Geothermics 59 (2016) 325–346

Contents lists available at ScienceDirect

Geothermics

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

Undeveloped high-enthalpy geothermal fields of the Taupo Volcanic Zone, New Zealand

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ARTICLE INFO

Article history:
Received 13 February 2015
Received in revised form 31 July 2015
Accepted 18 August 2015
Available online 14 October 2015

Keywords:
Taupo Volcanic Zone
Geothermal
Surface features
Fluid chemistry
Geology
Hydrothermal alteration
Fluid inclusions
Hydrology

ABSTRACT

In the Taupo Volcanic Zone there are 21 high enthalpy (>225 °C) geothermal fields with 7 utilised for power generation. This paper presents an overview of the undeveloped high enthalpy geothermal systems of the region; namely, Rotoma—Tikorangi, Tikitere, Taheke, Rotomahana—Waimangu, Waiotapu (including Waikite), Reporoa, Te Kopia, Orakei Korako, Mangakino, Horomatangi, Tokaanu—Waihi and Tongariro. Most of these geothermal systems are hosted in rocks of rhyolitic composition, although Tokaanu—Waihi and Tongariro are hosted in andesitic rocks. Some of the geothermal systems have extensive surface thermal manifestations (e.g. Waiotapu, 17 km^2), whereas others have few (e.g. Rotoma—Tikorangi), largely reflecting limited hydrological connectivity to the surface (i.e. impermeable rocks, structures). Uniquely, Horomatangi is fully submerged beneath Lake Taupo. All have liquid-dominated reservoirs of neutral pH alkali chloride waters, except for Tongariro which is inferred to have a vapour-dominated reservoir.

Volcanic and tectonic activity, both past and present has impacted the near surface hydrology of geothermal systems in the Taupo Volcanic Zone. For example, the 1886 volcanic eruption of Mount Tarawera resulted in a series of phreatomagmatic and hydrothermal eruptions through the Rotomahana geothermal system, and created new fluid flow pathways and established thermal features at Waimangu Valley. Similarly, tectonic activity with movement along the Paeroa Fault has disturbed the Te Kopia geothermal field by changing the hydrology and resulted in the juxtaposition of acid on neutral alteration minerals in the upthrown fault block. But despite these volcanic and fault interruptions, thermal activity has continued. Several systems show evidence of thermal decline (Mangakino, Orakei Korako, Te Kopia), and the occurrence of altered ground and relict sinter between Te Kopia and Orakei Korako suggest they may at one time have been been hydrologically connected in the near surface.

1. Introduction

Geothermal systems of the Taupo Volcanic Zone (TVZ) are world famous both for their natural surface phenomena (hot springs, geysers and mud pools) and as a heat resources that are predominantly used for electrical generation. There are 25 geothermal fields (Fig. 1) with 7 utilised for power generation (at Wairakei, Tauhara, Rotokawa, Ngatamariki, Mokai, Ohaaki and Kawerau). Of the other fields, some can potentially be developed for power generation (Rotoma—Tikorangi, Taheke, Mangakino, Atiamuri) or have restricted power developments (Rotorua, Tikitere, Tokaanu—Waihi), whereas several are protected to preserve thermal features of cultural (iwi/Māori) and national significance (e.g. at Waimangu, Waiotapu, Orakei Korako) as regulated by Environment Waikato and Environment Bay of Plenty. This paper provides an overview of the non-developed high enthalpy (>225 °C, c.f. Hochstein, 1988) geothermal fields in the TVZ, and include from northeast to southwest, Rotoma—Tikorangi, Tikitere—Taheke, Rotomahana—Waimangu, Waiotapu (including Waikite), Reporoa, Te Kopia, Orakei Korako, Mangakino, Horomatangi (Lake Taupo), Tokaanu—Waihi and Tongariro (Ketetahi); the Rotorua geothermal field is described in this Special issue by Scott et al. (2016). For many of these fields our understanding is based on the occurrence, distribution and chemical character of surface thermal features (i.e. springs, geysers, mud pools, fumaroles, steaming ground; Fig. 2) combined with various ground and airborne geophysical surveys (i.e. resistivity, micro-seismicity, magnetic and gravity). The subsurface geology, thermal structure and reservoir chemistry for many are inferred (e.g. Tikitere, Tokaanu—Waihi, Tongariro), whilst others are known from a limited number of exploratory wells

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http://dx.doi.org/10.1016/j.geothermics.2015.08.006
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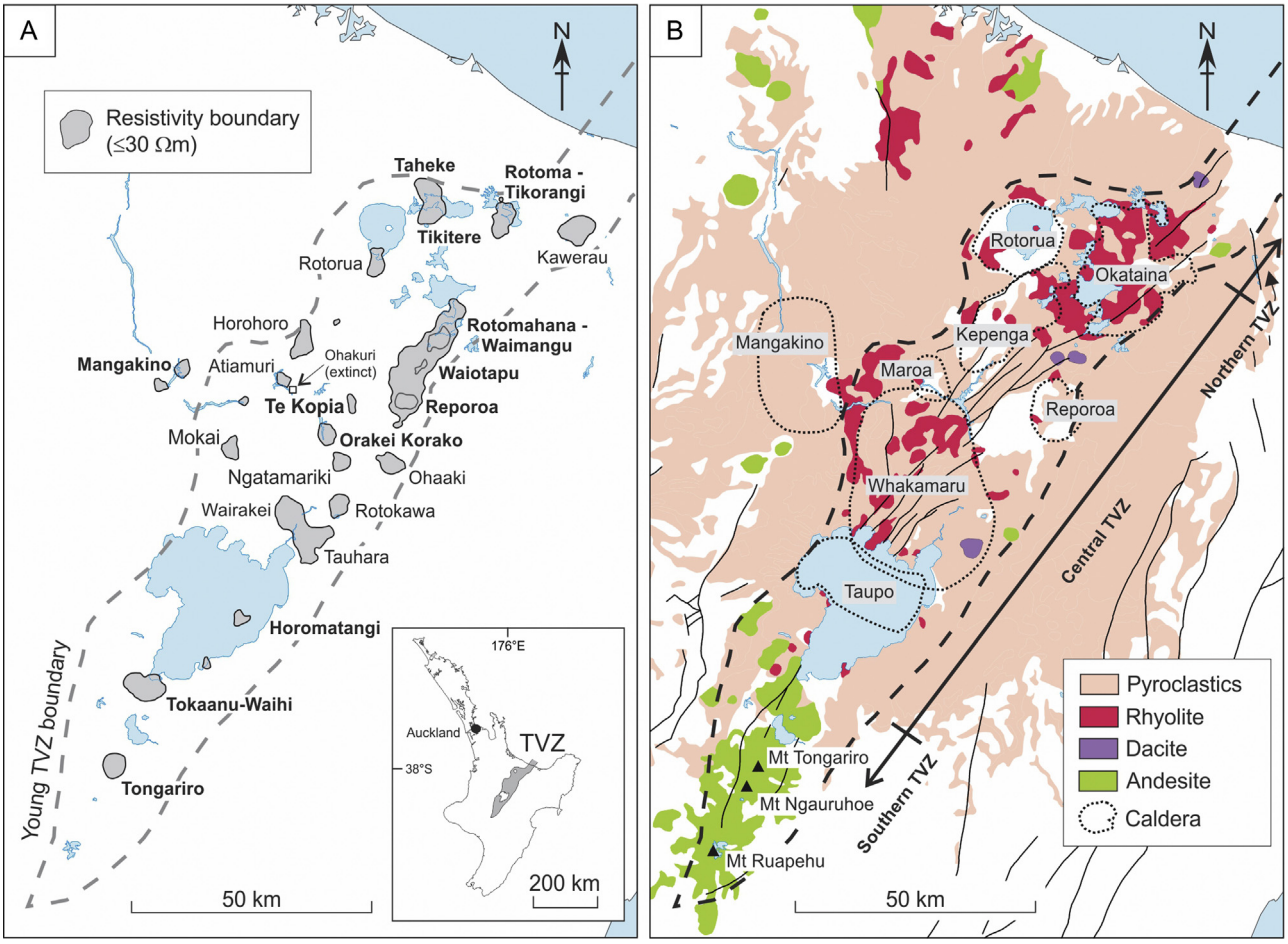

Fig. 1. Simplified maps of the Taupo Volcanic Zone (TVZ) showing (A) the general outlines for geothermal fields as approximated by their inferred resistivity anomaly (Hochstein and Bromley, 1979; Bibby et al., 1995; Stagpoole and Bibby, 1998) and (B) the geology (Leonard et al., 2010), caldera outlines and structure (Wilson et al., 1995; Wilson and Rowland, 2016). Inset shows location of the TVZ within the North Island of New Zealand.

(e.g. Mangakino, Orakei Korako, Waiotapu). The geothermal fields described here exhibit many similarities, but also diversity and each has unique attributes (i.e. chemistry, geology, hydrology and histories).

For clarity, a list of terms used in this paper require definition, and these include: undeveloped: a geothermal field/system that is not presently utilised by a large industrial user either for sustainable electrical power generation or a direct heat source (e.g. timber drying). Protected: a geothermal field/system valued for its outstanding natural, cultural and ecological values, and thus its source geothermal waters cannot be extracted and its surface thermal features cannot be damaged by unsuitable land uses. Geothermal field: the area or region defining the distribution of thermal manifestations (e.g. hot springs, geysers, steaming ground, fumaroles) and/or surficial projection of the shallow geothermal reservoir (<0.5 km depth) as delineated by geophysical techniques (e.g. resistivity). Geothermal system: a hydrostatic to hydrodynamic pressured rising convective column of deeply (>5 km) circulating water inferred to be driven by magmatic heat, that can have a range of surface thermal manifestations.

2. Taupo Volcanic Zone

The Taupo Volcanic Zone (Fig. 1) is the continental tip of the largely oceanic Kermadec—Tonga arc system formed due to westward-directed oblique subduction of the Pacific plate beneath the Australian plate since 2 Ma (e.g. Cole and Lewis, 1981; Schellart et al., 2006; Mortimer et al., 2010). Volcanism in the TVZ rifted arc extends ~250 km from White Island to Ruapehu with the northern and southern segments dominated by cone-building eruptions of andesite, whereas the central segment (125 × 60 km) is dominated by explosive caldera-forming eruptions of rhyolite (Fig. 1) with at least 6000 km^3 of magma erupted during the last 1.8 Ma (Healy, 1962; Cole, 1979; Wilson et al., 1995, 2009; Wilson and Rowland, 2016 and references therein). There have been at least 34 caldera forming ignimbrite eruptions from eight recognised caldera centres during three main periods; 1.68–1.53 Ma, 1.21–0.68 Ma, and 0.34 to present (Houghton et al., 1995).

Most geothermal systems discussed in this paper, with the exception of Kawerua, Tokaanu—Waihi and Tongariro, occur in the central segment of the TVZ (Fig. 1) and are hosted by thick sequences of pyroclastics and ignimbrites of rhyolitic composition that are intercalated with shallow lacustrine and reworked volcanic sediments and include rhyolite and local andesite flows that unconformably overly Mesozoic meta-sediments (Wilson and Rowland, 2016). Deep drilling at Ngatamariki has also intersected 'shallow' intrusions (<2 km depth) of diorite, microdiorite and tonalite (Browne et al., 1992; Chambefort et al., 2014). The geothermal systems have large and deep convection cells of modified meteoric water (>5 km) that are inferred to be heated by magmatic intrusions at depth (Henley and Ellis, 1983) and have been drilled to 3.4 km. The reservoir fluid consist of neutral pH chloride waters typically