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Seismogenesis and earthquake triggering during the Van (Turkey) 2011 seismic sequence

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ABSTRACT

A unique and very interesting earthquake of magnitude *Mw* 7.2 occurred in the Van region of Turkey on October 23, 2011 that caused a heavy loss of human lives and properties. The earthquake occurred on a blind oblique thrust fault oriented towards the NE–SW direction and dipping towards NW as evidenced by focal mechanism solution and aftershock distribution. In this study, we analyzed the seismogenesis and earthquake triggering during this sequence with the help of estimated seismological parameters (*b*-value of frequency–magnitude relation, *p*-value of aftershocks temporal decay and *D*-value of fractal dimension), 2D mapping of *b*- and *p*-values, 3D mapping of *b*-value and coseismic Coulomb stress modeling. The estimated seismic *b*-value equal to 0.89 reveals that the mainshock occurred in a highly stressed region and sequence comprised larger magnitude aftershocks due to the presence of large size asperities within the rupture zone. The normal estimate of *p*-value (0.98) suggests a tectonic genesis of the aftershocks sequence. The estimated *D*-value equal to 1.80 reveals that rupture propagated in a two-dimensional plane filled up by fractures. The spatial 2D and 3D mapping of seismic *b*-value suggests that the Van earthquake originated in a highly heterogeneous fractured rock matrix with fluid intrusions into it at deeper depth beneath the mainshock hypocenter region. The estimated coseismic Coulomb stress using the variable slip model for depth range 0–30 km exhibits a 'butterfly' pattern and most of the aftershocks fall (90%) in the region of enhanced Coulomb stress. This suggests that most of the aftershock activities have been triggered by transfer of positive Coulomb stress due to coseismic slip of the mainshock. The results estimated in the present study have potential useful implications in future seismic hazard assessment and risk mitigation in Van and the surrounding regions.

1. Introduction

A very strong damaging earthquake of magnitude *Mw* 7.2 occurred on October 23, 2011 (10:41:21 UTC, 13:41:21 local time) near Van City in the eastern region of Turkey (Fig. 1a). Seismicity of this region is mainly related to the continent–continent collision of the Anatolian and the Arabian plates. Conjugate strike-slip faults of dextral and sinistral character paralleling to the North and East Anatolian fault zones are the dominant structural features of the region (Bozkurt, 2001). Some of these structures are Çaldıran fault, Gevaş fault and Erciş fault (Fig. 1b). The Çaldıran strike slip earthquake of magnitude (M_S) 7.3 is the only largest earthquake in this region that occurred on November 24, 1976 and caused a huge loss of lives and properties in the surrounding regions.

Several national and international seismological agencies reported and located the 2011 Van earthquake (Table 1). There were some differences between the mainshock epicenter located by the Kandilli Observatory and Earthquake Research Institute (KOERI) and the USGS but the KOERI estimates are much reliable than that of USGS due to the local control of seismic stations. The source parameters of mainshock and some stronger aftershocks ($M \geq 5.0$) estimated by KOERI are given in Table 2. The Van earthquake caused deaths of nearly 650 people, and about 15,000 buildings and houses destroyed or damaged in the Erciş–Tabanlı–Van area (Taşkın et al., 2012). The earthquake was felt in all the neighboring countries such as Iran, Iraq, Armenia and Syria (Erdik et al., 2012). The intensity of the mainshock was IX on the modified Mercalli Intensity (MMI) scale in and around the Van–Tabanlı region (http://www.afad.gov.tr). The Peak Ground Acceleration (PGA) of the mainshock, measured at the

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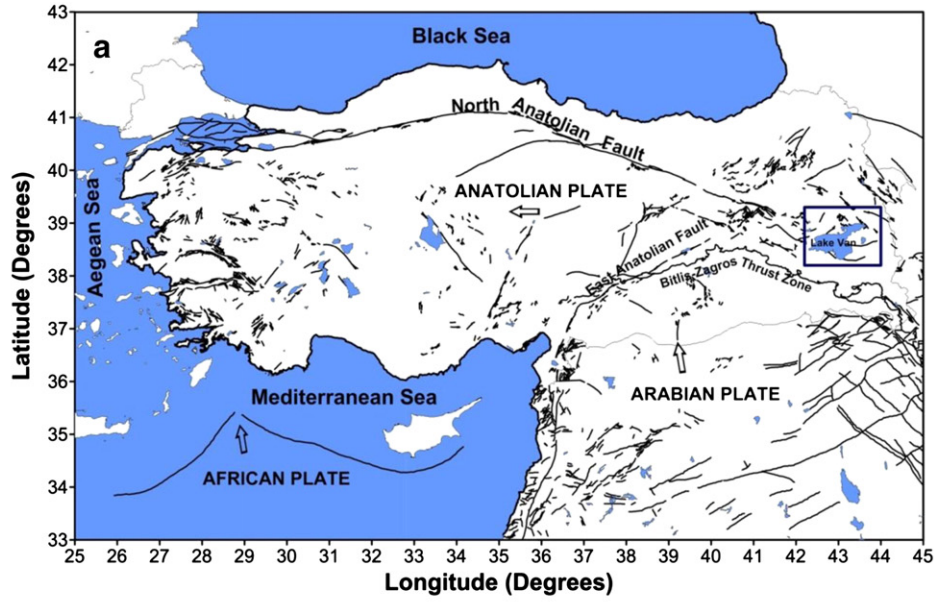
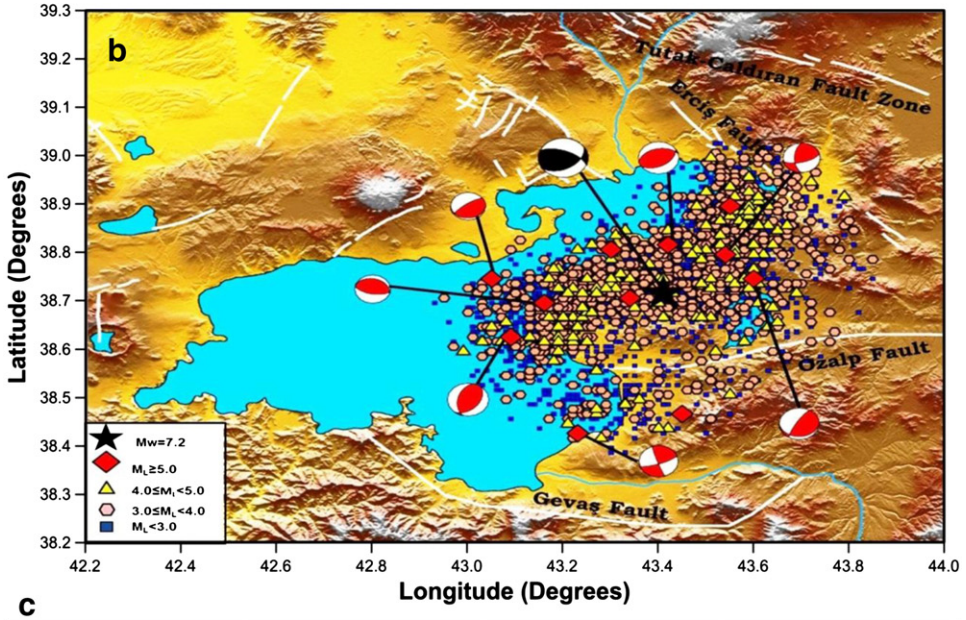
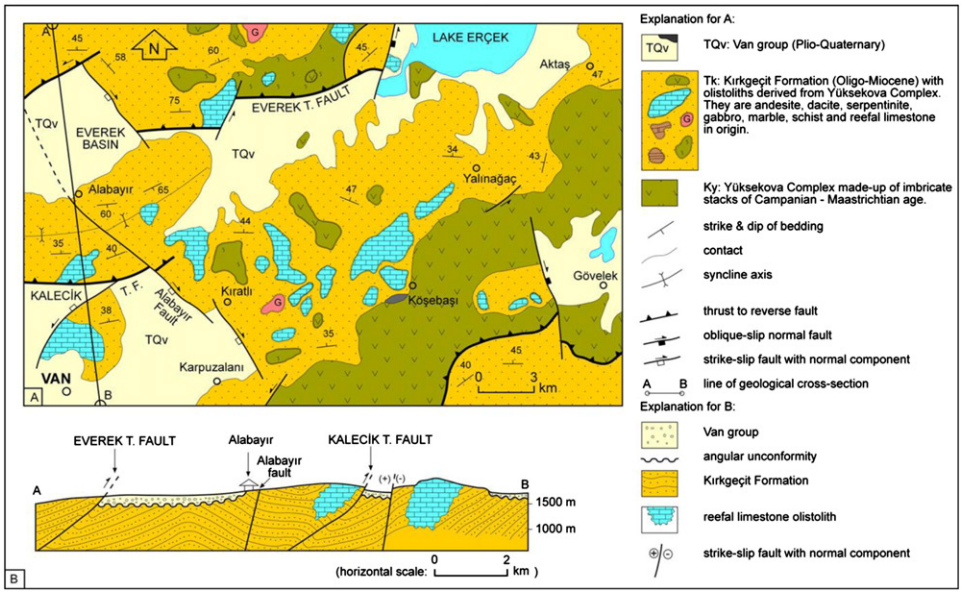

a
Black Sea
North Anatolian Fault
ANATOLIAN PLATE
Aegean Sea
East Anatolian Fault
Bitlis-Zagros Thrust Zone
Lake Van
Mediterranean Sea
ARABIAN PLATE
AFRICAN PLATE
Latitude (Degrees)
Longitude (Degrees)


b
Tutak Caldıran Fault Zone
Erciş Fault
Özalp Fault
Gevaş Fault
Mw=7.2
ML≥5.0
4.0≤ML<5.0
3.0≤ML<4.0
ML<3.0
Latitude (Degrees)
Longitude (Degrees)

c


LAKE ERÇEK
Aktaş
EVEREK T. FAULT
EVEREK BASIN
TQv
Alabayır
Yalınağaç
KALECİK
T. F.
Alabayır Fault
Kıratlı
Köşebaşı
Gövelek
Karpuzalanı
VAN
0 3 km
EVEREK T. FAULT
Alabayır
Alabayır fault
KALECİK T. FAULT
1500 m
1000 m
(horizontal scale: 0 2 km)
Explanation for A:
TQv: Van group (Plio-Quaternary)
Tk: Kırkgeçit Formation (Oligo-Miocene) with olistoliths derived from Yüksekova Complex. They are andesite, dacite, serpentinite, gabbro, marble, schist and reefal limestone in origin.
Ky: Yüksekova Complex made-up of imbricate stacks of Campanian - Maastrichtian age.
strike & dip of bedding
contact
syncline axis
thrust to reverse fault
oblique-slip normal fault
strike-slip fault with normal component
line of geological cross-section
Explanation for B:
Van group
angular unconformity
Kırkgeçit Formation
reefal limestone olistolith
strike-slip fault with normal component