Bull. angew. Geol. Vol. 10/1 Juli 2005 S. 75-86

The Alpine Molasse Basin – Review of Petroleum Geology and Remaining Potential

James Véron[1]

Keywords: Molasse Basin, Petroleum potential, Yet-to-Find, Austria, Germany

Abstract
Given the decades of exploration activities in the German and Austrian areas of the Molasse Basin, new large discoveries in the basin may be rare. However, technical progress, new seismic interpretation and geological models generated new prospects and increased exploration efficiency. The largest gas field in Upper Austria, was discovered in 1997 and several small to medium discoveries were found in the Austrian Molasse Basin since. The presented here Yet-to-Find analysis of the Molasse Basin indicates that up to several hundred (small to very small) fields can still be discovered, with the estimated total recoverable reserves exceeding 400 MMboe (million barrels of oil equivalent).

Zusammenfassung
Die langjährigen Explorationstätigkeiten in den deutschen und österreichischen Teilen des Molasse Beckens, lassen neue grosse Kohlenwasserstoff-Funde als eher unwahrscheinlich erscheinen. Neueste technologische Entwicklungen im Bereich der Seismik sowie neue geologische Modelle haben jedoch die Explorationserfolge erhöht. Das grösste Gasfeld Oberösterreichs wurde zum Beispiel im Jahre 1997 entdeckt. Mehrere andere neue Öl- und Gasfunde folgten danach. Die hier präsentierte «Yet-To-Find» Analyse des Beckens zeigt, dass einige hundert kleine Kohlenwasserstoff-Felder, mit einem geschätzten förderbaren Reservevolumen von über 400 MMboe (million barrels of oil equivalent), noch zu entdecken sind.

1 Introduction

The Molasse Basin is located to the north of the Alps and extends from France to the eastern border of Austria (Fig. 1). In its present day configuration, the basin is about 900 km long and up to 120 km wide in the German sector. The Molasse Basin is a Cenozoic Foredeep Basin, the basin fill of which fundamentally responded to flexural subsidence. Its substratum comprises Mesozoic, locally Permo-Carboniferous and crystalline/metamorphic basement rocks.

After decades of exploration – over 1'200 exploratory wells have been documented – and with some 192 discoveries, the basin is considered mature in terms of hydrocarbon exploration. However, several oil and gas companies are showing interest in the area as opportunities related to not yet fully explored specific plays might still exist in various types of prospects. For example, the latest discoveries in the basin, Zaggling and Strass were made by RAG (Rohöl-Aufsuchungs AG/Österreich) in 2004 in the southwestern corner of the Salzburg block, in Austria. Zaggling encountered gas in the Oligocene series, while Strass in the Miocene series.

[1] Basin Specialist, IHS Energy,
24 Chemin de la Mairie, 1258 Perly-Geneva

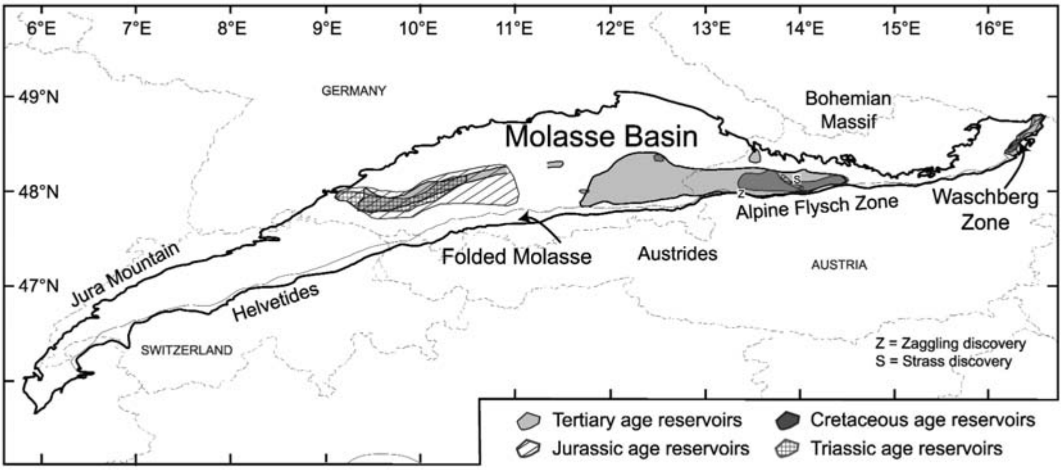

Fig. 1: Basin Location and Generalised Distribution Map of the Reservoirs in Germany and Austria.

2 Regional Geology

The Molasse Basin extends along the northern front of the Alpine Mountain Range of Central Europe. Trending WSW–ENE, it covers areas of France, Switzerland, Germany and Austria. Main areas of deposition are north-central Switzerland, southernmost Germany and eastern Austria.

The Molasse Basin and its substratum underwent four major evolutionary stages, termed here as Syn-rift, Epicontinental, Passive Margin and Alpine Foredeep. During Permo-Carboniferous times (Syn-rift phase), narrow troughs formed along the dominating ENE–WSW and WNW–ESE trends of the Variscan wrench faults. In the Molasse Basin area, those are the Giftthal, Bodensee and Entlebuch troughs. Epicontinental deposits of Triassic-Middle Jurassic age progressively overstep the Variscan Basement, or on Permo-Carboniferous series, from NW to SE (Boigk 1981), to the effect that neither the Landshut-Neuötting paleohigh of Eastern Bavaria nor major parts of the Austria Molasse Basin area are covered.

The passive margin stage was accompanied by transpressional and transtensional movements in Middle Jurassic to Early Cretaceous time (Malkovsky 1987; Nachtmann & Wagner 1987). The shift from the epicontinental to the passive margin setting is being correlated with Jurassic extensional events (Roeder & Bachmann 1996), apparently falling into the time of Middle Jurassic crustal separation in the western Tethys (Ziegler 1982). The Late Cretaceous to Paleogene was dominated by primarily strike-slip movements along NW–SE directions.

Deposition was resumed at basin-wide scale during the Paleogene, reflecting the flexural basin development in response to Africa-Europe convergence and subduction of the European Plate. Sediments were mainly sourced from the south, onlapping progressively to northwest and, in terms of facies evolution, changed from marine, turbidite sedimentation to non-marine, freshwater clastics. As a result of the flexural bending of the crust, mainly extensional stress was induced in an overall compressional setting, causing the formation of sets of synthetic and antithetic normal faults which trend mainly parallel to the basin axis.

Two geologically and geomorphologically differing entities are observed within the basin: the mainly undeformed part (Unfolded Molasse) which makes up more than 90%

of the basin, and the deformed part, the Folded and thrusted (subalpine) Molasse, which takes up the southernmost parts of the basin area, being limited to the south by different tectonic units of the Alpine mountain range. Locally, particularly in the Upper Austria area, the fold belt is absent, overridden by the southerly Alpine thrusts. The division of the Molasse Basin into deformed and undeformed sub-units dates back to times of field geological work, when the limit between the two domains was drawn along the northernmost thrust fault with surface expression, lacking seismic control. This definition is maintained here, although recent reviews of subsurface data indicated the presence of a frontal triangular zone at regional scale, separating both entities.
The Alpine Molasse Basin (Fig. 1) is limited along the northern margin, mainly on Swiss terranes, by the mountain range of the Jura Fold Belt. Along the transition from the Molasse lowlands to the Jura Mountains, the Molasse sediments – although unconformably resting on their substratum – depict the structuration, i.e. folding and faulting, of the Jura Fold Belt. This reflects the young (Late Miocene to Pliocene) age of the fold belt deformation. The Mesozoic platform area of the Swabian and Franconian Jura adjoins to the northeast, where youngest Molasse sediments onlap on that platform. The onlap sediments are partially eroded, indicating an original basin outline further north.
Along the northeastern border, in East Bavarian and Upper Austrian territories, the Bohemian Massif borders the basin along faults. Locally, the faults are covered by uppermost Molasse sediments onlapping the massif's tilted southern spur. Away from the St. Poelten area, a fundamental change in direction takes place, and the limit follows a SW–NE direction, along a major fault. This Neogene fault is locally buried under the overlying Molasse sediments. In the east, transition from the adjoining Vienna Basin in part is fault controlled and in part follows the onlap pattern of the Vienna Basin on the Waschberg Zone, the eastern equivalent of the Folded Molasse.
To the south, the Molasse Basin terminates along the various thrust fronts which delimit the Alpine system.

3 Petroleum Geology

3.1 Petroleum Systems

Four petroleum systems are believed controlling the occurrence of hydrocarbons in the basin (Fig. 2). However, due to the absence of unequivocal evidence, i.e. supportive oil/gas – source correlations, an element of uncertainty is inherent in the identification of the petroleum systems.

1) The Permo/Carboniferous - Triassic/Jurassic/Neogene Petroleum System

Upper Carboniferous and Lower Permian (Rotliegend) coal seams and bituminous shales provide the source rocks. The petroleum system, as the distribution of source rocks, is confined to narrow rift grabens.
Traps of those locally confined areas are antithetic, tilted fault blocks (particularly in the German Western Molasse area), and thrust sheets or subthrust fault blocks in the Folded Molasse area, as is the case of the Entlebuch discovery. Trap formation essentially took place at Oligocene to Mid Miocene times as far as the unfolded Molasse is concerned, and within the period Late Eocene to Late Miocene in the Folded Molasse areas.
Reservoirs range, within the Mesozoic, from Keuper and Lower/Mid Jurassic sandstones to Muschelkalk and Upper Jurassic carbonates and, at Neogene level, to the Chattian Baustein Beds, mainly.
Seals are mainly provided for by intraformational shales. Evaporites partly seal Triassic reservoirs. Shales and partly marls of Early Tertiary age provide seal for both Lower Tertiary and truncated Upper Jurassic reservoirs.

2) The Posidonia Shale - Cretaceous/ Neogene Petroleum System

Being controlled by both facies changes and erosional effects, the source rocks show almost complementary distribution patterns: the Posidonia Shale predominate in the northern sector, the Upper Jurassic source rocks in the southern sector.
Traps are provided for by antithetic, tilted fault blocks in the areas of the Unfolded Molasse and by subthrust fault blocks and particularly thrust sheets, as is the case in the Waschberg Zone of Lower Austria in the Folded Molasse. Trap formation essentially took place at Oligocene to Mid Miocene times as far as the Unfolded Molasse areas is concerned, and within the period Late Eocene to Late Miocene in the Folded Molasse areas.

3) The Lattorfian Fish Shale - Cretaceous/Neogene Petroleum System

It is predominantly an oil system and is responsible for the oil accumulations located within – and next to – the distribution area of mature Sannoisian source rocks, which are fish shales.
Traps are provided for by antithetic, tilted fault blocks in the areas of the Unfolded Molasse and by subthrust fault blocks and thrust sheets, as in the Waschberg Zone of the Lower Austria Folded Molasse. Trap formation took place at Oligocene to Mid Miocene times as far as the Unfolded Molasse areas is concerned, and within the period Late Eocene to Late Miocene in the Folded Molasse areas.
Reservoir rocks of this system are those aligned along migration paths with updip migration from deeper basin parts, being controlled by buoyancy and differential pressure. The range of oil reservoirs is therefore from Upper Austria's Dogger sandstone and carbonate and Cenomanian sandstone reservoirs to Upper Eocene sandstones and Oligocene carbonates and sandstones. Seal is mainly provided for by intraformational shales. In the case of the Dogger reservoirs, tight Upper Jurassic carbonates may act as additional seal, and in the case of the Campanian reservoir, being potentially truncated, Lower Tertiary shales may serve as additional seal.
The petroleum system is restricted to the areas of the Austrian and German Eastern Molasse and of parts of the German Western Molasse.

4) The Oligocene - Oligocene/Lower Miocene Petroleum System

Source rocks are of the Oligocene age and were identified on a basis of gas isotope analyses (Schoell 1984), demonstrating that part of the gas, particularly in Upper Austrian and German Western Molasse, is of biogenic origin. Reservoirs in the petroleum system are sandstones of Rupelian, Chattian, Aquitanian and Burdigalian age, as evidenced in the productive areas. Seals are provided for by intraformational Oligocene and Miocene shales. Gas generation is suggested having taken place from Middle Oligocene times onwards, and will be an ongoing process. Expulsion and migration obviously follow the same pattern, with respective retardation. Traps are antithetic fault blocks and stratigraphic traps, particularly sealed off bodies of channel sands. Trap formation was at Oligocene to Middle Miocene time, following deposition of post-reservoir intra-formational shale seals.

3.2 Source rocks

Primary source rocks for oil in the basin (Fig. 2) are considered to be the Oligocene marine fish shales (Lattorfian Fish Shale) and the Lower Jurassic (Toarcian) marine Posidonia Shale. The Upper Jurassic Quinten Limestone of the western areas of the basin and the Upper Jurassic bituminous marls of the eastern areas, both representing Tethys facies, are secondary oil source rocks. Upper

Carboniferous (Stephanian) and Lower Rotliegend (Autunian) coal seams and lacustrine shales may have yielded both gas and oil.

Gas that was identified in the gas reservoirs of the Eastern Molasse (e.g. Ampfing, Bierwang discoveries in Germany) and of the Upper Austrian Molasse (e.g. Diethaming 1A, Treubach field/discovery) is suggested having been generated mainly from Mid/Upper Oligocene (Rupelian/Chattian) and basal Miocene (Chattian/Aquitanian) marine shales.

Since the primary source rocks lack oil maturity next to the sites of the oil bearing reservoirs, it is therefore expected that oil (and gas) generation took place at greater depths, beneath the thrust belt (Gier 2000), thus involving lateral and updip migration.

3.3 Reservoirs

Productive reservoirs are present both at Mesozoic levels (54 MMboe – million barrels of oil equivalent – of recoverable reserves to date) and within the Tertiary Molasse section (483.3 MMboe; Fig. 2). Triassic reservoirs include: the Muschelkalk Trigonodus Dolomite, deposited along the basin rim, the Keuper nearshore shallow marine Kiesel (Chert) Sandstone, the lacustrine Stuben Sandstone and the littoral/deltaic Rhaetian Sandstone. The Jurassic shallow marine platform settings host the Lias-alpha and Dogger-beta sandstones, representing local bar sands, and Upper Jurassic reefal and fractured carbonates. Within the Cretaceous section, shallow marine glauconitic sandstones form the main reservoirs, i.e. the Aptian and Albian Greensand units, Cenomanian and Turonian glauconite sandstones and the Upper Campanian sandstone. They form important reservoirs of the Austrian Molasse, also in terms of reservoiring hydrocarbon volumes, holding some 13 Bscfg (Billion standard cubic feet of gas) in both the Voitsdorf and Schwanenstadt fields.

Reservoirs of the Tertiary Molasse are contained in both megasequences: the Upper Marine Molasse and Lower Marine Molasse. The Upper Eocene reservoirs are: the Basal Sandstone, Ampfing Sandstone and Lithothamnia Limestone. They were the early targets of exploration in both Germany and Austria, and offer detailed analyses of the reservoir characteristics, facies variations and distribution patterns. They all, together with the Isen Sandstone, represent shallow marine platform conditions.

In the German Haag field (5.5 Bscfg), the Isen Sandstone Formation reservoir is 4 m thick in average but shows an average porosity of 20% and permeability values of up to 200 mD (Milli-Darcy). The Lithothamnia Limestone reservoir (3.68 Bscfg) is much thicker (averaging 48 m) and has porosity values reaching 30% and permeability values of 10 mD in average.

Within the Lower Marine Molasse (Late Oligocene (Chattian) to Early Miocene (Aquitanian) reservoirs represent the entire range of marine environments. From west (Bavaria) to east (Upper Austria) these are: the marine-brackish Baustein Sandstone, the deltaic channel-deposition of the Chatt and Aquitan sandstones and the turbiditic Puchkirchen sandstone series (Robinson & Zimmer 1989). The Upper Marine Molasse contains two reservoir levels: the Burdigalian basal, transgressive marine Gendorf Sandstone in the west (Bavaria) and its eastern (Upper Austria) equivalent, the Hall Formation.

The basal Hall Formation and the underlying Upper Puchkirchen Formation are important reservoirs in several Austrian fields, including Puchkirchen (100 Bscfg) and Atzbach (120 Bscfg).

The Puchkirchen field, located approximately 4 km SW of the Atzbach gas field, was the first commercial oil field discovered in the Austrian Molasse Basin (Upper Eocene sandstone). However, the field became a gas and oil field after the discovery of the new non-associated gas horizons in 1969 and 1972 (Upper Puchkirchen and Hall formations).

By contrast, the Freshwater Molasse series

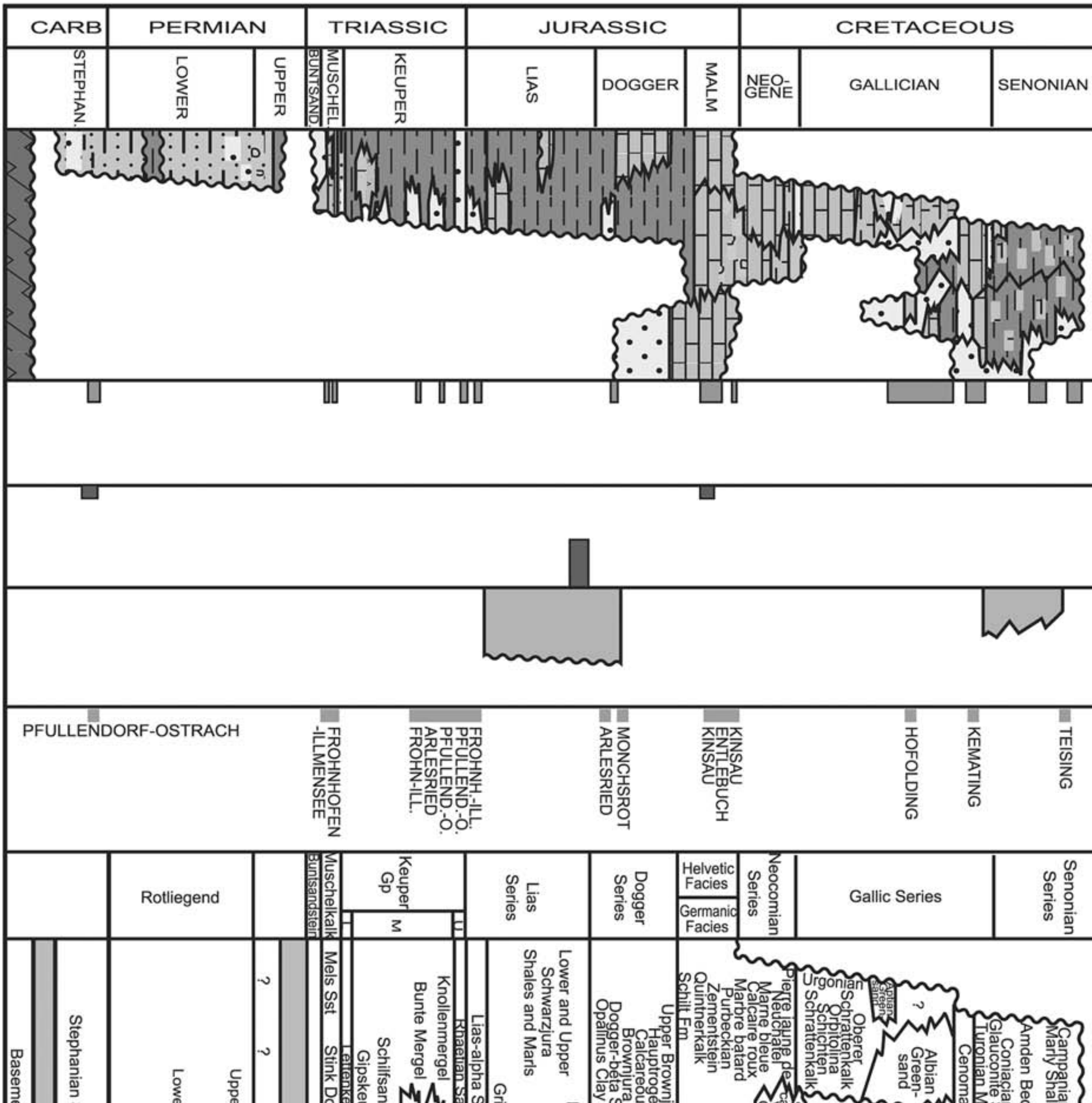

Fig. 2: Generalised Stratigraphic Chart of the Molasse Basin and its substratum.
Compiled after works from Boigk (1981), Kraus (1969), Bachmann & Muller (1991), Ziegler (1990), Aigner & Bachmann (1992), Bachmayer (1980), Malzer (1981), Kolmann (1977), Wessely (1988).

CHRONO-STRATI-GRAPHY
EOCENE
OLIGOCENE
MIOCENE
PLIOCENE
QUATERNARY
Bartonian
Priabonian
Rupelian
Chattian
Aquitan.
Burdigal.
Langhian
Serraval.
Tortonian
Messinian
Zanclean
Piacenz.
LITHOLOGY
W
E
scale change
RESERVOIRS
SOURCE ROCKS
SEALS
INTRAFORMATIONAL SEALS
MAJOR FIELDS
DARCHING
AMPFING TEISING
HOHENLINDEN TEISING
EGGERDING
ISEN HAAG
ARLESRIED
BIERWANG
MUNDERFING
GENDORF
ALT PRERAU WILDEN-DURNBACH
LITHOSTRATIGRAPHY
Groups
Formations
Lower Marine Molasse
Lower Freshwater Molasse
Upper Marine Molasse
Brackish Freshwater Molasse
Upper Freshwater Molasse
Lithothamnia Limestone
Ampfing Sst
Basal Sst
Lattorfian Fish Shale
Heller Mergelkalk Member
Baendermergel Member
Rupelian Marl
Rupelian Sst
Isen Sst
Baustein Beds
Rupelian Marl
Lower Puchkirchen Formation
Lower Section
Chattian Sst
Upp. Cyr.
U.Chattian Marl
Upper Section
Blaettermergel Neuhofen Schichten
Glauconite Sst
Hall Fm
Aquitanian Fish Shale
Kirchberg
Oncophora Beds
Innviertel
Legend
Silty
Calcareous
Sand, sandstone
Marl
Volcanic
Chert
Salt
Breccia
Mudstone, shale, clay
Conglomerate
Chalk, limestone
Siltstone
Anhydrite
Dolomite
Metamorphic
Coal

are almost devoid of productive reservoirs in the upper sequence, or the sandstone reservoirs are insignificant (lower sequence). Noteworthy, this does not strictly apply to the transition zone, i.e. the brackish freshwater environment. The Oncophora Beds of Lower and Upper Austria (considered for some time as part of the Upper Marine Molasse) are hydrocarbon bearing in a number of fields (Wildendurnbach, Roseldorf and Alt Prerau). In the Wildendurnbach field (60 Bscfg), the Oncophora Beds are up to 110 m thick (averaging 51 m), show porosity values of 13 to 33.8% and permeability values reaching 3000 mD (average 30 mD).

3.4 Seals

The Oligocene fish shales are the principal seal formation of the basin. They cap both the various base Tertiary reservoirs and, ultimately, the Mesozoic reservoirs subcropping below the Tertiary section. The conspicuous gas-bearing Middle Tertiary section owes its prospectivity to the presence of intraformational shales. Intraformational seals, if not locally replaced by evaporites, also form the seals of the Mesozoic reservoirs, exemplified by the Early Jurassic shales which act as seal to the Rhaetian/Lias-alpha sandstone reservoirs. The Mesozoic-age evaporites seem insignificant as seals.

4 Discussion

4.1 Remaining Prospects

Technical progress together with a better understanding of the geology of the area increased exploration efficiency in recent years. Application of the concepts of sequence stratigraphy and seismic stratigraphy yielded new prospects within the basin and opened potential for testing previously undeveloped plays. Such may be the case of the stratigraphic traps within the Mid-Tertiary turbiditic successions in the German Eastern Molasse and Upper Austrian Molasse, though the concept requires refining by additional 3D seismic acquisitions.
Sparked by introduction of the new geological models, a new exploration phase started in the late 1990s with a new major discovery, Haidach, in 1997 (the largest gas field in Upper Austria; 150 Bscfg of recoverable reserves). Since then, several small to medium size discoveries were made in the Austrian part of the basin, including Nussdorf West in 2000 (100 Bscfg).
Re-interpretation of the tectonically complex «triangle zone» in the Bavarian part of the basin, led to a surge of exploration interest. The «triangle zone play» is proposed within the duplex structure along the main Alpine thrust, with potential reservoirs in the Tertiary section. If positively tested the play may lead to the recognition of further similar prospects (though well-developed triangle zones in the basin seem more an exception than a rule). Additionally, the geometry of the zone changes along strike – the level of basal detachment horizon is critical for stacking of the reservoirs (i.e. Baustein Beds in Bavaria).
Other exploration possibilities include prospects in the sub-thrust positions, as well as prospects related to the Permo-Carboniferous grabens.

4.2 Yet-to-Find

The Yet-to-Find (YTF) tool attempts to provide an estimate and the distribution of remaining recoverable reserves for a specific basin. A principal empirical feature of the hydrocarbon distribution applied here is that, in a given basin, there are usually a few large fields and a great number of small ones. The assumption is that the biggest structures are drilled in the initial phase of exploration and, hence, the biggest discoveries are made first, with the smaller fields being found during the later exploration phases (the fields are discovered in order of declining size).
We construct a graphical representation of

the basin history (Fig. 3) by plotting sizes of the discoveries as a frequency function. The largest field is ranked 1 (one very large field), the second largest field(s) rank 2, with the smaller size fields (ranks) showing increasing frequency of occurrence. In the subsequent YTF graph (Fig. 4), the field sizes are plotted on the Y-axis for each rank on the X-axis (for comparison, reserves are shown in MMboe on a logarithmic scale). It has been observed that a plot of log field size against log of rank approximates to a straight line. One can envisage that in a fully exploited basin in which all field sizes are represented and have been discovered, the fields frequency graph would follow a straight line (we recognise that this pattern may not hold true for exploration in e.g. deep-water areas). Analyses of various basins showed that, in a partially exploited basin, the absence of medium and small field sizes results in a marked drop at the right part of the field frequency curve. In the areas where it is believed that the major discoveries have been made, such as in the Molasse Basin, the slope of the line can be estimated by the presence of large-size discoveries, to create a synthetic distribution of the Estimated Total Reserves (ETR), indicating the yet be made discoveries. The size of these discoveries is then calculated by subtracting the Reserves to Date (RTD) from ETR. By generating such curve, we aim at validating the success ration against the remaining potential of the basin.

By plotting known sizes of discoveries versus the number of discoveries in a basin, we obtain a field size distribution graph (Fig. 5). Also based on the assumption that reserves are lognormally distributed in nature, a

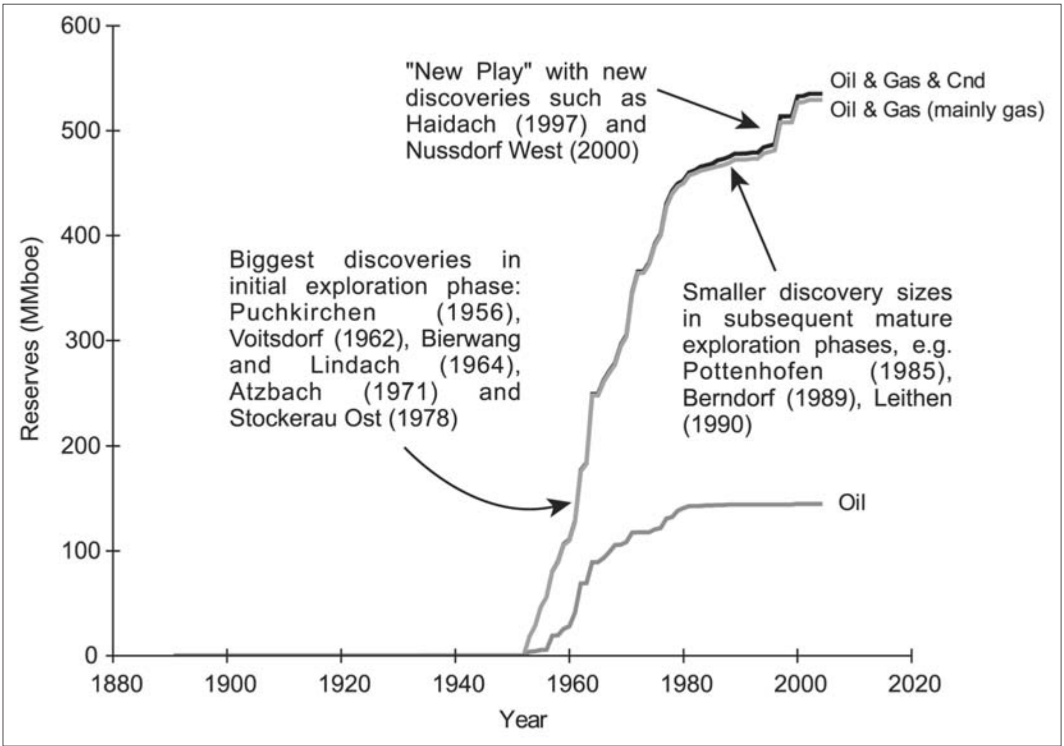

Fig. 3: Creaming Curve by Time Graph
The creaming curve displays cumulative reserves versus discovery date in a basin or area. The cumulative reserves are plotted in MMboe for comparison.

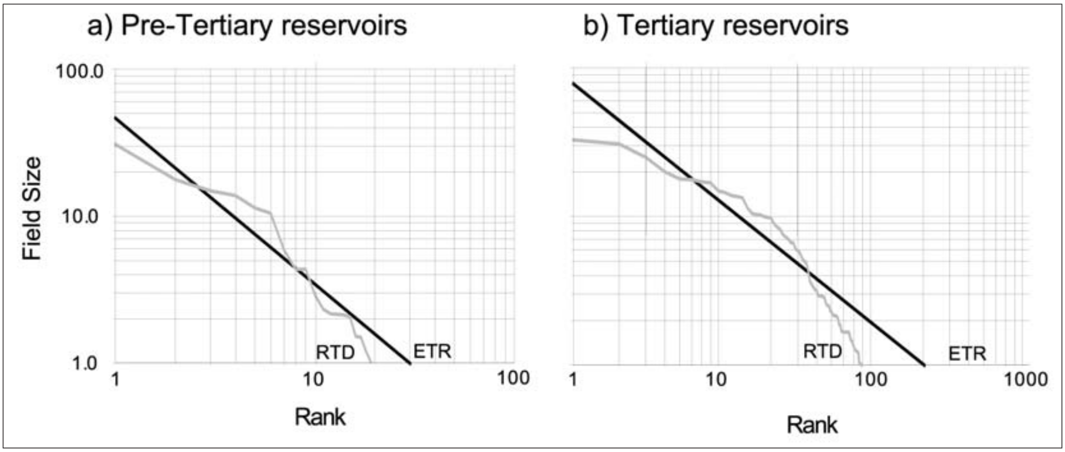

Fig. 4: Yet to Find Graph
The Yet to Find Graph is a line graph containing two series of data, the actual reserves (RTD) and the estimated reserves (ETR). The Y-Axis shows the Field Size in MMboe (lognormal scale). The X-Axis shows the Rank (lognormal scale) of Fields for each size.

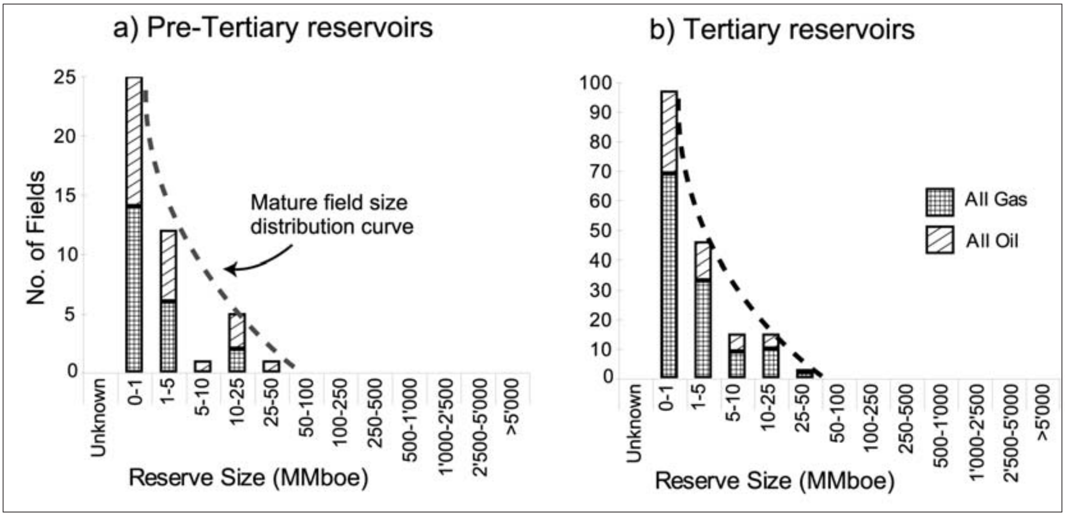

Fig. 5: Original Oil & Gas Field Size
Field size distribution graphs display the number of fields (Y-Axis) per reserves size category (X-Axis, semi-logarithmic scale). Reserves are displayed in million barrels oil equivalent (MMboe) for comparison.

mature field size distribution would show a logarithmically increasing number of fields with decreasing reserves size. The gaps between the actual number of fields and the mature field size distribution curve indicate the «missing fields».
In the here presented YTF analysis of the Molasse Basin, we tested separately reservoirs of the Mesozoic and Tertiary age with recoverable reserves exceeding 2 MMboe. Accordingly, yet-to-find reserves are estimated at 55 MMboe and 400 MMboe for the given geological interval. The analyses indicate also that only small to very small hydrocarbon accumulations remain to be discovered in the basin, with a few discoveries possible in the Mesozoic series and a few dozen small discoveries (5–10 MMboe) remaining within the Tertiary successions.

5 Conclusion

Despite the large number of fields discovered in the Molasse Basin areas of Austria and Germany, i.e. in the areas of prime prospectivity, and despite the decades of exploration activities, the basin is believed to still hold undiscovered accumulations of economical sizes.
Our empirical yet to find analyses show that it is highly unlikely that large discoveries will be found, but small discoveries within the Tertiary series may be expected in the ensuing years. It is possible that the basin's close proximity to the consumers will further attract exploration from the domestic companies that can make small-size discoveries economic.

Acknowledgments

The Author would like to thank IHS Energy Inc. for allowing the time and resources to make this article possible. Further credit and appreciation is extended to Piotr Gawenda for his comments on the earlier version of the manuscript. Thanks are also extended to Didier Arbouille and Dimitri Massaras for the support and review of this article.
For further information regarding this article and similar basin studies please contact James Véron (james.veron@ihsenergy.com) or Didier Arbouille (didier.arbouille@ihsenergy.com).

References

Aigner, T. & Bachmann, G.H. 1992: Sequence-stratigraphic framework of the German Triassic. Sedimentary. Geology, 80. Elsevier Science Publishers, Amsterdam, Netherlands, 115–135.
Bachmann, G.H. & Mueller, M. 1991: The Molasse Basin, Germany : evolution of a classic petroliferous foreland basin. In: Spencer, A.M. (ed), Generation, Accumulation and Production of Europe's Hydrocarbons, European Association of Petroleum Geoscientists Special Publication, 1. Oxford University Press, New York, United States, 263–276
Bachmayer, F. 1980: Erdöl und Erdgas in Oesterreich (Oil and Gas in Austria). Naturhistorisches Museum. Wien und F. Berger, Horn, Wien, Austria.
Boigk, H. 1981: Erdöl und Erdölgas in der Bundesrepublik Deutschland (Petroleum and natural gas in West Germany). Ferdinand Enke Publishers, Stuttgart, Federal Republic of Germany.
Gier, S. 2000: Clay mineral and organic diagenesis of the lower Oligocene Schoeneck Fishshale, western Austrian Molasse Basin. Clay Minerals, 35 (4). Mineralogical Society, London, United Kingdom, 709–717.
Kollmann, K. 1977: Die Öl- und Gasexploration der Molassezone Oberösterreichs und Salzburgs aus regionalgeologischer Sicht. Erdöl Erdgas Zeitschrift International Edition (Oil and Gas European Magazine), 93 (9). Urban-Verlag, Hamburg-Vienna, Federal Republic of Germany, 36–49.
Kraus, L. 1969: Erdoel- und Erdgaslagerstaetten im ostbayerischen Molassebecken. Erdoel Erdgas Zeitschrift International Edition (Oil and Gas European Magazine), 11. Urban-Verlag, Hamburg-Vienna, Federal Republic of Germany, 442–454.
Malkovsky, M. 1987: The Mesozoic and Tertiary basins of the Bohemian Massif and their evolution. In: Ziegler, A. (ed), Compressional Intra Plate Deformations in the Alpine Foreland, Tectonophysics, 137 (1–4). Elsevier, Amsterdam, Netherlands, 31–42.

Malzer, O. 1981: Geologische Charakteristik der wichtigsten Erdöl und Erdgastraeger der oberösterreichischen Molasse – Teil : II : Die Konglomerate und Sandsteine Oligozaens (Geological characteristic of the main oil and gas producing formations of the Upper Austrian Molasse Basin – Part 2 : the conglomerates and sandstones of the Oligocene). Erdöl Erdgas Zeitschrift International Edition (Oil and Gas European Magazine), 97 (1). Urban-Verlag, Hamburg-Vienna, Federal Republic of Germany, 20–28.

Nachtmann, W. & Wagner, L. 1987: Mesozoic and Early Tertiary evolution of the Alpine Foreland in Upper Austria and Slazburg, Austria. In: Ziegler, A. (ed): Compressional Intra Plate Deformations in the Alpine Foreland, Tectonophysics, 137 (1–4). Elsevier, Amsterdam, Netherlands, 61–76.

Robinson, D. & Zimmer, W. 1989: Seismic stratigraphy of Late Oligocene Puchkirchen Formation of Upper Austria. Geologic Modeling; Aspects of Integrated Basin Analysis and Numerical Simulation, Geologische Rundschau, 78 (1). Springer International, Berlin, Federal Republic of Germany, 49–79.

Roeder, D. & Bachmann, G.H. 1996: Evolution, structure and petroleum geology of the German Molasse Basin. In: Ziegler, P. & Horvath, F. (ed): Peri-Tethys Memoir 2: Structure and Prospects of Alpine Basins and Forelands, Memoires Museum National d'Histoire Naturelle, 170. Editions du Museum National d'Histoire Naturelle, Paris, France, 263–284.

Schoell, M. 1984: Wasserstoff- und Kohlenstoffisotope in organischen Substanzen, Erdölen und Erdgasen (Hydrogen and carbon isotopes in organic materials, petroleum and natural gas). Geologisches Jahrbuch, Reihe D: Mineralogie, Petrographie, Geochemie, Lagerstaettenkunde, 67. Schweizerbart in Komm., Stuttgart, Federal Republic of Germany.

Wessely, G. 1988: Der Tiefenaufschluss im Wiener Becken und der Molassezone als Ausgangspunkt fuer die Alpenexploration in Oesterreich (Deep exploration in the Vienna Basin and in the Molasse zone – impulse for Alpine exploration in Austria). Erdöl Erdgas Kohle (Oil and Gas Magazine), 104 (11). Urban-Verlag, Hamburg-Vienna, Federal Republic of Germany, 440–446.

Ziegler, P.A. 1982: Geological Atlas of Western and Central Europe. Elsevier Science Publishers, Amsterdam, Netherlands, 1–130.

Ziegler, P.A. 1990: Geological Atlas of Western and Central Europe. 2nd Edition. Shell International Petroleum Maatschappij B.V.