

# Converted-wave prestack time migration with a new approximate migration weight

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## Summary

A new approximate migration weight is described for Kirchhoff migration of converted-wave data. As with previous approximations it is based on the exact weight for a homogeneous medium. However, rather than assuming equality of travel path distances from source to image point and image point to receiver, it assumes that the total traveltimes is partitioned in a way consistent with common-conversion point reflection. The described approximation results in an efficient approach with no evaluations within the inner migration loop. Application of this new migration weight in prestack time migration of typical multicomponent land data shows that it yields migrated stacks and gathers very similar to those obtained using the exact homogeneous migration weight, and superior to those obtained using migration weights borrowed from P-wave migration theory, particularly in the near-surface region. In the case of migrated gathers, the improvement can be sufficient to make post-migration AVO analysis more feasible.

## Introduction

Large volumes of multicomponent data have been and are being collected every day. The potential of these data is enticing, but reality dictates that the geophysical community learn to use them one step at a time, as has been the pattern with compressional wave data over many decades. Through consistent effort the value of multicomponent data sets has become more evident, and at present the prestack time migration of reasonably flat geology has become a standard deliverable for a number of vendors. Even so, improvements are still possible, as described in the present study.

Essential to the proper treatment of amplitudes in migration is incorporation of proper migration weights; however these can be expensive to apply, requiring evaluation inside the inner loops of Kirchhoff migration. For P-waves an approximate method which balances efficiency and accuracy was presented by Dellinger et al. (2000) and Zhang et al. (2000), and this is in common use throughout the industry. Miao et al. (2005) presented an extension of the exact migration weight for PS data collected from horizontally layered media, and also sought to develop an efficient and accurate approximation similar to that used in the P-wave case. Their analysis did not examine the issue in detail however, and a more satisfying and optimal approximation is still desired.

In this work we review the strategy of migration weight approximation and present a new approximation for converted-wave migration weights which achieves the same degree of accuracy as current approximations in use for P-wave migration. Impulse responses as well as migrations to stacks and gathers are used to illustrate the value of this new method.

## Theory of approximate PS migration weights

**Review of PP case:** Zhang et al. (2000) show that in a constant velocity medium, the weight for a 3D common-offset prestack Kirchhoff migration of PP data is

$$\frac{z}{v^2} \left( \frac{t_s}{t_r} + \frac{t_r}{t_s} \right) \left( \frac{1}{t_r} + \frac{1}{t_s} \right) \quad (1)$$

with symbols defined in Figure 1. This expression must be evaluated in the inner migration loop in order to have access to the values of  $t_r$  and  $t_s$ , so it is time-consuming.

Following Dellinger (2000), Zhang et al. (2000) approximate  $t_r = t_s = t/2$ , which is exactly true for either zero-dip or for zero-offset configurations. This assumes that the weight can be approximated by the value it would have if it were a CMP reflection or if the source and receiver are at the equivalent offset position, as illustrated in Figure 1. The weight above in eq. 1 then simplifies to

$$\frac{8z}{v^2 t} = \frac{8}{v^2 t} \frac{t_0}{2v} = \frac{4t_0}{v^3 t} \quad (2)$$

The first quantity in eq. 2 is for depth migration while the last is for time migration. The  $1/t$  factor of the approximation can be applied to the input before the migration loops and the  $z$  or  $t_0$  factor can be applied to the image after the migration loops, so the additional time required for weighting is now negligible.

This is a good approximation for geologies which are largely horizontal as the CMP configuration makes the dominant contribution to the image, and in this approximation the CMP configuration is weighted correctly.

**PS case:** The exact constant-velocity weight for PS migration, analogous to eq. 1, can be obtained beginning with the expression for the horizontal layering case in Miao et al. (2005) and simplifying it for the case of a homogeneous medium. Like eq. 1 the resulting expression must again be evaluated in the inner migration loop; however it is more complicated than the PP expression, so that it would be even more time-consuming to apply.

Miao et al. (2005) suggest that the PS weight could be approximated following the same practice as in the PP case. Presumably they refer to the fact that in the CMP geometry (i.e.,  $t_r/t_s = v_p/v_s = \gamma$  so that the length of the P-wave leg,  $t_s v_p$ , is equal to that of the S-wave leg,  $t_r v_s$ ;  $v_p, v_s$  are P-wave and S-wave velocities) the PS weight is simplified to an expression of the same form as eq. 2, i.e., with  $8/v^2$  replaced by the constant factor  $(\sqrt{\gamma} + 1/\sqrt{\gamma})^2 / (v_p v_s)$ . We refer to this as the midpoint weight approximation (MPWA). However the CMP geometry of Figure 1 does not make the principal contribution to the image in PS migration, so the MPWA is not an ideal approximation for the PS case. For a largely horizontal geology the principal contribution to the image comes from the CCP (common

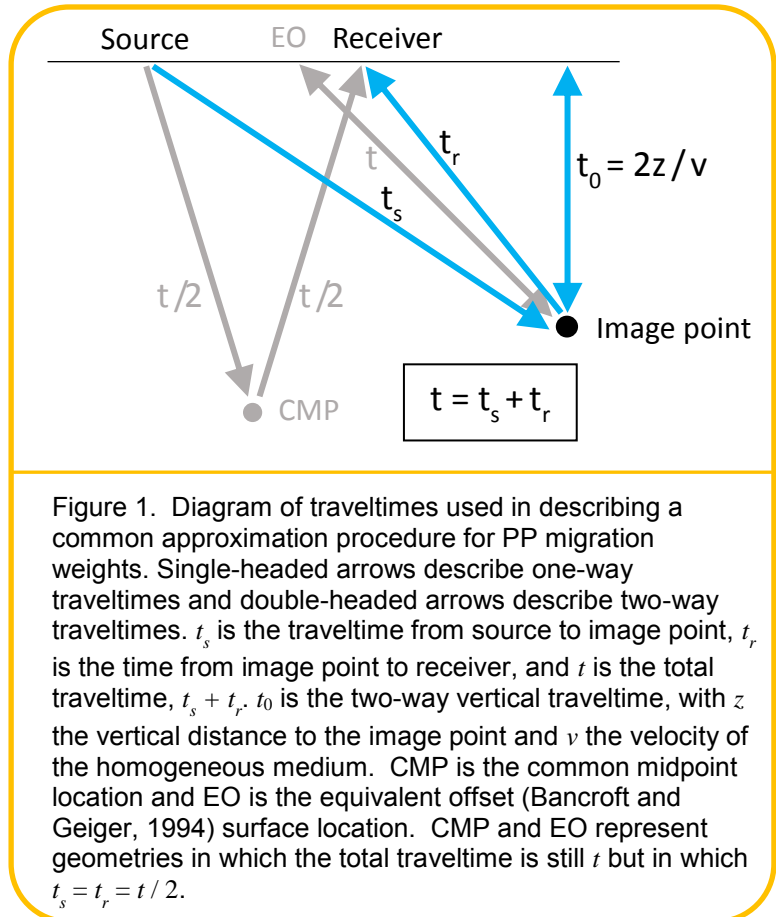


Figure 1. Diagram of traveltimes used in describing a common approximation procedure for PP migration weights. Single-headed arrows describe one-way traveltimes and double-headed arrows describe two-way traveltimes.  $t_s$  is the traveltime from source to image point,  $t_r$  is the time from image point to receiver, and  $t$  is the total traveltime,  $t_s + t_r$ .  $t_0$  is the two-way vertical traveltime, with  $z$  the vertical distance to the image point and  $v$  the velocity of the homogeneous medium. CMP is the common midpoint location and EO is the equivalent offset (Bancroft and Geiger, 1994) surface location. CMP and EO represent geometries in which the total traveltime is still  $t$  but in which  $t_s = t_r = t/2$ .

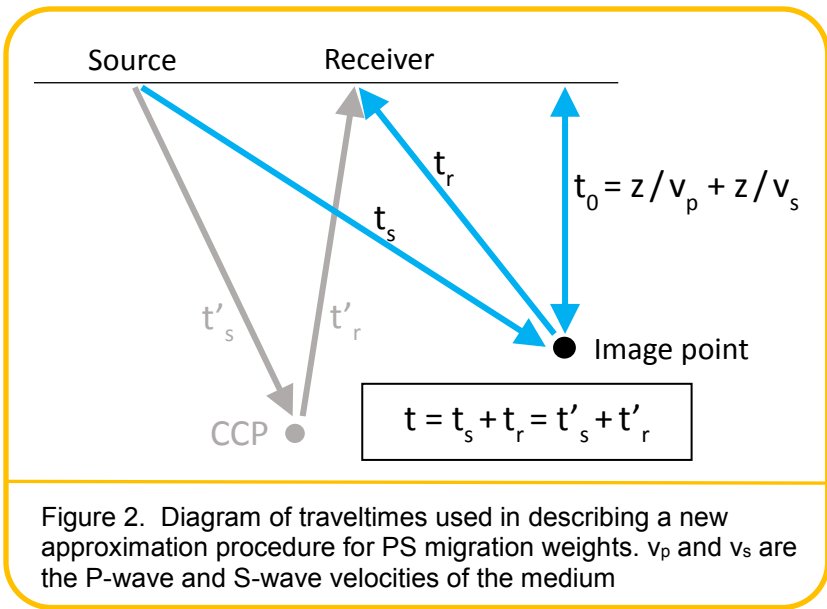


Figure 2. Diagram of traveltimes used in describing a new approximation procedure for PS migration weights.  $v_p$  and  $v_s$  are the P-wave and S-wave velocities of the medium

conversion point) reflections illustrated in Figure 2. The purpose of this abstract is to describe a new migration weight approximation which is as accurate for PS data as eq. 2 is for PP data.

The general strategy of the approximation, which we refer to as the CPWA (conversion point weight approximation), is very simple, namely, to set  $t_r$  and  $t_s$  to values which sum to the original total traveltime  $t$ , but which correspond to a CCP reflection. This requires solving a cubic equation, but this can be done outside the inner loop and is thus still not a burden in terms of computing time.

### Examples of prestack time migration with approximate and exact weights

In this section we demonstrate the effect of choosing either the MPWA or CPWA in converted-wave prestack time migration. We illustrate this with i) single-trace responses, ii) migrated stacks, and iii) migrated gathers.

All examples are from the Firestone 3C-2D dataset, shown by the red line in Figure 3 at right. These data were collected in February 2013 from both vibroseis and dynamite sources with 110 ft. source interval and 55 ft. receiver interval.

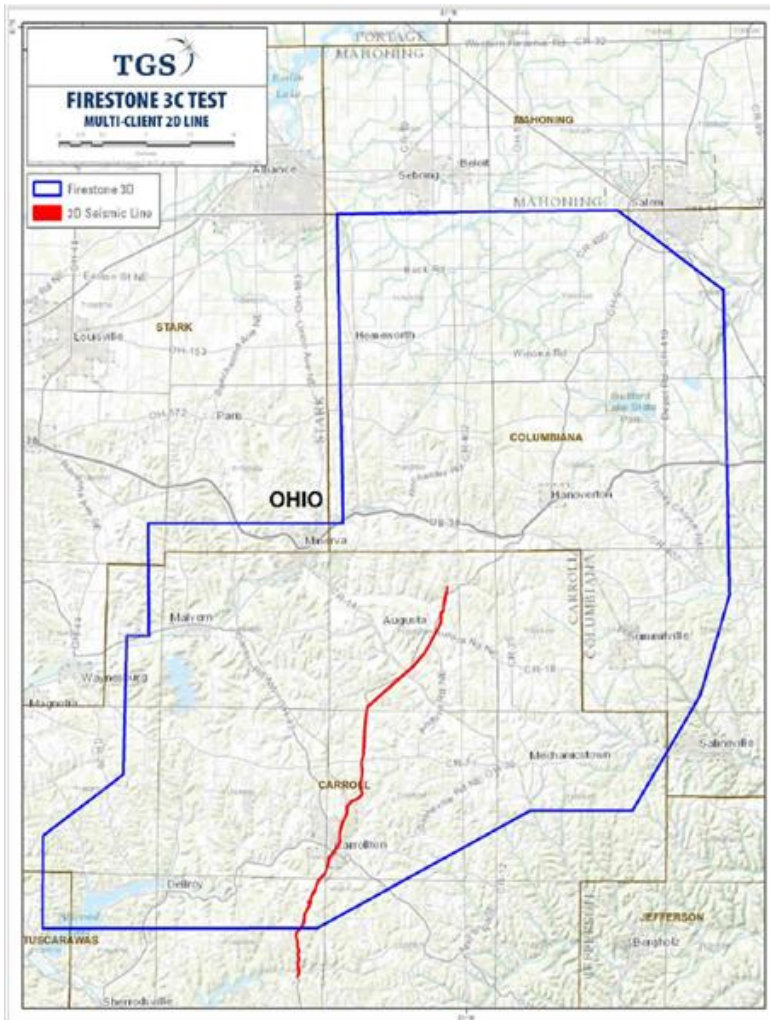


Figure 3. Map view of the Firestone 3C-2D survey shown by the red line. Examples below were obtained using this dataset.

**Single-trace responses.** Figure 4a illustrates migration of a single trace using the exact homogeneous weight obtained from Miao et al. (2005). Figure 4b shows the difference between Figure 4a and the analogous result obtained using the MPWA weight (which is of a similar form to the PP weight in eq. 2). As expected, for all times they are equal at the midpoint of the trace. However the difference between Figure 4a and the CPWA result shows that the position at which they are equal varies with time, tracing out the locus of CCPs. These results suggest that for the final migration products the CPWA will have its greatest advantage over the MPWA in the near surface.

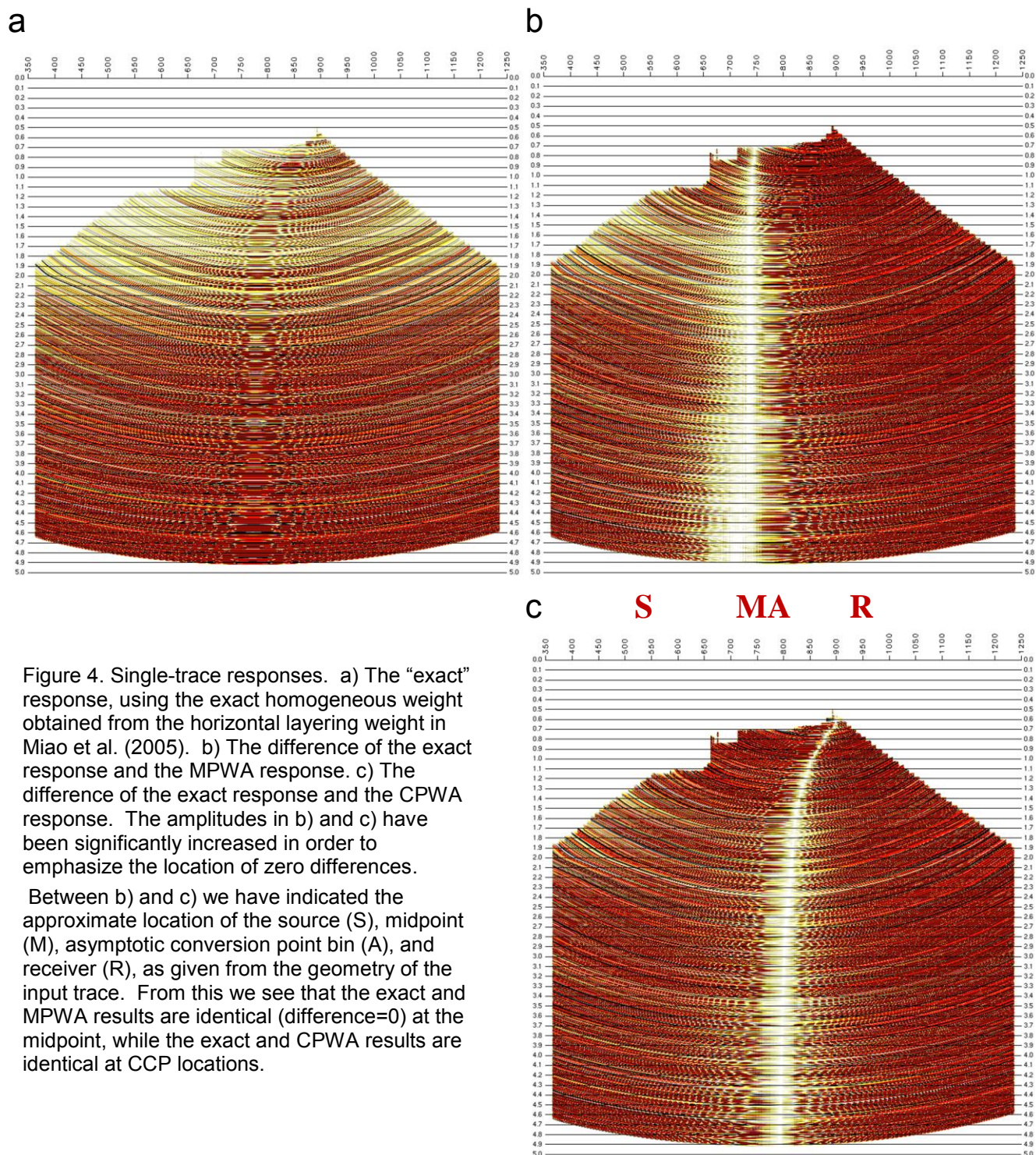


Figure 4. Single-trace responses. a) The “exact” response, using the exact homogeneous weight obtained from the horizontal layering weight in Miao et al. (2005). b) The difference of the exact response and the MPWA response. c) The difference of the exact response and the CPWA response. The amplitudes in b) and c) have been significantly increased in order to emphasize the location of zero differences.

Between b) and c) we have indicated the approximate location of the source (S), midpoint (M), asymptotic conversion point bin (A), and receiver (R), as given from the geometry of the input trace. From this we see that the exact and MPWA results are identical (difference=0) at the midpoint, while the exact and CPWA results are identical at CCP locations.

**Migrated stacks.** Figure 5 shows near-surface detail of the migrated stacks. As anticipated from the single-trace responses, the CPWA result is superior to the MPWA result in this region. At later times the results are more similar.

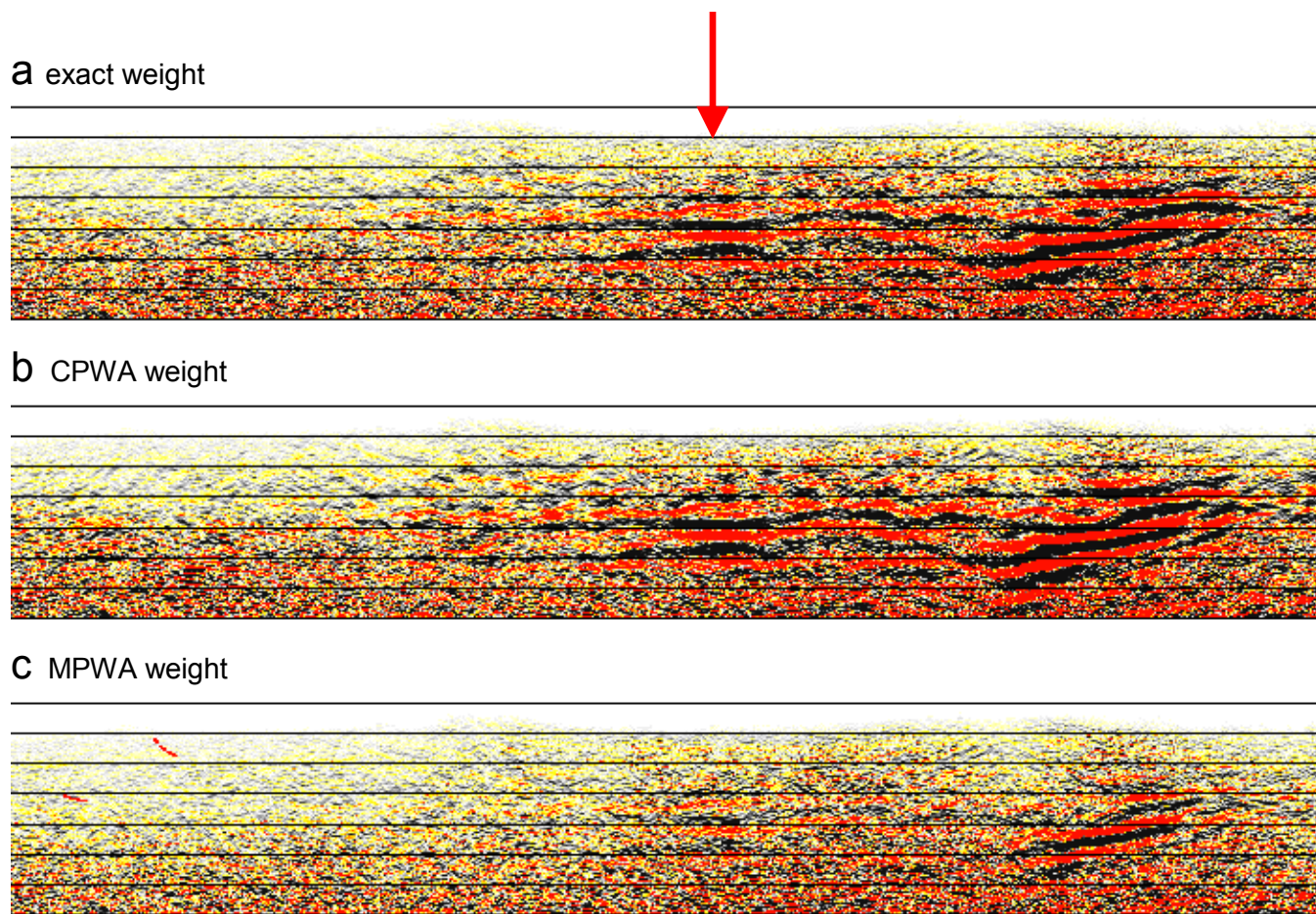


Figure 5. Near-surface detail of the a) exact, b) CPWA, and c) MPWA migrated stacks. The vertical time scale is from 0.0 – 0.7 s. The red arrow at top indicates the location of the migrated gather displayed in Figure 6.

**Migrated gathers.** Figure 6 shows near-surface detail of a single migrated gather. Both the MPWA and CPWA are most accurate at short offsets, but only the CPWA result would be viable for use in a post-migration AVO analysis. At later times the three results become more similar.

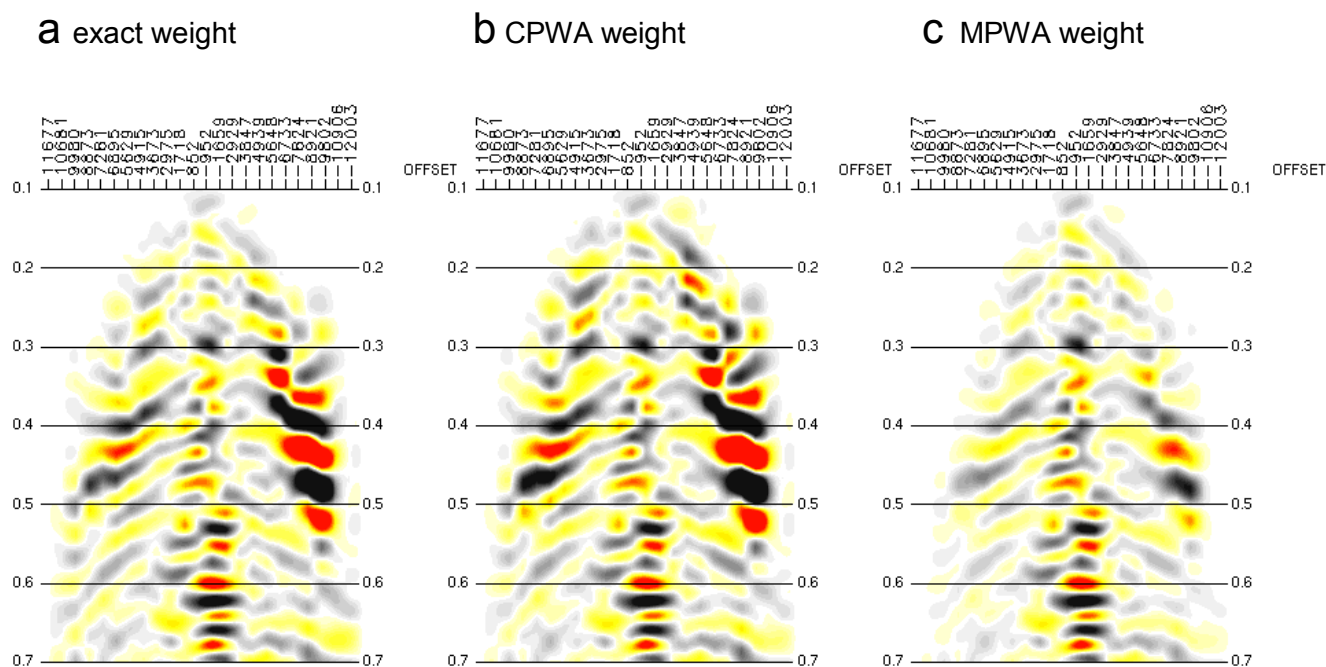


Figure 6. Near-surface detail of the a) exact, b) CPWA, and c) MPWA migrated gathers. The location of the gather in the stack is indicated by the red arrow in Figure 5.

## Conclusions

A new approximate migration weight has been obtained for prestack Kirchhoff migration of converted wave data. It is expected that this weight provides an optimal balance of accuracy and efficiency for current processing standards. It provides results very similar to the exact homogeneous weight for reasonably horizontal geologies, but requires no additional evaluation within the inner migration loop.

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