A new tectonic map of the Iranian plateau based on aeromagnetic identification of magmatic arcs and ophiolite belts.

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ABSTRACT

Iranian plateau is one of the most complex geodynamic settings within the Alpine belt. The PaleoThetys and NeoThetys ocean subduction is responsible for the formation several magmatic arcs and sedimentary basin zones within plateau. These zones are separated from each other by thrust faults that display the ancient suture zones and ophiolite belts. The known magmatic arcs like Urmia Dokhtar Magmatic Arc and unknown magmatic arcs, which is covered by sediments, tracked by aeromagnetic data. It is assumed igneous and ophiolite rocks have highest magnetic susceptibility values in contrast to the lowest magnetic susceptibility values in most sedimentary rocks.

In this study, averaged susceptibility map is estimated by using radially averaged power spectrum method. The high averaged susceptibility values shows a number of steep and gentle lineaments in correlation with magmatic arcs and ophiolites trends. In other hand low averaged susceptibility values indicates sedimentary basins. The results shows good correlation in the regions with high average susceptibility with known occurrences of Magmatic-Ophiolite Arcs (MOA). In the other hand the regions with low averaged susceptibility is coincides with well-known sedimentary basins like Zagros, Makran, Kopeh dagh, Tabas and other less known small basins. New proposed two parallel MOAs in eastern Iran and SE part of UDMA indicate a steeply dipping (>60º dip) subduction zone. In contrast, shallow subduction (<20º dip) of NeoTethys in the NW part of UDMA as well as in the Sabzevar-Kavir MOA.

Keywords: Aeromagnetic data, averaged susceptibility, Tectonic of Iranian plateau, magmatic arcs, ophiolites, sedimentary basins.

INTRODUCTION

The Iranian Plateau is a complex puzzle of continental and oceanic fragments that were amalgamated during the closure of the PaleoThetys and NeoThetys oceans. The structures of the plateau preserve information of the geological-tectonic evolution, including subduction, collision and magmatism in the Alpine–Himalayan orogenic system (Stampfli and Borel, 2002). The regional tectonic evolution was controlled to large degree by the opening of the Tethyan Oceans and their subsequent closure, which emplaced several discontinuous ophiolitic belts and long magmatic arcs on the Iranian Plateau (Berberian and King, 1981; Stampfli and Borel, 2002; Richards, 2015). The vast plateau area includes large remote parts, which are poorly studied and mostly covered by young and thick sedimentary sequences. Almost no information on basement ages is available in these regions but it cannot be excluded that some continental fragments trapped within the Iranian Plateau may be of Precambrian age. Due to the limited knowledge of the surface and deeper geology, aeromagnetic surveying provides an efficient geophysical tool for geological mapping of the vast areas of the Iranian plateau.
The highest magnetic susceptibility values are usually observed in igneous rocks and ophiolites in contrast to the low values in most sedimentary rocks (Figure 1.a)**Error! Reference source not found.**; Clark and Emerson, 1991; Hunt et al., 1995). The radially averaged power spectrum (RAPS) method (Maus and Dimri, 1995; Bouligand and et al., 2009) is widely used for estimating the Curie depth. Here we extend its application to calculation of the vertically averaged crustal magnetic susceptibility from aeromagnetic data. Application of this method provides an insensitive method to the latitude problem of magnetic methods to estimate the horizontal variation of susceptibility and provides opportunity for identification of the high susceptibility of rocks in magmatic and suture zones (Maus and Dimri, 1995). This approach provides an easy and fast routine in comparison to traditional inversion methods, which further are based on assumptions and requirement for a priority information for calculation of the vertical variation of susceptibility. We observe a qualitative correlation between susceptibility trends and the distribution of magmatic arcs, ophiolite belts and major sedimentary basins where the surface geology is known. On this basis, we extend our analysis to mapping similar features in the remote and sediment-covered parts of the Iranian Plateau. Our analysis allows us to identify unknown magmatic ophiolite arcs (MOA) and to provide new locations of the boundaries of sedimentary basins, and thereby we revise parts of the tectono-magmatic evolution of the Iranian Plateau.

RESULTS

A first order observation confirms mapped igneous and ophiolitic rocks correspond to areas with the highest values of susceptibility, and that major sedimentary basins generally correspond to areas with the lowest values of average susceptibility (Figure 1.b). The Zagros fold belt, KopeDagh and Makran accretionary prism have extremely low average susceptibility, which can be explained by the presence of major sedimentary sequences.

Sedimentary basins: Sedimentary rocks are usually not very magnetized and we mainly attribute low average susceptibility to sedimentary basins. The major well known sedimentary basins of Iran (e.g. in the Zagros, Makran and Kopeh Dagh) have very low average susceptibility due to their thick, non-magnetized sedimentary cover. The low susceptibility also indicates absence of substantial amounts of magmatic rocks and ophiolites in these basins. However, other basins show relatively high average susceptibility and sporadic anomalies which indicates the presence of significant volumes of volcanic and magmatic rocks in or below the sedimentary cover like in the eastern part of the Alborz and Great Kavir sedimentary basins. Further, the results indicate that the Sabzevar magmatic ophiolite belt may extend NW-ward into the Great Kavir basin below the sedimentary cover.

The Tabas and Yazd blocks: Our results show an unexpected pattern for the Tabas microplate in central Iran which has extremely low average crustal susceptibility. By analogy to the Zagros-Makran system, we interpret this observation by a large, deep sedimentary basin that lacks magmatic rocks. We propose that the Tabas basin is located on a microplate surrounded by highly deformed central Iranian microplates.

The Yazd block along of the SW margin of the Tabas block has a highly heterogeneous susceptibility where the parts with sporadic high susceptibility correspond to outcrops of Precambrian igneous rocks (**Error! Reference source not found.**Figure 1.b).

Sanandaj-Sirjan metamorphic zone (SSZ): The Sanandaj-Sirjan metamorphic zone at the NE side of Zagros shows variation in style along its strike. Its NW and SE parts show relatively low average susceptibility with sporadic high susceptibility spots that indicate a dispersed distribution of igneous rocks, e.g. at the Kermanshah and Neyriz ophilites zones. Our results suggest a possible continuation of these ophiolites under the sedimentary cover along the strike of the SSZ . Low susceptibility in the central part of SSZ indicates the absence of any magmatic and ophiolite complexes in agreement with surface geological observation, although the average susceptibility value is higher than in the Zagros Belt. We attribute these differences to compositional variability of the near surface rocks and note that metamorphic rocks often have slightly higher susceptibility than sediments.

Magmatic arcs and their relation to pale-subduction properties: We observe strong correlation between high average susceptibility and the location of magmatic arcs. Geological mapping identifies four major magmatic areas in the Iranian Plateau (**Error! Reference source not found.**d): 1- The Tertiary Urumieh–Dokhtar Magmatic Arc. 2- Sanandaj-Sirjan arc. 3-Sabzevar – Kavir magmatic ophiolite belt and 4- Lut volcanic-plutonic belt of the central eastern Iran.

Subduction zones are sites where tectonic processes destroy oceanic lithosphere and form new magmatic material that may be the building blocks of new continental crust (Tatsumi 2005). Magmatic arcs usually exhibit some characteristics of their associated subduction system. Two global different studies demonstrates that the volcanic arc width (Tatsumi and Eggins, 1997) and the depths to the tops of the zones of intermediate-depth seismicity beneath arc volcanoes (England and et al, 2004) shows negative linear correlation with the subduction angle. We use these results to estimate distance between trench and magmatic arcs and interpret the paleo-dip of subduction systems related to the MOAs in Iran.

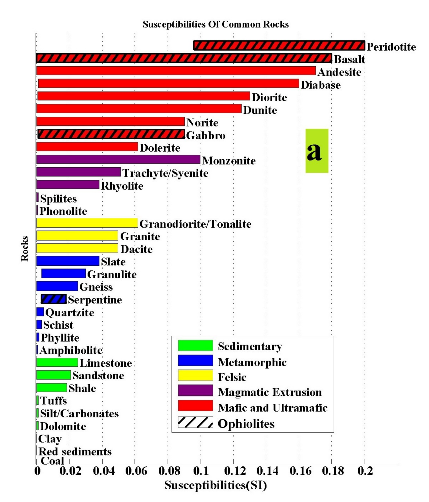
Urmia Dokhtar Magmatic Arc: The magnetic susceptibility results indicate that the UDMA could be divided into the 200 km wide Azarbayjan-Alborz Magmatic Arc (AAMA) north of 35° N, and the 1300 km long and 50 to 60 km wide Arak-Jazmurian magmatic arc (AJMA). The width of the magmatic arcs indicates very shallow subduction with a dip of <20 º and depth to subducted slab > 120 km for AAMA, whereas the AJMA was characterized by steep subduction at 50 º to 70 º dip angle and depth to subducted slab with ~80 km (Figure 1.c **Error! Reference source not found.**). Shallow subduction requires a high buoyancy slab. Absence of magmatic activity in the eastern part of Alborz from the Dmavand volcano to the east is supported by our hypothesis. By analogy with the central Andes we speculate that this part may have had a flat subduction angle such that the subducting plate did not reach depths that allowed the formation of a melting mantle wedge.

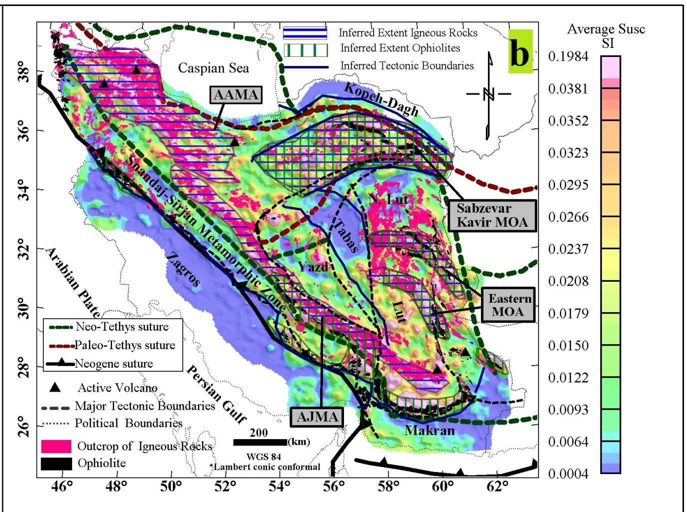
Sabzevar-Kavir MOA: Based on the susceptibility map we interpret the Sabzevar zone and Great Kavir Basin with its thick sedimentary cover as one tectonic block from the Afghanistan-Iran border to central Iran and southward limited by the Darouneh strike slip fault. It includes arch shaped anomalies typical of island arcs. The Sabzevar-Kavir MOA width of 100 km in the east and 200 km in the west suggests that the subduction angle had an east to west decrease from 50º to less than 20º (Figure 1.c**Error! Reference source not found.**). Our data indicates that this igneous and ophiolite complex extends westward into the Great Kavir basin.

Two MOAs of Eastern Iran: Eastern Iran includes a series of volcanic–plutonic ophiolite complexes which extend ca. 1000 km southward from the Sabzevar-Kavir MOA to the Lut block. Despite the occurrence of massive magmatic and ophilitic belts, there is no clear magnetic linear patterns as otherwise observed for volcanic arcs in surface.

We observe two clear parallel arches with high average susceptibility which have never been mapped before. These two zones match a trend of known ophiolites and magmatic arcs partially but the region is poorly studied and needs more investigation. We interpret these belts as two hitherto unknown magmatic arcs. The length of each arc is ca 400-450 km and the width is ca 40 km to 60 km similar to the AJMA corresponding to a dip angle of ca. 60 º and depth to subducted slab ca. 80 km (**Error! Reference source not found.**). The existence of two parallel magmatic arcs is unusual and we are unaware of any tectonic analogues, although deformation of the Paleozoic subduction complexes in Asia created a series of repeated magmatic complexes similar to Altaides (Şengör et al., 2014). However, the same subduction system could possibly have sourced the two parallel zones, which then would represent paired lines of volcanoes as proposed by Tatsumi (2005). In this case the joint system would be ca. 200 km wide, corresponding to a subduction dip angle of <20º.

Regions with poor correlation of susceptibility and MOA: Two areas with known presence of igneous and ophiolite rocks are characterized by low average susceptibility, mainly NW of the SSMZ and north of the Lut block. These low calculated susceptibility values may be caused by alteration of the original rocks or by effects arising from remanent magnetization. An inherent assumption of the RAPS method is that remanent and induced magnetization must be parallel. In any case, this observation indicates different origin and deformation history of these regions than other parts of the Iranian Plateau.





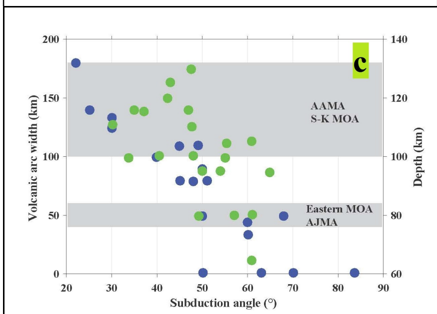


Figure 1. a) Magnetic susceptibility ranges for different rock types.
b) New tectonic interpretation based on average susceptibility and correlation with distribution of outcropped ophiolite and igneous rocks.
c) Tectonic characteristics of subduction zone magmatism demonstrating a negative correlation of subduction angle with volcanic arc width (Tatsumi and Eggins, 1997) and the depth to the top of the intermediate-depth seismicity beneath volcanic arcs (England and et al, 2004), which showed with blue and green circles respectively.

CONCLUSION(s)

We have applied the RASP method to calculate a map of average magnetic susceptibility in Iran. The results demonstrate that areas with high average susceptibility correlate with known occurrences of Magmatic Ophiolite Arcs (MOA), although the susceptibility is low at two MOAs. We conclude that magnetic susceptibility is a useful parameter for identification of MOAs in areas with sparse geological information, be it due to remote location or thick sedimentary cover.

We discover two parallel MOAs in eastern Iran which developed in a steeply dipping (>60º dip) subduction zone, although we cannot completely rule out that they represent two paired lines of volcanoes in a system with shallow subduction dip. Our results indicate shallow subduction (<20º dip) of NeoTethys in the NW (AMAA) and SE parts of the Alborz as well as in the Sabzevar-Kavir MOA. In contrast, the major, central part (AJMA) of the Alborz and the newly discovered eastern MOAs formed in steeply dipping (>60º dip) subduction systems. Based on the magnetic susceptibility results we identify new boundaries of the economically valuable Tabas sedimentary basin.

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