Geophysical Research Abstracts
Vol. 12, EGU2010-13047-3, 2010
EGU General Assembly 2010

Shallow reflection imaging by PSDM of dense, wide-aperture data: application to the causative fault of the 1980, M6.9, southern Italy earthquake

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Shallow reflection imaging of active faults in unconsolidated deposits is a challenging task. Main factors hindering seismic imaging are the presence of steep-dipping reflectors and strong lateral velocity changes across the fault-zone, which often make standard CDP processing inappropriate. This drawback can be in principle overcome by Prestack Depth Migration (PSDM). However, performance of PSDM strongly relies on the availability of an accurate background velocity model, which is critical to account properly for the seismic wave propagation and ray-path bending in the depth domain. Such a velocity model cannot be obtained by standard seismic reflection acquisition geometries due to the small-aperture of the receiver/shot array and to the difficulty in collecting good-quality near-vertical reflection data in the very near-surface. Consequently, PSDM of shallow reflection data is very rare in the scientific literature.

Recent applications of PSDM to very complex crustal structures have revealed that the use of non-conventional, dense wide-aperture acquisition geometries allows to successfully face the problem of the background velocity estimation. In this study, we investigate if the PSDM of dense, wide-aperture data can be an effective strategy for shallow imaging of complex structures, such as fault zone. We target the Irpinia Fault (IF), source of the 1980, M6.9, southern Italy normal-faulting earthquake. A 256 m long, ultrahigh resolution wide-aperture profile has been collected across the 1980 fault scarp in a small intermountain basin in the Southern Apennines range (Pantano di San Gregorio Magno). The source and receiver spacing is 3 m and 1.5 m, respectively, and the source is provided by a Buffalo gun.

The survey aims at imaging the first 100 m of subsurface and at providing valuable information on the fault zone architecture below a collocated paleoseismic trench.

The presence of unconsolidated deposits above a limestone basin substratum translates into strong velocity heterogeneities. To estimate a reliable smooth background velocity model, we used a first-arrival tomographic technique able to cope with sharp lateral Vp changes. The inversion procedure combines a multi-scale approach with a non-linear optimization scheme. A succession of inversions is run by progressively thickening the velocity grid, and for each inversion run the best fit model is found by a combined global/local search.

Several Kirchhoff PSDM runs are performed using different velocity models with progressively smaller wavelength contents, but also characterized by lower resolution depths. For each velocity model we check the performance of PSDM on the basis of CIGs analysis and the related pre-stack depth migrated sections. In our case, a velocity model with 35 m horizontal and 15 m vertical node spacing allows to image the short-wavelength components of the fault zone over the full thickness of the basin fill (up to $\sim$100 m), while maintaining metrical resolution.

The PSDM section provides superior imaging results compared to the related post-stack depth migration, where the fault plane and the shallow reflectors are hardly visible due to contamination of migration noise. The PSDM shows a clear fault plane that dips about 50° northeastward. Normal drag affects reflectors in both the fault footwall and hangingwall. In the hangingwall, the increase of tilting of reflectors with depth may indicate repeated co-seismic deformation episodes, as also suggested by fault related colluvial packages imaged by seismic tomography.