GEOMETRICAL MIGRATION OF LINE-DRAWINGS: A SIMPLIFIED METHOD APPLIED TO ECORS DATA

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Abstract. The geometrical migration of line-drawings can be an intermediate solution to the problem of migrating vertical-reflection data. Our method, based on the principle of the common tangent, quickly produces a depth-migrated line-drawing that is readily usable for interpretation.

Introduction

Migration is the process by which effects of dip and diffraction are removed. For deep seismic reflection data, conventional methods often produce poor results and, moreover, pre- or post-stack digital migrations are always time-consuming and require a great computer capacity (Sattlegger and Stiller, 1974; Warner, 1987). Consequently, vertical-reflection data are often represented unmigrated, and many interpretations are based on line-drawings of unmigrated time sections where the geometry of the dipping reflectors is largely distorted.

An alternative solution is to migrate the line-drawing, for instance using a ray-tracing method (Raynaud, 1987). Unger (1988) described an application of ray theory to migrate line-drawings, considering a velocity that increases linearly with depth. We tried to go here one step further into the direction of simplification, using a very primitive, but efficient, geometrical technique. This method is based on the principle of the common tangent of two spherical wavefronts (Hagedoorn, 1954). Velocity models with horizontal and vertical variations can be taken into account, provided the variations are smooth enough.

Description of the process

Consider the geometry of a spherical wavefront as reflected from a dipping interface with source and receiver in the same place (zero offset). On the unmigrated section, the reflection will be positioned along the vertical of the source-receiver pair, while the true location of this reflection is where the reflector is a tangent to the wavefront.

Suppose now an unmigrated reflective segment delimited by two points (Fig. 1). For each point, we can draw the corresponding spherical wavefront, using the intersection between the vertical of the point and the surface. The true position of this reflective segment will correspond to the common tangent of these two wavefronts, where reflection will be at normal incidence.

The input data are digitized unmigrated line-drawings, with each reflector being digitized into small individual reflective segments. The digitization step takes into account the lateral resolution, which decreases with depth as a consequence of the wavefront geometrical expansion with time (Sheriff and Geldart, 1982). Therefore, the length of any reflective segment should exceed a few ten metres in surface and a few hundred metres at depth.

Such a geometrical construction requires the same vertical and horizontal scale, and we first have to compute the unmigrated depth section. To transform the time section into a depth section, we define a velocity model, which is a grid of estimated velocities with horizontal and vertical variations (Fig. 2). For the subsurface, we use velocities obtained during the pre-stack process (velocity analysis); for the deep crust, we use velocities provided by deep-seismic-sounding data (long-range refraction and wide-angle reflection). The velocity anywhere in the model can be approximated using a double linear interpolation between neighbouring grid velocities, and the unmigrated depth section can be computed.

The migration process uses simple trigonometrical relations for computing the true position of each reflective segment (Fig. 3):

Consider the dipping segment A_1A_2 (dip β), positioned beneath the surface (dip α). The coordinates (x_1,z_1) and (x_2,z_2) of the points A_1 and

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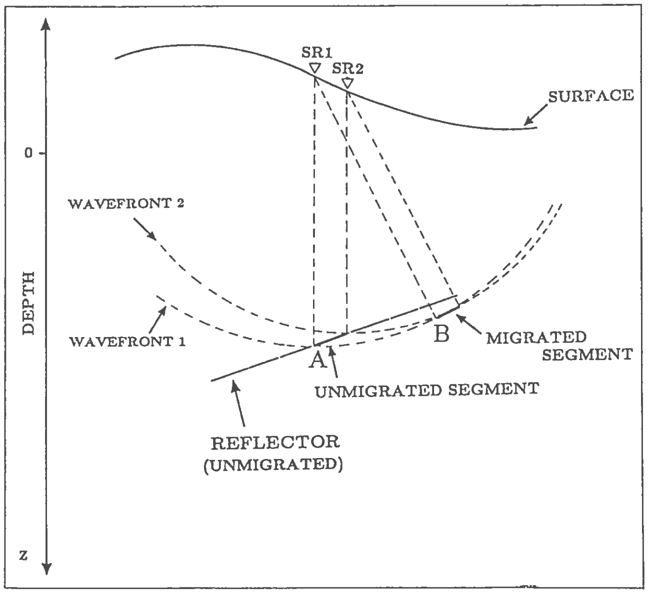

Fig.1 Geometrical migration of a reflective segment. Reflector A moves to B.

A_2 are computed using the digitized coordinates of the time section and the velocity model. Next, we compute the coordinates (x_1,z_{r1}) and (x_2,z_{r2}) of the points O_1 and O_2 situated on the surface, on the vertical of the two points limiting the reflective segment. The distance O_1O_2 is:

$$D=\sqrt{d^2+p^2},$$

with $\quad d=x_2-x_1$ and $p=z_{r2}-z_{r1}$.

Let $H=R_2-R_1$, with R_1 being the radius of circle C_1 and R_2 the radius of circle C_2. We can express dips α and β:

$$\alpha=\tan^{-1}\left(\frac{p}{d}\right) \qquad \beta=\tan^{-1}\left(\frac{z_2-z_1}{d}\right)$$

Applying trigonometrical relations to triangle O_1O_2T allows us to express angle γ in terms of H and D

$$\gamma=\sin^{-1}\left(\frac{H}{D}\right),$$

and the dip of the migrated segment is $\theta=\gamma+\alpha$. The coordinates of the two points B_1 and B_2 that define the migrated segment are:

$$B_1: \ x_{1m}=x_1-R_1\sin\theta \ , \ z_{1m}=z_{r1}+R_1\cos\theta,$$
$$B_2: \ x_{2m}=x_2-R_2\sin\theta \ , \ z_{2m}=z_{r2}+R_2\cos\theta.$$

The above equations are functions of the surface and reflector dips. Reflector with excessive dips cannot be migrated, which is the case for less than 1% of the data. When $\alpha=0$ (no altitude variation), β cannot exceed 45°.

The comparison between an unmigrated time section (Fig. 4a) and a migrated depth section (Fig. 4b) shows the transformation due to the process. Of course, dips are increased and reflectors moved laterally up-dip. This is especially clear for reflectors around 8 s TWT on the left side of the section. Moreover, entangled reflectors on the right side of the section (5–6 s TWT) are migrated into a more continuous reflective band.

Application to ECORS data

We processed the ECORS-CROP Alps data that provide a 320-km long section of the crust from the eastern Massif Central, France, to the Po plain, Italy (Bayer et al., 1987; Nicolas et al., 1990). The input data is the line-drawing of the unmigrated time section (Figs 5a and 6a). This line-drawing was produced by merging two stacks (near traces and far traces), and totals some 20,000 reflectors. We computed the unmigrated depth section, referring all depths to sea level, and giving special attention to altitude corrections. The velocity model was determined using velocities given by the contractor (C.G.G.) for the subsurface and those determined by deep seismic sounding for the lower crust. The final result is the migrated depth section (Figs 5b and 6b), represented with the same vertical and horizontal scale. The more stippled aspect of these two pictures is due to the splitting of each reflector into several reflective elements during the process. Data gaps on the line-drawing are due to locally-poor signal-to-noise ratio on the unmigrated section. Such gaps can also appear in case of a sudden change in the reflector dip — at least if we stick to a simple reflected ray geometry where diffraction is not taken into account. Some reflective segments can however be migrated in these blank areas during the process.

Migration is clearly indispensable beneath the Vanoise Massif (Fig. 6) where we can observe a two-band reflective zone. This structure corresponds to the Frontal Pennine Thrust that separates the external Alpine realm from the inner Alpine realm. These two bands merge into a single highly-reflective horizontal zone under the Gran Paradiso Massif. The close-up of Figure 4 shows the wedge geometry of the Belledonne massif that seems to have been both overthrusted and underthrusted by material from the inner Alpine realm.

Advantages and limits

The main drawback of this method is the subjectivity of the hand-picked input data. An

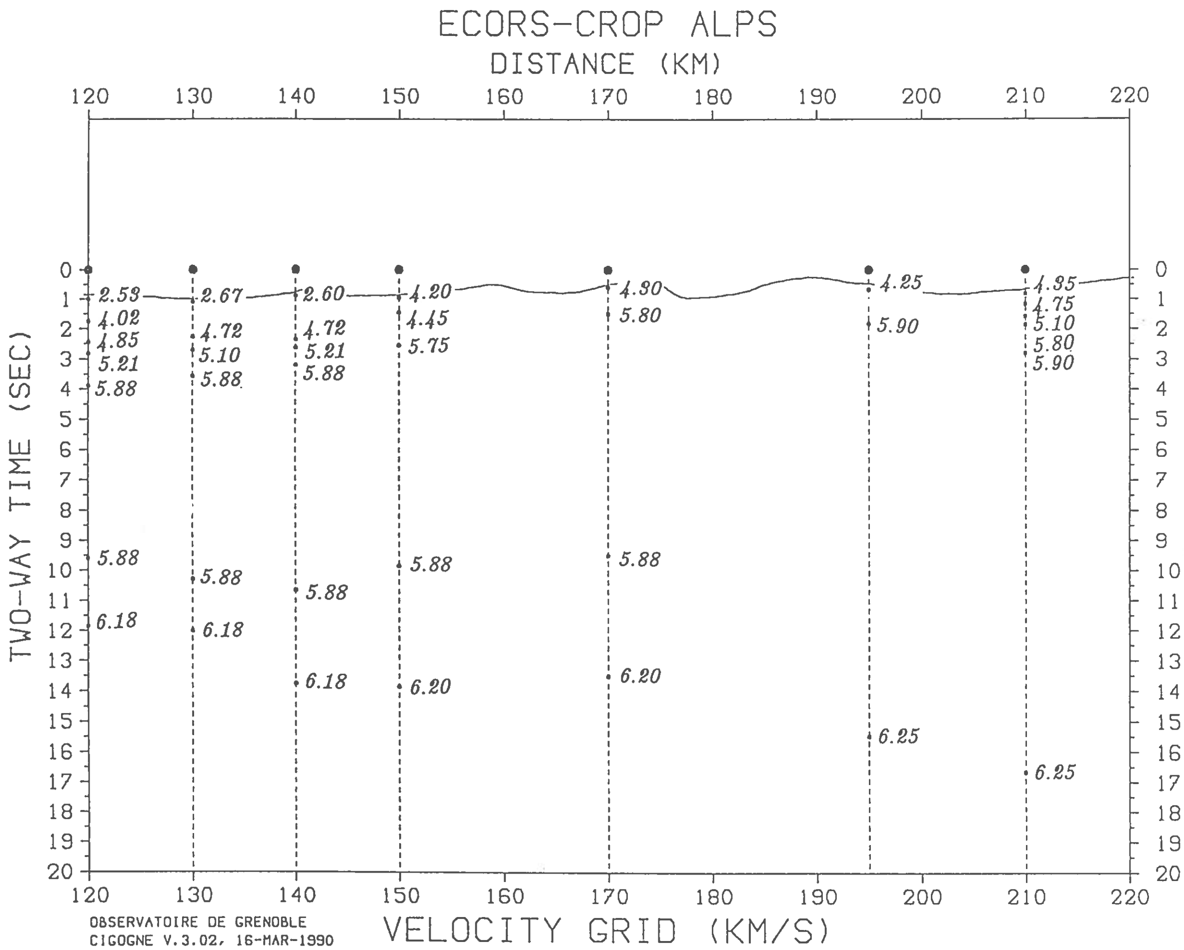

Fig.2 Example of velocity grid. (Surface is drawn using the elevation static corrections, datum plane at altitude 2400 m). Values are velocities in km/s, averaged from the surface.

automatic line-drawing can also be used if the signal-to-noise ratio is acceptable. We follow Stiller and Thomas (1990) in their statement that both methods complement each other and form a basis for a solid interpretation.

A second drawback is the use of spherical wavefronts, which may appear an oversimplification of the problem. To test this point, we checked that the velocity variation between the unmigrated and migrated positions of the reflective element is usually negligible: a velocity variation higher than .3 km/s is observed only for .5% of the data. Conventional digital migrations are always very sensitive to the velocity model (Yilmaz and Chambers, 1984; Berkhout, 1984), and in particular those based on ray-tracing methods result in migrated sections with unstable dips. The program proposed by Unger (1988) uses a linear velocity increase with depth and doesn't take into account altitude variations, two conditions that are not acceptable in the Alps. In our method, velocity is of course an important parameter to transform the time section into a depth section, but the migration itself is not so much sensitive to velocity variations.

The computing time amounts to a few seconds for processing several thousands of reflectors, whereas conventional digital methods require several hours. Very little computer memory is required, to such an extent that even a microcomputer can handle the work. The process can be interactive, which gives the possibility to test different velocity models and different line-drawings. For instance, several data files can be used to enrich the final section suitably.

Conclusion

The fastness of the process and the advantages described hereover make this method a good

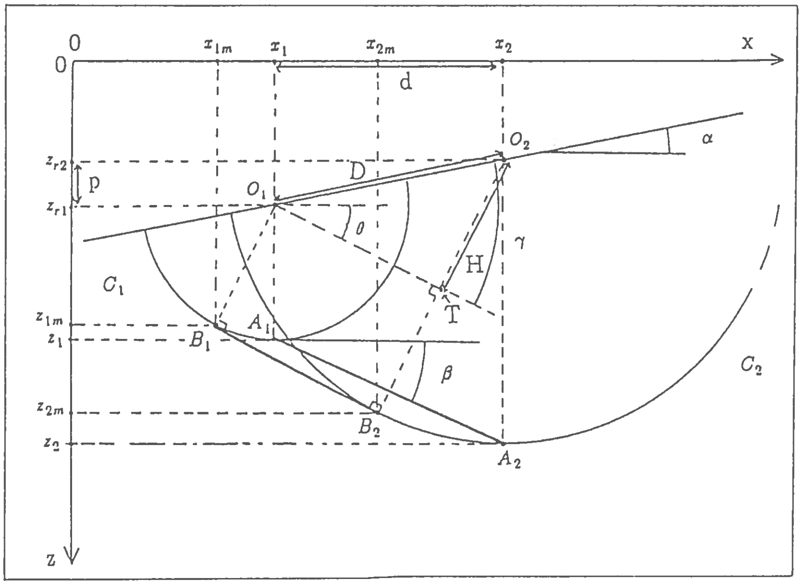

Fig.3 Trigonometric construction showing the relations between the dip of the unmigrated reflector A_1A_2 (β), the dip of the surface (α) and the dip of the migrated reflector B_1B_2 (θ).

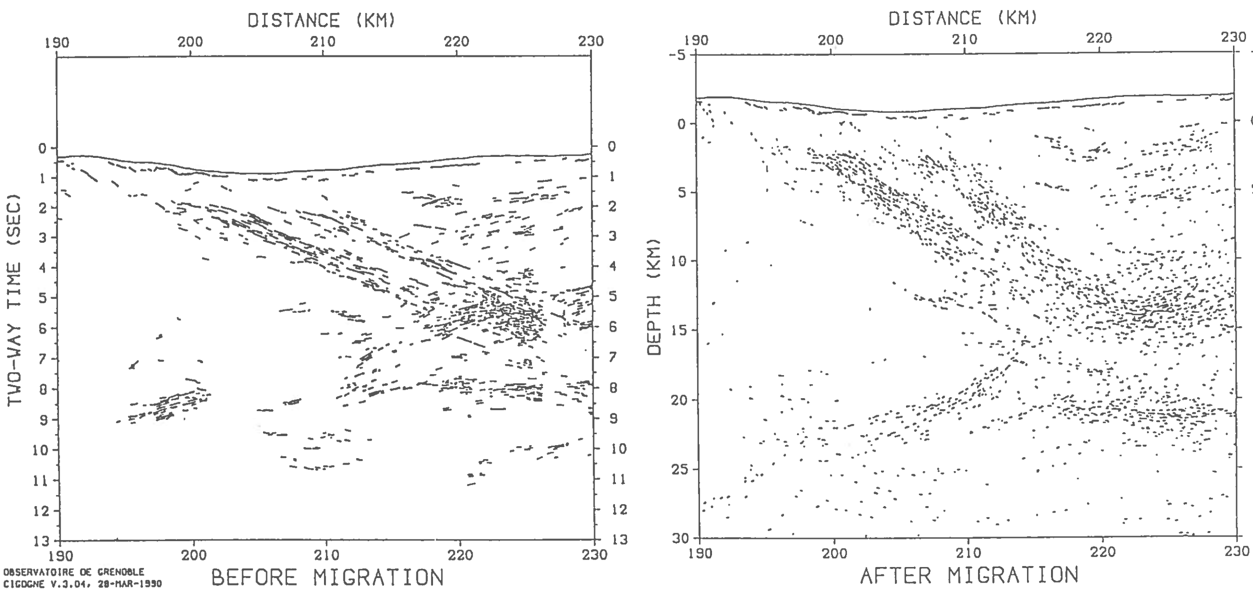

Fig.4 Unmigrated time section (a) and migrated depth section (b) of part of the ECORS Alps profile (ALP1). The two bands correspond to the Frontal Pennine Thrust.

alternative solution to the problem of migrating deep seismic data. These results are of course not claimed to be better than those obtained by other migrations (*e.g.* Damotte *et al.*, 1990). Simply, we believe that a comparison between several migration methods is highly commendable, especially at great depth where it allows us to confirm or reject some structural interpretations.

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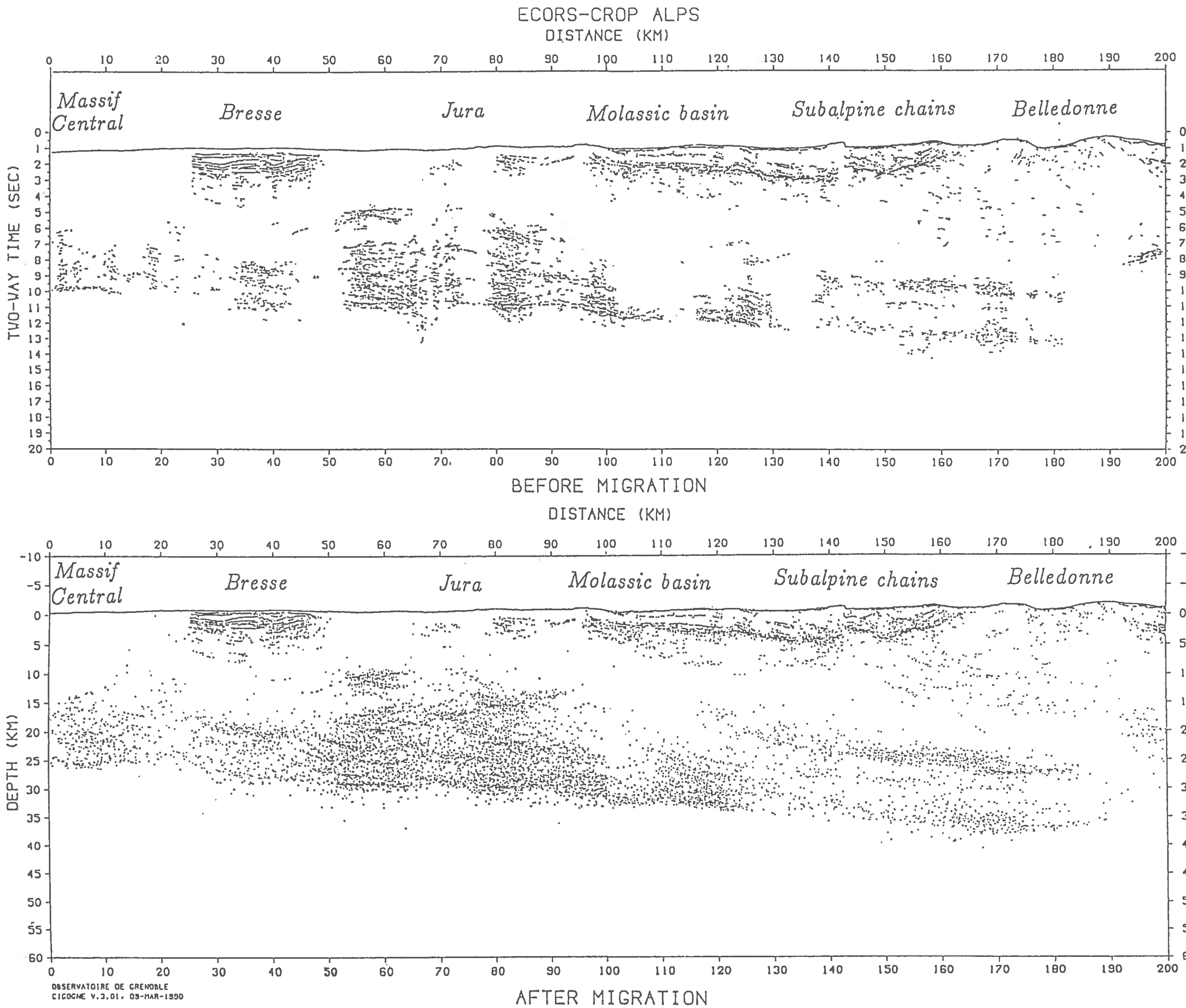

Fig.5 Unmigrated time section (a) and migrated depth section (b) of the line-drawing of the ECORS Alps profiles between Massif Central and Belledonne Massif.

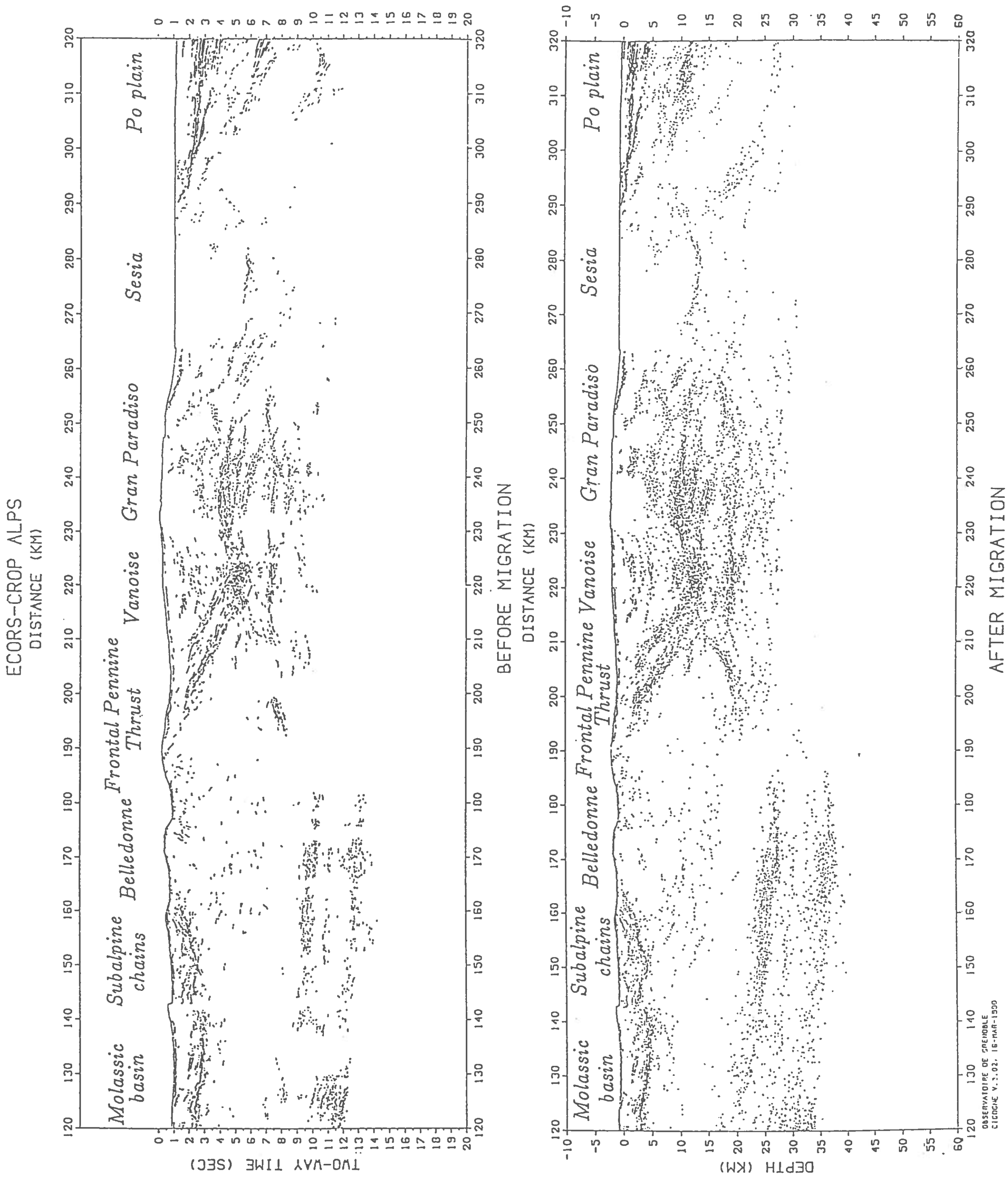

Fig.6 Unmigrated time section (a) and migrated depth section (b) of the line-drawing of the ECORS-CROP Alps profiles between the Belledonne Massif and the Po Plain.

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