Geothermics 39 (2010) 140–151

Contents lists available at ScienceDirect

Geothermics

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

Developing the geothermal resources map of Iran

Hossein Yousefi [a,*], Younes Noorollahi [b], Sachio Ehara [a], Ryuichi Itoi [c], Amin Yousefi [d], Yasuhiro Fujimitsu [a], Jun Nishijima [a], Kyuro Sasaki [d]

[a] Geothermics Laboratory, Department of Earth Resources Engineering, Kyushu University, 744 Motooka, Nishi-ku, 819-0395 Fukuoka, Japan
[b] Graduate School of the Environment and Energy, Science and Research Campus, IAU, Tehran, Iran
[c] Energy Resources Engineering Laboratory, Department of Earth Resources Engineering, Kyushu University, 744 Motooka, Nishi-ku, 819-0395 Fukuoka, Japan
[d] Resources Production and Safety Engineering Laboratory, Department of Earth Resources Engineering, Kyushu University, 744 Motooka, Nishi-ku, 819-0395 Fukuoka, Japan

ARTICLE INFO

Article history:
Received 3 April 2008
Accepted 3 November 2009
Available online 27 November 2009

Keywords:
Geothermal
Exploration
Geology
Geochemistry
Geophysics
GIS
Iran

ABSTRACT

Geothermal exploration involves a high degree of uncertainty and financial risk, and requires reliable exploration data to constrain development decisions. The paper describes a geothermal exploration and resource identification method that is based on building a map of potential geothermal resource areas by combining geological, geochemical and geophysical datasets; it is a powerful tool for visualizing new and existing data during decision-making processes. By performing suitability analysis and geothermal area identification, and by establishing criteria to define geothermal resources with development potential, a map of Iran was constructed highlighting 18 promising areas.

1. Introduction

Many geothermal systems, but not all, present surface manifestations, such as hot springs, fumaroles and mud pots. These discharges typically occur in areas that are hydrothermally altered and point to the possible existence of geothermal resources of economic importance at depth. Geothermal exploration programs tend to use such surface evidence, together with data from geological mapping, geochemical and geophysical surveys to delineate, characterize and develop conceptual models of areas with geothermal potential.

Usually a geothermal exploration program is performed in a step-by-step manner, comprising reconnaissance, and feasibility and assessment phases. During each stage the less favorable areas (including those presenting actual or potential detrimental environmental and/or development problems) are eliminated from consideration, and efforts are then focused on the most promising ones (Dickson and Fanelli, 2004).

The objective of this study is to develop a methodology that combines the results of a number of exploration programs, including a range of geological, geochemical and geophysical surveys, to locate promising areas for geothermal resource development in Iran, and to demonstrate its applicability to other developing countries where commonly only limited datasets are available.

Identifying areas of high geothermal potential can be a daunting task for exploration managers; however, the decision-making process can be made less cumbersome if better resource assessment tools and methodologies are available.

In many countries, Geographical Information System (GIS) methods have been successfully applied for regional scale exploration of mineral resources (Bonham-Carter et al., 1988; Bonham-Carter, 1991, 1994; Katz, 1991; Chung et al., 1992), and have also been used in geothermal energy exploration to identify areas of high geothermal potential (Prol-Ledesma, 2000; Coolbaugh et al., 2002, 2005a,b; Noorollahi et al., 2007).

We propose a geothermal exploration management strategy that identifies the location and extent of areas warranting detailed investigation; i.e. to find promising areas for geothermal exploration and potential future development. The GIS Model for Geothermal Resources Exploration (GM-GRE) combines the results of geological, geochemical and geophysical studies.

Previous efforts based on manually integrating multidisciplinary geo-scientific field data allowed identification of 14 promising geothermal areas in Iran (Noorollahi et al., 1998) (Fig. 1). However, that method required a great deal of time and manpower, and introduced the possibility of human error and arbitrariness. Consequently, these authors were unable to define in detail the extent of every promising geothermal prospect. The objective of

* Corresponding author at: Geothermics Laboratory, Department of Earth Resources Engineering, Kyushu University, Room 419, 744 Motooka, Nishi-ku, 819-0395 Fukuoka, Japan. Tel.: +81 90 8624 4344; fax: +81 92 8023324.
E-mail address: yousefi@kyudai.jp (H. Yousefi).

0375-6505/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.geothermics.2009.11.001

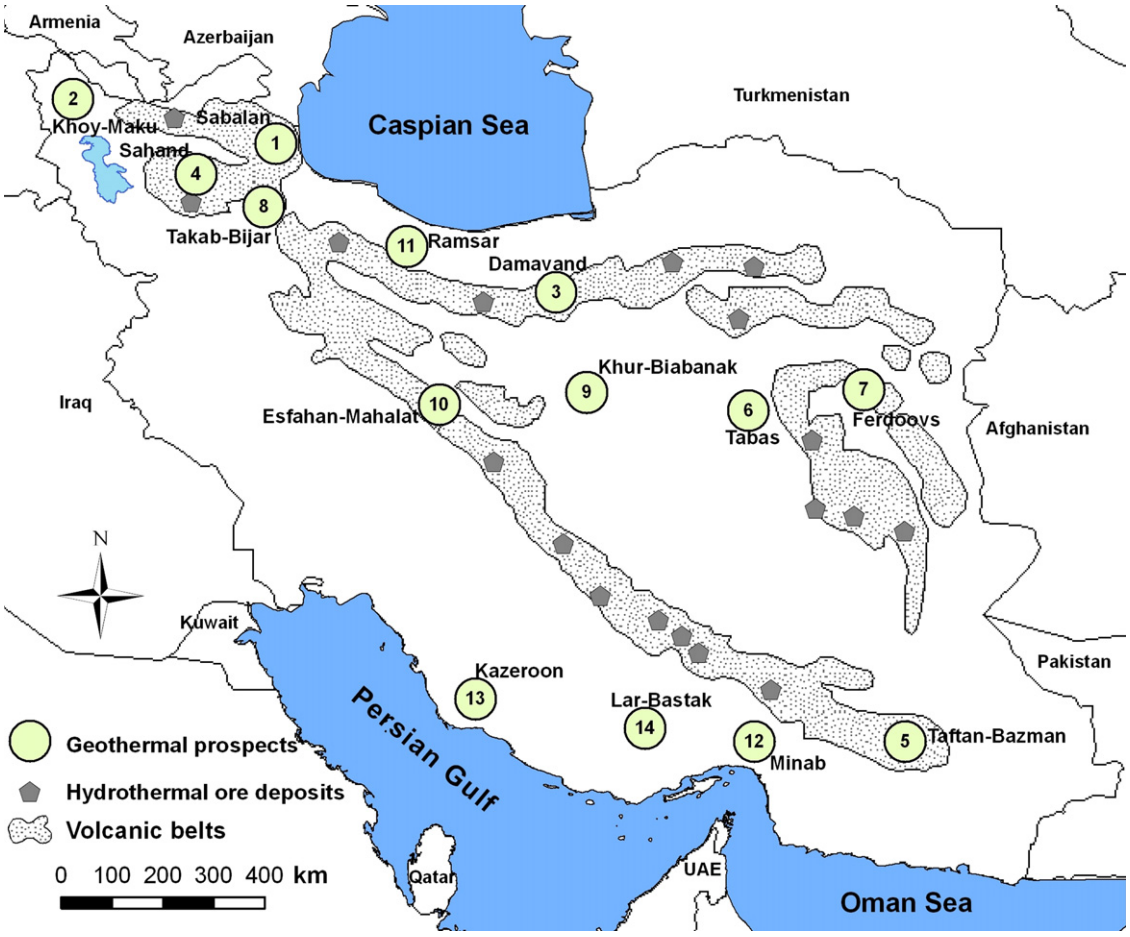

Fig. 1. Geothermal energy resources map of Iran (modified from Noorollahi et al., 1998). The 14 geothermal areas are ranked in order of importance (i.e. Sabalan has the highest rank; Lar-Bastak has the lowest).

our study was to improve the approach used by Noorollahi et al. (1998) and others, and to create a better defined map of promising geothermal areas for Iran based on available geo-scientific data.

2. Geothermal resources of Iran

2.1. Geology of Iran

The Iranian Plateau can be divided into five major structural (tectonic) regions (Fig. 2), which are (from southwest to northeast): the Zagros Active Folded Belt, the Sanandaj Sirjan Orogenic Belt, Central Iran, the Alborz Mountains and the Koppeh Dagh Ranges (Berberian, 1981).

Tectonic studies indicate that the Iranian Plateau is transected by closely spaced active and recent faulting, dominated by reverse faults (Berberian, 1981). These structures reflect the location of the Iranian Plateau, which is confined by the convergent movement of the Arabian and the Eurasian Plates in the northwest, impinging on the Asia-Minor Plate to the west and the Indian Plate to the east.

2.2. Geothermal development in Iran

Although hot springs have been utilized in Iran for hundreds of years (e.g. in baths and spas), geothermal energy development guided by the Iranian Ministry of Energy only started in 1975, with an exploration program in the northwestern part of the country. The results of these investigations indicated four geothermal areas with development potential; i.e. Sabalan, Damavand, Khoy-Maku and Sahand (ENEL, 1983). Subsequent exploration studies conducted between 1996 and 1999 by the Renewable Energy Organization of Iran (SUNA) identified ten additional areas; their rankings are shown in Fig. 1.

The first geothermal power generation project in Iran started in 1995 at the Sabalan geothermal field, where a range of exploration and feasibility studies had delineated five promising areas. Of the five, the NW Sabalan geothermal field was selected for exploration drilling (KML, 1998). In 2002–2004, three deep wells were drilled to determine the subsurface geology and the geothermal reservoir characteristics in that area. A maximum temperature of 240 °C was recorded at 3197 m depth, while reservoir simulation studies estimated the capacity of the NW Sabalan field to be 50 MWe (KML, 1998).

In addition to the planned 50 MWe geothermal power project at Sabalan, 105 MWt of direct utilization for geothermal heat pumps and tourist recreation sites (e.g. swimming pools and spas), have been identified for development nationwide (Yousefi et al., 2009).

The Government of Iran plans to promote the development of the country's indigenous renewable energy sources. The exploitation of Iran's geothermal energy will help reach this goal and contribute to the local economy. A number of geothermal projects are currently being evaluated by the Government for power generation and direct uses of the endogenous heat.

At the same time, by investing nearly €200 million (Yousefi et al., 2008) and promoting a range of pilot projects and feasibility studies, the Government will prepare the ground for the private sector to invest in the development of Iran's geothermal resources. As reported by Yousefi et al. (2009), the Government considers this to be a key factor in making geothermal energy competitive in the