New imaging results at the Chan Chich archaeological site

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ABSTRACT

The Chan Chich archaeological site in Belize has been the location for two experimental high-resolution 3-C seismic surveys, one each in 2000 and 2001. In spite of poor data quality on the 2000 survey, interesting and consistent images were produced for both the vertical and inline horizontal components of the survey, through the use of unconventional imaging techniques. Only the vertical component of the 2001 data set has been imaged to date, however, and a tomographic image created from the first breaks. Presented here are four final images from the 2000 Chan Chich 3-C survey, illustrating a curious ambiguity between the vertical and inline components, as well as the image from the 2001 vertical component and the tomographic results. Significantly, an anomaly tentatively identified on two of the images from 2000 seems to be present on both the 2001 reflection image and the tomographic image.

INTRODUCTION

One of the more interesting uses for near-surface seismic techniques is surveying archaeological sites to help locate and outline potential targets for early excavation. In this connection, a near-surface 3-C survey was conducted at the Chan Chich archaeological site in Belize in 2000, both to test the method, and to attempt to detect any anomaly attributable to a suspected but unconfirmed burial site. Site conditions and equipment difficulties contributed to seismic data that proved to be poor in quality. Nevertheless, efforts to image two of the three components were successful (Henley, 2000). Subsequent to that imaging effort, further processing was carried out on both components, with the interesting result that the image formed using either component appeared to depend more on which processing flow was used than on which component was processed (Henley, 2001). Either set of geophone channels appears to contain significant contributions from both longitudinal and transverse particle motion.

To investigate further, a new 3-C survey was conducted in 2001 over the same profile as the 2000 survey. The new survey has both more extensive coverage and better quality data, only one component of which, the vertical, has been processed to date. One notable difference between the two vintages of data is the significant increase in near-surface velocity observed on the 2001 records compared to the previous year's records, a likely consequence of significantly different surface environmental conditions at the site (very wet in 2000, very dry in 2001).

The newer data contained significant levels of source-generated noise, as in the previous year. However, the noise level was somewhat lower, probably due to a different acquisition technique (single sledgehammer blows, rather than multiple stacked blows); and adequately attenuating the noise did not require quite such aggressive techniques as filtering the 2000 data (Henley, 2000).

The near-surface structure at the Chan Chich site is thought to be a layer of low-velocity unconsolidated material overlying high-velocity bedrock, a condition favourable for the propagation of turning-rays, beyond a certain critical angle at the bedrock. Hence it was decided to pick first-break times on the shot gathers and attempt to delineate the near-surface velocity structure using turning-ray tomography. Tomographic results are always suspect, subject as they are to bias by the local ray density during ray-tracing and by the starting velocity model. The technique was thought to be potentially useful here, however, since lateral velocity anomalies (trenches) were the target, rather than detailed vertical velocity structure per se.

Careful monitoring of ray-tracing results and the errors between pick times and ray-trace times is required to successfully use tomography. In this case, however, only about 400 picks were available, so it was possible to examine each pick carefully and to adjust the layercake input model whenever any systematic error pattern was detected between pick times and ray-trace times. One such pattern seen early in the tomographic work appeared to define a steep shaft or cavern at some considerable depth in the bedrock. Such a feature was considered unrealistic; and subsequent examination of the tomography revealed that the anomaly was due to a mere 3% of the picks being attributed to unrealistically steep and long sub-critical raypaths in the model. Simply constraining the maximum depth of the model resulted in these picks being properly attributed to more realistic raypaths in the shallower portions of the model, removing the deep anomaly.

RESULTS

2000 vintage data

The image in Figure 1 was formed from the inline horizontal component of the 2000 survey, using processing parameters designed for the extremely low transverse-wave velocities and the implied high V_P/V_S. The major feature of this image is the single interface at about 40 ms, as well as the potential anomaly indicated by the arrow. The image formed from the vertical component of the same survey, using processing parameters designed for the higher velocity of longitudinal waves is shown in Figure 2. The reflected interface appears much shallower here (about 12 ms) and also has an apparent anomaly in a similar position to that of Figure 1. These two images appear to confirm, using two different modes of wave propagation (P-P reflection and P-S_V conversion), the presence of an anomaly somewhere near the centre of the profile.

Figure 3, however, shows the vertical component data imaged using the ‘inline’ horizontal parameters. The interface at 40 ms appears quite strong in this image, but there is no clear indication of an anomaly. On the other hand, the inline data processed with the higher velocity ‘vertical’ (longitudinal wave) parameters yields the image in Figure 4, in which a faint anomaly is visible in a position similar to that of Figure 2. Apparently, a P-P or a P- S_V converted-wave image can be created from either the record of vertical particle motion or the record of inline horizontal particle motion. The apparent anomaly just beneath the level of the reflected horizon is not convincingly consistent on all the images, however.

2001 vintage data

The 2001 results presented here are preliminary, and subject to change with further work. Because the data coverage was better than in 2000, and the data quality was better as well, the following modifications were made to the processing sequence described for the 2000 data (Henley, 2000). Instead of forming shot supergathers of traces for coherent noise attenuation, the shot gathers were successfully filtered individually using the radial trace algorithm. Stacking and migration velocities were still measured and confirmed on a common-offset supergather, but the stack itself was high enough in quality that the wavefront healing step used in the 2000 imaging results was omitted. Kirchhoff migration and predictive deconvolution were included in the flow, as in 2000, however.

Figure 5 shows the complete image for the vertical component data from 2001. Of interest in this image is the fact that the strong reflected horizon is much shallower than in 2000, due to the greatly increased velocity in 2001 (a function of near-surface environmental conditions). Of more interest is the distinct anomaly just beneath this shallow reflection near the centre of the profile. More detail is shown in the blow-up in Figure 6.

The tomographic results are of considerable interest here, since they can be considered to be derived from a set of observations (first-break picks) nearly independent from those used for the reflection image (seismic trace amplitudes). Figure 7 shows the layercake starting velocity model for the tomographic ray tracing, with a velocity of 500 m/s at the surface and 1200 m/s at the bottom of the model. A steep gradient just above 3 m approximates the bedrock interface. Using this model, the velocity structure of the near surface as deduced via turning-ray tomography of the first-break times is shown in Figure 8. The large low-velocity trench near the centre of this image coincides remarkably well with the reflection anomaly in the two reflection images, and adds considerably to the confidence level that a real physical anomaly is being observed.

DISCUSSION

One of the issues raised by experience with the 2000 Chan Chich data set is understanding the details of the near-field particle motion at both source and receiver in a shallow seismic environment where dimensions are small and elastic parameters are extreme (low velocities, low Q, high V_P/V_S). In such an environment, it is not clear what information is contained in the seismic response, nor how best to utilise it. It may be that in some situations, useful reflections will not be observable, and some other wave mode will provide the best information about the shallow medium. In addition to the reflection imaging and turning-ray refraction discussed here, other methods that might prove useful are broadside refraction and measurement of waveguide mode characteristics.

The use of seismic methods for archaeological surveying is still very much in its infancy, and the techniques will continue to be modified and improved for the foreseeable future. The analysis of data sets currently in hand will also continue, with guidance from previous results. While other geophysical methods like ground penetrating radar have already developed a track record in archaeological work, seismic techniques have yet to gain much acceptance, and still mostly await confirmation by excavation.

ACKNOWLEDGEMENTS

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FIGURES

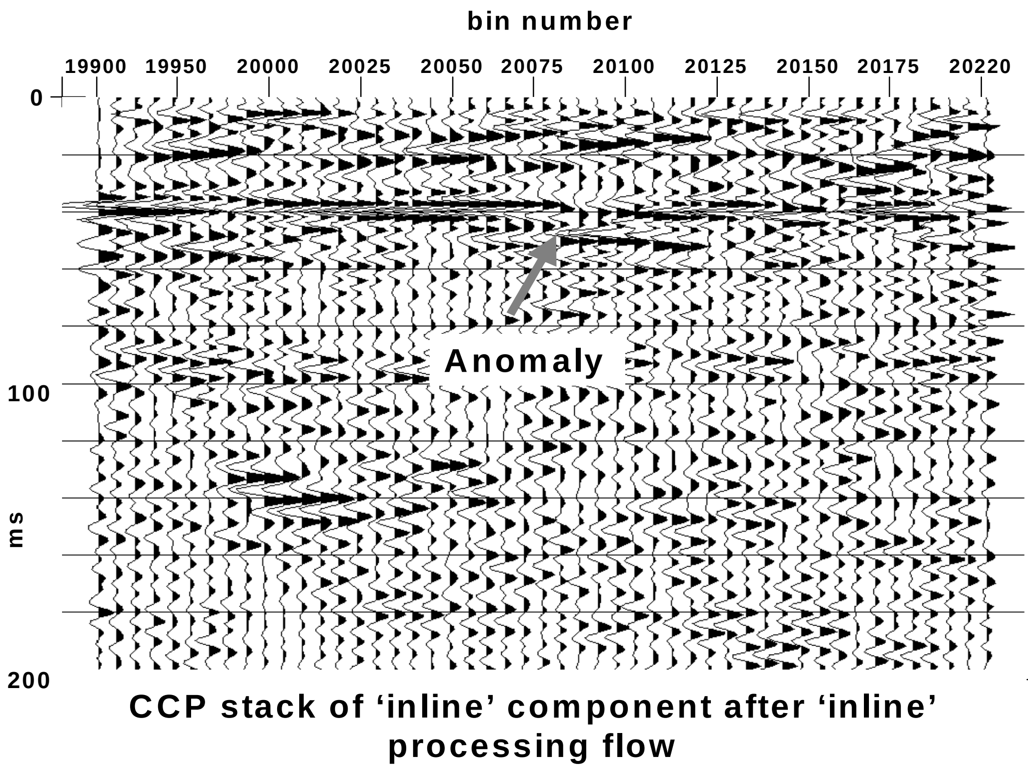

FIG. 1. Image obtained from 2000 inline horizontal component using processing tailored for 'inline' component.

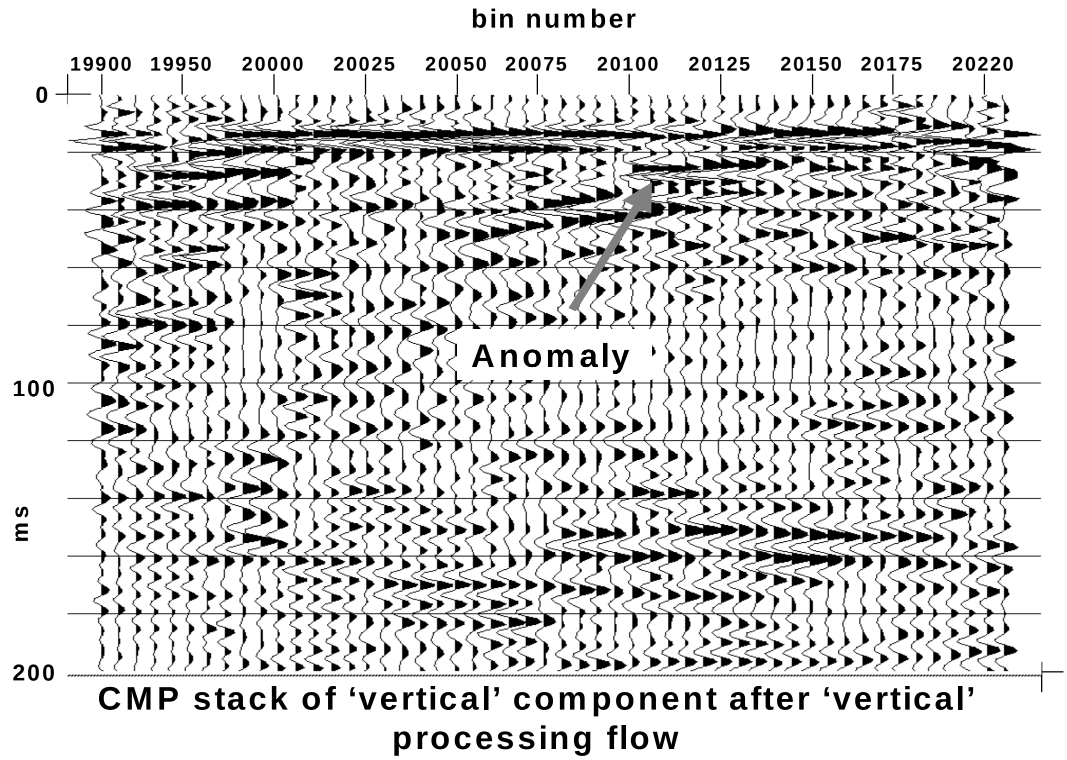

FIG. 2. Image obtained from 2000 vertical component using processing tailored for 'vertical' component.

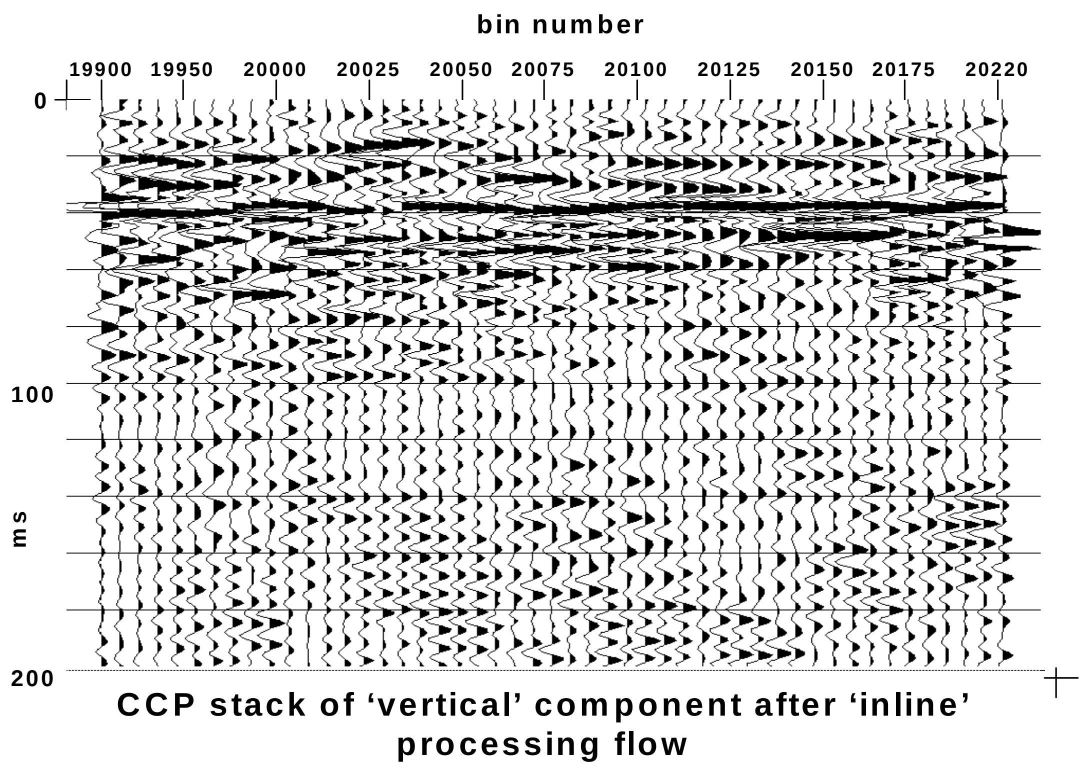

FIG. 3. Image of 2000 vertical component after processing tailored for 'inline' component.

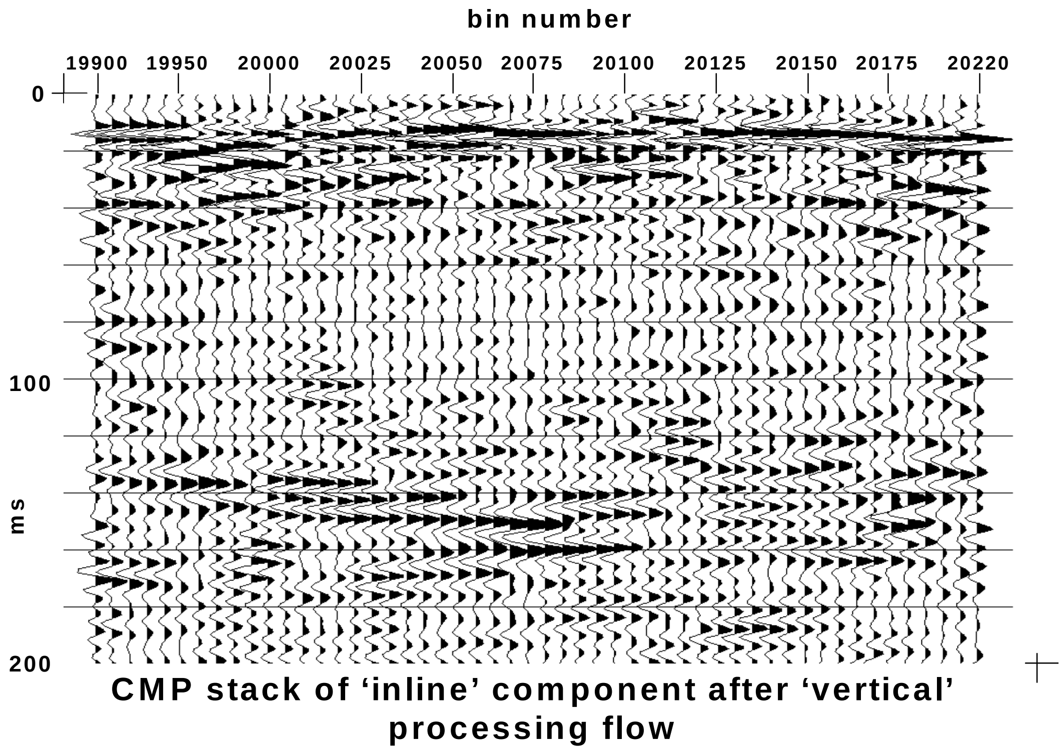

FIG. 4. Image of 2000 inline horizontal component after processing tailored for 'vertical' component.

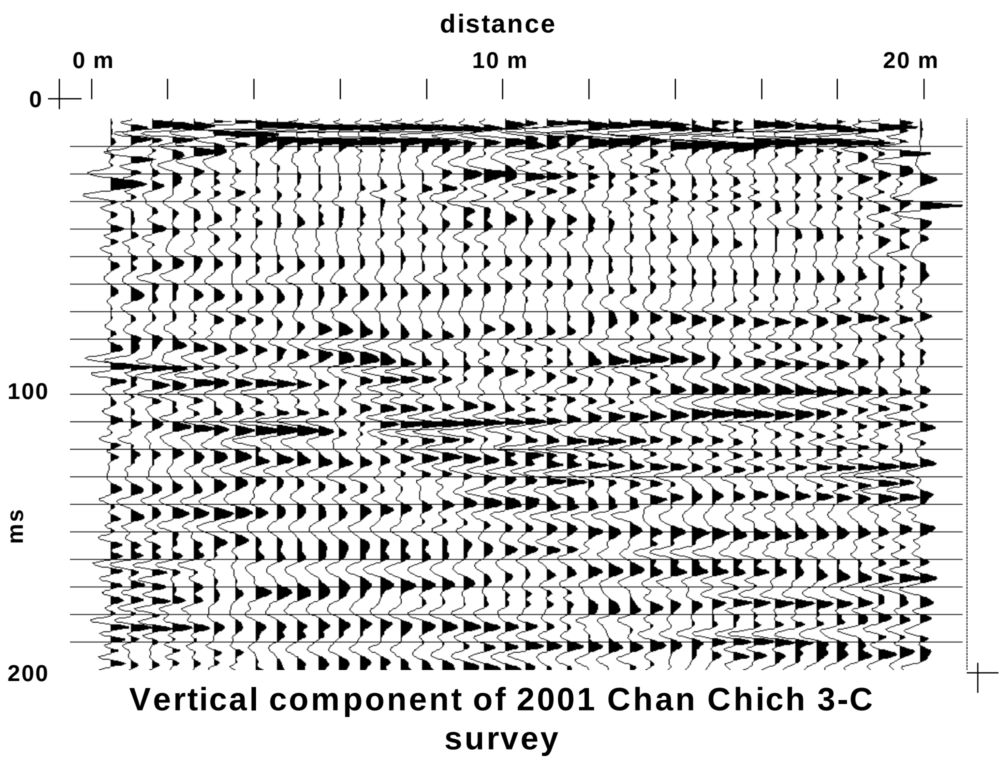

FIG. 5. Image of 2001 vertical component showing a clear anomaly near the centre.

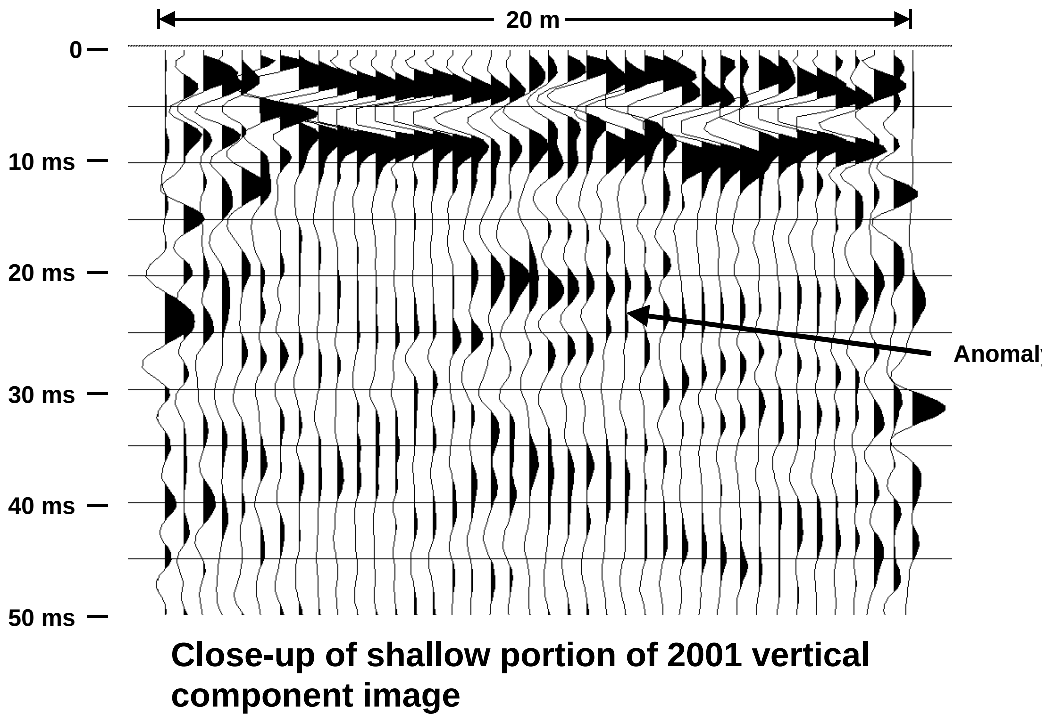

FIG. 6. Close-up image of 2001 vertical component data, showing anomaly.

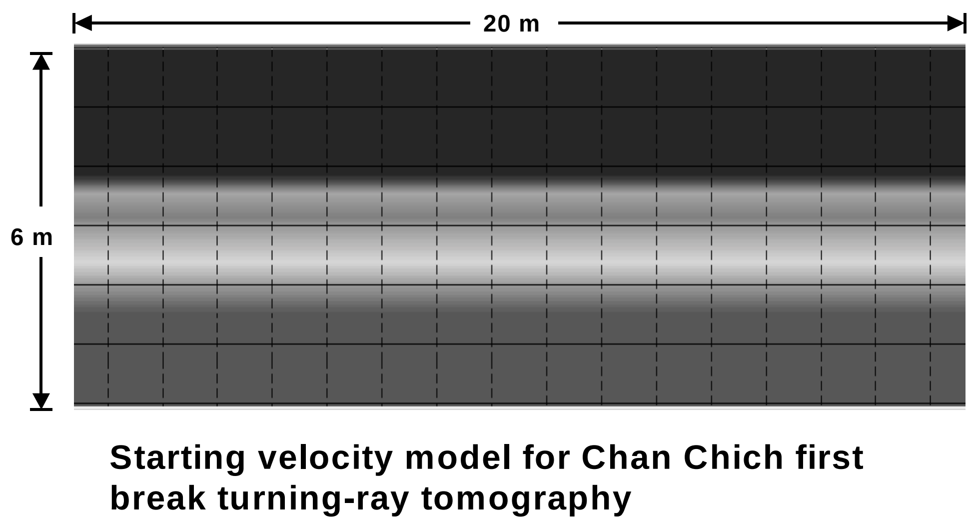

FIG. 7 Starting velocity model for Chan Chich first break turning-ray tomographic imaging. Velocities range from 500 m/s at the surface to 1200 m/s at 6 m depth, with a large gradient just above 3 m.

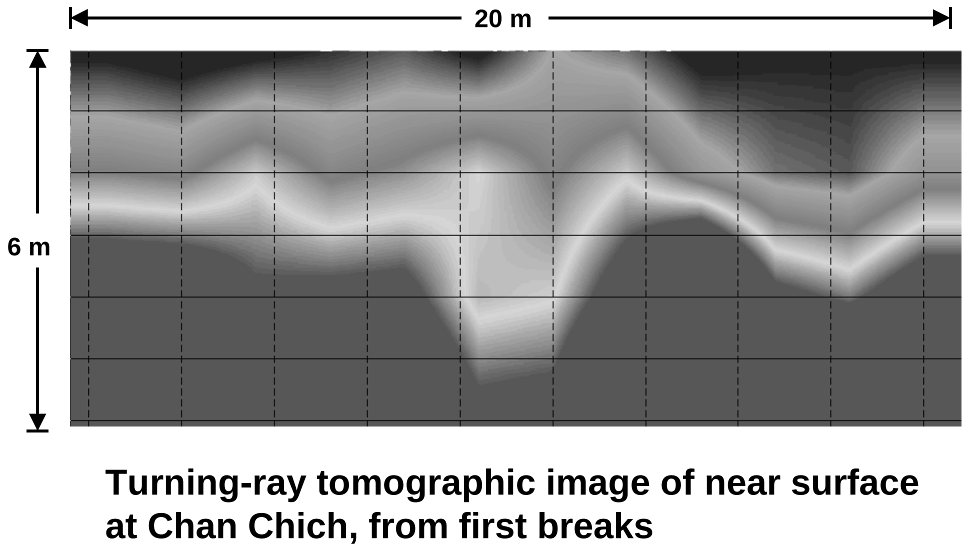

FIG. 8. Near-surface velocity structure at Chan Chich, as determined using turning-ray tomography based on first break picks. Velocity ranges from about 500 m/s at the surface to about 1200 m/s at the interface near 3 m depth. The anomaly in the centre is obvious. Grayscale has been contracted to emphasize the contours of the structure. Velocity in the centre of the anomaly is about 750 m/s, compared to 1100 m/s on either side.