Introduction

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1. Introduction

1.1 **Regional setting** (Fig. 1)

The Upper Rhine Graben is the most conspicuous part of the west European Tertiary rift system. Extending for some 300 km in a NNE direction between the Jura Mountains near Basel and the Rhenish Schiefergebirge NW of Frankfurt, it cuts at an acute angle several NE striking units of Variscan basement and of its mainly Mesozoic cover. The system is continued to the south and the north by the Bresse Graben and the Hessian depression, respectively, the individual elements being dextrally offset en échelon with respect to each other.

The Upper Rhine Graben is situated at the southern flank of a major structural feature, the Rhenish Massif (Ziegler 1982) or Rhenish Shield (Cloos 1939) which was uplifted as from the Late Jurassic. In the basement of the present graben shoulders, sinistral wrench faults of Late Paleozoic age are known to lie parallel to the graben edges. A sinistral shift of magnetic anomalies crossing the graben was observed (Edel & Lauer 1974). These observations suggest that an old, inherited zone of weakness exists in the basement under the present graben. The thickness and facies of the Triassic and Jurassic cover are not affected by this zone, but it most probably controlled the location of Cretaceous and Tertiary igneous activity mentioned below, as well as the location of the graben, once it was suitably oriented with respect to the regional stress field. Volcanic activity in the form of igneous dykes of mantle origin, started as early as 100 Ma b.p., i.e. around the boundary between the Albian and the Cenomanian. These dykes and related volcanic phenomena are said to bear witness to the growth of a mantle diapir and a mantle cushion within the lithosphere, assumed in turn to be related to the origin of the Upper Rhine Graben. The graben subsided as from the Middle Eocene. Most authors appear to agree that the graben-forming processes are related to the Alpine deformation, although the mechanism of this relation is still in dispute.

Graben subsidence started in the M. Eocene with the formation of a chain of lakes marking the location of the later graben. Subsidence continued from the Late Eocene to the Late Aquitanian, accompanied by intense faulting from the Chattian. It was accompanied and/or followed since the latest Aquitanian or earliest Burdigalian by a general uplift and erosion of the southern part of the graben (south of the latitude of Karlsruhe) and its shoulders. The extrusion of the Kaiserstuhl volcanics is dated as Burdigalian. Deposition resumed towards the end of the Miocene („Pontian“) in the north as well as in the south, but subsidence up to the present was significant only in the northern part of the graben. Differential uplift of the graben shoulders, mainly during the Quaternary and stronger in the south than in the north, is responsible for the morphological expression of the Graben.

1.2 Hydrocarbons and hydrocarbon exploration in central and southern Alsace before 1970

In the southern part of the Rhine Graben, surface hydrocarbon occurrences have been exploited since the Middle Ages in the Pechelbronn area north of Strasbourg. But also south of the latitude of Strasbourg, hydrocarbon seepages and indications have long been known from both sides of the Rhine river (Fig. 2; Sittler 1972, 1985; Albiez 1935). The most remarkable of all are the seepages and oil-impregnated Late Oligocene sandstones of the so-called Alsatian Molasse in the Oelbach valley

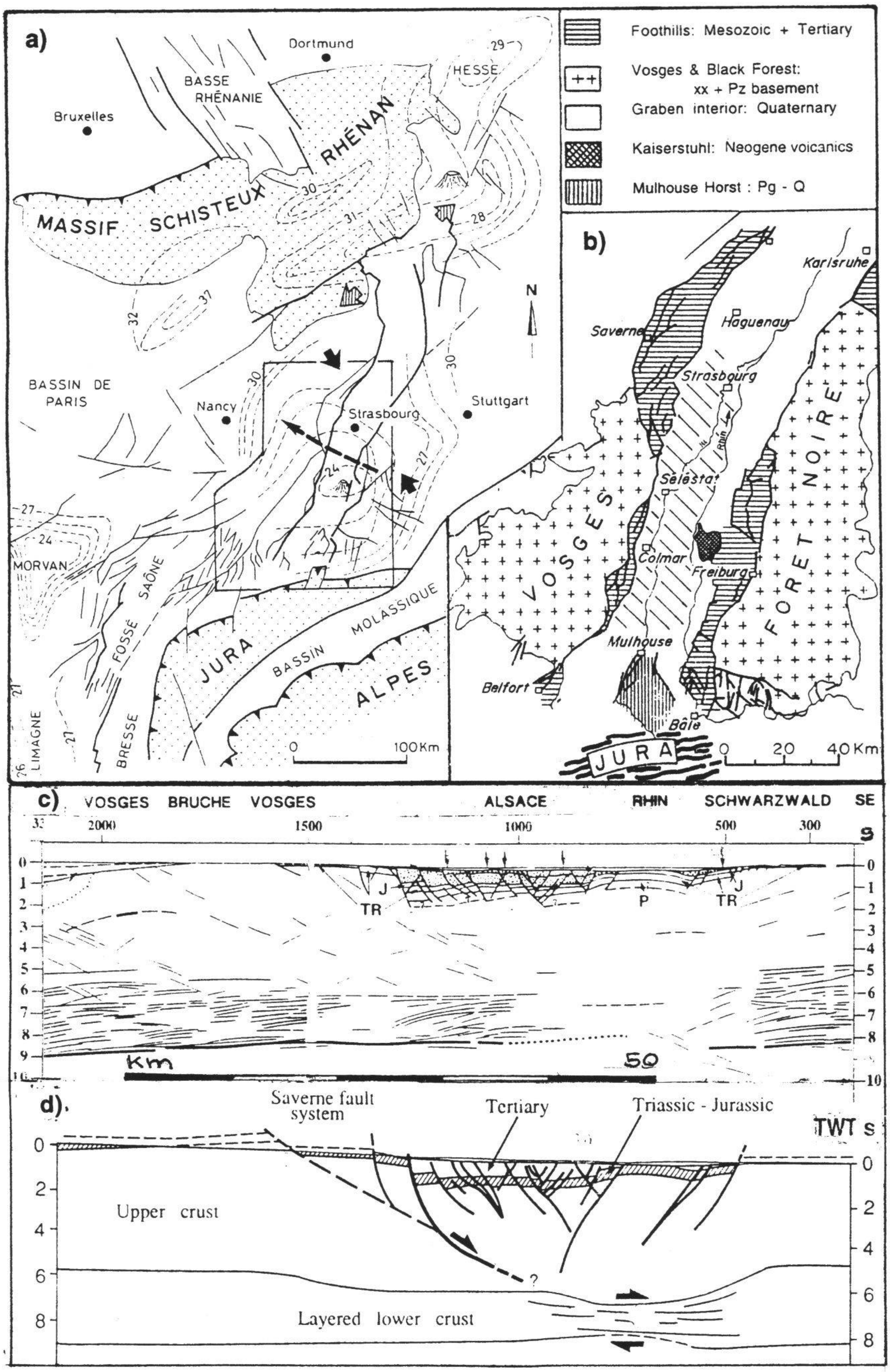

Fig. 1: Southern Upper Rhine Graben: Geographic and geological/structural setting:
a) Regional frame (from Sittler 1992: Fig. 5, after Larroque et al. 1987, amended); depth contours of MOHO in km; inset: position of b); dashed arrow S of Strasbourg: location of c) and d).
b) Southern Graben and adjacent areas (Duringer & Gall 1993: Fig. 1); obliquely hatched: area discussed in this paper.
c)-d) ECORS-DEKORP seismic reflection profile, line drawing and interpretation (Brun et al. 1991: Fig. 2b and 5)

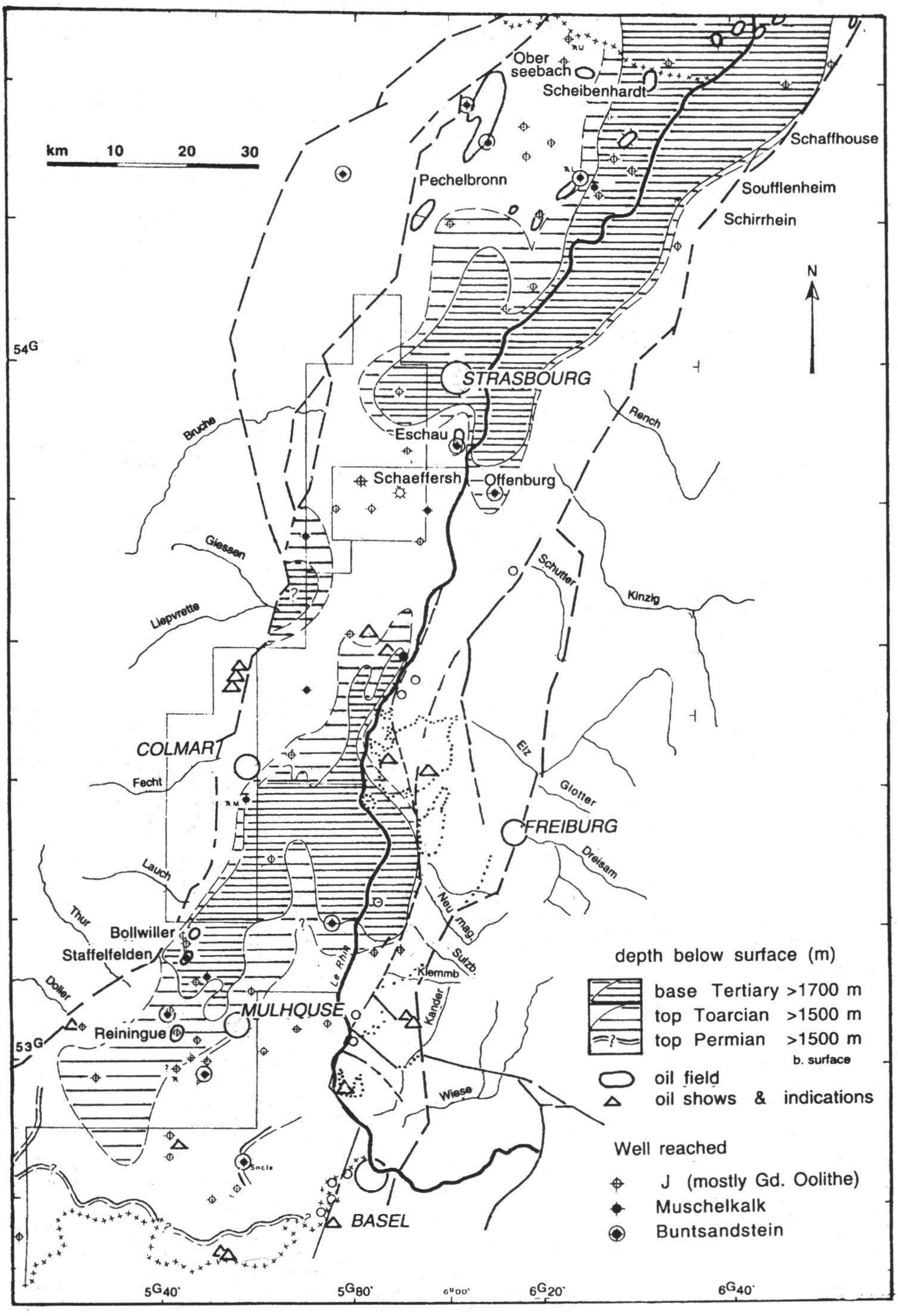

Fig. 2: Southern Upper Rhine Graben: Oil and gas fields, shows and kitchens; wells to the Mesozoic (1970).

near Hirtzbach, some 20 km SSW of Mulhouse (Sittler 1972; Vonderschmitt 1942). These surface shows triggered some drilling activity in the last century as well as between 1928-1939, as did the shows in the Doller valley at the margin of the Vosges west of Mulhouse and in the Sundhouse area E of Séléstat. In 1951, MDPA[1], the Alsatian potash mining company, discovered by serendipity an oil accumulation in the Grande Oolithe, a Middle Jurassic reservoir, near Staffelfelden, some 10 km NW of Mulhouse. This initiated a period of active exploration in the southern Rhine Graben for hydrocarbons trapped in Mesozoic reservoirs, in particular in the Grande Oolithe. During the decade that followed, large areas were surveyed by reflection seismic and some 66 wells were drilled in the Alsatian part of the Rhine Graben south of Strasbourg. Two more small oil accumulations were discovered in the Greater Mulhouse area, viz. Bollwiller (Grande Oolithe, 1951) and Reiningue (Upper Jurassic Rauracian limestones, 1957). In the area south of Strasbourg, the Grande Oolithe was found to be oil-bearing in Eschau (1955), gas-bearing in Schæffersheim (1955), and with good oil- and gas-shows in Meistratzheim-1 (1962).

A similarly intense exploration effort on the eastern, Badish side of the southern Rhine Graben during the fifties and early sixties was not rewarded with success.

As from 1960, exploration activity was drastically reduced for technical and economic reasons. Geological results of the previous period, however, become published or otherwise accessible. They confirmed and improved the general picture of the thickness and facies distribution of the Tertiary fill known from the earlier

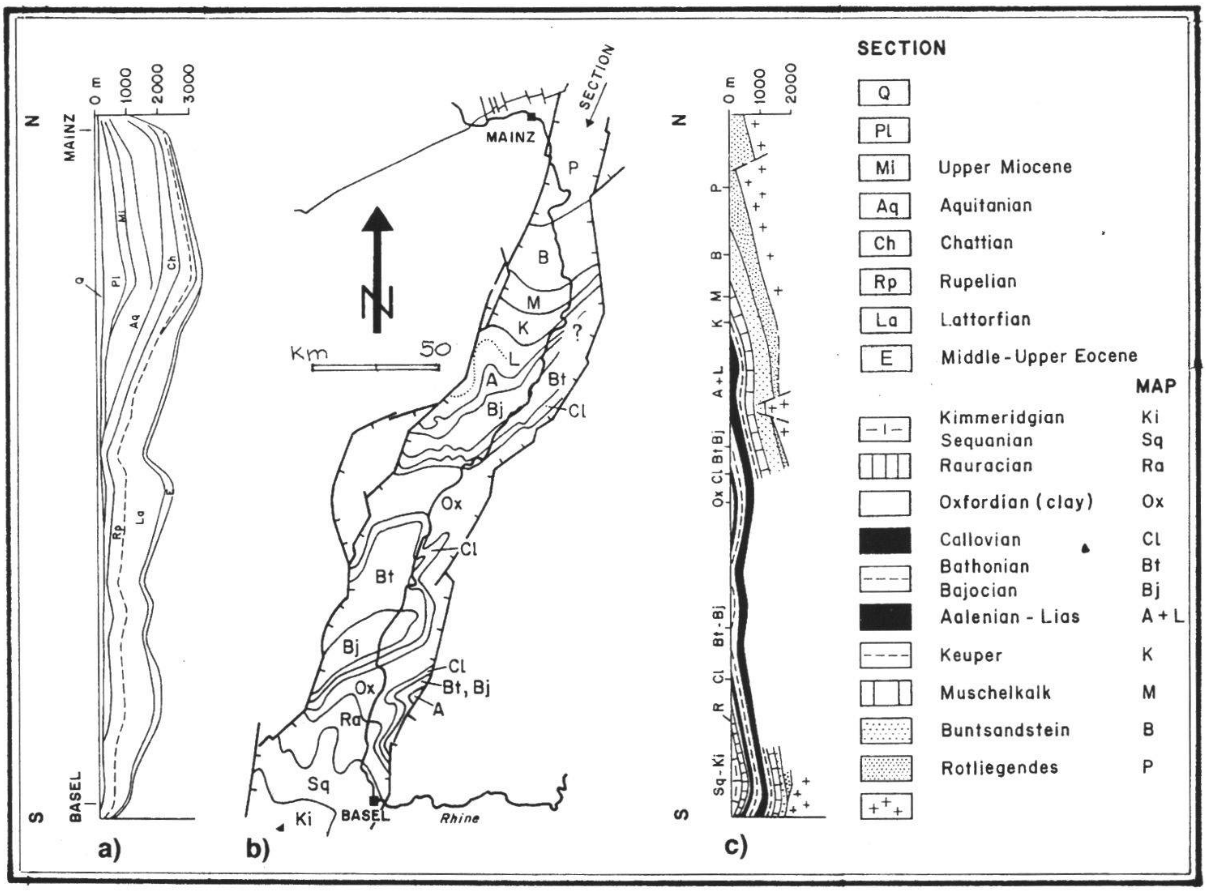

Fig. 3: U. Rhine Graben: **a)** Tertiary sedimentary fill. **b)** subcrop below Tertiary. **c)** Mesozoic preserved below Tertiary (Diebold 1972 (unpublished) after Sittler 1965, 1969).

potash exploration activities (Fig. 3a, 4; Maikovsky 1952) and permitted mapping of the subcrop of the Mesozoic strata below the base of the Tertiary (Fig. 3b, c; Sittler 1965). At the same time, advances in seismic technology based on digital recording and processing improved seismic resolution and seismic penetration, thus opening up new depth ranges to exploration and allowing the elucidation of even more complex structures. Also, the relation of organic maturation and hydrocarbon generation (Tissot & Welte 1978), and the importance of the relation in time and space between hydrocarbon generation and trap formation became better understood.

1.3 Mesozoic plays in central and southern Alsace

In the late sixties, geologists of Shell (and of SNEA(P), we assume) realized that in the southern Rhine Graben and the adjoining Swiss and French Jura mountains, the Lower Triassic Buntsandstein and the carbonates of the M. Triassic Upper Muschelkalk and Lettenkohle had been hardly drilled, but could form exploration objectives, where adequately sealed and having access to an active hydrocarbon kitchen. A play concept was developed, which assumed:

- Lower Triassic sandstones and Middle Triassic carbonates as *reservoirs;*
- *sealed* by Middle and/or Upper Triassic evaporites and claystones;
- fault- and dip-bound *traps;*
- filled with hydrocarbons being generated from either of two conceivable *source rocks:*

a) Upper Carboniferous - Lower Permian coals and bituminous shales, deposited and preserved in Variscan (Hercynian) post-orogenic troughs or grabens; or
b) Lower Jurassic (Toarcian) bituminous shales generating oil in deeply buried fault blocks, and juxtaposed by major faults to the Triassic reservoirs in adjacent high blocks.

The concept appeared encouraging enough to justify the acquisition of large acreage tracts in the French and Swiss Jura Mountains, where concealed Permo-Carboniferous grabens were expected (Bitterli 1972; Beck 1975: Fig. 12).
In the Alsace, the interest was mainly directed towards the little explored central and southern part south of Strasbourg. The northern part, with the famous Pechelbronn oilfield, had already been intensely explored and was partially covered by exploration or production permits. It was therefore less attractive.

Primary objectives in this area south of Strasbourg were reservoirs in the clastic sequence of the Buntsandstein, and within the carbonates of the U. Muschelkalk and Lettenkohle. They had been penetrated by only few wells: 3 wells had penetrated the whole Buntsandstein, 6 more had just reached its upper part, and some 15 wells had penetrated the Lettenkohle-U. Muschelkalk reservoirs (Fig. 2). Both formations were, however, well known from outcrops at the Graben margins. The M. Jurassic Grande Oolithe was regarded as a secondary target only, as its reservoir properties had been shown earlier to be highly variable and of often poor to moderate quality.

Marls and evaporites of the Lower and Middle Muschelkalk and of the Keuper were assumed to provide seals for the Triassic reservoirs, Upper Dogger marls and Paleogene claystones and evaporites for the Grande Oolithe.

The Lower Jurassic (Toarcian) Posidonia Shale was regarded as the main potential source rock, generating hydrocarbons in the deepest part of the graben, i.e. in the

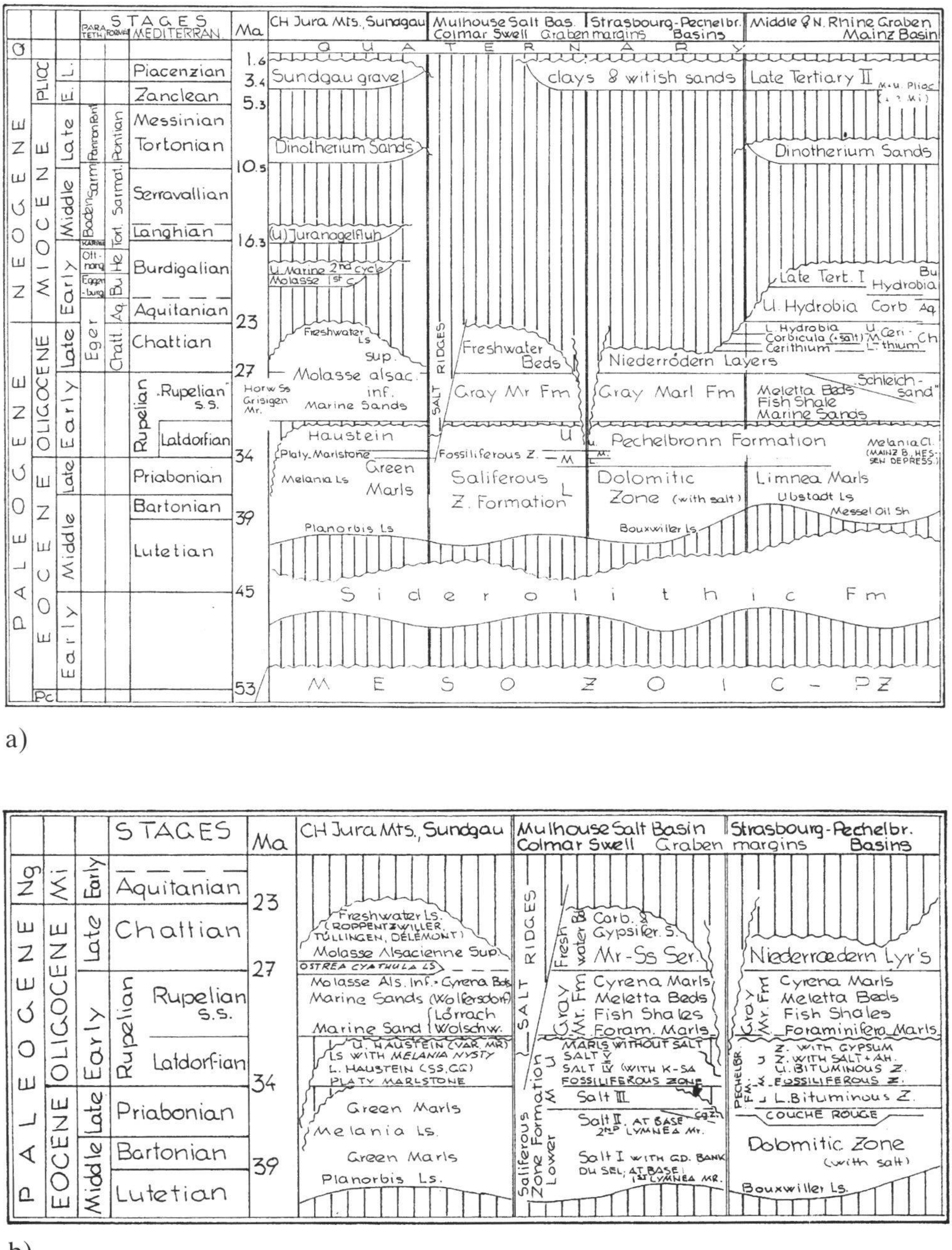

Fig. 4: Stratigraphy of the Tertiary of the U. Rhine Graben:
a) overview; **b)** Southern U. Rhine Graben: detailed stratigraphy of the Paleogene. After Sittler & Schuler in Vinken (1988: 41-47); ages (Ma) from Grahmann (in Vinken 1988: Fig. 267); position of Central Paratethys and formerly used, stages adapted from Doppler (1989: Tab. 1) after Roegl & Steininger (1983).

Mulhouse, Séléstat, and Strasbourg (Zorn) depressions (hatched area in Fig. 2). Wherever the mature source rock and the Triassic reservoirs were juxtaposed by major faults, hydrocarbons would be able to migrate into the stratigraphically older reservoirs; the structural relation between Triassic hydrocarbon accumulations and the presumed Toarcian source rock in the Greater Pechelbronn area was taken as a model (Schnæbelé 1948: Plate IX (section 4); Blumenrœder 1962: Fig. 12). Fault throws needed to juxtapose the Lower and Middle Triassic reservoirs with the Toarcian source rock, would be some 550 m and 300 m, respectively.
In the Sundgau area, south of Mulhouse, a possibly source-rock-bearing Permo-Carboniferous trough or graben was expected to be present between the well Wintersingen (some 20 km E of Basel), which had drilled oil-shale-bearing Autunian, and the outcropping Stephanian coal measures, mined in the Ronchamp area on the SW slope of the Vosges. Further north, the occurrence of Late Paleozoic source rocks was regarded less likely, except possibly in a NE-trending belt crossing the Rhinegraben between Séléstat and Offenburg, connecting scattered occurrences of Late Paleozoic strata west and east of the Rhine Graben (Fluck & Weil 1975: Fig. 26). In the Vosges (Fluck in BRGM 1972b: 6-7, 24, 32-36), isolated patches of Westphalian west of St. Hyppolyte (6 km SW of Séléstat) contain uraniferous bituminous shales (0-50 m thick) and coal lenses; while Stephanian and Autunian coal was mined near Villé at the edges of the Permian Villé Basin. Here, as in the Permo-Carboniferous trough of northern Switzerland, the faulted Autunian is overstepped by less deformed Saxonian strata, thus recording the so-called Saalian movements. Comparable and possibly related occurrences of Lower Permian to Upper Carboniferous strata are found in the Black Forest near Offenburg (anthracite-bearing Westphalian of Diersburg-Berghaupten, and Stephanian of the Geroldseck near Lahr) and near Baden-Baden (Geyer & Gwinner 1991: 49).
Minor source rocks were assumed to exist in the Lettenkohle and the Lower Muschelkalk.

Traps were expected to resemble known structural traps like Staffelfelden in the south, and Eschau, near Strasbourg, in the north: These comprise eastward-tilted fault blocks, bounded by major antithetic faults in the west, and dip-bounded in the east (Blumenrœder 1962: Fig. 14, 18).

Blumenrœder (1962: 43) had discerned in the area of interest two regional highs, the „dorsale de Colmar-Gerstheim“ and the „seuil d'Erstein“ which he assumed to have been positive features at the beginning of the Tertiary deposition. As a rule, oil accumulations in Mesozoic reservoirs in the Alsace had been found in structures, that existed already in or before early Tertiary time (Blumenrœder 1962: 45), so these two highs, and in particular the hardly investigated Colmar-Gerstheim swell, were regarded as particularly prospective.

2. Summary and results of Shell-SNEA(P)'s exploration activities 1970-1990

In order to explore the play described, Shell Française applied in 1970 for large permits in the southern and central part of the Alsace, and SNEA(P) in the central and

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[1] 1^G = 1 gon = 100\` = 0.9°; on French official maps, geographical coordinates are given in gons, with the Paris Meridian as origin for longitudes