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Heat flow and geothermal resources in northern Italy

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ABSTRACT

This paper gives an up-to-date overview of the surface heat flow and the geothermal resources of northern Italy on the basis of both already processed data and new pieces of information. Temperature data up to 7240 m depth, derived from exploration oil wells, were processed and thermal conductivity was estimated under any possible condition of depth. Radiogenic heat was evaluated by means of both natural gamma-ray logs and gamma-ray spectrometry measurements on core samples. These data together with information from previous investigations allow us to map the temperature at a depth of 2000 m in the Po Plain and to give a new picture of the surface heat flow throughout northern Italy. The most important hydrothermal systems occur in the Alps and the Northern Apennines, in areas where meteoric water leaks to shallow–medium depth and originates thermo-artesian springs. In the eastern sector of the Po Plain, important thermal anomalies appear to be controlled by the morphology of the deep carbonate formation. Thermal rather than forced convection can take place in this formation, which acts as a reservoir hosting low-medium enthalpy water.

Contents

1. Introduction

Studies on the geothermal resources in Italy have been traditionally focused on the high enthalpy fields scattered in the central-southern part of the country. Northern Italy, which includes the Po Plain, part of the Alps and the northern portion of the Apennines (Fig. 1), has instead drawn less attention, although it exhibits, in some areas, promising low-medium enthalpy resources. The main tectonic, structural and hydrothermal characters of northern Italy are well known from several geological and geophysical studies, both at the local and regional scale [1,2]. Among the regional studies, international scientific projects such as EGT [3] and ECORS-CROP [4,5] should be mentioned. Drillings carried out during several years of hydrocarbon exploration and regional seismic sections, integrated with magnetic and gravimetric modeling, have also given a contribution of paramount importance [6]. In the Mesozoic, the whole region experienced extensional events, which led to the formation of a wide carbonatic platform. Subsequently, the tectonic regime turned into compressive, producing, since the Oligocene, south-verging thrusts in the Southern Alps and north-verging thrusts in the Northern Apennines. At present, the carbonate platform crops out in the Southern Alps and is buried beneath the Po Plain.

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The pieces of available geological and geophysical information permit to distinguish the following tectonic units (Fig. 1):

- Southern Alps, related to the post-collisional (Oligo-Miocene) deformation of the Alps, consisting of thrust sheets, partly buried beneath the Po Plain Plio-Quaternary cover (SAB). The regional detachment surface of the thrust sheets corresponds to the top of the Eocene deposits. The few thermal springs occurring in this unit are often carbonic, of shallow–medium depth origin and with rather low temperature.
- Undeformed Po Foredeep (UPF), filled by terrigenous sediments deposited since Upper Eocene–Oligocene times and characterized by an impressive contribution of dismantling debris of the Alps and, only in recent times, of the Apennines. In the northern part of UPF, there occur outcrops of the carbonate formation together with Paleocene–Oligocene volcanic and subvolcanic products (Exposed Adriatic Foreland). With the exception of few thermal springs of minor importance, water, often salty, seems confined in the deep carbonate layers buried beneath the terrigenous sediments [2].
- Northern Apennines, consisting of thrusts sheets, which have developed since the Oligo-Miocene. Their external front is arcuate and buried beneath the Plio-Quaternary cover (NAB). The thermal springs occurring in this unit consist of either fossil, salty water, often associated with hydrocarbon reservoirs, or sulfate/sulfurous water related to the Messinian evaporitic series. Water can leak to shallow – medium depth only at few zones and originates thermo-artesian systems.
- Western Alps, including the deformed Alpine European foreland and the Pennine thrust sheets (ophiolitic unit cover and basement thrust sheets). Thermal springs generally originate from groundwater circulating in crystalline rocks. Important reservoirs occur also beneath the sedimentary cover of the Tertiary Piedmont Basin, structurally developed between the Western Alps and the Northern Apennines.

In this paper, we process deep temperatures from petroleum exploration wells of the Po Plain and carefully evaluate the rock thermal properties and the radiogenic heat in order to infer information on the surface heat flow. The new data, together with those so far available [2,7–12], allow us to describe the thermal regime and the characteristics of the main hydrothermal systems, and to outline an up-to-date picture of the geothermal resources of northern Italy.

2. Subsurface temperature

Temperatures recorded in hydrocarbon wells are the main source of information on the subsurface thermal state of the Po Plain. A huge number of drilling reports is contained in the open access file of the Italian Economic Development Ministry (Energy Department, General Direction for Energy and Mining Resources). Among the available well reports, we selected only those containing both temperature records and exhaustive lithostratigraphic descriptions. The position of the 98 selected wells is shown in Fig. 1.

As a whole, 295 temperature data from 280 – 7240 m depth range were analyzed. The dataset includes 277 temperatures measured at the hole bottom (BHT) and 18 recorded during drill stem tests (DST). BHTs are perturbed by the drilling mud circulating in the well. Thus, they had to be processed to infer the formation temperature. DSTs record the fluid (oil and gas) temperature, supposed to be in equilibrium with that of the surrounding rocks, and therefore no correction was necessary [13].

Depending on the information available in the well reports, we applied different methods to correct BHT data. When the well radius was unknown, we applied the empirical relation proposed by Pasquale et al. [10] based on the methods by Horner [14] and Cooper and Jones [15]. This approach was possible for most of the BHT data. When information on the well radius, shut-in time and mud circulation time was available, we applied the method by Zschocke [16]. In wells where repeated BHTs at a given depth were recorded together with the mud circulation time and the shut-in time, we used a method that envisages the well as a long hole of small diameter, drilled quickly and filled with water at temperature lower than the formation temperature (see for details [12]). In general, the correction for the circulating mud applied to BHTs ranges from 6 to 13 °C. The corrected BHTs and DST temperatures of the main tectonic units of the Po Plain as a function of depth are plotted in Fig. 2. The inferred thermal gradient varies little and it is minimum in NAB (21.7 mK m^{-1}) and maximum in SAB (24.5 mK m^{-1}).

Fig. 3 outlines the temperature distribution at a depth of 2000 m across the Po Plain. In the few wells that do not reach such a depth, temperatures were calculated by extrapolation. In the eastern part of the Po Plain (in correspondence of the UPF unit), the available data were too sparse to allow contouring (cfr Fig. 1). Thus, the temperature was estimated at the nodes of a regularly spaced grid (25 km × 25 km) from the thermal gradients of the sedimentary cover inferred from inversion of temperature data with a technique based on a lateral constant thermal gradient [17]. The stratigraphic column was schematized as indicated by

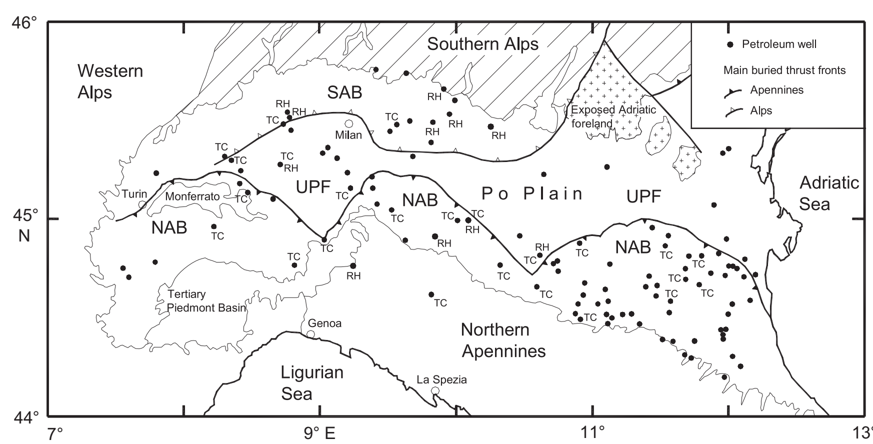

Fig. 1. Tectonic sketch of northern Italy and location of petroleum wells (full circles) providing temperatures, thermal parameters and lithostratigraphic information. Codes TC and RH next circles indicate wells which supplied cores for laboratory measurements and radiogenic heat data, respectively. NAB – Northern Apennines Buried, SAB – Southern Alps Buried, UPF – Undeformed Po Foredeep units.