THE HYPERBOLIC RADON TRANSFORM AND SOME OF ITS APPLICATION IN SEISMIC DATA PROCESSING

by
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ABSTRACT

The Radon transform has been used in exploration seismology for a decade. It consists of stacking seismic traces along a line of constant ray parameter p. This transform is used to map seismic data from time distance space into tau-p space, where tau is the intercept time.

A modified version of the Radon transform, i.e., the hyperbolic Radon transform has been proved to be useful for seismic data processing. It converts an hyperbolic moveout of the seismic reflection into a point. The multiple identification becomes easier, which facilitates its suppression.

Using the hyperbolic Radon transform, an improvement in the velocity analysis procedure can be realized. Automatic picking of the reflected arrival can also be performed easily. Experiments demonstrate the effectiveness of the hyperbolic Radon transform applied to synthetic as well as real data for the following purposes: velocity analysis and depth conversion, dip finder, multiple suppression and automatic reflection picking. The results are encouraging.

I. INTRODUCTION

The Radon transform (Radon, 1917) has been used in crustal seismology for more than a decade for analysis and inversion of seismic refraction profiles (see for example Bessonova et al., 1974; 1976; Kennett, 1981; Clayton and Mc Mehan, 1980). Its applications have been expanded in exploration seismology to cover several important processing steps such as interval velocity estimation (Schlutz and Claerbout, 1978; Diebold and Stofa, 1980), multiple suppression (Tatham, 1984; Harlan et al., 1984; Moon et al., 1986), migration of seismic reflection data (Hubral, 1980; Ottolini and Claerbout, 1984), wave field separation (Moon et al., 1986) and many others.

The Radon transform has been known by many names:

the Slant Stack (Schultz and Claerbout, 1978), tau-p transform (Tatham et al., 1982), plane wave decomposition (Treitel et al., 1982) and the Radon transform (Chapman, 1981). Mathematically, it is a line integral over a specified limit. From the point of view of seismic implementation, it is equal to stacking seismic traces along a slanted straight line. From the aspect of physics, the Radon transform enables the geophysicist to present a spherical wave as a series of plane waves.

In seismic tomography, the Radon transform plays an important role in developing forward projection theorem as well as back projection theorem (Worthington, 1984; Stewart, 1990). The forward Radon transform constitutes the basis of the forward projection theorem, while the inverse Radon transform provides us with the idea for the imaging or reconstruction technique.

In this paper we introduce a modified version of the Radon transform by stacking along hyperbola. Following Bazelaire et al. (1991) we will call it the hyperbolic Radon transform. The hyperbolic Radon transform is equivalent to the hyperbolic Hough transform from the point of view of seismic implementation (Suprajitno, 1992). The latter has been used succesfully in image processing. The attractiveness of the hyperbolic Radon transform is that it can transform an hyperbolic reflection moveout into a 'point'. This property enables the geophysicist to use the hyperbolic Radon transform as a powerful tool in seismic data processing and analysis. We will demonstrate the effectiveness of this transform for velocity analysis, dip finder, automatic picking of reflection events or later arrivals and multiple suppression. The detailed mathematical aspect of this process will not be discussed here.

II. THE RADON TRANSFORM

Basically the Radon transform or Slant Stack consists of summing the seismogram along lines of constant apparent dips. The principle can be simplified as illustrated in Figure 1. The heavy line is the hyperbolic moveout from reflection events. For a fixed intercept

Figure 2. A Synthetic record consisting of primaries (RI and R2) multiples (M1 and M2) and head wave (H). M1 and M2 are the first and the second order multiples in layer 1.

time t, summation is performed for all traces along a line of constant ray parameter P. This process is carried out from Pmax to Pmin, then, the intercept time is incremented and the whole process is repeated. The increment of intercept time is usually chosen as equal to the sampling rate of the seismic data.

The hyperbolic Radon transformation is a similar process, but instead of stacking along a straight line we stack along an hyperbola. The curvature of the hyperbola is controlled by the velocity and the two way travel times (TWT). The curvature of the hyperbola is steep for low velocity and small TWT. It must be acknow ledged that the velocity resolution decreases for deep horizon (high TWT) with high velocity.

To illustrate the difference between the linear Radon transform and the hyperbolic Radon transform, let us observe a synthetic record (Figure 2). The linear Radon transform of Figure 2 is shown in Figure 3. We observe that the hyperbolic patterns of the reflection events have been transformed into ellipses, while the straight line signifying the head wave has been transformed into a point. By contrast, the hyperbolic Radon transform in Figure 2 is shown in Figure 4 where all hyperbolic moveout has been converted into points.

If we observe Figure 4, we can see that the multiple reflection has the same stacking velocity as the primary

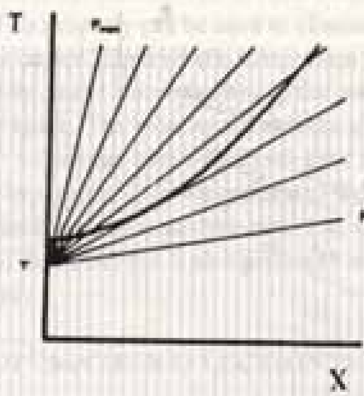


Figure 1 Basic principle of the Radon transform or slant stacking

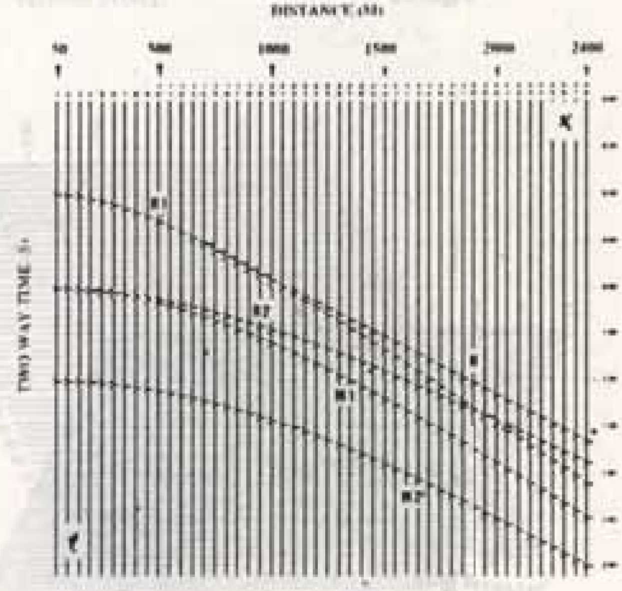


Figure 2 A synthetic record consisting of primaries (RI and R2) multiples (M1 and M2) and head wave (H). M1 and M2 are the first and the second order multiples in layer 1

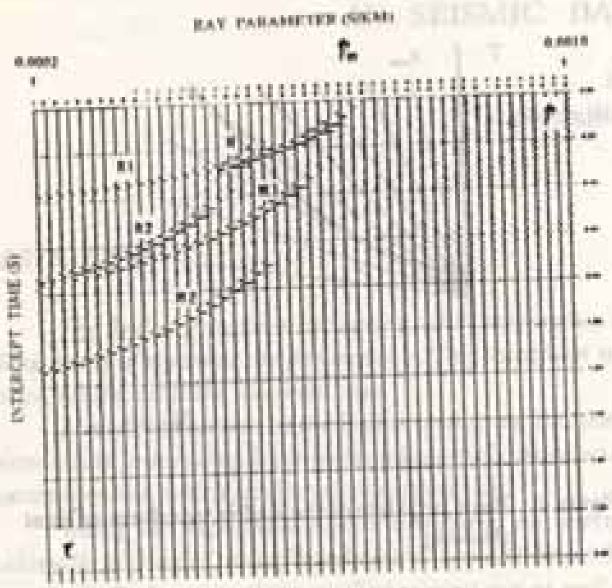


Figure 3. The Radon transform of the synthetic record in Figure 2

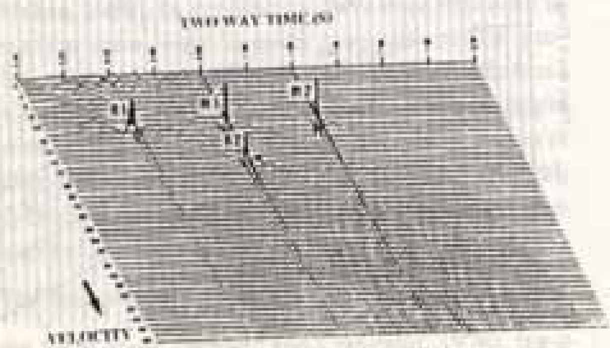


Figure 4. The hyperbolic Radon transform of the synthetic record Figure 2. Observe that the multiples are periodic with respect tothe primary

but it is periodic with respect to the zero offset TWT of the primary. This property facilitates the use of the hyperbolic Radon transform as a powerful tool for multiple identification or suppression and velocity analysis.

III. VELOCITY ANALYSIS AND DEPTH CONVESION

The peak of the primaries (R1 and R2) in Figure 4 can be connected to produce a velocity as a function of two way time which is needed for velocity analysis. A more complicated example is given in Figure 5. It is clear that in order to produce the velocity function we only need to mute the multiple reflections. Since the multiple reflection have been converted into points, they are easy to mute owing to their periodic properties with respect to their primaries.

Figure 6-b shows an example of a velocity function generated by the hyperbolic Radon transform of real seismic data from the Java Sea (Figure 6-a). There is a velocity drop (see window) which can be observed after 2.30 sec in TWT.

Since the abscissa of the velocity function is the zero offset two way time, the conversion from time to depth is straight forward. This conversion can be done before executing the hyperbolic Radon transform by changing the two way time by the depth divided by half of the velocity. To increase the precision, the depth increment can be made small. Figure 7 is the depth conversion of Figure 4. The real data example of time to depth conversion using the hyperbolic Radon transform is shown in Figure 8. This example is taken from Java Sea.

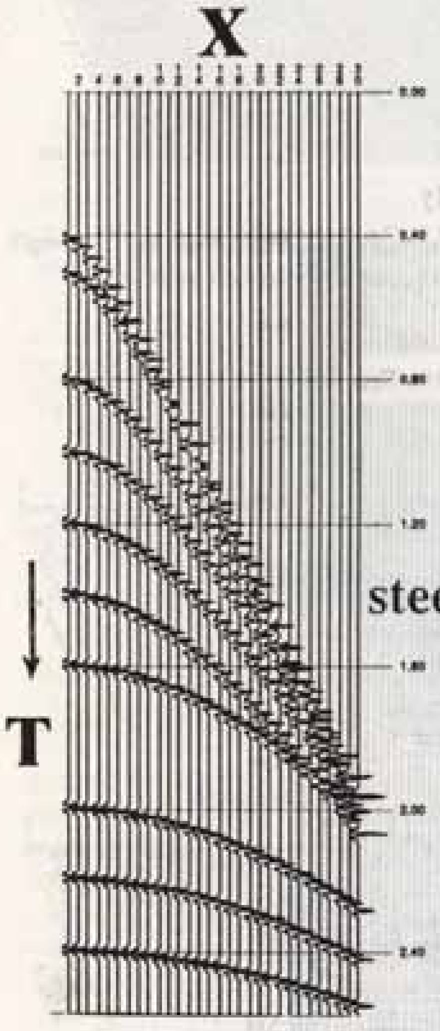
IV. MULTIPLE SUPPRESSION/ELIMINATION

The weakness of the hyperbolic Radontransform is the existence of amplitude smearing in the velocity function. This amplitude smearing is caused by loss of resolution to distinguish events with small moveout differences. This happens particularly at high velocities and deep horizons. When the amplitude smearing exists, the peak in the velocity function does not appear as a 'point', but as a line.

When there is no amplitude smearing, the Radon transformation is reversible. The inverse Radon transform is exact. This property can be used to eliminate multiples or coherent noises. For multiple elimination we simply erase or mute the peaks corresponding to the multiples from the velocity space. The velocity space is the space of stacking velocity versus the two way travel time (Figure 4). The inverse hyperbolic Radon transform of the muted velocity space yields the multiple-free record as shown in Figure 9. A real data example is also presented as can be seen in Figure 10.

V. AUTOMATIC REFLECTION PICKING

A simple procedure than the multiple elimination process can be done for the purpose of automatic reflection picking. In this case, instead of muting unwanted events, we only need to select the peak(s) whose reflected travel times are required. The inverse hyperbolic Radon transform can be executed to yield the picked travel times for various offset.



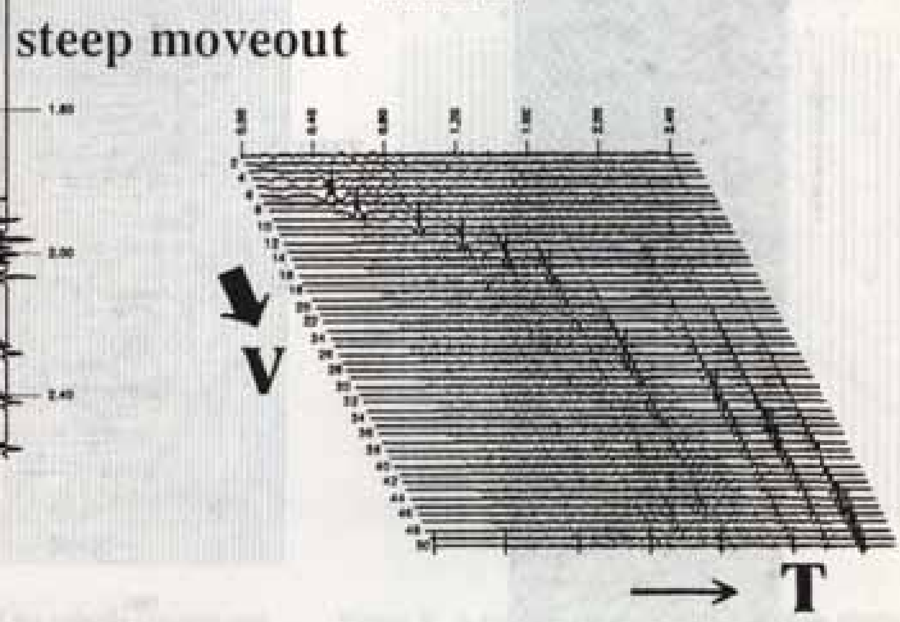


Figure 5 Basic principle of velocity analysis using the hyperbolic Radon tranform applied to synthetic data. The velocity function appears automatically as the first arrivals in the velocity space (V versus T)

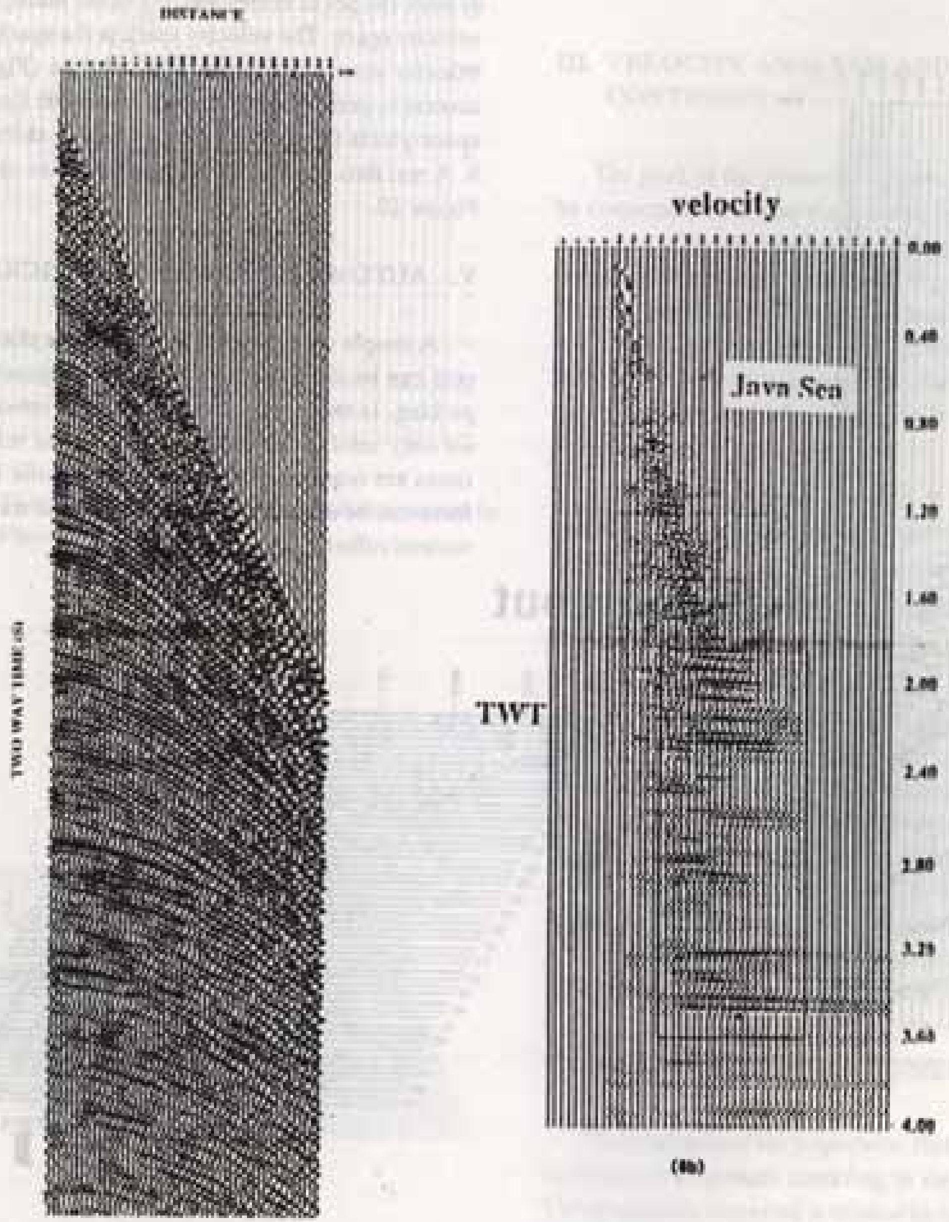


Figure 6 Areal data example of the velocity analysis from a shot record from Java Sea

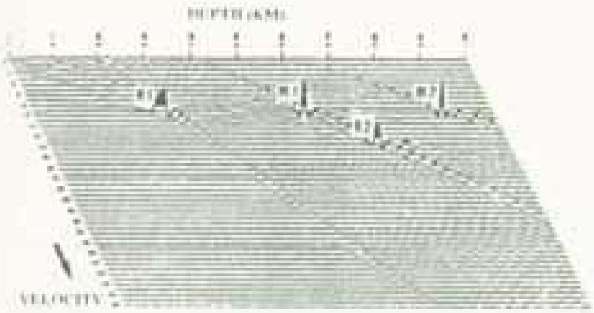
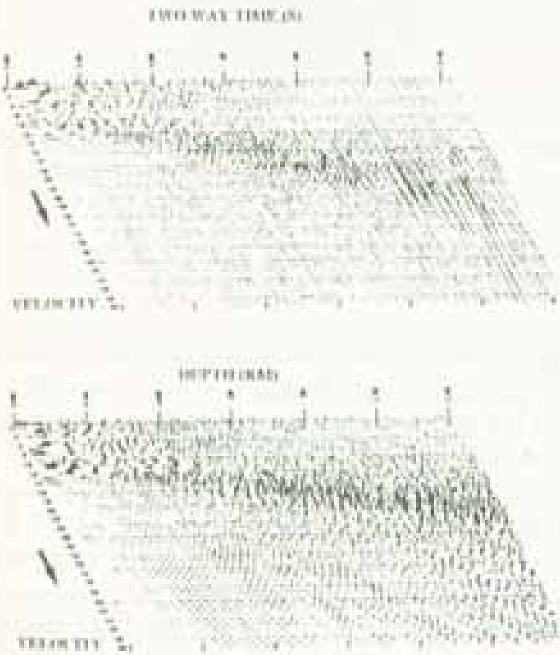


Figure 7 The depth conversion of the velocity space Figure 4, using the hyperbolic Radon transform

Figure 11 is a real data example of automatic picking of reflected events. It demonstrates how the later arrivals (not the first break) can be picked effectively using the hyperbolic Radon transform. In most practical applications we only need one reflected event from a common shot gather for further analysis.

VI. DIP FINDER

The hyperbolic Radon transform can also be applied for finding the dip of the reflector. The dip of the reflector must be searched in conjunction with the stacking velocity. Figure 12-b and c demonstrate the principle how the dip and the velocity appear as the maxima in the dip-depth space and velocity-depth space after application of the hyperbolic Radon transform to a synthetic record of Figure 12-a.



Java Sea

Figure 8 A real data example of the velocity function and time to depth conversion from a shot record from the Java Sea

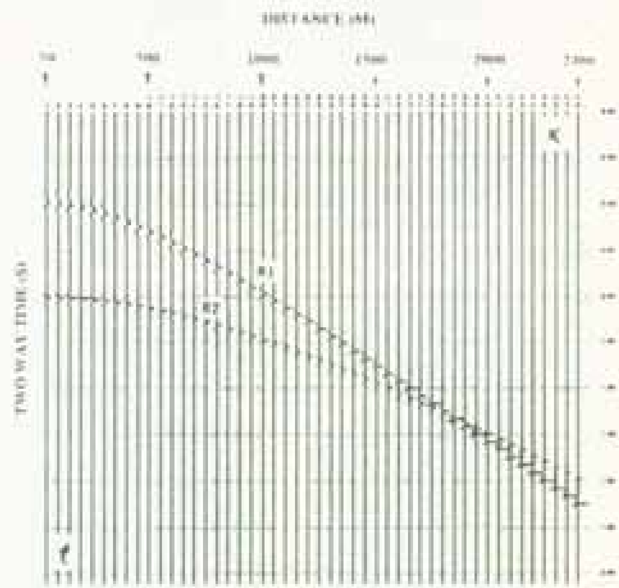


Figure 9 A synthetic example of the multiple elimination using the hyperbolic Radon transform. This result was obtained by erasing peaks M1 and M2 of Figure 4, followed by inverse hyperbolic Radon transform.

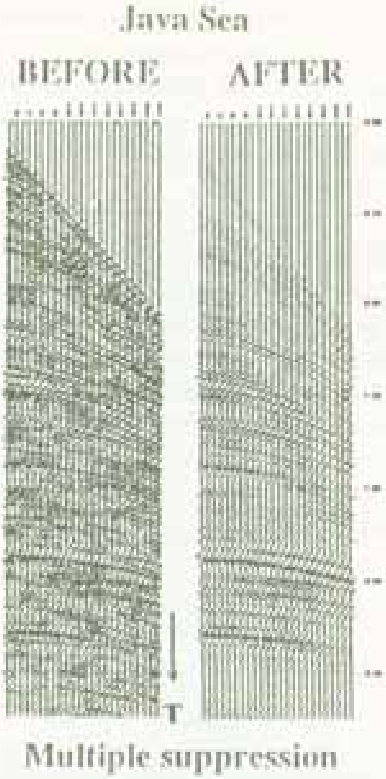


Figure 10. A real example of multiple supression from a shot record from the Java Sea using the hyperbolic Radon transform.

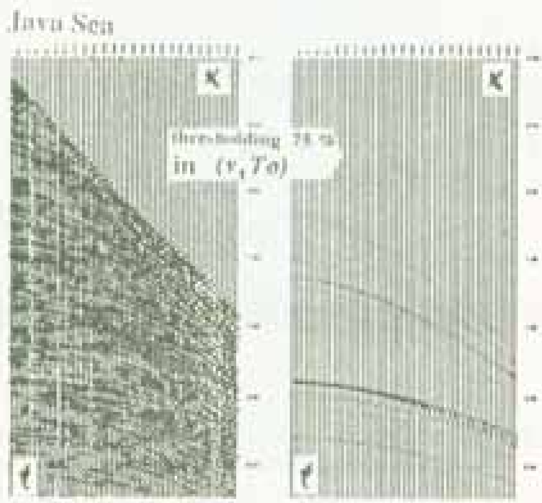


Figure 11. A real example of automatic picking of reflection event from the Java Sea. The picking has been made easy using the hyperbolic Radon transform

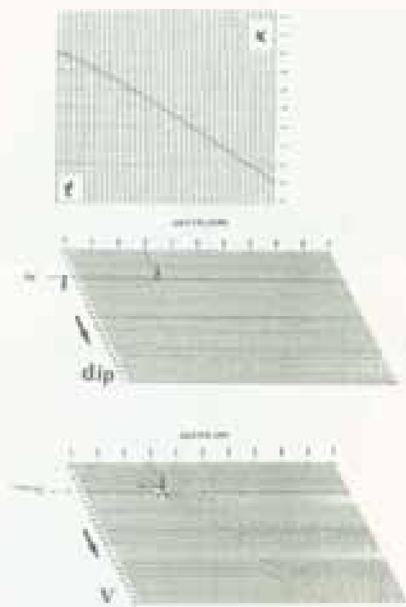


Figure 12 A synthetic example of finding the dip and velocity of the reflection using yhe hyperbolic Radon transform

VII. CONCLUSION

The Radon transform (linear) in exploration seismology is usually referred to as slant stacking. It converts a straight line into a point, an hyperbola into an ellipse, an ellipse into an hyperbola and vice versa.

A modified version of the linear Radon transform, i.e., the hyperbolic Radon transform, has been proposed; it converts an hyperbola into a point. It can play an important role in seismic reflection data processing because reflection moveouts are hyperbolic, so that any process which is based on moveout difference can be executed directly by the hyperbolic Radon transform.

The applications of the hyperbolic Radon transform in velocity analysis, depth conversion, finding the dip of the reflector, multiple identification, suppression/elimination have been proved to be simpler and more efficient than the standard process. The weakness of the hyperbolic Radon transform is that it fails to focus the hyperbolic moveout into a point when the curvature of the hyperbolic moveout is gentle; this is the case for a deep horizon with a high velocity.

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