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BGR's GEOTHERM Program 2003 – 2015

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ABSTRACT

With climate protection and sustainable development of natural resources as objective, in 2003 the German government had initiated a program to support the utilization of geothermal energy in developing countries within the scope of Technical Cooperation. The program was headed by BGR (German Geological Survey) and intended to remove the development obstacles in geothermal energy which are high upfront costs, high risk of failure (exploration wells), inadequate political, institutional and economic framework conditions and lack of Know How. In 9 countries (Chile, Eritrea, Ethiopia, Kenya, Rwanda, Tanzania, Uganda, Vietnam, Yemen) 12 projects had been performed. This talk will highlight the impacts (Surface Exploration, Capacity building, Strengthening of local institutions) of the GEOTHERM Program, our cooperation with KfW's (German Development Bank) risk mitigation fund and shall throw a light on the changes that had happened to geothermal development (mainly Eastern Africa) over the past 12 years.

1. INTRODUCTION

As a result of the increasing demand for energy in developing countries, these countries are increasingly spending their foreign currency reserves for fossil fuels, increasing emissions of greenhouse gases, and using their natural resources in a not sustainable way. For this reason, many countries are seeking to diversify their energy supplies through the use of renewable energy sources. In addition to wind and hydroelectric energy, biomass, and solar energy, geothermal energy has the potential to considerably increase the share of renewable energy in the mix of energy sources of all countries.

This potential is utilized only to a limited extent and only at particularly favorable locations. There are two reasons for this: insufficient investigations to determine favorable locations and the resulting unwillingness of investors and banks (at least when GEOTHERM begun) to take the initial high investment risk. Geological, engineering, economic, and environmental impact analyses are prerequisite for obtaining financing from investors and banks. With the project presented here Germany wanted to promote the use of geothermal energy in developing countries. The project supported projects independently of the state of geothermal development in the project area. Project support ranged from geoscientific analyses, advice about technological application, economic analyses, to advice about possibilities for financing.

With climate protection and sustainable development of natural resources as objective, the German government had initiated a program for the support of renewable energy projects, specifically within the scope of Technical Cooperation. Within the framework of this program, the GEOTHERM subprogram for the support of geothermal energy projects was begun in early 2003, headed by BGR (German Geological Survey).

GEOTHERM intended to remove the development obstacles in geothermal energy which are high upfront costs, high risk of failure (exploration wells), inadequate political, institutional and economic framework conditions and lack of Know How. In many Eastern African countries hydro energy constitutes the base load power generation but is frequently affected by drought. However, Geothermal energy is a local resource which is environmentally clean and has e.g. in Kenya's Olkaria a very high availability factor. Where possible, it should become the preferred base load power source.

In the GEOTHERM program, partner countries had to be aided in planning and carrying out geothermal projects, especially for providing electrical power in rural areas that are not on the national grid. Decisive for support within the scope of GEOTHERM was a realistic possibility for the project to be successfully carried out. And this, as well as the pledge for obtaining financing from investors, was determined on the basis of a geoscientific and economic assessment of the geothermal resource.

Partners of the BGR within the GEOTHERM project had to be organizations interested in the commercial exploitation of geothermal resources, e.g., ministries, geological surveys, governmental agencies, or energy providers, but not research institutions. The GEOTHERM program offered support for the planning of suitable projects, including detailed project development for a specific site. From 2003 to date in 9 countries (Chile, Eritrea, Ethiopia, Kenya, Rwanda, Tanzania, Uganda, Vietnam, Yemen) 12 projects had been performed. In almost all projects the following geoscientific methods had been applied regarding surface exploration at each prospect:

- Literature survey (desk top study)
- Site selection (prioritizing sites, go for most promising site)
- Remote sensing (satellite images, aerial photographs, thermal IR, InSAR)
- Geologic survey (tectonics, active faulting, age dating of youngest volcanic activity, surface manifestations, alteration zones)
- Geochemical survey (chemical and isotopic composition of fluids and gases, geo-thermometry, soil gas survey)

• Hydrogeological survey (meteorological data, discharge rates of springs, water table, hydraulic gradient, mean residence time)

• Geophysical survey (temperature gradient, resistivity methods, TEM, MT, gravity, magnetics, micro-seismicity methods)

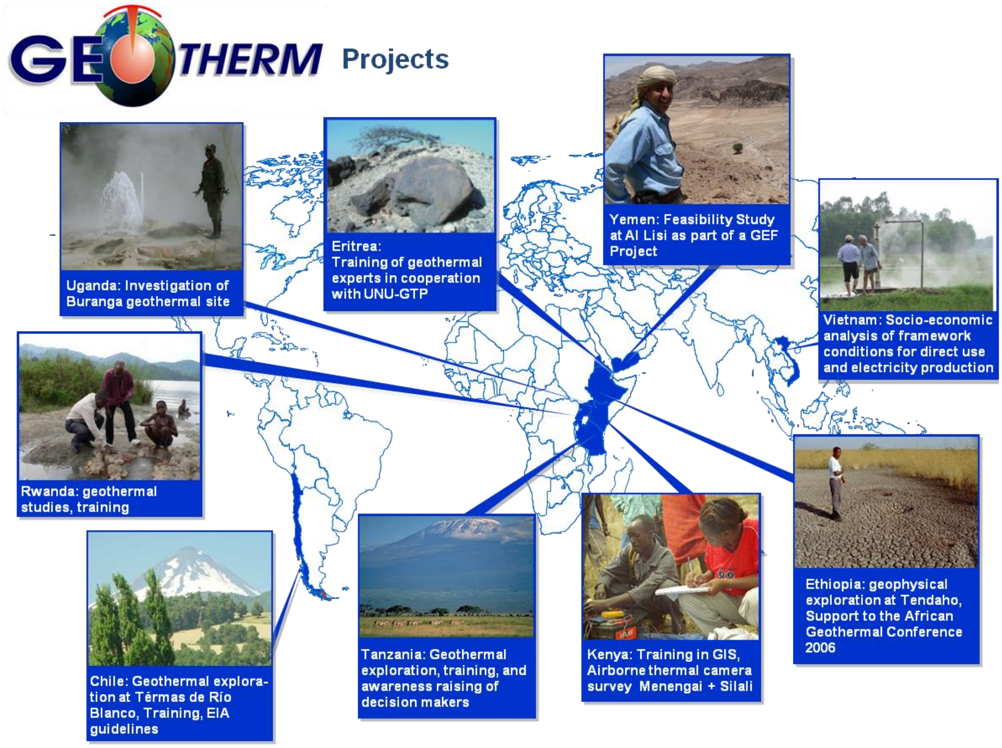

Figure 1: The figure shows the worldwide GEOTHERM Partner Countries where surface exploration studies had been performed; in some of the countries more than one project was conducted, e.g. Kenya. After 2005 a concentration on East African Countries took place.

Two examples of the case histories concerning surface exploration studies shall be inspected more closely:

2.1 Microseismic Study at the Buranga geothermal Site, Western Uganda

The BGR supported the Government of Uganda in the geoscientific investigations at the Buranga geothermal prospect since 2004. The objective of the project was to raise the knowledge about Buranga to a level (pre-feasibility status) that can be the base for planning of exploration wells.

Geochemical findings, which have been achieved in the framework of the joint project, proofed the existence of a magmatic body that most likely serves as the heat source of the hot springs. Hence the task of active ground geophysics was detecting and delineating this magmatic intrusion. The known high seismicity (about 500 local earthquakes per month) suggested that Buranga provides excellent requirements to apply seismology.

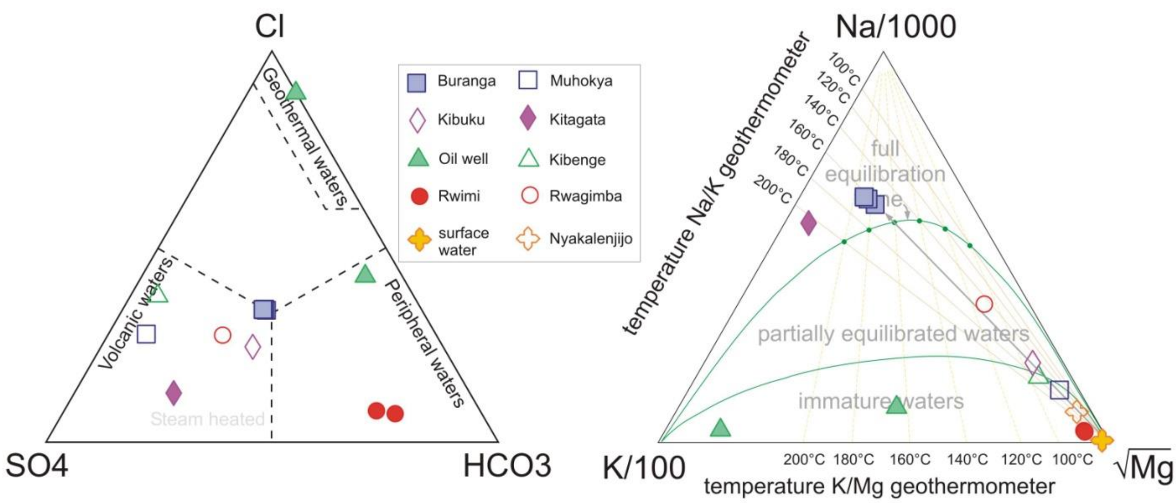

Figure 2: In all of the GEOTHERM surface exploration projects geochemical analyses played a major role. The figure shows an example from Uganda where fluid evolution and reservoir temperatures were derived from fluid samples.

4185 earthquakes have been localized in the period January to August 2006 with 15 stations. This huge data set was suitable to apply an inversion method called seismological tomography. The results of the tomography clearly reveal definite low velocity anomalies in the subsurface. The strongest P-wave velocity anomaly (-9 %) in 10 km depth is located directly south of the Buranga hot springs (Figure 3). Taking the findings of geochemistry into account, the most plausible conclusion for the observed velocity reductions are high temperature anomalies. These temperature anomalies could be a result of a hot actively degassing magma intrusion, which is the heat source for the hot springs.

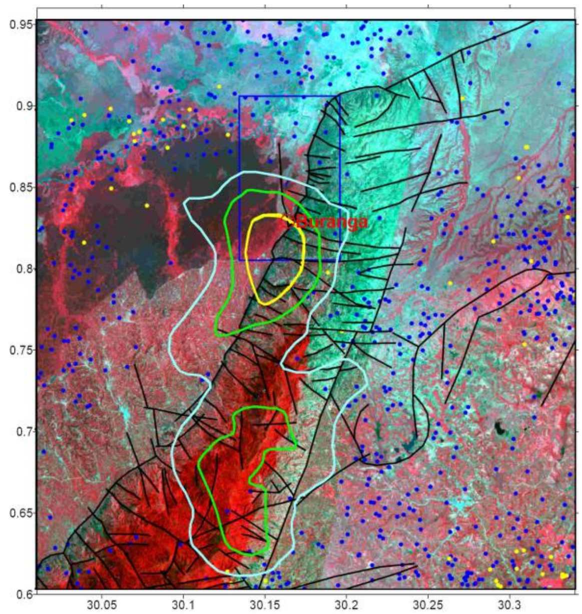

Figure 3: Northern part of a ASTER Satellite image of the Rwenzori Massif, overlain by the lineament pattern and anomalies of P-velocities in 10 km depth derived from seismic tomography (light-blue: -3 % dV/V, green: -6 %, yellow: -9 %). Dots represent relocated epicentres; different colours indicate different focal depth.

By combining all findings a conceptual model for the Buranga geothermal prospect was developed and on the basis of this model a possible drilling location was suggested. Assuming favourable conditions a decentralized ORC power plant might be feasible in this area.

On the basis of the presented conceptual model a possible drilling location should be located within the yellow contour (Fig. 3). This area marks the major velocity reduction in all tomographic inversions so far done. In combination with the geochemical results it is interpreted as the major heat source in the investigated area.

According to the hydrological results the Bwamba Fault is the major pathway for the geothermal fluids. Therefore the Bwamba fault is the drilling target. To enhance the chances to encounter zones of highest permeability the drilling location should be at the intersection of Bwamba- and perpendicular faults known from structural interpretation (Fig. 3).

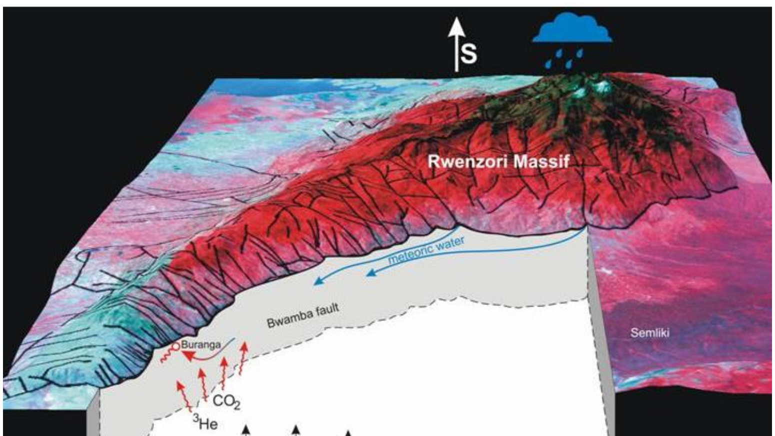

Figure 4: A 3-dimensional view of the Rwenzori Massif from space as seen from the North overlain by a lineament pattern and integrated conceptual model (vertical section along the Bwamba fault) of the Buranga geothermal prospect (not to scale).

Two concepts of exploratory drilling can be suggested: (1) Shallow gradient holes followed by a deep exploration well or (2) take a higher risk and drill a deep exploration well right away.

The shallow temperature gradient wells would be useful to investigate the upper part of the seal of the geothermal system, could confirm an enhanced geothermal gradient above the magmatic intrusion and help to determine the dip angle of the target faults. The deep exploration well should reach the Bwamba fault at depth (ca. 2000 m) where high flow rates and reservoir temperatures of up to 160°C are expected.

2.2 The Ngozi crater lake in the Mbeya Region, SW Tanzania

Geothermal surface exploration in Mbeya area, Tanzania, started in 2006 and lasted until 2013. The Tanzanian cooperation partners are the Ministry of Energy and Minerals, the Geological Survey of Tanzania and Tanesco, the National Electricity Supplier.

The area of investigation belongs to the Rungwe Volcanic Province near Mbeya which is located at the intersection between the western and eastern branches of the East African Rift System (EARS), forming a triple junction. From geochemical and isotope hydrological results the distinction between two main geothermal systems proposed by earlier investigators was confirmed and refined (i) Northern system (Songwe and other hot springs related to Ngozi volcano) and (ii) Southern system (hot springs related to Rungwe & Kiejo volcanoes).

The calculated reservoir temperature for the Northern system is above 200°C (i.e. high-enthalpy) whereas the Southern system is significantly below 200°C (medium-enthalpy), therefore detailed exploration including geophysical surveys focused on the Northern system.

Geophysical surveys included 30 magnetotelluric soundings (MT) and 50 transient electromagnetic soundings (TEM). A joint 1D inversion of MT and TEM data provided evidence of low resistivity zones typical for geothermal systems. The results at shallow depth (<10 Ohmm) might be interpreted as clay mineral alteration zone. A conductive structure which extends to great depth is seen as the reservoir of this geothermal system.

This observation is supported by a magnetic low in the same area indicating demagnetization by alteration of the magnetic iron oxides within the originally magnetic volcanic rocks. Similar indications and resistivity structures in the subsurface are found at a number of high-enthalpy geothermal system in the EARS and had been proven as promising indications for a viable geothermal resource. BGR emphasized to increase the number of TEM/MT-soundings to achieve denser resistivity information. On this basis it would be justified to suggest a site for an exploration well.

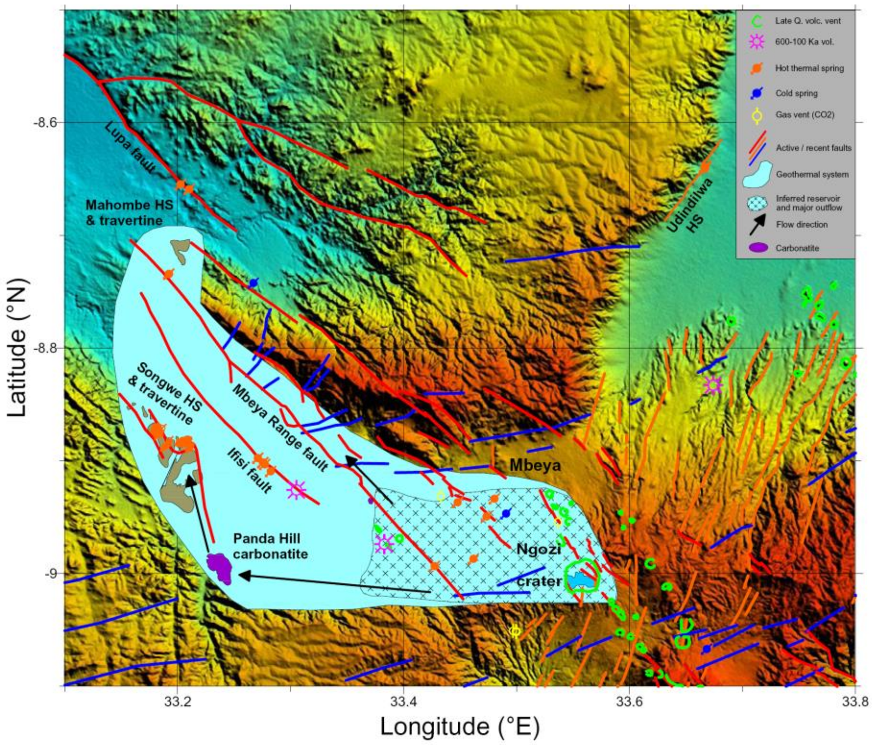

Figure 5: The figure shows a map view of proposed conceptual model with approximate area of upflow zone causing clay alteration (area marked with crosses) and main outflow zone (light blue area) to the west and northwest of Ngozi (Kraml et al. 2008).

The resistivity results of joint inversion of MT and TEM data show a geothermal system with three major resistivity zones delineated. The upper surface partly shows high resistive zones >70Ωm which is interpreted as the unaltered rock at the surface.

The low resistivity areas around Lake Ngozi noted at the surface (ca. 2000m asl) about <10Ωm and extending down to about 1000m asl in some parts are indicative for surface alteration. These are presumed to be the conductive clays and low temperature alteration minerals situated close to the surface. This very conductive layer of <10Ω m could be part of the conductive clay cap to the geothermal system (Compare conceptual model, Figure 6).

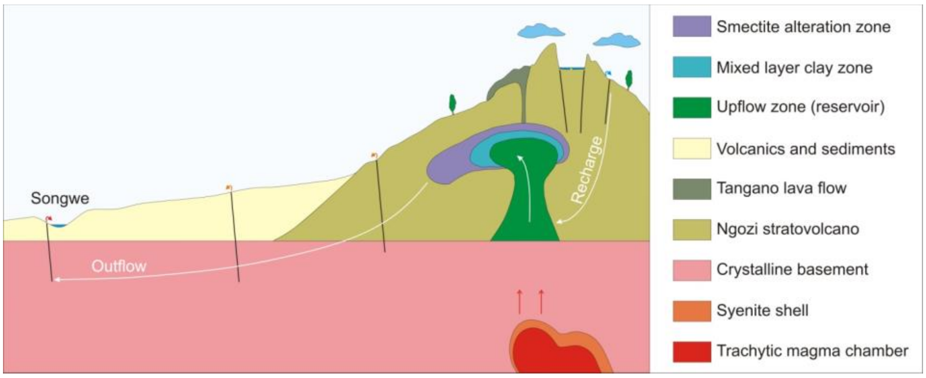

Figure 6: Schematic cross section through the Ngozi-Songwe geothermal system (not to scale) derived from mainly geochemical, geological indications (Kraml et al. 2008)

A more general notice of Muñoz (2014) says that at lower temperatures (70–150 °C), the clay cap is mainly characterized by smectite. At higher temperatures, illite (in acidic rocks) and/or chlorite (more abundant in basaltic rocks) become interlayered with smectite, forming a mixed layer with increasing proportions, especially above 180 °C. At temperatures over 220–240 °C, alteration is mainly in form of chlorite and epidote minerals, which show a higher resistivity signature than its lower temperature counterparts. The low temperature (150 °C) alteration species (illite–smectite) are significantly more conductive than the higher temperature (chlorite–epidote) species. As long as no boreholes exist in this area and the composition of alteration minerals is not known exactly the classification remains speculative.

Below this layer (below 1000 m asl) the majority of the area exhibits relatively high resistivities of over 50 Ωm which is due to mixture of sediments and volcanic material of the Ngozi stratovolcano. A small area northeast of Lake Ngozi remains low resistive (< 10 Ωm) and is interpreted as the upflow zone (reservoir) according to the conceptual model. At greater depth the low resistivity area expands (> 3000m bsl) and continues to the final depth of our models (8000m bsl). While the conductive area is increasing at depth the high resistive area is decreasing.

If one looks at the low resistivity values which are close to the surface and have been interpreted as conductive clay cap (smectite-illite zone) and the deeper parts which were supposed to be the upflow zone (reservoir) it is noticed that their absolute values are quite similar. It is believed that the deep conductors reflect fissured rock and conductive void filling. The reason why the fissures and intrusions are so conductive is not clear. Maybe the void volume is mainly two phase fluid at which the share of brine is much higher than steam, but that is a speculative assumption. The suggested drill holes for geothermal wells in Ngozi would be on top of the upflow zone (reservoir).

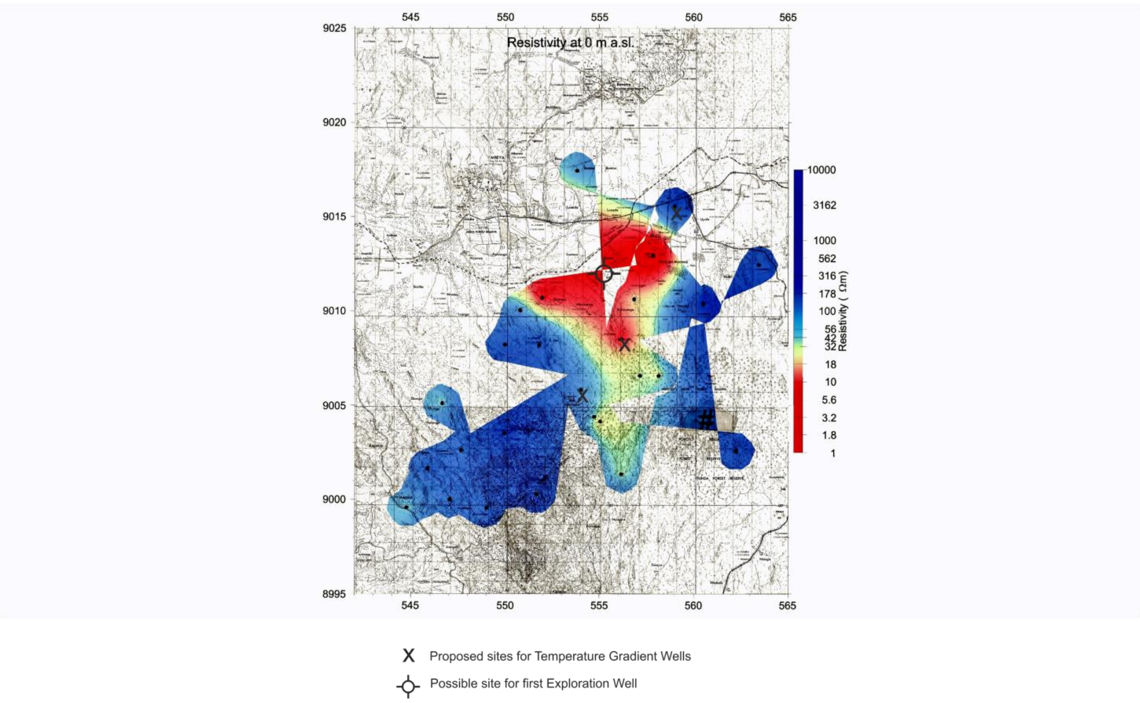

Figure 7: The figure shows the proposed sites for Temperature Gradient and Exploration Wells. Nevertheless the number and spatial distribution especially of the MT soundings is severely limiting the significance of the electromagnetic measurements. Therefore the author strongly recommends additional TEM and MT soundings before drilling.

Based on the geophysical results obtained from TEM and MT measurements taken at Ngozi crater three points to drill temperature gradient wells were selected. Criteria for selection of drilling sites were the accessibility to the site and thickness of clay cap mainly derived from TEM measurements (Figure 7).

It was emphasized many times, that BGR´s first recommendation is to increase the number of TEM/MT-soundings to achieve denser resistivity information. On this basis it would be justified to suggest a site for an exploration well. If this approach cannot be followed for any reason and the higher drilling risk can be accepted than an exploration well could be tried in the centre of the low resistivity area (Figure 7).

3. IMPACTS OF GEOTHERM PROGRAMME

3.1Capacity Development

In all 12 GEOTHERM-Projects BGR performed training of the scientific staff in the partner countries either during field surveys or in the class room. 6 groups from different countries we invited to BGR offices in Germany or to specialized companies in Germany to attend specialized training courses; 8 students from different countries were sponsored to attend 6 months training at United Nations University in Iceland.

As well we supported a number of regional conferences (e.g. ARGeo C1, C2, C3, C4) or workshops for engaged persons from Ministries or agencies (e.g. Decision-makers Workshops Addis Ababa, June 2009) and over the runtime we sponsored a larger number of persons (~100) to participate at these meetings.

3.2 Results of geo-scientific work

All 12 GEOTHERM surface exploration projects were finished with final reports and the outstanding result was usually a recommendation for a promising exploration drilling location in the proper prospect area (e.g. Chile, Ethiopia, Kenya, Rwanda, Tanzania, Uganda and Yemen). Unfortunately until GRMF arose (see below) there usually were now funds available for financing drilling of exploration wells.

3.3 Strengthening of local institutions

In many GEOTHERM-Projects BGR assisted organizations to establish activities in geothermal development in Eastern Africa. We put geothermal working groups into operation, we assisted in the development of National geothermal road maps and we supported e.g. geological surveys in developing concepts for geoscientific investigations.

4. OTHER FACILITIES OR ORGANIZATIONS ACTIVE IN GEOTHERMAL DEVELOPMENT IN EASTERN AFRICA

4.1 ISOR - Iceland GeoSurvey

Iceland GeoSurvey is a self-financing, state-owned, non-profit institution. It receives no direct funding from the government and operates on a project and contract basis like a private company.

Iceland GeoSurvey was established 2003, when the GeoScience Division of Orkustofnun, the National Energy Authority of Iceland, was spun off as a separate entity. It is based on six decades of continuous experience in the field of geothermal and hydropower research and development. During this period Iceland GeoSurvey has provided consulting, training, and scientific services to the Icelandic power industry and the Icelandic government, and to numerous foreign companies and governments all over the world. Although ISOR's focus is on geothermal exploration, development, and utilization, their experience covers many other geoscience-related fields as well, including groundwater studies, marine geology, and environmental monitoring.

In Eastern Africa ISOR had performed Projects in Eritrea, Djibouti, Ethiopia, Kenya, Uganda, Rwanda and Burundi. ISOR is definitely longer active in supporting geothermal prospects than BGR's GEOTHERM prospect and their men power, experience and number of projects is exceeding BGR by far.

4.2 GRMF - Geothermal Risk Mitigation Facility

The African Union Commission (AUC) on the one side and the German Federal Ministry for Economic Cooperation and Development and the EU-Africa Infrastructure Trust Fund via KfW Entwicklungsbank (KfW) on the other side have agreed to establish the Geothermal Risk Mitigation Facility (GRMF) to fund geothermal development in East Africa (Ethiopia, Kenya, Rwanda, Tanzania, Uganda).

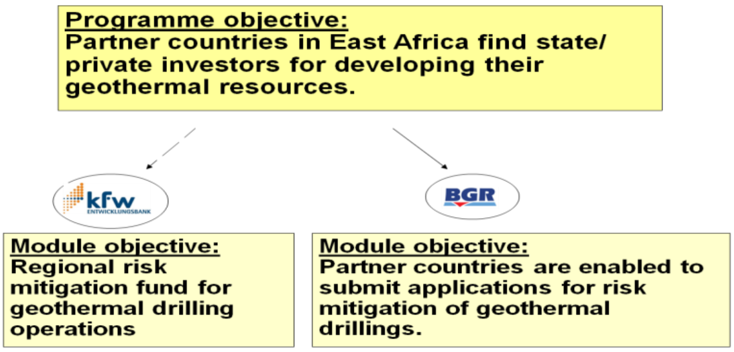

Figure 8: Since 2009 a new cooperation between BGR (German Geological Survey) and KfW (German Development Bank) concerning technical and financial development within the scope of GEOTHERM was established.

Objectives

The objective of the facility is to encourage public and private investors as well as public private partnerships to develop geothermal prospects for power generation in Eastern Africa by providing grants for two types of activity:

1. Surface studies to determine the optimal location of reservoir confirmation wells at the most promising geothermal prospects.
2. Drilling and testing of reservoir confirmation wells at the most promising geothermal prospects to assist Developers secure financing for subsequent reservoir confirmation and/or well field development wells.

GRMF will provide financial support to assist in mitigating the geothermal exploration risk. It is thus expected to improve access to equity or other funding source and thus play a catalytic role in establishing geothermal energy as a strategic option in power expansion planning of the participating countries of Eastern Africa. As a result, reduced risks and costs for early stage geothermal development are expected to encourage the development of further geothermal investments.

GRMF is operative since 2012 and brought a big push to geothermal development in Eastern Africa.

4.3 ARGeo - African Rift Geothermal Development Facility

The African Rift Geothermal Development Facility (ARGeo) Project is a GEF funded project being implemented by United Nations Environment Programme (UNEP). ARGeo originally started even before GEOTHERM in 2002. In the beginning some problems arose so that it became a bit quiet about ARGeo for some time but ARGeo was officially re-launched in November 2010 at the opening session of the Third African Rift Geothermal Conference (ARGeo-C3) in Djibouti. The African Rift Geothermal Development Facility (ARGeo) Project is a GEF funded project being implemented by United Nations Environment Programme (UNEP).

UNEP-ARGeo project aims at supporting the development of the large untapped geothermal resource potential in the Eastern Africa region with the main objective of reducing the risks associated with the resource's exploration. ARGeo also aims to reduce greenhouse gas (GHG) emissions by promoting the adoption of geothermal energy in the region.

ARGeo will also help demonstrate that the resource is reliable, cost effective and indigenous as compared to other sources of power in the Eastern Africa region. The utilization of the resource in agriculture and industry will also be promoted. ARGeo's objective is to encourage both public and private developers to accelerate development of geothermal resource in the East African Region and ARGeo provides fast targeted and demand driven technical and financial support to East African Countries.

UNEP is responsible for overseeing the successful achievement of the project objectives and will also be the international implementing and executing agency for its project components. UNEP/DTIE is the implementing agent whereas the UNEP(ROA) is the executing agent. The ARGeo Project Management Unit (PMU) is located at UNEP -ROA at the headquaters of UNEP in Nairobi.

4.4 SREP - Scaling Up Renewable Energy Program in Low Income Countries

The Scaling Up Renewable Energy Program in Low Income Countries (SREP) is a targeted program of the Strategic Climate Fund (SCF), which is one of two funds within the framework of the Climate Investment Funds (CIF). SREP was launched by Multilateral Development Banks (African Development Bank (AfDB), Asian Development Bank (ADB), European Bank for Reconstruction and Development (EBRD), Inter-American Development Bank (IADB), International Finance Corporation (IFC) and World Bank (WB)).

The SREP was established to scale up the deployment of renewable energy solutions and expand renewables markets in the world's poorest countries. It aims to pilot and demonstrate the economic, social, and environmental viability of low carbon development pathways.

SREP financing supports technologies such as solar, wind, bio-energy, **geothermal**, and small hydro technologies.

It stimulates economic growth by working with governments to build renewable energy markets, engage the private sector, and explore productive energy use.

Pilot Countries	
Ethiopia	Honduras
Kenya	Liberia
Maldives	Mali
Nepal	**Tanzania**

SREP's activities are differently evolved in the different countries but the volume of the funds is promising. They are looking for co-operations with other donors.

5. CONSEQUENCES ON GEOTHERMAL PROJECTS AND DEVELOPMENT IN EASTERN AFRICA

After 2012 the number of Facilities or Organizations active in geothermal development and geothermal projects in Eastern Africa increased strongly and with it the amount of available funds. The local entities involved in geothermal development like geothermal working groups in geological surveys, energy ministries or power suppliers did not increase in the same degree. As a consequence of this the risk of overstressing local groups is increasing as well as the risk of failure of projects.

On one hand exactly that is happening what BGR wanted from the beginning of GEOTHERM – increase of geothermal development in Eastern Africa. But we have to take care that we do not buy it with an increasing number of failures. The average failure rate in geothermal drilling is about one third – we have to keep it in that range. As a geophysicist I am convinced that proper exploration work can even improve the failure rate. We have to be attentive that this happens and not an increasing number of projects produce higher failure rates.

On the other hand according to our expectations with the currently available money the geothermal industry in Eastern Africa has to get off the ground finally. If it cannot be done now forget it for the future. If the now available amount will not be seriously spent we must be afraid that this lucky situation will not be repeated in the future.

Definitely all organizations and facilities should strive for co-operations and synergy effects; that could give another push to the whole development.

For the GEOTHERM – project there are consequences as well. Compared to the above named Facilities or Organizations our financial means belong to the smallest which makes us less attractive for counterpart organizations. In the past years the number of co-operations with partner countries decreased within the GEOTHERM-project. Maybe BGR should develop another "business model" like quality control in geothermal projects or use synergy effects with similar institutions like ISOR or ARGeo what training or capacity building is concerned.

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