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GEOCHEMICAL STUDY OF THE ALID HYDROTHERMAL SYSTEM,

DANAKIL DEPRESSION, ERITREA

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ABSTRACT

Detailed geological studies indicate that a relatively young, large, shallow, and still hot magmatic heat source is probably present beneath the Alid volcanic center in the northern Danakil Depression of Eritrea. Fumaroles and boiling pools are distributed widely on the north half of Alid, suggesting that an active hydrothermal system underlies much of that part of the mountain. The area of high convective heat flow covers at least 10 square kilometers. Gas geothermometers indicate likely reservoir temperatures in the range 250°C - 325°C. The isotopic composition of condensed fumarolic steam is consistent with 220-300°C boiling of groundwaters that may have come from various sources, including local lowland rain, fossil Red Sea water, or conceivably, highland rain water that evaporated significantly before percolating underground. Some gases in the reservoir fluid, particularly CO_2, H2, and H_2S may be derived, directly or indirectly, from a silicic intrusion that very likely exists beneath Alid.

INTRODUCTION

There is an urgent need to develop new domestic sources of energy to foster expansion of the Eritrean economy while minimizing the importation of costly fossil fuels. To help address this need, the USGS was funded by USAID to undertake the first phase of a study of the geothermal energy potential in the eastern lowland region of Eritrea. The Alid volcanic center was selected for detailed study because (1) it is the focus of geologically young rhyolitic volcanism within a background of spreading-related basaltic volcanism and (2) it is the site of many fumaroles (U.N.D.P., 1973; Beyth, 1994). The collection of waters and gases for chemical and isotopic analyses was carried out in February 1996. Standard sampling and analytical procedures were used for water and fumarolic gas samples (Trujillo et al., 1987; Giggenbach and Goguel, 1989; Fahlquist and Janik, 1992).

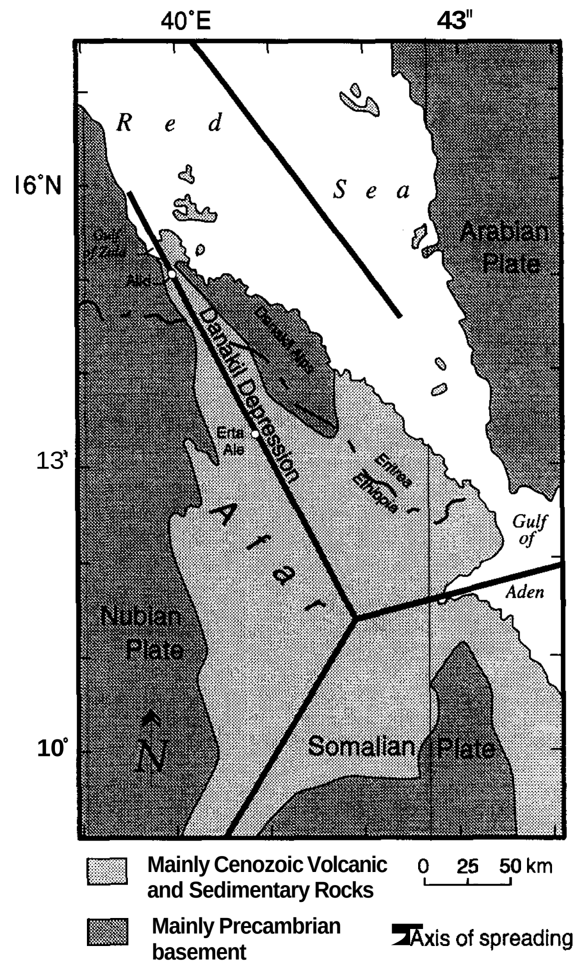

Figure 1. Simplified plate-tectonic map of the Afar Triangle region. Modified from figures in Barberi and Varet (1977).

GEOLOGIC SETTING

The Alid silicic volcanic center is located along the axis of the Danakil Depression, the graben trace of a crustal spreading center that radiates NNW from a plate-tectonic triple junction situated within a complexly rifted and faulted basaltic lowland called the Afar Triangle (Figure 1). The Danakil Depression is an off-set subaerial segment of the spreading system that is opening to form the Red Sea (Barberi and Varet, 1977). The northern Danakil Depression lies near or below sea level for much of its extent. It is a graben bounded by the Danakil Alps to the east, which in this area rise to elevations of 400 to 650 masl and the Eritrean plateau or highland to the west, which rises to elevations of 2000-3000 masl. Alid volcanic center is an elliptical structural dome located at the center of the graben. The summit of Alid sits roughly 700 meters above a field of Quaternary basaltic lava that laps unconformably against the north and south flanks of the mountain. The major axis of the mountain is 7 kilometers, elongate in an ENE-WSW direction, perpendicular to the trend of the graben (Figure 2). The minor axis is about 5 kilometers long, parallel to the graben. The dome apparently formed as a result of shallow intrusion of rhyolitic magma, some of which was erupted (Clynne et al. 1996a, 1996b). The doming uplifted Precambrian mica and kyanite schists and deformed an overlying sequence of initially flat-lying Pliocene or Pleistocene sediments capped by lava flows of basalt, basaltic andesite, and rhyolite composition. These sediments and lavas now dip steeply and radially away from the center of uplift (Clynne et al., 1996a, 1996b). Subsequent to structural doming, there were eruptions of pyroxene rhyolite lavas on the flanks of the mountain. Still later, rhyolite was erupted as pumice and a pyroclastic flow from a graben-like summit depression.

REGIONAL HYDROLOGY

The meteorological characteristics of northeastern Africa, including Eritrea and the Danakil region, have been described in various publications and reports, including Food and Agricultural Organization (1983), Michael (1986), Eklundh and Pilesji (1990) and Beltrando and Camberlin (1993). The annual rainfall on the central highlands is generally 500-700 mm and comes from storms propelled by monsoonal winds blowing from the southwest toward the northeast. This rain occurs mostly in July and August. Little, if any, rain falls on the central highlands from December through February. In contrast, the eastern lowlands receive most of their rain in December and January from storms propelled by monsoonal winds blowing across the Red Sea from the northeast toward the southwest. Here less than 300 mm per year of rain generally falls, but it may be very spotty with no rain falling for a year or more on parts of the lowland region while other parts are subjected to brief, torrential down-pours. Rivers and streams flowing to the eastern lowlands from the high plateau disappear into alluvial fan deposits, or pond in closed-basin lakes where the water evaporates to form playas. There is also the potential for lenses of relatively fresh and non-evaporated water to pond in the subsurface over deeper bodies of denser brine.

GEOTHERMAL MANIFESTATIONS

Fumaroles and boiling pools are distributed widely on the north half of Alid, suggesting that a hydrothermal system underlies much of the volcanic center (Figure 2). The presently identified area of this high heat flow is at least 10 square kilometers. We visited nine fumarole areas and selected six as being suitable for sampling of gas and water emanations (Table 1). All vent areas contain fumaroles at temperatures near the boiling point for their elevation. The physical nature and geochemical environment of the hot springs and pools at these sites strongly suggest that the waters consist of mixtures of condensate of fumarolic steam mixed with cooler, shallow groundwater.

Table 1. Selected geothermal features of Alid volcanic center

Sample #	Name	Elev m	Temp °C	6 D ‰	$\delta^{18}O$ ‰
Thermal Pools					
ELW96-5	Ilegedi #1	515	50	50	9.69
ELW96-6	Ilegedi #2	515	36	30	3.85
ELW96-7	As'ela #1	480	54	33	3.18
ELW96-8	As'ela #2	480	57	35	3.61
ELW96-9	Ilegedi #3	515	66	24	4.44
ELW96-10	Humbebet	480	<60	12	-0.93
Fumaroles					
ELG96-1	Hulma	225	77	n.a.	n.a.
ELG96-2	Darere	580	95	10	-3.98
ELG96-3	Ilegedi #1	515	95	5	-0.88
ELG96-4	As'ela	480	95	5	-1.69
ELG96-5	Ilegedi #3	515	84	n.a.	n.a.
ELG96-6	Abakri	485	94	-1	-2.81

n.a. not analyzed

Fumaroles vent through rhyolite breccia (Abakri, As'ela, Darere), siltstones (Humbebet), and Precambrian basement rocks (Ilegedi). Therefore, location of the thermal features does not appear to be controlled by lithologic type or contacts of different lithologic units. Most of the thermal manifestations are located at elevations between about 460 and 600 meters, though hot rock and steaming vents also are present as low as 225 meters (Hulma) and slightly higher than 760 meters (Airole). Some fumaroles are

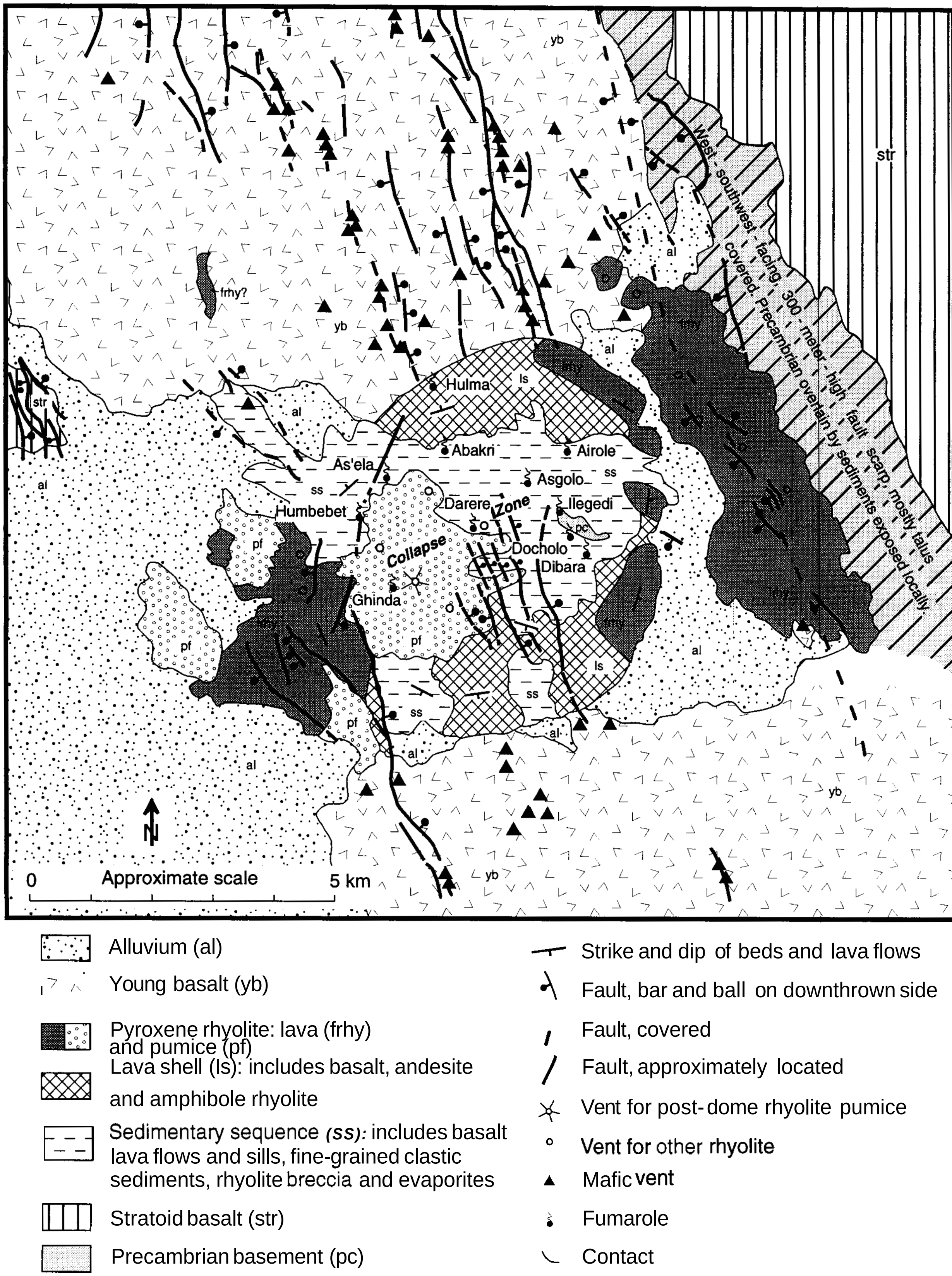

Figure 2. Generalized geologic map of Alid volcanic center. Because map was traced from lines on air photograph, the scale is approximate and varies somewhat across the area.