JOURNAL OF THE CANADIAN SOCIETY OF EXPLORATION GEOPHYSICISTS
VOL. 18, NO. 1 (DEC. 1982), P. 34-42

MULTIPLE REFLECTION ANALYSIS IN T-T SPACE[1]

J.C. PFLUEGER[2]

ABSTRACT

T-T Space is an orthogonal coordinate system defined by the two-way transit times of the two legs of first-order surface multiple reflections. In this "space", starting from a known velocity function, one can map the geometrical properties of multiples: their RMS velocities, moveouts and stack responses. The "maps" also relate the multiple-attenuation property of deconvolution to that of CDP stacking.

The scheme does not predict the presence of multiples; rather it defines their properties if they are present, as an aid to data processing and interpretation.

INTRODUCTION

Multiple reflections may be classified in various ways. One useful method of classification is to sort them into reverberations, surface multiples and interbed multiples (Fig. 1). Of course these catagories overlap. An internal reverberation, for instance, is a special case of a complex interbed multiple. Also, the system comprised of a primary reflection and the first short leg of a surface reverberation can be considered a member of the first-order surface multiple family.

Although multiples of all these classes are present on seismic data as disturbing events, in many cases the severest multiples are near-surface reverberations and first-order surface multiples. This is particularly true in marine work, or in prospects on land where the air-ground interface is flat and exhibits a high acoustic contrast. The diagrams presented in this paper were from a desert prospect that had a particularly severe multiple problem.

T-T Space, as here developed, is directed toward the analysis of first-order surface multiples, which are illustrated in greater detail in Figure 2. As shown there, first-order surface multiples have two legs, not necessarily of equal length, separated by a downward reflection from the surface or near-surface. To establish continuity between primary and multiple reflections, a primary event is considered equivalent to a multiple event with a short-leg transit time of zero.

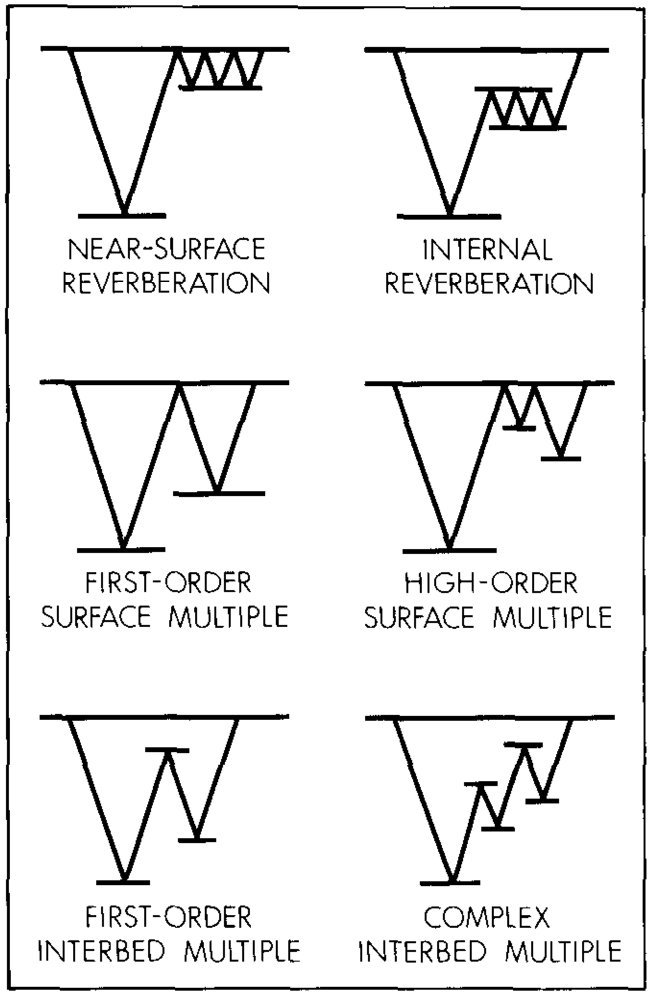

Fig. 1. One system for classifying multiple reflections. There is some overlap between the various classes.

The study from which these data were taken was part of a much larger one dealing with the origin and attenuation of multiple reflections. Regretfully, seismic sections cannot be shown for proprietory reasons.

[1]Presented at the CSEG National Convention, Calgary, Alberta, May 13, 1981.

[2]International Geophysical Consultants Ltd., Calgary, Alberta.

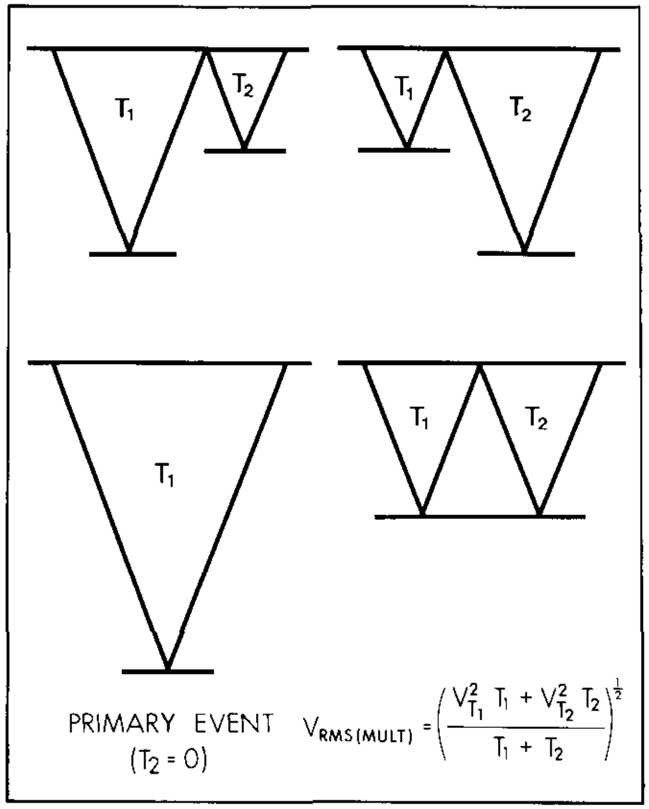

Fig. 2. First-order Surface Multiples. The equation defines their apparent RMS velocities.

Geometry of T-T Space

A coordinate system is set up, as illustrated in Figure 3, with the two-way travel time of the first leg of the multiple (T_1) as the vertical axis, and the two-way travel time of the second leg (T_2) as the horizontal axis. Various single-valued functions can be contoured in this plane. Only an octant of the plane need be shown, as T_1 and T_2 are always positive, and functions are symmetrical about the $T_1 = T_2$ line.

Along the line $T_1 = T_2$, the two legs of a multiple are the same length; that is, the two upward reflections arise from the same interface. Primary reflections lie along the vertical axis ($T_2 = 0$). These are the two extremes of a continuous range of events which range from primary reflections to multiples with equal legs. Most multiples will have unequal legs and will lie in the body of the plane between the two extremes.

Lines drawn up and to the right at 45° from the primary axis represent lines of constant arrival time. Stated another way, a primary event arriving at one second will arrive coincidentally with any multiple for which the transit times for the two legs add up to one second. This obvious property of T-T Space serves as the basis for its utility.

Parameter Mapping

Figure 4 shows the basic parameter which may be mapped in T-T Space, multiple-reflection RMS velocities. The function on the left is from a well survey. In this well, a high-velocity carbonate layer was encountered at about 0.4 s, underlain by softer carbonates of lower velocity, forming an interval velocity inversion. The resultant RMS velocity is almost constant between 0.5 and 1.2 s. By using this velocity and the Dix equation, the RMS velocities of all possible first-order surface multiples were calculated by varying T_1 and T_2 independently. V_{T1} is the primary velocity function evaluated at a record time of T_1, while V_{T2} is the same velocity function evaluated at T_2. In computing V_{MULT}, T_1 and T_2 were varied in even increments; in this case, 10 ms. The resultant RMS velocity values were then posted at their appropriate positions in T-T Space and the field contoured. On the primary (vertical) axis, the contour values agree with the original velocity function.

In the case illustrated in Figure 4, a primary event of significance occurred at one second. From the diagram, at this arrival time, one can see that the multiple velocity decreases from the primary velocity of 10,680 ft/s to a minimum value of 10,040 ft/s, when $T_1 = 0.7$ s and $T_2 = 0.3$ s, then increases to 10,450 ft/s when the two legs are equal.

These extremes define the permissible range of first-order multiple velocities at this arrival time. The multiples may be present or not; no predictive value can be applied to the plot.

Figure 5 carries the analysis a further step. By knowing the effective spread length, the total moveout to

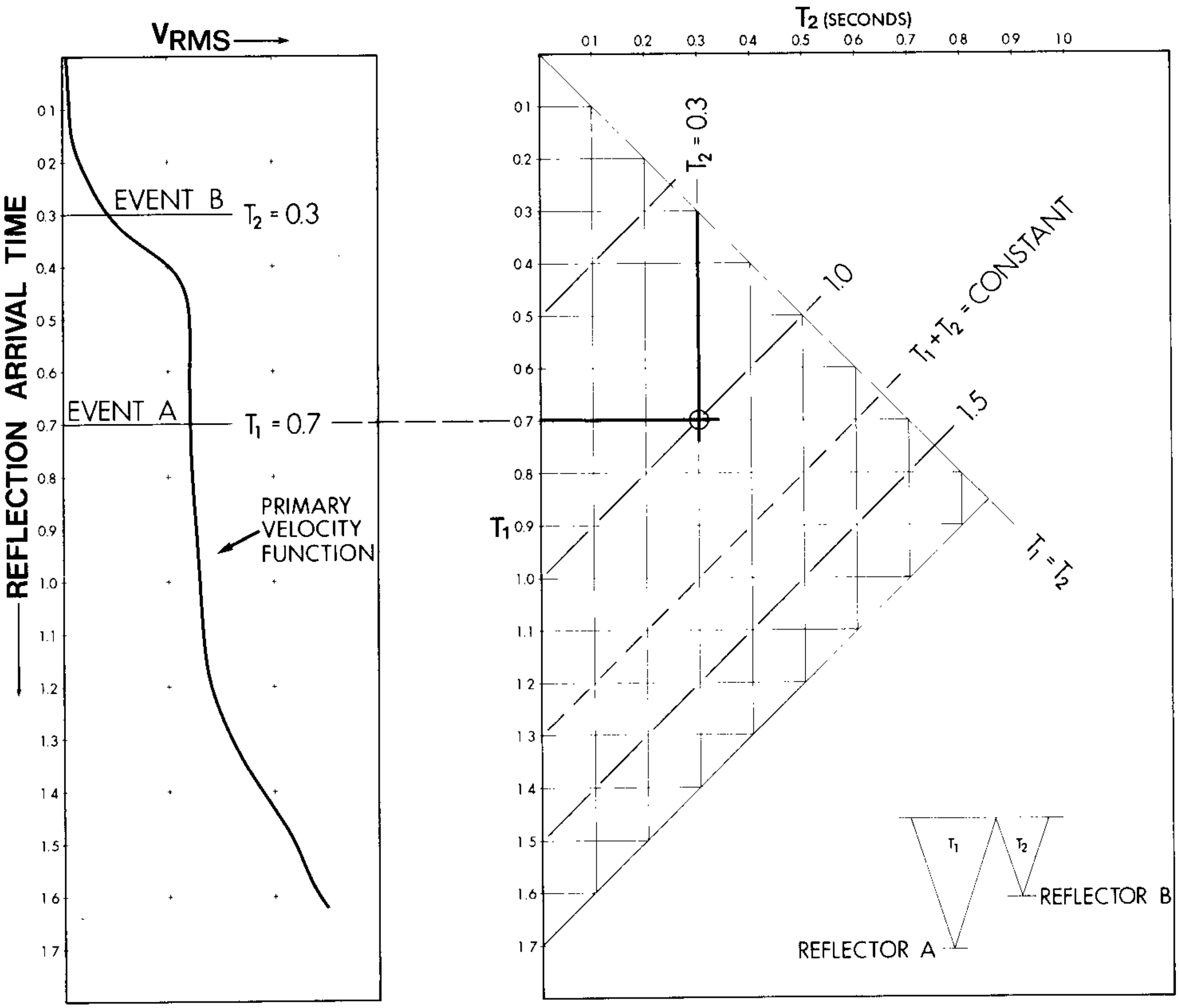

Fig. 3. Geometry of T-T Space. The coordinates are the two-way transit times for the two legs of first-order surface multiples.

the farthest trace can be calculated from the RMS velocity values. The effective spread length, (X_{MUTE}), is not the length of cable on the ground, but is the distance from the shot to the mute cut-off, out to a maximum equal to the physical cable length. The relevant equation is simple:

$$\Delta T_{MULT} = \left[(T_1 + T_2)^2 + \left(\frac{X_{MUTE}}{V_{MULT}}\right)^2\right]^{\frac{1}{2}} - (T_1 + T_2)$$

where X_{MUTE} is defined at each arrival time, which is the sum of T_1 and T_2.

The above equation illustrates that moveout always decreases with increasing record time and always increases with increasing effective spread length. In the example shown on Figure 5, the moveout increase due to the increase of effective spread length more than compensates for the moveout decrease with increasing arrival time, resulting in a "map" that shows moveout continuously increasing to a maximum value at the maximum arrival time. In this example, the effective spread length never reached the physical spread length because of the mute cut-off, to the maximum record time measured by the well survey.

Figure 5 is only a way-station on the road to Figure 6. To arrive at Figure 6, total moveout values along the primary axis have been subtracted from multiple-moveout values for all arrival times. As an example, .160 s was subtracted from all values underlying the $T_1 + T_2 = 1.0$ s line of Figure 5 to yield the values at 1.0 s for Figure 6.

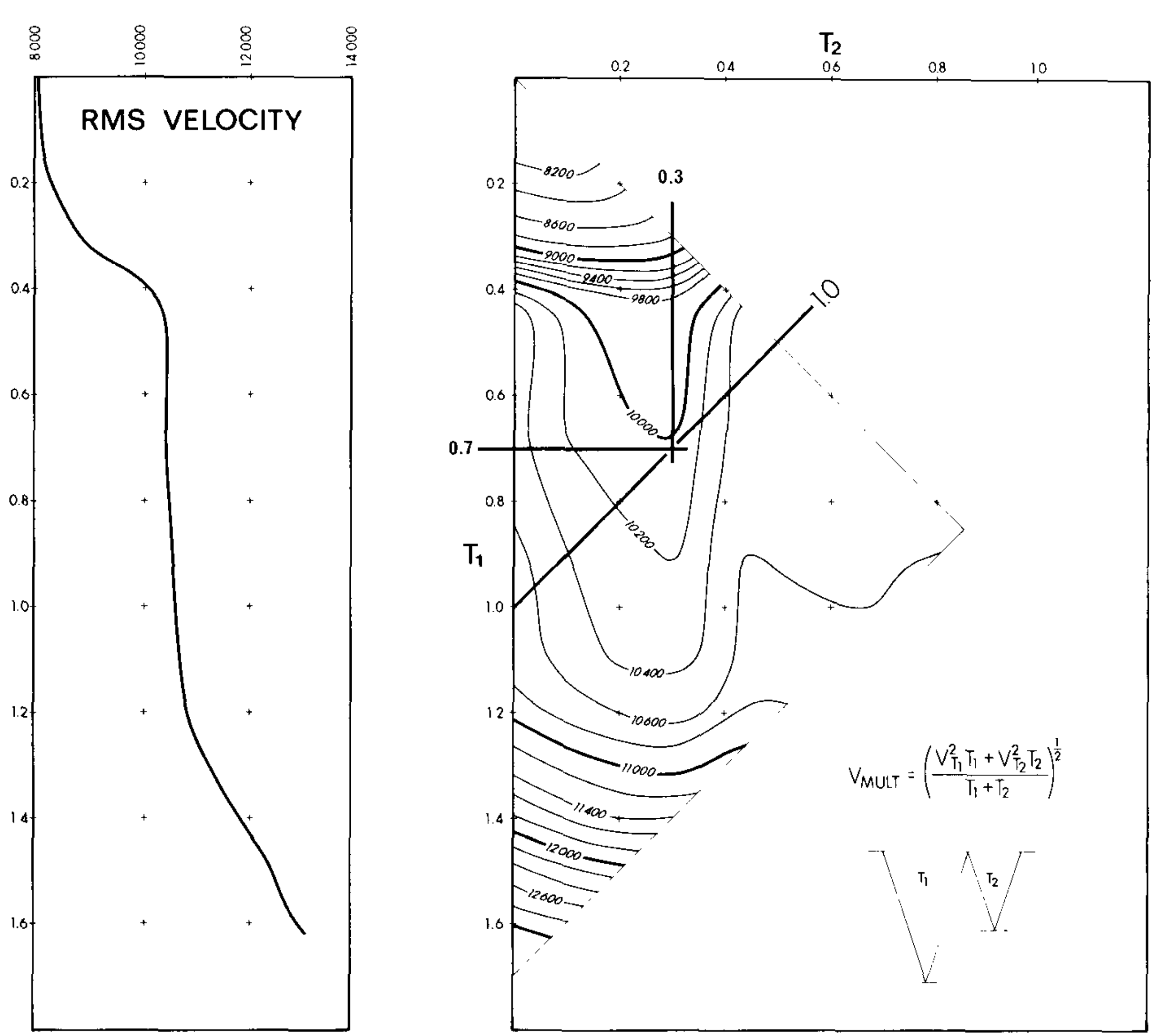

Fig. 4. RMS Velocities of first-order surface multiples; Well No. 1.

From Figure 6 we can see that, if data have been appropriately corrected for the primary velocity function, the maximum residual moveout we can expect for first-order surface multiples is 20 ms at an arrival time of 1.0 s.

Figure 6 might be a good stopping place in that it displays, in an easily understandable fashion, what the multiple problems for a given velocity function could be. However, one additional display may be developed, that of "stack response."

Stack response, in the general case, is defined as the output resulting from adding a number of CDP input traces, each of which has been excited by a unit impulse. Seismic reflections are never unit impulses, however, and a more realistic definition of stack response is to consider it as the summation output from exciting the input traces with a simple band-limited wavelet, such as the zero-phase wavelet shown in the inset of Figure 7. As it is impossible to depict the details of the output wavelet by using only T_1-T_2 coordinates, the "Maximum Stack Response" is further restricted to be the greatest amplitude, in absolute value, of the output wavelet. To determine the Maximum Stack Response at a given point in T-T Space, the spread geometry (trace spacing, minimum offset and effective spread length) must be specified as well as the correction velocity applied and the multiple reflection RMS velocity. It is convenient to express the Maximum Stack Response in db down from the response of the CDP system to a perfectly corrected event.

Using this definition and the appropriate field parameters, the "Maximum Stack Responses" for events

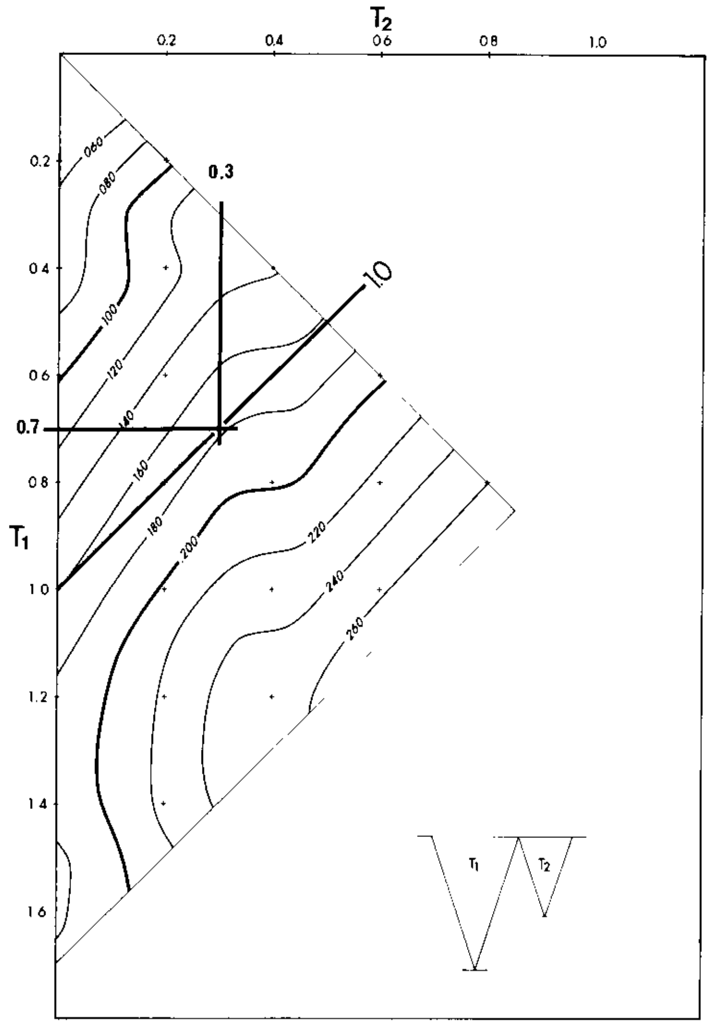

Fig. 5. Total Moveout to Mute for first-order surface multiples; Well No. 1.

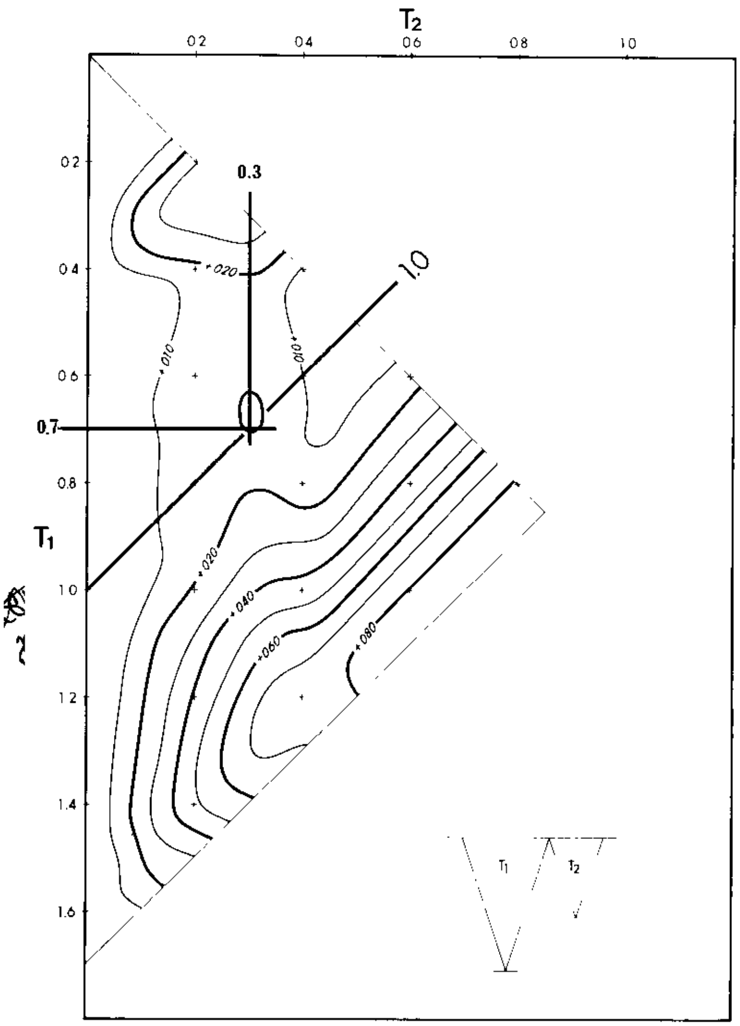

Fig. 6. Residual Moveout to Mute for first-order surface multiples; Well No. 1.

after correcting for the primary velocity function were calculated from Figure 6 to yield Figure 7. A multiple arriving at one second with T_1, T_2 values of 0.7, 0.3 would undergo 6 db attenuation, not a large amount if the multiple had high amplitude going into the stack. All other multiples arriving at this time would be attenuated to a lesser degree. The zero attenuation contour is coincident with the primary axis, since events along this axis are presumed to be perfectly flat entering the stack.

Other Examples

The study that resulted in the development of this geometry for multiple analysis was done in a sparsely explored basin which exhibited very strong and persistent multiple reflections.

Well 2 is about 80 km from Well 1 with no well control between. The first high-velocity carbonate decreases in depth from Well 1 until at Well 2 it is at a seismic time of only 0.2 s. Figure 8 shows the primary RMS velocity function for Well 2 along with the resultant residual moveout plot. This plot diagrams a truly intractable problem for the attenuation of multiples through stacking, as a large portion of the T-T plane exhibits negative residual moveout. Moreover, with this type of function, determining the primary velocity from analysis of the seismic data becomes a very difficult and unreliable exercise. Before this plot was produced, it was known that the multiples could not be stacked out, but it was not known why they could not. Fortunately, velocity functions with this shape are rare on a worldwide basis.

Figure 9 is an example of a T-T plot taken from a seismic velocity study made about midway between Wells 1 and 2. In this area a strong multiple exists with a T_1 leg of 0.54 s and a T_2 leg of 0.32 s, arriving at 0.86 s. As it has a residual moveout of only 10 ms, it passes through the stacking process virtually unscathed to distort or obliterate Event C, a structurally significant primary event. On Line X, the stacked seismic data exhibited many events in the time interval between 0.8 and 1.25 s. The T-T plot shows that in this interval the

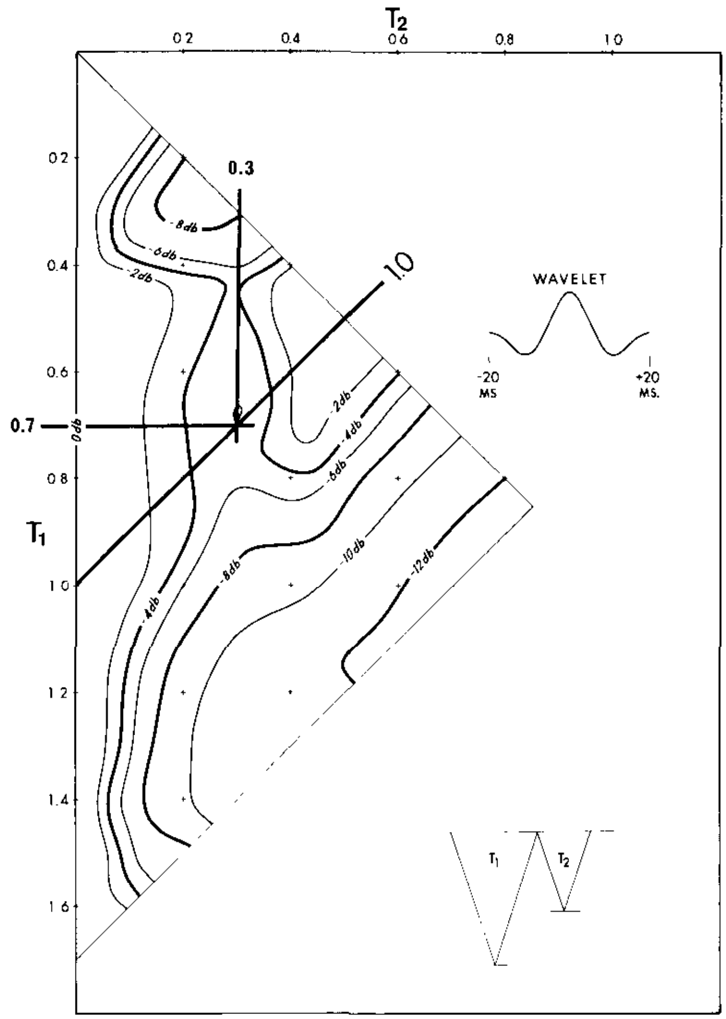

Fig. 7. Maximum Stack Response for first-order surface multiples after correcting data for the primary velocity funciton; Well No. 1. The hypothetical zero-phase input wavelet used for computing the response is shown.

multiple residual moveout was essentially zero, and most of the observed events were unquestionably multiples. Below 1.25 s, multiple residual moveout increased, and fewer events passed through the stack, including several clean, mappable primary reflections. This line was an example where the multiple reflection content of the data after stacking decreased with increasing record time, contrary to the usual situation.

Deconvolution

Throughout this development, no attention has been directed to the portion of the T-T plane close to the primary axis, although it is apparent from the diagrams that residual moveout in this region is always very small. Fortunately, stacking is not the only available method for attacking multiples. When T_2 is small, a first-order surface multiple can be considered part of a near-surface reverberatory sequence, and should be attenuated through deconvolution. Figure 10 redisplays Figure 9 with the addition of the effect of deconvolution on the data. In this example deconvolution should effect good attenuation of multiples with T_2 legs smaller than .14 s (or half the length of the deconvolution operator), and some, but less, attenuation of events with T_2 legs between .14 and .28 s. The multiples in the rest of the T-T plane must be attenuated by stacking techniques, if they can be attenuated at all. The strong multiple arriving at 0.86 s (shown by a circle on Figure 10) is unaffected by a 0.280 s deconvolution operator because the transit time for the short leg exceeds the operator length.

In a sense, T-T Space geometry provides a "bridge" between the effect of deconvolution and that of stacking on multiple attenuation.

Conclusions

Multiple-reflection analysis in T-T Space is no cure-all. Firstly, it deals with only one class of events,

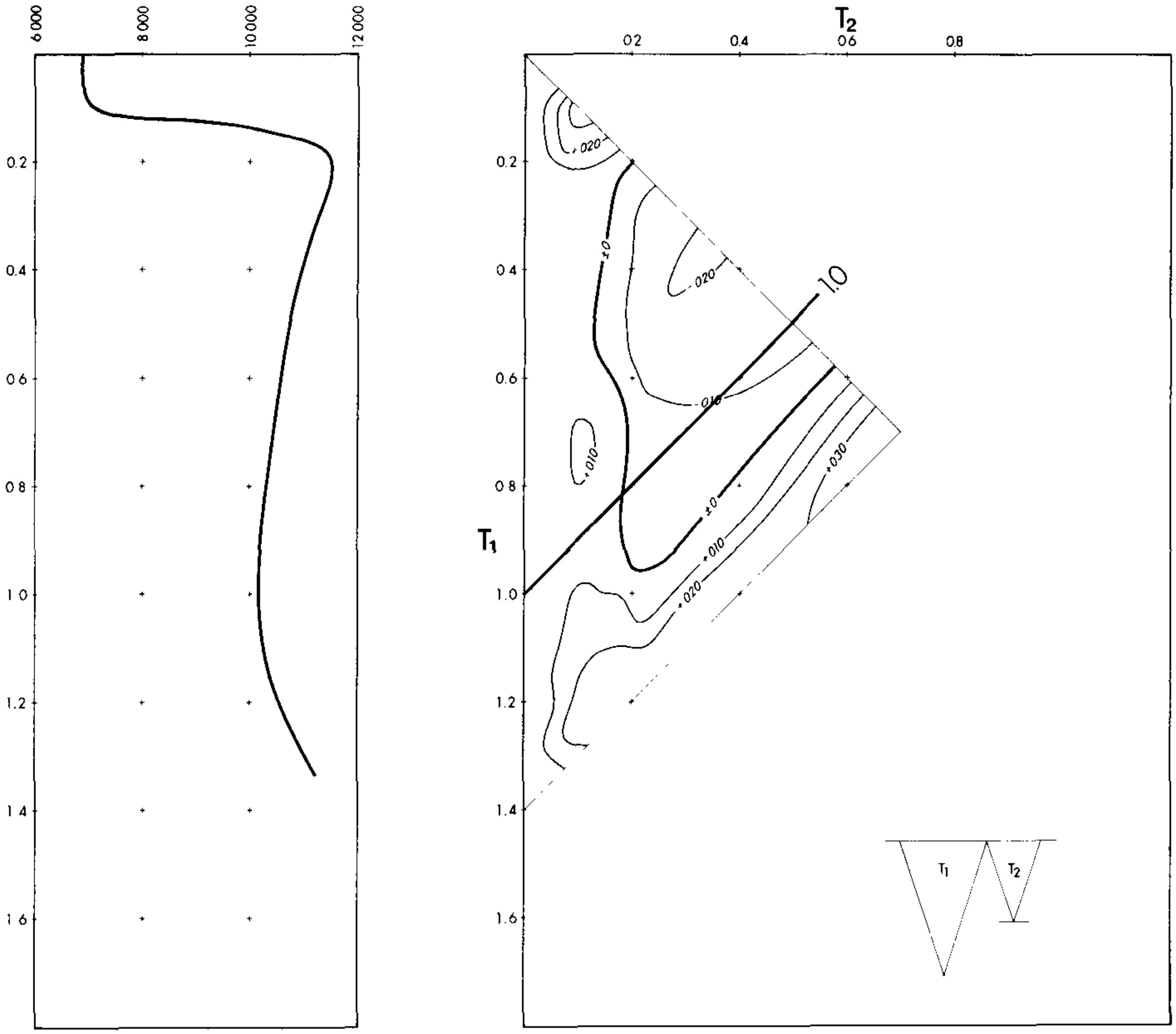

Fig. 8. LEFT: RMS Velocity measured in Well No. 2. RIGHT: Residual Moveout to Mute for first-order surface multiples; Well No. 2. Note the large area of negative residual moveout.

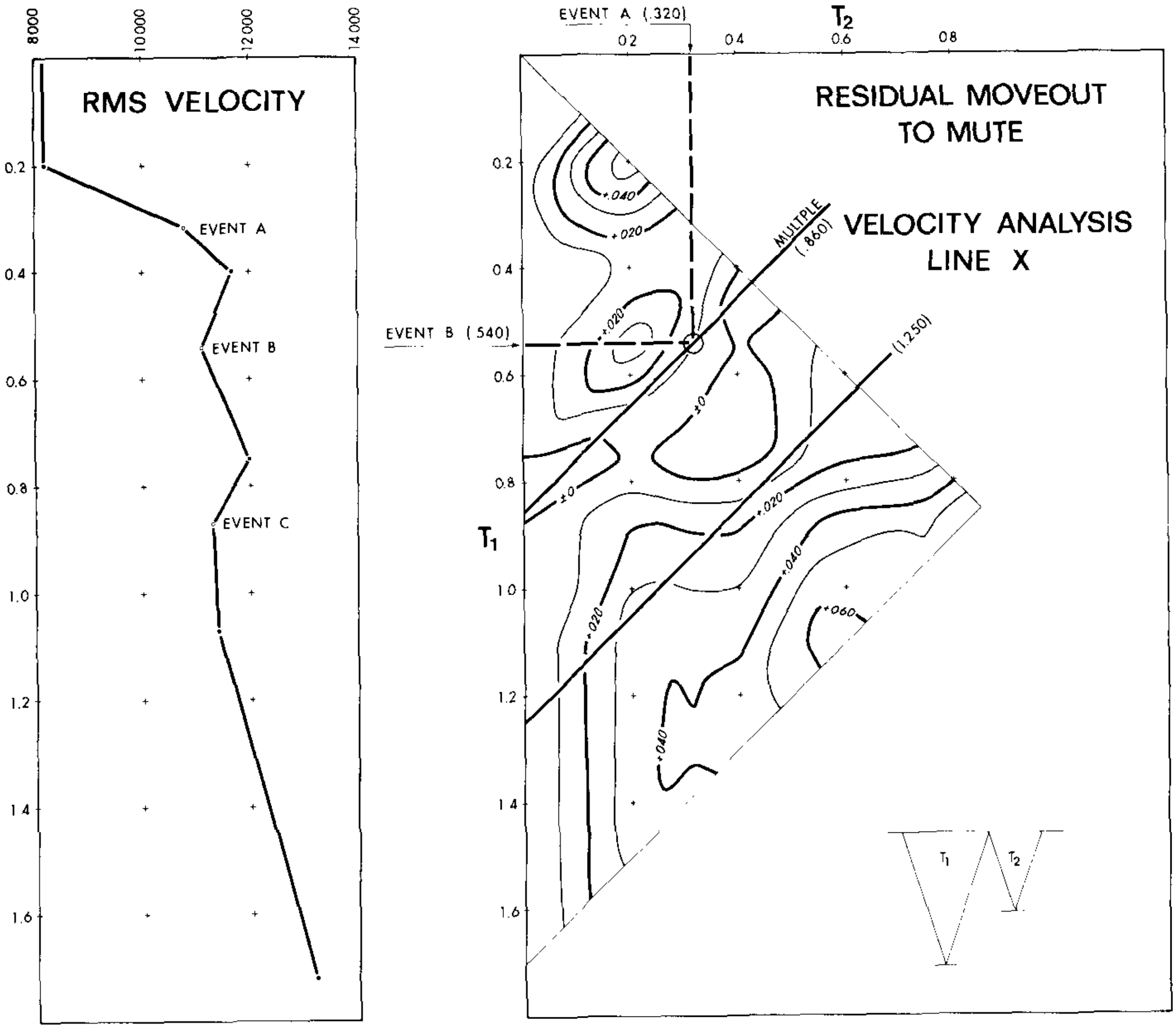

Fig. 9. LEFT: RMS Velocity measured from seismic data on Line X. RIGHT: Residual Moveout to Mute for first-order surface multiples; Line X. Note the areas of zero or slightly negative residual moveout.

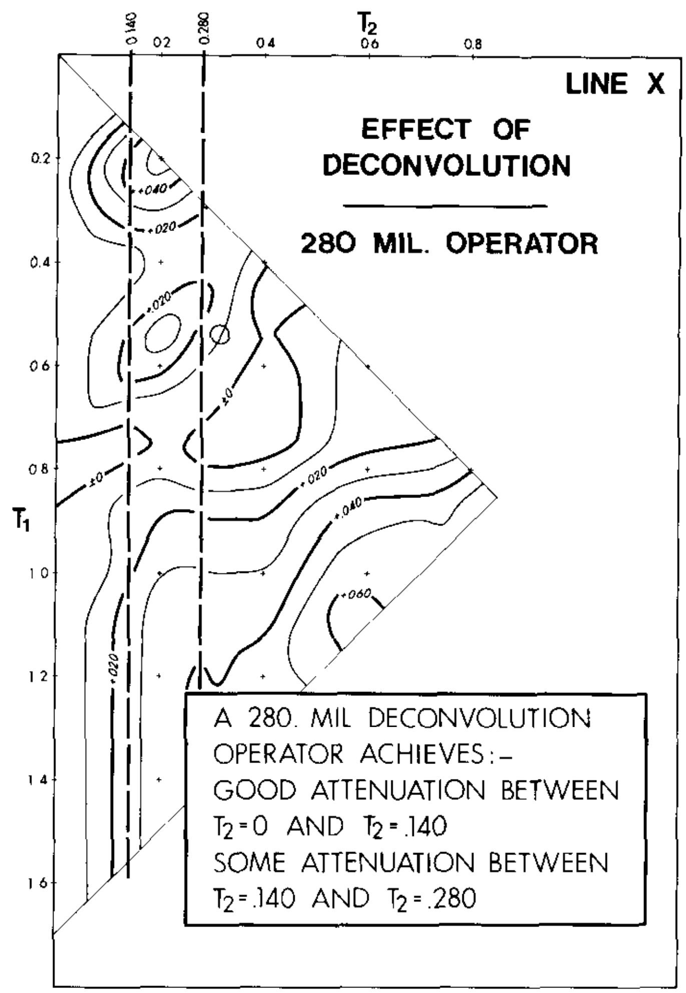

Fig. 10. The effect of deconvolution on multiple reflections, expressed in the T-T plane.

first-order surface multiples. Secondly, it offers no predictive value as to which multiples are present.

In spite of its limitations, however, it can be a useful tool. Should first-order surface multiples be a major problem on a prospect, it affords a means of displaying all the relevant multiple parameters in a concise, readily digestible form. Moreover, it is "quick and dirty". All the T-T diagrams illustrated in this paper were originally computer-generated and -contoured, with redrafting only for clarity.

After the initial software has been coded, the plots can be produced with minimum effort along with the generation of synthetic seismograms. They can be of value to the data-processing staff, in that they provide a bridge between what can be accomplished through deconvolution and what must be achieved through stacking.

Finally, if an interpreter observes on a T-T plot an arrival-time interval where residual multiple moveout is small, say below .020 s, he should be alerted that strong, continuous multiple reflections may be present, which could be easily mistaken for primary reflections.