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TECTONICS OF THE CENTRAL JURA AND THE MOLASSE BASIN. NEW INSIGHTS FROM THE INTERPRETATION OF SEISMIC REFLECTION DATA

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Abstract

More than 1500km of seismic reflection lines from the petroleum industry have been interpreted in the Central Jura mountains and Molasse basin. They allowed to constrain and correlate the surface geology with subsurface data and thus helped shed new light on the relations between the sedimentary cover and the basement in the Jura mountains.

The unit 2 of the Triassic series, composed of evaporites, clays and pure salt, has a variable thickness ranging from 50m (in the S) to 1200m (Laveron drill hole in the N). In the Molasse basin, these interval changes form "salt pillow" structures. An isopach map of this layer shows clearly that these pillows, oriented NE-SW, control the anticline formation in the cover. These folds are of low amplitude. In the Central Jura mountains (Haute Chaîne) anticlines are formed above NNW vergent thrusts of at least kilometric throw and have a high amplitude. These thrust surfaces root in the basal décollement horizon located at the base of the Triassic evaporites. Both, the "salt pillows" and the ramp anticlines show that the interval of unit 2 is clearly involved in the development of fold and thrust structures in the cover of the Jura Mountains.

A depth to the basement map of the studied area highlights a smooth flat basement dipping 1° to 3° to the S-SE. No significant change in depth and trend of the basement top can be seen below major tear faults (Pontarlier, La Sarraz) in cover rocks. Comparing the isopach map of the unit 2 of the Triassic series and the contour map of the basement top, no structural relation can be detected. We thus conclude, that the basement is not involved in the formation of folds, thrusts and tear faults in the central Jura mountains and the Molasse basin. The cover has been deformed over a main décollement level, located at the base of the Triassic evaporites.

Résumé: Tectonique du Jura Central et du Bassin Molassique. Nouveaux aspects basés sur l'interprétation de données de sismique réflexion.

Quelques 1500km de lignes sismiques pétrolières du Jura neuchâtelois, du Plateau Molassique, du Jura vaudois ainsi que des régions de la France voisine ont été étudiées et interprétées (fig. 1, 2). Ce réseau a permis d'obtenir une image de la géométrie des structures du Jura central depuis le Bassin Molassique jusqu'à la zone des Plateaux du Jura externe. L'interprétation de lignes sismiques pétrolières confirme la vieille théorie souvent contestée du «Fernschub» pour la formation du Jura. Cette théorie propose que la couverture Mésozoïque et Cénozoïque du Jura plissé (Haute Chaîne) est déplacée de plusieurs kilomètres, en direction NW, à la faveur d'un décollement basal dans les couches évaporitiques du Trias.

Les interprétations de ces lignes sismiques soulignent une succession de réflecteurs majeurs qui représentent le toit de certaines unités lithostratigraphiques (toit du Malm, toit du Dogger, Lias, Trias et toit du socle). Ce réseau est calé par rapport aux données de forages. La vérification en boucle de toutes les intersections de lignes parallèles et perpendiculaires aux structures, confirme la cohérence interne de l'interprétation.

Deux résultats importants pour la tectonique du Jura et du Plateau Molassique ressortent de ces analyses. Le premier consiste en la reconnaissance d'importants coussins de sels présents dans la deuxième unité des couches du Trias (fig. 5). Les plis de faible amplitude et de grand rayon de courbure du Bassin Molassique sont essentiellement dus à la présence de tels coussins, résultant d'un empilement de roches évaporitiques et argileuses entre un toit de socle plat et une couverture raccourcie par le plissement. Le second résultat montre que les plis de la Haute Chaîne jurassienne sont de grande amplitude et sont systématiquement associés à des rampes de chevauchements dans la couverture (fig. 4). La série Mésozoïque est ainsi redoublée sous la plupart des anticlinaux de la Haute Chaîne du Jura.

Les interprétations des lignes sismiques ont été converties en profondeur réelle en utilisant des vitesses sismiques appropriées pour les différentes formations. Les vitesses sont calées sur des puits pétroliers. Les profondeurs ainsi obtenues ont permis de dresser une carte d'isohypses pour le toit du socle, ainsi qu'une carte d'isopaches pour l'intervalle sismique appellé unité 2 des séries du Trias. Ainsi la carte du toit du socle, voire de la base du Trias évaporitique (fig. 6) montre une structure régulière plongeant faiblement avec un angle de 1° à 3° vers le S ou le SE. Des irrégularités sont cependant présentes dans le toit du socle, par exemple, dans la région d'Yverdon. Des changements dans la direction générale sont visibles entre le Jura de la région du Mt Risoux orienté SW-NE et le Jura neuchâtelois de direction sensiblement E-W. La carte d'isopaches de l'unité 2 des couches du Trias (fig. 5) montre des variations considérables, de 200m à plus de 1000m, dans ces niveaux riches en évaporites et argilites. Le maximum d'épaisseur correspond à la Haute Chaîne du Jura, alors que vers le NW et le SE, les épaisseurs diminuent fortement. Les coussins d'évaporites sous le Bassin Molassique sont donc responsables du développement des plis à faible amplitude qu'on observe en surface.

1. INTRODUCTION

The aim of this research is to elucidate the geometry of the cover folds and thrusts and their relation to the basement in the central Jura and Molasse Basin area. The availability of more than 1500km of seismic reflection lines (fig. 2, grid) gives the opportunity to complement the surface geological observations accumulated over a century by field geologists with subsurface data gathered during the last two decades. This new contribution has greatly increased our knowledge about the deep structures of the central Jura Mountains and Molasse Basin. This permits us to test the various models for the formation of the Alpine foreland and Jura arc.

The present study covers a large portion of the central Jura, including the "Haute Chaîne", the Plateaus and the "Faisceaux" Jura units. According to BURKHARD (1990) and LAUBSCHER (1992), the tectonics of the Jura belt and the Molasse Basin are intimately linked. In order to examine these structural relationships, the study area has been extended southward to include the Plateau- and Subalpine-Molasse, between Neuchâtel and Nyon (Figs 1, 2, 3).

The seismic grid is constrained by drill hole data. Each intersection of seismic lines has been checked in order to obtain an internally consistent interpretation. Seismic time (two way time) was converted to depth (meters), in order to construct contour or isopach maps. Contour maps are useful for understanding the regional geology and isopach maps emphasize the variations of layer thicknesses. Seismic velocities were constrained by nearby drill holes. In the Jura area, a simple velocity model attributing a constant velocity to each major interval (Tertiary, Cretaceous, Jurassic and Triassic) was used. In the Molasse Basin region, however, more complex depth-dependant conversion functions were used in order to account for increased velocities due to the considerable thickening of Tertiary sediments. The most remarkable structures recognized from the seismic lines are a doubling of Mesozoic series within the Jura folds and "salt pillows", which control the anticlines of the Molasse Basin (fig. 4).

2. GEOLOGICAL SETTING

The Jura is a small arcuate fold belt located in front of the western Alpine arc (fig. 1, 3). The Jura arc is surrounded by Tertiary basins: to the N, the Rhine Graben, to the W the Bresse Graben and to the SSE the Molasse Basin. The Rhine and Bresse Grabens are associated with the Oligocene West-European rift system, whereas the Molasse Basin corresponds to an Oligo-Miocene foredeep basin which developed in front of the Alpine orogen. During the Mesozoic era, the Jura and Molasse Basin realm was an epicontinental sea, in which a total thickness of up to 2 km of alternating limestones and marls were deposited. During the Oligocene and Miocene periods alternating fluvial, lacustrine and marine clastic Molasse sediments were deposited. They progressively onlap the underlying Mesozoic rocks towards the North. The thickness of this sedimentary wedge decreases from South (up to 4 km) to North (a few hundred meters). These series crop out mainly within the Molasse Basin and they are also preserved in many Jura synclines (Val de Ruz, La Chaux-de-Fonds - Le Locle, Val de Travers, Delémont basin, ...). The Jura Mountains and the Molasse Basin are composed of folded Mesozoic and Cenozoic beds, that are detached from the pre-Triassic basement. This crystalline basement is never exposed in the Jura and Molasse basin proper; it has been attained by a few drill holes, however, and laterally it crops out in the Vosges, Black Forest to the North, in the external crystalline massifs to the South and in some small isolated outcrops along the northwestern external border of the Jura Mountains.

The Jura itself is divided into two major structural zones (CHAUVE *et al.* 1980): the external Jura and the internal Jura.

a) The external Jura

The external Jura (fig. 1) is composed of flat areas, Plateaus, limited in the North and separated from each other by the so called "Faisceaux". "Faisceaux" are narrow areas affected by strong deformation characterized by a succession of numerous small-scale imbricate thrusts and tear faults. The Plateaus correspond to weakly faulted areas, horizontal or slightly SE dipping.

b) The internal Jura

The internal Jura, also called folded Jura, "Haute Chaîne" or "Faisceau helvétique" consists in a well developed fold train representing a natural present day northern limit to the Molasse Basin. At a large scale, deformation is characterized by major folds, thrusts and tear faults. The amplitude of the Jura folds depends on the cover thickness (800m-2000m) and the

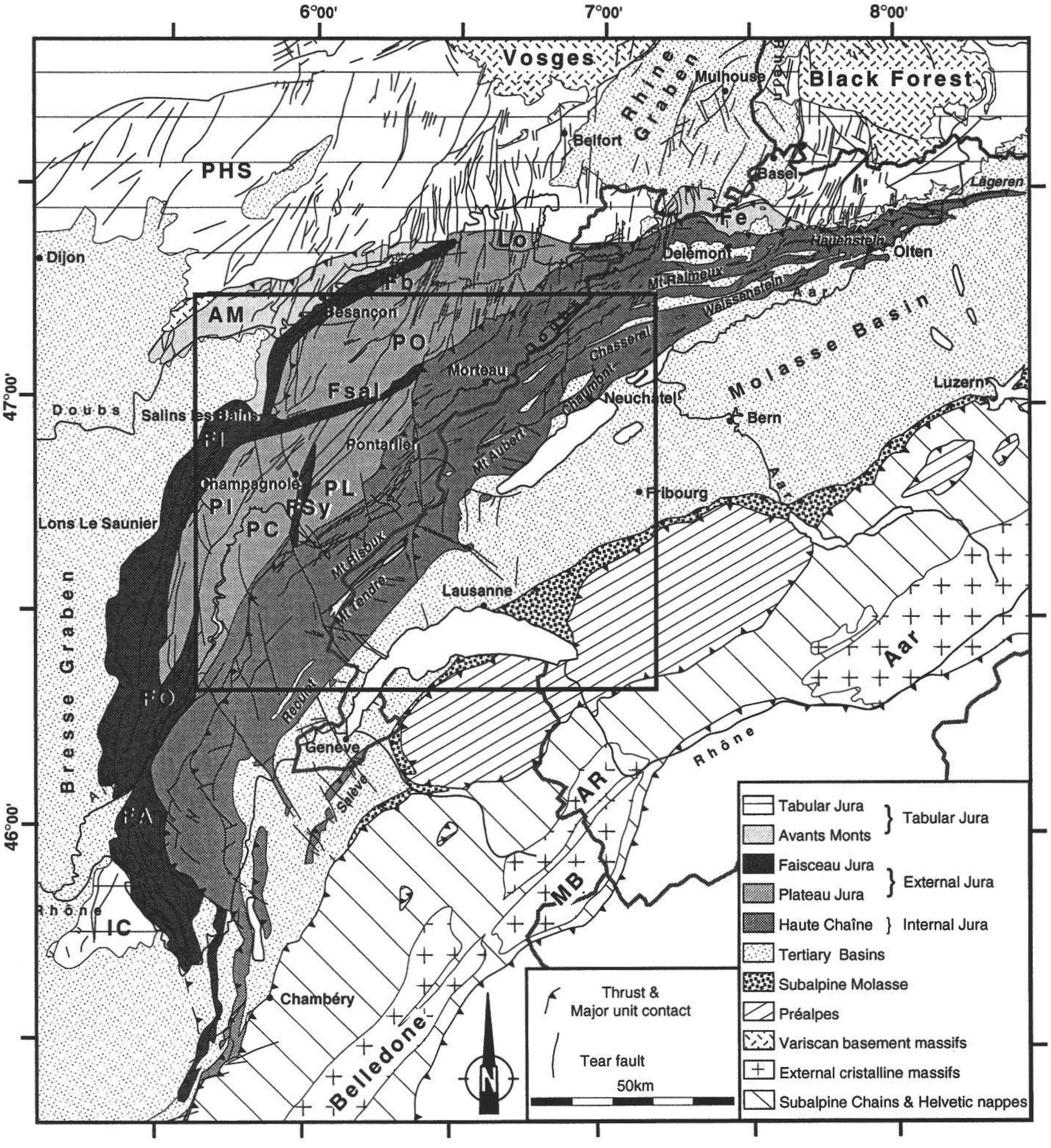

Fig. 1: Tectonic map of the Jura arc with main structural units. Location of the studied area is shown by square. Legend: PAS = Plateau de Haute-Saône; IC = Ile Crémieu; AM = Avants-Monts; Fe = Ferette; FA = Faisceau d'Amberieu; Fb = Faisceau bisontin; Fl = Faisceau lédonien; FO = Faisceau d'Orgelet; Fsal = Faisceau salinois; FSy = Faisceau de Syam; Lo = Lomont; PC = Plateau de Champagnole; PL = Plateau de Levier; Pl = Plateau lédonien; PO = Plateau d'Ornans; AR = Aiguilles Rouges; MB = Mont Blanc. Modified after CHAUVE *et al.* (1980).

Carte tectonique de l'arc jurassien avec les unités structurales majeures. La situation de la région étudiée est indiquée par le carré. Légende: PAS = Plateau de Haute-Saône; IC = Ile Crémieu; AM = Avants-Monts; Fe = Ferette; FA = Faisceau d'Amberieu; Fb = Faisceau bisontin; Fl = Faisceau lédonien; FO = Faisceau d'Orgelet; Fsal = Faisceau salinois; FSy = Faisceau de Syam; Lo = Lomont; PC = Plateau de Champagnole; PL = Plateau de Levier; Pl = Plateau lédonien; PO = Plateau d'Ornans; AR = Aiguilles Rouges; MB = Mont Blanc. Carte modifiée d'après CHAUVE *et al. (1980).*

degree of shortening. It is highest in the internal part of the central Jura and decreases outwards. Folds are thrust related and end laterally either with plunging axes or abruptly against tear faults. Some major sinistral tear faults cutting the whole cover are recognized; their orientation is N-S in the eastern Jura and changes gradually along the chain to a WNW-ESE direction at the western end. The outer border of the folded Jura is thrust over the Plateau Jura. At the southern border, the Mesozoic beds dip below the Oligo-Miocene sediments of the Molasse Basin.

The clastic wedge of the Molasse Basin is actually subdivided into three geological units (HOMEWOOD *et al.* 1989) (fig. 1):

- Jura Molasse: the northern feather edge of the Molasse Basin has been passively involved in Jura folding and thrusting. Only isolated patches of Molasse are preserved within major synclines of the internal Jura.

- The Plateau Molasse represents the central portion of the Molasse foreland Basin. It is only weakly affected by broad anticlines and tear faults. The northern edge of the Plateau Molasse is an erosion limit which coincides with the most internal high amplitude folds of the Jura.

- Subalpine Molasse: the southern portion of the Molasse Basin has been involved in thrusting and folding at the front of the advancing higher alpine nappes. These Molasse imbrications are called Subalpine.

3. FORMATION OF THE JURA

The formation of the Jura has been discussed in many papers since the beginning of the century. Beside various other hypotheses, two fundamentally different models have been put forward to explain the Jura fold belt in general and the relations between strike-slip faults and folds in particular. On the one hand, PAVONI (1961) and WEGMANN (1963) interpreted the Jura fold belt as essentially composed of "wrench folds", formed above strike slip faults rooting deep within the underlying crystalline basement. In this "autochtonous" interpretation, the Jura folding would have resulted from horizontal shortening oblique to the general fold axes trend. Stretching in this model is essentially subhorizontal as well, expressed by the presence of tear faults. The amount of stretching should be comparable to the amount of shortening. Lately GORIN *et al.* (1993) have adopted this kind of interpretation for the Molasse Basin, based on the interpretation of seismic lines. On the other hand, a majority of authors agree with BUXTORF (1907) and LAUBSCHER (1961; 1965; 1973) who interpret the Jura as a typical foreland fold and thrust belt, resulting from a distant push (= "Fernschub" in German) from behind (by the Alps), transmitted through Mesozoic and Cenozoic strata of the Molasse Basin. The Jura represents the most external Late Miocene deformation zone of the northwestern Alps. The Mesozoic cover together with the overlying Tertiary Molasse is folded and thrust toward the NW for 2 to 25km, above a main décollement horizon located within the Triassic evaporite beds. This model assumes a smooth underlying basement dipping 2° to 3° toward the South (fig. 6). Tear faults are interpreted as the result of some minor stretching parallel to the chain, due to the overall arcuate shape of the Jura (HEIM 1915; LAUBSCHER 1972; BURKHARD 1990). The presence of a reasonably smooth basement top and a continuous, weak décollement layer involving evaporites and/or shale below the Jura and Molasse are essential requirements for the Fernschub hypothesis. These requirements could only recently be tested and confirmed by the interpretation of a dense grid of reflection seismic lines (fig. 2).

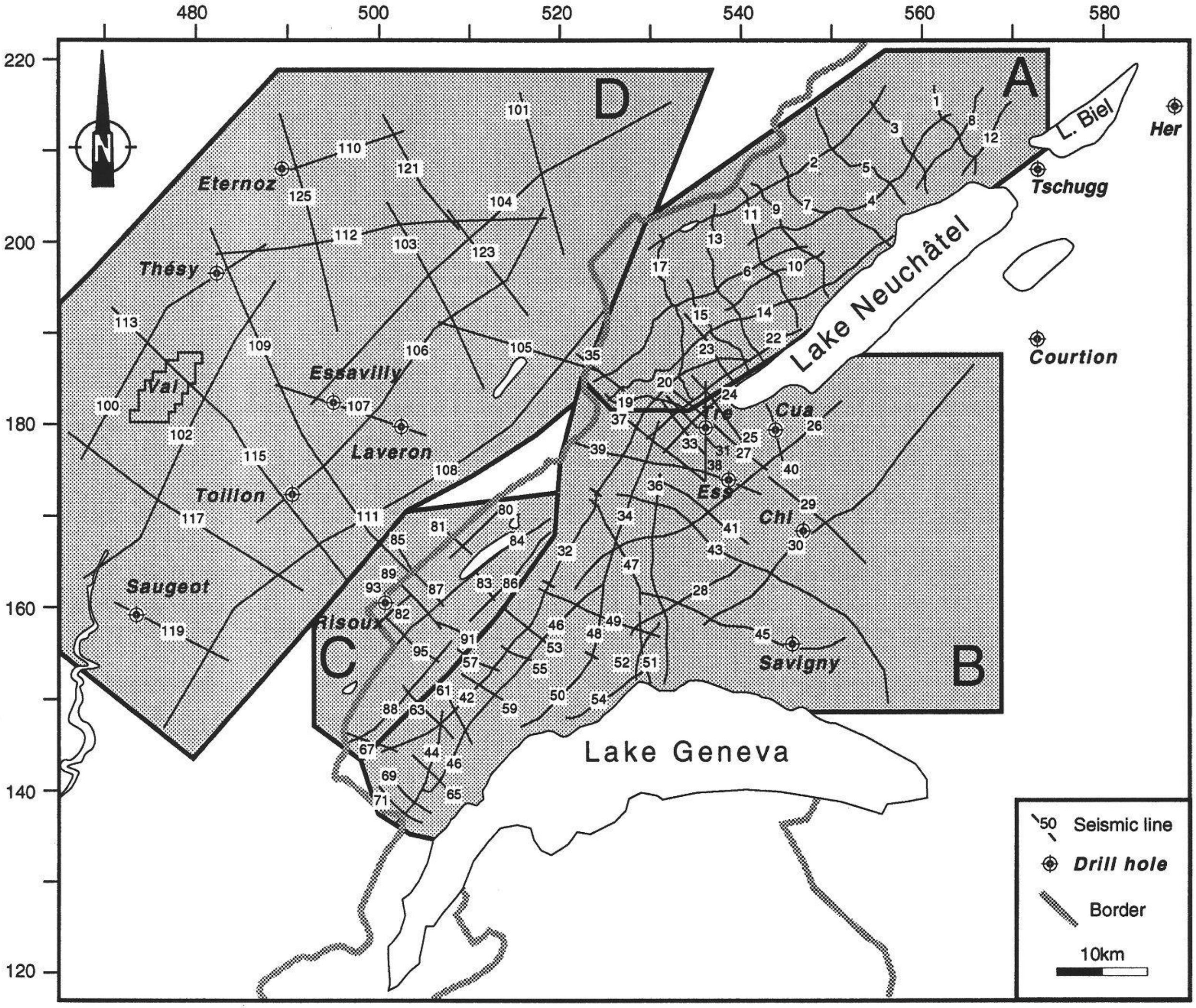

Fig. 2: Seismic grid with location of the various sectors: A = Neuchâtel and Vaud Jura Mountains. B= Molasse Basin. C = Mont- Risoux Jura Mountains. D = Champagnole-Mouthe Jura Mountains. Well legend: Chl = Chapelle; Cua = Cuarny; Ess = Essertines; Her = Hermrigen; Tre = Treycovagnes; Val = Valempoulières.

Grille sismique avec situation des différents secteurs: A = Jura neuchâtelois et partie Est du Jura vaudois. B= Bassin molassique. C = Mont-Risoux, Jura vaudois. D = Région de Champagnole-Mouthe. Légende des forages: Chl = Chapelle; Cua = Cuarny; Ess = Essertines; Her = Hermrigen; Tre = Treycovagnes; Val = Valempoulières.

Accordingly, some 20-30 km of horizontal displacement must have been absorbed within the Alps, presumably at the base of the external crystalline massifs. This tectonic interpretation is schematically represented on the bloc-diagram of Figure 3 which shows the links between the Jura, the Molasse Basin and the Alps.

4. DATA

Surface geological information, reflection seismic data and wells provide the data sets for this research. The surface geology data consist of a large number of published and unpublished geological maps, near-surface cross-sections and lithostratigraphical logs. Industry seismic

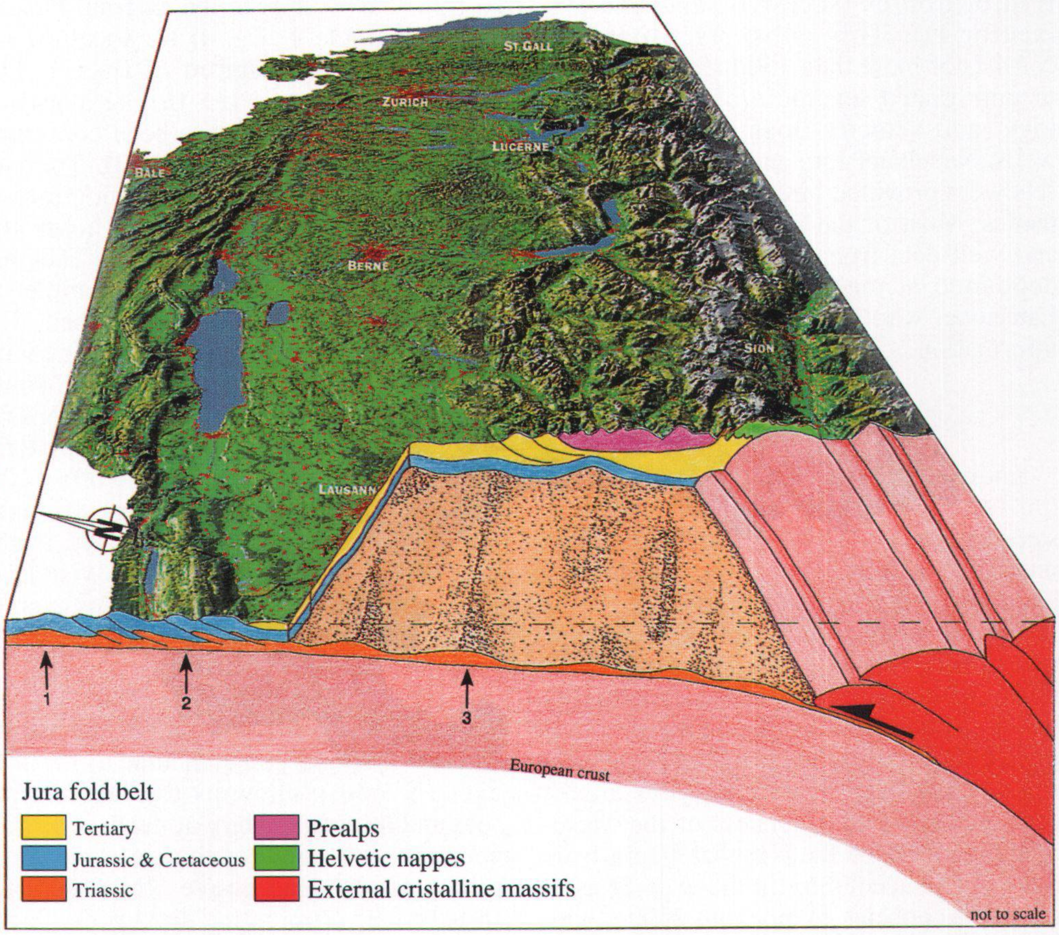

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Fig. 3: Schematic bloc-diagram from the Jura Mountains to the Alps, across the Molasse Basin. The topography of "salt" related anticlines is highlighted. Numbers 1, 2 and 3 refer to the example of figure 4.

Bloc diagramme schématique allant des Alpes au Jura en passant par le Bassin Molassique. Les reliefs formés par les anticlinaux reliés au sel sont mis en valeur. Les numéros 1, 2 et 3 font référence à la figure 4.

reflection surveys were conducted in the study area between 1970 and 1988 by different companies: British Petroleum (sector A in fig. 2), Shell Switzerland (sector B and C), Société anonyme des Hydrocarbures (sector B) and Shellrex (sector D). This subsurface data set consists of more than 1500 km of migrated or unmigrated seismic profiles and lithology- and velocity- logs of some twenty wells. Neuchâtel Jura and French Jura data sets were provided directly by the oil companies. Most of the industry seismic lines and well data from Canton Vaud area are deposited at the Musée de Géologie at Lausanne, who kindly gave access to this information.

5. RESULTS

Knowledge about stratigraphy is essential for seismic interpretation. As a first step drill hole logs were compiled. Based on wells, seismic stratigraphic units have been defined and correlated through the whole seismic grid jumping from one line to another. Thanks to the good quality of strike lines, mainly shot along synclines, it has been possible to constrain the stratigraphic column at depth. This is especially important for Triassic layers never exposed. The total thickness of the Mesozoic layers below the Neuchâtel Jura from the top Cretaceous to the base of Triassic evaporites appears to be about 2000m with an estimated uncertainty of ± 200m. Jurassic layers thicken progressively from Neuchâtel towards SW (Geneva) and decrease slightly towards the North-West (Besançon). The unit 1 of Triassic evaporites as defined on seismic lines has a fairly constant thickness around 200m. The underlying unit called unit 2 on the other hand varies considerably in thickness. Thickness changes of the layers of unit 2 represent stacks of evaporites, clays and salt, due to "salt tectonics" during the deformation of the Jura and Molasse Basin. Such structures overlying a flat basement are often called "salt pillows" or "salt anticlines" (JACKSON & TALBOT 1994). Pillows or half pillows have been observed in the Molasse Basin (Example 3, fig. 4) as well as in the external Plateau Jura (Example 1, fig. 4; for location see schematic bloc-diagram of fig. 3). The Laveron pillow is the thickest pillow observed so far and it has been confirmed by a drill hole (BITTERLI 1972). The isopach map of the unit 2 of Triassic series in the Molasse Basin (fig. 5) shows the regional pattern of these pillows. They are aligned along a NE-SW trend, parallel to the general trend of the Jura fold belt. The maximal "salt" thickness coincides with the most internal Jura anticlines. Some major sinistral tear faults oriented NNW-SSE to N-S and the conjugate dextral system WNW-ESE crosscut and offsets the pillows. In the western Swiss Molasse Basin, evaporite stacks are located in the core of the low amplitude folds visible at the surface (Example 3, fig. 4). Apparently the stacking of these pillows caused the folds above.

Transverse lines located in the Haute Chaîne, oriented perpendicular to the fold axes (NW-SE), allow us to constrain the fold and thrust geometry at depth. The new seismic data confirm that internal anticlines are formed above NNW verging thrusts with kilometric dipslip displacement. Important thrusting results in a doubling of the entire Jurassic sequence, as shown in example 2 of Figure 4. This line drawing shows a cross-section located in the SW part of the Neuchâtel Jura. The major thrust roots in the basal décollement horizon located at the base of the Triassic evaporites. The latter are clearly involved in thrusting. The Mt Risoux anticline (fig. 1, 2, 3) presents another example of a high amplitude fold formed above a frontal NNW verging ramp with a major associated backthrust. This is the first Jura

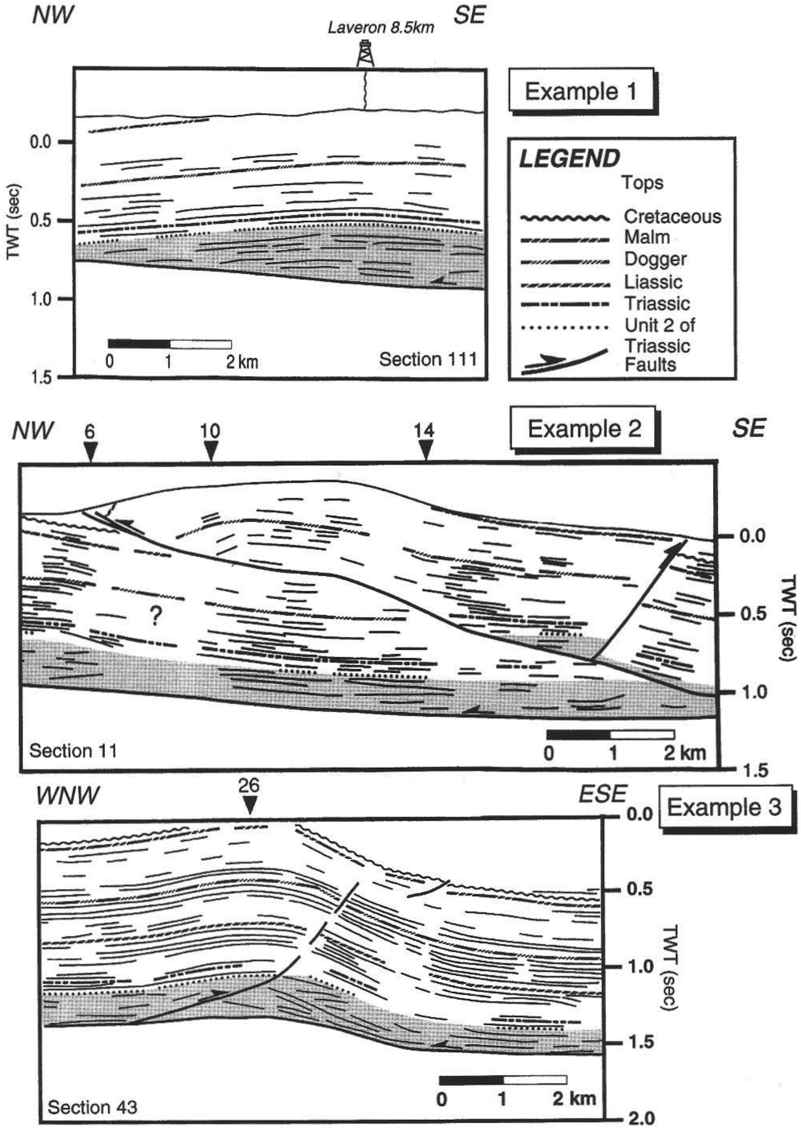

Fig. 4: Line drawings of examples of fold structures in the Jura and the Molasse Basin (example numbers refer to fig. 3). Horizontal scale is in meters, whereas vertical scale is in seconds (two way travel time). The unit 2 of the Triassic beds is highlighted in gray. Example 1 (Section111 on fig. 2) is located in the Plateau Jura; example 2 (Section 11) is located in the SW Neuchâtel Jura (Haute Chaîne); example 3 (Section 43) is located in the Molasse Basin. Examples 1 and 3 show anticlines due to evaporite stacks within the unit 2 of the Triassic interval. Example 2 represents an high amplitude fold related to a thrust.

Exemples de plis dans le Jura et le Bassin Molassique, dessinés à partir de l'interprétation des lignes sismiques (numéros d'exemples font référence à la figure 3). L'échelle horizontale est en mètres, l'échelle verticale en secondes (temps double). L'unité 2 des séries d'âge triasique est soulignée en gris. L'exemple 1 (section 11 sur la fig. 2) est situé sur un Plateau du Jura; l'exemple 2 (section 11) est situé dans la partie SW du Jura Neuchâtelois appartenant à la Haute-Chaîne; l'exemple 3 (section 43) est situé dans le Bassin Molassique. Les exemples 1 et 3 montrent des anticlinaux résultant de l'empilement des évaporites au sein de l'unité 2 des couches du Trias. L'exemple 2 montre un pli de grande amplitude associé à une rampe de chevauchement dans la couverture mésozoïque.

anticline where a doubling of the Jurassic series has been confirmed by a drill hole (WINNOCK 1961). At the surface, most thrusts are obscured by a veneer of Quaternary sediments, and therefore it is often difficult to map them in the field. Accordingly, on geological maps (and in many older interpretations of cross-sections) most of the major thrusts are missing. The style of thrust-related folds from the Haute Chaîne Jura is different from the broad and very gentle anticlines due to evaporite or salt stacks found in the Plateau Jura and Molasse Basin.

Some seismic lines cross major "tear faults", e.g., the Pontarlier fault (fig. 1). These faults appear on seismic lines as transparent zones, which do not show any offset of the basement top from one side to the other. Accordingly these mappable faults are either tear faults restricted to the cover or related to lateral ramps. No evidence for an extension of these faults into the basement could be found (compare fig. 5 and fig. 6).

Figure 6 represents a map of the depth to the top of the basement. Depth data are the result of depth converted seismic lines. This map highlights a smooth basement top dipping regularly 1° to 3° to the SSE. Some broad irregularities, appear in fig. 6, however. An apparent flat area (with a high at Treycovagnes) at the SW edge of Lake Neuchâtel is visible. The East-West trend of the Neuchâtel Jura (N part of fig. 6) is different from the NE-SW trend of the Risoux Jura (SW half of fig. 6). Depths from drill hole data fit +/-200m the depths obtained from depth converted seismic time lines. Discrepancies are due to the use of inappropriate seismic velocities. It seems that our velocity model tends to be on the fast side (seismically obtained values are slightly deeper than drill holes). Thus the values of this contour map are not absolute, however, Figure 6 gives a good account of the morphology and general orientation of the basement structures.

It has to be emphasized again, that "salt pillows" or "salt anticlines" are floored by subhorizontal layers at their base. No evidence has been found for thrusts to continue downwards into the pre-Triassic basement in opposite to GORIN *et al.* (1993) and GUELLEC *et al.* (1990). Any irregularities which might exist in the top of the basement are small compared to the thickness of the Triassic unit 2. Nowhere has this basal décollement layer been disrupted by later thrusts.

6. CONCLUSIONS

Interpretation of seismic lines confirm the "Fernschub" hypothesis for the formation of the Jura: the Mesozoic cover of the Jura Mountains and the Molasse Basin has been pushed to the NW. Folding and thrusting took place above a main decoupling horizon within the thick unit 2 of the Triassic evaporites. The thickness of this interval ranges from 200 m to more than 1 km. Broad folds of the Molasse Basin and the external Plateau Jura are controlled by "salt pillow stacks" within the unit 2 of the Triassic layers. The high amplitude folds of the Jura Haute Chaîne are related to thrusts stepping up from the main décollement level through the entire Mesozoic cover series. According to the contour map of the basement top, the basement is not involved in the formation of folds and thrusts in the central Jura and the Molasse Basin.

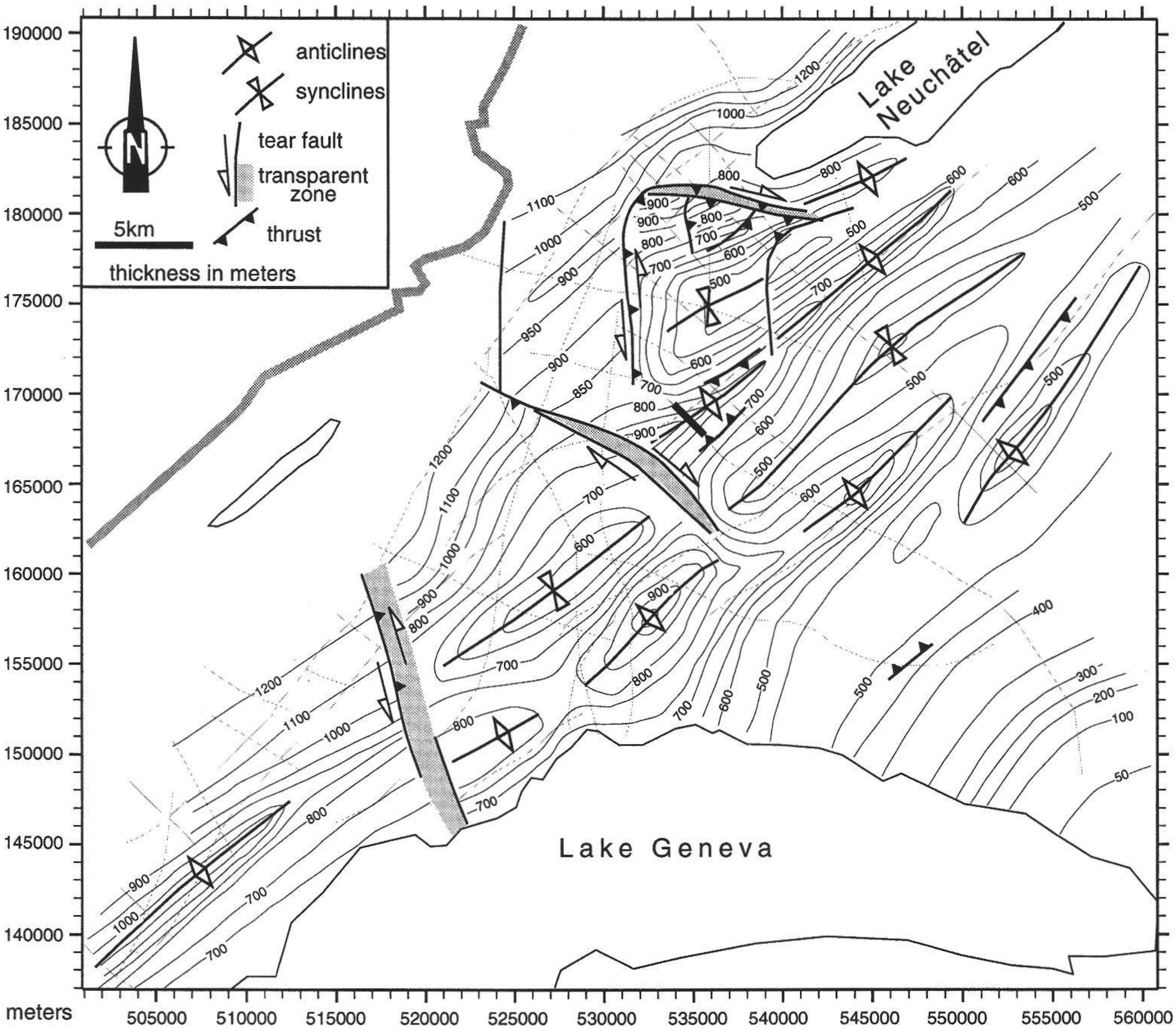

Fig. 5: Isopach map of the unit 2 of the Triassic beds from the western Swiss Molasse Basin. Thicknesses are in meters. Gray thin lines represent the seismic grid. Anticline axes emphasize thick zones ("salt anticlines", see text for more explanations), syncline axes show thin zones. Thick black segment localizes the example 3 of Figure 4. Coordinates in meters are according to the Swiss geographic reference grid.

Cartes des isopaches de l'unité 2 des couches du Trias du Bassin Molassique occidental. Les épaisseurs sont en mètres. Les fines lignes grises indiquent la grille sismique. Les axes des anticlinaux indiquent les zones épaisses («anticlinaux de sel», voir texte pour plus de détails), les axes de synclinaux montrent des zones peu épaisses. L'épais trait noir localise l'exemple 3 de la Figure 4. Les coordonnées (m) correspondent à la grille de référence géographique de la Suisse.

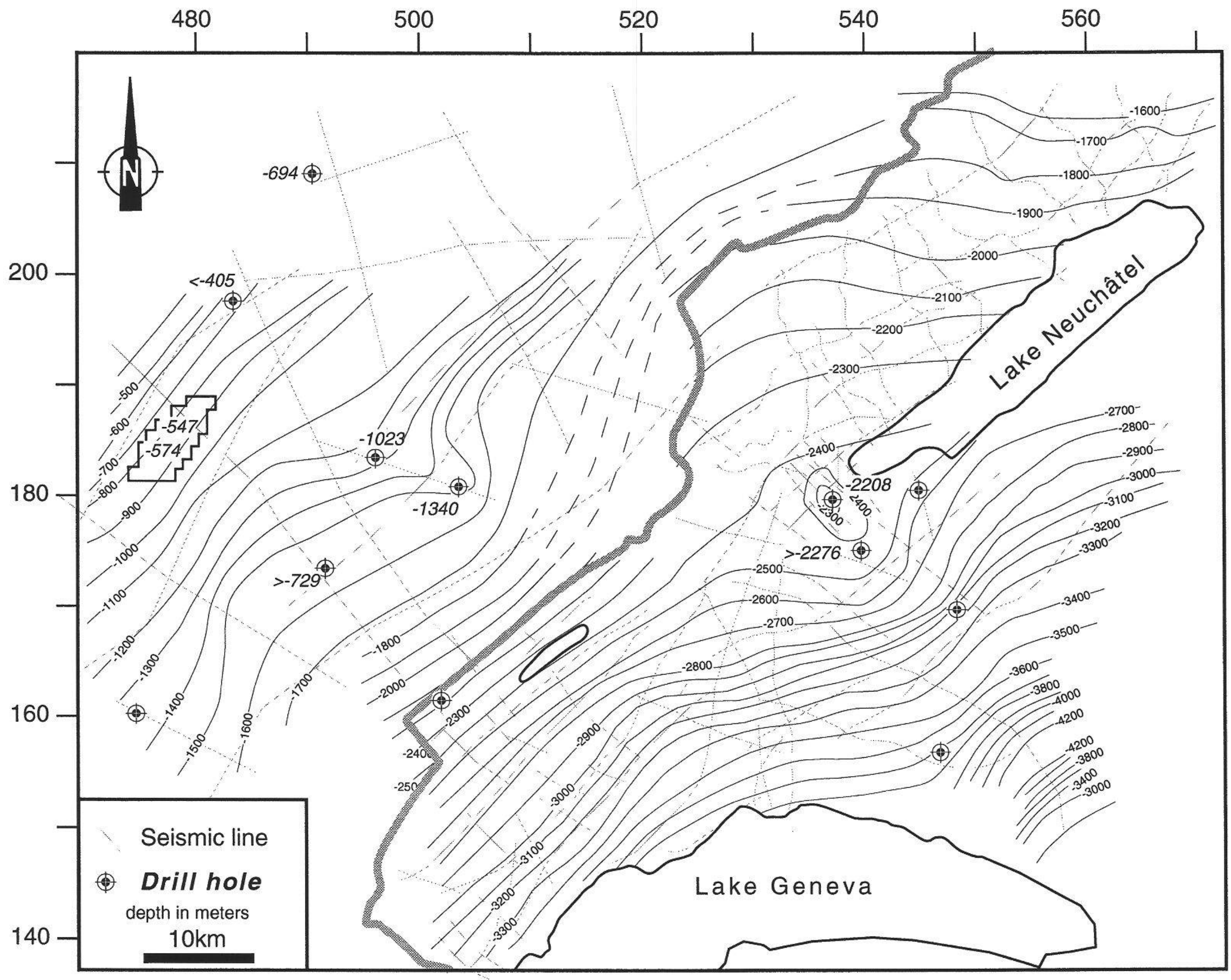

Fig. 6: Map of the depth to the basement top. Depth is in meters with reference to the sea level. Gray thin lines represent the seismic grid. Numbers close to drill holes correspond to the depth of the basement top from drill hole data. Minimal depths (>....) are given for drill holes which ended within the Triassic layers. No depth indication are given for drill holes which not attain the Triassic. Coordinates (in km) are according to the Swiss geographic reference grid.

Carte du toit du socle. Les profondeurs sont en mètres par rapport au niveau de la mer. Les lignes grises fines représentent la grille sismique. Les chiffres à côté des forages indiquent la profondeur du toit du socle dans le forage. Les profondeurs minimales (>...) sont indiquées pour les forages se terminant dans les couches du Trias, tandis qu'aucune indication n'a été donnée pour les sondages n'atteignant pas les séries du Trias. Les coordonnées (en km) correspondent à la grille de référence géographique de la Suisse.

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BIBLIOGRAPHIE:

BITTERLI, P. 1972. Erdölgeologische Forschungen im Jura. Bull. Ver. Schweizer. *Petrol.-Geol. u. Ing.* 39 : 13-28.

BURKHARD, M. 1990. Aspects of the large scale Miocene deformation in the most external part of the Swiss Alps (Subalpine Molasse to Jura fold belt). *Eclogae geol. Helv.* 83 : 559-583.

BUXTORF, A. 1907. Zur Tektonik des Kettenjura. *Ber. Vers. oberrh. geol. Vers.* 30/40 : 79-111.

CHAUVE, P., ENAY, R., FLUCK, P. & SITTLER, C. 1980. L'Est de la France (Vosges, fossé rhénan, Bresse, Jura). In: 26e Congrès Géologie International, Paris. *Géol.* 4 /1 : 3-80.

GORIN, G.E., SIGNER, C. & AMBERGER, G. 1993. Structural configuration of the western Swiss Molasse Basin as defined by reflection seismic data. *Eclogae geol. Helv.* 86 : 693-716.

GUELLEC, S., MUGNIER, J.L., TARDY, M., & ROURE, F. 1990. Neogene evolution of the western Alpine foreland in the light of ECORS data and balanced cross-section. In: ROURE, F., HEITZMANN, P. & POLINI R., Eds., Deep structures of the Alps. *Mém. Soc. géol. suisse. Zürich 1.*

HEIM, A. 1915. Die horizontalen Transversalverschiebungen im Juragebirge. *Geol. Nachlese Nr.22,. V. Natf. Ges. Zürich* 60 : 597-610.

HOMEWOOD, P., RIGASSI, D. & WEIDMANN, M. 1989. Le bassin molassique Suisse. In: Dynamique et méthodes d'étude des bassins sédimentaires (Ed. by Technip). *Assoc. Sédim. Française. Paris.* 299-314.

JACKSON, M.P.A. & TALBOT, C.J. 1994. Advances in Salt Tectonics. In: Continental Deformation. (Ed. Paul L. Hannock) . *Pergamon Press Ltd. Oxford.* 159-179.

LAUBSCHER, H.P. 1961. Die Fernschubhypothese der Jurafaltung. *Eclogae geol. Helv.* 54 : 221-280.

LAUBSCHER, H.P. 1965. Ein kinematisches Modell der Jurafaltung. *Eclogae geol. Helv.* 58 : 232-318.

LAUBSCHER, H.P. 1972. Some overall aspects of Jura dynamics. *Amer. J. Sci.* 272 : 293-304.

LAUBSCHER, H.P. 1973. Jura Mountains. In: Gravity and Tectonics. (Ed. by K.A. De Jong et Scholten). *Wiley. New York.* 217-227.

LAUBSCHER, H.P. 1992. Jura kinematics and the Molasse basin. *Eclogae geol. Helv.* 85 : 653-676.

PAVONI, N. 1961. Faltung durch Horizontalverschiebung. *Eclogae geol. Helv.* 54 : 515-534.

WEGMANN, E. 1963. Le Jura plissé dans la perspective des études sur le comportement des socles. In: Livre Mém. Prof. P. Fallot. (Ed. by Soc. géol. France). *Paris. Mémoire hors série 1* : 99-104.

WINNOCK, E. 1961. Résultats géologiques du forage Risoux 1. *Bull. Ver. Schweizer. Petrol.-Geol. u. Ing.* 28 : 17-26.