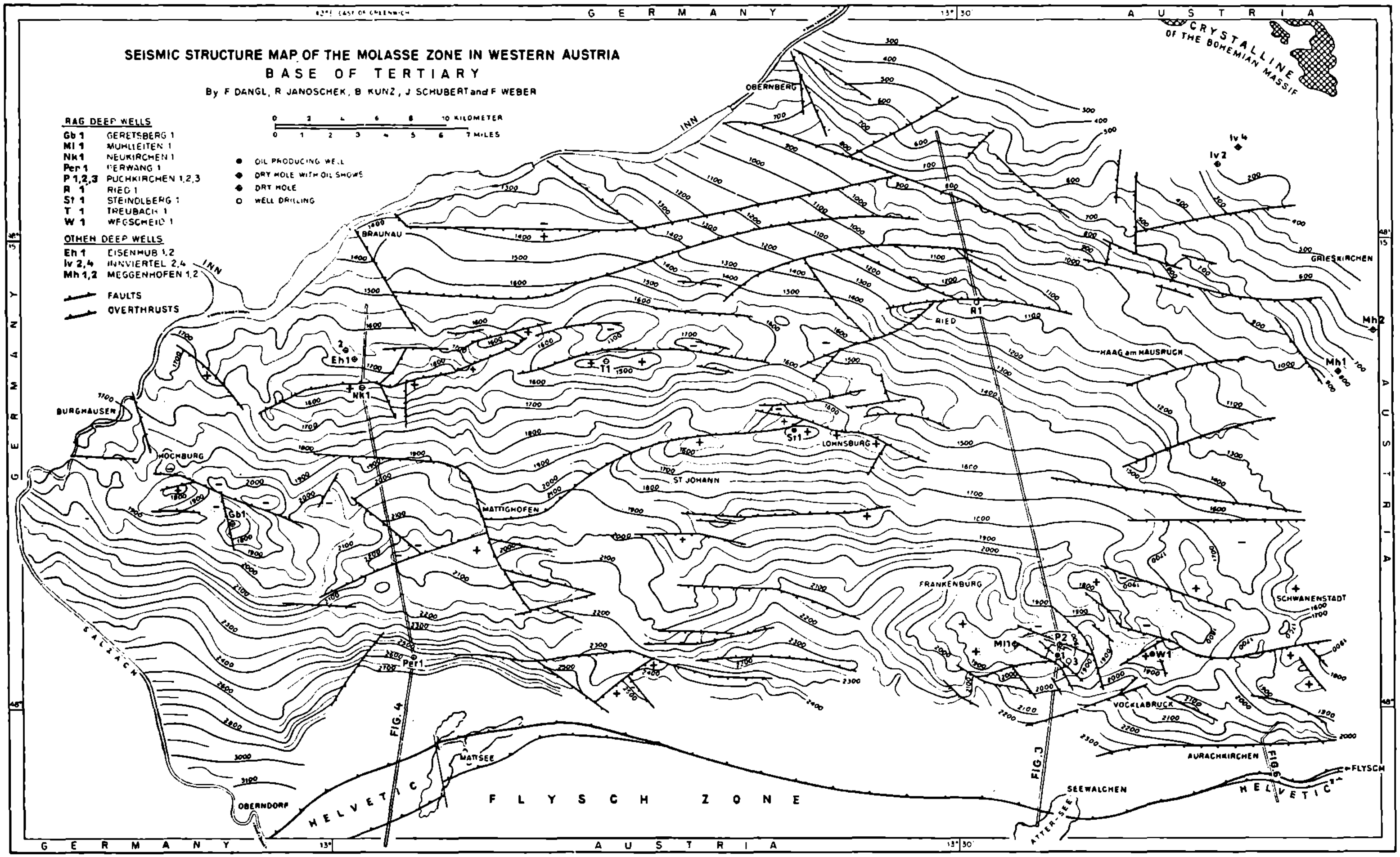
SEISMIC STRUCTURE MAP OF THE MOLASSE ZONE IN WESTERN AUSTRIA
BASE OF TERTIARY
By F DANGL, R JANOSCHEK, B KUNZ, J SCHUBERT and F WEBER
RAG DEEP WELLS
Gb 1 GERETSBERG 1
Ml 1 MUHLLEITEN 1
Nk 1 NEUKIRCHEN 1
Per 1 PERWANG 1
P 1,2,3 PUCHKIRCHEN 1,2,3
R 1 RIED 1
St 1 STEINDLBERG 1
T 1 TREUBACH 1
W 1 WEGSCHEID 1
OTHER DEEP WELLS
Eh 1 EISENHUB 1,2
Iv 2,4 INNVIERTEL 2,4
Mh 1,2 MEGGENHOFEN 1,2
FAULTS
OVERTHRUSTS
OIL PRODUCING WELL
DRY HOLE WITH OIL SHOWS
DRY HOLE
WELL DRILLING
KILOMETER
MILES
GERMANY
AUSTRIA
CRYSTALLINE OF THE BOHEMIAN MASSIF
INN
OBERNBERG
BRAUNAU
RIED
HAAG am HAUSRUCK
GRIESKIRCHEN
BURGHAUSEN
HOCHBURG
LOHNSBURG
ST JOHANN
MATTIGHOFEN
FRANKENBURG
SCHWANENSTADT
VOCKLABRUCK
AURACHKIRCHEN
SALZACH
MATTSEE
OBERNDORF
SEEWALCHEN
ATTER-SEE
HELVETIC
FLYSCH ZONE
FLYSCH
FIG. 3
FIG. 4
FIG. 6
13° 30'
48°

Fig. 5

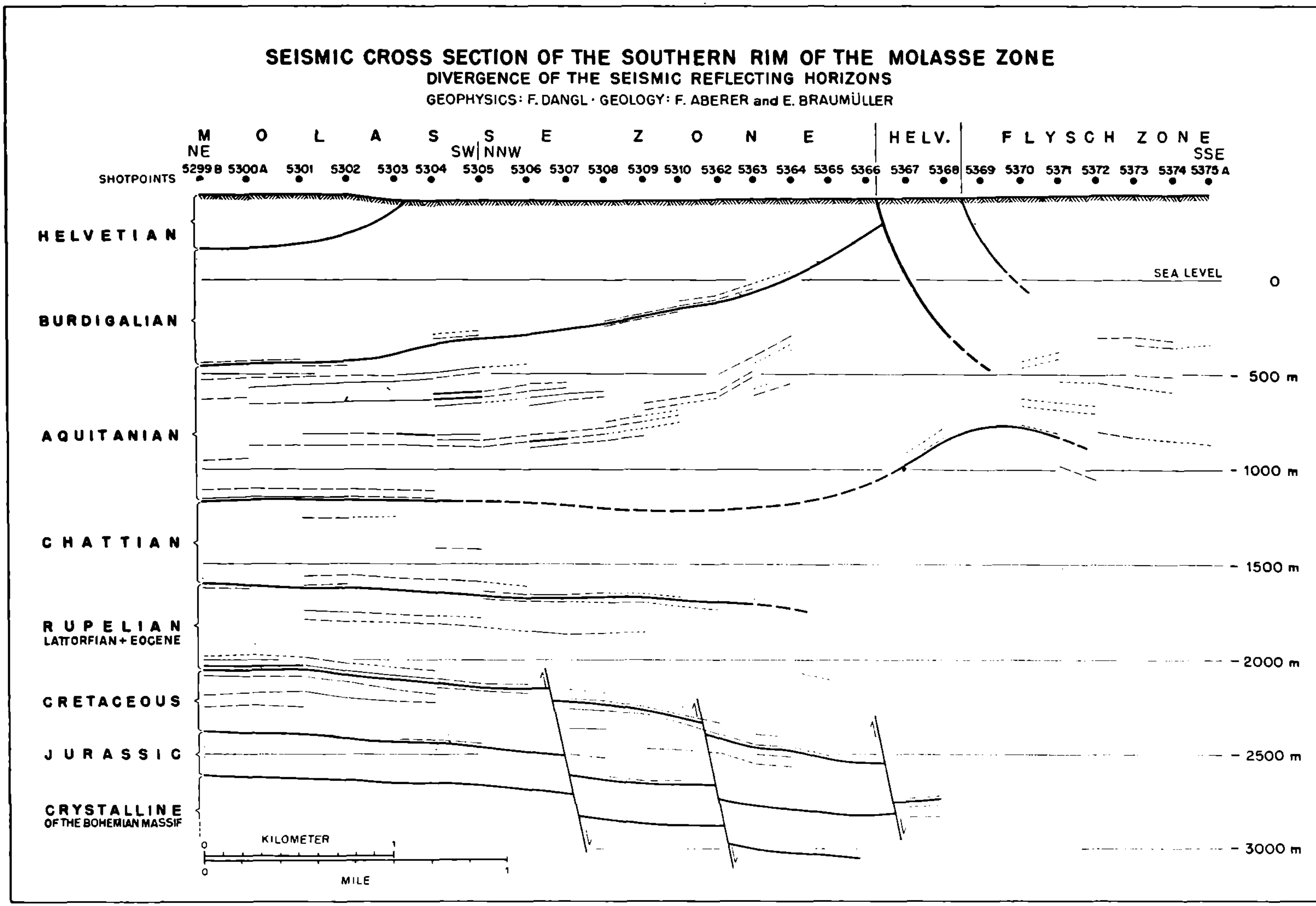
SEISMIC CROSS SECTION OF THE SOUTHERN RIM OF THE MOLASSE ZONE
DIVERGENCE OF THE SEISMIC REFLECTING HORIZONS
GEOPHYSICS: F. DANGL · GEOLOGY: F. ABERER and E. BRAUMÜLLER
M O L A S S E Z O N E
HELV.
FLYSCH ZONE
NE
SW | NNW
SSE
SHOTPOINTS
5299 B 5300A 5301 5302 5303 5304 5305 5306 5307 5308 5309 5310 5362 5363 5364 5365 5366 5367 5368 5369 5370 5371 5372 5373 5374 5375 A
HELVETIAN
BURDIGALIAN
AQUITANIAN
CHATTIAN
RUPELIAN
LATTORFIAN + EOCENE
CRETACEOUS
JURASSIC
CRYSTALLINE
OF THE BOHEMIAN MASSIF
SEA LEVEL
0
500 m
1000 m
1500 m
2000 m
2500 m
3000 m
KILOMETER
0
1
MILE
0
1

Fig. 6

which form the base of the Tertiary section lie on Upper Cretaceous while at the base of the normal basin section they overlie Triassic (?) beds. This suggests that the "schuppen" originate from a portion of the molasse basin section lying to the south of the well where Upper Cretaceous again underlies the Tertiary. It was also found that the Upper Eocene of the Perwang well, both in the "schuppen" of the imbricated zone and in the normal basal section, shows a completely marine facies without the limnic series, as well as the Cerithium beds, replaced by Discocyclinae marls containing some sandstone layers. The geological map (Fig. 1) and the seismic structure map for the base of the Tertiary (Fig. 5) show that the Perwang 1 well lies in an area where the Alpine thrust front forms a salient projecting several miles to the north. Since the seismic lines to the west near the Salzach river, and also those lying east of this salient, show only the usual divergence of the individual reflecting horizons as the Alpine thrust front is approached, it seems probable that the imbricate structure found in Perwang 1 is present only in the area of the salient. The Perwang 1 well lies close to the southeastern prolongation of the Landshut-Neuötting high through the Burghausen-Geretsberg high zone. It seems possible that the buttressing effect of this ridge may have resulted in a shallower overthrusting of the helvetic and flysch zones, and that during the early stages of this movement, portions of the Tertiary section of the deepest part of the molasse basin together with the underlying Cretaceous were sheared off and moved northwards. These movements may have been in progress up to Lower Aquitanian time, but not later, since the Upper Aquitanian is transgressive over the imbricated structure.

Oil and Gas Accumulation

Although an artesian well drilled near Wels in 1891 encountered natural gas, and some heavy crude oil was discovered as early as 1906 from hand-dug wells near Leoprechting, no large production of gas or oil has yet been obtained in the molasse basin of Western Austria. The early discovery of shallow gas in the Miocene beds near Wels was followed by the drilling of more than 100 wells to depths ranging from 650 to 1000 feet in that area. Some of these are still producing minor quantities of gas for small enterprises, but during 1957 the total production for the year amounted to only 1,034,700 cubic feet (29,300 cubic meters). An attempt to develop the oil impregnated Chattian sands at Leoprechting by drilled wells was made in 1925, but the character of the crude, which has a gravity of 13° API (S.G. 0.980) made exploitation uneconomic. In a renewal of activities during the period 1946-1952, attempts to heat the reservoir by steam injection or electric heaters in the wells appear to have been only partially successful because operations were discontinued as uneconomic in 1952. At that time, the cumulative production from 124 wells amounted to only 27,745 barrels (± 4,311 metric tons).

During World War II, some deep wells were drilled chiefly on the basis of refraction seismic surveys, but with the sole exception of slight gas production from thin sand layers in the Lower Miocene "Schlier" in one well near Wels, the results were negative.

It was only with the commencement of the seismic reflection surveys of RAG in 1951 that data became available from which an interpretation of the stratigraphy and structure of the lower Tertiary section, and also to some extent of the basin floor, within the central and southern part of the molasse basin could be made.

The first deep well drilled on the basis of these results, Puchkirchen 1, was a discovery, as mentioned previously in the part of this paper dealing with structure. The Wegscheid 1 well, located on the crest of a local structure to the east of Puchkirchen 1 and on the same general high zone, encountered oil impregnation in a thin sand within the same stratigraphic zone as the Puchkirchen 1 well. It yielded, however, a production of only a few barrels of oil per day on the pump and was abandoned as uneconomic after prolonged testing.

In November, 1958, the Steindlberg 1 well, located to test a local closure on the St. Johann-Steindlberg-Lohnsburg fault system, encountered oil in a porous layer of the Upper Eocene Nullipore limestone between 6,265 and 6,278 feet. The oil is of quality similar to that of Puchkirchen 1, and the well is now pumping at a daily rate of about 100 barrels.

In April, 1959, the Reid 1 well, located on the Reid fault system, encountered oil of the same quality and in the same beds between 4,460 and 4,507 feet. The well is now pumping at a daily rate of about 120 barrels.

All other wells drilled so far on the basis of the new seismic surveys were unsuccessful. It may also be noted that none of the deep wells drilled so far has encountered significant gas accumulations such as have been found in similar structures in the molasse basin of

Bavaria. The question as to the origin of the oil remains unsolved. As mentioned in the stratigraphic part of this paper, the main part of the molasse basin contains several thousand feet of gray shales with intercalated sands and sandstone layers deposited under marine conditions. None of the wells drilled so far has encountered oil or gas within these beds. All oil occurrences have been found at the base of the Tertiary sediments within an Upper Eocene zone which is only 50 to 300 feet thick (15-100 meters), and which consists for the most part of limestones and sandstones, and only in small part of shales or marls. The wells lying to the south, such as Puchkirchen 1 and 2, show no increase in sediments which might be regarded as source rocks, but in Perwang 1, the basal part of the Tertiary section does appear more fully marine in character.

Still greater thicknesses of such marine marls may be expected in the southernmost part of the molasse basin, now overthrust by the helvetic and/or the flysch zones. If, however, these are the source beds, a northward migration of the oil over many miles must be postulated.

Let us hope that future wells will provide the answers to at least some of the questions concerning the structure of the southernmost part of the molasse basin and the origin of the oil.

Acknowledgments

The author wishes to express his thanks to his associates who have taken part in the exploration of the area covered in the foregoing pages, and also to Socony Mobil Oil Company, Inc. and Royal Dutch Shell for permission to publish this paper.

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Discussion

J. E. SANDERS *(Yale University, New Haven, Conn., U.S.A.)* Janoschek's lucid description of the stratigraphy and structure of a portion of the Molasse basin of Western Austria invites comment by way of comparison with other areas in two respects:

1) As an example of "layers of geology" [Levorsen, 1943] or what petroleum geologists from the Mid-Continent, U.S.A., call "layer-cake geology," and
2) As an example of an area in the frontal zone of the Alps that is underlain by molasse, but which is tied to its "basement," in contrast with the type area of the molasse, the Swiss Plain, which, along with the Jura, seems to have been thrust northward over its "basement," on a zone of décollement in the Upper Triassic evaporites. The problem of the boundary between these two areas, whose tectonic styles are so different, and their stratigraphic and structural history will be briefly considered here.

American readers of Janoschek's paper will immediately notice the close similarity between the geology of the molasse basin he described and that of the northern Mid-Continent area, Oklahoma and Kansas (Fig. 1A, B). The Tertiary molasse and Mid-Continent Pennsylvanian deposits are analogous; and the underlying sandstones, shales, and carbonate rocks of the Austrian Upper Cretaceous and Upper Jurassic are somewhat similar to pre-Pennsylvanian carbonates

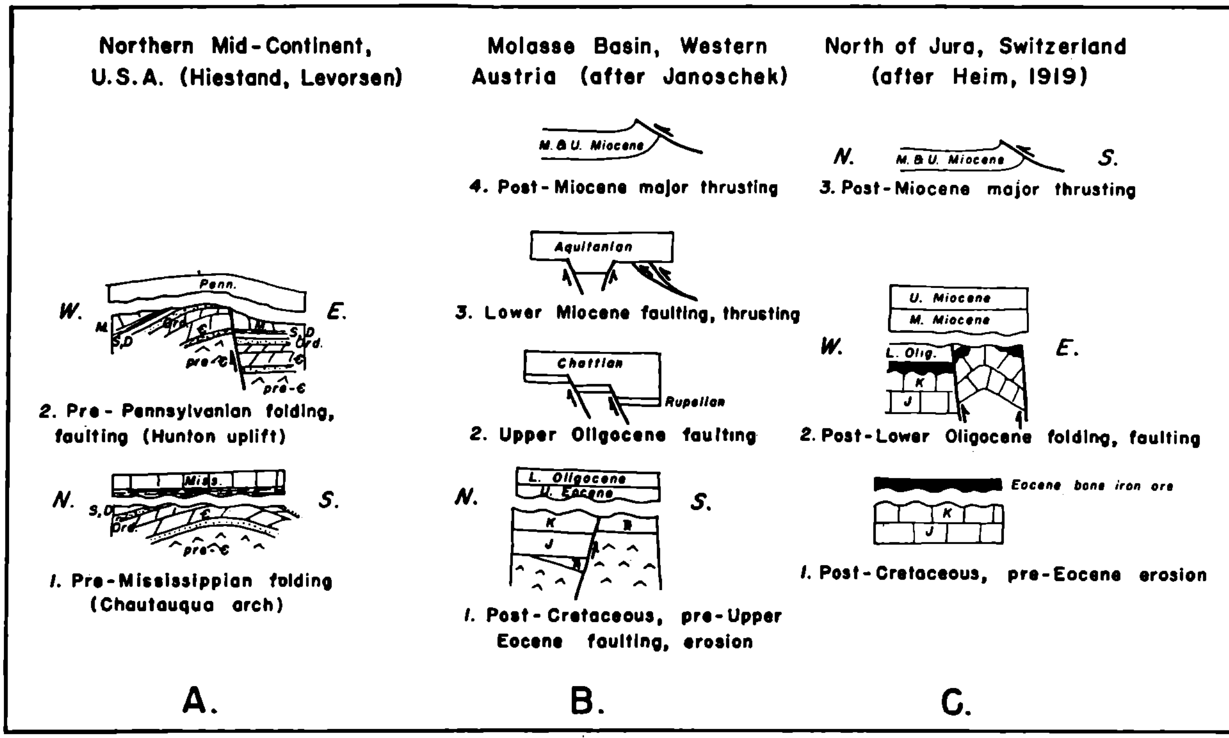

Fig. 1—Schematic Representation of Layers of Geology.

and other rocks of the Mid-Continent region. In Austria, Tertiary marine sedimentation commenced in the upper Eocene after a post-Cretaceous episode of deformation and erosion; some Tertiary sediments were influenced by structures which were actively moving upward at various times during deposition. The Tertiary also overlaps all earlier deposits and rests on the pre-Late Paleozoic "basement." In the Mid-Continent area the Mississippian marine limestones covered the eroded Chautauqua arch and the Pennsylvanian marine deposits buried older structures (Hunton, Nemaha uplifts) after an interval of erosion and were themselves influenced by structural movements which occurred during their sedimentation.

The Lower Tertiary molasse has shown minor amounts of petroleum, but the reservoir possibilities of the rocks in the area described by Janoschek appear somewhat limited. If lessons from the Mid-Continent, U.S.A., are applicable in Austria, then attention should be devoted to exploration in the Upper Jurassic carbonates and Upper Cretaceous sandstones beneath the pre-upper Eocene overlap, as well as to those parts of the Tertiary (Chattian and Aquitanian) sediments which were deposited near buried hills and ridges. In the Mid-Continent area initial discoveries were made in the Pennsylvanian beds, but much larger quantities of petroleum were found in the pre-Pennsylvanian carbonate rocks and sandstones on structures that were obscured by the Pennsylvanian strata.

The subsurface geology of the Austrian molasse basin portrayed by Janoschek clearly indicates that the molasse and other covering rocks are firmly united to their underlying "basement," which crops out at the surface in the Bohemian massif to the north (Fig. 2). Just the opposite appears to be true for the molasse basin of the Swiss Plain (and the Jura), where a large-scale décollement has been inferred by several (but not all) investigators. [See Buxtorf, 1908, 1916; Heim, 1919; Glangeaud, 1944, 1949a, for proponents; Aubert, 1945; and Umbgrove, 1948, for disputants.] To one familiar with the Southern Appalachians, U.S.A. [Rich, 1934; Rodgers, 1950; Wilson and Stearns, 1958], or the foothills of the

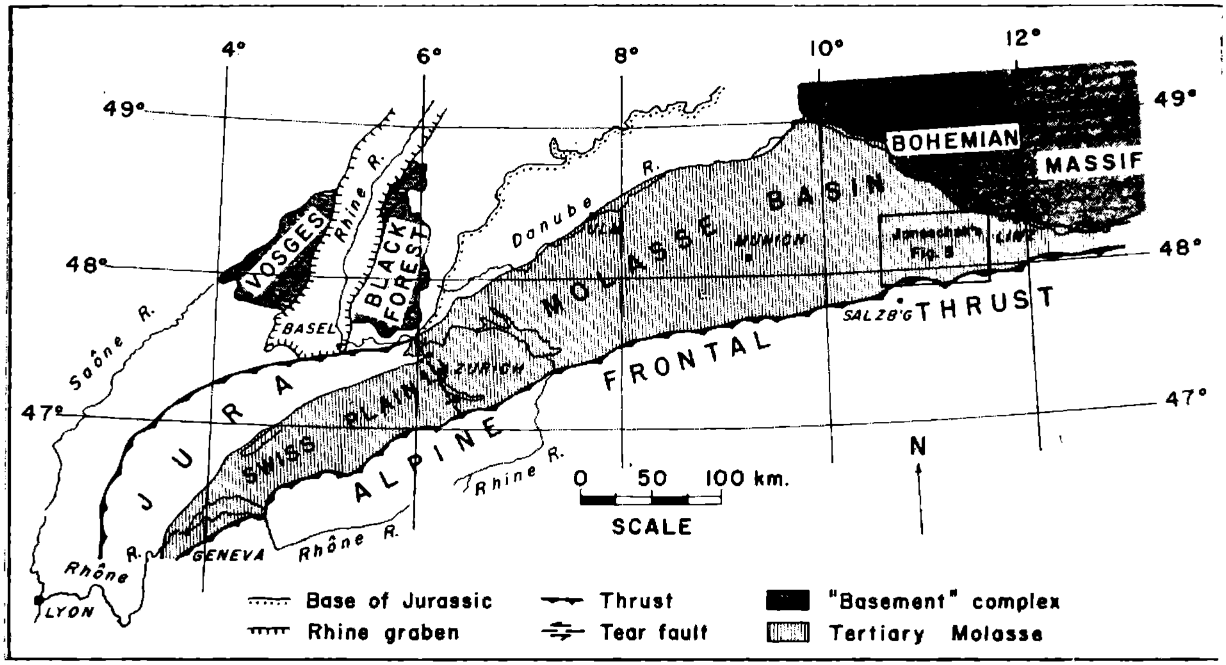

Fig. 2—Schematic Tectonic Map of the Area North of the Alps in France, Switzerland, Germany and Austria.
Base after W. Schriel, 1931.

Rockies in Alberta [Link, 1954; Hume, 1957], the décollement interpretation seems preferable.

If the décollement hypothesis is true for the Jura and Swiss Plain, however, then some unsolved problems can be raised concerning the boundary between the two molasse basins in question. During northward thrusting, the Swiss Plain and the Jura appear to have been rotated counterclockwise, with displacement increasing toward the northeast and east, paradoxically, in the direction of the area where the molasse and its subjacent strata are firmly joined to their basement. This suggests that the décollement block is bounded by a right-lateral tear fault in the neighborhood of Zurich. Such a fault has been indicated on Figure 2, but to the discussor's knowledge, no such fault has yet been found near Zurich or elsewhere in eastern Switzerland. If this fault exists, as is here suggested, then it separates flat-lying molasse from flat-lying molasse, and might easily pass unnoticed, as indeed, similar structures in the flat-lying Pennsylvanian rocks of Tennessee were unappreciated for many years [Jillson, 1923; Rodgers, 1950; Stearns 1954, 1955; Wilson and Stearns, 1958]. This postulated fault in Switzerland is comparable with the Russell Fork fault of the Pine Mountain thrust block [Wentworth, 1921; Rich, 1934] and the Emory River fault zone of the Cumberland Plateau thrust block [Wilson and Stearns, 1958] of the Southern Appalachians.

The eastern limit of the décollement block in Switzerland should correspond closely to the depositional limit of Upper Triassic evaporites, and of thick, competent Jurassic carbonate rocks, subjects which may be of interest in their own right, and may subdivide areas of molasse sedimentation where faulting of the basement occurred during molasse deposition on the east from areas on the west where the basement was not faulted during molasse deposition.

In the outer parts of the Jura and in areas to the north, however, the "basement" was not altogether passive. Evidence found in the relatively flat-lying rocks north of the Jura folds [in the *Tafeljura*, Heim, 1919, p. 560-571] indicates that coincident with origin of the Rhine graben, important post-lower Oligocene faults and folds with north-south orientation were formed (Fig. 1C). Structures of comparable age in Austria are oriented east-west. It seems probable that no early Tertiary structures affected the internal parts of the folded Jura or the Swiss Plain, but Glangeaud [1944, 1949a, 1949b; Glangeaud and Schneegans, 1949] has suggested that certain outer Jura anticlines were localized by faults of Oligocene age which cut the "basement." This suggests the presence in France and Western Switzerland of east-west structures comparable to those in Austria. The stratigraphic evidence north of the Jura does not permit distinction between the syn-Chattian (upper Oligocene) and syn-Aquitanian (lower Miocene) movements recorded in Austria.

In both Switzerland and Austria, large-scale thrusting occurred after deposition of the Sarmatian beds (uppermost Miocene).

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R. H. JANOSCHEK *replies.* Dr. Sanders' comparison of the molasse basin geology with the northern Mid-Continent area of Oklahoma and Kansas is very interesting. I regret that my knowledge of this area of the United States is insufficient to allow me to comment on this part of his discussion.

As regards Dr. Sanders' remarks on the contrast between the molasse basin of Western Austria and the so-called type area of Switzerland, I must point out that such contrast is not due to the differences in the tectonic developed within the molasse sediments, but to the difference in behavior of the pre-Tertiary strata of the basin floor. Thus, the zone of décollement and the northward movement referred to in the Swiss portion of the basin are linked to the presence of the Triassic evaporites within the Mesozoic complex which form the basin floor of the molasse zone. The Mesozoic and Upper Paleozoic beds which overly the crystalline rocks of the Bohemian massif, contain no such evaporite section, and hence no zone of décollement would be expected in Western Austria.

From this point of view the reference by Dr. Sanders to the problem of the position of the boundary between two molasse basins actually refers to the position of the boundary within the Mesozoic rock of the basin floor, and not to any boundary within the molasse sediments themselves.

From its western extension near Geneva, through the Bavarian and Austrian portions of the basin, and eastward around the arc of the Carpathians, the local tectonics of the molasse sediments are influenced by many factors. For example, pre-Tertiary relief developed on the basin floor strata as in Landshut-Neuötting high of Eastern Bavaria and its continuation in Austria, and the buried hill of Puchkirchen or, as in the Rumanian, diapiric folds due to movement of salt beds present within the molasse in that area.

In this connection, I cannot agree with Dr. Sanders' reference to the Swiss plain as the type area for the molasse, except insofar as it was first described in this area; the term molasse is now applied to a much larger unit running throughout the area from Geneva to Rumania.

As regards the time of folding and thrusting of molasse sediments in Western Austria, the Perwang 1 well and seismic profiles in its vicinity provide clear evidence that movement occurred as early as post-Chattian, pre-upper Aquitanian within the molasse sediments. It is also clear that the late Miocene movement affected the younger sediments of the molasse basin, all along the Alpine thrust border, but did not affect the beds within the basin itself.

F. BREYER *(Preussische Bergwerks- und Huetten-A.G., Hannover, Germany).* I would like to point out that the statements of Dr. Janoschek should be understood as an important step in the investigation of the tectonic events of the Austrian part of the Prealps. We should keep in mind the fact that the various parts of the Alps have their own geologic history, and that it is dangerous to correlate the geology from Geneva to Vienna, in spite of the fact that the Alps all together, constitute only one very large structure.

My investigation in the Western Bavarian folded molasse showed that the sequence of tectonic events is different from that of Switzerland. Even more different is the evolution in Austria. There is a necessity to establish a well-based tectonic idea from one point to the other. The various sections from west to east of the Alps, are handled individually. The observations in one region are not applicable to the other—at least, over such distances as are involved here.

I wish to point to the Alteshofen well, which is in the middle of Switzerland, west of the line Dr. Sanders drew on his picture. This well penetrated the molasse and the underlying Mesozoic to the Middle Triassic and showed no signs of thrust planes, etc. I would point out that the orogenic epochs in the various parts of the Alps have various intensities. The Aquitanian events which took place in Austria show that the Aquitanian orogeny is a very strong one. In the western part of Bavaria the Aquitanian orogeny cannot even be detected—there are only very slight indications of it.

On the other hand, the Western Bavarian post-

Tortonian orogeny is a very large one, a very important one. It does not occur, except to a very low degree, in Austria. In Switzerland all these events are quite different, and one should bear all this in mind if one parallelizes the events of Switzerland, Bavaria and Austria.

R. W. FAIRBRIDGE *(Columbia University, New York, N.Y., U.S.A.)*. In congratulating Dr. Janoschek on his interesting description of the Austrian Molasse Basin in the light of recent drilling, I would like to point out that I do not see any analogy at all between the U.S. Mid-Continent Carboniferous facies and those of the Austrian Molasse, which was drawn by the discussor, Dr. Sanders, and earlier by Dr. Pettijohn.

I think this is based on a complete misreading of the facies problem and it is simply a regrettable error that has crept into a standard American textbook. Last year I published what I believed was an explanation of this error in the Journal of Geology; it was called, "What is a consanguineous association?" I am not sure that I answered it, but at least I asked the question. The post orogenic or late orogenic association in time and place of molasse facies in general precludes any such conclusions.

It is interesting to compare the Alpine molasse sequences with others in world geology, but the tectonic setting is an essential descriptive parameter. The molasse-type basins generally appear to be dominated by piedmont deposits from newly elevated mountains. The intrasedimentary "Schuppen" units demonstrated by Dr. Janoschek emphasize this point. Generally the facies of different molasse basins seem to be dominated by continental conditions; thus, they are fluvial and lacustrine, with only a variable ratio of marine origin.

May we ask Dr. Janoschek to discuss briefly the ratio of marine to continental facies, and also to picture the sedimentary environments of the Austrian molasse?

R. H. JANOSCHEK *replies*. In Austria, in this connection, the question is very easily answered. Above the crystallines we have the continental series of the Carboniferous which is completely penetrated by one well and is clearly not marine; we have continental Triassic and all the rest of the Mesozoic is marine. Only a small part of the Eocene, about 30 or 40 meters, is lymnic, with coal layers, varicolored clays and so on, without fossils. But the remainder of the Eocene is marine. All of the Oligocene and Miocene, through the Helvetian, is marine. Sometimes we have a little brackish influence at the top of the Helvetian. And then, separated by a big unconformity, we have clay with coals, sands and gravels and the youngest sediments are freshwater beds or gravels from rivers and so on.

Only a very small part of the whole Tertiary section, i.e., the fill of the molasse basin, is lymnic and a small part is a little brackish. There is also a big change in the molasse basin of Germany.

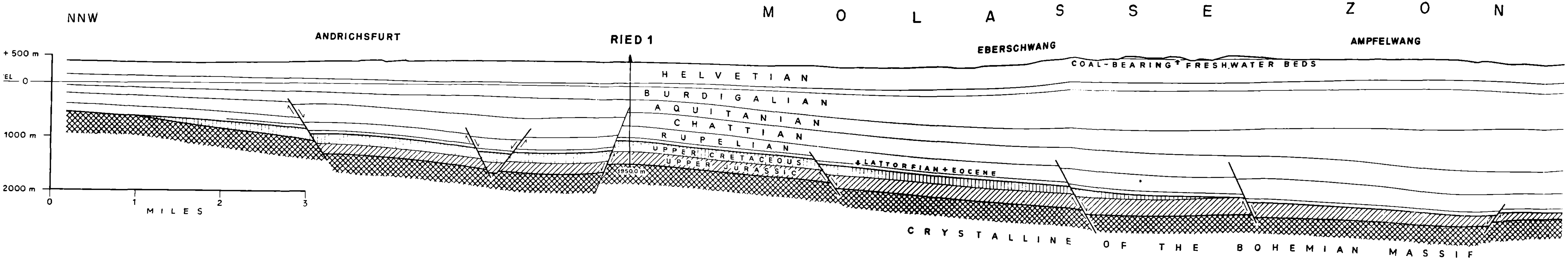


Fig. 3—Geological Cross Section of the Molasse Zone, Ried-Puchkirchen.

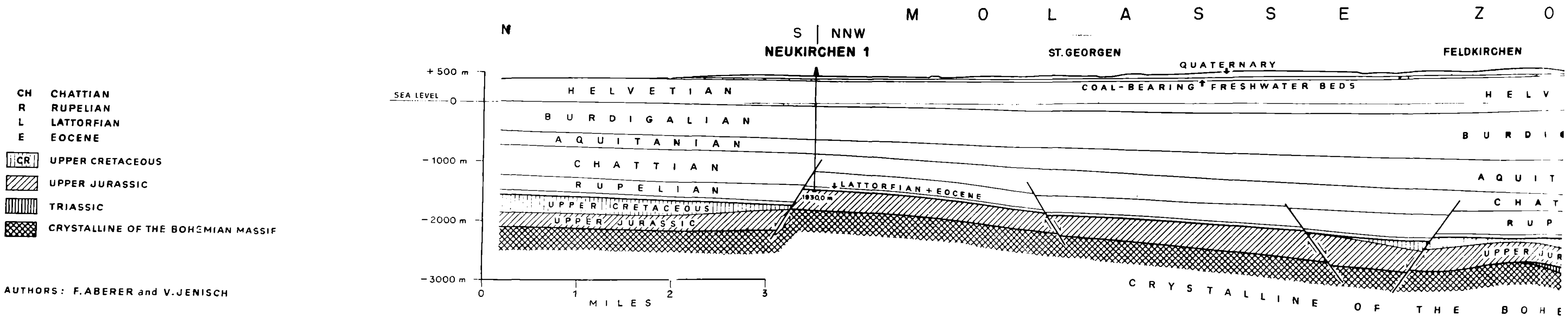
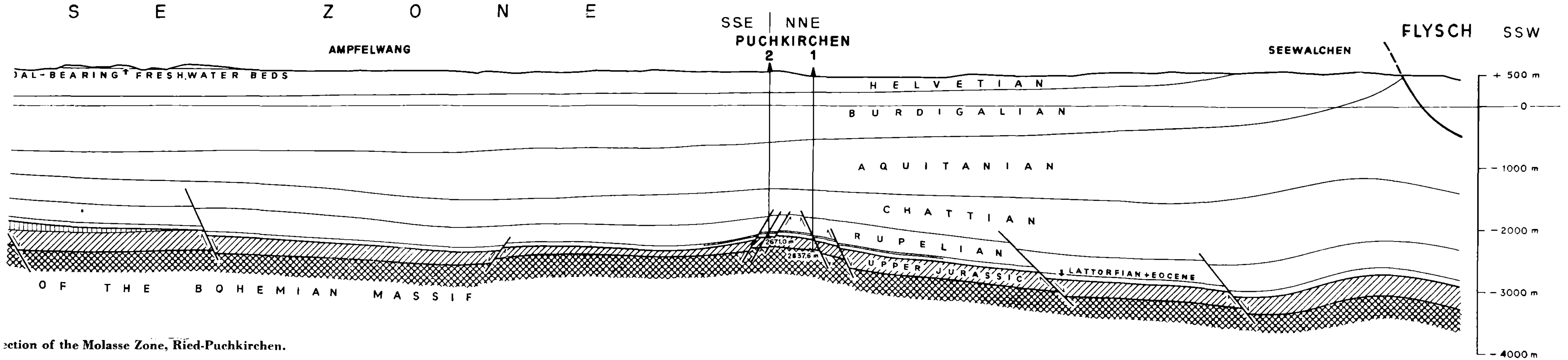


Fig. 4—Geological Cross Section of the Molasse Zone, Neukirchen-Perwang.



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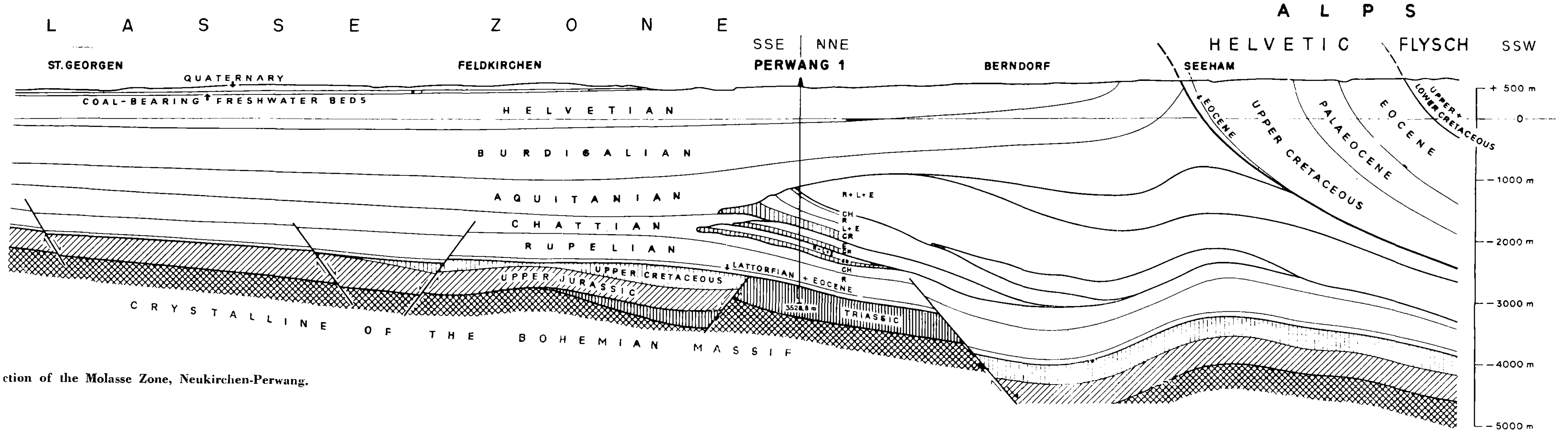

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