Soil Dynamics and Earthquake Engineering 100 (2017) 428–444

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

journal homepage: www.elsevier.com/locate/soildyn

Seismic hazard assessment for Harrat Lunayyir – A lava field in western Saudi Arabia

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ARTICLE INFO

Keywords:
Saudi Arabia
Volcanic areas
Seismic hazard
Analysis of uncertainty

ABSTRACT

Distribution of earthquakes along the western part of the Arabian Peninsula is related to the Red Sea floor spreading and volcanism. The Arabian Peninsula contains Cenozoic lava fields (harrats) extending from Yemen in the south up to Syria in the north. Harrat Lunayyir that is a very young volcanic area has suffered from two earthquake swarms with maximum magnitude M_W 5.7 caused by the dike intrusion. The area was not considered as a seismic source zone when constructing seismic hazard maps used in the current issue of Saudi Building Code (SBC-2007). In this work, probabilistic seismic hazard is estimated for the Harrat Lunayyir area and the town of Alays located a few kilometers to south-east of the Harrat. Two models of seismic source zones describing seismic process in Harrat Lunayyir are considered as alternatives in the logic tree scheme, namely: the areal source model and the fault (characteristic earthquake) source model. The results of probabilistic estimations of seismic hazard show that the area is characterized by significant level of hazard. The expected peak ground amplitudes at rock site and for return period 2475 yrs are larger than 200 cm/s^2 and 140 cm/s^2 for the central part of the area and the town of Alays respectively. The level of uncertainty quantified in terms of "relative uncertainty" is the largest in the central part of the area.

1. Introduction

The Arabian Peninsula contains extensive Cenozoic lava fields (harrats) extending from Yemen in the south up to Syria in the north [31–33]. The first phase of continental volcanism, from about 30 to 20 million year, produced tholeiitic to transitional lavas along NW faults that correspond to passive mantle upwelling during extension of the Red Sea Basin. The second phase, from about 12 Million year until now, produced transitional to strongly alkalic lavas emplaced along NS trends [33] that correspond to a major period of crustal uplift. The axis of the uplift corresponds to the Makkah-Madinah-Nafud (MMN) volcanic line (Fig. 1) that is thought to be a line of thermal upwelling beneath the lithosphere [31,75].

Historical records of seismic (e.g. Refs. [20,74]) and volcanic activity (e.g. Refs [84,91]) suggest the occurrence of more than 20 within-plate volcanism eruptions in the Arabian Peninsula during the past 1500 years and indicate the possibility of recurring volcanic hazards in the western region of Saudi Arabia, as shown by the latest well documented eruption in northern Harrat Rahat near the Al-Madinah city in 1256 CE, the eruption was accompanied by a series of earthquakes [34,48,67].

Distribution of earthquakes along the western part of the Arabian Peninsula (the Arabian Shield) is related to the Red Sea floor spreading and volcanism. Northwestern Arabia is characterized by strong historical earthquakes [9–12,47,74], the largest of which occurred in 1068 CE (epicentral intensity up to IX) causing about 20,000 deaths and major damage in Tabuk, near the Dead Sea, and in the Sinai Peninsula [11]. A large M_W 7.3 earthquake occurred on 22 November 1995 in the northern part of the Gulf of Aqaba and shook north-western Saudi Arabia and the adjacent territory [57,79]. One of the largest events with magnitude M_S 6.5 occurred on 11 January 1941 near the current Saudi Arabia–Yemen border (epicenter 16.4° N and 43.5° E, epicentral intensity MSK VIII). [12]. On January 23, 2014, an earthquake sequence was recorded about 50 km northeast of Jizan city; the magnitude of the largest event was estimated as M_L 5.1 [45,46]. The earthquake was recorded by several strong-motion stations of the Saudi Geological Survey (SGS) strong-motion network, with a maximum value of peak ground acceleration of 297 cms^{-2}.

Amongst recent earthquakes in western Saudi Arabia, the following should be mentioned [8,45,46,72]: a sequence of earthquakes in June

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http://dx.doi.org/10.1016/j.soildyn.2017.06.009
Received 27 February 2017; Received in revised form 22 May 2017; Accepted 11 June 2017

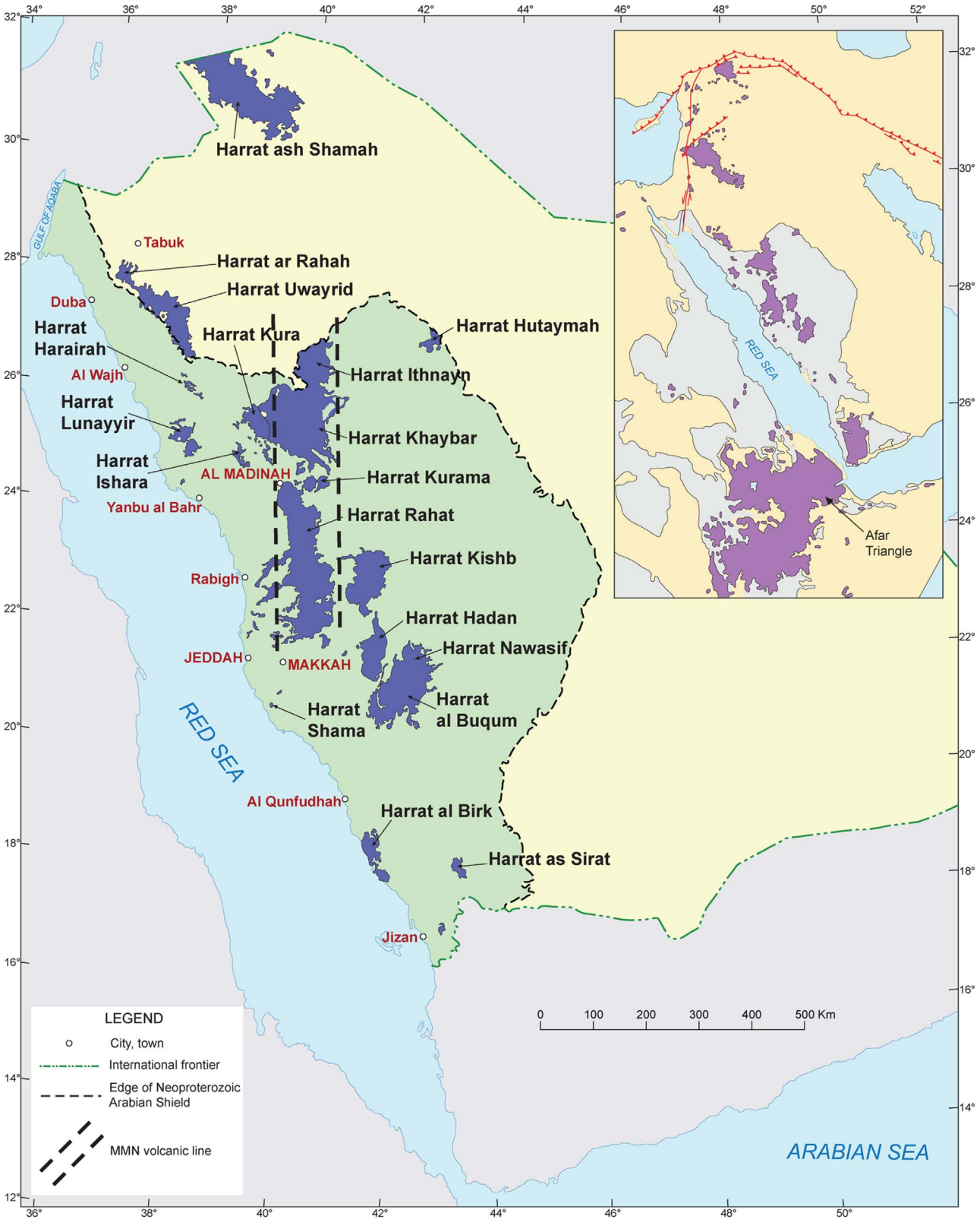

Fig. 1. Cenozoic lava fields (harrats) of western Saudi Arabia (after [73]).

2004, approximately 60 km southwest of Tabuk city, with the largest event of M_L 5.2 occurring on 22 June; a M_L 5.1 event occurred on August 27, 2009 (38.75 N, 24.13E) about 45 km north of Badr city, and an earthquake swarm occurred in Harrat Lunayyir with the largest event of maximum magnitude M_L 5.4 on May 19, 2009. The earthquake caused minor damage to structures in the town of Alays located a few tens kilometers to south-east from the earthquake swarm area (Fig. 2).

Characteristic of the earthquake swarm occurred in 2009 in the Harrat Lunayyir are described in detail in several papers [1,18,43,68,72]. More than 15,000 seismic events with magnitude $M > 0$ occurred during the period from 15.05.2009 to 30.09.2010, including 19 earthquakes of M 4.0 or greater with a M_L 5.4 (M_W 5.7)