S41B-2441

Applying time-reverse-imaging techniques to locate individual low-frequency earthquakes on the San Andreas fault near Cholame, CA

Tobias Horstmann[1], Rebecca M. Harrington[2], Elizabeth S. Cochran[3], David R. Shelly[4]

[1]Geophysical Institute, Karlsruhe Institute of Technology, Hertzstrasse 16, D-76187 Karlsruhe — tobias.horstmann@kit.edu
[2]Earth & Planetary Sciences, Mcgill University, 3450 University St. Montreal, QC, Canada H3A 2A7 — rebecca.harrington@mcgill.ca
[3]US Geological Survey, 525 S. Wilson Ave, Pasadena, CA 91106 — ecochran@usgs.gov
[4]US Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025-3561 — dshelly@usgs.gov

1 Introduction

In spite of the abundance of LFE observations in recent years, locating tremor remains a difficult task due to the lack of distinctive phase arrivals. Here we use time-reverse-imaging techniques that do not require identifying phase arrivals to locate individual low-frequency-earthquakes (LFEs) within tremor episodes on the San Andreas fault near Cholame, California.

We propagate a time reversed seismic signal back through the subsurface using a staggered-grid finite-difference code. We then search for wave field coherence in time and space (e.g. LFE energy in 1.5 second time window filtered between 1-5 Hz) to obtain the source location and origin time where the constructive interference of the curl field energy is a maximum. The grid point and time window occupying the spatial median of cross-correlation values within 10% of the maximum value indicates the source location and origin time.

Location errors are based on the spatial extent of all cross-correlation coefficient values exceeding 90% of the maximum value. Horizontal and vertical errors are on the order of 4 km and 3 km respecitively. A test using earthquake data shows that the method produces an identical hypocentral location (within errors) to that obtained by standard ray-tracing methods. We check the locations determined here with an LFE catalog determined by stacking hundreds of LFEs [Shelly and Hardebeck, 2010]. The LFE catalog uses stacks of at least several hundred templates to identify phase arrivals used to estimate the location. We find that the epicentral locations determined here using the time-reverse-imaging technique are within ~4 km of the catalog LFE locations [Shelly and Hardebeck, 2010]. LFEs locate at depths between 15-25 km, similar focal depths to previously published locations of LFEs or tremor in the region. Overall, the method can provide robust locations of individual LFEs without identifying and stacking hundreds of LFE templates, and is more accurate than envelope location methods with errors on the order of tens of km [Horstmann et al., 2013]. Location errors may be further reduced with increased velocity model resolution.

2 Data & Methods

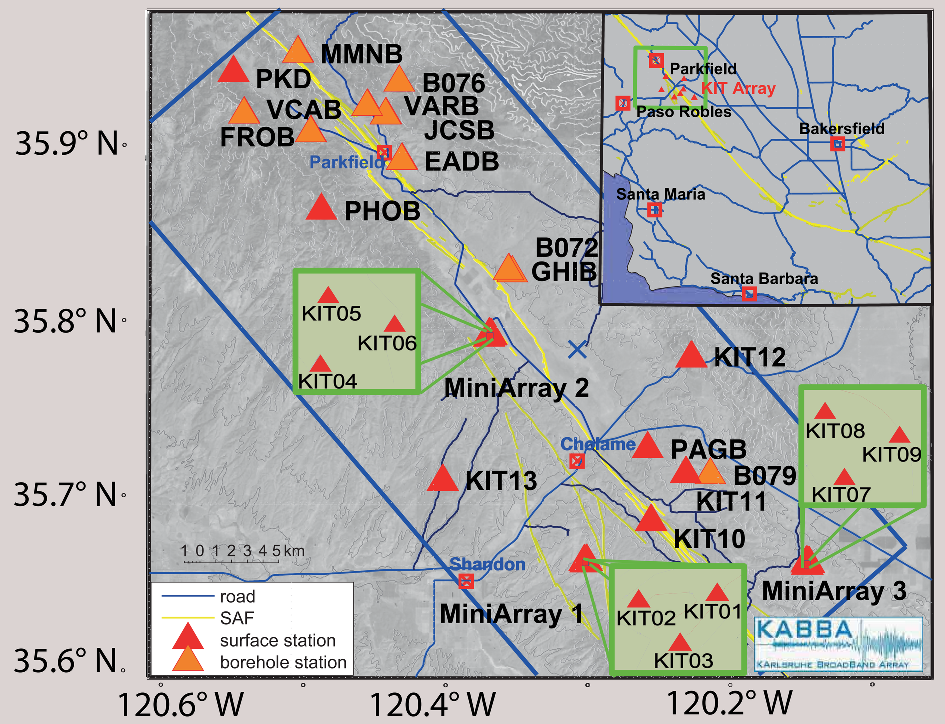

Figure 1: Station distribution

We use continuous broadband waveforms from the PERMIT array (KIT stations), HRSN and PBO borehole stations, and stations from the BK and NC networks.

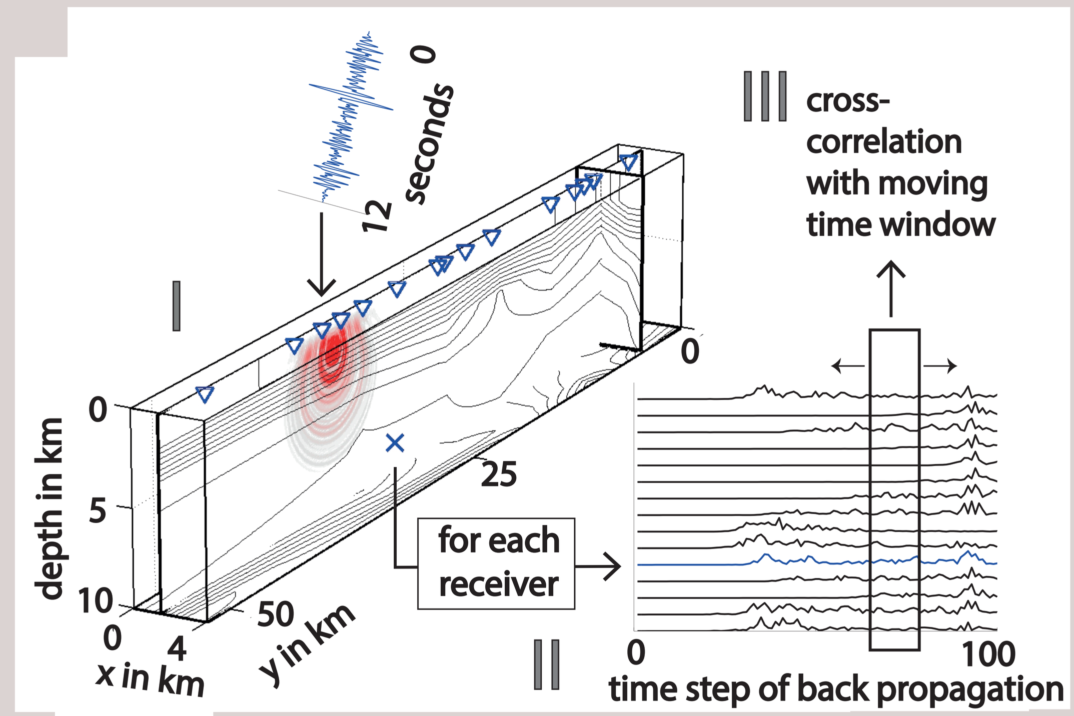

Figure 2: Schematic of the method

1. back-propagate time-reversed waveforms recorded at each station through the velocity model.
2. obtain a time-dependent curl field at each grid point.
3. time-dependent curl functions are then cross-correlated in a moving time window.
4. highest cross-correlation value in space and time provides the tremor source location.

We use the 3D velocity model of Thurber et al. [2006] interpolated to a grid spacing of 100m. Back-propagations are calculated using a staggered-grid, finite-difference code with 5 ms steps.

3 Results

Location of a M 1.4 earthquake

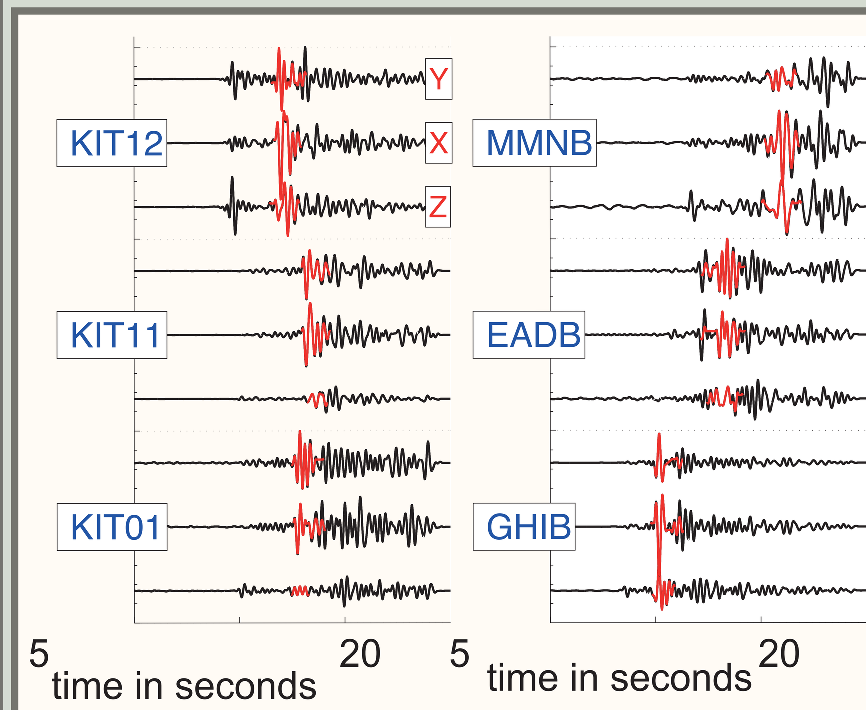

Figure 3: Back-propagated seismograms

Seismograms of a cataloged M 1.4 earthquake at selected stations with origin time 04:27:00, 06/24/2010, and epicenter at 35.85 N, 120.42 W. The window highlighted in red indicates the back-propagated waveform.

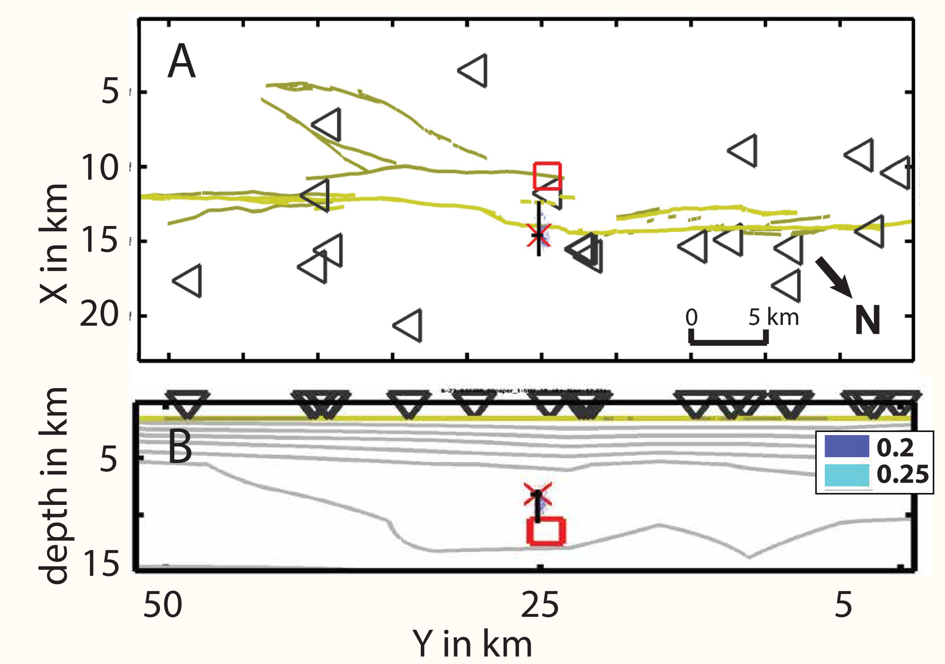

Figure 4: M 1.4 hypocentral location

(A) Map view and (B) fault plane view of the hypocentral location (red X) using time-reverse-imaging (TRI). Red square marks the catalog solution of Käufl [2012]. Black lines show error range determined by the spatial mean error, and the colorbar indicates the correlation coefficient values. Stations used shown by black triangles, and the surface trace of the San Andreas fault shown in yellow.

Location of an individual LFE

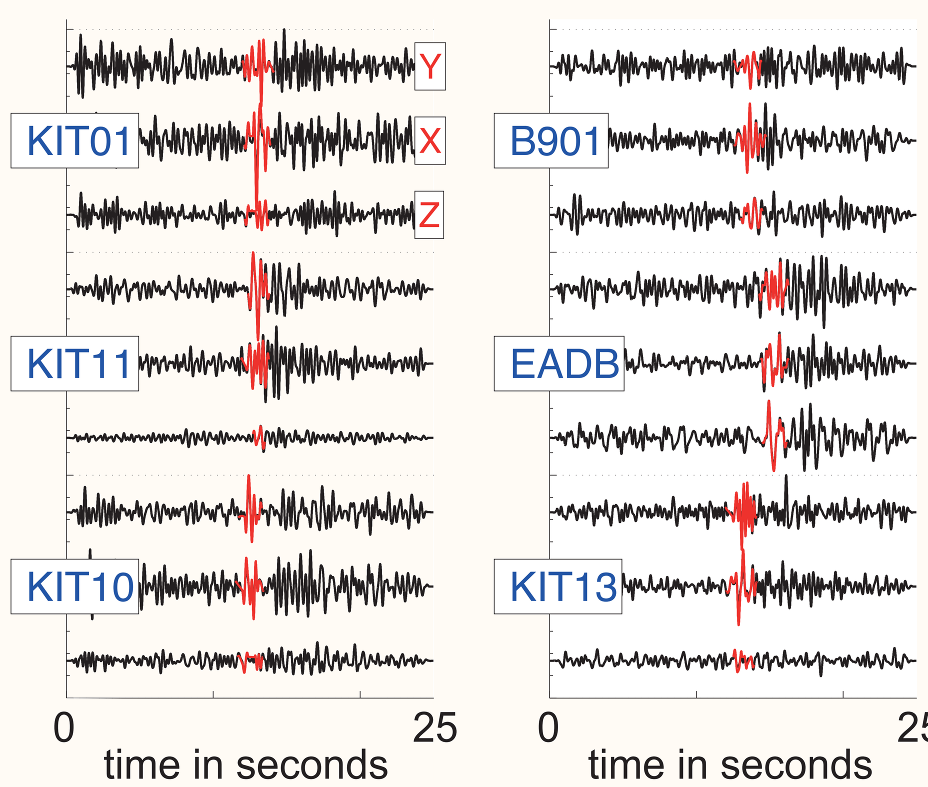

Figure 5: LFE seismograms

Seismograms of a LFE at selected stations recorded at 19:27:40, on 09/02/2010. The window highlighted in red indicates the back-propagated waveform.

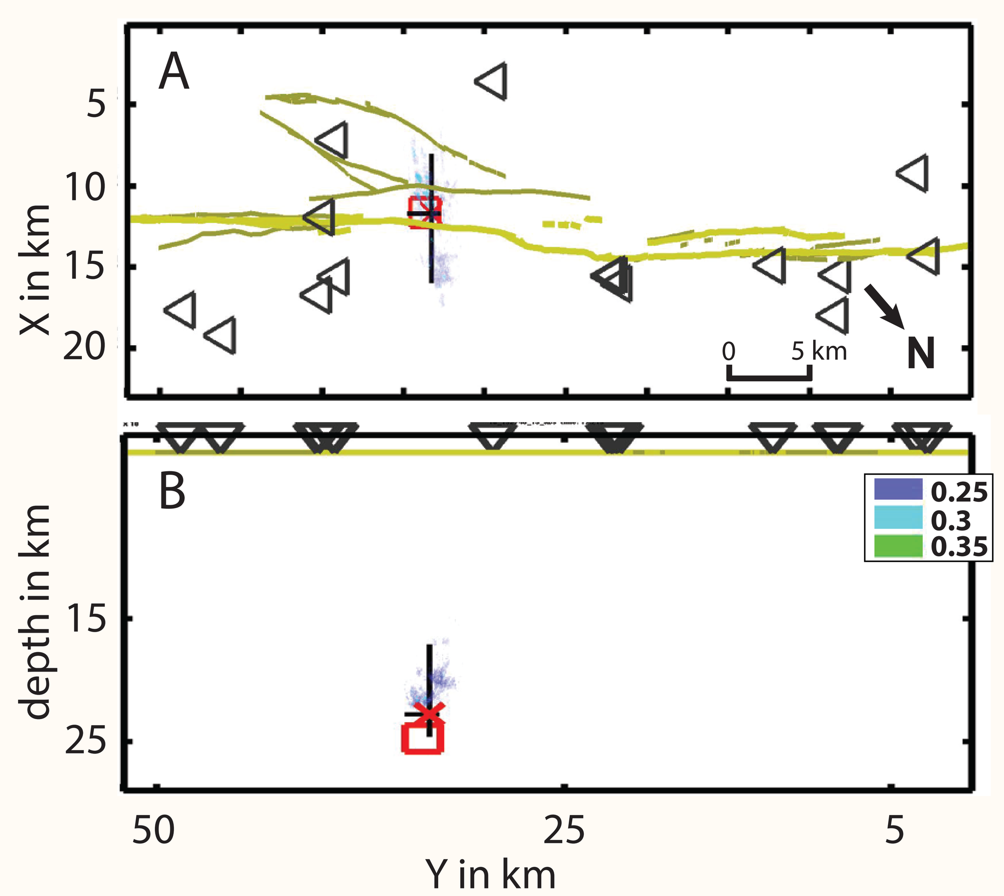

Figure 6: Individual LFE hypocentral location

Symbols and colors are the same as shown figure 4, but here the red square indicates the location of a LFE family from Shelly and Hardebeck [2010] for comparison.

Location of multiple LFEs

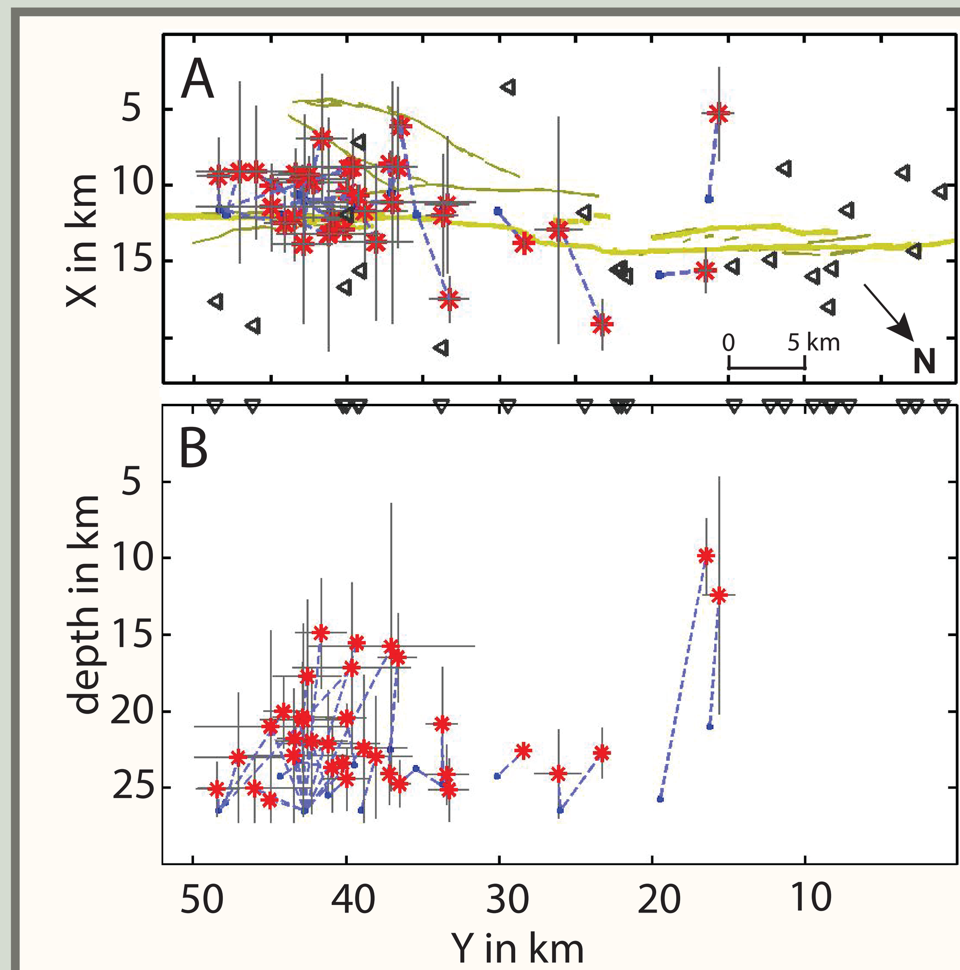

Figure 7: Individual LFE hypocentral locations

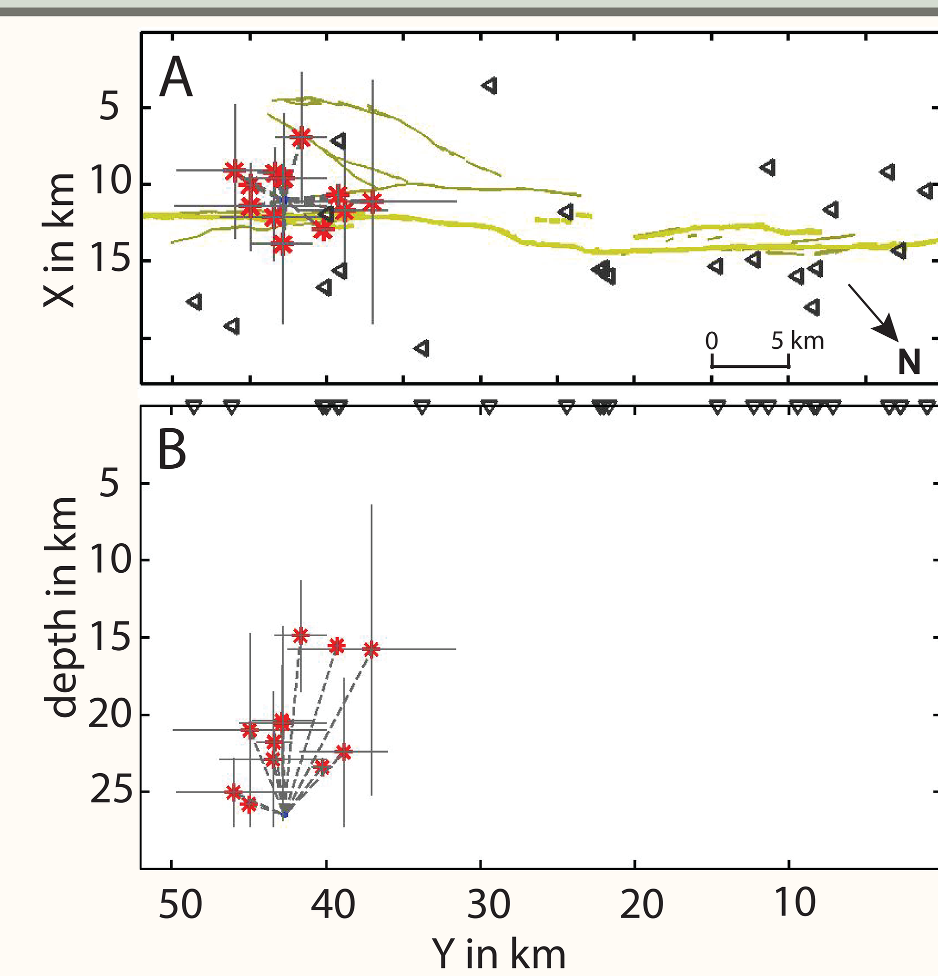

Figure 8: Hypocentral locations of a single LFE family

(A) Map view and (B) fault plane view of hypocentral locations for 35 individual LFEs (Figure 7) and 12 LFEs in a single LFE family (Figure 8). Red stars indicate source position, black lines show the estimated error range. Small blue dots mark the stacked LFE family solution of Shelly and Hardebeck [2010]. Black triangles denote all possible station positions and the yellow lines indicate the San Andreas Fault surface trace.

4 Conclusions

We demonstrate the ability of time-reverse-imaging to locate a M 1.4 earthquake to within comparable accuracy as determined by ray-tracing methods at station distances of up to 26 km.

Further, we demonstrate the ability to locate an individual LFE to within 4.3 km uncertainty. For comparison, the same individual LFEs were located using other methods and result in location errors of ~20 km.

We find epicentral locations for 34 individual LFEs based on the TRI technique are within 4 km relative to the LFE catalog of Shelly and Hardebeck [2010] which determines locations by stacking events.

Hypocentral source locations of individual LFEs in a single LFE family show scattering around the stacked family location within error. Therefore, scattering in hypocentral distribution within the single LFE family located here is not resolvable using the TRI method and the current velocity model. Improved velocity model resolution or a higher signal-to-noise ratio would reduce error and improve location accuracy.