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Pinpointing Deep Geothermal Upflow in Zones of Complex Tectono-volcanic Degassing: New Insights from Aluto Volcano, Main Ethiopian Rift

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ABSTRACT

Active rifts release large amounts of volcanic gases from deep sources to the atmosphere. The objective of this paper is to present a geothermal exploration strategy for areas, which have limited hydrothermal surface expressions and are unsuitable for fluid sampling and analyses. In such areas soil gas surveys can complement established exploration strategies. We report CO_2, ^{222}Rn and ^{220}Rn emissions from the Aluto volcanic complex (Ethiopia) to improve our understanding of tectonic and volcanic controls on the existing geothermal system. Results will help to optimize the understanding of geothermal systems and to identify major, deep-reaching permeable structures with active fluid circulation, suitable as drilling targets for geothermal production wells. Significant differences in gas signatures have been used to identify predominantly volcanically and/or tectonically influenced compartments. Major gas emissions have been observed in areas jointly affected by tectonic structures and volcanic driving forces (tectono-volcanic) indicating significant fluid circulation at depth. Predominantly fault-controlled sectors also show hydrothermal fluid circulation, but to a lower extent compared to tectono-volcanic sectors. Within the Aluto volcanic complex geothermal production wells mainly target such fault-controlled domains, whereas results of the study indicate strongest fluid circulation in tectono-volcanic sectors. This result should be considered for the future exploration and development strategy of the site. This paper is a brief summary of the following publication: *Pinpointing Deep Geothermal Upflow in Zones of Complex Tectono-Volcanic Degassing: New Insights from Aluto Volcano, Main Ethiopian Rift (Jolie et al., 2019)*.

1. INTRODUCTION

Major faults in the East African Rift System are controlled by tectonic and volcanic mechanisms (Corti, 2009). Surface gas release and hydrothermal fluid circulation in active rift systems are not only related to its magmatic source, but also reflect local and regional tectonic controls in the subsurface (Brune et al., 2017; Goerner et al., 2009; Jolie et al., 2016). In this setting increased degassing along fracture zones outline deep-rooted permeable segments of active faults and points to major upflow and outflow zones of hydrothermal fluids. Fault segments with strong gas emissions are characterized by increased slip- and dilation tendencies (Jolie et al., 2015a, 2016). Analyses of a variety of soil gases have proven their suitability for assessing the tectonic and volcanic controls on geothermal systems (Jolie et al., 2015b, 2016; Hunt et al., 2017; Lee et al., 2016). These gases provide crucial information for the exploration of geothermal fields and help in targeting wells in the most permeable segments of fault zones with the greatest flow rates of high-temperature hydrothermal fluids (Fridriksson et al., 2016). Soil gas surveys do not require heavy equipment and can be performed in a relatively short time even in some of the most difficult terrain. Many techniques allow in-situ analysis in the field (e.g., accumulation chamber method, alpha spectroscopy, gas chromatography), which gives much flexibility in the planning of field campaigns (Jolie et al., 2015b).

In this study, we show the results of a multi-method approach which focuses on the identification and characterization of degassing fluids that ascend from a magmatic system along tectonic faults (tectono-volcanic interaction). Tectono-volcanic interactions have an effect on soil degassing within the Aluto volcanic complex and result in more intense gas emissions. Our approach consists of a combination of systematic alpha-spectroscopic measurements as well as CO_2 efflux measurements based on an area-wide, regular grid (Jolie et al., 2015b, 2016). Results illustrate that substantial information on permeable subsurface structures and lateral outflows can be obtained by the analysis of surface degassing. This provides more detailed information to the results of conventional surface structural mapping, which is often limited in geothermal areas with fast geomorphological changes (typical for the East African Rift). We show that soil gas surveys can help provide a more comprehensive analysis of geothermal systems and are well-suited for identifying targets for geothermal development.

2. METHODS

A large-scale soil gas survey (Fig. 1) was performed in 2016/17 covering a significant area (5.7 km × 3.5 km) of the two dominating structures (i.e., Artu Jawe Fault Zone - AJFZ, Ring Fault) as well as the area in between the two structures (referred to as 'Central Area'), building up on previous efforts by Hutchison et al. (2015, 2016). The NE-SW extension of the study area is 5.7 km with a maximum NW-SE extension of 3.5 km. The following parameters were determined during the field survey: CO_2 efflux by the accumulation chamber method; ^{222}Rn and ^{220}Rn activity concentration by alpha-spectroscopic measurements; and soil temperatures (T_S) at 50 cm depth.

The accumulation chamber method is a technology where a chamber is placed on the ground and the increasing CO_2 concentration in the chamber is measured (2-3 min) by an infrared gas analyzer (LI-COR 820, accuracy <3 % of reading). The increase in CO_2 concentration correlates to the CO_2 efflux at the interface between the geosphere and atmosphere. Throughout the survey we used a

WEST Systems Type A accumulation chamber (WEST Systems, 2019). Temperature measurements have been performed using a Greisinger GMH 285-BNC thermometer with Pt1000 sensor in a 620 mm long stainless steel probe (accuracy ±0.1 K). ^{222}Rn and ^{220}Rn activity concentrations are determined by a radiometric measurement (~15 min), which determines their short living radon daughter nuclides ^{218}Po and ^{216}Po from soil gas samples collected 1 m below the surface and pumped to the analyzer (Jolie et al., 2015b). Measurements have been performed by a Sarad RTM 1688 and RTM 2200 using a high-voltage measuring chamber with electrostatic precipitation of ionized nuclides on the surface of a 2 cm² semiconductor silicon detector (accuracy: 3 counts/minute).

3. RESULTS

The Aluto volcanic complex is characterized by variable emission rates of volcanic gases and soil gas concentrations (Fig. 1), which can be explained by its tectonic, volcanic and tectono-volcanic setting. Apart from the two main structural features, i.e. Artu Jawe Fault, Ring Fault, further sectors with increased gas emissions have been identified in between (Fig. 2). Gas release along the Artu Jawe Fault reflects the general NNE-trend of the Wonji faults and is increasing from the tectonically dominated North towards the volcanic centre in the South. This correlating trend is reflected in all parameters (CO_2, ^{222}Rn, ^{220}Rn, T_S). Significant differences in quantity of soil gas between A1 to A2 suggest a differentiation between a tectonic and tecto-volcanic compartment. A possible explanation for this is the combination of volcanic (vicinity to a magmatic volatile source) and tectonic (structural permeability) impacts in SAJFZ, whereas the northern part of Artu Jawe is mainly tectonically influenced (permeable, but distant from magmatic volatile source). The transition from the Northern to the Southern Artu Jawe Fault Zone in the vicinity of the Aluto-Langano geothermal powerplant is a particularly interesting area, since outcropping segments of the Artu Jawe Fault are accessible without a cover of recent eruptive deposits (Hutchison et al., 2015). Here, we observe a change from tectonic (North) to tectono-volcanic mode (South). The geothermal surface expressions at the Ring Fault are considered a result of volcanic and tectonic interactions (tectono-volcanic) and are similar to the southern part of the Artu Jawe Fault.

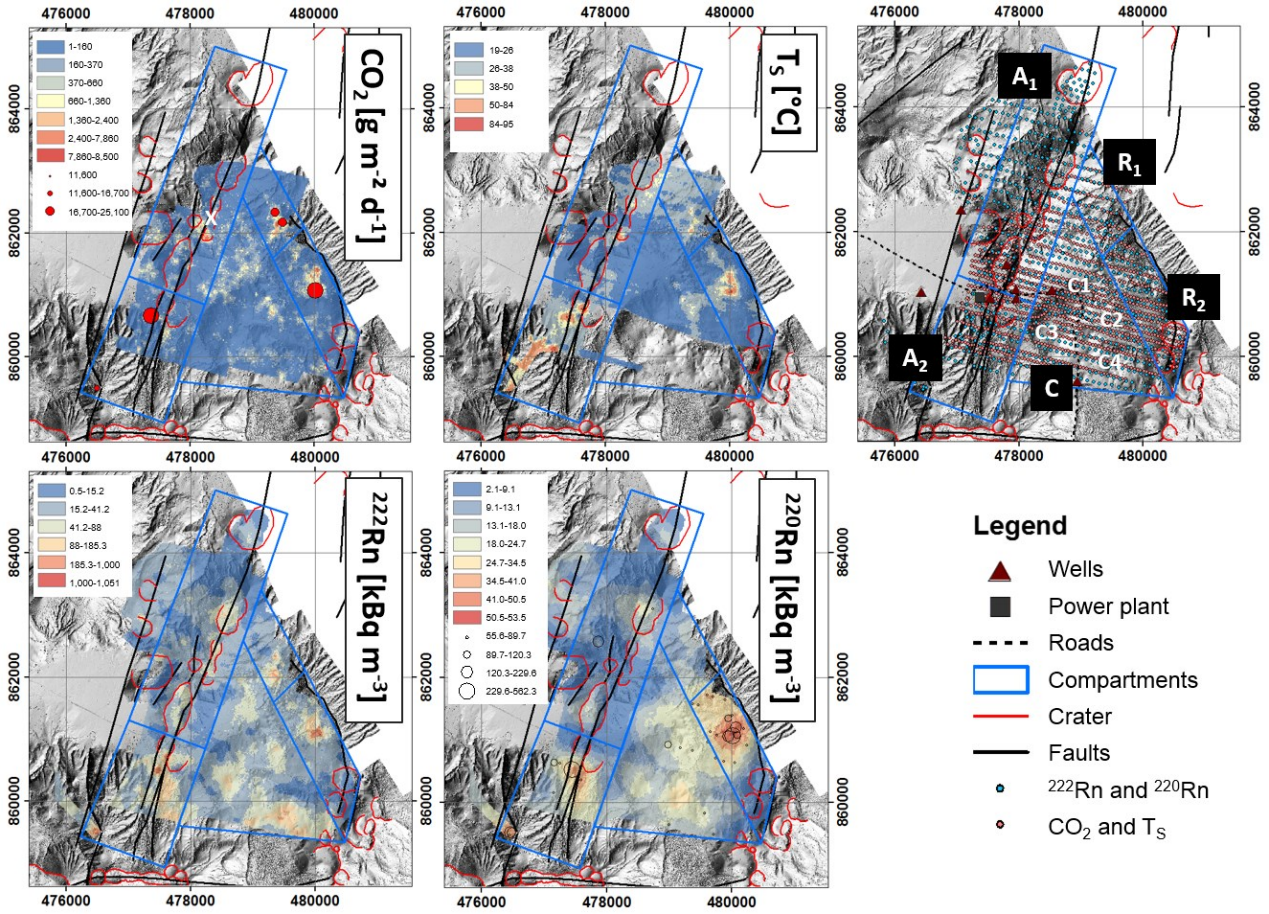

Figure 1: Interpolated maps for CO_2, T_S, ^{222}Rn and ^{220}Rn. Fault lines, craters have been digitized on the basis of a map from Kebede et al. (1985). Figure from Jolie et al. (2019). A_1 – Northern Artu Jawe Fault Zone; A_2 – Southern Artu Jawe Fault Zone, R_1&R_2 – Ring Fault; C – Central Area.

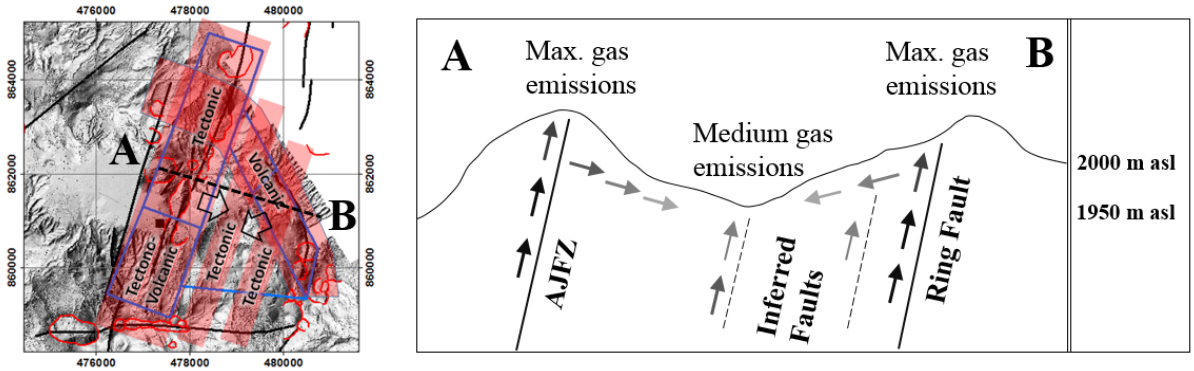

Figure 2: The developed conceptual model simplifies the complex tectonic and volcanic setting of the Aluto volcano. The Southern Artu Jawe Fault Zone is dominated by tectono-volcanic gas emissions. Along the Northern Artu Jawe Fault the tectonic setting dominates surface gas emissions. The Ring Fault is a volcanic feature, which is likely to be affected by NNE-oriented structural features. Geothermal outflow zones are indicated by arrows. Figure from Jolie et al. (2019).

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