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IV

Comparison between two techniques of line-drawing migration (ray tracing and common tangent method)

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IV.A. – Introduction

Deep seismic sections are often interpreted on the basis of unmigrated data. Numerical migration is applied only at .he very end of classic processing procedures, yielding ·esults which are generally disappointing or ambiguous at great depth due to the very weak signal/noise ratio [Warner, 1987]. However, for the ECORS-CROP Alpine traverse as well as the ECORS Jura-Bresse segment – where certain reflectors are probably steeply dipping – it was considered necessary to work on depth migrated cross-sections in order to avoid serious errors in the interpretation. In particular, this is a prerequisite for constructing balanced crustal sections.

The experience gained from the interpretation of deep seismic sections had led to an efficient method, which

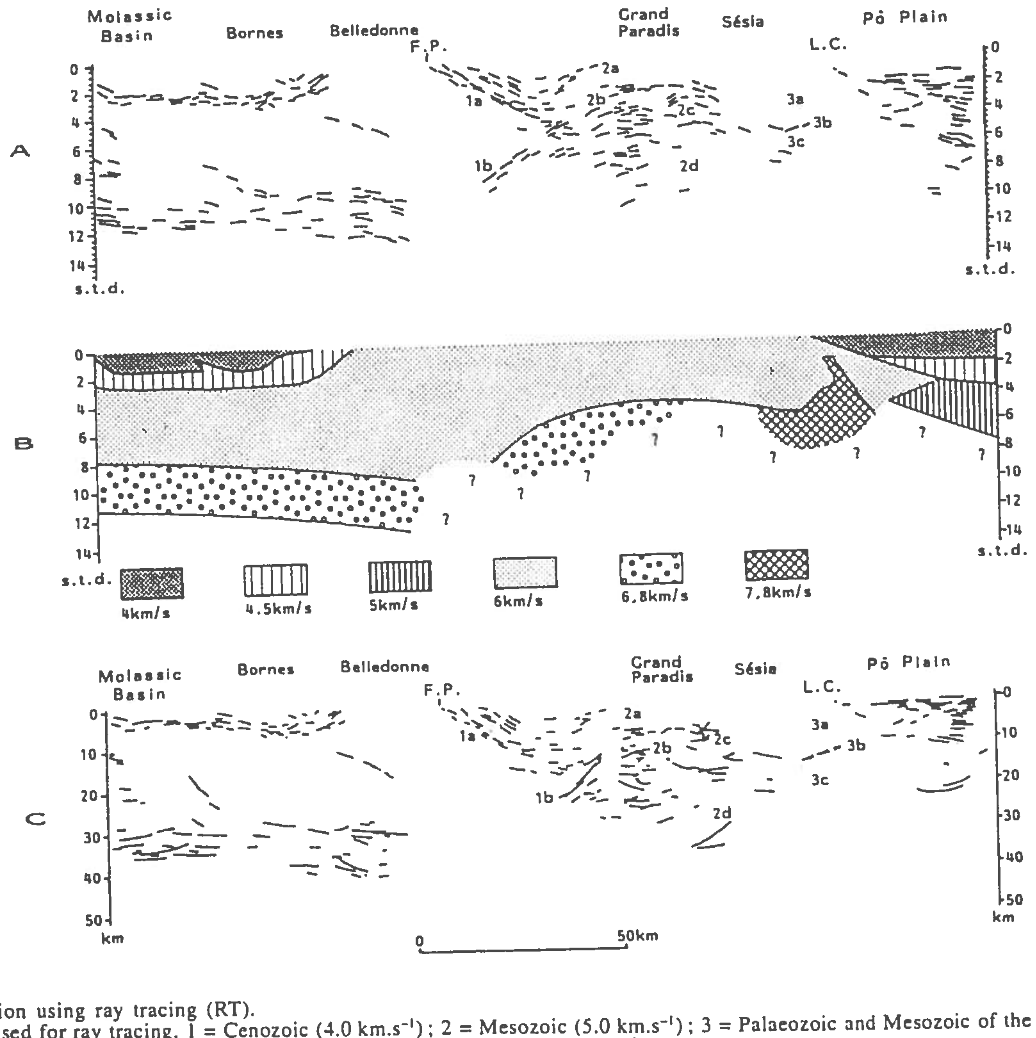

Fig. IV-1. – Migration using ray tracing (RT).
A) Velocity model used for ray tracing. 1 = Cenozoic (4.0 $km.s^{-1}$) ; 2 = Mesozoic (5.0 $km.s^{-1}$) ; 3 = Palaeozoic and Mesozoic of the Po Plain (5.8 $km.s^{-1}$) ; 4 = upper crust (6.0 $km.s^{-1}$) ; 5 = lower crust (6.8 $km.s^{-1}$) ; 6 = Ivrea body (7.8 $km.s^{-1}$).
B) Picking decision used for migration.
C) Result of migration, with filtering to eliminate reflections having dips steeper than 60°.

Fig. IV-1. – Migration par tracé de rayons (RT).
A) Segments sélectionnés pour la migration.
B) Modèle de vitesse utilisé pour le lancer de rayons. 1 = *Cénozoïque (4.0* $km.s^{-1}$*)*; 2 = *Mésozoïque (5.0* $km.s^{-1}$*)*; 3 = *Paléozoïque et Mésozoïque de la Plaine du Pô (5.8* $km.s^{-1}$*)*; 4 = *croûte supérieure (6.0* $km.s^{-1}$*)*; 5 = *croûte inférieure (6.8* $km.s^{-1}$*)*; 6 = *corps d'Ivrée (7.8* $km.s^{-1}$*).*
C) Résultats de la migration, avec filtrage pour éliminer les réflexions qui ont des pendages supérieurs à 60°.

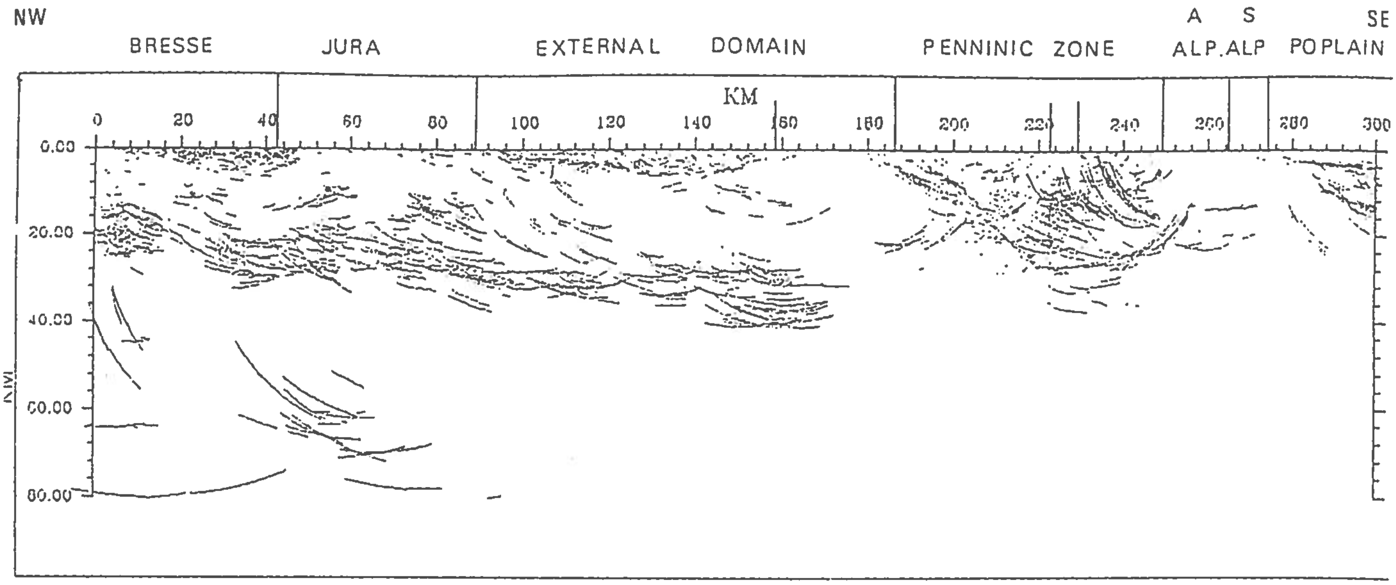

FIG. IV-2. – Unprocessed result from RT migration, without dip filtering (cf. fig. IV-1 C).
FIG. IV-2. – *Résultats bruts de la migration par rayons, sans filtrage des pendages (cf. fig. IV-1 C).*

consists of repositioning each reflector indidually by means of elementary geometrical techniques [Warner, 1987]. In the present study, we present two attempts at geometrical migration which were carried out with the common objective of converting the seismic data into a series of depth sections. Both approaches start with the manual picking of reflectors, so there is a significant amount of interpretation during the selection procedure. In the first example, use is made of ray tracing to reposition the reflectors, while the second example is based on the simplifying assumption that the mean velocity above each reflector is locally constant.

IV.B. – MIGRATION BASED ON RAY TRACING

The picked events used in this study [Truffert, 1989; Guellec *et al.*, 1990; Truffert *et al.*, 1990] constitute about 3,000 reflections distributed throughout the length of the ECORS Jura-Bresse profile as well as the ECORS-CROP profile across the Alps (fig. IV-1 B). The choice was restricted to the highest amplitude reflections, having lengths of more than about 50 m. With the exception of a few particular details – notably, consideration of mantle reflections beneath the Jura – this selection corresponds to the events finally picked out by the profile working group.

After digitization, each reflection was migrated using the RAYMIG program [Reynaud, 1988], which is available at the IFP. This program is based on the tracing of rays in a two-dimensional medium (with vertical and lateral variations in velocity). So it therefore takes the refraction of rays into acount. Consequently, it is necessary to define a preliminary velocity distribution along the entire length of the section. This is an important and difficult step, even if an attempt is made to link up with the results of experimental seismics.

Figure IV-1b was largely constructed by considering, at least within the internal zones, an interpretative gravimetric section. The velocities of the non-sedimentary units were calculated using a standard relation [Perrier and Ruegg, 1973]. In the external zones, velocities were adopted for the upper crust, lower crust and mantle, which are very distinct. The sedimentary units of the Bresse plain, Jura and Molasse Basin were assigned an overall mean velocity, which is in agreement with the work of Bergerat *et al.* [1990]. In order to be able to analyse the data in two-dimensions, treatment of the selected reflections by RAYMIG was carried out assuming a null value for ß, the angle between the profile direction and the main dip direction of structures.

For a certain number of reflections, in particular those situated in the Penninic zone or in the deep mantle beneath the Jura-Bresse region, there is an important distorsion effect produced by ray tracing (RT), which leads to the appearance of pronounced curvature (fig. IV-2). The concave-upwards cups produced in this way are classic artefacts of the treatment used in migration. These cups are easily removed in the present study by means of appropriate filters, but this is a drastic process which is partly arbitrary in nature. An example of this type of filtering is given in figure IV-1c, in which only those reflections with dips less than 60° are retained after migration.

IV.C. – MIGRATION USING THE COMMON TANGENT METHOD

A second attempt at migration was carried using the common tangent method (CTM) [Sénéchal, 1989; Thouvenot *et al.*, 1990; Sénéchal and Thouvenot, 1991]. Taking a highly simplified view of the problem, an unmigrated seismic section is considered as a plane in which the mean velocity between the surface and each reflector is variable in both the vertical and lateral direction. Thus, we can assume that a given reflector of very small size is located in a medium which locally has a constant mean velocity. For each of the extremities of the reflector, the geometrical locus of all possible dip values defines an arc which is centered at a point on the surface vertically above the respective extremity. The migrated position is obtained by constructing the tangent common to both arcs.

This technique assumes that variations in velocity distribution are regular. In particular, it should be ascertained whether the mean velocity between the surface and the reflector is fairly similar to the value obtained before mi-

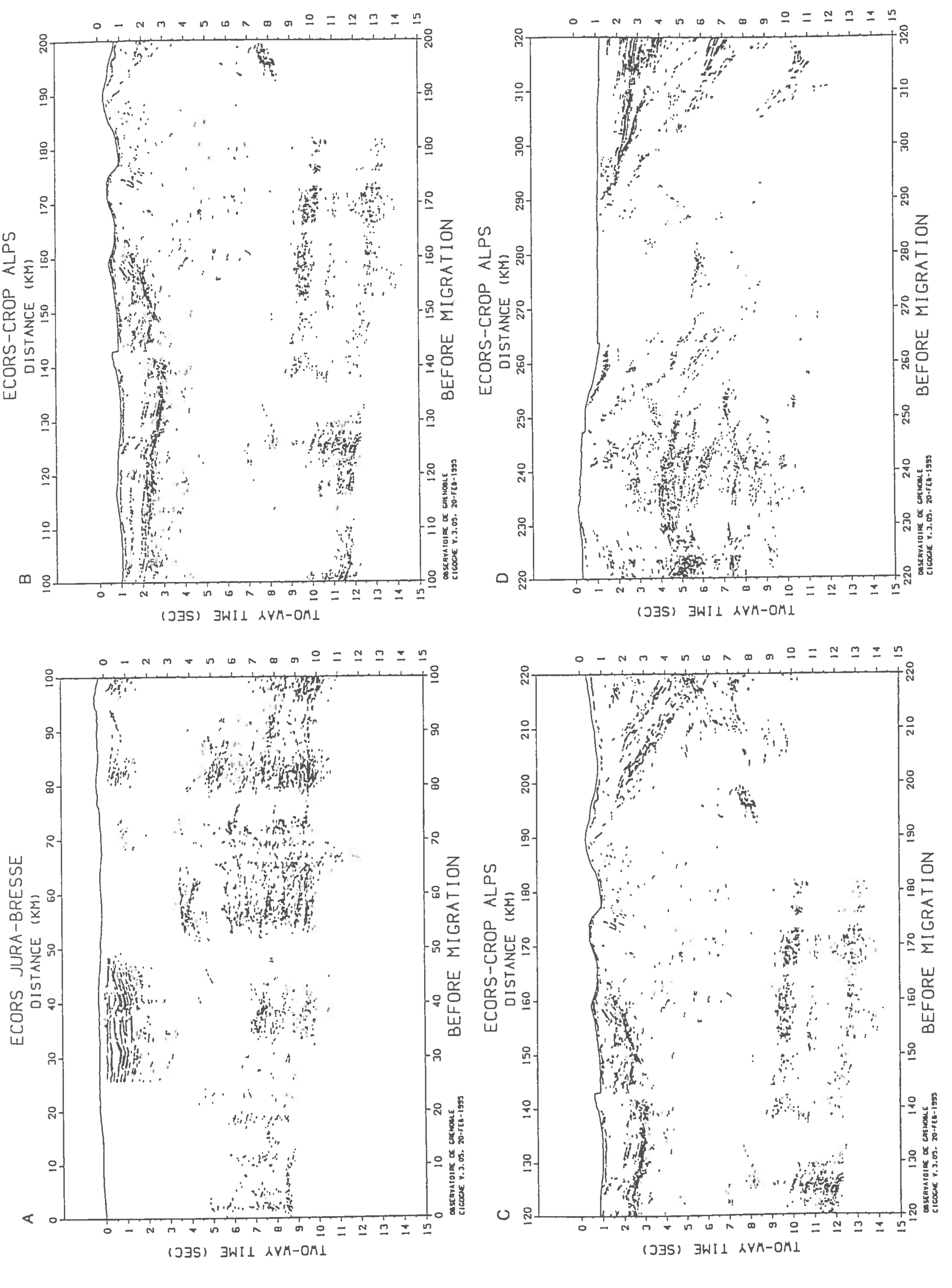

FIG. IV-3. – Picking decision used for migration based on the common tangent method (CTM).

FIG. IV-3. – *Segments sélectionnés pour la migration basée sur la méthode de la tangente commune* (CTM).

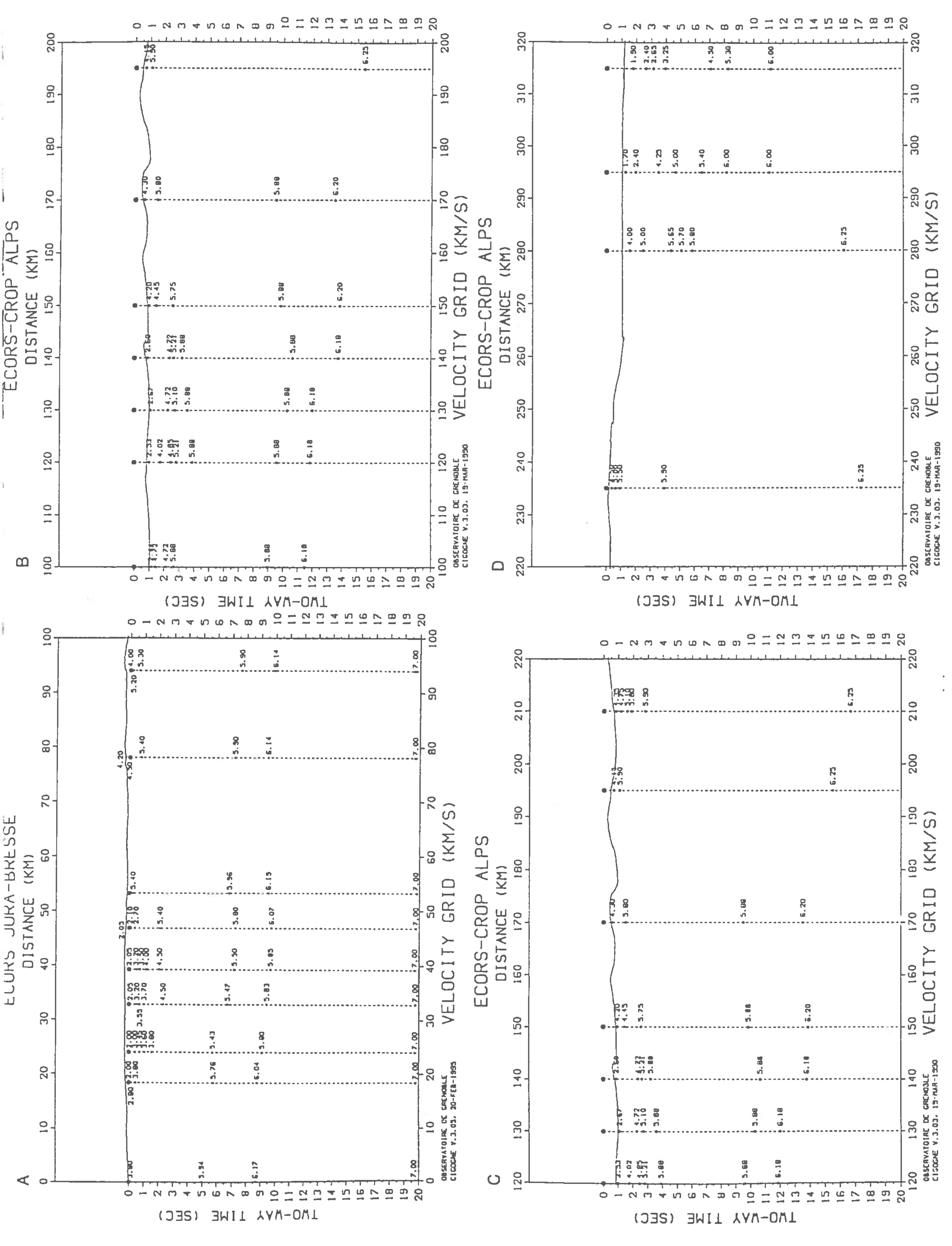

FIG. IV-4. – Velocity grid used for CTM migration.

FIG. IV-4. – *Grille des vitesses utilisées pour la migration CTM.*

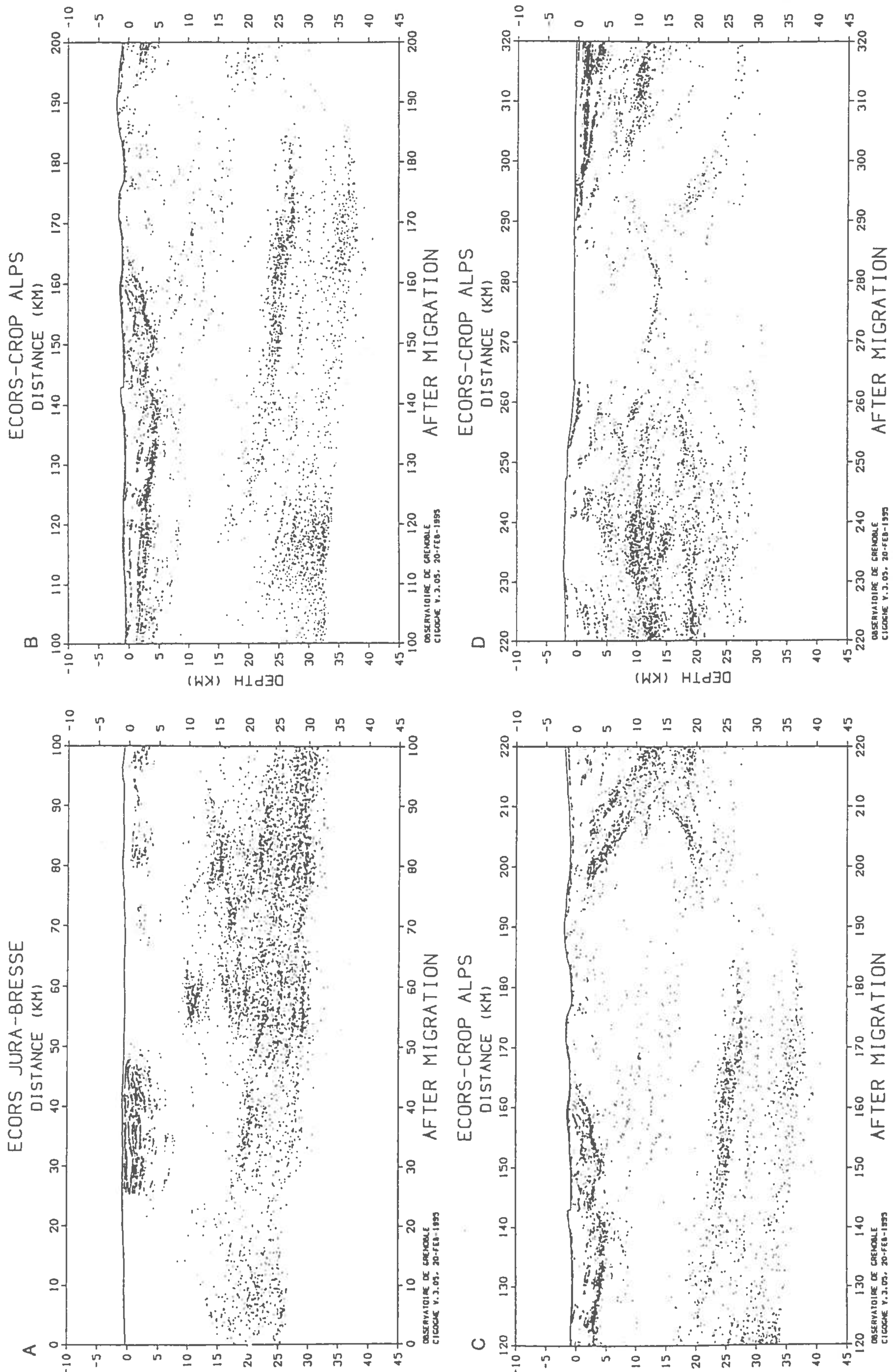

FIG. IV-5. – Unprocesseded results of CTM migration.
FIG. IV-5. – *Résultats bruts de la migration CTM.*

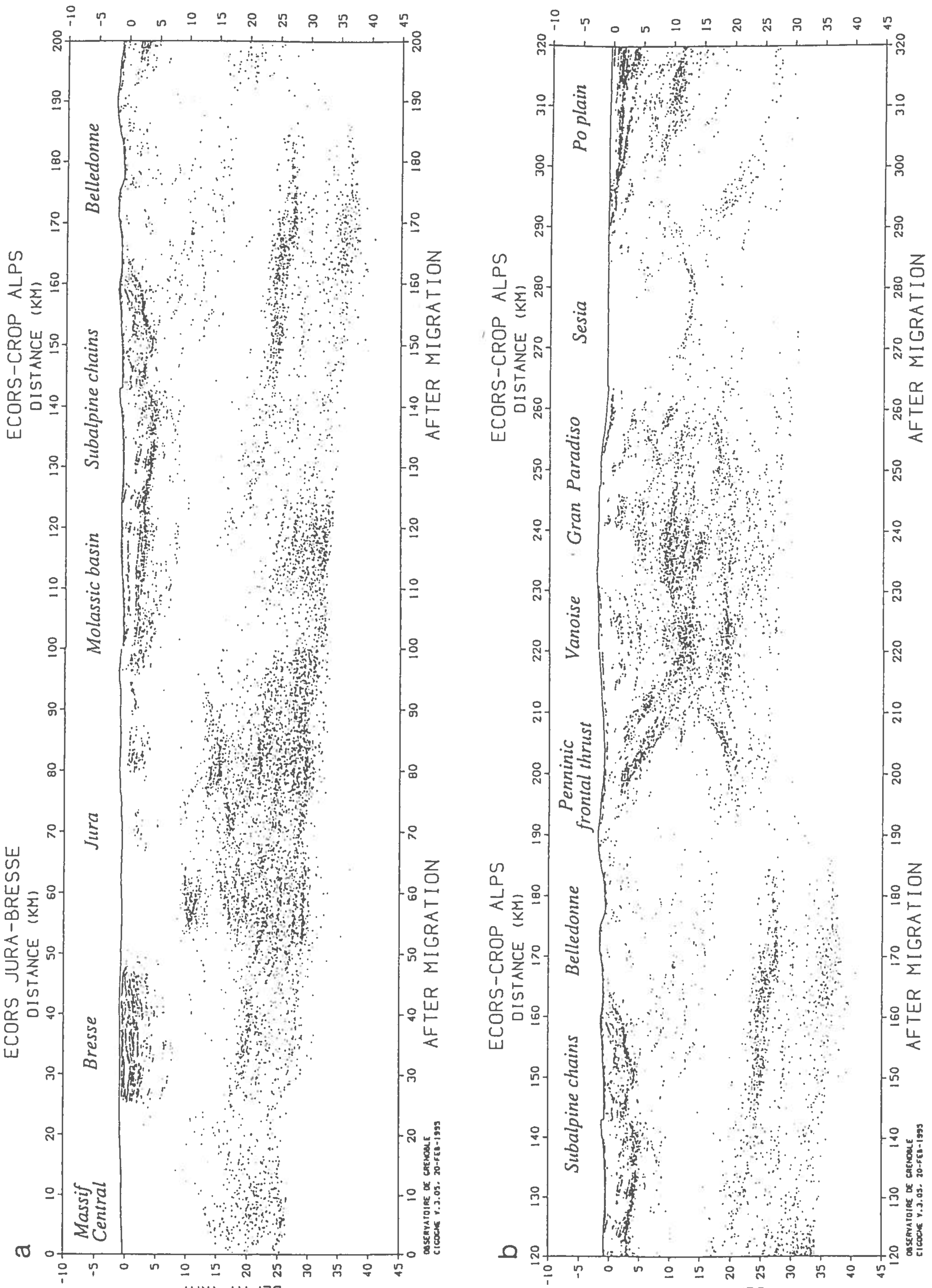

FIG. IV-6. – CTM migration :
a) Massif Central-Bresse Plain-Jura-Alpine foreland.
b) Foreland-Alps-Po Plain.

FIG. IV-6. – *Migration par la méthode de la tangente commune :*
a) Massif Central – Bresse – Jura– avant-pays alpin.
b) Avant-pays – Alpes – Plaine du Pô.

ration. In fact, a study of two specific areas (Bornes and arentaise) shows that, for most reflectors, this difference s much less than 0.1 km s^{-1} (order of magnitude of uncertainty on the mean velocity). In such a way, even though t is very approximate compared with the result of strict ay tracing, the common tangent method appears to be ppropriate in the present case.

Picking was undertaken on all the available sections, in articular those corresponding to near and far stacked races. By proceeding in this manner, reflecting zones are nhanced when they are visible on both sections. This election of events differs from the preceding one because nore care was taken to avoid unjustified interpolation of he various reflectors. However, in broad outline, the two icking decisions yield very similar results (fig. IV-3).

Here, the velocity distribution is defined within the two-way travel time field in terms of a velocity grid (fig. IV-4). On a given perpendicular, the variations in mean velocity between the surface and the reflections are derived – for he first few seconds – from the velocity relations obtained by CGG and OGS. An additional requirement is that these estimates should not exceed a value of 6 $km.s^{-1}$. At greater depths and in the external zone, experimental seismic data were used [Perrier and Ruegg, 1973; Thouvenot, 1976; Michel, 1978], revealing mainly a well differentiated lower crust. It is harder to fill in the velocity grid in the internal zones, so we have simply modelled an increase of the average crustal velocity on the concave side of the arc.

A total of more than 20,000 reflections were digitized. Strictly speaking, there are 20,000 reflecting elements of length 200 m or less. A single reflection, being continuous but not straight, can be subdivided into just as many elements. Each element was then migrated using the CI-COGNE program (developed at LGIT). The computation time for the whole section is of the order of several tens of seconds. Because of the important changes in altitude along the profile, as well as the different reference planes adopted for the processing of sections, particular attention was paid to the calibration of reflections with respect to sea-level. In this way, it was possible to draw up the depth sections as shown in figures IV-5 and 6.

The same CTM migration technique was used to reposition the wide-angle reflectors discovered during the 1985 survey. By combining these data to the results discussed here, it is possible to obtain an image of deep structures across the same section of the Alpine belt based on different angles of incidence.

IV.D. – Comparison

The principal difference between the results of RT and CTM migration concerns the number and length of reflecting elements that are migrated. As a matter of fact, CTM migration only operates with elements having a maximum length of 200 m, whereas RT migration emploies undivided reflections, which may attain lengths of several kilometres. Moreover, there was a preference for picking discontinuous reflections in the case of CTM migration. On the other hand, the picking decision used for RT migration is far more interpretative in nature (i.e. interpolation of certain reflecting horizons). As a result, the CTM migration has a more grainy appearance, which is nonetheless more detailed.

Both migration methods bring out the regular dip of the Moho beneath the external zones, as well as the reflectivity of the lower crust. The calibration at depth of the main horizons is generally closely comparable. On the RT migration, deep structures beneath the Bresse plain continue to display a pull-down effect which is less marked on the CTM migration. Beneath the Jura, the CTM migration reveals the presence of wedge-shaped structures situated at depths of less than 10 km. A sudden deepening of the Moho is seen beneath the Subalpine ranges on the RT migrated section, although such an effect does not appear on the CTM migration. In part, this is due to problems caused by the linking up of profiles ALP2 and ALP1 (at km 140). Through a careful consideration of the surface topography, the CTM migration shows a basement step at this location, with the SE block lying 2-3 km above the NW block. Since the two profile are relayed here en echelon, with a lateral offset of about 10 km, it is difficult to discern any possible dip across this break in level. It is nevertheless possible that such a structure may represent a slice of Subalpine basement which is more external than the main Belledonne thrust slice.

The shear zone situated at the bottom of this main thrust slice has a different appearance on each of the migrated sections. The more interpretative RT picking decision tends to generate a larger number of reflections. The CTM migration shows only a slight increase in reflectivity at this point, even if some other zones actually appear locally more reflective. On the other hand, the characteristic shape of the southeastern bottom of the Belledonne slice – highly transparent at this point – is to be found on both migrations. Immediately beneath the reflections of the Penninic front, a notch is seen in the Belledonne slice which suggests a possible underthrust structure.

By contrast, the RT migration has difficulty in sorting out the interdigitation of reflectors beneath the Vanoise and Grand Paradis massifs. In this segment, on the contrary, the CTM migration reveals several reflective horizons with an anticlinal form beneath the Grand Paradis. The dominant impression here is that of internal units which were being thrust towards more external parts of the belt and which were blocked by a rigid wedge made up of External Crystalline Massifs. In this case, we are dealing with a clear example of "crocodile tectonics".

IV.E. – Conclusions

Except for the ALP 1-ALP 2 boundary, where out-of-the plane lateral events could have disturbed the signal, most of the ECORS-CROP profile where orthogonal to major structural trends. However, explosive shots have locally provided evidence of oblique dips of reflectors compared to the studied profile (see Chap. II.3).

Unlike in the Swiss studies [Stauble *et al.*, 1993; Litak *et al.*, 1993], no 3D effects has been taken into account for the proposed migrations.

From the two attempts at migration presented here, we may conclude that, when migrating sections with elementary geometrical techniques, it is essential to avoid the excessive interpolation or extrapolation of reflections. It is probable that more objective results can be obtained by only picking reflections in localized areas where a high amplitude signal is actually present. Both these methods are evidently very quick to implement, and they also show the advantage of providing depth sections which can be used directly, in particular for the construction of balanced cross-sections.