OMAN SEISMOLOGICAL NETWORK AND SEISMICITY

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ABSTRACT

Sultanate of Oman unique location on the southeast corner of the Arabian Plate makes it susceptible to felt earthquakes over the years. Information on earthquakes in the vicinity of Oman can be found in literature includes examples of devastating events such as the earthquake that damaged several villages in the vicinity of Muscat 1883, the earthquake that damaged Qalhat in northern Oman at the end of the fifteenth century, and earthquake events that occurred in the Musandam region (northernmost Oman) in 977 AD, 1184 AD, and 1483 AD. Those historical earthquakes and the surrounding active tectonics along the Makran subduction zone, the Gulf of Aden, and the Zagross collision zone; along with the fast development of Oman in the last few decades all necessitated the establishment of a local seismic network to monitor seismic activity in and around the Sultanate. In order to record earthquakes and mitigate earthquake hazard by a good manner, a multi-phase program was approved by the authority and followed by the earthquake Monitoring center (EMC) at Sultan Qaboos University (SQU).

Oman Seismological Network (OSN) consists of twenty broadband stations. The phase I of OSN consisted of ten three component short period sensors (SS-1) distributed at remote locations in north and south Oman regions. Those remote stations transmit recorded seismic data continuously via the VSAT satellite to the Earthquake Monitoring Center (EMC) at Sultan Qaboos University (SQU). The phase II of OSN consisted of three broadband seismograph stations. Two of these stations are located in northern Oman in Musandam and Alburaimi areas and the other one is located in Dhofar region; Southern Oman. In 2011, the OSN enhanced by the completion of installing phase III stations. This phase consists of seven broadband seismograph stations distributed to fill in the gap between separated stations and where more seismicity is expected. Thus, two of them located in the north, one in Al-Sharqiyah region, two in Al-Wusta and two in Dhofar region; Southern Oman. Recently, the short period stations have been upgraded to broadband. By conducting this phase the records of local seismicity increased especially in the north (Masafi-dibba) region as well as in the south. To sum up, this phase enhanced the network coverage and more small magnitude local seismicity starts show up. Current seismicity shows that the earthquakes are concentrated along the known tectonic sources.

INTRODUCTION

Oman is located in the southeastern part of the Arabian Peninsula. Tectonically, it is situated in the south eastern part of the Arabian plate. Arabia as a part of the megacontinent "Gondwana", was located south of the equator throughout the palaezoic era. Initially, it was geometrically 'up-side-down' relative to the poles as "Gondwana" moved south across the South Pole (and came up the other side the 'right-way-up') under the influence of plate tectonic processes.

The Arabian plate moves to the north direction away from African plate. This caused the creation of oceanic lithosphere along Aden and the Red sea plate boundaries. However, the continental crust of the Arabian plate collides with the Eurasian plate along the Bitlis and Zagros stature zone in the north and northeast part of the Arabian plate. Zagros accommodates part of the convergence between Arabia and Eurasia. Its mountain belt is approximately 1500 km long, 250-400 km wide [6], and runs from eastern Turkey, where it connects to the north and east Anatolian faults to the Sea of Oman, where it dies out at the Makran subduction zone. The northern Oman mountains form an arc extending for 700 km from Musandam in the north to the east coast at Ras al Hadd. The mountains define an obduction zone where the mid-oceanic rocks and deep ocean sediments of the ancient Tethys Ocean were thrust upwards and over the continental shelf and slope rocks of the Arabian platform.

The Arabian plate moves at a rate of 18 +/-2 mm/yr relative to the stable Eurasian plate [5].
In terms of plate tectonics, northern Oman is sited closest to the subduction type plate margin of Makran and Sea of Oman and to the transform type margin of the Owen-Murray Fracture zone. In the southeast, the Owen-Murray Fracture zone separates the Arabian and Indian plates, along a line just about parallel to the east Oman coastline 450-600 km offshore. On the other hand, the Dhofar region (southern part of Oman) is only about 250 km from an active spreading ridge to the south in the Gulf of Aden (Figure).

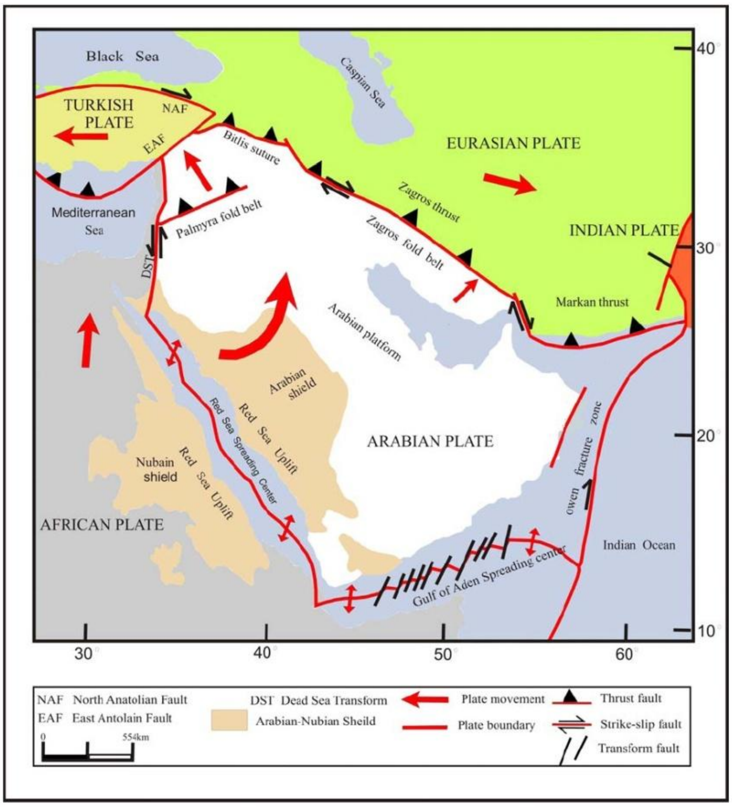


Figure 1. Oman location relative to major tectonic elements (modified after Johnson, 1998).

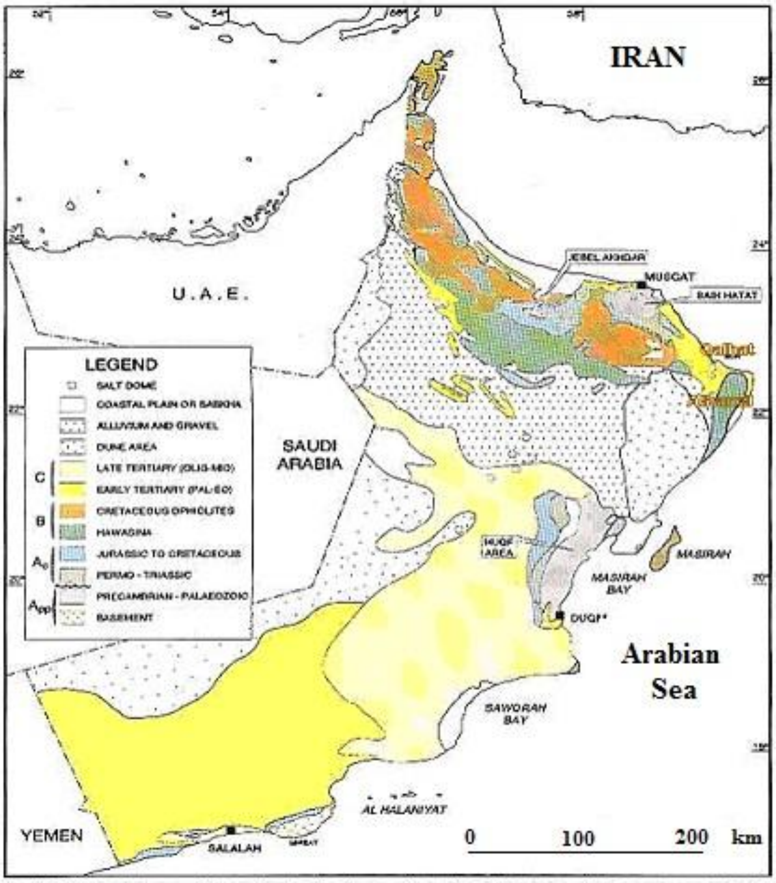
NEOTECTONICS OF OMAN

Earthquake hazard assessment includes evaluation of regional neotectonics that can be carried out by studying the crustal movements in the last 25± million years. Existing data is not sufficient for detailed evaluation except in very general terms. Initial studies has been done by Glennie, 1974 and current BRGM work has reported the present of various late Cenozoic landforms and deposits suggestive of neotectonic or possibly past seismic activity.

It has been found that:

- Multiple terrace wadi and alluvial fan deposits found in the Batinah piedmont, in interior basins, major drainages along the northern coast and along the Salalah piedmont area.
- Multiple staged terraces, marking ancient coast-lines and rising to heights of up to 300m above present sea level, has been observed at many places along the northern coast from Muscat to Ras Al-Hadd, and in the Mirbat area of Dhofar.
- Deeply entrenched drainages, some obviously antecedent to present topographic relief and expression.
- Evidence of submergence along the highly indented ria-type coastline of the Musandam Peninsula.
- Large scale landslide deposits, such as in Wadi-Mayh (Yitti track) and Wadi Mistal, which may be related to major slope failures during significant earthquakes.

The phenomena described above indicate periodic or irregular changes in relative sea level, and or climate and might reflect regional tectonic uplift that could still be continuing. The amount to which slow continued uplift may still be occurring accompanied by the occurrence of earthquakes is debatable.



Simplified geological map of Oman showing the three major geological provinces, the Oman mountains in the north (including the Musandam Peninsula), the Huqf area west of Masira Island and the Dhofar mountains.

Figure 2. Geological map of Oman.

SEISMICITY OF OMAN

The Sultanate of Oman forms a major part of the Arabian plate, which is directly affected by geodynamic processes acting in the Red and Arabian Seas. Such processes result in deforming this plate in different ways. The most obvious is a related movement towards the north-northeast and the creation of certain regional faults and fault systems that run in the north, northeast, northwest and east-west directions (Figure). Earthquake activity shows a clear concentration along the boundaries of this plate and its intra-regional fault systems. Recent, historic and pre-historic data clearly indicate the occurrence of some destructive earthquakes in and around this plate with a noticeable correlation with the major tectonic elements.

The destruction of old Qalhat could be an evidence of historical seismicity. In addition, Al-Kamil earthquake that has a magnitude of 5.1 instrumentally recorded by USGS occurred on March 1971 is an evidence of seismological activity in the region (see Figure). Furthermore, the Dhamar earthquakes, 5.7 in magnitude occurred in 1982 has been felt by some people in Salalah region is an evidence of earthquake hazard in the region. In addition, an earthquake swarm occurred in Rustaq area in 1998 and 1999. Twenty out of 120 events felt by people where the highest magnitude was about 3.2 in Richter scale.

According to these facts, execution of a national seismic monitoring program is necessary to assist and mitigate the earthquake hazards. The first phase of this program has been completed in 2001 represented by ten remote stations and the earthquake monitoring center (EMC) that located at SQU. The network has been enhanced by three broadband stations in 2004 (phase II). In 2011, phase III has been conducted with seven broadband stations.

EMC is responsible for monitoring earthquakes that occur in and around the Sultanate through many seismic stations deployed in different parts in the country. The main objective is to assess the seismic hazard in the Sultanate by locating all seismic zones and determining their characteristic and effect in all types of civil constructions. Such result forms the major input data for planners and civil engineers to mitigate the effect of this hazard. Based on these, building codes that account for horizontal dynamic earthquake loads on constructions can be prepared and practiced. Earthquake information is disseminated to the planners by the Center annual publication that includes earthquakes parameters such as location, magnitude and time. The center also aims to conduct scientific research in seismology and related fields, coordination and cooperation with the different international earthquake monitoring centers, offering advice and consultations, conducting earthquake-related seminars and conferences and spreading knowledge to the public about earthquakes, and ways of reducing their hazards.

Figure illustrates the seismicity of Oman from the year 2012-2014. It can be seen that the seismicity is concentrated along the known existing faults such as Zagros suture, Makran trench, Owen Murray Fracture zone and Gulf of Aden. In addition, quiet few events occurred along Masirah fault. Figure 4 shows the locations of felt events from year 2001 till 2013.

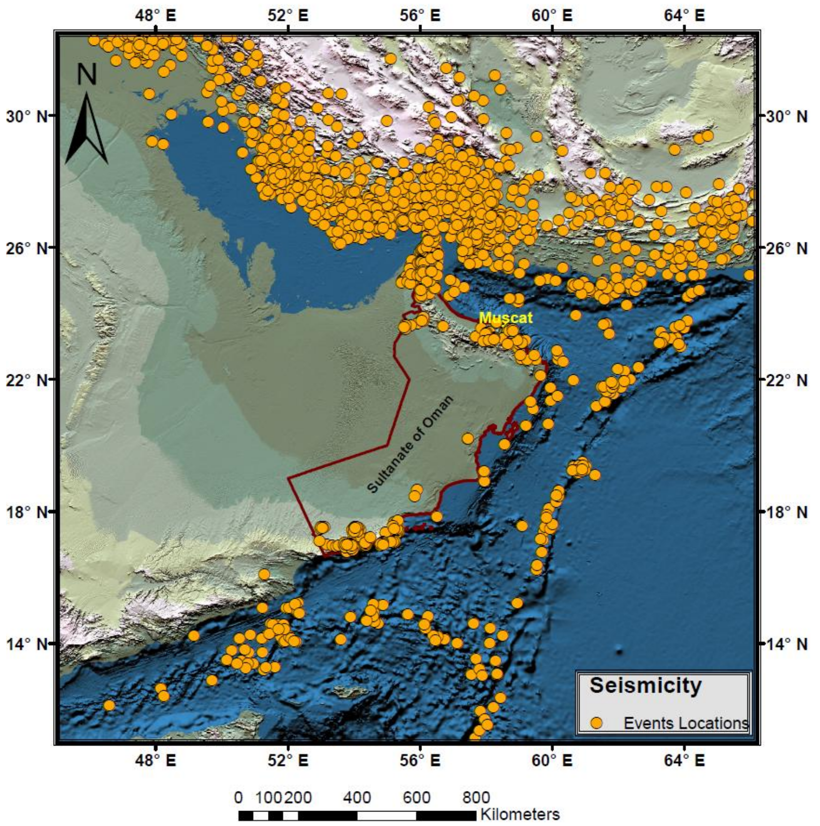


Figure 3. Map illustrates the seismicity.

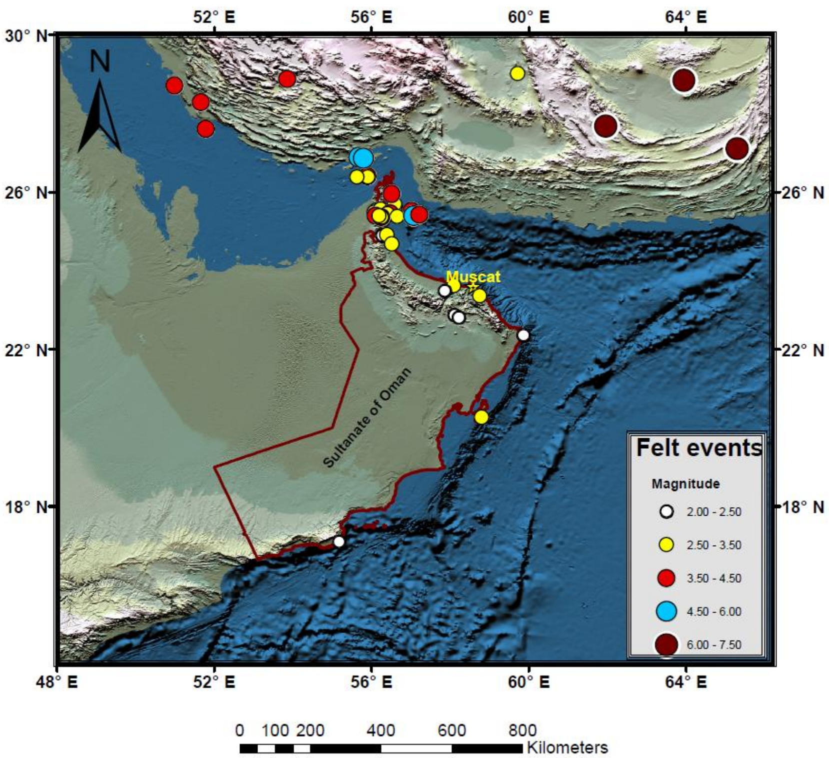


Figure 4. Map illustrates the locations of the felt events.

OMAN SEISMOLOGICAL NETWORK

The EMC at the SQU operates Oman Seismological Network (OSN) which consists of twenty seismographic stations. It started recording with ten short period stations since July 2001 (Phase I). The other ten are broadband seismograph stations; three of them established in June 2004 (Phase II) while the remaining seven started recording in March 2011 (Phase III). In 2013, the short period stations were upgraded to broadband stations. The geographic distribution of the seismic stations is shown in Figure .

These remote stations transmit the continuous recording of ground motion via a satellite (VSAT) to the EMC at SQU. The EMC started utilizing data from some stations from the Global Seismological Network (GSN) during 2007 and also CTBTO stations during 2011 to improve the location of teleseismic earthquakes. EMC also started utilizing data from Dubai Seismic Network since 2006 as well as UAE stations during 2011 to improve the accuracy in locating the Dibba-Masafi events.

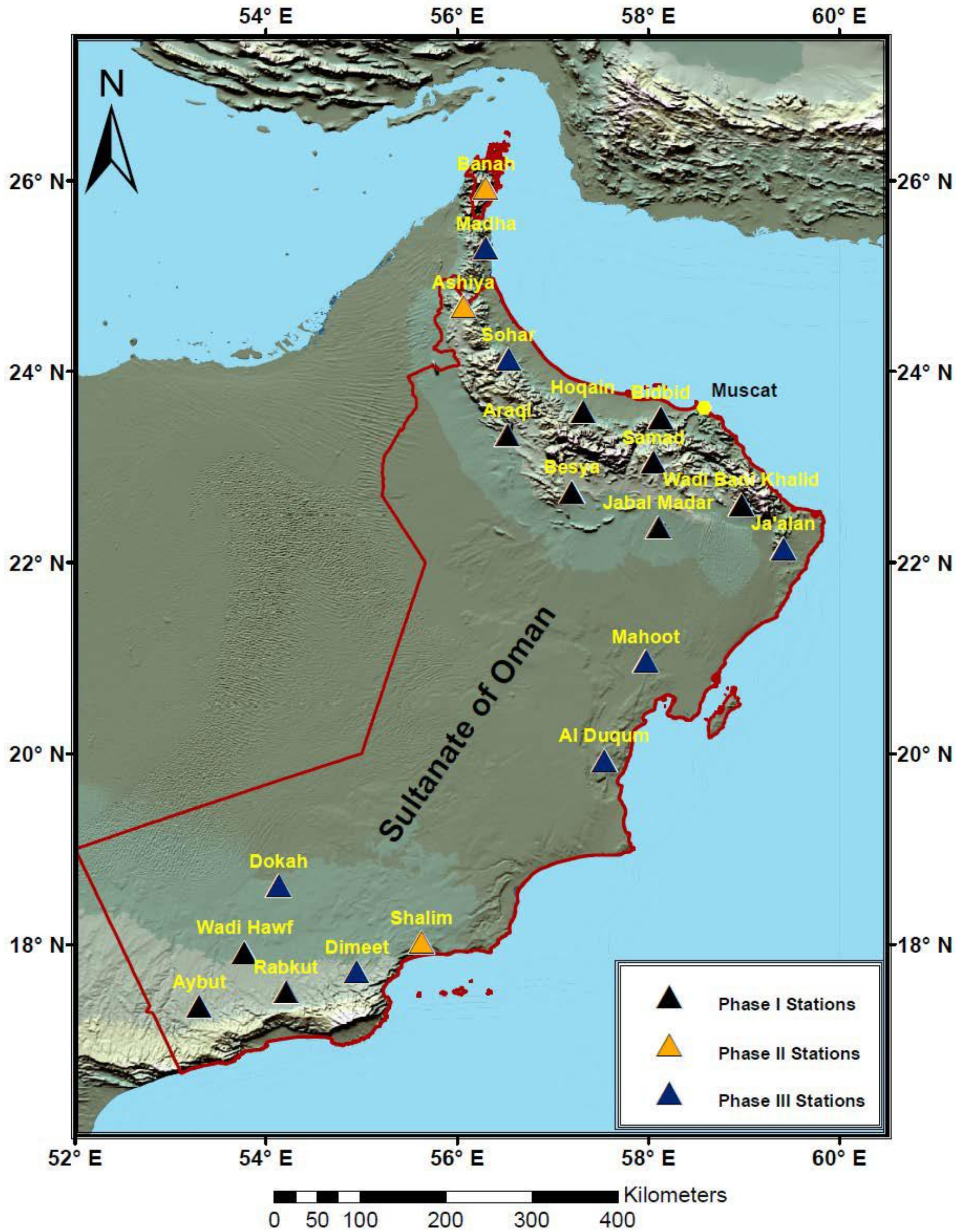


Figure 5. the locations of the seismic remote stations.

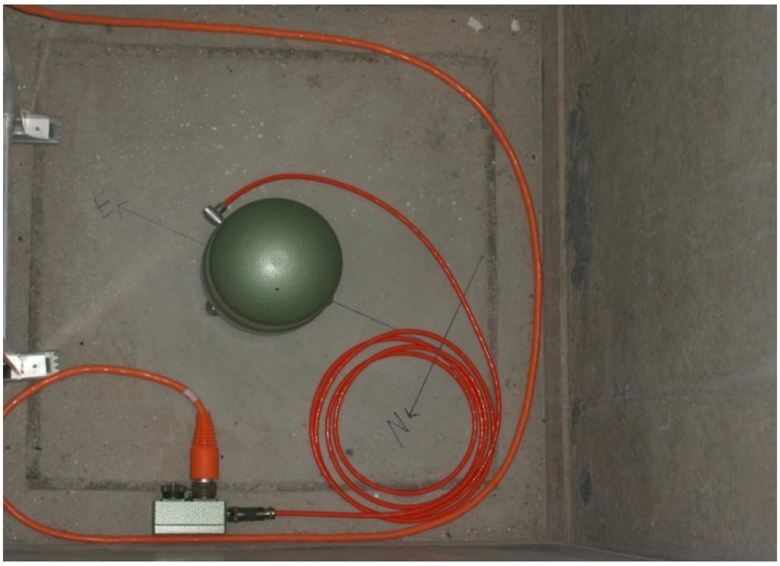


Figure 6. STS-2 seismometer

Figure 7 shows a general view of one of the remote stations. All the stations equipped with a broadband seismometer such as STS2.5, Trillium 240 and STS-2 (Figure 6) with Q330 datalogger. The Q330 datalogger is an advanced 3 or 6 channel broadband high resolution seismic systems (Figure). Table 1 shows detailed information about OSN stations.

Table 1. Stations information of the Oman Seismological Network.

Sta. Name	**Code**	**Lat.**	**Lon.**	**Elev.[m]**	**S-Type**	**Datalogger**
Samad	SMD	23.0589	58.0492	1000	STS-2.5	Q330HRS
Jabal Madar	JMD	22.3701	58.1035	350	STS-2.5	Q330HRS
Wadi Bani Khalid	WBK	22.61	58.97	450	STS-2.5	Q330HRS
Araqi, Ibri	ARQ	23.3366	56.5219	400	STS-2.5	Q330HRS
Bidbid	BID	23.5211	58.1269	200	STS-2	Q330HRS
Bisya	BSY	22.7446	57.1995	450	STS-2.5	Q330HRS
Hoqain, Rustaq	HOQ	23.5824	57.3109	350	STS-2.5	Q330HRS
Wadi Al-Hawf	WHF	17.919	53.7706	550	STS-2.5	Q330HRS
Rabkut	RBK	17.5035	54.2039	550	STS-2.5	Q330HRS
Aybut	ABT	17.3538	53.2966	650	STS-2.5	Q330HRS
Shalim	SHA	18.0228	55.6251	292	STS-2.5	Q330HRS
Ashyiah	ASH	24.6839	56.0583	546	STS-2	Q330HRS
Banah	BAN	25.9233	56.2996	504	STS-2	Q330HRS
Sohar	SOH	24.1342	56.5336	100	Trillium240	Q330S
Madha	MDH	25.2987	56.2983	185	Trillium240	Q330S
Jala'an	JLN	22.1505	59.4108	190	Trillium240	Q330S
Mahoot	MHT	20.9698	57.968	101	Trillium240	Q330S
Al-Duqum	DQM	19.9289	57.5393	169	Trillium240	Q330S
Dokah	DOK	18.618	54.1288	161	Trillium240	Q330S
Demeet	DMT	17.7163	54.9475	161	Trillium240	Q330S

Figure **7.** General view of remote station.

The datalogger digitizes the seismic signal at 100 sps. The satellite system transfers the IP data packets to the Central Data Acquisition System (CDAS) at EMC using TCP/IP and UDP/IP protocols. Each station transmits the data to a central hub where the data is gathered and transmitted in one channel to EMC at SQU (Figure). The data also transmitted via a dedicated link from the central hub to the Multi hazard early warning center at DGMET. The CDAS at EMC consists of a communication server and Antelope software package. The communication server merges all incoming and outgoing data streams and forwards them to the Local Area Network (LAN) from which they are distributed to the appropriate workstation using the specified protocol socket connection.

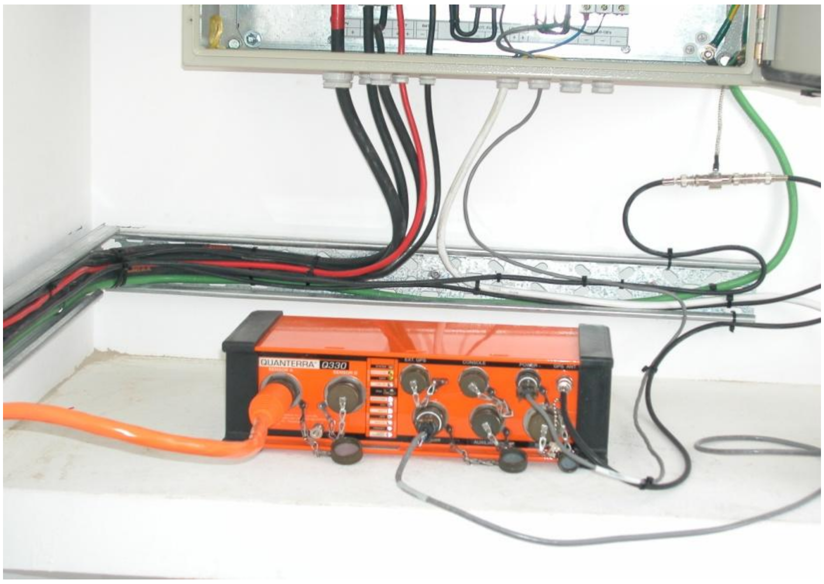


Figure 8. Q330 datalogger.

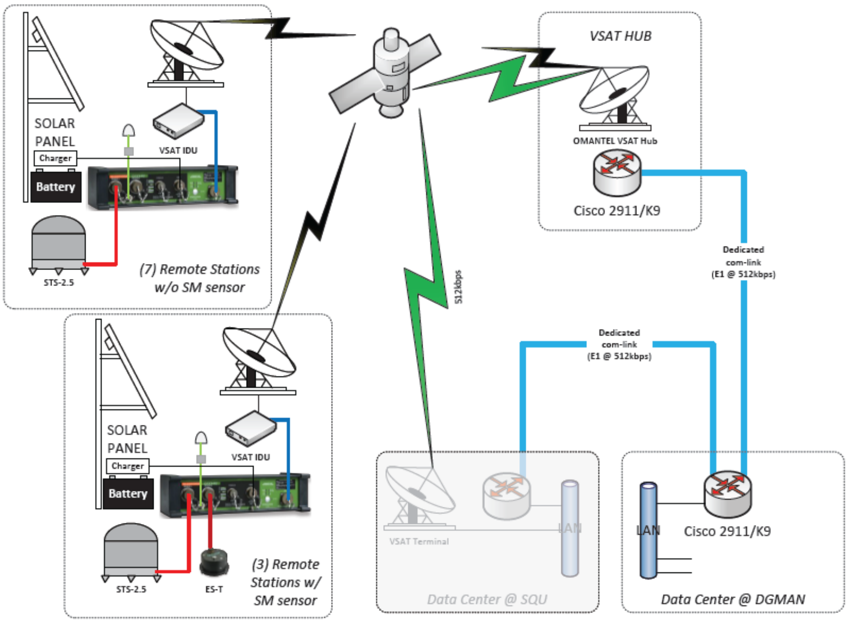


Figure 9. Satellite link.

Antelope is a software package for real time seismic network data acquisition and processing. It is a system of software modules that implement acquisition, transport, buffering, processing, archiving and distribution of environmental monitoring information. It provides a Real-Time Graphical User Interfaces, point-and-click modules for overall system monitoring and control and real-time display of raw waveform data (Figure). In addition to those modules antelope provides Field Interface Modules that can connect with field sensor/digitizer hardware and acquire data. These modules can also obtain state of health information about the different field units.

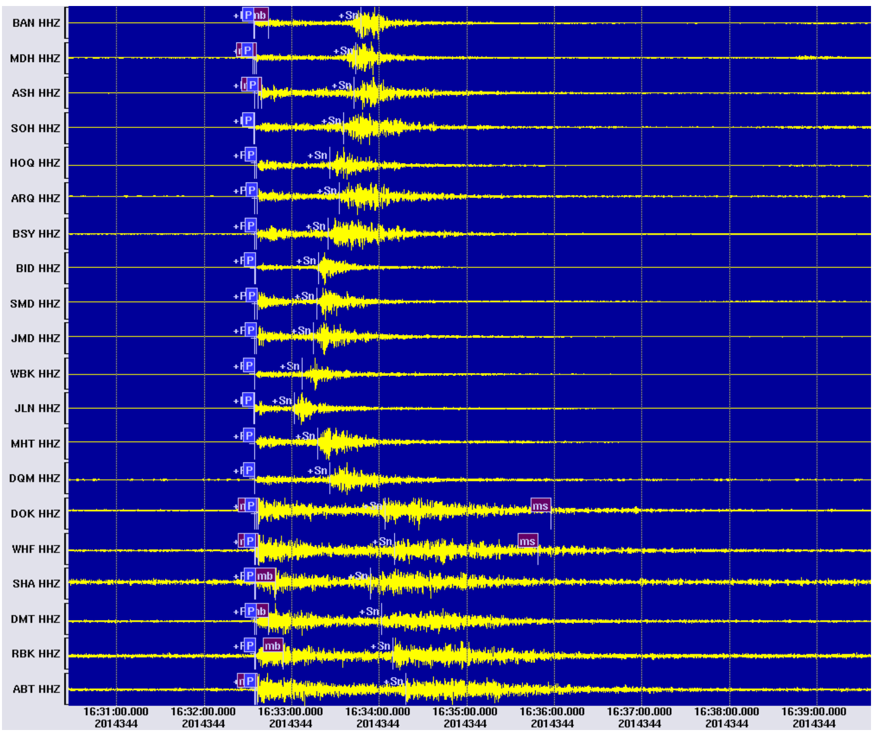


Figure 10. Real-time display of raw waveform data.

CONCLUSIONS

Oman seismological network has enhanced its ability in locating the earthquakes in and around the Sultanate.

By correlating the seismicity map with the faults map in Figure , it can be observed that the earthquakes concentrate along Zagros and Makran belts from north direction, Owen-Murray Fracture zone from east direction and Sheba Ridge in Gulf of Aden from south in addition to the local faults within the Sultanate. In addition, as can be seen in the seismicity map many earthquakes occurred along Masirah fault. Thus, it can be concluded that Masirah fault is potentially active.

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