2nd TRIGGER International Conference

2018

Book of Abstracts

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Trans-disciplinary Research on Iranian Geology, Geodynamics, Earthquakes and Resources

November 12-14

University of Tehran
Tehran, Iran

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Book of Abstracts

Edited by: Soroush Modabberi, Philippe Agard, Parisa Gharibnejad, Elham Shabani, Mahsa Tashakor

2nd TRIGGER International Conference

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TRIGGER

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School of geology, University of Tehran
Tehran
Iran

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About the TRIGGER Conference:

TRIGGER, "Trans-disciplinary Research on Iranian Geology, Geodynamics, Earthquakes and Resources", is an international scientific coordination network meant to pursue and develop the collaboration between Iran and France in the fields of Geology/Geodynamics, Earthquakes (and hazard assessment) and Mineral resources.

This network continues the already established collaborations between Iranian and French organizations (e.g. Geological Survey of Iran, National Cartographic Center of Iran, International Institute of Earthquake Engineering and Seismology, and the universities of Paris, Montpellier, Strasbourg, Grenoble and etc.) at the start of the millennium but with a broader scope and more participants, both from the Iranian and French sides.

The first Trigger conference was held on May 6-7, 2017 at Geological Survey of Iran, Tehran, Iran with participation of Iranian and French scientists. Following this conference, the steering committee of TRIGGER network decided to hold the second conference on 12th-14th of November 2018 and the University of Tehran was selected as the organizer and host of this conference.

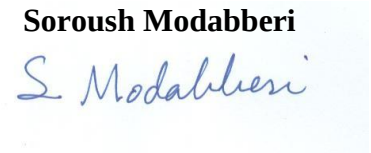
TRIGGER conference is actively supported by the National Research Center of France (CNRS) through the Institut des Sciences de l'Univers (INSU; "GDRI" programme). Participation of scientists from other European countries is also foreseen.

The secretariat of the 2nd TRIGGER International Conference would like to thank researchers who supported us by sending abstracts to the conference in spite of the shortage of time and we cordially appreciate the keynote lecturers and participants from France, Switzerland, Italy, the Netherlands, Germany, Denmark, and Iran for their heartening support.

We hope you a fruitful conference and pleasant stay in Tehran.

With compliments

Soroush Modabberi



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Trans-disciplinary Research on Iranian Geology, Geodynamics, Earthquakes and Resources

Paleoseismic Behavior of Slow-Slipping Intracontinental Strike-Slip Faults

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The available decadal geodetic and longer-term geologic observations illustrate that continental interiors experience low rates of deformation. These limited internal deformations, however, remain sufficient to create strong, and destructive earthquakes on seismogenic structures far from plate boundaries. As a consequence of low strain rates, large earthquakes may repeat with long recurrence intervals beyond the time span covered by historical seismic catalogs. In the past decades, several devastating intracontinental earthquakes occurred on fault segments that had not generated a surface-rupturing earthquake over their historical times. The occurrence of catastrophic earthquakes in Iran (Rudbar-Tarom, 1990; Bam, 2003), India (Bhuj, 2001), Pakistan (Kashmir, 2005), and China (Wenchuan, 2008) are representative examples of such a situation. Thus, understanding the seismic behavior of slow-slipping intracontinental faults in longer times is a crucial step in forecasting the likely size of future earthquakes on faults seem to be seismically quiescent during the last few millennia. Such active faults, in turn, may pose a significant seismic hazard to adjacent areas. This lecture summarizes the paleoseismic records of several intracontinental strike-slip faults characterized by low rates of slip across three separate tectonic contexts: the Central Iran plateau, the external Dinarides, and mainland Portugal. In Central Iran, the paleoseismic investigations along three major strike-slip faults (Dehshir, Anar, and Nayband), whose geologic slip rates range between 0.7 and 2.5 mm yr^{-1} uncovered the evidence of infrequent large ($M_w \approx 7$) earthquakes over late Pleistocene and Holocene time periods. The most recent earthquakes on the Nayband and Dehshir faults occurred after A.D. 1200 and shortly before ~2 ka, respectively. However, these events went unnoticed in the available historical seismic records, challenging any seismic hazard assessment without geologic information. The paleoseismic records show that Central Iran does not behave totally as a rigid block and that its limited internal deformation is nonetheless responsible for a significant seismic hazard. Paleoseismic studies also performed along two other strike-slip faults in the external Dinarides (Raša fault) and mainland Portugal (East Lower Tagus Valley fault), where the fault traces partly obscured by vegetation cover and extensive agricultural activities. The airborne Light Detection and Ranging (LiDAR) datasets were processed and used to overcome these limitations, which allow detecting youthful, subtle surface expressions. Combining the LiDAR datasets, drone-derived high-resolution topographic data, field observations, and paleoseismic studies along the Raša and East Lower Tagus Valley faults reveals the occurrence of infrequent large earthquakes in their late Quaternary histories. These findings add to previous works performed across intracontinental areas characterized by low rates of deformation and indicate that paleoseismology is a robust tool to improve seismic history of such seismotectonic settings. In addition, the results illustrate that large infrequent earthquakes typify the slow-slipping strike-slip faults slicing continental interiors in Central Iran, external Dinarides, and mainland Portugal.

Tectonic-Stratigraphic Evolution of the Iranian Domain since the Late Permian: the DARIUS Palaeotectonic Maps

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The DARIUS Programme (2010-2015) was a multi-disciplinary geological program sponsored by Major Oil Companies and Research Organizations. The main objective was characterizing the tecto-stratigraphic evolution since the Late Palaeozoic of the Central Tethys domain. 116 original scientific projects, executed by 150 research institutions from 25 countries, were funded by DARIUS. The DARIUS Programme was designed ultimately to provide new and modern insights on the geodynamic-tectonic development of this region through a set of 20 Palaeotectonic maps ranging in age from the Middle Permian to the Pliocene.

The maps of the DARIUS atlas are palinspastic reconstructions of the south-central Eurasian and north African-Arabian plates starting after the Late Palaeozoic orogenies. The maps depict the major tectonic-geodynamic features as well as the main paleofacies and paleoenvironments. Our reconstructions are based on (1) an up-to-date kinematics reconstruction of the Africa, India and Arabia with respect to Eurasia, and (2) an accurate timing of the tectonic-stratigraphic events that have succeeded since the Late Permian.

Three main periods have succeeded since the Late Palaeozoic during the subsequent opening and closure of the Neo-Tethys oceanic domain. The first period, lasting from Permian to Liassic times, is related to the evolution of the Cimmerian blocks that successively (1) detached from the northern margin of southern Pangea in the Early Permian, (2) drifted northward during the closure of the Paleo-Tethys oceanic domain during the Mid-Late Permian to Triassic times, and (3) finally collided with northern Pangea from mid-Triassic to Liassic times.

The second period is mainly characterized by the northward subduction of Neo-Tethys beneath the southern Laurasian-Eurasian margins. This long subduction (from Jurassic to Early Cenozoic) is associated with the openings of back-arc and marginal basins in the overriding plate (Laurasia-Eurasia) during the Mesozoic (Black Sea, Great Caucasus, South Caspian, Central Iran).

The third period is the time of the Cenozoic Alpine collisions involving major continental plates (Africa, Arabia, India) and Eurasia (Fig.3). The first deformations initiated in the latest Cretaceous-Paleocene in the Dinarides-Hellenides. The major alpine events initiated in the Early Eocene with the collision of the (1) northern Indian promontory, and (2) Anatolian blocks with the southern Eurasian margin, followed by the Arabia-Eurasia collision in the Late Eocene. At the end of the Eocene, with the ongoing plate convergences, the entire Neo-Tethys oceanic domain was subducted. Continent-continent collisions were developing all along the southern Eurasian active margin originating the main alpine chains.

Coseismic slip distribution of the 2017 Sarpol-e Zahab earthquake inferred from InSAR

Sanaz Vajedian[1] , Mahdi Motagh[1,2], Zahra Mousavi[3] , Khalil Motaghi[3], Eric. J. Fielding[4], Bahman Akbari[5], Hans-UlrichWetzel[2] and Aliakbar Darabi[5]

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We investigated the source processes and tectonic significance of Sarpol-e Zahab earthquake occurred on 12 November 2017 with a magnitude of Mw 7.3 at the NW of Zagros Mountains. It was the largest instrumental earthquake that occurred in the region which generated a unique opportunity to investigate the source of large earthquakes in the Zagros. We used the Interferometric measurement generated from Sentinel-1 Terrain Observation with Progressive Scan (TOPS) data and ALOS-2 ScanSAR to produce the coseismic deformation map. We detected earthquake-triggered landslide and secondary fault using coseismic displacement map in Mela-Kabod and Qasr-e Shrin, respectively. We used Bayesian Inversion to apply non-linear inversion for the fault geometry. The inversion results agree well with single fault geometry, striking 354°, dipping 17°, and slipping 4 m with a rake of 141°. Once the geometry of the fault plane with uniform slip was estimated, we expanded the fault plane in along-strike and down-dip directions to obtain the distributed slip on the fault plane. The variable slip model presents a homogenous pattern elongating along the strike direction. The maximum slip of 5 occurred at depth between 14 and 20 km. Considering 30 Gpa for the rigidity modulus, we estimated magnitude of 7.29 Mw. The InSAR-derived fault geometry shows that the rupture area has a shallow dip angle of 17.5–19.5° at depth of ~18.7 km. Thus, we suggest that the responsible rupture for 2017 Sarpol-e Zahab earthquake is located on a low-dip-angle ramp connecting to a flat shear zone between MFF and MRF (two major faults of the study region). The thrust ramp and flat shear zone (i.e., decollement) are required if strain partitioning is occurring in the north Zagros, and they help the oblique convergence to be accommodated by the overthrust MFF and the strike-slip MRF.

Keywords: Sarpol-e Zahab earthquake; Zagors, InSAR geodesy; earthquake source parameters, decollment

Source parameters and ground motion simulation of 2017 Ezgele-Kermansh earthquake, Iran

M.R. Ghayamghamian

On November 17, 2017 at 21:48 (local time), a devastating earthquake of Mw =7.3 occurred near Ezgele City in Kermansha province, Iran at (34.91ºN, 45.96ºE). The earthquake shook large areas in west and north-west of Iran as well as east of Iraq The recorded motion at Sare Pole-Zhab station showed a long-period pulse suggesting a near-fault forward directivity effect contributing to the heavy damage observed in SarePole-Zhab city. In this study, the long-period (0.1-1.5 Hz) strong ground motions were simulated to answer some ambiguities in source parameters for fully description of the observed motion at Sare Pole-Zhab station. To this end, the Hisada's kinematic model accounting for both heterogeneous source characteristics and underground geology is applied to simulate the long-period ground motion. Different source scenarios suggested by previous studies are examined and the optimum scenario that could provide the best fitting between the simulated and observed motions was introduced. The slip model and asperities as well as velocity structure parameters are optimized in order to have the best possible fit between the simulated and observed velocity time histories. The good agreements between the simulated and observed low-frequency motions indicate a successful identification of source and slip parameters of the Ezgele-Kermansh earthquake.

Keywords: Ezgele-Kermansh earthquake (2017), heterogeneous source model, near-fault ground motion.

Geotechnical Aspect of 12 November 2017 Sarpol-e-Zahab Earthquake

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A destructive earthquake (Mw=7.3, Depth=18Km) struck the city of Sarpol-e Zahab and a vast region in west of Iran on 12th of November 2017 at 21:48 local time. The epicenter was reported near the Iran-Iraq border at a distance of 10 km from Ezgeleh and 37 km North West of Sarpol-e Zahab. The concentration of damages in the city of Sarpol-e Zahab and its surrounding area that result in the earthquake was so called Sarpol-e Zahab earthquake, seems to be partly related to the local geological and geotechnical conditions. On the other hands the earthquake has induced many slope instabilities of different types and dimensions.The present paper reviews these 2 aspect of Sarpol-e Zahab resulted from field visits after the earthquake occurrence as well as the ongoing researches by different teams of IIEES members. In first part we discuss the effect of local site condition on the earthquake ground motion for the city of Sarpol-e Zahab, based on damages distribution over the city and also ambient noise measurements and seismic refraction surveys. The results shows a relatively good matches between damages distribution and the proximity of buildings and soil natural periods. Another geotechnical aspect of this earthquake was the different types of slope instabilities, including deep seated huge landslides, rock falls, rock avalanches, and flows, that were occurred over a vast area with a length of 150 km from the Iran-Iraq borderline at the north-west to the city of Chovar (Ilam province) at the south-east. These instabilities led to some fatalities, destruction of several buildings, blockage of many main and secondary roads and other damages. Such a large distribution and diversity of geotechnical phenomena in comparison with seismic events of similar magnitude are notable and can provide valuable information for future studies. Many of these instabilities were occurred over old landslides deposits especially around the Rijab perched syncline that show the importance of old landslides in earthquake inducing geohazard. On the other hand the existence of these huge landslides may be the indicators for the historic large earthquake at this region. In addition to old landslides the susceptible geological formation combining with steep slopes are of most important factors for very high landslide hazard in the region. The results of landslide hazard zonation using Nero-Fuzzy method reveled very high susceptibility for the region around the Rijab syncline, northern slope of Dalahoo Mountains and also many of mountains ridges in the region.

Seismicity, Strong Motion Catalogues and Seismic Hazard Assessment of the Middle East Earthquakes; With Special Reference to Iran

Mehdi Zare[1], Mustapha Meghraoui[2], Jacques Hinderer[2], Farnaz Kamranzad[3], Hossein Memarian[3]

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In this paper, we present the most important researches on the seismicity catalogueues, strong ground motion databases and seismic hazard analysis of Iran and other active zones in the Middle East and south Asia. An emphasis in this paper is to represent the important controlling factors for the seismic source determinations, seismicity parameters and ground motion models.

From the seismotectonic point of view, the Iranian Plateau and the Middle-East region are exposed to high seismic activity and are greatly influenced by the continental convergence and active crustal shortening between the African, Arabian and the Indian plates to the NE and northward with respect to the Eurasian plate. According to the regional tectonic regime of the Iranian plateau, the focal mechanism solutions of the most earthquakes are compressional, strike-slip or a combination of these two mechanisms (Fig. 1).

The GPS-derived velocity field for the zone of interaction of the Arabian, African (Nubian, Somalian), and Eurasian plates indicates counterclockwise rotation of a broad area of the Earth's surface including the Arabian plate, adjacent parts of the Zagros and central Iran, Turkey, and the Aegean/Peloponnesus relative to Eurasia at rates in the range of 20–30 mm/yr (Reilinger et al., 2006) (Fig. 2). Central Turkey (Anatolia) moves in a coherent fashion with internal deformation <2 mm/yr. The motion of Anatolia is bounded on the north by the right-lateral North Anatolian fault and on the southeast by the left-lateral East Anatolian fault. Upper bounds on fault slip rates for these faults are 24±1 mm/yr and 9±1 mm/yr, respectively. Relative to Eurasia, the southwestern Aegean-Peloponnisos moves toward the SSW at 30±2 mm/yr in a coherent fashion with low internal deformation (<2 mm/yr) (McClusky et al., 2000). The similar measurements in the Iranian continent and northern Oman performed by Vernant et al., (2004) indicate that most of the shortening is accommodated by the Makran subduction zone (19.5±2 mm/yr) and less by the Kopet-Dag (6.5±2 mm/yr). The Central Iranian Block moves consistently with internal deformation smaller than 2 mm/yr. In the western part of Iran, distributed deformation occurs among several fold and thrust belts. Between the Central Iranian Block and the Arabian Plate, the central Zagros accommodates about 7±2 mm/yr of north–south shortening. North of the Central Iranian Block, the Alborz mountain range accommodates 8±2 mm/yrof north–south compression. According to the GPS measurements by Wang et al. (2001), the southern parts of the Himalaya show northward movement (N19°-22°E) at a rate of 36 to 38 mm/yrwith respect to stable Eurasia. Bangalore in southern India has a northward velocity of 35.9±1 mm/yr. The maximum velocity (38 mm/yr) in the northern Ganges plains approximates the rate of convergence between the Indian and Eurasian plates. All these GPS analysis indicate high rates of deformation in the Middle-East region and the Iranian Plateau, so that the region is exposed to all-round pressures caused by the collision of lateral tectonic plates.

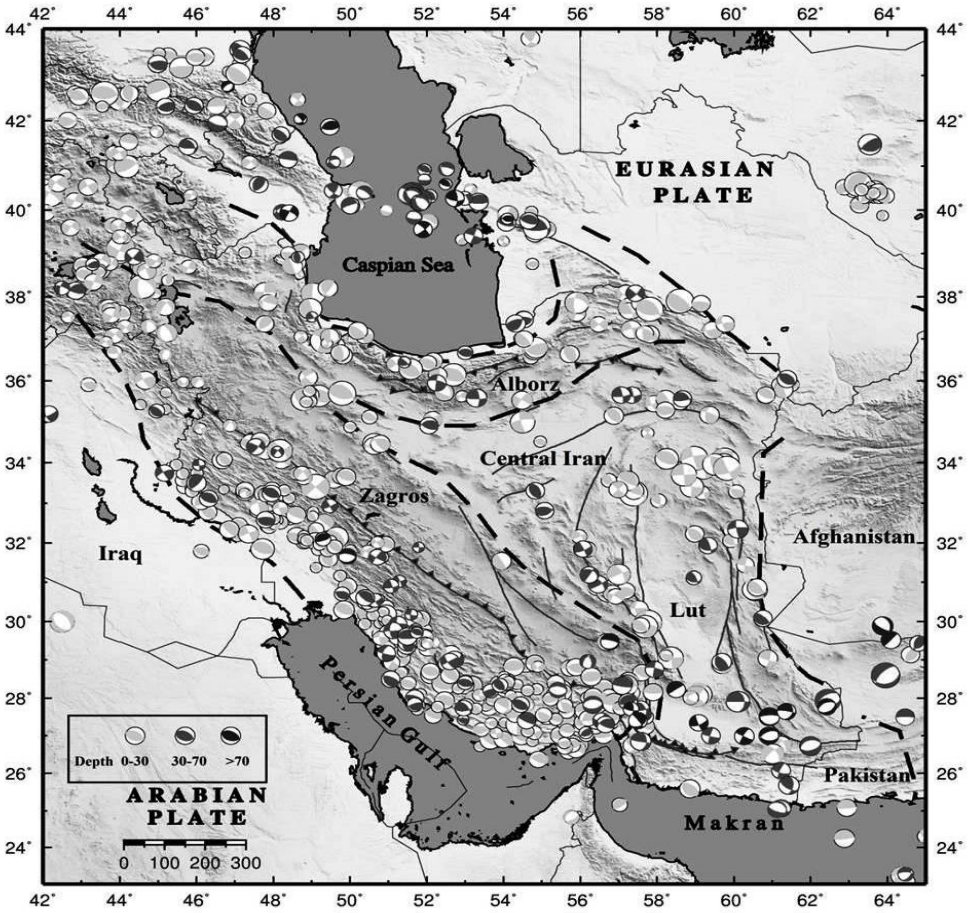

Fig 1. Focal mechanism of the main earthquakes recorded in Iran during the last century. dashed lines: borders of the 3 main tectonic zones of Iran. solid line: major faults (adapted from Shahvar et al., 2013).

Therefore, the geodetic, seismic and tectonic studies in the region confirm the existence of a complex active tectonic framework with high deformation rates, a part of which expressesin terms of earthquakes. This region experiences different earthquake magnitudes each year, some of them may reach Mw8 (e.g. 27 November 1945 Mw8.1 Makran earthquake). Many destructive earthquakes with magnitude≥7.0 have occurred during the last century such as the 1909 Silakhor (Mw.7.3), 1930 Salmas (Mw.7.1), 1962 Bou'in-Zahra (Mw.7.1), 1968 Dasht-e-Bayaz (Mw.7.4), 1978 Tabas (Mw.7.4), 1990 Manjil (Mw.7.4),1997 Ghaen (Mw.7.3), 2003 Bam (Mw.6.6), 2013 Savaran (Mw.7.8) earthquakes in Iran, 1939 Erzincan (Mw.7.8), 1970 Gediz (Mw.7.2), 1976 Çaldıran–Muradiye (Mw.7.0), 1999 Izmit (Mw.7.6), 1999 Düzce (Mw.7.2), 2011 Van (Mw.7.1) earthquakes in Turkey, the Nuweiba earthquake south of the Dead Sea fault and in the Gulf of Aquaba in Egypt, the 1935 Quetta (Mw.7.7), 1945 Balochistan (Mw.8.1), 2005 Balakot (Mw.7.6), 2011 Dalbandin (Mw.7.2) and 2013 Awaran (Mw.7.7) earthquakes in Pakistan, and the 2002 Hindu-Kush (Mw.7.4) and 2015 Hindu-Kush (Mw.7.5) earthquakes in Afghanistan (Fig. 3).

Taking into account the seismotectonic framework and high seismicity with destructive earthquakes as well as the large population density settled in the earthquake-prone areas, the necessity for the development of a database with field investigations for the seismic hazard and risk assessment is critical.

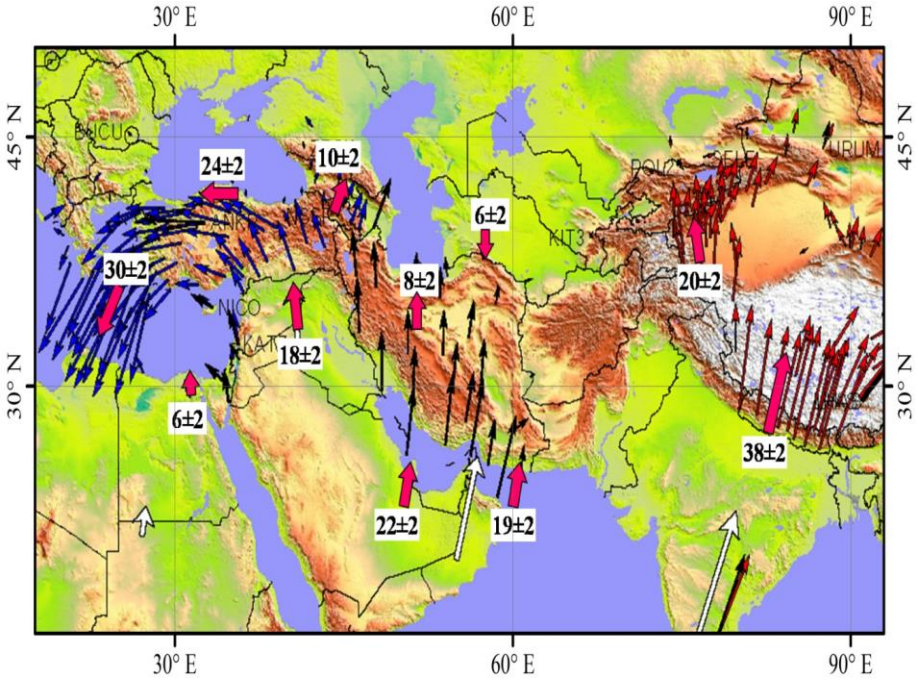

Fig 2. Horizontal velocity field for a major part of Alpine-Himalayan chain. The blue vectors are by Reilinger et al., (2006) and McClusky et al. (2000) and the red vectors are by Wang et al. (2001). The black vectors are by Vernant et al. (2004). The white vectors are the Nuvel1-A plate velocity model by DeMets et al. (1994).

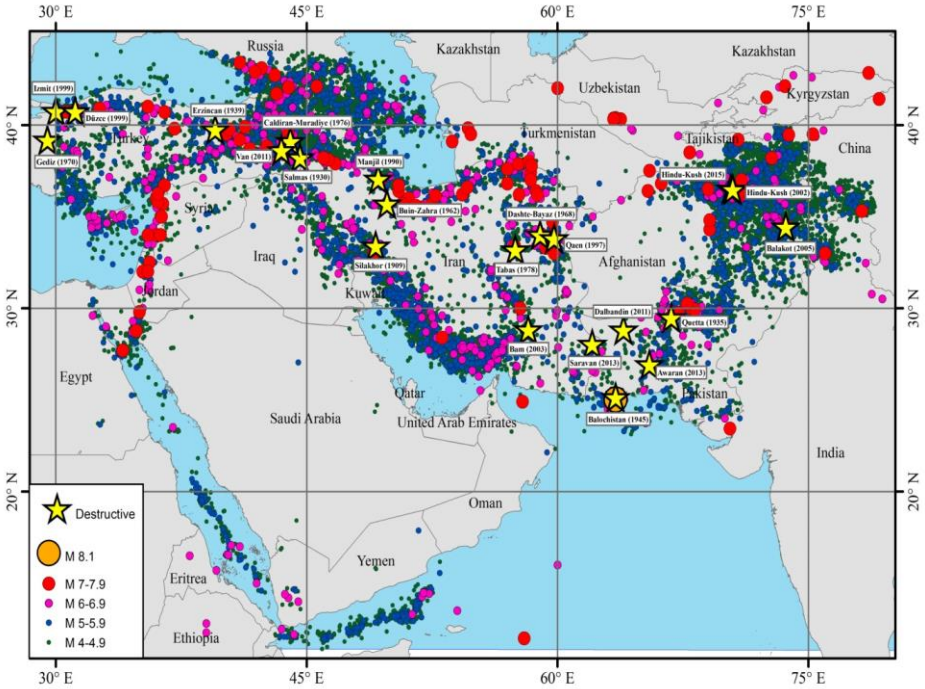

Fig. 3. Seismicity map of the Middle East region before declustering represented by epicenters of earthquakes (4≤Mw). Yellow stars indicate some of the destructive seismic events (with 6.5≤Mw) during the last century. Source of data: EMME earthquake catalogue (Zare et al., 2014).

After some earthquakes (such as the 1990 Mw7.3 Majil earthquake and 2003 Mw6.5 Bam earthquake), some questions were raised on the reliability of the seismic hazard zoning maps and on the comparison between the recorded and previously assessed ground motions. These triggered the importance of input dataset and the level of knowledge of the seismic source parameters in the region (fault geometry and mechanics, return periods of large and destructive earthquakes, etc..).

Another aspect of this paper is to represent the seismotectonic zoning and the critical review of seismic hazard studies performed by the first author during the last 17 years. We also show the necessity of the re-evaluation of seismic parameters and the development of seismic hazard studies in the middle east region, with a special reference to the seismic hazard assessment in Iran. The presented updated database of large and moderate earthquakes, background seismicity and strong motion catalogues, with the development of regional attenuation models, including uncertainties, is critical for seismic hazard analysis.

The application of most popular seismic hazard analysis methods such as the Deterministic Seismic Hazard Analysis (DSHA) as well as the Probabilistic Seismic Hazard Analysis (PSHA) in this region is explained. It should be noted that reliable seismic hazard studies depend on having a robust earthquake catalogue, good knowledge on the tectonic framework and rate of active deformation,and relevant attenuation model. The better input for hazard analysis results in more reliable the parameters and the seismic hazard assessments, so that precise input data such as comprehensive catalogues, seismicity parameters as well as charactersitic of seimotectonic zones lead to decrease uncertainties of the analaysis. There have been several efforts to prepare uniform earthquake catalogues of the Middle-East and Iran in the recent years such as a new earthquake catalogue of the Middle East region which has been developed consisting historical, early and modern instrumental events recorded between 1250 B.C. and 2006 (Zare et al., 2014). This effort was undertaken under the framework of Global Earthquake Model (GEM) and Earthquake Model of Middle East (EMME) projects and the final goal was to establish a unified catalogue of seismicity by incorporating regional and international data to be used for homogeneous estimation of seismic hazard in the region. In addition, two seismicity catalogues including a uniform catalogue for the Iranian earthquakes with a moment magnitude range of MW 3.5–7.9, from the third millennium BC until April 2010 (Karimiparidari et al., 2013) as well as a unified instrumental catalogue for the Iranian Plateau (1900–2011) with Mw≥4 (Shahvar et al., 2013) were prepared. In this regard, we also present the way of compiling raw metadata and the reason of declustering the most important recent catalogues as the comprehensive available databank.

Urban Microgravity Surveys

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Microgravity survey is one of the most promising geophysical methods in urban areas. Several case studies in urban areas for different targets are demonstrated in this paper. These case studies are carried out in urban and noisy environment for detecting and modeling the cavities, sink-holes and interfaces. Pits, man-made tunnels and buildings are considered as topographical effects and were corrected. Ground shakes due to the running facilities were also preventing us of a calm measurement. Despite all unwanted factors at site, we delineated the sink holes and interface quite accurately. The depth and the shape of the interface has been modeled by 2-D inversion of micro-gravity data.

Keywords: Microgravity, sink-holes, cavities, interface.

Joint Interpretation of Magnetotelluric and Seismic Velocity Data; Investigating the South Zagros Suture Zone

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Inversion results obtained from magnetotelluric (MT) data were jointly interpreted with the seismic velocity model along coincident profiles for more accurately recovering structural boundaries in the South of the Zagros mountain belt. A multi-site and multi-frequency approach was used for the strike analysis of regional structure and decomposition of distortion effects contaminated MT data. Distortion corrected MT data were then used for two- dimensional inversion modeling. The results image a conductive overburden in the southwest of the profile and a high conductivity contrast in the middle of the profile. Comparison with the s- velocity structure, obtained by joint inversion of P-wave receiver functions and the surface wave dispersion data, shows that these main conductive features are spatially correlated with a low-velocity layer representative of the sedimentary cover overlying the Arabian platform and a velocity contrast bounded by the main Zagros thrust (MZT) fault, indicating the presence of fault zone fluids.

High Resolution Maps of Full Gravity Gradient Tensor for the Iranian Plateau: Geophysical Approach and Implications for Sedimentary Basins

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The gravitational potential (geoid), gravity, and gravity gradients are inversely proportional to the distance from Earth by factors of r, r^2, and r^3, respectively. Such inverse relationship results in attenuation of deeper effects in higher order derivatives of the gravitational potential. Thus, calculating the full gravitational tensor from the available global gravity models allows generating high resolution maps that are considerably more sensitive to shallower effects (e.g. sediments) that deeper ones. In addition, the gravity gradiometry provide higher vertical and lateral resolutions. This work presents the first high resolution gravity gradiometry maps of Iran calculated from a geophysical standpoint rather than the usual geodetic framework. The geophysical data processing procedure is first explained, then the maps are presented and a preliminary qualitative interpretation is provided. Finally, the distinction between the gravity and gradiometry data is established in case of the sedimentary cover in the South Caspian Basin.

Investigation on Land Subsidence in Iran Using Gravity, GNSS Andprecise Levelling Data

Abdoreza Saadat[1], Jacques Hinderer[2], Hamideh Cheraghi[1], Jean-Daniel Bernard[2], Yahya Djamour[1], Masoomeh Amighpey[1], Seyavash Arabi[1], Hamidreza Nankali[1], and FarokhTavakoli[1]

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Population growth, coupled with the expansion of exploitation of groundwater resourcesfor agricultural and industrial purposes, has led Iran to face the adverse consequences of thequantitative and qualitative aspects of water resources. In this regard, the necessity of properuse and sustainable management of existing water resources is quite obvious. Increasing theuse of underground water has led to land subsidence in different parts of Iran. In order tounderstand the wide range of deformations caused by underground water changes, valuablegeodetic data collected in gravity, GNSS and precise levelling networks developed throughoutIran can be used. Based on repetition of 1st order precise leveling network of Iran,about 44 subsidence areas were identified and authorities in disaster management of the country were informed.Also, the continuous data collected by the Iranian permanent GNSS andgeodynamic network (IPGN) indicate that the elevation change due to vertical motion in someparts of the country is more than one meter. New absolute gravity campaigns were performed inIran in 2017 in cooperation with EOST Strasbourg team in France. Several new absolute gravitystations were established and former stations, first measured between 2000 and 2007, were repeated showing thatthe gravity values of many stations have changed in time. Ongoing research is done to relate these gravity changes and land subsidence to water depletion in Iran with the help of piezometric measurements.

Hydrocarbon Exploration Using High Resolution Local Passive Seismic Tomography; An application to the Dehdasht region, southwest Iran

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With the growing global demand for energy resources, passive seismic tomography started to be used widely for producing 3D images of the sub-surface structures using micro-earthquakes as a new revolutionary method in hydrocarbon exploration even in difficult mountainous terrains areas. In this study we used non-linear travel-time tomography technique to resolve seismic velocity structures in the Dehdasht area/Zagros region. The study area can be considered as an excellent place for studying passive methods due to frequent occurrence of small to moderate earthquakes. More than 8000 small seismic events, micro-earthquakes, were detected to image a 3D volume of Vp and Vs sub-surface structures. The final 3D VP and Vp/VS velocity models reveal several high and low velocity anomalies in the upper 3.0 km of the study area where shallow low-angle thrusts and synclines signify the complexity of the volume studied. We present the results of local passive seismic tomography in one of the most prone structures of the Earth for the hydrocarbon exploration; showing that a 3D image of the given region can be obtained for hydrocarbon exploration purposes at lower cost compared to classical 2D seismic control source studies.

Makran: where to?

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Recent work on the Makran region has allowed reassessing the stratigraphy, structure and signifcance of the Iranian Makran, in particular through the distinction of four main litho-tectonic units. The lithological content of these four units is briefly described to discuss the sedimentary environments, which record the general filling of an oceanic basin with clastic sediments derived from the north. The petrology of ophiolites, exposed in the backstop region to the north of the accretionary wedge itself, demonstrates the existence of an oceanic basin formed in the Jurassic-Late Cretaceous to the north of continental slivers, which had separated from Central Iran. There is petrological evidence for a subduction-related magmatic arc during the Late Cretaceous, which sourced much of the clastic material in the Cretaceous-Lower Miocene turbidites present throughout the wedge. The literature survey shows that the Late Cretaceous to Present evolution of the Pakistan part of the Makran fold-and-trust belt is in its major attributes similar to that of the Iranian Makran. These observations and results are discussed in a tectonic model that integrates knowledge on the Oman Mountains, on the other side of the current Oman subduction. In the light of this background, the remaining questions, problems and investigations that should be addressed will be emphasized.

New Insights into Present-Day Deformation of the Makran Subduction Zone From Continuous GPS: Impact of the Saravan Intra-Slab Earthquake in 2013 and First Evidence of Silent Earthquakes

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The Makran subduction zone (MSZ) along the SE Iranian and Pakistan coast accommodates ~30 mm/yr of northward motion of the Arabian oceanic plate with respect to the Eurasian plate. It is seismically silent, with only some rare earthquakes of magnitudes larger than Mw 6 recorded since the last century. Therefore, aseismic motions and silent slip events (SSE) are expected to occur in the MSZ. Only now, sufficient continuous GPS measurements belonging to the Iranian permanent GPS network run by the National Cartographic Center of Iran are available to provide evidence for the occurrence of eventual transient motions in the Iranian part of the MSZ.

Ten years of continuous GPS measurements at 9 stations in the Iranian part of the Makran subduction zone allow to establish the interseismic velocity field. It shows that seismic coupling decreases from west to east and from south to north, with values varying from 61% to 5%. A simple 1D model in an elastic half space fits the GPS displacements in average with a subduction interface dipping weakly by 5° and with low coupling of 10% from 50 km to 350 km from the trench.

The permanent GPS data allowed to monitor the Saravan earthquake in southeast Iran that occurred with a magnitude of Mw 7.7 on 16/04/2013. It is an intra-slab earthquake with a normal faulting mechanism at 50 km depth in the MSZ. The event is also visible in InSAR radar satellite images. Co-seismic displacements of 9 stations in up to 450 km distance from the epicenter and from the InSAR co-seismic displacement field are compared to predictions of a direct model of surface displacement, computed considering a dislocation consistent with the CMT mechanism. The closest GPS station SRVN 60 km south of the epicenter imposes some constraints on the exact location of the earthquake, but the GPS network is too sparse to distinguish between a north and a south dipping fault plane of the earthquake mechanism. For some of the stations, enough data are available to establish distinct inter-seismic and post-seismic velocities.

Interestingly, the closest station SRVN shows a post-seismic velocity indicating higher coupling of the subduction interface after the intra-slab event than before (increase from 5% to 23%). While in South American subduction zones these intermediate depth intra-plate earthquakes have the reputation to precede a large inter-plate event with decreasing the inter-plate coupling (c.f. Chili Tarapaca 2005 - Iquique 2014 earthquake sequence), the increase of coupling in the weakly coupled Makran subduction zone might bring the subduction interface closer to a classical inter-plate event as well.

Until today, no shallow inter-plate event occurred, but the GPS data indicate a horizontal offset of 23 mm at the CHBR station close to the Makran coast, during a data gap between end of 2013 and mid-2015. The fact that no instrumental changes affected the station during this time interval, and that the horizontal offset is directed in exactly the opposite direction as the interseismic motion, convinces us that we might observe here the first evidence of a slow slip event in the MSZ. The offset of 2.3 cm in the horizontal components above a subduction zone at shallow depth (10 km) can be translated into 5-7 cm of slip on the subduction interface, which yields, with a surface of the slipping patch of 50x50 km, an equivalent magnitude Mw of up to 6.4. The surface has been chosen not to include the next closest stations as they do not show any related offset because their data end at the end of 2013. Therefore, the slipping patch might be larger and the estimation of the equivalent magnitude represents a minimal value. An eventual triggering of the SSE by the Saravan earthquake needs to be investigated. In any case, the post-seismic increase of coupling at SRVN station is not modulated during the time interval of the SSE.

Thus, the occurrence of SSEs could explain the lack of classical seismic activity in a part of the MSZ. However, the observed spatio-temporal variability of coupling throughout the MSZ could limit the extent and the recurrence time of SSEs and leave place for classical earthquakes.

Structure of the Western Makran Subduction Zone from Seismological Studies

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We apply the receiver function method to new data from a temporary seismic network deployed in the western Makran region to image the geometry of the subducting and overriding plates the subduction zone. A migrated depth section of receiver functions shows a gently northward-dipping slab (~14°) with depth increasing from 30 km in the coastal region to about 100 km beneath the Taftan volcanic peak. A clear interface at 10 km depth beneath stations near the coast indicates the base of the sediments. The continental Moho of the overriding plate is observable at depths between 40 and 50 km. Furthermore, our results show intracrustal interfaces at 15 km depth in the crust of the overriding plate.

Deep Structure of the Makran Subduction Zone

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The Makran subduction zone is known as an end-member case thanks to its low subduction angle and related abnormal width. The mantle structure beneath the Makran, though, remains enigmatic due to the low seismicity and subsequent badly defined Benioff zone. We here discuss the 3D structure of the Makran subduction based on upper mantle tomography and surface information with a focus on the lateral variations.

Located between the Zagros and the Indian plate, the Makran slab subducts northward under Eurasia that locally is composed of two separate blocks, Lut and Helmand separated by the Late Cretaceous-Paleogene Sistan suture. On top of the subducting slab, the accretionary wedge represents a single 900 km long in front of the two overriding plates. A closer look at the surface geology reveals a marked difference between and east and west Makran, roughly coinciding with the two overriding plates.

As expected, the slab under western Makran is dipping NNE ward into the upper mantle, parallel to the Arabian plate motion. Under central Makran, the slab rotates towards dipping NW-ward under the Helmand block. The 070° orientation of the volcanic arc is in line with the slab below. The slab is continuous under west and central Makran with at ~200 km depth a slab window under the Afghan section starting east of Kuh-e Sultan, the most eastern volcano of the volcanic arc. The slab length under the western Makran is in the order of 500 km suggesting that at a Neogene subduction velocity of ca. 2 cm/yr (= velocity of the Arabian plate), subduction started at the end of the Oligocene, in accordance with the late Oligocene age for the oldest observed growth strata in the western Makran.

The Long-Term Structural Evolution of the Doruneh Fault Region: A Key to Understanding the Tectonic Response of Central Iran to the Arabia-Eurasia Convergence

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A better understanding of intraplate deformation requires the knowledge of the space-time scales involved in its development and to decipher possible links with the dynamic evolution of the plate boundaries.
Central Iran provides an ideal test site to approach this scientific issue, since it is characterised by a prolonged history of Mesozoic-Cenozoic intraplate deformation that has been interfering with the spatio-temporal re-organization of the Zagros convergence zone along the Eurasia plate boundary. Few quantitative temporal and kinematic constraints are available from these deformation zones, hampering a full assessment of the style and timing of intraplate deformation in Iran and the understanding of the possible linkage to the tectonic reorganization of the Zagros collisional zone.
This contribution presents a synthesis of the studies carried out in the last six years in the region that bounds to the north the Central East Iranian Microcontinent (CEIM) and discuss implications at regional scale. The focus is on the Doruneh Fault (DF) region that is considered as the northern mechanical boundary of the CEIM. By combining field investigations with low-temperature apatite (fission track and (U-Th)/He) thermochronology and (U-Th)/He dating of hematite coated fault surfaces carried out in areas both to the south (Kuh-e-Faghan Fault; Calzolari et al., 2016a, 2016b, 2018) and to the north (Tadayon et al., 2017, 2018) of the active trace of the sinistral transpressive Doruneh Fault, we present a revised tectono-stratigraphic scenario for the DF region.
The main results can be summarised as follows:

1) A long-lasting history of fault-related exhumation, burial and cooling starting in the Upper Cretaceous is documented for the DF region;
2) The DF region operated as a zone of residual stress accommodation and transfer in the hinterland domain of the Zagros convergence zone throughout the Cenozoic times.
3) At the Miocene-Pliocene boundary, a major change in the tectonic regime is recorded within the DF region, as a consequence of a shift in the regional maximum compression direction from ca. NW-SE to NS.
4) The present trace of the DF represents the last shear deformation increment of a polyphase and long-lasting zone of intraplate deformation sited at the northern edge of the Lut block of Central Iran.

When framed in the regional scenario, our results indicate:

1) The northern boundary of the CEIM was affected by a major and polyphase dextral deformation during the Cenozoic;
2) The Zagros convergence zone and its hinterland domain were fully mechanically coupled since ca. 40-35 Ma, a time lapse that is here referred to as the onset of continental collision along the Arabia-Eurasia plate margin.
3) A major transition from NE-directed escape to NS indentation tectonics is reconstructed at the Miocene-Pliocene boundary. This corresponds to a major regional re-organisation of the plate boundary, following the transition from an infant to a mature stage of continental collision in the region.

The interplay of advancing and retreating stages of the convergent plate margin may be proposed as the main cause of the intraplate deformation in the hinterland domain of the Arabia-Eurasia convergence zone during Mesozoic-Cenozoic times.

Results of this study further support the potential of the intraplate deformation zones to be used as a proxy to reconstruct the long-term dynamics and evolution of the deforming plate margins.

Towards a Reconciliation Between Petrological and Structural Data on the Initial Geometry of the Sistan Subduction Zone (Eastern Iran): Contribution of The Study Of Cretaceous Lavas

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Progressive closure of the Neotethys ocean led to the building of numerous mountain belts from the Alps to the Himalayas. In Iran, collision is responsible for the formation of the Zagros and Alborz mountains, the build-up of the Iranian plateau, and also the formation of the Sistan moutain belt in Eastern Iran, further inland. The Sistan belt stretches N-S along ~700 km at a high angle to adjacent mountain belts. It is characterized by a wealth of preserved Mesozoic ophiolites, large scale Mezo-Cenozoic basins, profuse Cenozoic magmatism, and varied metamorphic rocks, including high-pressure low-temperature relicts. The Sistan belt results from the closure of a small oceanic branch of the Neo-Tethys ocean from the end of Mesozoic to the beginning of Cenozoic. Currently, two mains geometry and timing of the oceanic subduction are proposed: 1) a northeast-dipping subduction starting during the Upper Cretaceous (Campanian), based on structural observations and 2) southwest-dipping subduction occuring during the Middle Cretaceous (pre-Aptian), based on petrological and geochemical studies of magmatic rocks.

In order to arbitrate between this two models, we looked for the oldest post-spreading magmatic rocks in this area and we made a petrological and geochemical analysis of them. Our mains results are 1) these rocks are always in the Eastern part of the Sistan belt; 2) they are intrusive into the Campanian to Maastrichtian flysch and always below the unconformity of the Paleocene reef; 3) they are made of basalts to rhyolites forming a typical calc-alkaline series as indicated by major and trace elements; 4) some of these samples are clearly high-silica adakites.

We conclude that an early magmatic arc grows up during the Upper Cretaceous in the eastern part of the Sistan belt and confirm that the subduction of the Sistan ocean dipped toward the Northeast as proposed by the previous structural studies in this area.

Drastic Spatial Changes in The Modern Stress Field of Northwest Iran

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The present-day tectonic configuration of NW Iran is characterized by two tectonic domains dominated by different NE and SE direction of maximum horizontal compressions; both the nature and location of the boundary remains unknown. To study the modern stress regime in NW Iran, we measured fault kinematics data in 90 sites distributed over three distinct areas in both N- and S-side of North Tabriz Fault (NTF). These areas were selected at the southern flank of the Bozqush Mountains (SBM), along the Garmirud fault zone (GFZ) and in the Mahneshan-Mianeh Cenozoic Basin (MMCB). The inversion method applied on the geologically measured fault-slip data indicates predominant compressional modern stresses at all three localities, but with drastically different directions of compression. The maximum horizontal stress is NE-trending in the MMBC (~N047°) and along the GFZ (~N030°), while, it changes into NW direction at the SBM (~N140°). This drastic spatial change indicates that the NTF and the GFZ define the sharp boundary between the two tectonic domains of NW Iran.

Keyword: Stress regime, NW Iran, Fault kinematics, Inversion method, Mianeh fault zone, Bozqush Mountains, Mahneshan basin

Multiscale deep structure imaging beneath northern portion of the Zagros collision zone

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Abstract:

We present the result of multiscale imaging of deep structure beneath the northern portion of the Zagros collision (including Lorestan salient arc) to explain how the convergence is accommodating on the region and how the shallow features are affected by the convergence. We combined the results of a migrated receiver function section, a joint inversion of receiver function and dispersion data, an ambient noise tomography and a Bayesian modelling of the InSAR measurements. Our model shows that the Arabian plate is underplating beneath Central Iran in lithospheric scale and the suture between two plates are connected to a decollement shear zone extended beneath the whole Zagros at depth of ~17, located above a weak low velocity layer. A ramp is connecting this decollement with the surface exposure of the Mountain Frontal Fault.

Keyword:

Zagros, deformation, underplating, decollement, MFF

Deep Structure across the Zagros and Alborz Continental Collision Zones from Seismic, Gravity, and Thermal Modeling

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The Moho fluctuation and upper-mantle structure across the Iranian plateau along the Ilam – Tehran transect in length ~650 km is investigated using the joint inversion of P-receiver function and compose of group and phase surface-wave dispersion data. The robustness of derived absolute S-wave velocity model is evaluated using the conversion of velocity into density by Nafe – Drake relation and then inverted linearly to Bouguer anomaly data. Temperature is one of the key-parameters which mainly governing the dynamics and rheology of the crust and upper-mantle. Hence, for the first time in the Iranian plateau, the obtained velocity model inverted into the thermal structure using the NCFMAS system of semi – Phanerozoic structures considering the effect of Anelasticity. The results introduce a moderate variation in Moho thickness across whole profile which its maximum located beneath SSZ / UDMA. In the other hand, the obtained models present a thick lithosphere beneath MFF toward the Arabian plate and an interesting thinner one beneath MZT which all consistent with seismological and geological evidences.

U-Pb Zircon Ages, Geology And Petrology of The Eocene Extrusive Rocks And Hypabyssal Intrusions in The NE of Torud Region, Central Iran

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Basic and intermediate Eocene volcanic rocks exposed NE of Torud in north Central Iran include lava, subvolcanic bodies, and dikes. The mid-Eocene paleontological ages of limestone interlayers in the volcanic rocks correlate with U-Pb zircon ages of lava, subvolcanic bodies, and dikes. The zircon ages define two mid-Eocene and mid-Cretaceous clusters in the concordia diagram. While the mid-Eocene cluster represents crystallization of the subvolcanic bodies, the mid-Cretaceous ages are similar to the zircon ages of the enclaves in the subvolcanic rocks. These age dates support the hypothesis that partial melting of the remnants of the Neotethys in north Central Iran has played a role in the formation of volcanic rocks of NE Torud. The Eocene volcanic rocks in the study area reveal high-K calc-alkaline to shoshonitic magmatic trends. The patterns of enrichment in the Light Ion Lithophile Element (LILE) and depletion in the High Field Strength Element (HFSE) in the REE and spider diagrams in these rocks correlate with those in subduction zones. These geochemical patterns and the $^{144}Nd/^{143}Nd$ and $^{87}Sr/^{86}Sr$ isotopic ratios suggest a depleted sub-continental lithospheric mantle (SCLM) source for the volcanic rocks of NE Torud and metasomatism by subduction components that were originated from the partial melting of the subducted Neotethyan slab. The Eocene volcanic rocks of NE Torud may have formed in an extensional geodynamic setting during or after a collision that occurred as a result of the closing of the Neotethys in northeast Iran and convergence of the Central Iran microplate and Alborz-Kopeh Dagh during Alpine-Himalayan orogeny and collision of the Arabian and Eurasian plates.

Keywords: ophiolite, calc-alkaline, shoshonite, subvolcanic, Torud

Tethyan Peridotite-Hosted Magnetite Deposits: An Overview of Present and Future Outlook

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Recent years have seen an increased interest in the study of a peculiar occurrence of magnetite mineralization in the serpentinized peridotites from Tethyan ophiolites, which consists in magnetite veins, lenses and pods. Only a few examples of these magnetite enrichments are known from the Mesozoic ophiolites in Greece (Olympus, Vermion, Edessa and Skyros Island), Central Iran (Nain), Oman (Aniba) and Italy (southern Aosta Valley, Western Alps) as well as from the Late Proterozoic Bou-Azzer ophiolite in Morocco. These deposits have diverse thickness (from a few centimeters up to 50 m) and length (2 to >500 m). Magnetite-mineralized rocks show variable microstructures, including massive, nodular and banded ores, veins, net and fine-grained disseminations in serpentinites. The problem of the genesis of ophiolite-hosted magnetite is still controversial. It is well known that the serpentinization of mantle olivine can produce magnetite, however processes of iron leaching, mobilization and concentration must be invoked to account for the formation of such magnetite deposits. Several hypotheses have been produced: (i) precipitation from a high-temperature (~300–400 °C) fluid in a seafloor hydrothermal system; (ii) low-T (100–300 °C) serpentinization at high water-rock ratio; (iii) mechanical and chemical weathering and subsequent low-T serpentinization (< 400 °C); and (iv) multi-episodic serpentinization (~300–400 °C) at high water-rock ratio during an advanced stage of ophiolite obduction. In particular, the formation of magnetite can be favored by phase separation processes in the hydrothermal fluid, fluid flow through nonconformity surfaces or shear zones, nucleation and growth on chromian spinel or chromite upon hydrothermal alteration, and metasomatism of preexisting podiform chromitite bodies. The modal volume of mantle olivine, peridotite composition, chemistry and amount of hydrothermal fluids, mechanism of transportation and precipitation, fluid/rock ratio, structural controls such as cracks, shear zones and unconformity are critical factors controlling the mineable size of magnetite ore bodies in ophiolitic complexes. However, further detailed investigations are needed to figure out the nature of the processes that promoted magnetite formation in ophiolitic peridotites during serpentinization and metamorphism.

Keywords: Tethyan realm, magnetite ore bodies, ophiolitic peridotites

Geochemistry, Petrogenesis and Tectonic Setting of I-Type Haji-Abad pluton, SW Buin Zahra, Iran

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Abstract

The Haji-Abad intrusion is located in Central Iran zone of 30 km southwest of Buin Zahra city. The pluton has generally granodiorite, diorite and tonalite composition, and shows granular medium-grained and poikilitic textures. It contains plagioclase, K-feldspar, quartz, hornblende, pyroxene and, accessory minerals are zircon, titanite and apatite. Zircon U-Pb age determination of this intrusion yieldes a concordant age of 40.0±0.7 Ma. Geochemically these granites are metaluminous (A/CNK =0.69-1.03), calc-alkaline and I-type in composition, exhibiting SiO_2 conents ranging from 59.7 to 66.77 wt.%, and $Mg^{\#}$ ranging from 38.6 to 52.2. The Chondrite normalized REE plot are characterized by LREE enrichment and show slight negative Eu anomalies (Eu/Eu^{*}= 0.60-0.93). Whereas the primitive mantle normalized multi-elemental spiderdiagram indicates interaction between both mantle and crustal components in their genesis. Whole rock Sr-Nd isotopic compositions show $^{87}Sr/^{86}Sr_i$ ratios ranging from 0.70498 to 0.70591, positive $\varepsilon_{Nd(t)}$ values from +0.21 to +2.3, and T_{DM2} from 760 to 909 Ma, that together with petrographic and gechemical composition indicate this rocks originated by interaction between lower crust-derived felsic magma and mantle-derived mafic magma. Enrichment in LILEs and depletion in HFSEs, and tectonomagmatic discrimination diagrams indicate a subduction-related magmatic origin formed in an active continental margin arc environment, that is consistent with subduction of the Neotethys oceanic crust beneath the Central Iranian microcontinent.

Keyword: Sr-Nd isotope; U-Pb dating; I-type granitoid, Haji Abad; Arc magmatism; Urumieh-Dokhtar; Iran.

Role of Bulk Composition Vs. Effective Bulk Composition (EBC) in Phase Diagram Calculations for Metamorphic Rocks: Examples From Symplectitic Textures in Migmatites, Hamedan, Iran

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Calculation of phase diagrams in metamorphism, is usually based on the Bulk Composition of metamorphosed rocks and could generate valuable information on overall P-T history of rock, but it cannot explain some textures, such as symplectite and their mineralogy. It means that in the development of symplectite textures, the whole-rock composition is not appropriate for modeling of such a domainal microstructure and the effective bulk composition (EBC) must be determined. In the Hamedan area, cordierite + spinel ± plagioclase ± gedrite symplectites, replacing andalusite is common in migmatites from Simin and Sarabi areas. P-T pseudosection calculated for the model bulk rock composition for both area, show that peak P-T condition in Simin area is occur at ~745 °C and ~4.5 kbar, and at ~760 °C and ~3.7 kbar for Sarabi area. However, the fact that spinel does not occur in either calculated phase diagram suggests that the whole-rock composition was not the effective bulk composition during the formation of spinel-bearing symplectite. It means that formation of such a symplectites, was likely controlled by a compositional “microdomain” and for phase equilibria modeling of symplectites, it is necessary to use effective bulk composition EBC. In this study, point counting method used to obtain EBC, using average chemical composition of minerals. In calculated model based on EBC, spinel + cordierite is stable over wide range of P and T, with plagioclase in Simin area and orthoamphibole in Sarabi area. Temperature and pressure for symplectite formation, estimated on 745 °C and 4.3 kbar in Simin area and 745 °C and 4.1 kbar in Sarabi area, both within the uncertainty of conditions calculated for the bulk composition. In many case, these symplectites are interpreted as a consequence of near-isothermal decompression; i.e., during the decompression segment of "clockwise" paths at upper amphibolite to granulite facies conditions and rarely reported as record of "anticlockwise" P-T path with a component of isobaric cooling. Based on calculations in Hamedan area, decompression is not main control for symplectites formation and they could form during peak or near peak P-T conditions, but it is necessary to use appropriate chemical composition to obtain correct P and T.

Gold Mineralization and Exploration Criteria in the Urumieh Dokhtar Magmatic Arc and Sanandaj Sirjan Zone in Iran

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There are several Carlin, epithermal and orogenic gold as well as gold-rich porphyry copper deposits in the northern and middle sections of the Urumieh Dokhtar Magmatic Arc (UDMA and the Sanandaj Sirjan Zone (SSZ)), product of Neogene closure of Neo-Tethys Ocean in Iran. Zarshuran sediment-hosted Carlin type, Sari Gunay low sulphidation epithermal, and Dalli gold-rich porphyry copper deposits are the major gold deposits in these two metallogenic zones. Geodynamic model of the UDMA and SSZ, magnetic data as well as detailed geological maps, mineralogical and petrographic studies, litho-geochemical data, Pb206/U238 age dating and fluid inclusion studies at these three gold deposits are used to characterize the controls on gold mineralization and define the key recognition criteria for gold exploration targeting. The results showed that gold mineralization at Sari Gunay and Zarshuran, despite their different host rocks, show some similarities, while it is very different at Dalli. Dalli only shows some similarities with the deep underlying low-grade porphyry Cu-Au portion of the Saari Gunay mineralization.

Key Words: Gold mineralization, Zagros belt, exploration criteria, Dalli, Zarshuran, Sari Gunay

Linking Tectonics, Climate and Supergene Mineralization: The Case of Non-Sulfide Zinc Deposits

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While global geodynamics played a crucial role for the spatial and temporal distribution of ore deposits, multiple local to regional factors controlled the formation of such abnormal concentration of metal in rock material. Among them, tectonics and climate parameters are essential features in weathering process that may lead to secondary concentration of economic elements. Since twenty years, supergene zinc deposits have been reconsidered for exploration and exploitation. In this review, Moroccan and Iranian non-sulfide zinc deposits are compared based on their mineralogical, structural and geochemical features. They follow laboratories to study ore evolution and interaction with tectonics and climate. While climate conditions are generally of regional extent, differential deformation is recorded along belts, leading to variable structural features. This has a direct influence on the amount of uplift and the local erosion of the strata, and it also controls the water table level and the ability to concentrate zinc metals in carbonate, silicate and hydrated equivalents. Further studies coupling economic geology, structural geology and paleoclimate characterization in these two domains could help to better understand the relative contribution of regional to global parameters; this could also give key information and guidelines for exploration of non-sulfide zinc deposits.

Geology and Geochemistry of the Middle Eocene Qarachilar Cu–Mo–Au Deposit, NW Iran

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Qarachilar is a small (0.2 Mt) vein-type Cu–Mo–Au deposit related to Cu–Mo porphyries in the Ahar–Arasbaran metallogenic zone (AAMZ), north-western Iran. It is occurs as three NW-trending quartz-sulfide veins hosted by granodiorite-quartz monzodiorite rocks of the Qaradagh batholith (QDB). Three stages of ore-formation could be identified at Qarachilar: (I) chalcopyrite-molybdenite-pyrite-quartz veins; (II) Au-bearing pyrite-quartz veins and breccias; and (III) barren post-ore carbonate veinlets. Microthermometric measurement on quartz-hosted fluid inclusions indicate that the mineralization may have taken place between 190 to 530 °C, from a medium- to high-salinity (9.2 to 55 wt.% NaCl equiv.) fluids. Oxygen isotopic data (+5.7‰ to +9.7‰) signifying that the fluid may have had a magmatic source, but was ^{18}O-depleted by mixing with meteoric water. The average calculated $\delta^{34}S_{H2S}$ values are 1 ± 1‰ for pyrite, chalcopyrite and molybdenite, consistent with a magmatic source for sulfur. Combined, the fluid inclusion and stable isotope data indicate that fluid boiling and mixing facilitated hydrothermal alteration and mineralization at Qarachilar. Molybdenite Re–Os dating shows that mineralization occurred at 42.35 ± 0.16 Ma. This middle Eocene age is much older than porphyry Cu–Mo mineralization in the AAMZ and Urumieh-Dokhtar magmatic arc (UDMA), but overlap the age ranges of porphyry Cu–Mo mineralization at Agarak, Hanqasar, Aygedzor and Dastakert deposits in the Lesser Caucasus, which suggests that collision between Arabia and Eurasia were oblique and thus diachronous.

Keyword: Fluid inclusion; Stable isotopes; Re–Os dating, Qarachilar; Ahar–Arasbaran; Iran

Ore potentials in Sistan suture zone, East of Iran

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The Sistan Suture Zone (SSZ) in East of Iran is generally regarded as a deformed accretionary prism that was emplaced during the destruction in the late Cretaceous-Paleocene of a narrow branch of the Neotethys Ocean between the Lut and Afghan continental blocks. This zone stretches N-S along ~700 km, has well preserved Mesozoic ophiolite, different sedimentary rocks and varied metamorphic units, including high-pressure, low-temperature relicts, which all of them have been cut by upper cretaceous to present magmatic rocks. These rocks belong to various tectonic settings during the birth of this branch of Neotethys Ocean to its death after closure. Different type of sedimentary successions beside various magmatism from tholeiitic lavas at oceanic spreading centers to calc-alkaline volcanic and plutonic rocks related to subduction, collision and post collision setting provide a collection of different mineralization's as syngenetic and epigenetic in SSZ. There are several chromitite bodies in ophiolitic melange part in this zone and some of them are as active mine now. Massive sulfide deposits related to oceanic volcanism has reported. Porphyry Cu–(Mo) deposits and Fe skarns are plutonic related deposits in this area. Nehbandan fault system could control the circulation of mineralizing fluids and hence ore deposition. Hydrothermal mineralization such as the listvenites enriched in Au, Ag, Hg, and Sb, and magnesite veins are results of this event. Nickel laterite as a residual mineralisation in peridotite has been explored recently in this zone.

Key words: Neotethys Ocean, East Iran, Chromitite, Sistan suture zone, Nehbandan fault, Hydrothermal mineralization, Porphyry Cu–(Mo) deposits

Geometrical Identification of Hydrothermal Mineralization Potentials in Nikooyeh District (North of Iran)

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Geometrical identification of hydrothermal mineralization potentials, is a new method introduced by author for improving the efficiency of the mineral prospectivity modeling in north of Iran. a Fibonacci sequence containing ordinary and random set, has used for 50 litho-samples to identify the self-organized zonation in a few elements such as gold and silver. Variations of the golden ratios in pathfinder elements, indicate quasi spiral accumulation of Au, Ag and Pb in altered regions related to Paleogene volcanic outcrops. Therefore, a series of spatial and geometrical analyses consist of inverse distance weighting, concentration-area equation, perimeter- area power law relation, Fibonacci sequence and Pythagorean theorem have used to verifying the statistical results of mineralization process by nonlinear techniques. Also some evidences of ore-forming minerals found in Pyrite, Chalcopyrite and Galena, which have sampled from prone areas based on variations in Pythagorean "key numbers" and golden ratios. Considering, specifications of 6 major elements, a pattern recognition technique has introduced for assessment the hypogenic mineralization processes in Nikooyeh district. This method is founded based on tendency of supra ore elements to accumulate in spirals that is similar to their natural abilities for self-organized distributions around the source rocks.

Keyword: Fibonacci Sequence, Fractals, Geometrical analysis, Golden Ratio, Iran.

Estimation of Shear Wave Velocity Structure in Alborz Region and its Application in Physics-Based Seismic Hazard Assessment

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One of the most important applications of the estimated velocity and attenuation structure is the Physics-Based seismic hazard assessment. In this research, the investigated region is Alborz region that has been located in the north of Iran, including Tehran city as the capital. The Alborz Mountains represent a tectonically and seismically active convergent boundary in the Arabia-Eurasia collision zone, in western Asia. We present a 2D velocity model constructed by the assemblage of 1D shear wave velocity (Vs) models from 26 seismic stations, mainly distributed along the southern flank of the Alborz Mountains. The shear wave velocity structure has been estimated beneath each station using joint inversion of P-waves receiver functions and Rayleigh wave dispersion curves. A substantiation of the Vs inversion results sits on the modeling of Bouguer gravity anomaly data. Our velocity and density models show low velocity/density anomalies in uppermost mantle of western and central Alborz at a depth range of ~50–100 km. In deeper parts of the uppermost mantle (depth range of 100–150 km), a high velocity/density anomaly is located beneath most of the Mountain range. The spatial pattern of these low and high velocity/density structures in the upper mantle is interpreted as the result of post collisional delamination of lower part of the western and central Alborz lithosphere. By dividing Alborz region to the eastern and western parts, the mean V_S models were determined for the eastern and western Alborz. Based on the Neo-Deterministic Seismic Hazard Assessment (NDSHA) at the regional scale, the investigated territory should be divided by some polygons corresponding to different attenuation-velocity structural models (representing bedrock conditions), to define the physical properties of the source-site paths. Other input data set consists of seismogenic zones, focal mechanisms and the catalog of past seismicity. The seismic hazard, expressed in terms of maximum displacement (PGD), maximum velocity (PGV) and design ground acceleration (DGA), is extracted from the synthetic seismograms and mapped on a regular grid of 0.2°×0.2° over the entire region. The results of this first order NDSHA zoning indicate a high seismic hazard in the Alborz region and may represent an important knowledge basis towards detailed and comprehensive seismic microzonation studies.

Key words: Alborz region; Velocity Model; Physics-Based Seismic Hazard Assessment.

Mechanism of Earthquake Migration: Case study Lut block Area, Eastern Iran

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The Lut block (LB) in the eastern part of Iranian plateau bordered by large strike-slip faults which concentrated an intercontinental deformation due to convergence the Afro-Arabian and Eurasian plates. Several large earthquakes occurred in the LB. The mechanism of the earthquake sequences in the LB studied by using of the variation functions and major earthquake epicentre movements, thickness of earth crust, it's underneath viscosity, Momentum, and variation stresses analysis investigated and by fuzzy logic were analysed. Ratio of the geodetic moment rate to the seismic moment rate obtained more than 3.07 which ratio reflects the important role of the inter-seismic deformation in this area. The results indicate that south-eastern part of LB has a highest potential of seismicity. Geostatistics process show whole faults have seismic migration, in addition to earthquake migration on the strike of maximum regional stress, large part of migration observed on the south and south-eastern of LB.

Keywords: Lut Block, earthquake migration, Seismic Moment, Coulomb stress changes, Fuzzy logic

Fully Exposed Subducted Seamount (Siah Kuh, SE Zagros) Constrains Seismogenesis

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Millions of seamounts on modern and past seafloor end up being subducted, and only small pieces are recovered in suture zones. How they are metamorphozed and deformed is however critical to understand how seamount subduction can impact subduction zone geometry, fluid circulation or seismogenic conditions, and more generally to trace physical conditions along the subduction boundary. Since geophysical studies mostly reach the shallowest subducted seamounts and miss internal structures due to low resolution, there is a high need for fossil seamount exposures. We herein report on a fully-exposed, 3D example of seamount that we discovered in the Siah Kuh massif, Southern Iran. Through a series of sections across the whole massif and the combination of magmatic-metamorphic-sedimentary petrological data, we document several distinct stages associated with seamount build-up on the seafloor and with subduction. In particular, we constrain different stages of metamorphism and associated mineralogy, with precise conditions for subduction-related metamorphism around 250°C and 0.7 GPa, in the middle of the seismogenic zone. Examination of the seismogenic potential of the Siah Kuh seamount reveals that it was not a mega-earthquake asperity, and possibly behaved as a barrier to earthquake propagation. We finally discuss the nature of high-pressure fluid circulation preserved in this seamount.

Zagros blueschists: Episodic underplating and long-lived cooling of a subduction zone

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Pressure–temperature–time (P–T–t) trajectories of high-pressure rocks provide important constraints to understand the tectonic evolution of convergent margins. New field observations and P–T–tconstraints for the evolution of the only known blueschist-facies exposure along the Zagros suture zone in Southern Iran are reported here. These blueschists, now exposed in tectonic windows under the Sanandaj–Sirjan zone (upper plate), constitute accreted fragments of the Tethyan domain during N-directed Cretaceous subduction. Three units were identified in the field: from top to bottom, the Ashin unit (mafic and felsic gneisses), the Seghin complex (mafic tuffs and ultramafics) and the Siah Kuh massif (coherent volcanic edifice). Microstructural observations, P–Testimates and Rb–Sr deformation ages indicate that the Ashin unit possibly underwent burial down to 30–35km and 550°C along a relatively warm P–Tgradient (c.17°/km) and was ultimately deformed between 85 and 100Ma. The Seghin complex exhibits remarkably well-preserved HP–LT assemblages comprising lawsonite, glaucophane, aragonite, omphacite and garnet. P–T–treconstruction indicates that this slice was subducted down to c.50km at temperatures of c.500°C along a very cold subduction gradient (c.7°/km). Deformation in the Seghin complex stopped at around 65Ma, close to peak metamorphic conditions. Field relationships and estimates of the P–Ttrajectory followed by the Siah Kuh volcanic edifice indicate that this massif was lately subducted down to 15km depth along the same very cold gradient.

This slice-stack represents a well-preserved field example (i)highlighting the existence of transient underplating processes juxtaposing pluri-kilometric tectonic slices along the subduction channel and (ii)imaging the discontinuous down-stepping of the active main subduction thrust with ongoing accretion. The Zagros blueschists also record an apparent cooling of the Zagros subduction zone between 90 and 65Ma, most likely as a thermal response of a geodynamic perturbation toward the end of the Cretaceous.

Parallel Transpressional Deformation Belts With Different Shear Senses in the Zagros Hinterland Fold-and-Thrust Belt, Iran

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The oblique collision between the southwestern margin of the Iranian microcontinent and the northeastern margin of the Arabian platform resulted to the transpressional deformation in the Zagros orogenic belt within the central part of the Alpine-Himalayan orogenic belt. Based on the occurrence of several kinematic shear sense indicators, we documented a new shear belt which has been developed parallel to the Sanandaj-Sirjan HP-LT metamorphic belt with different sense of shear in the Zagros orogenic belt. A sinistral top-to-the NW non-coaxial deformation regime has been occurred in the Zagros hinterland fold-and-thrust belt parallel to the crustal-scale shear belt of the Sanandaj-Sirjan HP-LT metamorphic belt with dextral top-to-the SE sense of shear. The development of these parallel shear belts may be due to relative rotation of the convergence direction during the long-standing continental convergence.

Keywords : transpression, shear sense, parallel shear belts, hinterland, Zagros, Iran

Where Are The Boundaries of the South Caspian Basin?

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The widely accepted view on the borders of South Caspian Basin (SCB) puts its southern and western borders along the Khazar and Talesh faults, respectively. The faults are considered active and dipping towards land. In this work, we investigate whereabouts of borders and nature of SCB crust by presenting three new P receiver function (RF) and P teleseismic tomograms sections across west Alborz and one acrossTalesh, a number of relocated seismic clusters along the southern borders of SouthCaspian Basin and constrained gravity and magnetic modeling. Our RF sections show no underthrusting of SCB beneath Alborz and Talesh and put the borders of the SCB crust along a line before the peak of the Alborz and Talesh Mountain ranges. Comparison of the seismicity with the RF sections and P teleseismic tomograms along the sections shows a sudden jump of focal depths across the boundary between the SCB crust and its neighboring crustal blocks. Combining this new finding with a previous RF section in Central Albroz and ML shear wave tomography map of the region provides us clues to find the borders in central and eastern borders of SCB. Likewise the western Alborz and Talesh, no underthrusting of SCB beneath Central and eastern Alborz has been diagnosed and the borders of the SCB crust lies along a line before the peak of the Alborz Mountain ranges. Our 2-D magnetic and gravity model along a seismic section in the western Alborz shows a continental nature for the SCB crust beneath Gilan province. The pattern of seismicity does not correlate in anyway with the postulated Khazar and Talesh faults. Our extensive neotectonics field work along the Talesh and Khazar (except for its eastern part) faults shows no convincing evidence for significant deformation and recent activity of the faults. Almost all the features previously recognized as active fault traces correspond to Plio-Pleistocene shorelines of the Caspian Sea. These new findings significantly reduces the estimated level of seismic hazard in southern borders of the SCB.

Keywords: South Caspian Basin, Seismicity, Receiver functions

Tethys Subduction and Continental Collision Imaged by Magnetic and Gravity Modelling

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We present a new 2D crustal-scale model of the NW Iranian plateau based on gravity-magnetic modeling along the 500 km long CIGSIP seismic profile across major tectonic provinces of Iran from the Arabian plate to the South Caspian Basin (SCB). The seismic P-wave receiver function model along the profile is used to constrain major crustal boundaries in the density model. Our 2D crustal model shows significant variation in the sedimentary thickness, Moho depth and the depth and extent of intra-crustal interfaces. The Main Recent Fault between the Arabian crust and the overriding Central Iran crust dips at ~13° towards the NE to a depth of ~40 km. The geometry of the MRF suggests ~150 km underthrusting of the Arabian plate beneath Central Iran.

Our results indicate the presence of a high-density lower-crustal layer beneath Zagros. We identify a new crustal-scale suture beneath the Tarom valley between the South Caspian Basin curst and Central Iran and the Alborz. This suture is associated with sharp variations in Moho depth, topography and magnetic anomalies and is underlain by a 20 km thick high-density crustal root at 35-55 km depth. The high density lower crust in Alborz and Zagros might be related to partial eclogitization of crustal roots below ~40 km depth. Our 2D crustal density model does not support Airy isostasy along the profile in particular around the Tarom valley.

Neither gravity, nor magnetic modeling supports an oceanic origin for the crust below the southern South Caspian Basin (SCB). Our crustal model indicates a highly extended continental crust for the SCB crust along the profile. Low observed susceptibility at the Kermanshah ophiolites probably implies that the ophiolite rocks only form a thin layer thrusted over the sedimentary cover.

Keywords: 2D forward crustal modeling, Gravity and Magnetic anomalies, Receiver function, Iranian plateau, Moho, Sediment thickness.

Lake URMIA (NW Iran) environmental changes during the Holocene inferred from the lake deposits: preliminary results

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The ongoing changes affecting Lake Urmia are revealed by the lake water level decrease (more than 7 m in the last 15 yrs), desertification and formation of dust storms threatening the health conditions of local population. That presents an ecological problem directly impacting on the society development and is the object of the Iranian government preoccupation. Water level drop was attributed to the decrease of rainfall (~10%) and to the anthropic causes, principally construction of numerous dams on rivers supplying the lake. However, the exact role of natural and anthropogenic factors that influence the state of the lake is still not identified. Indeed, the lack of the detailed record of environmental evolution in the past, limits the understanding of actual and future processes and the capability to develop integrated management of this water resource.

The Franco-Iranian project initiated by bilateral Gundishapour program (2016/2017), aims to obtain a high temporal resolution records of past environmental and climate changes in the Lake Urmia area for the whole Holocene. The process integrates geophysical, hydrogeological, hydrological and lake sediments studies. The interpretation of environmental data will be done with reference to modern hydrogeochemical and geological systems. It is indispensable since the main problem encountered for paleoclimatic reconstructions using various proxies at a global scale from cored lacustrine sequences remains the establishment of a reliable ^{14}C time-scale. During the fieldworks in 2016-2017, realized in frame of the Gundishapour program, sediment cores have been obtained from recently dried out part of the lake close to the city of Urmia, and sampling of the lake, river and ground water has been done. Preliminary analyses of 5 first meters sediment core Golman 3 show important changes of the biological activity, sources of detrital material and transport energy, conditions of lake water evaporation states and during early diagenesis. All these parameters are in relation with lake water level fluctuations. Ongoing analyses for ^{14}C AMS dating on rests of plants will allow the establishment of the accurate chronology for observed changes.

Geochemical Fingerprinting of Modern and Paleo Dust over the Iranian Plateau

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As a major component of the Earth's system, mineral dust plays a crucial role in global biogeochemical cycles and in regulating the global radiation budget. In modern times, dust plumes can be associated with their source origin(s) using satellite and land-based measurements and back-trajectory reconstruction of air masses. In contrast, reconstruction of past changes in the sources of mineral dust to receptor sites is made possible if the geochemical composition of dust from the source provenance(s) is constrained. We present the first record of variations in radiogenic Sr-Nd-Hf isotope systematics and Rare Earth Element (REE) anomalies (Eu/Eu* and La_N/Lu_N) as tracers of modern dust sources as well as past changes in the sources of mineral dust over the Iranian Plateau. A multi-proxy reconstruction of climate variability at sub-decadal to centennial resolution from an ombrotrophic (rain-fed) peat core from NW Iran has shown that dust fluxes were high prior the onset of the Holocene (11,700 years ago). Dust input was significantly reduced between 10,000-6,000 years ago but increased again during mid-late Holocene. A combination of organic traces also showed that the early Holocene was wet, consistent with lake and other records from Africa and the eastern Mediterranean region. In contrast, West Asia became drier during mid-late Holocene and was punctuated with at least eight episodes of elevated dust fluxes. The grain size of dust varies in a narrow range (<μ8m) through the entire record suggesting the long range transport of aerosols. The transition from the Younger Dryas (YD) to the Holocene is marked by a significant shift to less radiogenic Nd ($^{143}Nd/^{144}Nd$) and Hf ($^{176}Hf/^{177}Hf$) isotopes during the early Holocene, indicating a marked shift in the source(s) of dust during this period. The values gradually become more radiogenic and more similar to those in the pre-Holocene samples with a plateau around 8000 years ago. A similar pattern is observed for Sm-Nd model age, where mineral dust samples from the early Holocene represent relatively older ages compared with those of the YD and mid-late Holocene. The shift in radiogenic isotopes is also coincident with a gradual decrease in solar insolation over the northern hemisphere. A comparison between the radiogenic

Sr ($^{87}Sr/^{86}Sr$), Nd and Hf isotopic composition of paleo-dust samples reveals that atmospheric mineral dust deposited over NW Iran during the last 13,000 years likely did not originate from known sources in Africa or deserts from East China and Mongolia based on the available surface samples from these regions. To further investigate the cause of the observed shifts in dust sources, climate simulation experiments were utilized to examine how variations in Holocene insolation influenced the dominant atmospheric circulation regimes over the region. Three-day air mass back-trajectory simulated using HYSPLIT model for selected days in winter and summer as a modern equivalent of the early and mid-late Holocene. Additionally, the impact of insolation changes from early to late-Holocene on climate was examined in a transient fully coupled climate model simulation of the last 21 ka (TraCE) using the National Center for Atmospheric Research (NCAR) Community Climate System Model version 3 (CCSM3). These simulations suggest Northern Hemisphere Summer Westerly Jet was displaced poleward across the study area during the early Holocene when Northern Hemisphere insolation was higher due to the Earth's orbital configuration. This shift, coupled with lower dust emissions simulated based on greening of the Afro-Asian Dust Belt during the early Holocene likely led to potential sources in Central Asia dominating dust export to West Asia during this period. In contrast, the dominant western and southwest Asian and Eastern African sources have prevailed during the mid-Holocene to modern times. Sr-Nd-Hf isotopic values as well as REE anomalies for surfacial samples collected from the potential dust sources over the Iranian Plateau indicated that each region has a distinct isotopic signature. Isotopic signature of modern aerosol collected at Sarpol Zahab, Abadan, Ahwaz and Tehran suggest different distal and local source regions for the dust events recorded at these cities. Nd and Hf isotopic composition of dust samples suggest that the annual aeolian flux to Tehran, Abadan and Sarpol Zahab originated from potential distal sources in Mesopotamia while 2014 Tehran and 2015 Ahwaz dust storms were originated from local sources.

Keywords: Holocene, West Asia, Paleo-dust, Sr-Hf-Nd isotopes, NW Iran, Atmospheric Circulation, Dust Provenance

Contribution of Deflation-Based Fast ICA to the Separation of Geochemical Signals in the Field of Mining Geochemistry: A Case Study on the Kuh Panj Porphyry System, Kerman, Iran

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The vertical zonality index (Vz) is a practical tool for separating Blind Mineralization (BM) from Zone Dispersed Mineralization (ZDM) in the field of mining geochemistry. The ratio of supra-ore elements of Pb and Zn to sub-ore elements of Cu and Mo is an essential Vz for the separation of BM and ZDM in the porphyry systems. This paper investigates the effectiveness of deflation-based Fast Independent Component Analysis (Fast ICA) for optimizing the performance of Vz, and its application to the identification of hidden orebodies in the Kuh Panj porphyry system in Urmieh-Dokhtar volcano-plutonic arc. 95 surface litho-geochemical samples were taken from the study area. Fast ICA has been used to separate the independent source signals from surface mixtures. To construct an improved Vz, supra-ore and sub-ore ICs have been used instead of supra-ore and sub-ore elements, respectively. The performance of two approaches has been evaluated using core data from seven exploratory boreholes. The results show that the proposed approach provides significantly more accurate results compared to the traditional Vz. The introduced technique allows for a computational distinction between the BM and ZDM without exploratory drilling.

Keywords: Geochemical source signal, Fast ICA, Sub-ore, Supra-ore, Kuh Panj porphyry deposit.

Paleostress field along strike-slip faults in Sistan and Baluchestan

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The Arabia-Eurasian convergence at 2-3 cm/year is partly taken up by the deformation of the Iranian plateau. At the eastern boundary of the Iranian plateau, the N-S dextral Sistan-Baluchestan strike-slip zone stretches over 500 km along the border between Iran to the west and Afghanistan and Pakistan to the east, between the Lut block and the Afghan-Helmand block, which is fixed relative to Eurasia. This strike-slip zone is made up of a series of N-S trending strike-slip faults associated with NW-SE trending folds, thrust faults, and topographic highs. Earthquake focal mechanisms attest to a dextral motion along the N-S strike-slip faults and of a reverse motion on the related thrust faults, controlled by a consistently NE-SW oriented regional compression. GPS data indicate that that the Sistan-Baluchistan strike-slip zone takes up a dextral motion of about 15 mm/year, with the Nayband and Gowk strike-slip faults at 58°E on the west side of the Lut block.

This study present the results of a recent field survey conducted in the Late Cretaceous to Cenozoic Baluchistan sedimentary series to characterize the evolution of the stress field at the southern end of the Sistan-Baluchistan strike-slip zone. The analysis of outcrop-scale fractures in this succession allows us to reconstruct local stress tensors and to infer the regional paleostress field during the Cenozoic. The Cenozoic tectonic history of Baluchestan is dominated by a compressional or strike-slip stress field. Preliminary results reveal drastic changes of the direction of compression (σ1), clustering at N135°E, N90°E and N45°E. These results are interpreted in the framework of the geodynamic evolution of Iran since the Zagros collision.

Potential of Sentinel-1 InSAR to study for active tectonics of Eastern Iran

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In Eastern Iran, about 2 cm/y of the convergence between the Arabian plate and the Eurasian Plate is accomodated over about 1000km. Several active faults, like the Doruneh fault are contributing to the active deformation. However, because of their low slip rate and because of the sparsity of the GPS network, their is still large uncertainties about their slip rates and about their potential for seismic hazard. Space-borne SAR interferometry can be use in complement to GPS data in order to considerably increase the spatial density of surface displacement measurement. Previous studies using ENVISAT satellite have been limited by the not-systematic acquisition strategy resulting in a poor temporal coverage. The new generation of Sentinel-1 satellites, starting in 2014 offers now a far better dataset to investigate the low deformation rate in Eastern Iran. Here we investigate for some test sites if the Sentinel-1 dataset is effectively as dense as expected from the nominal acquisition strategy of the Sentinel-1 mission. 4.5 years after the launch of the Sentinel-1 mission, nearly 4 years of data have been acquired over Eastern Iran. Looking at different test sites, it turns out that the datasets effectively acquired can differ significantly from the nominal acquisition plan, which is one acquisition every 24 days from end of 2014 to sept 2016 and then every 12 days. On the test site of the Doruneh fault there are a major data gap from March 2017 to March 2018. On the test site near the Kopegh Dagh (Baghan Quchan Fault Zone), acquisitions have been more regular, however they did not reach yet in 2018 the nominal 12 days revisit time. Decorrelation of the signal from 12 days to 24 days turns out to be not critical on our test sites. On the Doruneh test site, 1-year interferograms preserve enough signal, that will ensure the continuity in the time series analysis. The main limitation with the present dataset is then the number of available images with respect to the target that is detecting 2mm/year over 100km tectonic deformation: a larger number of images may be needed to average the turbulent part of the atmospheric noise. By 2020 this number should be reached for most of Eastern Iran.

Flexural Folding Mechanism in The Metamorphic Rocks of Almabolagh Region, West Iran

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Almabolagh region is located in northwestern part of the Sanandaj-Sirjan zone of Zagros orogen in western Iran. Three rock units consisting of volcani-sediments (Almabolagh sequence) at the lower part, carbonate (Chenarsheikh sequence) in the middle, and slate (Hamadan slate) at the upper part are identified. These rocks that are metamorphosed at green schist facies have been exposed in a dome structure. Three stages of Ductile deformation (D1, D_2, D3) are identified in the tectonites. The mechanism of D_2 folding in this stage is flexural shearing and before this folding homogenuse deformation deformed rocks by layer parallel shortening.

Keyword: Folding, Flexural flow, deformation, Almabolagh, Hamedan

Structural and Thermal Constraints in Musandam Peninsula and Central Oman During Obduction and Collision Tectonics

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In the Oman Mountains, Hawasina deep-water sediments and Semail Ophiolite were obducted abovethe Permian-Mesozoic sedimentary rocks of the Arabian passive margin during the late Cretaceous. Samples from subophiolite sediments (Permian-Mesozoic sedimentary rocks collected in the Hawasina, Jabal Akhdar, and Saih Hatat domes as well as at the Jabal Salakh Range) were investigated by X-ray diffraction of the clay size fraction. The 1D thermal modeling allowed to conclude that subophiolite units of central Oman were overthrust by ~4.5 km-thick Semail Ophiolite and Hawasina units during the Coniacian, and exhumed since the late Campanian. Moving southward the subophiolite rocks at the Jabal Salakh Front were buried under ~3.35 km of clastic and allochthonous units. Structural analyses performed in the Musandam area show that the NE-SWtrending thrust fronts are characterized by a first phase of dip slip and a second phase of dextral strike slip kinematics. We conclude that (1) the thickness of the allochthonous units (i.e., Semail Ophiolite and Hawasina units) decreases moving southward and that (2) the kinematics recorded in the Musandam area could be related to the Zagron-Makran right-lateral transfer zone (Minad-Zendan Fault System).

Keyword: ophiolite, obduction, Zagron-Makran transfer zone, Oman, thermal maturity.

Decay of Aftershock Activity for Large Earthquakes in Iran

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Many studies have tried to provide a systematic explanation of aftershock decay rate. Examples include Omori, Reasenberg, Kisslinger and Shcherbakov methods. In this study, the decay of the aftershock-sequence of some of the major earthquakes in different tectonic regims of Iran are discussed, such as Rigan, Ahar-Varzghan, Goharan, Saravan, Sefidsang and Ezgeleh considering different magnitude thresholds (Mc). After defining spatial and temporal windows based on the Gardner and Knopoff (1974) method, the graphs and parameters of each decay rate were computed and analyzed for each sequence. The decay rates of each sequence were compared to find the best fit for each sequence. The results show that the modified Omori is the best fit for Rigan, Ahar-Varzaghan and Ezgeleh sequences, and for the Goharan and Sefidsang sequences the modified Omori and Kisslinger both are found as the best fits. Considering different threshold magnitudes, the Reasenberg, Shcherbakov and, to some extent, Kisslinger decay rates show some changes, but there is no systematic pattern for their behavior. The rate of decreasing is not constant due to the changes in the threshold magnitudes. The mean value of the parameter p, for the studied earthquakes, regarding the Omori's law for the primary aftershock is 1.1. The mean value of the parameter p of the Reasenberg, Kisslinger and Shcherbakov values are 4.8, 0.53, 2.3, respectively. The values of the parameter p of the Raesenberg and Shcherbakov are slightly larger compared to the Omori, but the parameter p of the Kisslinger is slightly smaller compared to the Omori. The parameter c has an inverse relationship with the threshold magnitude.

Keyword: Aftershocks sequence, decay rate, Omori, Reasenberg, Kisslinger, Shcherbakov, Rigan, Ahar-Varzaghan, Goharan, Sefidsang, Ezgeleh

Focal Mechanism and Probabilistic Seismic Hazard Analysis of Kerman Region

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Kerman City has been constructed and expanded on the young Quaternary alluvial deposits. Due to geological conditions, the young and active faults of the region and old faults have been a tremendous history in terms of seismicity. According to researchers, the main reason for the occurrence of earthquakes in Iran is the movement and pressure of Saudi Arabia towards the north due to the opening of the Red Sea. In order to investigate the seismicity of the study area, the required catalogs from different institutes including IRIS, IRSC, ISC and USGS were collected and obtained.
Pick Ground Acceleration (PGA) of Kerman Earthquakes containing recent earthquakes as well as Focal mechanism which refers to fault system and its propagation perpendicular to earthquake directivity have been calculated by catalog declustering (removing event dependences) and b-value was obtained. Using KIJKO in order to gain other seismicity parameters and at last using CRISIS gave a better solution Probabilistic hazard analysis of the study area for a specific reoccurrence time and period including PGA scale.

Temporal Pattern of Seismicity at the Southern Termination of the Lakarkuh Fault in Hojedk Region, Southeast Iran

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Time distribution of some types of earthquakes exhibit meaningful patterns their analysis can lead to identify temporal patterns of earthquakes occurrences. Hojedk area in Kerman province (SE Iran) has experienced 9 earthquakes with magnitude of Mw≥5 in a short time interval between 2017 December and 2018 January. Three of these earthquakes with magnitude of Mw≥6 occurred only in 2 days and during the period of 10 days. These earthquakes are in associated with the southern termination of the Lakarkuh fault activities. In this study, we present a temporal pattern of seismicity in Hojedk region based on temporal distribution of both historical and instrumental earthquakes. Additionally, according to the availability of some Paleoseismological results as well as historical and instrumental data of Golbaf fault located in southeast of Hojedk, we compared our obtained results with the seismicity pattern of Golbaf fault. Results indicate that recently occurred earthquakes on Hojedk and Golbaf regions have a clustering pattern. Furthermore, we analyzed 843 earthquakes with Mw≥2.5 during the 2017 December and 2018 January in Hojedk area and determined earthquake swarm pattern in this time interval.

Keyword: Seismicity, Earthquake Clustering, Earthquake swarm, Earthquake Triggering, southeast Iran

The Effect of the Biggest Strike-Slip Faults on Anisotropy Direction in the Southeast of Iran

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Ongoing convergence between Arabian and Eurasian plates provides a natural laboratory for studying the dynamics of continental-oceanic collision. In the study area, the Arabian plate subducts beneath the Eurasia plate. We have analyzed shear wave splitting of SKS, SKKS and PKS phases at three permanent broadband stations that are located near the active faults (Saravan and Zendan-Minab) in the Southeast of Iran. We obtained delay times larger than 1.0 s at these stations with fast polarization directions subparallel to the faults strike. These consistent observations among these stations imply that the observed anisotropy is likely related to the strike-slip motion of these faults. Therefore, simple shear is likely the source of the anisotropy.

Keywords: Anisotropy, shear wave splitting, Saravan fault, Minab-Zendan fault, Southeast of Iran

Lower Crust Anisotropy Beneath the Zagros and Central Iran

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Seismic velocity changes and shear wave anisotropy analysis can provide insights into deep structures. This study presents shear wave anisotropy within crustal structure of the Zagros and Central Iran zones. We use waveform data of 327 distant earthquakes with magnitudes larger than 5.0 in a distance range between 30° and 90° from eleven broadband seismic stations lying on the area of study. Three-component, receiver's functions were computed for all earthquakes recorded at each station in a frequency range between 0.05 and 0.5Hz. Considering t_o as the arrival time of the Ps converted phase on radial receiver functions in the isotropic case, we estimate the effective arrival time for the overlapping phases of the split shear waves as a function of back azimuth. Then, we find the anisotropy parameters ($\varphi, \delta t$) by fitting the best curve on Ps arrivals using grid-search method. Over the study area, an average size of shear velocity anisotropy δt = 0.31- 0.97 sec was determined, providing a good constraint on seismic anisotropy in comparison with crustal seismic anisotropy range. The fast motion direction analysis showed that φ changes parallel to the direction of surface structures and in agreement with GPS velocity vector measurements. This implied that deformation in lower structures reveals as brittle shallow crust and active fault zones throughout the surrounding region.

Key words*:* anisotropy, azimuthal coverage, crustal structure, Moho discontinuity, Shear wave, Zagros

Can the Seismic Hazard of Makran be Answered from the Deformation of its Accretionary Wedge?

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The Makran accretionary prism results from the convergence of the Arabian and Eurasian plates at a rate of 2cm/year. The mode of behavior of this subduction is still a matter of debate. Few large historical earthquakes have occurred along the Pakistane Makran, and too few stations located along the coast could not clearly define the coupling of the megathrust. Due to this lack of data, we here propose to study the deformation of the accretionary wedge to retrieve the frictional properties of the megathrust and discuss the presence of possible seismic asperities. We take advantage of 3 well resolved seismic profiles distributed along strike to study the evolution of the deformation and of the effective friction of the megathrust.
From recent studies, we now know that seismic megathrusts are characterized by very low effective frictions (<0.03) while aseismic megathrust have larger effective friction (>0,1). The friction properties of eastern profile requires for the activation of the large coastal normal faults a transition from low to very low effective friction ($\lambda = 0.8$, from $\mu_b = 0.05$ to $\mu_b = 0.003$), before an increase toward the toe of the prism ($\mu_b = 0.02$) Such very low effective friction could be explained both by a seismic asperity or the presence of mud volcanoes.

Collision Tectonic and Young Movements in the Central- Eastern Alborz

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Although numerous studies have done within Alborz mountains, but there has been little detailed work on the Quaternary events based on the alluvial fans. They are located on the front of the southern limb of central- eastern Alborz mountains. This paper focused on analysis the morphology and morphometry alluvial fans. These investigations are include of analysis and interpretation of: Geological data based on the 1:100000 geological maps sheets, Field work, Boreholes, Geoelectic profiles and Satellite images. They were used for calculating 17 Morphological Characteristics such as As, WLF, Bull, Fa, Fs, Fg, Fc,R, Da, AF, T. Bs, Fmf, Smf,Vf,Fd,Sl for fans in three groups Eyvanekey, Garmsar and Semnan with three generations, drainage basins, mountain fronts and rivers. The morphometry results shows that young movement in this area is uplift along structures in the Alborz mountains and their evolution are related to the Quaternary events.

Keyword: Central and eastern Alborz Mountain, Quaternary events, Morphometric index, uplift

3D P-wave Teleseismic Tomography of the Iranian Plateau

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The Iranian plateau is one of the most complex tectonic areas in the world. Remnants of the Neotethys Ocean slab, process of continent-continent collision in the mantle and the difference in the timing of slab break-off and collision in this area yield a complex system in the upper and lower mantle. For determination of structures in this area we present a 3D teleseismic tomography. We first propose a method for inverting five seismic networks simultaneously. For correcting the traveltimes data we calculate receiver functions on three temporary networks. Then we perform a checkerboard test for finding the best resolved part of our model. We have interpreted the high velocity anomalies observed in appropriate depths as remnants of the Neotethyan slab underneath the western and middle parts of the Iranian plateau.

Keywords: 3D Tomography; Structure of Mantle; Slab Break-off; Continental Tectonics; Lithosphere-Asthenosphere Boundary; Receiver Functions

Potential of Luminescence Dating for Landslides as Paleoseismic Indicators in Iran

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Moderate to large earthquakes usually trigger landslides of variable sizes. If the past landslides can be dated, then a corresponding paleo-earthquake can be inferred which helps to reconstruct the seismic shaking history, and to extend the catalogue of earthquakes in the region. Different processes can reset the luminescence dating clock of related dosimeters (e.g., quartz and feldspar) during a landslide or rock avalanche. The luminescence dosimeters within the buried surfaces under mass movements and deposits of lakes dammed behind landslides and surface of breakaway zone of mass movements can directly provide the date of the event. The possibility has been successfully examined in some local studies. Therefore, luminescence dating has a great potential to provide age of the mass movements that have occurred in different regions of Iran. This will enable us to evaluate seismic sources close to the mass movements, and explore if they have triggered the movements; a practical approach for completing seismic records of major active faults in the Iranian plateau.

Keywords: luminescence dating, landslides, earthquakes, paleoseismic indicators

Seismotectonics of the Shahrud Valley in Western Alborz

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The Shahrud fault in western Alborz is traditionally considered as a south-dipping reverse fault extended between the longitudes of 49.5 to 50.5°E and latitudes of 36.25 to 37°N on the southern side of the Shahrud Valley. The northwestern end of the Shahrud fault zone overlaps the southeastern termination of the left-lateral Rudbar fault zone through an offset of 10 km. There is no evidence of historical seismicity along the fault, while records of instrumental seismicity are significant within the Shahrud Valley at the SE termination of the Rudbar fault. Since September 2015, the Deylaman temporary local seismic network has been installed over the area by the Institute of Advanced Studies for Basic Sciences (IASBS - Zanjan) investigating the pattern and kinematics of seismicity of the area in relation with major geological structures like the Shahrud fault. During this period of time, no important seismic activity was directly observed along the fault to reveal its active kinematics. According to our seismological and active tectonic results, the traditional definition and geographic extension of the “Shahrud thrust” is geologically unreliable. The Shahrud fault zone is, in fact, a complex structural assemblage produced by both kinematic and structural interactions of two distinct NNE-striking dextral and NW-striking sinistral fault trends at the southern flank of the Shahrud Valley.

Key words: Shahrud fault, Seismicity, Single-event location, Focal mechanism, Deylaman temporary local seismic network, fault relay zone.

Geohazard susceptibility zoning of Balarud region in northern Khouzestan province using analytical hierarchy process

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Identifying and classifying areas prone to geohazards is an important step in assessing environmental hazards and plays an undeniable role in optimal management of hazards. Investigating the factors affecting the level of risk of a region and the zoning of hazards can greatly help to predict and reduce the damage to this event. In this research, using an analysis hierarchical process (AHP) method, the factors influencing the geologic danger of the region of Balarud that are affected by the fault zone of Balarud in northern Khouzestan include: earthquakes, structural factors such as faults and fractures, anticline, landslide, slope, lithology, as well as drainage network (rivers and canals). These layers of information are weighted using expert opinion tailored to their effect on the Export Choice software and overlap with the application of the weight of the layers in the GIS environment. Finally, a map of geohazard zonation is developed to identify and assess areas with potential geohazard in the area.

Multiple Ore Enrichment and Mineralisation in Siah-Kamar Porphyry Mo Deposit (Urumieh-Dokhtar Magmatic, NW Iran)

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Molybdenum porphyry-type deposits are mainly associated with subduction-related settings, such as volcano-plutonic magmatic arcs, back-arcs and continental collision orogens (Taylor, Hammarstrom, Piatak, & Seal II, 2012; Westra & Keith, 1981). The majority of the porphyry Cu–(Mo, Au) deposits in Iran occur along the Cenozoic Urumieh-Dokhtar magmatic zone (Aghazadeh, Hou, Badrzadeh, & Zhou, 2015; Richards & Sholeh, 2016).The Siah-Kamar Mo deposit (SKMoD) is located at the northwestern termination of Urumieh-Dokhtar magmatic zone and it is the only Mo ore reserve in Iran. The exploration program held by the property within the SKMoD revealed a 39.2 Mt proved reserves @ 539 ppm Mo and 66.4 Mt probable reserves @ 266 ppm Mo (Aria Kansar Samin Co., 2013). The geology of the SKMoD is characterized by the intrusion of a multiphase dioritic to quartz-monzodioritic stocks, which intruded the Eocene volcanic country rocks and formed an alteration zone, about 4 × 3 km in size, with a general NW-SE trend. A late phase of acidic porphyritic intrusive phase, granitic to dacitic in composition, intruded and post-dated the main alteration zone. The alteration zones grade from potassic-sodic within the main porphyry stock to phyllic and peripheral propylitic halos. A two-stage Mo mineralisation was distinguished, including (i) stage-1, disseminated molybdenite, coeval with the formation of potassic-sodic alteration and minor, microscale Fsp, Bt, Qz+Po veinlets; and (ii) stage-2, high-grade molybdenite+carbonate (± sericite) stockwork veins. Two samples, one from the early mineralised monzodiorite porphyry and one from a barren gabbro-diorite porphyry, yielded U-Pb zircon Concordia ages of 31.7 ± 1.0 Ma and 30.4 ± 1.2 Ma, respectively. Two samples from the subsequent acidic intrusive phase (granitoid to dacitoid) yielded U-Pb zircon Concordia ages of 28.9 ± 0.4 Ma and 28.3 ± 0.4 Ma, respectively. The later ages overlap with two molybdenite samples from Mo-bearing veins which yielded nearly concordant Re-Os molybdenite ages of 28.3 ± 0.2 and 28.7 ± 0.2 Ma, confirming an Oligocene age for the main Mo mineralisation in the SKMoD. Our Re-Os molybdenite ages are considerably younger than reported by Nabatian, Wan, and Honarmand (2017) (ca.42 Ma) but in full agreement with ages which reported by Simmonds, Moazzen, and Selby (2017) (ca.29-28 Ma). Integration of petrographic and geochronological evidence suggests an uncommon porphyry Mo mineralisation, associated with intensive carbonate precipitation during a long-lasting magmatic phase, from ca. 32 to 29-28 Ma. We highlight the dominant role of acidic fluid neutralisation in ore enrichment during polyphase magma intrusion as the dominant factor controlling Mo mineralisation in the SKMoD. Importance of most likely a temperature dropdown for precipitation of coeval carbonate and molybdenite to form high grade ore zones which should be considered in geometallurgical programs.

Sedimentology of the Upper Quaternary Cores from the Urmia Lake, Iran

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Endangered Urmia Lake, NW Iran, has attracted many geologists, biologists, ecologists,… during the past years. Source of this interest was the critical environmental condition of the lake due to considerable lowering of its water level in a relatively short time span, mainly caused by great decrease in the water inflow to Lake Urmia. Our French-Persian research group (empowered by the Gundishapour bilateral program) is one of the teams recently involved to study sedimentology, geophysics, hydrology, and hydrogeology of the lake for the purpose of paleo-environmental and paleo-climatic reconstruction for the whole Holocene.

Current study, as a part of that comprehensive project, focused on sediment analysis of the cores obtained from the upper parts of the lake substrate in order to indicate evidences of the lake level fluctuations. Detailed sediment analysis of the upper Quaternary deposits of the Golman-Khaneh area (based on field observations and laboratory studies) has led to recognition of sandy ooid grainstone and peloid (fecal pellet) grainstone facies. Occurrence of carbonate/mixed siliciclastic-carbonate facies in the overwhelmingly silicilcastic environment indicates reduction in sediment influx from the land and considerable lake level drop during the latest Holocene. Thinness of the carbonate strata in the studied cores is attributed to shortness of this period or some subsequent erosional phases.

Application of the RSCM geothermometry approach to estimate the peak temperature in a metamorphic context: South of Sanandaj-Sirjan zone

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Iran is made of an aggregation of continental blocks that formed and separated during opening and closure of Tethyan oceanic basins. Since the onset of convergence between the Arabian and Central Iranian plates during the lowermost Jurassic, the Sanandaj-Sirjan zone (SSZ) has been representing the active upper plate margin above the subduction zone. Like the Zagros orogenic fold and thrust belt, the SSZ was later affected by collision since the Oligocene.

The SSZ hosts strongly deformed, predominantly Precambrian to Cretaceous metamorphic rocks but many ambiguities remain on their age, nature and metamorphic conditions. Based on petrographic and geodynamic studies, somewhat contrasting evolutions were suggested along strike the SSZ, but most studies have so far focused on the north (Hamadan, Golpaygan,…) and quantitative P-T estimates are completely lacking in the south.

This study focuses on peak temperatures condition in the southern SSZ to shed light on the regional-scale geodynamic context. Samples with abundant carbonaceous matter were collected along the two sections. Peak temperatures were estimated using the Raman spectroscopy calibration of the degree of (irreversible) graphitization of carbonaceous material inside the samples. Thermodynamic modelling and estimation of P-T paths is still in progress.

Maximum temperatures range is from 316±12°C to 585±11°C. Permian samples show the lowest grade, with temperatures < ~400°C, while temperatures for Paleozoic and Precambrian samples are generally > 500°C (the latter ones showing slightly higher temperatures). Also, there ia a linear correlation between the R2 parameter and the peak temperature [T(°C) = - 415 R2 + 634].

This high-resolution spatial distribution of temperatures places constraints on the structural evolution on our representative transects (in progress) and provides a refined tectono-metamorphic frame, with implications for the geodynamic evolution of the Sanandaj-Sirjan zone.

Mass-balance analysis of copper mass flux during supergene enrichment process, Case study: MIDUK PCD., IRAN

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This paper introduces a method for interpolation and downscaling of the preliminary mass-balance analysis to highlight the role of geological features on evolution of the supergene process. Using only copper assays and not requiring relict sulfide mineralogy, this approach can be used to approximately identify the geographic direction of metal movement in exotic copper deposits, and thus serve as an initial exploration guide in prospecting for exotic deposits. For this, a vertical columnar block model was constructed for each of the supergene weathering zones and preliminary analysis of mass-balance was conducted to reconstruct the apparent total leached zone column height assuming zero lateral flux. This analysis was applied to each of the vertical block model columns. The results of mass-balance were interpolated in a 5×5 m grid by sequential Gaussian simulation method and simulated surface of total leached zone was conflated with geological features. The role of topography and argillic alteration, were identified in the transport of supergene solutions in the Miduk copper deposit of Iran. In the northern section of the deposit, which is in accordance with the topography gradient and presence of argillic alteration zone, the computed top total of leaching is below the actual surface topography, whereas the hypogene isograde curves confirm the expansion of primary copper in these areas. The northern section of the deposit was introduced as a susceptible area for the removal of copper-bearing solutions from the supergene enrichment system.

Keywords: Mass-balance modeling, Supergene process, Exotic copper, Porphyry copper deposit, Geostatistics, Sequential Gaussian simulation.

Abgareh Cu deposit and its Situation in the Toroud-Chah Shirin Mineralized Belt

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South Abgareh copper ore deposit (north of central Iran), is located in Toroud-Chah Shirin volcanic-sedimentary belt in Semnan province, 100 km far from S-SE Damghan. This main body of this ore deposit placed in volcanic-brecciated Eocene andesites, and is mainly in the form of vein and pore filling. Based on field observations, experimental investigations and chemical analysis (XRD, XRF, ICP-MS), it has been identified that the constituent rocks of this ore deposits are andesite, trachy-andesite, andesite-basalt, diorite-quartz diorite, dacite, tuff (andesite, riodacite, andesite-basalt) and aglomera. The most important minerals constitute the ore deposits are malachite, chrysocolla and chalcocite, which are scattered in the matrix as well as vein and pore filling of the intrusive rocks. Based on all mineralogical, geochemical and textrual characteristics and comparison to some similar ore deposit (such Kalate Mehran, Chah mosa and Chah Gole) and another ore deposit in Iran and other parts of the world, it can be concluded that South Abgareh copper ore deposit is categorized as vain copper deposits.

Keywords: Toroud-Chah Shirin magmatic arc, copper vein mineralization, subvolcanic andesitic masses-Abgareh.

Petrographical Investigation of the Prismatic Columns Rocks in the North of Zanjan (NW Iran)

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Late Cenozoic trachyandesite volcanic rocks cover scatter areas in the North of Zanjan Province, in NW Iran. These rocks crop out in eight distinct areas (Rashid abad, Korain, Zangi, Qarloq, Zangi kooh, Uchbulaq, Islam abad and Bahram beyk). They show prismatic structures. By petrographical studies, some of these rocks have microliticporphyric, glomeroporphyritic and trachytic textures. Based on mineralogical studies, samples consist of plagioclase, amphibole, clinopyroxene and K-feldspar phenocrysts with some xenocrysts of quartz which surrounded by reaction rims of pyroxene needles. There are also some microscopic textures (sieve texture, small lath shaped plagioclase within large plagioclase and spongy cellular dissolution/melting textures in plagioclase) indicating the magma mixing process. In petrography studies, the samples are indicated crustal assimilations, fractionation, contamination (AFC) evidences. The most important evidences can be mentioned by mafic enclaves, xenocrysts, glomeroporphyritic, sieve textural zones and resorption rims in feldspars which show a disequilibrium stage in magmatic chamber. A variety features suggest that the lava flows were contaminated by crustal materials during accenting lavas to the surface.

Keywords: Late Cenozoic**,** Volcanic Rocks, Crustal Contamination, prismatic column, NW Iran, Alborz-Azerbaijan

Geochemistry of Fluid Seepage and Authigenic Carbonate of Makran Mud Volcanoes, Southeast Iran

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Mud volcanoes are fluid escape piercing structures formed by extrusion of gas and mud-fluid mixture. Onshore and offshore mud volcanoes are extensively identified in Makran accretionary prism, formed as a consequence of the Arabian and Urasian plates convergence. This study describes the chemical and isotopic composition of non-hydrocarbon and hydrocarbon-rich gases discharged from four active onshore mud volcanoes namely Ain, Borborok, Sand Mirsuban and Napag and Pirgel which is located far away between Taftan and Bazman volcanoes, for evaluating their source region and probable relationship with the neighboring volcanic systems. Gas geochemistry data revealed two main gas types, CH_4-rich and CO_2-rich gases from onshore mud volcanoes and Pirgel in the land, respectively. The $\delta^{13}C_{CH4}$ values showed thermogenic origin with no biogenic contribution for all investigated mud volcanoes. The isotopic composition of CO_2 combined with He isotopes in CO_2-rich gas emitting mud volcano indicate minor input of mantle-derives CO_2 probably related to nearby volcanoes systems. Cylindrical shaped carbonate deposits associated with the Ain mud volcano also indicate variable $\delta^{13}C$ values of mainly thermogenic origin with possibly interaction with seawater. According to these data, Coastal Makran in the past was submerged by the Oman Sea, which is in agreement with the strong uplift that affected this area, as revealed by geological evidences.

Keywords: mud volcanoes, southeastern Iran, gas isotope geochemistry, non-hydrocarbon-hydrocarbon gas origin, authigenic carbonates

Mineralogy, Hydrothermal Alteration and Genesis of Chomalu Au (Ag)-Polymetallic Mineralization, NW IRAN

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The Chomalu ore deposit contains silver- and base metal-rich epithermal veins is located in northwestern Iran. Potential by-products are silver and gold. The host rocks are High-K calc-alkaline to shoshonitic volcano-plutonic rocks, which are part of the Tarom-Hashtjin Metallogenic Province. It consists of Eocene-Oligo-Miocene volcano-plutonic rocks including basalt, andesite, trachyandesite, dacite, rhyolite and porphyry quartzmonzonite, quartzmonzosyenite and quartmonzodiorite. The Chomalu deposit occurs as hydrothermal veins in basalt and andesite rocks adjacent to intrusive igneous rocks. The mineral assemblage includes galena, sphalerite, fluorite, quartz, chalcopyrite and pyrite as well as Zn-Pb non-sulfide ore, gold, electrum, tetrahedrite, hematite, malachite, magnetite, limonite and goethite. Silver is associated with tetrahedrite. The ore-bearing veins comprise three paragenetic stages: (1) early Cu-Fe-bearing minerals, (2) middle stage Pb-Zn-F-Cu-Ag-bearing minerals, and (3) late supergene stage. Gold occur in late supergene stage and less common in hypogene stage (stage 1). Early hydrothermal activity was responsible for the formation of three hypogene alteration types of decreasing intensity: silicification, sericitization and argillic alteration. Hydrothermal alteration at Chomalu covers an area of about 2 km^2 and is well zoned. Propylitic alteration is supergene alteration which occur in basaltic to andesitic rocks in outer parts of mineralized veins and consists of chlorite, calcite and epidote. Plagioclase phenocrysts are almost replaced by carbonate and chlorite. The inner zone is characterized by intense silicification, with a remnant quartz-dickite- jarosite assemblage. Vuggy and crustiform-colloform quartz textures are locally preserved in this zone. The intermediate zone has sericitization alteration with a quartz-chlorite-pyrite-sericit assemblage. The outer zone is characterized by an argillitic alteration with a quartz-montmorillonite-kaolinite assemblage. Field observations, alteration, mineralogical study and minerals textures suggest that the Chomalu polymetallic deposit is a type of intermediate epithermal ore deposit.

Keywords: Tarom-Hashtjin Metallogenic Province, Chomalu, Hydrothermal alteration, Intermediate epithermal veins

Geochemical Anomaly Separation by Fractal Modeling in Moaleman 1:100,000 Sheet, NE Iran

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One of the modern technique for separating geochemical anomalies which is important for mineral exploration is fractal methods. The aim of this research is separation of Cu, As, Au, Pb, and Zn anomalies from the background by using concentration–number (C-N) fractal modeling in Moaleman 1:100,000 Sheet, which is located in Semnan province, NE Iran. The study area is situated in central Iran structural zone and composed mainly intermediate to basic submarine lavas, volcaniclastic rocks, and massive trachyandesite. C-N fractal method is very useful and high level method for separating of geochemical populations. To this purpose, C-N logarithmic diagrams were drawn for elements and anomalies were separated. High intensity anomalies thresholds for Cu, As, Au, Pb, and Zn are 199 ppm, 22 ppm, 141 ppb, 2511 ppm and 2511 ppm, relatively. Finally, elemental distribution maps were drawn in the area.

Keyword: Geochemical Anomaly, Fractal Modeling, Concentration-Number, Moaleman

Reservoir Zonation of the Kangan Formation: A Case Study one of Wells of the Gas Fields in the Folded Zagros Subzone

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The Kangan Formation (Early Triassic) is one of the most important Source rocks in the gas fields of southern Zagros and the northern Persian Gulf. The studied gas field is located in the west of Hormozgan Province and is one of the most important gas fields in Iran. In order to evaluate the depositional environment of the formation in this well, 48 microscopic thin sections were made of 19.9 m core and were studied which resulted in the identification of seven microfacies that deposited in four depositional environments including tidal flat, lagoon, mainly shoal and open marine. By studying and analyzing existing data, especially petrography, it can be concluded that Kangan Formation in this well was deposited mainly on the shoal environment. Also, this study aimed to investigate the quality and extension of reservoir zones by Interactive Petrophysics Software, because the Kangan Formation has been classified according to the reservoir properties into four general zones in previous studies, but in this study, using the digital files obtained from wells' studies and extension of this information in the relevant software environment, and finally by combining interpretive information of output charts including logs SGR, DT, RHOB, PHIE and lithology columns with sections of petrography, Kangan Formation in the wells of the studied field has been divided into three general reservoir zones for the first time.

Keyword: Reservoir Zonation, Kangan Formation, folded Zagros subzone.

Evaluating the Role of Faults in Deposition of Copper Using Fry Analysis – Case Study: Dehaj, Kerman Province, Iran

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The studied area is located in Dehaj - Sarduiyeh, northwest of Kerman province, along the intrusive volcanic belt of Iran, which has the potential of high-grade copper mineralization. The area consists of Eocene Epoch acidic-neutral-basic volcanic rocks and has sedimentary horizons in base and center. The sedimentary horizons indicate some dormant periods of time in volcanic activities. A semi-deep intrusive mass (from Oligo-Miocene age) intruded these layers and created alteration and mineralization in this area. The aim of this study is to investigate the role of structural controllers in locating porphyry copper deposits using Fry analysis in order to study the location distribution and ore deposit evaluation. The results demonstrate that highest convergence is observed along with northwest-southeast for 12 kilometers. Thus, the simultaneous survey of mineralization points distribution and intersection faults points could be considered as an exploratory data layer.

Keyword: Fry analysis - Structural controllers- Copper mineralization

Implication of Framboidal Pyrite in Genesis of Sedimentary Hosted Copper Deposit, Nahand-Ivand Area, NW- Iran

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The Nahand- Ivand area is located in the north of Tabriz, NW Iran. Mineralized units of Upper red formation were analysed by ICP-MS and show an enrichment of Cu content up to 35% with an average of 1.4% Cu. According to microscopic study and EPMA analysis pyrite (pre- ore stage sulfide) is followed by hypogene sulfides (chalcopyrite, bornite), that replaced by supergene sulfides (digenite and covellite). These minerals have a narrow stability range and preserve compositional variation of the hydrothermal fluids during the progressive evolution of the deposits. Diagenetic alteration of cu-rich sulfide such as digenite in acid and oxygenated solutions is accompanied by the more rapid transfer of Cu (relative to S) into the solution and subsequently lead to the sequential replacement of this mineral by Cu-poor sulfides such as covellite. Occurrence of supergene Cu oxide minerals such as malachite and azurite concentrated along cracks and faults indicates that the Cu of the hypogene sulfide was leached, remobilized, and enriched by surface/near-surface processes, during the exposure of the host rocks. The supergene enrichment could cause a major increase in the Cu ore grade, from a few percent up to 35%, and is therefore of great economic importance.

Keyword: copper, mineralization, alteration, EPMA

CO_2-Rich Magmatic-Hydrothermal Fluid Controlling Cu-Mo Mineralization at Haftcheshmeh Porphyry Deposit, NW Iran

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The Haftcheshmeh Cu-Mo porphyry deposit (NW Iran) is a part of the Cenozoic Arasbaran Metallogenic zone (AMZ). The ore-forming mineralization associated with the Haftcheshmeh porphyritic granodiorite to diorite stocks can be divided into three stages characterized by vein-veinlets: Stage I with barren quartz containing minor metal sulfide (pyrite ± chalcopyrite) veins and K-feldspar-biotite alteration, Stage II with quartz- molybdenite- chalcopyrite- pyrite- magnetite± hematite associated with biotite stable alteration, Stage III with quartz-pyrite-chalcopyrite-molybdenite-galena-sphalerite veins and sericitic alteration. Based on petrography, microthermometry and laser Raman spectroscopy analyses, four types of fluid inclusions (FIs) are associated with these three mineralization stages: Type 1 (LV), Type 2 (VL), Type 3 (LV daughter and mineral bearers) and Type 4 (V_{CO2}+L_{CO2}+L_{H2O}). These FIs are homogenized in divergent modes at similar temperatures, suggesting that fluid boiling took place from stage I to III. Stage I FIs, belonging to NaCl-H_2O-CO_2 system, mainly homogenized from >599 to 310°C, with salinities ranging from 4.8 to 59.4 wt. % NaCl equiv. Stage II FIs, belonging to NaCl-H_2O-CO_2 system, yielded homogenization temperatures of 266-500°C and salinities of 5.6-45.1 wt. %NaCl equiv. Stage III FIs, belonging to H_2O-NaCl±CO_2 systems, homogenized between 200 and 396°C, with salinities of 1.3-43.1 wt. %NaCl equiv. The decrease of inclusions containing calcite daughter minerals and increase of inclusions containing chalcopyrite daughter mineral from stage I to II; the presence of magnetite and hematite in stage II; have indicated that reduction of sulfate by iron oxides crystallization in stage II have been promoted the Cu-Mo mineralization in stage II. The fluid inclusion study shows that stage III quartz veins associated with sericite alteration zone are characterized by coexistence of the boiling 3b and 2a subtype inclusions containing chalcopyrite daughter minerals, and progressive temperature decrease of fluids by the incorporation of meteoric water from 396 to 200 °C; apparently promote the Cu deposition in stage III.

Keyword:
Haftcheshmeh, porphyry Cu-Mo deposits, fluid inclusions, Laser Raman spectroscopy, CO_2-rich fluids, Iran

Thermal Springs as the Last Phase of The Volcanic Activity in The Sabalan Volcanic Field, NW Iran

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Thermal springs are the latest emanations and expressions of volcanic activities in magmatic systems which are considered as picturesque and interesting features for tourists especially because of their therapeutic applications. In Iran, the thermal springs surrounding Mount Sabalan are famous and unique in this regard. Thermal springs have clustered around the Mount Sabalan in three areas of Mshkinshar, Neer and Sar eyn. The thermal springs in Meshkinshahr area were studied in this research. These are located in northwestern part of Sabalan, near the caldera and on the youngest volcanic lava flows. Clusters of thermal springs in this area consist of eight springs and some of them are used as spas. In order to investigate the chemical parameters, 7 samples of springs water and 13 powder samples from sinters (springs sediments) precipitated from springs were sampled. ICP analysis was carried out on samples. The results showed the relationships and correlations between elements which are typical for epithermal mineralization. These elements are discussed fully in this paper. This group of elements is supposed to be derived from the magmatic-hydrothermal system through the interaction of hydrothermal fluids with the rocks they have passed through. The geochemical analysis of elements showed that the Meshkinshahr volcanic system indicate an active hydrothermal system occurring in the magma chamber beneath.

Keywords: Thermal springs, Hydrothermal system, Sabalan volcano, Iran

Granite emplacement in an Transpressional Tectonics, an AMS study of Tafresh Plutons, Central part of Urumieh-Dokhtar Magmatic Arc, Iran

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This research studies emplacement of Ghahan and Kasva stocks as a part of Urumieh-Dokhtar magmatic arc (west Iran) by using Anisotropy of Magnetic Susceptibility (AMS) technique. These two granitoidic stocks are intruded into the Eocene volcano-sedimentary series which are composed of dacite, and andesitic lavas. The studied stocks belong to the ferromagnetic and I type granites, similar to other intrusive rocks of Urumieh-Dokhtar magmatic arc. Also, the geothermobarometry results of hornblend indicate that these two stocks have emplaced in shallow depths (2 to 4 Km). In general, the bulk magnetic susceptibility of studied stocks ranges between 105 µSI to 56378 µSI. The comparison between bulk magnetic susceptibility (Km) and precise petrographic studies of fresh and altered rocks suggests that alteration has affected Km values and has controlled its magnitude. Anisotropy values is rather low and rarely exceeds P% = 10%. The magnetic ellipsoid shape (T) also varies between -0.47 and 0.71 with average of 0.1. Each stock also contains separated feeder zone in which magnetic lineations show high plunging (>60º). It seems that constitutive magmas of both stocks have ascended from central parts of Ghahan and specifically from the northern margin alongside of Kasva. Most of the magnetic foliations are vertical or close to vertical, outline a circular pattern on surface. The circular pattern of the lineations may be due to the changes in strain during the distribution and ascending of the magma. Magnetic fabric results of both Ghahan and Kasva stocks associated with field observations and structural evolutions reveal that a rightward transpressional tectonics has been dominant at the time of emplacement of the two bodies, providing a suitable pull-out space for ascent and emplacement in Urumieh-Dokhtar magmatic arc.

Keyword: Anisotropy of magnetic susceptibility (AMS); Emplacement, transpressional shear zone, Urumieh-Dokhtar magmatic arc, Iran

Mineral Chemistry, Geothermobarometry, Teectono – Magmatism a Mineralization in Siljerd Granitoid Rocks Of Saveh west, Iran

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The study region is located in the Urmia-Dokhtar volcanic zone in the North-East of Saveh, Iran. These intrusions have got a various lithology including rhyolite, rhyodacite, trachyandesite, andesite, quartz andesite and andesite t that rhyolites have the mos volume among them. For this study , 600 points of rock forming minerals by EMPA method have been analyzed by the CAMECA SX-100 machine. Regarding the chemistry of halogens, it can be said that due to the lack of Cl and its effective role in the transfer of mineralization metals, this is one of the most important reasons for the lack of fertility in the siljerd granitoid rocks. The obtained results from the mineral chemistry in this study indicate that the studied amphiboles are calcic amphiboles, and in terms of chemical composition they can be called Edenite. Plagioclase are from andesian type. Regarding the chemistry of halogens, it can be said that due to the lack of Cl and its effective role in the transfer of mineralization metals, this is one of the most important reasons for the lack of fertility in the siljerd granitoid crocks. Different methods were used to perform thermobarometry, the best of which showed that the formation temperature of granitoid mass has been in the range of 708°C and a pressure of 1.14 Kb.

Mineral Chemistry of Tanbur Metamorphic Rocks in Sirjan North East, Iran

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The study region is located in the North-East of Sirjan, Iran. For this study , 400 points of rock forming minerals by EMPA method have been analyzed by the CAMECA SX-100 machine. The obtained results from the mineral chemistry in this study indicate that the studied amphiboles are calcic amphiboles, and in terms of chemical composition they can be called Magnesiohomblende. Plagioclase are oligoclase. The results indicate that the chemical composition of biotite is not within the phlogopite range and Due to the fact that Fe (Fe + Mn) ratio is greater than 0.33, it is not within the range of phlogopite. The study of biotite confirms theirRequilibrated primary properties.

The Kinds of Mineralization Types in The Koppeh Halvaei Area – North Anarak – Central Iran

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Koppeh Halvaei area is located in distance 280 kilometers of Northeast of Isfahan and south brink of Doruneh lineament fault and Dashte Kavir's great desert. The major part of area is covered by quaternary eolian sand sediments. The most typically rocks blocks in this area are seem as diffuse outcrops in central part that named Koppeh Halvaei. These rocks are dependent on Upper Eocene to Oligocene and include sandstone, conglomerate, marl, andesite, basalt and listvenite mainly. Regard to tectonic setting of the region and tensional forces occurrence of faulting lineaments turnover, the faults are most importance structure controls of mineralization in this region. The ore body host rock in Koppeh Halvaei shows instance sensible of brecciation. Regard to the chemical nature of anomalous elements, mineralization host rock and field observations two main type mineralization have been distinguished in Koppeh Halvaei area. The first and most important type is vein and stockwork copper mineralization associated to hidden intrusive rocks. The host rock of this type is Upper Eocene red sandstone chiefly. In mineralogy studies, copper ores such as malachite, chalcocite, chalcopyrite, hematite and goethite have been distinguished. The second type is mineralization in listvenite rocks associated Ashin ophiolite. The alteration processes associated to listvenitazation have an important role in anomalies of nickle, cobalt, arsenic and chromium in study area. According to Micro thermometric studies on quartz fluid inclusions, 3 different groups of fluid have been observed. The first group includes monophase gas-rich inclusions, than shows indicating boiling condition of mineralizing fluid. In many cases, these fluids uses for qualitative studies of hydrothermal environments. The second group is two-phase (liquid-gas) inclusions type and the third group is three-phase (liquid- solid-gas) inclusions type. Based on frequency versus homogenization temperature diagram, had recognized minimum two mineralization phases in this region. According to geochemical studies the elements such as copper, nickel, cobalt, arsenic, chromium, lead and zinc have high values in some parts. The copper has been topmost correlation with nickel, lead and Arsenic. In final heavy minerals sands, evaporates and colored agates to be recommend as other economic potentials in study area.