Collaborative Research with University of Southern California, Harvard University, and the USGS: Methodology for defining concealed earthquake sources -- application to the Puente Hills blind-thrust system, Los Angeles, California – 00HQGR0006 and 00HQGR0045

Annual Project Summary - 2000

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Summary
We began a multidisciplinary, collaborative effort to define the earthquake potential and late Quaternary expression of the Puente Hills blind-thrust system (PHT) beneath metropolitan Los Angeles. The PHT extends from downtown Los Angeles southeast into northern Orange County, and consists of three distinct geometric segments that may pose significant hazards to the metropolitan region. In 2000, we developed a 3-D model of the PHT and its overlying folds using industry seismic reflection profiles and well control. Structural relief and kink-band widths at the modeled base Quaternary were used to define minimum long-term slip rates of 0.5 to 0.9 mm/yr for these segments.

To assess late Quaternary activity on the system, we acquired a set of high-resolution seismic reflection data in collaboration with USGS researchers Tom Pratt, Rob Williams, Jack Odum, and Bill Stephenson. These profiles image folds above the PHT extending continuously upwards to less than 8 m depth, where well-defined dip panels are on the order of ~20 m wide. These shallow folds support recent activity on the PHT, which reportedly sources the 1987 Whittier Narrows (M 6.0) earthquake (Shaw and Shearer, 1999). Moreover, these folds, which did not grow during the 1987 event, imply that much larger earthquakes have occurred on the PHT that include localized surface deformations. Having demonstrated that recent folding is clearly discernible at borehole/trench depths, and that the active growth triangle extends into the shallow subsurface as a discrete feature, we plan in 2001 to proceed with the excavation phase of this research. Excavations will define the precise geometry of near-surface folding, and provide ^{14}C samples for age control. These data will provide the basis for defining fault slip rates, slip/event, and the ages of past events given the known location, depth, and geometry of the underlying Puente Hills thrust.

3D Model Construction

The Puente Hills blind-thrust system consists of at least three distinct fault segments extending from downtown Los Angeles east to the Coyote Hills in northern Orange County (Shaw and Shearer, 1999). Each of these fault segments is overlain by one or more folds (kink bands) that deform Quaternary strata. These fault-related folds develop in response to motions through bends in fault planes or above propagating fault tips (Suppe, 1983; Suppe & Medwedeff, 1990). Moreover, these folds grew while sediments were being deposited above them, yielding patterns of deformed growth strata that reflect underlying fault geometries and slip (Suppe et al., 1992). In 2000, we combined images of these growth folds with direct fault-plane reflections to model the three-dimensional geometry of the PHT (Figure 1) and to map Quaternary slip on the fault segments.

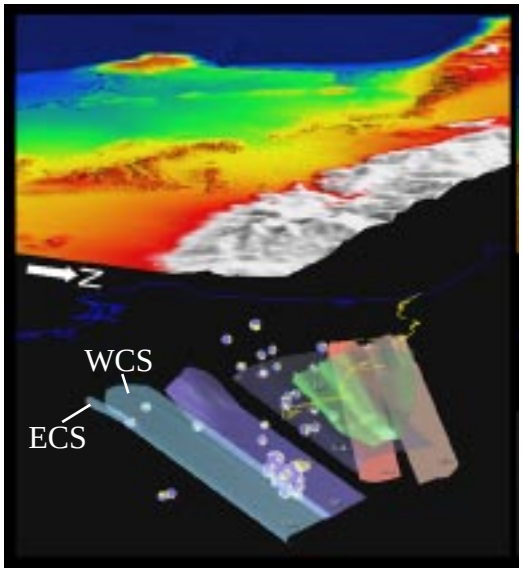

Figure 1: Perspective view of 3D model of the Puente Hills blind-thrust system beneath northern Los Angeles. WCS: Western Coyote Segment; ECS: Eastern Coyote Segment.

The size and shape of segments of the Puente Hills blind thrust should dictate the patches that rupture in large earthquakes, thereby controlling event magnitudes. Three geometric segment boundaries in the fault system were proposed by Shaw and Shearer (1999). In 2000, we have extended our mapping to define the eastern portion of the fault system beneath the Coyote Hills. The mapped surface contains a discrete kink band that follows the trend of the south-facing fold scarp and the inferred fault ramp (Figure 2). Topographic distinction of the Western and Eastern Coyote Hills (Wright, 1991), and the change in trend of the subsurface kink band, suggests that an additional segment boundary exists between Western and Eastern Coyote Hills. We are in the processes of refining the fault map to determine if this new segment boundary is limited to the upper few kilometers of the fault, or if it persists at depth and thus may form an earthquake segment boundary. The most reasonable scenario based on current geometric and mechanical modeling results suggests that the Eastern and Western Coyote ramp segments merge above 6km depth, and thus may not be expected to behave as independent seismic sources.

Using a new 3-D model of the Quaternary folds based on seismic images and wells, we calculated total slip and slip rates along the ramp segments using measures of both fold limb width and total uplift (Figure 2). Minimum long-term average slip rates for the segments vary from 0.5 to 0.9 mm/yr, and slip rates generally decrease by a factor of one third near the segment boundaries. These results suggest that the geometric segment

boundaries of the faults have played a role in slip accrual, and thus may represent earthquake segment boundaries. To verify this, we plan to compare long-term slip rates across each of the fault segments with late Quaternary slip rates and paleoseismic records obtained through ongoing near-surface investigations.

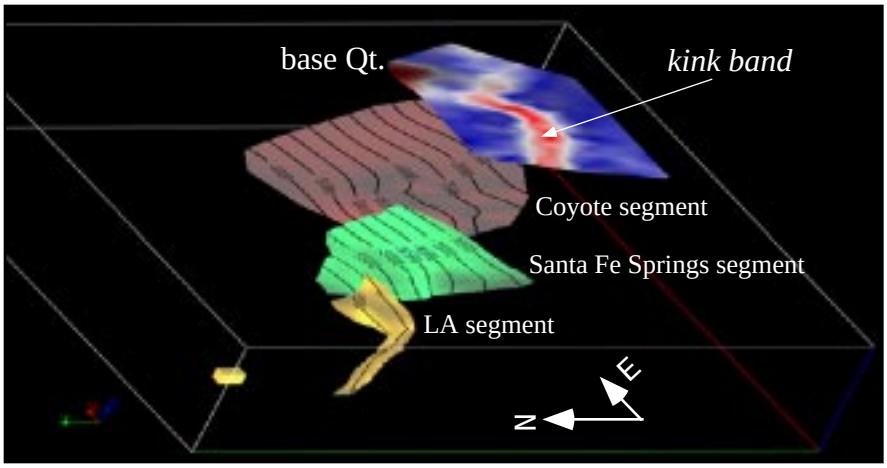

Figure 2: Perspective view of 3D structural model showing the mapped segments of the Puente Hills blind thrust and the base Quaternary horizon beneath the Coyote Hills segment. Dip magnitude is displayed as colors on the Quaternary surface. Red colors correspond to steeply dipping regions, and illuminate the kink band developed above the tip of the Coyote thrust ramp.

High-Resolution Seismic Data Acquisition

In 2000, we acquired four reflection profiles at two sites above the Santa Fe Springs (1: Carfax Avenue) and Western Coyote (2: Trojan Way) segments of the Puente Hills thrust. Preliminary processing of these data from the Carfax site indicate that we imaged a kink band (growth triangle) above the Santa Fe Springs thrust segment that extends upwards to at least 8 m depth (Figures 3, 4). The standard Minisosie data imaged a package of coherent reflections that define the kink band at 150 to 250 m depth (Figure 3). The fold is imaged precisely above the shallowest portion of the kink band defined by the deep industry seismic data. The kink band imaged in the Mini-Sosie data dips to the south at about 15 degrees, and is about 200 meters wide at 200 meters depth.

High resolution hammer-source data at the Carfax site images the fold at depths up to 8m (Figure 4). The shallow fold involves six discrete seismic reflections in the upper 25 meters. The shallowest fold scarp is located on the north side of the profile, precisely above the surface projection of the anticlinal axial surface imaged in the Mini-Sosie and industry reflection data. At ≈12 m depth, the fold consists of two discrete dip panels across a disturbed zone that is 60 meters wide. The two panels may represent folding above a multibend fault-bend fold, or separate surface folding events. At 8 m depth, the fold has narrowed to less than 20 meters in width, consistent with the narrowing upward patterns that are diagnostic of growth folding above fault-related folds that grow by kink-band migration (Suppe et al., 1992).

These discrete folds imply that large earthquakes with localized surface displacements have occurred on the PHT. Definition of the locus of shallow folding above anticlinal versus synclinal axial surfaces in the high-resolution data will help to differentiate between fault-bend and fault-propagation fold kinematics. This distinction dictates the appropriate method

of defining long-term geologic slip rates on each fault segment. Moreover, the images define that the folding extends to depths that can be reached by standard borehole excavations. The presence and continuity of seismic horizons imaged in the hammer-source data suggest that distinct horizons will be penetrated by the surface excavations, which we plan to begin in 2001. These investigations will yield late Quaternary fault slip rates, the details of the segmentation of the fault and associated folds, and the ages past earthquakes on the thrust system. Potentially, trench investigations will provide estimates of slip/event (a proxy for magnitude) for these paleoearthquakes. By combining these near-surface and deep subsurface investigations, we will address the fundamental question of how blind-thrust earthquakes are manifested in folded near-surface deposits through a confluence of subsurface and surface data. Thus, our results will document a significant earthquake hazard beneath Los Angeles, while developing new methods to identify and characterize blind faults elsewhere in the world.

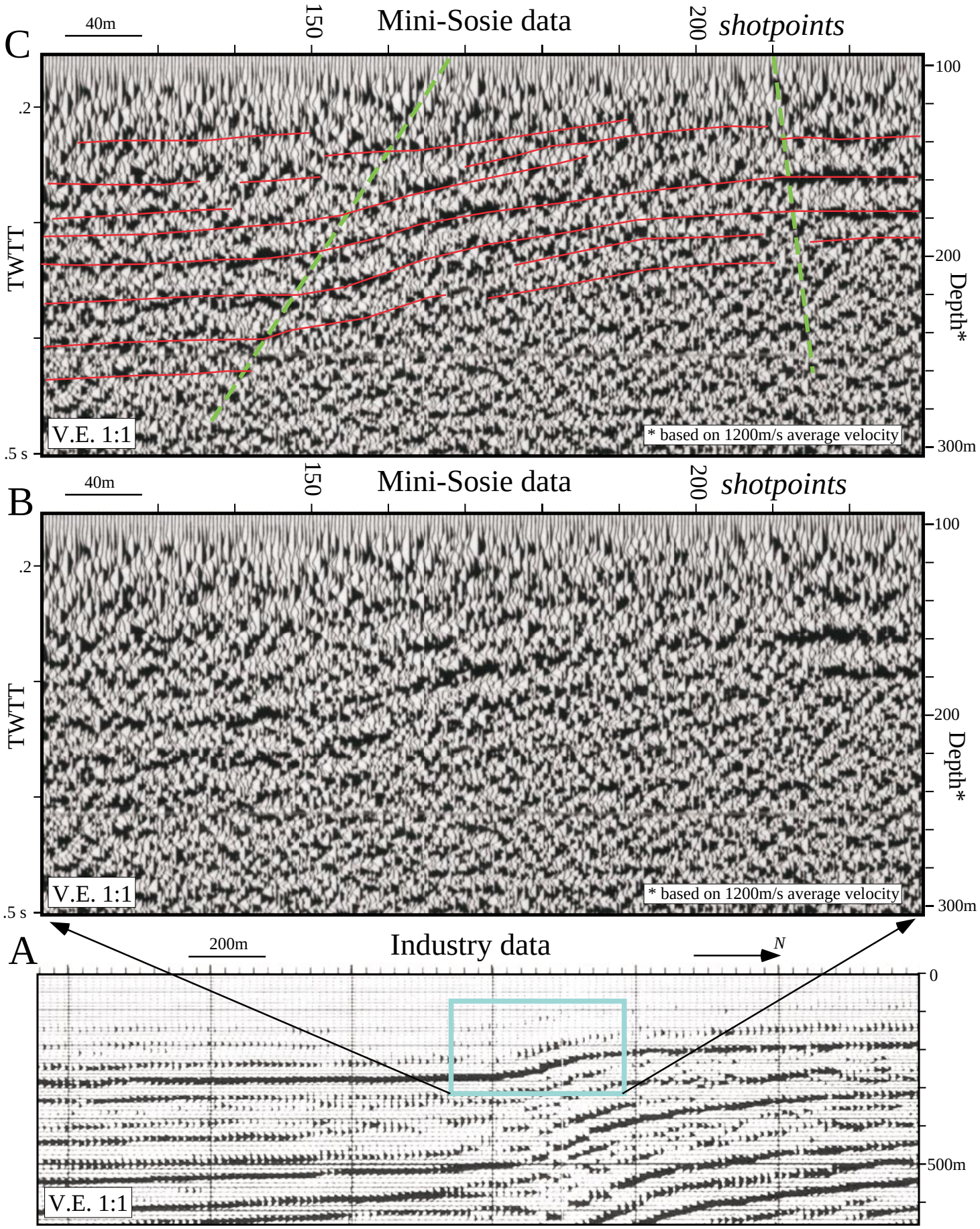

Figure 3: A) Industry data imaging a forelimb growth triangle above the Santa Fe Springs fault segment. B) Mini-Sosie data (preliminary processing) acquired at Carfax site imaging the fold limb between 100 and 250 m depth. C) Interpreted version of Mini-Sosie data with folded horizons and axial surfaces.

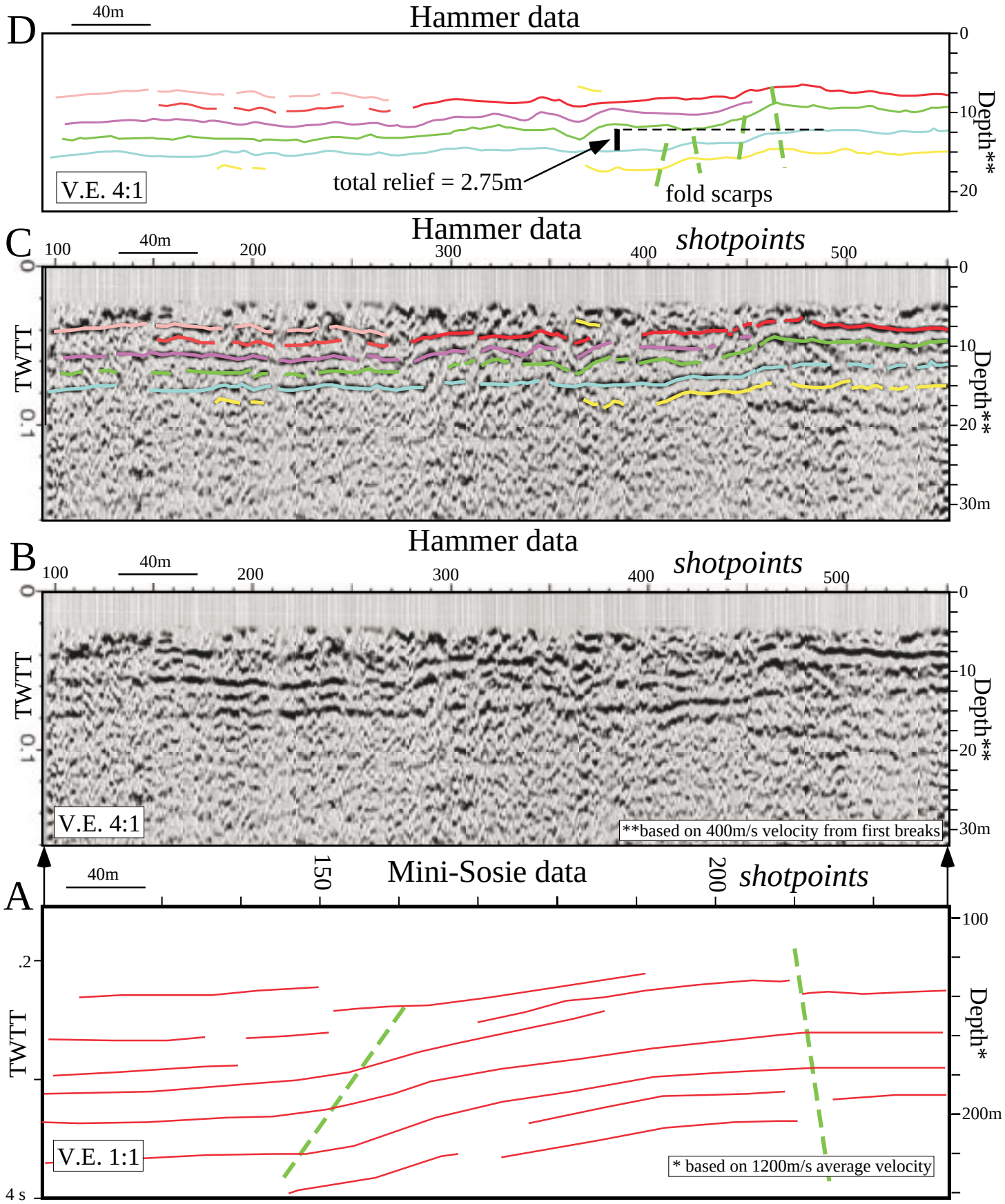

Figure 4: A) Interpretation of Mini-Sosie data at Carfax site from Figure 3. B) High-resolution hammer-source reflection profile acquired along the same path (Note shotpoints numbers change to reflect closer source spacing on hammer line). C) Interpreted version of Carfax hammer line, showing folded horizons between shotpoints 400 and 470. D) Interpretation of Carfax hammer line, with automated horizon interpolation. The shallow fold scarps are located above the anticlinal axial surface imaged in the Mini-Sosie data, and produce about 2.75 m of structural relief at about 8 m depth.