Inverting Resistivity and Seismic Data to Find Subsurface Faults

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Abstract
The goal in paleoseismology is to estimate the sizes and recurrence intervals of ancient earthquakes [1]. This information is usually retrieved by trenching across a fault and examines the geological cross-section for signs of ancient faulting activity. A Colluvial wedge is a geological feature associated with normal faults; it is a wedge-shaped deposit that accumulates at the base of a scarp following a surface rupturing event [1]. Larger earthquakes produce greater displacement along the fault; so, wedge thickness is proportional to earthquake magnitude, while the depth interval between contiguous wedges is proportional to the recurrence interval between the corresponding earthquakes. Sediments that accumulate at the wedge are usually of lower velocity than surrounding sediments. However, its resistivity depends on the water content.

Trenching studies of colluvial wedges are expensive, environmentally intensive, typically limited to depths less than 10 m, and reveals only a 2D section of the geological record. Geophysical methods can be used to overcome the disadvantages of the trenching approach. Seismic refraction, resistivity, and reflection are examples of the geophysical methods that can be used in shallow geological applications such as locating colluvial wedges, faults, or boundaries between subsurface layers. These methods can provide deeper and wider, but less resolved images of faults and colluvial wedges than the standard excavation and logging of trenches across faults [2, 3, and 4].

Recently, electric resistivity tomography (ERT) [5], refraction tomography [6], and reflection [7] are used in near-surface applications of geophysics such as fault and void detections, geological mapping, environmental applications, etc. In this work we use ERT, refraction tomography, and seismic reflection to find and map a normal fault and its associated colluvial wedge.

Data Acquisition and interpretation

We used 64 electrodes with 5 m electrode spacing to record the resistivity data. The Syscal R2 instrument is used for the data collection and Res2DInv software is used to invert the collected data. While for the seismic data, we collected 109 common shot gather (CSG) with 109 receiver/CSG, where the shot/receiver interval is 3 m.

The collected electric resistivity data are inverted to get electric resistivity tomogram that shows the true resistivity values of the subsurface, here we found 5 different subsurface units:

1. A low resistivity layer (5 to 30 Ω.m) is shown at an offset x=211-252 m and depth z=5.2-23 m from ground surface. This low resistivity zone is interpreted as the colluvial wedge (CW) associated with the Qademah fault which is partially to fully saturated with saline water coming from the sea (2 km west of the site).

2. A high resistivity layer (> 600 Ω.m) is shown to the east of the colluvial wedge at offset x > 255 m, this is associated with dryer loose sediments (sand, silt, and gravel (SG)).

3. A very low resistivity layer that has a thickness of 1 - 2 m and resistivity < 10 Ω.m. It is corresponding to Sabkha (S) deposits

4. Below the Sabkha layer there is a layer with thickness of 2 - 5 m and resistivity 100-200 Ω.m. It corresponds to fan (F) deposits and consists of fine grained sand and gravel.

5. The lowermost layer has high resistivity values (> 1000 Ω.m) which is corresponding to limestone (LS) deposits.

The Qademah fault and antithetic fault are clearly shown on the final tomogram.

For seismic data, first arrival travel times of the 109 CSGs are picked and then inverted to get the subsurface velocity (refraction) tomogram. Three units are shown in this tomogram:

1. The upper layer has a thickness of 7 - 9 m from ground surface and velocity < 800 m/s. This layer corresponds to the Sabkha-fan deposits (S and F). The seismic tomogram does not show the Sabkha-fan deposits contact, because their velocities are nearly the same.

2. The lower layer shows velocities ranging between 1800 to 2000 m/s, which corresponds to the limestone (LS) layer.

3. A low velocity zone (LVZ) is shown at offset x=200-248. This LVZ corresponds to the colluvial wedge (CW) associated with the Qademah fault. Its horizontal offset matches well with that shown on the ERT.

The same seismic data set is used to generate a seismic stacked section. To generate this stacked section we (1) applied AGC, (2) the CSGs are FK filtered to remove the surface waves, (3) deconvoultion, (4) bandpass filter, (5) convert the data to common midpoint gather to get the stacking velocity, and (6) and finally, apply NMO and stack. The Qademah fault and the antithetic fault appears at offset x=241 and x=202 m, respectively, which is similar to both the ERT and the refraction tomography results. However, another antithetic fault appears at offset x=150-160 m. The absence of this antithetic fault on both the ERT and refraction tomogram could be due to the absence of a colluvial wedge, i.e. no low resistivity or low velocity zone is associated with this fault.

References

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Short-Bio

Ass. Prof. Sherif Hanafy received his B.Ss. (1993) and master (1997) degree in geophysics from Cairo University, Egypt. In 1999 he went to Kiel University, Germany for Ph.D. in a scholarship funded by DAAD, he got the Ph.D. degree in 2002 from Kiel University, Germany – Cairo University Egypt. He worked as associate professor of geophysics in Cairo University from 2002 to 2007, a post-doctor fellow at University of Utah from 2007 to 2009, adjunct associate professor at University of Utah in 2009, then senior research scientist at KAUST, KSA from 2009 till now. Research interests of Professor Hanafy include shallow applications of geophysics (using seismic refraction, reflection, GPR and resistivity methods), seismic tomography, migration, and interferometry. Professor Hanafy has more than 35 scientific papers published in pre-reviewed international journals and conferences. Prof. Hanafy is a member of SEG, EAGE, and EGS.