Zeitschrift: Eclogae Geologicae Helvetiae

Herausgeber: Schweizerische Geologische Gesellschaft

Band: 85 (1992)

Heft: 3: Symposium on Swiss Molasse Basin

Artikel: Swiss Molasse Basin : geodynamics, recources, hazards : an introduction

Autor: Ziegler, Peter A.

DOI: https://doi.org/10.5169/seals-167018

Eclogae geol. Helv. 85/3: 511–517 (1992)

0012-9402/92/030511-07 $1.50 + 0.20/0
Birkhäuser Verlag, Basel

Swiss Molasse Basin: Geodynamics, resources, hazards: An introduction

By Peter A. Ziegler [1])

In spring 1991, the Swiss Committee of the International Lithosphere Program (CHILP) proposed to the Swiss Geological Society to jointly organize a symposium on the geodynamics, resources and hazards of the Swiss Molasse Basin. The objective of such a meeting was to analyze the present status of knowledge on the Molasse Basin and to assess outstanding problems requiring further research. Following acceptance of this proposal, the Swiss Hydrological and Geological Service and the National Research Program on "Deep Geological Structure of Switzerland" (NFP-20/PNR-20) were invited to cosponsor this meeting, which was held November 22–23, 1991 in Bern at the Natural History Museum. This meeting was attended by some 80 delegates from Swiss academic institutions; the Petroleum Industry, Nagra, consulting firms and Federal agencies.

The Molasse Basin underlies the Swiss Midlands which contains some 80% of the population of Switzerland and most of its major industrial centres. These have a high energy and water demand and produce, apart from radioactive also non-radioactive waste, the disposal of which poses environmental problems.

The structural framework and the internal architecture of the Molasse Basin is poorly known outside the Petroleum Industry which has at its disposal a largely proprietary data base consisting of an extensive grid of reflection-seismic lines and numerous deep wells. For want of access to this data base, academic institutions are unable to analyze and model the geodynamic processes governing the evolution of the Molasse Basin.

So far exploration for hydrocarbons has failed to establish significant reserves in the Molasse basin (Lahusen, this volume). Its geothermal energy potential requires careful analysis in view of the economics of producing such renewable energy and increasing concerns about the level of CO_2 emission (Rybach, this volume). The pre-Quaternary aquifers of the Molasse Basin have been hardly tapped and little is known about the chemistry of waters contained in them, their production potential and the hydrodynamics of the basin (Kiraly, this volume). Systematic studies are being carried out by Nagra to identify potential sites for storing radioacitve waste in its subsurface (Thury, this volume). The problem of disposal of non-radioactive industrial waste increasingly becomes an environmental concern (Huggenberger, this volume). Seismologically speaking, the Swiss Midlands correspond to a zone of relatively low earth-

[1]) Geological-Palaeontological Institute, Bernoullistr. 32, CH-4056 Basel, Switzerland

quake frequency; however, repeated earthquakes with magnitudes up to 4.2 and focal depth between 8 and 30 km have been registered (Pavoni 1980). Together with results of geodetic and stress measurements (Becker et al. 1987; Blümling et al., this volume; Müller, this volume), this indicates that the area of the Molasse Basin is tectonically still active and that occurrence of even larger earthquakes cannot be excluded.

In view of the important role the Molasse Basin plays as host of the majority of the Swiss population and its industrial centres, the solution of its inherent resource and environmental problems demands the combined effort of the Swiss academic and industrial Earth Science communities. As a first step towards such an effort, this meeting aimed at assessing the availability of a commonly accessible data base for the Molasse Basin and to evaluate whether additional data are required in order to 1) better define its structural and stratigraphic configuration, 2) resolve geodynamic processes governing its evolution and present seismic activity, 3) be able to contribute towards the development of its natural resources and 4) improve the protection of its environment.

Summary of Basin Evolution

The Swiss Molasse Basin is limited to the northwest by the Jura Mountains and to the southeast by the Alps. Its sedimentary fill consists of a southeastward expanding, up to four kilometres thick wedge of Tertiary sandstones, conglomerates and shales which rests disconformably on truncated Mesozoic carbonates, shales and clastic rocks ranging in thickness between one and two kilometres. The latter overlay a Hercynian basement complex and, more locally, several kilometre thick Permo-Carboniferous clastics contained in fault-bounded troughs.

The Mesozoic evolution of the area occupied by the Swiss Molasse Basin was dominated by tensional stress regimes related to the break-up of the Late Palaeozoic Pangea. Its Tertiary evolution was closely linked with the development of the Alpine orogen and the folding of Jura Mountains, resulting from the collision of Africa with Europe; development of the Cenozoic Rhine-Rhône rift system influenced the development of the Molasse Basin probably only marginally (Trümpy 1980, Ziegler 1990).

The crystalline basement underlying the Swiss Molasse Basin consists of pre-Hercynian gneiss series and Hercynian plutonites ranging in age between 330 and 315 Ma (Mazurek et al., this volume). Following the Late Westphalian consolidation of the Variscan fold belt, Stephanian-Autunian wrench-faulting gave rise to the subsidence of often narrow fault-bounded troughs in which continental clastics accumulated (Ziegler 1990; Diebold, this volume). At the same time the Variscan fold belt was uplifted and deeply eroded. Late Permian, Triassic and Early Jurassic series transgressed over this erosional surface under a regional tensional tectonic setting. This led to the gradual establishment of a broad basin which occupied the area of the future Swiss and German Molasse Basin, extended northwestwards into the Paris Basin and was linked to the north with the Northwest European Basin (Ziegler 1990; Bachmann, this volume). Rifting activity culminated in Mid-Jurassic crustal separation in the Penninic domain. Subsequent transtensional opening of the oceanic South-Penninic Trough persisted into Early Cretaceous times. During the Middle and Late Jurassic and Cretaceous platform sediments accumulated on the passive Helvetic

Shelf flanking the North-Penninic Trough, which was separated by the Briançonnais High from the South-Penninic ocean. The broad Helvetic Shelf occupied large parts of southern Germany and extended through the area of the future Swiss Molasse Basin into the Paris Basin. Early Cretaceous tectonic instability of this shelf can be related to transtensional movements in the Penninic domain and to rifting activity in the North Sea and the area of the Bay of Biscay. Late Cretaceous activation of subduction processes in the Penninic domain was followed during the latest Cretaceous and Paleocene by the transmission of compressional stresses into the Helvetic Shelf, giving rise to its uplift, deformation and the development of a regional hiatus (Ziegler 1990, Bachmann, this volume). Thrust-loading of the Helvetic Shelf commenced apparently during the Eocene, as evident by the gradual development of a foreland basin in which syn-orogenic clastics accumulated. Following the Paleocene erosional phase, sedimentation resumed in the southernmost parts of the evolving Swiss Molasse Basin during the late Eocene-early Oligocene (Herb, this volume) and rapidly progressed northward during the middle Oligocene. Sedimentation in the Molasse Basin persisted under alternating shallow marine and continental conditions until Late Miocene times. During its evolution, the sourtheastern parts of the Molasse Basin were partly overridden by the advancing Alpine nappes and partly deformed and destroyed as a consequence of imbrication of the foreland crust, resulting in uplift of the external Aare Massif (Pfiffner 1986). Folding of the Jura Mountains commenced during the Middle Miocene and terminated probably at the end of the Miocene (Laubscher 1987 and this volume). At the same time the Molasse Basin was uplifted and its sedimentary fill subjected to erosion whereby the degree of uplift and erosion increases towards the southwest in tandem with increasing shortening in the Jura Mountains.

The generally accepted kinematic model for folding of the Jura Mountains implies insequence thrust propagation from the Alpine orogen into the foreland, involving imbrication of the basement forming the Aare Massif and the development of a detachment horizon within the Triassic evaporites of the Molasse Basin, and at some stage, also the reactivation of pre-existing basement fractures within the Molasse Basin, inducing partial inversion of Permo-Carboniferous troughs (Laubscher 1974, this volume; Jordan, this volume). This model, which is mainly based on the amount of shortening evident in the Jura Mountains, requires further refinement by an analysis of the fault patterns evident on industry-type reflection-seismic profiles crossing the Molasse Basin.

Understanding of the Alpine orogen demands a detailed analysis of the deformation of its forelands. During the Alpine orogeny the area of the Helvetic Shelf was affected by such processes as lithospheric deflection in response to thrust loading (craton-ward migration of the foreland basin axis and foreland bulge), the projection of collision-related compressional stresses into the foreland lithosphere (lithospheric buckling, reactivation of crustal discontinuities resulting in uplift of basement blocks and basin inversion), as well as by rifting activity and related thermal disturbance of the lithosphere. The contribution of these different processes to the evolution of the Molasse Basin can only be deduced from a detailed analysis of its sedimentary record and its present structural configuration. This could yield fundamental scientific as well as practical results, for instance by establishing a possible relationship between the pattern of neotectonic deformations and the geothermal field.

Results of Hydrocarbon Exploration

In the Swiss Molasse Basin exploration for hydrocarbons commenced with the founding of the Swisspetrol Holding A.G. in 1956. Since then the Swisspetrol Group, in partnership with the international Petroleum Industry, has acquired some 8500 km of reflection-seismic lines and drilled 35 deep wells. These efforts resulted in the discovery of the small Finsterwald gas accumulation which is the only commercially exploitable hydrocarbon accumulation in Switzerland. In view of these results, the hydrocarbon potential of the Swiss Molasse Basin must be considered as high-risk and ultimate rewards are uncertain. Despite this, exploration of the basin continues, partly with the aid of Federal loans (Lahusen, this volume).

In contrast, exploration activity in the Austrian and German parts of the Molasse Basin has been rewarded by the discovery of some 24×10^6 tons of oil and 38×10^9 m^3 gas contained in numerous accumulations hosted in Mesozoic and Cenozoic reservoirs (Bachmayer et al. 1980, Boigk 1981). Causes underlying the obvious differences in hydrocarbon potential of the various parts of the Molasse Basin are seen in lateral changes of its stratigraphic and structural framework which control the distribution of source-rocks and reservoir-seal pairs and the configuration of structural and stratigraphic traps, respectively (Beck 1975, Brink et al., this volume).

For the Austrian and German parts of the Molasse Basin extensive publications by the Petroleum Industry provide regional lithofacies-palaeogeographic, structural and base-Tertiary subcrop maps, as well as structural cross-sections and some seismic lines. These publications give a good impression of the structural and stratigraphic framework of the respective parts of the Molasse Basin. In contrast, only very limited data acquired by the Petroleum Industry in the Swiss part of the Molasse Basin have so far been released for publication. Correspondingly, relatively little is known in the public domain about its deep structure and internal configuration. Moreover, legislations provide only in the Canton Vaud for the release of data 10 years after their acquisition by the Petroleum Industry.

Non-Hydrocarbon Resources of the Molasse Basin

Non-hydrocarbon resources of the Molasse Basin include groundwater and geothermal energy. Furthermore, non-permeable rock formations may be suitable for the disposal of industrial waste products.

Within the Molasse Basin, groundwater is mainly produced from Quaternary gravels and sands which infill in part deeply incised valley systems. Waters contained in the deeper Tertiary and Mesozoic aquifers are largely untapped and their composition is poorly known. The production potential of these deep aquifers is essentially unknown.

Existing models of the hydrodynamic regime of the Molasse Basin are based on poorly constrained geological cross-sections. These models can only then attain practical significance if they are based on detailed knowledge of the structural and stratigraphic framework of the basin (Kyraly, this volume). This could only be achieved by regional mapping of aquifers and seals with the aid of a grid of reflection-seismic lines which are calibrated by the available deep wells. A detailed knowledge of the hydrodynamic regime of the Molasse Basin is, however, a precondition for the potential production of deep formation waters, either for consumption and industrial use or in conjunction with the recovery of geothermal energy, as well as for the evaluation of potential industrial waste storage sites.

The thick sediments of the Molasse Basin represent a potentially important reservoir of geothermal energy that is located in the immediate vicinity of major population and industrial centres. Stratiform aquifers and/or zones of increased fracture porosity may present primary targets. Although development of this renewable energy source does at present not appear to be economically attractive, the Federal policy decision to reduce emission of CO_2 should provide an impetus for initiating already now the necessary geological and geothermal background studies that are later required for the assessment of specific projects.

Nagra has been charged by the Federal authorities with the task to evaluate the possibility of storing high-level radioactive waste in the subsurface of Switzerland. To this end Nagra has so far drilled 7 wells in northern Switzerland and has acquired some 750 km of reflection seismic lines; these cover the northeastern parts of the Molasse Basin and the adjacent Jura. Nagra publishes extensively on the results of its studies and its data base is publicly accessible. No specific storage sites have as yet been identified (Thury, this volume).

Studies aimed at the disposal of non-radioactive industrial waste are carried out on a less systematic basis, generally by private enterprises. However, also these studies demand detailed knowledge about the hydrodynamic regime of the basin and the distribution of impervious layers in its subsurface, such as thick clay series or massive halites. This, in turn, requires access to an extensive reflection-seismic data base. Increasing environmental concerns lend urgency to such projects (Huggenberger, this volume).

Publicly Accessible Subsurface Data

For the Cantons Vaud and Geneva, industry-type reflection-seismic data, calibrated by such wells as Essertine-1 and Savigny-1, provide a good structural picture of the southwesternmost parts of the Molasse Basin (Gorin, this volume). Data acquired by Nagra are largely concentrated in the northern, shallow parts of the Molasse Basin. Only a very limited amount of reflection-seismic data acquired by the Swisspetrol Group in the Molasse Basin is publicly accessible. These include reflection-seismic lines along two traverses crossing the Molasse Basin which were acquired by the NFP-20 from the Swisspetrol Group under a data exchange agreement. To date, only the lines along the eastern of these two traverses (St. Gallen, Thurgau) have been processed, interpreted and published (Stäuble & Pfiffner 1991). Lines along the western traverse, crossing the Bernese part of the Molasse Basin, are now being processed and analyzed.

Correspondingly little is known in the public domain about the structural and stratigraphic configuration of large parts of the Molasse Basin.

Conclusions

Although the Swiss Molasse Basin has been the subject of extensive surface geological studies, in part dating back to the last century, of regional gravity, magnetic and refraction seismic surveys and corresponding interpretative studies carried out by Swiss universities on behalf of Federal organizations (Kingelé, Ansorge, this volume), and of a major effort by the Petroleum Industry (Lahusen, this volume), it is one of the less well documented sedimentary basins of Western Europe.

For instance, a structural map at the base Tertiary level, as available for the German and Austrian parts of the Molasse Basin, has never been published for the Swiss Molasse Basin and cannot be constructed on the basis of the publicly available data. Similarly, isopach and facies maps of the Tertiary and Mesozoic strata are not available and the distribution of the partly coal-bearing Permo-Carboniferous series is largely unknown. Gravity back-stripping, using isopach maps of the Tertiary and Mesozoic sediments, could possibly assist in mapping the gross lithological composition of the basement and maybe the distribution of major Permo-Carboniferous troughs.

The lack of a publicly accessible reflection-seismic data base covering the entire Molasse Basin, as well as the lack of free access to the available well data impedes the evaluation of its structural and stratigraphic framework and an assessment of the geodynamic processes which governed its evolution and control its present-day deformation. For instance, the kinematic model proposed for the deformation of the Jura Mountains and the late uplift of the Molasse Basin cannot be constrained without access to such data. Moreover, the role played by fault systems transecting the basin as possible focal lines of earthquakes cannot be evaluated. Similarly, an assessment of the non-hydrocarbon resources of the Molasse Basin, such as groundwater contained in deep aquifers and their geothermal energy potential, can only be carried out if access to the well data and a network of reflection-seismic lines can be obtained. On the basis of these data considerably more realistic models of the hydrodynamic regime of the basin could be constructed. A similar data base is required for the mapping of impervious layers, such as thick shale packages and halite pillows, in which industrial waste may be stored.

At the end of this meeting a consensus was reached that a major effort ought to be directed towards solving the many outstanding problems inherent to the understanding of the geodynamics, resource potential, environmental problems and neotectonic deformation of the Molasse Basin. Corresponding studies, aiming at the geodynamic analysis of the basin and the development of a regional framework, serving as a basis for project oriented analyses, could possibly be the subject of a new National Research Program (NFP) in the Earth Sciences. In the context of such a program, ways and means would have to be found to develop a generally accessible data base; this might require the recording a set of new high-resolution reflection-seismic lines through the basin and the acquisition of existing data from the Swisspetrol Group. Cooperation of academic institutions with the Swisspetrol Group, specifically in terms accessing their data base during the construction of regional structural and stratigraphic maps, would be highly desirable and would be mutually beneficial.

REFERENCES

BECK, R. H. 1975: Die Deckung des Erdölbedarfs West-Europas aus eigenen Quellen. Bull. Ver. Schweiz. Petroleum-Geol. u. Ing. 42, 14–36.

BECKER, A., BLÜMLING, P. & MÜLLER, W. H. 1987: Recent stress field and neotectonics in the Eastern Jura Mountains, Switzerland. Tectonophysics, 135: 277–288.

BOIGK, H. 1981: Erdöl und Erdgas in der Bundesrepublik Deutschland. Erdölprovinzen, Felder Förderung, Vorräte, Lagerstättentechnik. Ferdinand Enke Verlag, Stuttgart.

BACHMAYER, F., BRIX, F. & SCHULTZ, O. (Eds.) 1980: Erdöl und Erdgas in Österreich. Naturhist. Museum and F. Berger, Horn, Wien.

LAUBSCHER, H. P. 1974: Basement uplift and decollement in the Molasse Basin. Eclog. Geol. Helv. 67, 531–537.

– 1987: Die tektonische Entwicklung der Nordschweiz. Eclog. Geol. Helv. 80, 287–303.

PAVONI, N. 1980: Crustal stesses inferred from fault-plane solutions of earthquakes and neotectonic deformation in Switzerland. Rock Mech. Suppl. 9, 63–68.

PFIFFNER, A. O. 1986: Evolution of the northern Alpine foreland basin in the Central Alps. In: Foreland Basins. (Ed. by P. A. ALLEN and P. HOMEWOOD) Internat. Ass. Sediment., Spec. Publ. 8, 219–228.

STÄUBLE, M. & PFIFFNER, A. O. 1991: Processing, interpretation and modeling of seismic reflection data in the Molasse Basin of eastern Switzerland. Eclog. Geol. Helv. 84, 151–174.

TRÜMPY, R. 1980: Geology of Switzerland, a guide book. Part A: An outline of the Geology of Switzerland. Wepf & Co. Publishers, Basel, New York.

ZIEGLER, P. A. 1990: Geological Atlas of Western and Central Europe, 2nd. Ed. Shell Internationale Petroleum Mij. and Geol. Soc., London.