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Seismic profiles as related to wrench-faulting in the Swiss Molasse basin

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ABSTRACT

Seismic lines, covering parts of the Swiss Molasse basin, display frequent "blind areas" that three-dimensional study, completed by regional survey of surface structures, discloses to be trapezoid shaped blocks, aligned in a SE-NW direction and pertaining to a wrench-faults zone, well defined in the Swiss and French Jura and analog the eastern border of Prealpine nappes. The tectonic event characterizing this zone, is herein termed "Thunersee-Charquemont wrench-faulting".

Opinion is expressed that such strike-slip faults, crossing the Swiss Molasse basin, are very likely to provide a northern closure to some prospective structures under consideration in the present oil exploration program.

RÉSUMÉ

De nombreuses «zones sourdes» apparaissent dans les sismogrammes du bassin molassique suisse. La reconstitution tridimensionnelle de ces volumes asismiques et une étude régionale des structures de surface, permettent de les assimiler à des blocs, de forme géométrique très particulière (trapézoïdale), alignés selon une direction générale SE-NW et appartenant à une zone, de part et d'autre de laquelle s'opèrent changements de direction et forts décrochements des axes structuraux.

L'extension de cette zone, à travers le Jura franco-suisse et en bordure des nappes préalpines, lui confère les caractéristiques, facilement observables, sur le terrain, de zone de décrochement latéral que nous avons nommé «décrochement de Charquemont-Thunersee», soulignant ainsi son importance régionale et ses incidences sur l'exploration pétrolière en cours.

1. Introduction

The starting point of the present, briefly described study is a subsurface structural mapping carried out, for oil exploration, in the western part of the Swiss Molasse basin.

Analysis of 310 kilometers of seismic lines, covering about 570 square kilometers, led to some controversial interpretations of a prospective structure, due to the fact that the northern and eastern part of this structure displayed frequent aseismic zones.

The difficult task to find the significance of these blind areas required a regional study, which was extended, from the seismically surveyed part of the Molasse basin, south-eastward, down to the border of the Prealps and, north-westward, across the Swiss and French Jura.

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2. Some seismic data

The horizontal distribution of the reflection seismic lines is given in Figure 1. It can be seen that the lines constitute a fairly dense network, which includes the only deep well drilled in the studied area: *Courtion No. 1* (see Fig. 1).

The stratigraphic sequence, crossed by Courtion well (T.D. = 3084 m), comprises the Tertiary Molasse, the lower Cretaceous, the Jurassic, the Triassic down to the Muschelkalk.

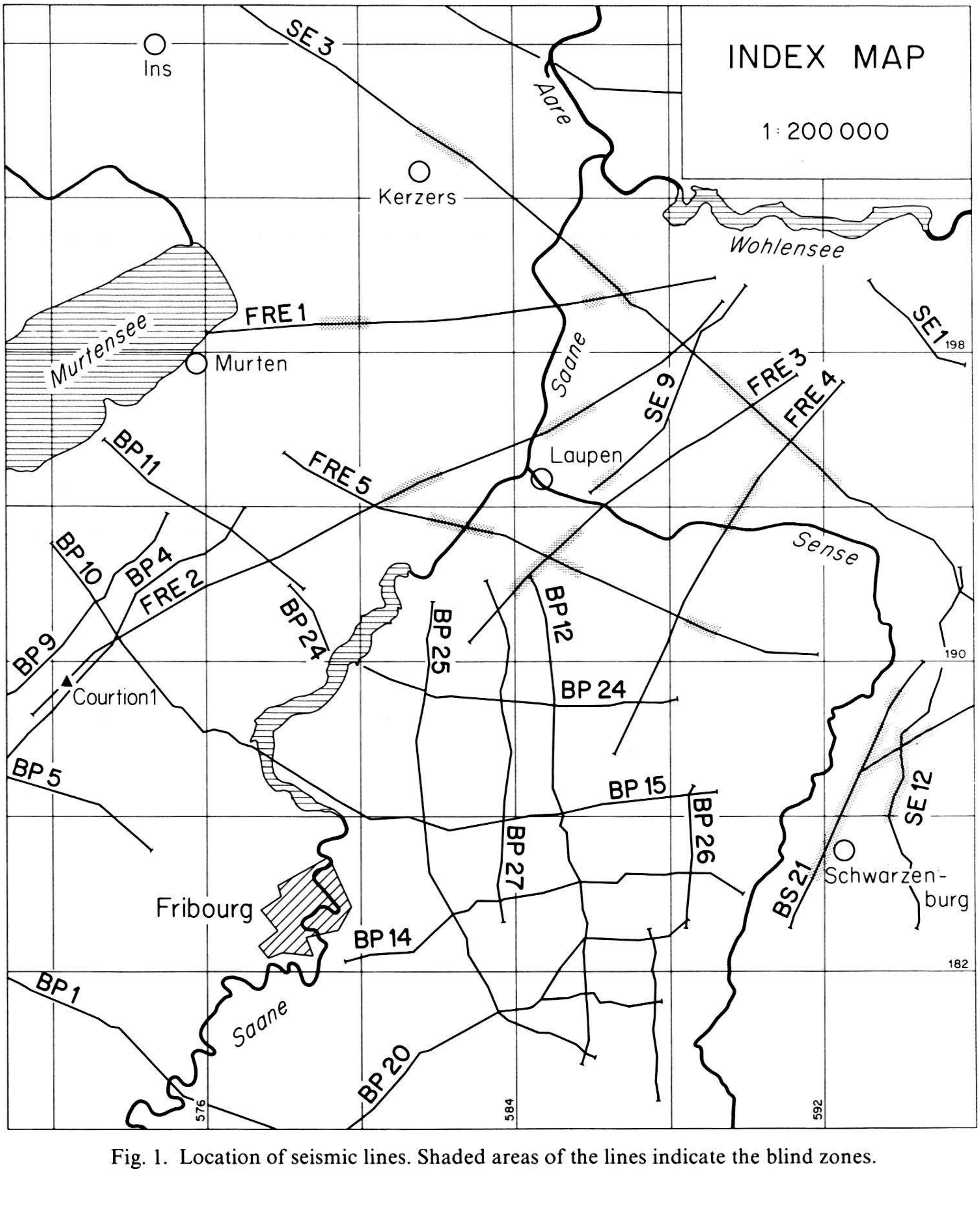

Fig. 1. Location of seismic lines. Shaded areas of the lines indicate the blind zones.

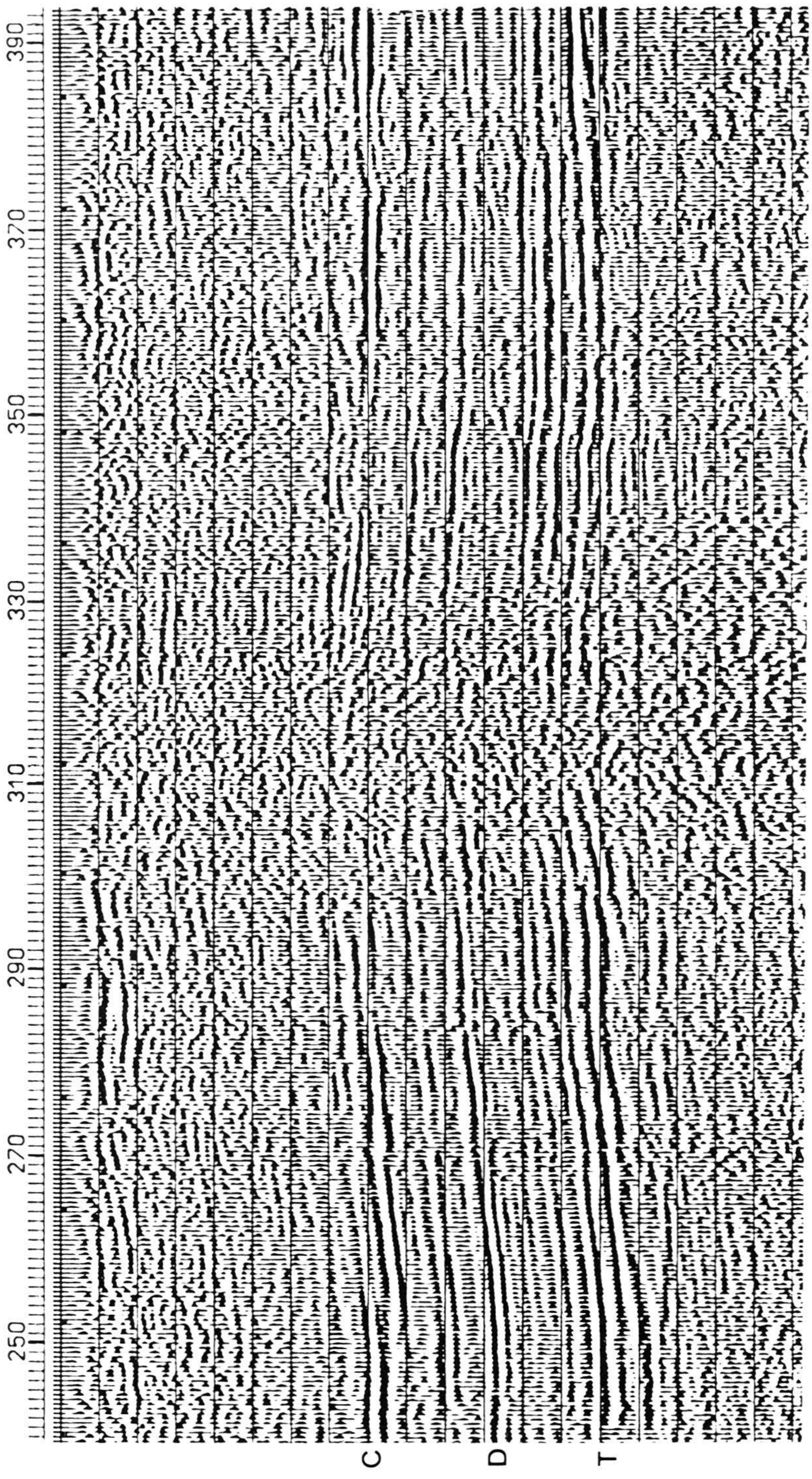

Fig. 2. Reflection seismogram displaying effects of postulated inhomogeneous lateral displacements.
Horizontal scale 1:50,000. Two-way time: 1 sec. = 5 cm.

The general geophysical characteristics of the stratigraphic sequence, visible on the seismic records, are the good reflection from its middle part and weaker reflection from shallower and deeper horizons (Fig. 2).

In order to identify stratigraphically the best seismic markers, both lithological log and continuous velocity log of Courtion well have been plotted on a linear time versus linear depth scale.

The first strong velocity contrast, below the almost entirely blind Tertiary Molasse, corresponds to the erosional surface of lower Cretaceous. A good marker is to be found immediately below the eroded surface *(marker C* of *lower Cretaceous age)*. Deeper in the section, the top of the Dogger has been identified *(marker D* of *middle Jurassic age)*. Down section, several reflections are discernable. Some markers are pinching out, some other ones appear fairly continuous. The deepest of the latter has been taken to be probably a dolomite horizon from the Muschelkalk *(marker T* of *Triassic age)*. Weaker and weaker reflection is obtained from the sequence below the marker *T*.

Besides these three major velocity discontinuities, the most prominent features, displayed by the seismograms, are the very numerous diffracted events along all the lines and the singularities in form and size of some aseismic zones along the lines located in the northern part of the surveyed area (lines FRE 1, 2, 3, 4, 5 and SE 3, 9 in Fig. 1).

We shall not deal, in the present short study, with the diffraction pattern, partly due to faults delineating horst-and-graben structures. As regards the form and size of the northern aseismic zones, Figure 2 gives an example of such a zone, comprised between shotpoints No. 298 and 325 of the seismic line FRE 2.

At both the left and the right sides of the blind area, sharp breaks affect the markers *C, D* and *T*. At the level of marker *C (lower Cretaceous)*, the blind area is about 1½ km in maximum width, slightly less than 1 km at marker *D (Dogger)*, 0.250 km at marker *T (Triassic)* and, finally, does not exist any more in the strata underlying the marker *T*. As shown in Figure 2, such a trapezoid configuration, observable also in lines FRE 1, 3, 4 and 5, might lead to various interpretations, the most simple of which would take the said sharp breaks to be convergent normal faults, with little vertical displacements. However, observed facts and field evidences do not seem to fit with the requirements that should be met if such an interpretation were valid.

3. Interpretation of aseismic zones

The fairly dense network, constituted by the seismic lines, has enabled us to attempt a three-dimensional interpretation of the aseismic zones, the cross-section of which shows the configuration briefly described in chapter 2.

Actually, the three-dimensional approach is materialized by the two-way time maps of markers *C, D* and *T*, in which the trend of the blind areas ought to be evident from the shape of the isochrons. Striking enough is the fact that these blind areas are aligned in a SE–NW direction, from the right bank of the Sense river to the area located between the lake of Murten and the junction of Sarine and Aare rivers (Fig. 1).

These SE–NW trending seismic anomalies are grouped and constitute three main parallel linear features, that are often separated by wide "paliers" (flat lying horizons). One of these "paliers" is shown in Figure 2 (shotpoints No. 359 to 373).

On the time map of the Dogger, the three main parallel linear features, together with the intermediate "paliers", cover an area about 23 km in length and 4 to 7 km in width. In their shape and orientation, the isochrons, south of this area, are in sharp contrast with those located north of it. This contrast appears still more obvious after translation of reflection times into depths.

In fact, on the structure contour map of the Dogger, anticlines and synclines, situated south of this area, are well developped, S–N trending structures, while their homologous, located to the north, are small, flat-topped, SW–NE trending structures.

Thus, the aseismic zones, with their adjacent "paliers" play the part of a "structure divide", at least along the 23 km seismically surveyed.

What is the regional significance of such a "structure divide"? In seeking to answer this question, we proceeded on the two assumptions that this NW–SE oriented "divide" should be expressed in the surface structures and that it could extend south-eastward and north-westward.

The first assumption proved correct within the seismically surveyed area. Actually, despite a slight disharmonic folding, the surface anticlines of Courtion and Wünnewil and the surface syncline of Fribourg coincide with the subsurface structures located south of the "divide" and the abrupt shift of their homologous, north of the "divide" (Niederried and Wohlen surface anticlines, Frienisberg surface syncline), can easily be recognized.

In order to verify the second assumption, field work was carried out, starting to the south-east, along the lake of Thun (Thunersee). There, on the eastern border of the Prealpine nappes, structural complications arise, which have previously been studied by geologists of Bern University. In the vicinity and north of the village of Reutigen, lateral displacements of limestone units are conspicuous and more so are the shearing movements that affect the Subalpine Molasse in Wattenwil area. There is little doubt that shallow-seated wrench-faulting exists and constitutes this zone of disruption, marked by major effects on the structure and even on the topography, which extends from Reutigen, north-westward, up to the vicinity of Schwarzenburg.

As regards the farther north-western extension of the "structure divide", the field work failed to give an accurate account of lateral displacements in the area comprised between the lakes of Murten, Neuchâtel and Biel, for this area is filled with fluviatil deposits and moraines. Worth mentioning, however, is the structural position of small synclines, such as the Vully, Grossholz and Jolimont synclines, that might be indicative of the existence of individual blocks, which have moved in relation to one another along both sides of a fault.

From this alluvial plain, proceeding north-westward, we enter the Swiss Jura mountains, where strong horizontal displacements of structures have been mapped by geologists of Neuchâtel University and Zürich.

The maximum length of slip, that we have measured, is to be found between the Chaumont and the Chasseral anticlines, two structures proved to be homologous elements on either sides of the wrench-faulting zone termed Combe-Grède. Here, a

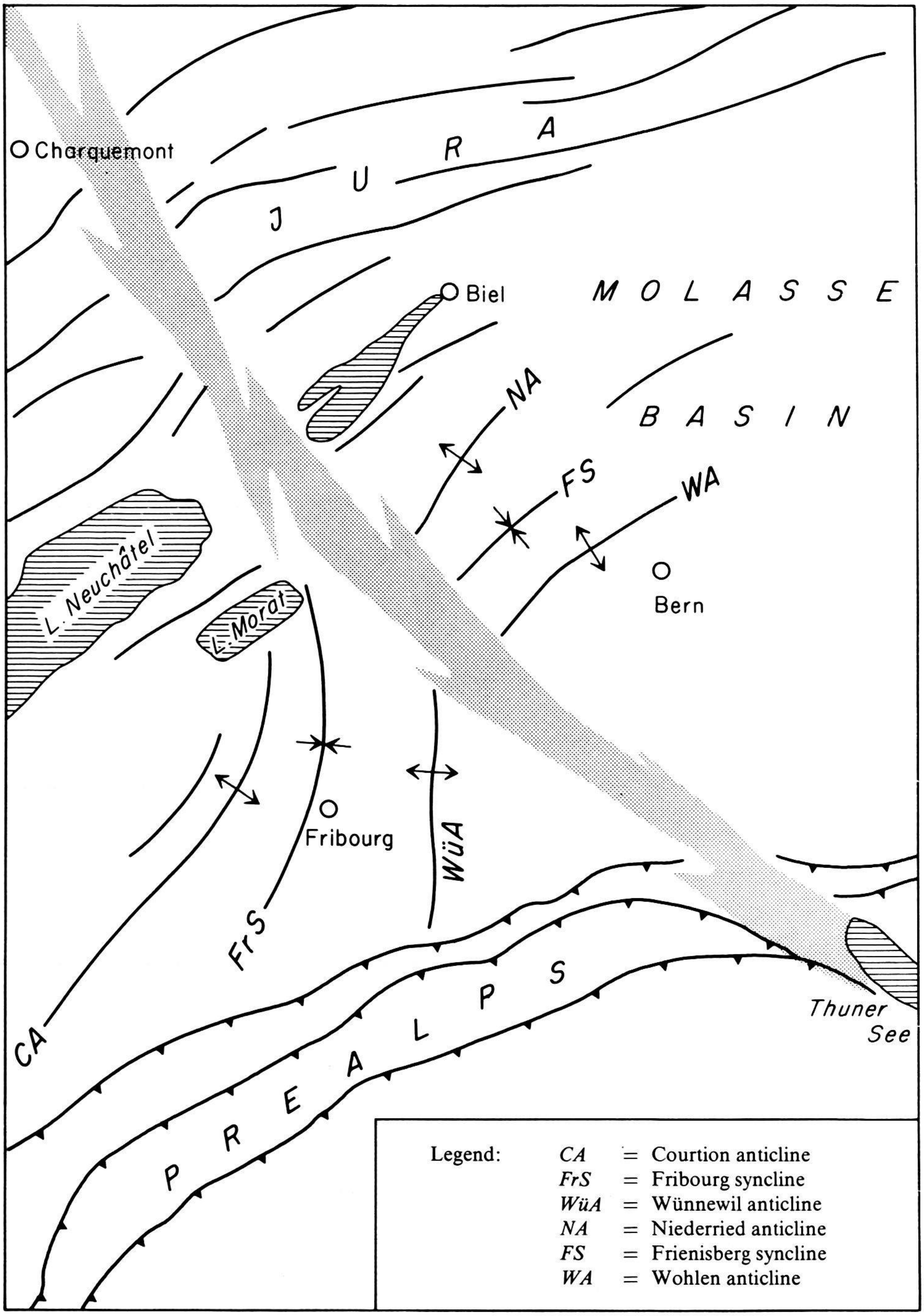

Fig. 3. Sketch map showing the Thunersee–Charquemont wrench-faults zone (shaded area) and the axis of bordering structures. Scale 1:500,000.

broad belt of brecciated, crushed limestone blocks can be traced until it branches off in several directions, the main one remaining north-westward.

The wrench-faults, shifting the axis of homologous structures, can be observed along the Doubs river and up to the hills surrounding the village of Charquemont on French territory. Flat lying limestone beds, outcropping on both sides of the zone of major disturbances, are, most likely, the structural equivalents of our seismic "paliers". Beyond Charquemont, the major effect of the wrench faulting is the sudden change of the anticlines and synclines trends (from SW–NE to W–E), along a line that can be traced from Maîche to the Lomont Mountains, on the north-western border of the French Jura.

Thus, on the basis of regional field evidences, collected in the Swiss Molasse basin and across the tectonic units bordering it (a structural belt about 115 km in total length) we may be entitled to consider that our aseismic zones can no longer be misunderstood as they could have been, when only a small portion (23 km) of the subsurface "structure divide" was available for study.

Although, in the faults delineating the blind areas (ref. Fig. 2 and description page 56), a vertical component of the displacement is never altogether absent and may, locally, be important, the mere fact of the "trapezoid configuration" suggests that our SE–NW aligned aseismic zones are mainly due to a lateral compressive stress, the amplitude of which decreases regularly from the marker *C* to the underlying markers *D* and *T*. Actually, the brecciated, crushed rocks, giving no reflection, form a broader belt in the Cretaceous limestone than they do in the Dogger and in the Triassic, for the horizontal stress was generated in near-surface conditions, being weaker from top to base of the aseismic mass, in contrast with disturbances caused by deep-seated, vertical motions. Hence, in the interpretation of our seismic profiles, we take the blind areas to be due to the same regional wrench-faulting that can be observed, along NW–SE trending lines, in the Thunersee area and in the Swiss and French Jura.

4. Conclusions

To the field study of the major effects of wrench-faulting in the area of Thunersee and in the Jura, the oil exploration program, carried out in the Swiss Molasse basin, has added seismic data, some of which have been briefly described and interpreted in chapters 2 and 3.

Figure 3 is a sketch map summarizing the main results of the present study of subsurface and surface structures. In the south-eastern part of the sketched area, the surface tectonic units of the Prealps and of the Subalpine Molasse, are shown as they appear on the Tectonic map of Switzerland, on 1:500,000 scale, with the exception, however, that we take the abrupt shift of the Subalpine Molasse to be due to wrench-faults observed in the vicinity of the lake of Thun (Thunersee).

The axis, displayed in the Molasse basin, are the axis of subsurface structures, traced at the top of Dogger. The horizontal displacements of anticlines and synclines, along the north-western extension of the Thunersee wrench-faults, can also be observed in the surface anticlines of Courtion and Wünnewil and in the surface syncline of Fribourg and their homologous, located, respectively, south and north of the strike-slip faults.

In the Jura, the structure axis shown in our sketch (Fig. 3) are conform to Swiss and French maps but our field observations led to a different interpretation of the fault pattern, previously mapped as small, isolated north-south striking faults.

We have termed "Thunersee-Charquemont wrench-faulting» (décrochement latéral de Thunersee-Charquemont) the tectonic features which cause the shifting of structures through all the Subalpine Molasse, the Swiss Molasse basin and the Jura (shaded area in Fig. 3). In the oil exploration under way, the Thunersee-Charquemont wrench-faulting is taken to provide, very likely, a good northern closure to some prospective structures of the Swiss Molasse basin. As a matter of further general interest, we would recommend a regional study related to the most probable north-western extension of this wrench-faults, outside the studied area.