Reflected refracted events on seismic sections

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Refracted rays do not normally produce events on seismic sections. Muting before stacking is designed to remove any far-trace arrivals due to refracted rays travelling along a high velocity layer, but if these same rays are reflected at a discontinuity in the high velocity interface they can produce events in the record. Here we will consider as reflected refractors those rays which retrace their path in the refracting medium, returning to the surface along a path parallel and near to their outgoing path. Figure 1(a) shows the simple case. Where the head ray is reflected back into the refracting medium, as in Fig. 1(c), the resulting seismic record is indistinguishable. Multiple events with a refractor component (Fig. 1b) will not be discussed.

Before the introduction of common depth point (CDP) stacking in exploration seismology, reflected refracted events were occasionally identified in the seismic record, and several case histories have been published. A full discussion is given in Brauch (1958) and Seabrooke (1961). In a CDP gather, provided the ray remains in the plane of the seismic array and that plane intersects the refractor in a straight line, there will be no move-out on the event, and where the applied move-out correction is small such an event will appear in the stacked section. Reflected refracted events then are likely when using a short cable, or, if using a long cable, at the top of the record where because of severe muting only a few traces are included in the stack or deep in the section where long travel times are involved. If the ray path is not confined to a plane through the cable or if the refractor does not intersect that plane in a straight line, the event will show move-out in the gather and applying a normal move-out correction may lead to enhancement through stacking. However, only when the ray remains in the plane through the cable (normally vertical or near vertical) is there likely to be significant energy returned along the length of the spread: in this case a curved refractor concave downwards will have a move-out similar to normal move-out in a CDP gather and the event may appear prominent in the section.

If the refractor is non-planar, its structure will be repeated in changes in the slope of the reflected refracted event (Fitch 1976). For a planar refractor, the reflected refracted event will be a straight line, and we will show here that in some cases such an event may be distinguished from a reflection from a plane by its slope on the seismic section. Consider the case of a refracting plane (horizontal or dipping) cut along strike by a linear discontinuity, a situation that frequently occurs when high velocity layers are faulted at the edge of a sedimentary basin. If the sediments are downthrown relative to the flanks of the basin, reflected refracted events will be produced which dip towards the basin centre.

Assuming the simple geometry of Fig. 2, the event could be mapped as though it were a geological horizon and it can be shown that the separation $S$ of two-way travel time isochrons would be given by

$$2S = V_1 V_2 \frac{\sin \theta \sin \phi \times \cos \theta \cos \phi}{V_2 \sin \theta + V_1 \cos \phi}$$

where $S =$ distance in km between one second isochrons; $V_2 =$ velocity of refractor; $V_1 =$ velocity of medium. 

Fig. 3. Separation of one second contours (S) as a function of angle of dip of the refractor (θ) for different refractor velocities (V₁) and different velocities of rocks above the refractor (V₂). Negative values of θ correspond to the case where the discontinuity is down-dip of the source and receiver, and positive values of θ when up-dip.

For a given upper medium velocity (V₁), Fig. 3 shows how the separation of the isochrons (S) varies with the dip of the refractor for different values of refractor velocity. In each case the contour separation is less than half the refractor velocity when the discontinuity is up-dip of the source and receiver, and greater than half the refractor velocity when down-dip.

For comparison, Fig. 5 shows how the slope of an event produced by a reflector (Fig. 4) varies with the dip of the reflector for different velocities of the medium above. Except at very low velocities, the slope of the event on the seismic section will be shallower than 1/3 km sec⁻¹ for low angles of dip. That is, the 1 sec isochrons will be more widely spaced than 3 km for most practical velocities and dips likely to produce events in seismic sections. In contrast, S is less than 4 km for the majority of cases which give rise to a reflected refracted event, so
in many cases it should be possible to distinguish between the two types of event, provided an event can be identified on at least two seismic lines so that an estimate of S can be made.

Ray theory predicts that the refracted ray will be reflected back along its path only when the fault plane is perpendicular to the refractor. Model experiments by Von Guha (1966) and Koefoed, van Ewyk and Bakker (1958), however, and calculations based on Fresnel diffraction theory, show that this is not so, although the amplitude of the reflected ray is reduced when the fault is not perpendicular to the refractor.
The only other phenomenon likely to be confused with a reflected refracted event is the envelope of a series of diffractions. Although individual diffractions are readily identified by their distinctive curvature, one may imagine a situation where a steeply dipping fault plane generates a large number of diffractions which interfere with each other to produce no events, except on the edge of the envelope where only one diffraction is present. The slope of the envelope will depend on the slope of the fault plane and the velocities of the rocks, and in many cases the flanks of the envelope may be approximately linear.

Figure 6 shows strata terminating against the Oygarden Fault Zone on the eastern edge of the Horda Platform under the Norwegian sector of the North Sea. The strong, steeply inclined event A in the centre of the picture is interpreted as a refraction in horizon B which has been reflected at the fault. The other steeply dipping events are diffractions, and multiple diffractions, from reflectors ending at the fault. The top of the basement is at C.

A seismic section from the margins of a sedimentary basin is reproduced in Fig. 7 and shows several events below the top of the basement. A is a reflected refracted event from either the top of the basement (B) or from the strong reflector C. Superimposed on A is the diffraction D. E is believed to be the reflection from the sole plane of a nappe succession, and reflections from other thrust planes may be seen parallel to and above E. F is a diffraction from a discontinuity in the sole plane. From our interpretation of parallel lines, we believe that reflected refracted events may be distinguished on character from primary reflectors in the basement by being continuous, straight, and having a moderately high frequency with only one or two cycles.

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References