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Structural compartmentalisation of a geothermal system, the Torre Alfina field (central Italy)

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ABSTRACT

Recent surging of renewed industrial interest in the exploration of low and medium enthalpy geothermal fields makes the accurate assessment of the geothermal potential essential to minimise uncertainties during both exploration and exploitation. The Torre Alfina field is a case of abandoned, but promising, geothermal field of central Italy where the roles of the internal structural setting and of the recharge areas on the hydrothermal circulation are largely unconstrained. In this paper, field structural data integrated with geomorphic lineament analysis document the occurrence of post-orogenic deformation structures controlling the compartmentalisation of the Torre Alfina geothermal field. Strike-slip and subordinate normal fault systems (with associated network fractures) cut and dislocate the internal architecture of the reservoir and prevent its hydraulic connection with Mount Cetona, considered to be the recharge area and where hydrothermal manifestation, including travertine deposition, occurs. $^{230}Th/^{234}U$ radiometric dating of superposed travertine units gives 200, 120 and 90 ka respectively, inferred to correspond to the age of the fossil hydrothermal circulation during tectonic activity. The results have been used for illustrating a new geological conceptual model for the Torre Alfina area where the geothermal system is composed of different compartments. Tectonic structures define the main boundaries between compartments, helping the understanding of why productive and non-productive wells were found in apparently similar structural settings within the Torre Alfina field.

1. Introduction

Geothermal energy resources are expected to play an increasing role on the future power demand, addressing large incentives from policymakers and capturing the attention of industries. A renewed world-wide interest for geothermal energy is also presently stimulated by technological advances in exploration and exploitation of medium-enthalpy systems.

Geophysical methods (e.g. Árnason et al., 2010; Bibby et al., 1995; Garg et al., 2007; Jousset et al., 2011; Newman et al., 2008), together with expensive explorative drillings, are commonly used for assessing the configuration of the main geothermal components (reservoir units, seal rocks, recharge area), as well as the characteristics and the hydrodynamic network of the endogenous fluids. An accurate interpretation of geophysical data depends on the reliability of the geological conceptual model of the investigated geothermal system. In particular, reconstruction of the geothermal setting is invariably connected with the geological history of the site, and evaluation of the main geological features in the area is a primary goal before planning the exploration. The incorrect definition of the geological model can lead to main failures both in the exploration stage and during the exploitation of the geothermal field.

Fluid circulation depends on the permeability contrast in a reservoir, which favours the localisation of subsurface thermal anomalies (e.g. Guillou-Frottier et al., 2013; McLellan et al., 2010). In addition, geothermal reservoirs are usually described in areas with active tectonism, with fault systems and fracture networks perturbing the circulation of endogenous fluids and localising the hydrothermal manifestations at the surface (e.g. Barberi et al., 1984; Giordano et al., 2012; Kaven et al., 2011; Traineau et al., 1997; Wood, 1994). It has been demonstrated that the interplay between deformation, fracturing and sealing may generate a complex fluid-rock pattern in both active and fossil tectonic settings (Cox et al., 2001; Oliver, 1996; Rossetti et al., 2011; Rowland and Sibson, 2004; Sheldon and Ord, 2005; Sibson, 2000), including near vertical channelized fluid flows along unsealed discontinuities (e.g. Cas et al., 2011; Sibson, 2000) and limited horizontal fluid migrations within fault-barriers rock-bounded (e.g. Faulkner and Rutter, 2001).

Central Italy is characterised by a great number of geothermal fields that have been successfully exploited since the last century (e.g. Barberi et al., 1994). Larderello system is the best known example, but the presence of fossil and active hydrothermal manifestations distributed all along the Tyrrhenian margin has renewed the economic interest by private companies. Consequently, a large number of new research

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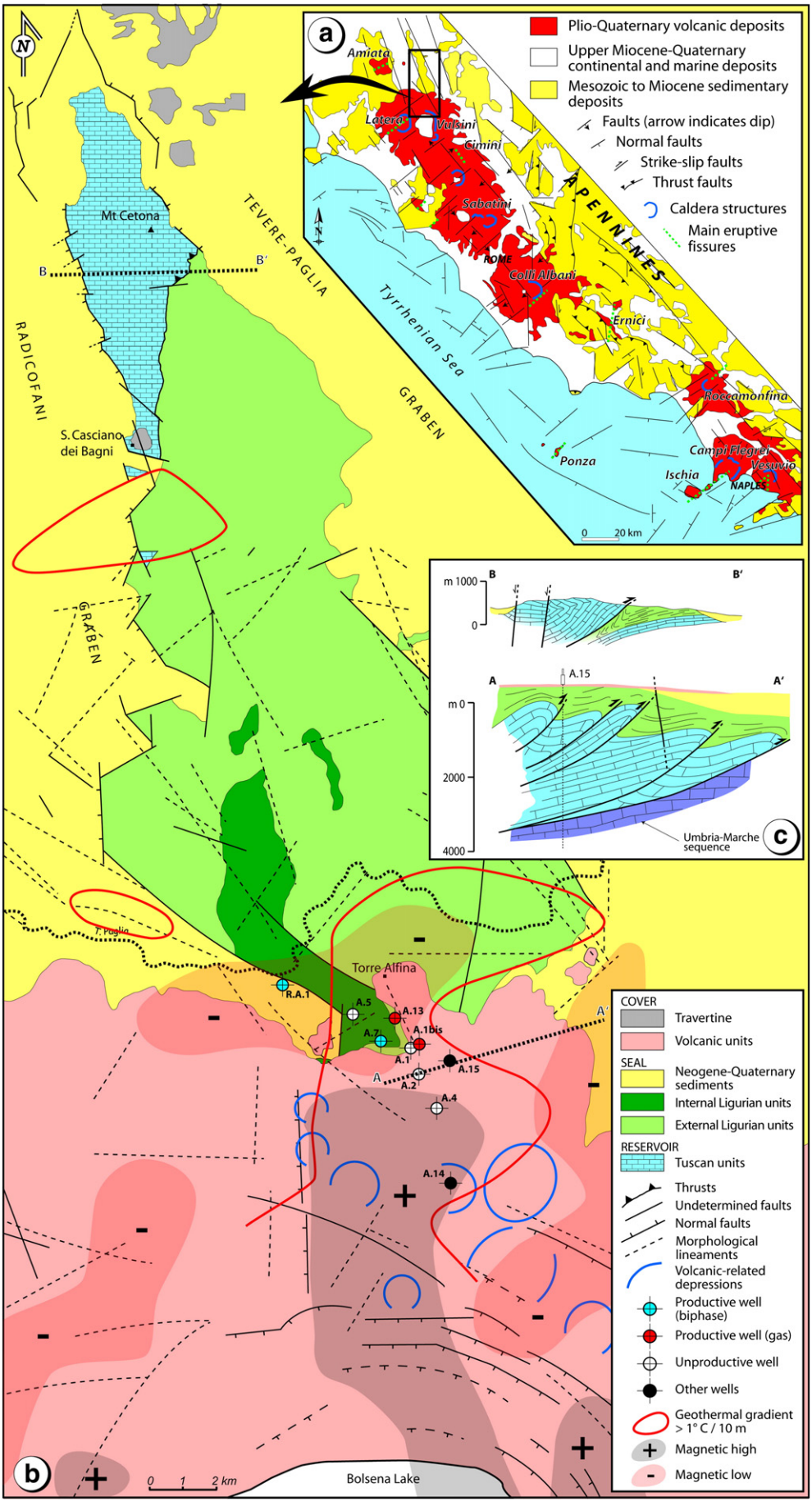
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Plio-Quaternary volcanic deposits
Upper Miocene-Quaternary continental and marine deposits
Mesozoic to Miocene sedimentary deposits
Faults (arrow indicates dip)
Normal faults
Strike-slip faults
Thrust faults
Caldera structures
Main eruptive fissures
Amiata
Latera
Vulsini
Cimini
Sabatini
ROME
Colli Albani
Ernici
Roccamonfina
Campi Flegrei
Vesuvio
NAPLES
Ischia
Ponza
APENNINES
Tyrrhenian Sea
GRABEN
0 20 km
Mt Cetona
B
B′
TEVERE-PAGLIA
RADICOFANI
GRABEN
S. Casciano dei Bagni
m 1000
0
A
A′
A.15
m 0
2000
4000
Umbria-Marche sequence
c
T. Foglia
Torre Alfina
R.A.1
A.5
A.13
A.7
A.1bis
A.1
A.15
A.2
A.4
A.14
b
0 1 2 km
Bolsena Lake
COVER
Travertine
Volcanic units
SEAL
Neogene-Quaternary sediments
Internal Ligurian units
External Ligurian units
RESERVOIR
Tuscan units
Thrusts
Undetermined faults
Normal faults
Morphological lineaments
Volcanic-related depressions
Productive well (biphase)
Productive well (gas)
Unproductive well
Other wells
Geothermal gradient > 1° C / 10 m
Magnetic high
Magnetic low