LRPS MADA-2017 - 9133458

Pilot Exploration and Production Project
Alternative groundwater sources
Androy, Madagascar

Phases 1 & 2
Final report

January 2018

Contents

1 INTRODUCTION AND PROJECT DESCRIPTION

This pilot project aims to implement modern geophysical exploration techniques, used today in the mining sector, to try to highlight alternative groundwater sources in an area where known groundwater sources are considered to be unproductive and mineralized (salty). These alternative sources highlighted, surveys will be conducted to assess the quantities of water that can be mobilized and the quality of the resource, before possible exploitation.

The alternative groundwater sources discussed and targeted in this project are flows and upwelling of "primary" water, which are absent from the hydrological cycle (see concept note below). The geological context of the Androy region has a significant potential to find this type of upwelling.

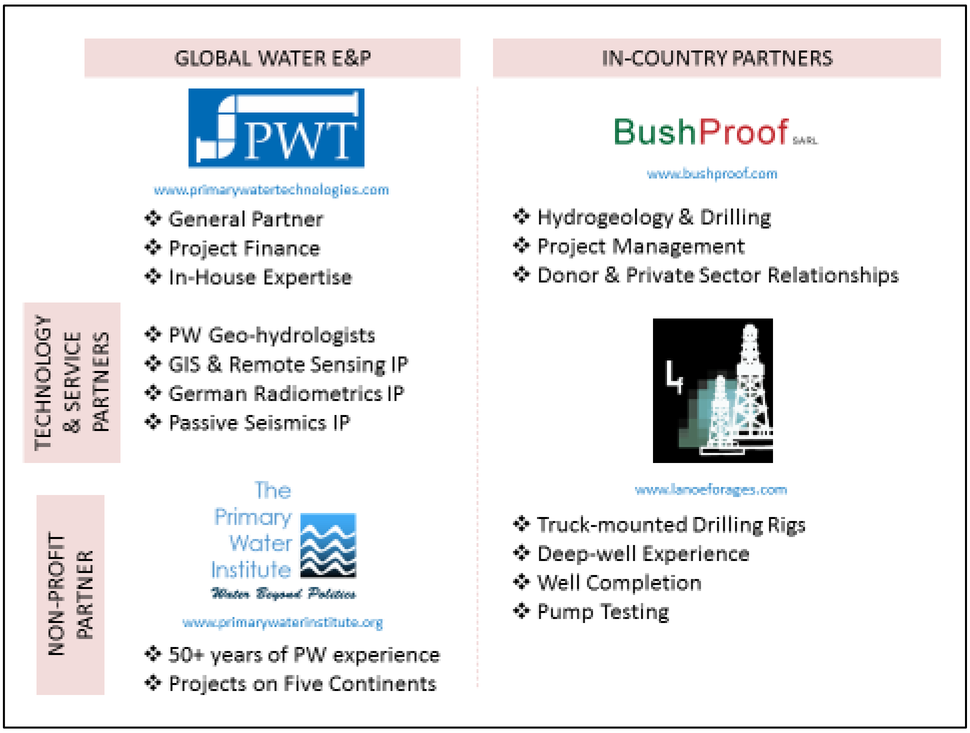
The targeted region is facing a persistent drought and its population has only very limited access to water, the exploitation of alternative water sources will improve locally this situation. The beneficiaries of the project are the communities living in villages located in the areas targeted by UNICEF Madagascar's interventions, prioritized by DREEH Androy.

The pilot project will be divided into five distinct phases :

1. Description of the context and known hydrogeology of the target area. Detailed study of the lineaments, allowing to highlight the most favorable zones to present deep structures.
2. Exploration - A field survey including deployment of modern geophysical means (radiometric and passive seismic) and observation of local geology.
3. Production - Drilling, progress observations, equipment and tests of the wells.
4. Analysis of the facies and the quality of produced water, possible thorough analysis of certain parameters of scientific interest.
5. Operation of the wells.

The first two phases (1 and 2) were carried out and allowed to highlight drill points with potential to tap alternative water sources. The present report presents and discusses observations made during these two phases, and gives indications in order to be able to direct the continuation of the project and the realization of phase 3. The realization of phases 4 and 5 will then depend on the progress of phase 3.

The project is funded by UNICEF and led by a consortium whose members bring specialized expertise in the various fields necessary for its achievement. The organization of the consortium, described below, includes four organizations: Primary Water Technologies (PWT, USA), The Primary Water Institute (PWI, USA), Lanoé Forages (Madagascar), and BushProof (Madagascar).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2 ENVIRONMENTAL CONTEXT OF THE TARGET AREA

2.1 Geography

The project targets the Androy region in southern Madagascar. Four areas were pre-selected by UNICEF, before the study, considering population density and current access to water (quantity or poor quality). The four zones include the surrounding towns of Beloha, Tsihombe and Ambovombe, as well as an area near Cape Sainte-Marie, at the southest point of the island of Madagascar.

The table below shows the location of the preselected zones:

Commune	Latitude S	Longitude E
Beloha	25°10'24.5''	45° 3'33.0''
Tsihombe	25°18'58.7''	45°29'08.4''
Ambovombe	25°10'42.0''	46°05'19.5''
Cap Ste-Marie	25°32'36.7''	45°10'36.4''

Localization of the targeted zones

The areas covered by the project are spread in Beloha, Tsihombe and Ambovombe districts. Obviously related to the geology, the sites then selected for further exploration are themselves spread in these zones. The inhabited area proximity criterion has then been considered in order to preserve the most interesting sites for the following stages.

2.2 Climate

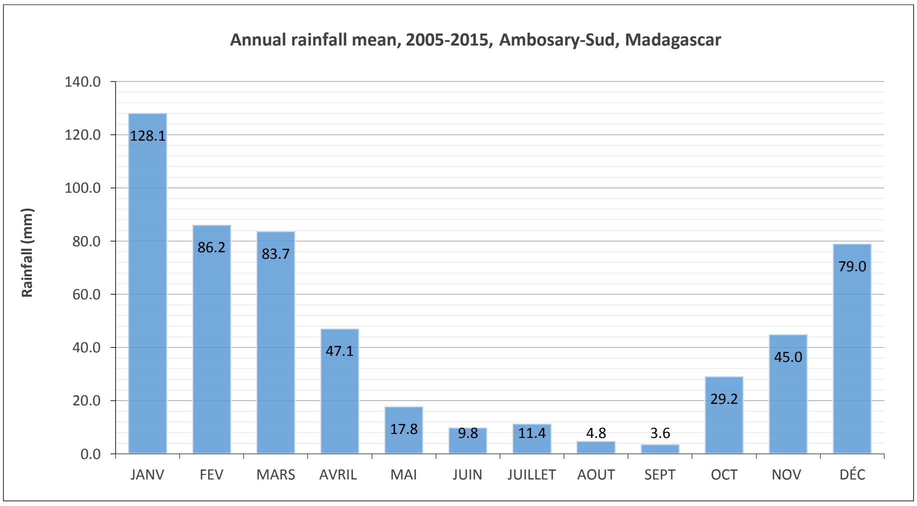
South of Madagascar knows, by its latitude close to the tropic of Capricorn and protected from the wet winds by the relief of the mountain chain of Anosy, a semi-arid type climate. The region is tempered by the proximity of the ocean on the one hand, and by the winds (coming from sea or land) on the other hand. The average annual temperature turns around 23°C, with minimums of 10°C and maximums reaching 32°C. A strong thermal amplitude can be felt.

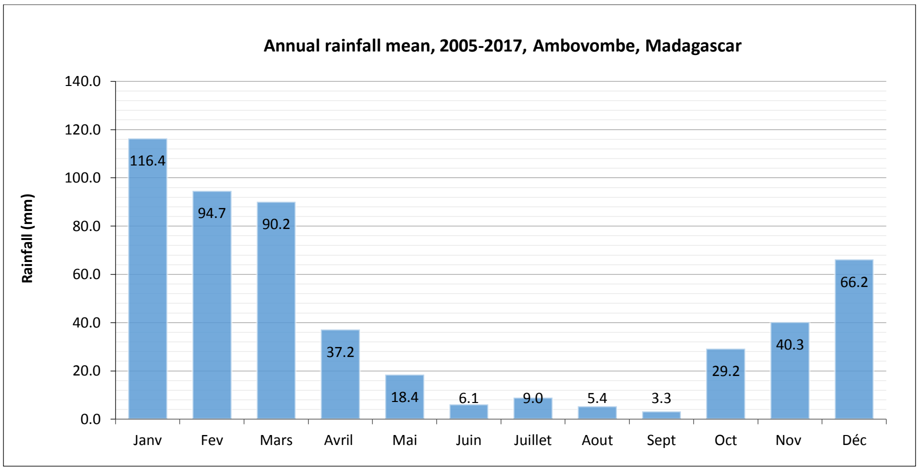
2.2.1 Pluviometry

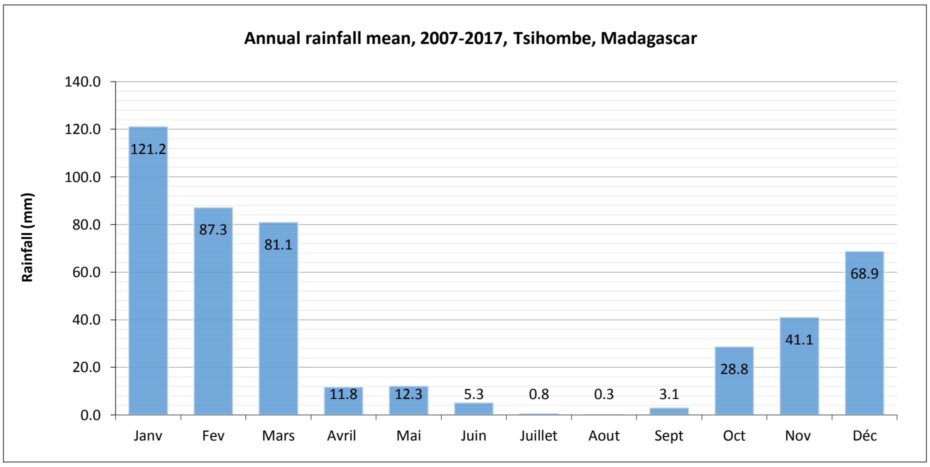
La saison pluvieuse s'étale sur quatre mois, de décembre à mars, et concentre environ 70% des précipitations de l'année. Elle est suivie de huit mois de saison sèche. La quantité de précipitations annuelle atteint 545 mm à Amboasary (moyenne 2005-2015), à la limite orientale de la zone d'intérêt, 516 mm à Ambovombe (moyenne 2005-2017), 462 mm à Tsiombe (moyenne 2005-2017), et 422 mm au sud de la de la zone d'intérêt (Faux-Cap, moyenne 2005-2017). Une grande partie des pluies tombe sous la forme d'événements intenses durant la saison des pluies (cyclone), mais les crachins de saison sèche constituent aussi une part non-négligeable du total pluviométrique. À noter que la région est aussi régulièrement affectée par des périodes de sécheresse.

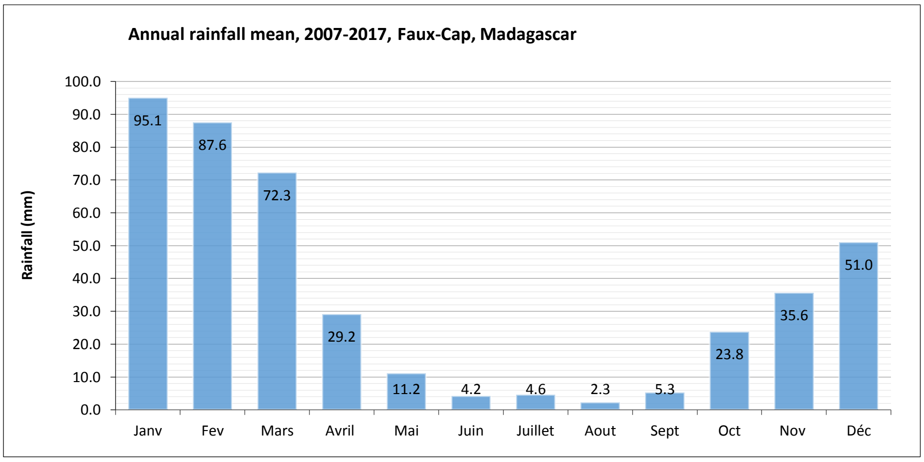
Pluviometry

The rainy season is usually four months long, from December to March, and totalize for about 70% of the year's rainfall. It is followed by eight months of dry season. The annual rainfall amounts to 545 mm at Amboasary (average 2005-2015), at the eastern limit of the area of interest, 516 mm at Ambovombe (average 2005-2017), 462 mm at Tsiombe (average 2005-2017), and 422 mm south of the area of interest (Faux-Cap, average 2005-2017). Much of the rains fall in the form of intense events during the rainy season (cyclone), but dry season drizzles are also a significant part of total rainfall. Note that the region is also regularly affected by periods of drought.







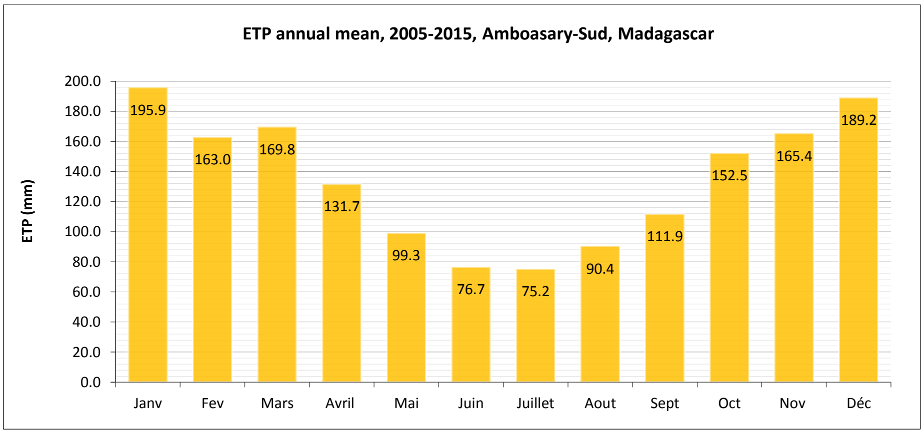


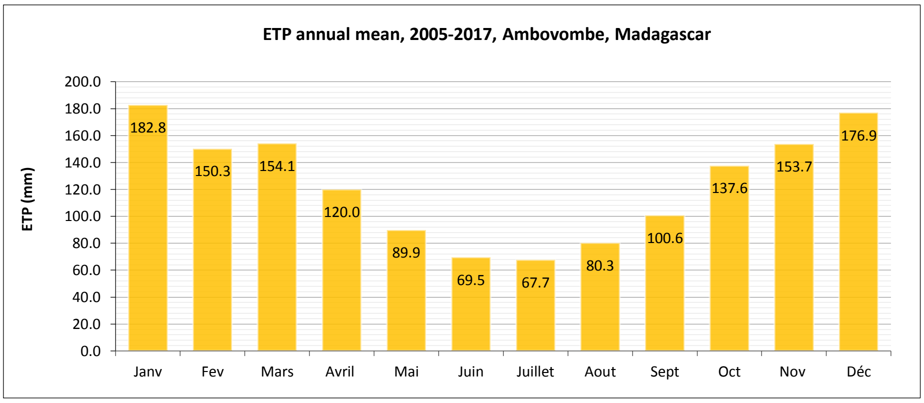
Source : Service Météorologique de Madagascar

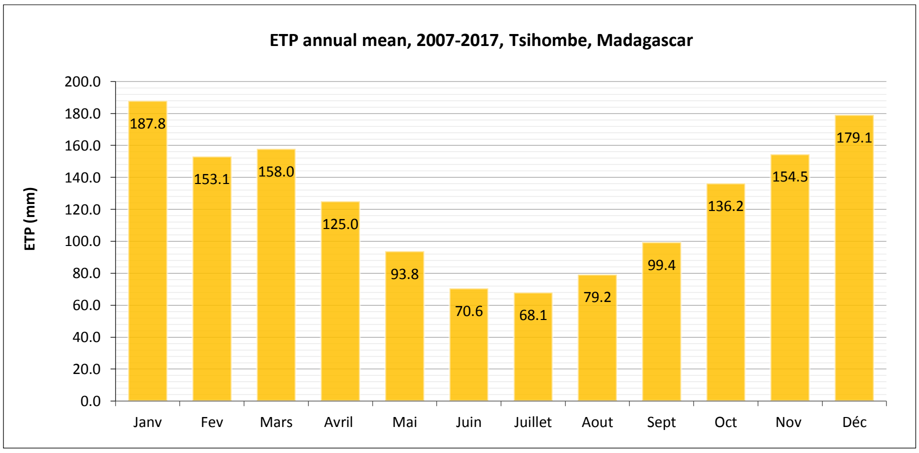
2.2.2 Evapotranspiration

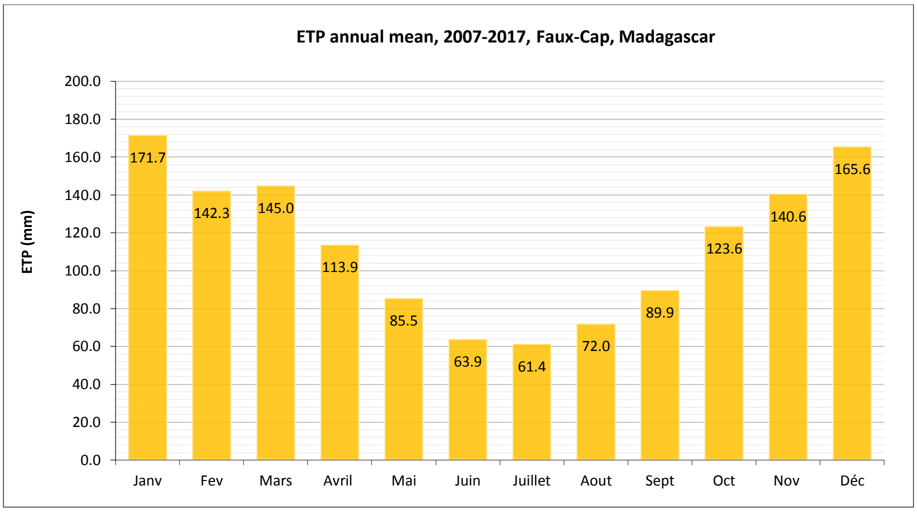
Potential annual evapotranspiration (ETP) greatly exceeds the total rainfall. It ranges from 1,620 mm in Amboasary, 1,483 mm in Ambovombe, and increases to the west to reach 1,504 mm in Tsiombe and 1,375 mm in Faux-Cap. Actual evapotranspiration (ETR), impossible to calculate exactly, must approach

350 mm / year in the central Androy and reach 500 mm/year on the Amboasary side, depending on the quantity of water available. The ETR thus reaches about one third of the ETP.









Source : Service Météorologique de Madagascar

2.3 Geology

2.3.1 Morphology

The sedimentary basin of the extreme south of Madagascar, in which the intervention zone is located, covers an area of 9,500 km^2. This continental peneplain is divided into several zones with different morphological characteristics. Most of the basin has a gentle and slightly hilly terrain. High plateaux and large-scale depressions (several hundred km^2) are observable. Two closed watersheds (without any discharge point) are evidence of past flows. In the southern part, the topographic slope is more and more marked towards the sea. In the littoral zone, constituted of sand dunes oriented WNW-ESE by the action of the marine currents, the slope plunges into the sea on the last kilometer of land. The western and eastern limits of the basin are marked by the cut of the courses of Menarandra (west) and Mandrare (east) rivers. The basin is surrounded by ancient reliefs of plutonic and volcanic origin to the north, and by the sea to the south. Only one stream flows into the center of the sedimentary basin: the Manambovo River. His course is not permanent.

2.3.2 Sedimentary units

Two sedimentary units are distinguished in the extreme south basin : Ambovombe basin and Beloha basin, which have the same kind of morphology.

- The Beloha basin, located to the west between the major shear zone of Ampanihy and Betroka where the base is part of the Bekily belt. The belt is characterized by sillimanite, cordierite and garnet paragneisses, quartzites, marbles and pyroxenites. For the most part it is made up of the same formations as those of Ambovombe. The Beloha sedimentary basin is subdivided into two sub-basins: the low coverage basin constituting the Lovokarefo plateau in the north and the semi-deep basin forming the Karimbola plateau in the south. These two sub-basins are separated by a lineament characterized by the Imaririny river.

- The Ambovombe basin, located in the East, corresponds to a large sedimentary gulf. It is limited to the North, by the first heights of the crystalline massif (Antanimora) and volcanic (Angavo), to the East, by the Mandrare river and to the West, by the crystalline spur of Tsihombe. It is also barred to the South by a dune cord of a height exceeding 200 m. This basin is essentially made up of continental Neogene and Quaternary sediments.

2.3.3 Stratigraphy

The Far South sedimentary basin started to form only recently, during the Neogene (-20 million years), making it the most recent sedimentary basin of the island of Madagascar. The quality of the different stratigraphic components of the basin, overlaying the Precambrian basement and the rocks of the Androy volcanic complex (Cretaceous), are described below by sub-periods:

- Continental Neogene : clays, argillites, sands, clay sands, conglomerates, clayey sandstone, soft sandstone.
- Quaternary continental : sandy shells and alluvial deposits. Quaternary formations consist of sands of eolian origin, cemented by a notable proportion of calcareous material (results called limestone-sandstone). Calcareous crusts are also observable. Three dune periods are distinguished in the geological history of the area :
  - Ancient dunes of the ancient Aepyornian or Tatsimian.
  - Karimbolian dunes.
  - Recent dunes of Flanders.
- Recent and superficial deposits:
  - Red sands (*sable roux*).
  - Ambondro white sands.
  - Alluvial deposits in the lower basins of the Mandrare, Manambovo and Menarandra rivers. The Recent deposits of the Ampamolora depression are also listed as alluvium (ancient alluvial deposits).
  - Sands of Ambovombe.

The sedimentary structures of the Far South basin have a monoclinal structure, with a slight dip pointing southward down to the sea.

2.3.4 Precambrian basement

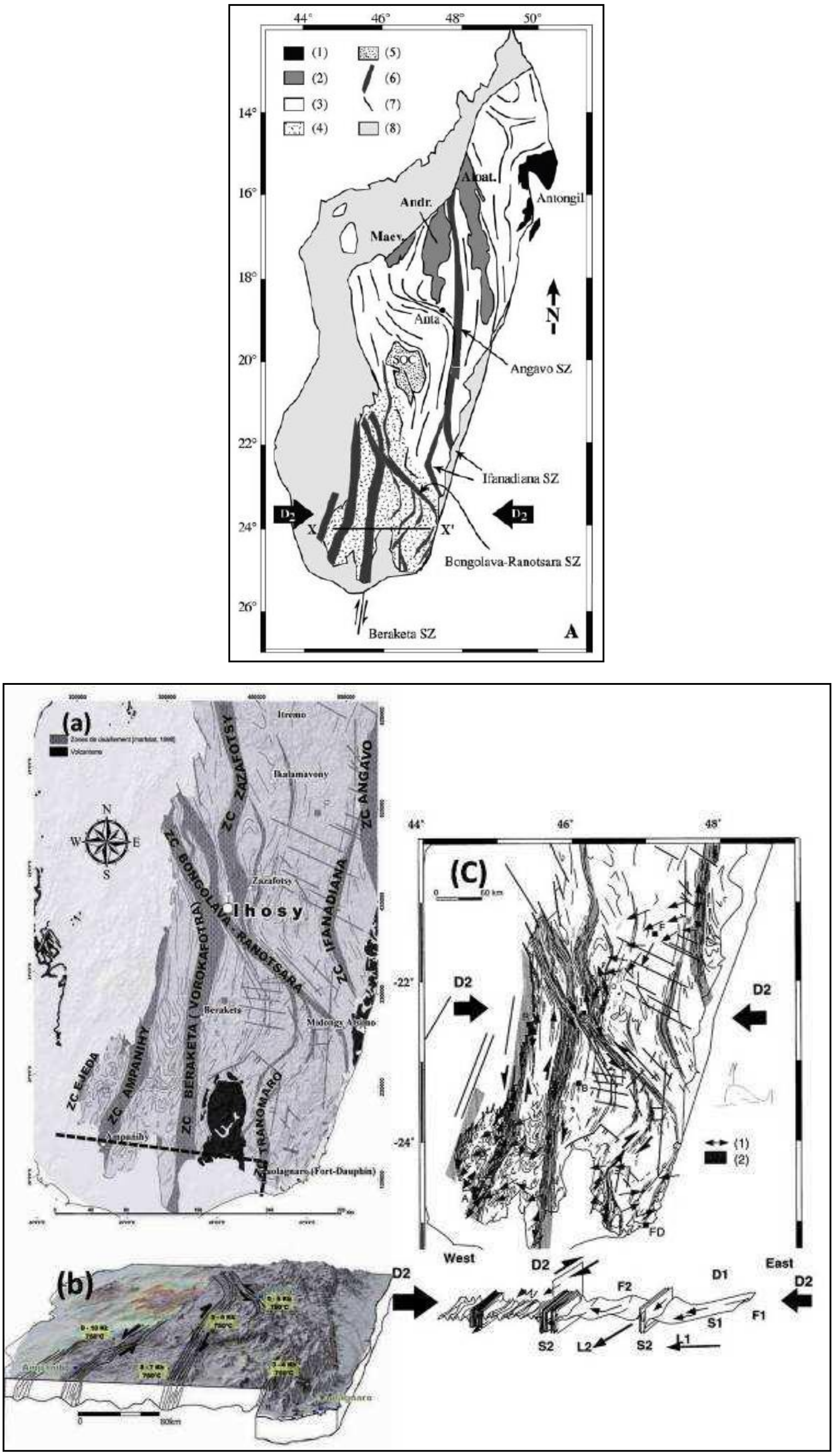
Precambrian basement is covering all the north part of the Androy region. Composed of the two main orogenesis of the Androy and the graphite systems. It shows rocks going granite to diverses metamorphic degrees rocks (gneiss, paragneiss, leptynite, graphite and pyroxene). The Precambrian basement shows deformation due to high constraint along the time.

2.3.5 Androy volcanic event

Androy volcanic event is of Cretaceous age (145 to 66 M years ago), and is linked to the separation of Gondwana supercontinent. The event has produced basaltic and ryolitic rocks and puncture the Androy system, creating different zones of contact metamorphism around it. Lava flows are listed to the coast, under the youngest sediment and probably cover basement rock of a large part of the east part of Androy basin (under the Ambovombe basin).

2.3.6 Tectonics

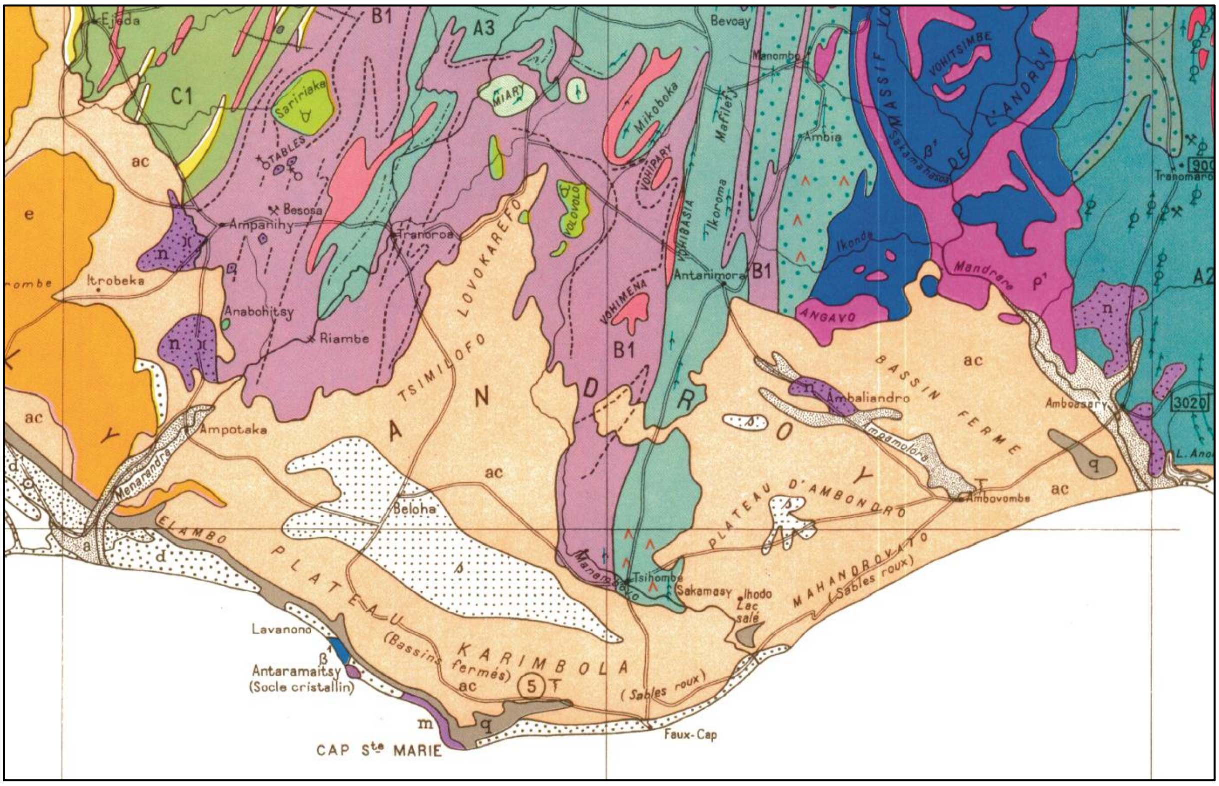
The south of Madagascar shows, by the shape of the visible basement area, multiple zones of fracturation. Three main N-S shear zones are repertoried under the west part of the basin. They are visible in the north part where basement is outcropping. The main event, called Beraketa shear zone, is separating the two main orogenesis of Androy system (older) and Graphite system. This event is passing approximately under Tsihombe. If main direction of shear is following a N-S direction, secondary fracks are following a NW-SE direction.

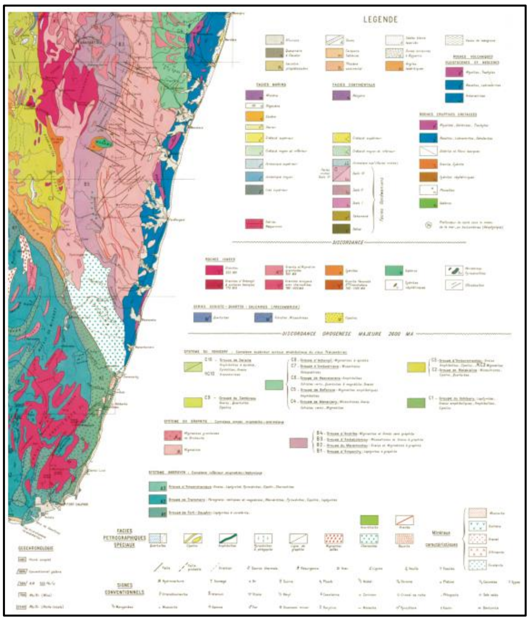


Carte tectonique du sud de Madagascar (Martelat, 1998)

The south of Madagascar is today a seismically stable area, indicating that the various fractures and faults in this area are old. The tectonics of the zone is linked to the Gondwana separation event that lasted from the end of the Carboniferous to the Pleistocene.

2.3.7 General geological map of the region





Sample of the geological map 1/1'000'000, focus of the Androy sedimentary basin (Besairie, 1964)

2.4 Hydrogeology

Several different aquifer units are known in the Far South sedimentary basin. At a local level, superficial water tables are observable in most recent deposits. Then, at a regional level, the different geological units each have aquifer potential.
The different known aquifers in the survey area, as well as their general characteristics, are described in a directory of Madagascar's main groundwater bodies (Rakotondrainibe, 1974, 2006). Information regarding the specific depths and flows presented should be considered with caution as they are not based on a large amount of data.

31 - Alluvial beds : lithology : clayey sands; type of porosity : porous; type of aquifer : captive; static level : 2-3 m; depth of structure : up to 20 m; aquifer thickness : about 5 m; water quality : brackish to salty water, high iron content; specific yield : 1 to 5 l/sec/m.

32 - Aquifer of the Beloha white sands : lithology : fine clay sands; type of porosity : porous; type of aquifer : free; static level : 2-3 m; depth of structure : 5-10 m; aquifer thickness : 1-5 m; water quality : fresh water; with fine clay particles in suspension; specific yield : 0.2 l/sec/m.

33 - Aquifer of Ambondro white sands : lithology : fine clay sands; type of porosity : porous; type of aquifer : free; static level: 2-3 m; depth of structure: 5-10 m; aquifer thickness: 1-5m; water quality: fresh water (charged with fine particles); specific yield : 0.2 l/sec/m.

34 - Aquifer of coastal sands and recent dunes : lithology : fine sands; type of porosity : porous; type of aquifer : free; static level : 2-3 m; depth of structure : 1-5 m; aquifer thickness : 1-3 m; water quality : fresh water, brackish to salty; specific yield : 0.4 to 2.6 l/sec/m.

35 - Middle Quaternary aquifer of Ambovombe : lithology : fine clay sands; type of porosity : porous; type of aquifer: free; static level : 5-10 m; depth of structure : 10 to 20 m; aquifer thickness : 1-5 m; water quality : brackish; specific yield : 0.04 to 0.55 l/sec/m.

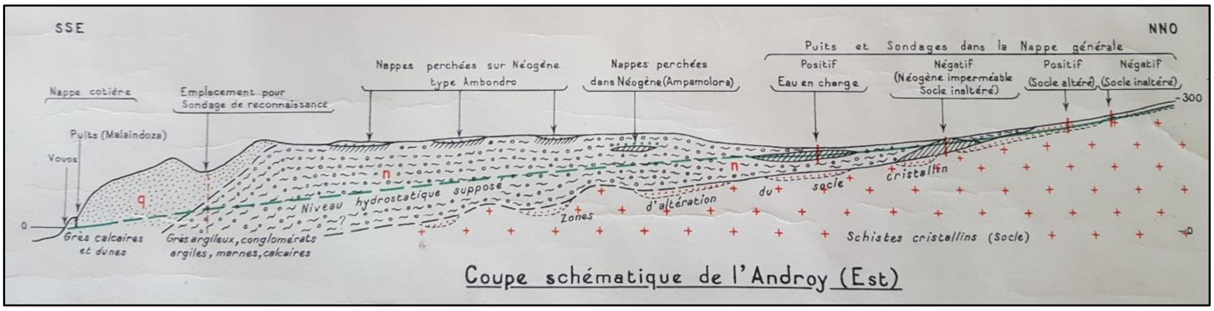
36 - Ancient Quaternary aquifer : lithology : fine clay sands; type of porosity : porous; type of aquifer : free; depth of structure : 50 to 150 m; water quality : brackish; specific yield : 0.04 to 0.55 l/sec/m.

37 - Neogene aquifer : lithology : sandy sandstone; type of porosity : porous (limestone zone possibly partially karstified); type of aquifer : free; depth of structure : 50 to 200 m; water quality : brackish to salty; specific flow rate : 0.019 to 1.55 l/sec/m. This unit represents the general aquifer, extending throughout all the area.

38 – Fissured aquifer : lithology : crystalline basement; type of porosity : fissures; type of aquifer : free; static level: 2-3 m; depth of structure : 5-80 m; aquifer thickness : about 10 m; water quality : fresh water, sometimes brackish to salty; specific yield estimated at 0.8 to 1.4 l/sec/m.
To this description of the fissured aquifer, valid for the North of the region, could be added the fissure of the basement in place under the sedimentary basin. The basement rocks are of plutonic metamorphised origin or of volcanic origin, and probably shows fissures exploitable by setting up of deep well (+ 200 m). No identification of these fissures has been done until today.

The recharge of these aquifers consists of infiltrated precipitations, transfers of water masses between rivers and aquifers (during flood events), and inter-aquifer transfers. Their drainage is towards rivers and towards the sea. Human exploitation is also a part of it, probably negligible at the regional level, but which becomes important at a local level, as in the case of small-sized perched aquifer. Note that the recharge (precipitation) occurs only on the quarter of the year, and drainage over a period four times longer.

The general flow direction of each of these aquifers will follow the dip of the geological structures. This sense can be locally disturbed near streams during flood events in the rainy season.



Hydrogeological profile of the Androy, representing the main aquifer units (Aurouze, 1957)

The waters circulating in known aquifers and currently exploited are generally considered of good chemical quality, according to the observations made on existing windows. However, the waters of all known aquifers in the area (including some non-exploited superficial water bodies) may also have highly mineralized waters.

In addition, perched aquifers may produce turbid water (very fine particles in suspension). Finally, the infiltration being fast, the water of the perched aquifers or aquifers of beach sands can easily be loaded with external contaminants (breeding, fertilizers).

Note that all known aquifers in southern Madagascar are considered to be unproductive (low yielding aquifers). Previous studies and experiments reveal a complicated groundwater exploitation in the area, both qualitatively and quantitatively.

2.5 Geo-hydrology approach

The approach advocated by the consortium implementing this pilot project does not fall under traditional hydrogeology. The hydrogeological context, related to the hydrological cycle and presented above, is not considered here directly, except to justify the difficulties of access to groundwater in the area. Since primary water circulation is not part of the cycle, there is no other link to make. Aquifers and known flows are not considered. On the other hand, the formation of deep structures allowing possible upwellings being linked to the geological history of the area, the knowledge of the geological context is considered for the selection of prospecting areas.

The defended approach is described as geo-hydrology. The observation of the geology indicates possible deep fracturing zones, allowing possible deep flows of interest. Some deep structures are sought after, such as volcanic structures, structures indicating degassing, or pressure releases during tectonic stresses, known to release water in liquid or gaseous form.

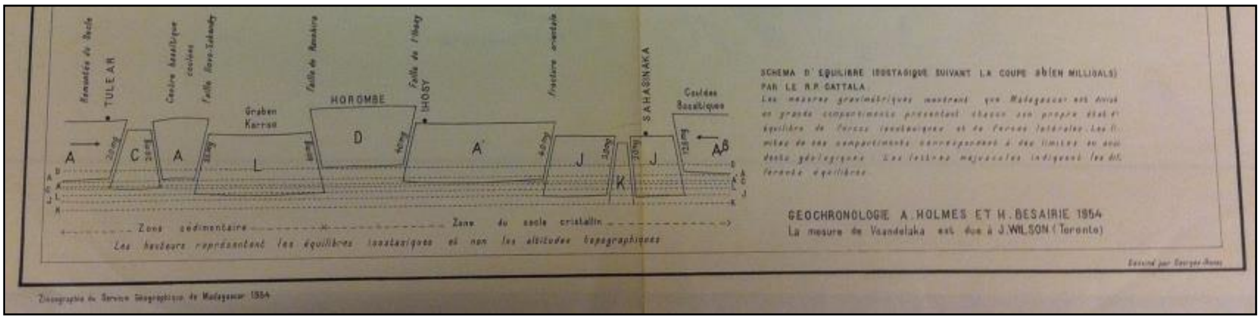
The study of lineaments allowing to highlight deformations, areas of contact, fractures or shear, represents a solid basis for the selection of prospecting area. The geological context of the zone then makes it possible to define the most favorable zones to present the mentioned structures. Note that it is not necessarily interesting to consider existing wells, implanted according to a classical method, with this approach. This does not bring any important information.

Primary waters, to travel to an aquifer, to an ocean, or to the surface, must have a very deep descending passage. They are therefore related to the structures of the basement (primary era).

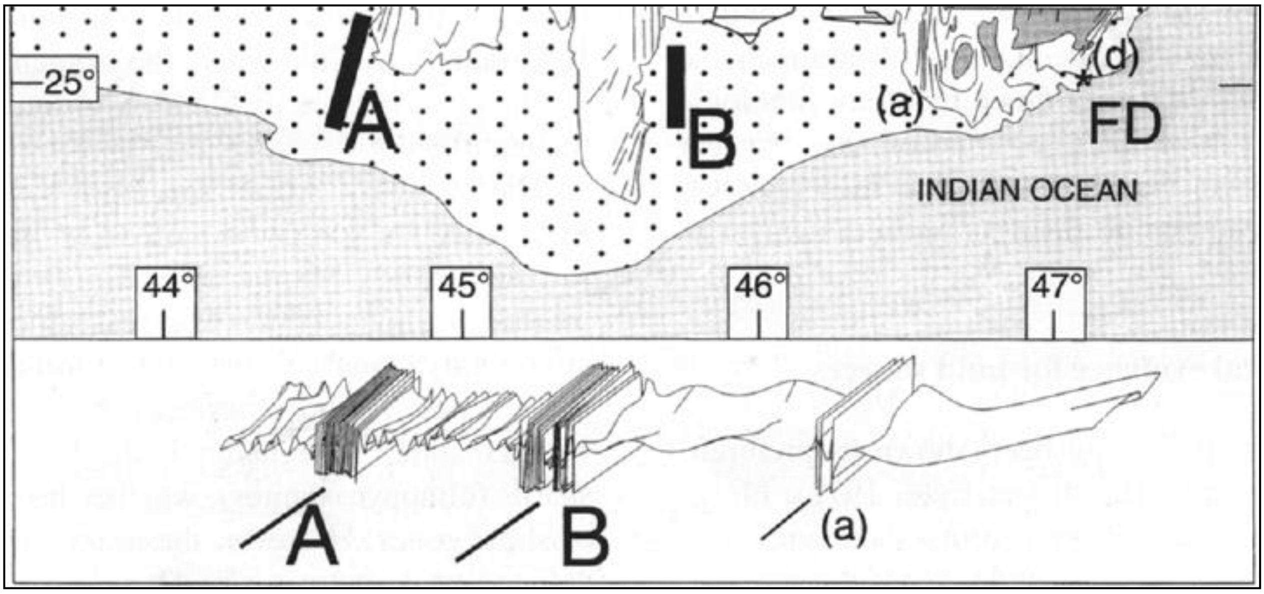
The drilling that could be carried out on the highlighted points will touch the underlying base, precisely on the interesting structures. The implementation of such surveys requires significant technical means, and knowledge of the structures and their formation process in order to place them properly.

2.6 Primary Water Geo-Hydrological Context

The Primary Water geo-hydrological context is best reflected in Madagascar studies by Pili et al. (University of Lyon): "Lithospheric shear zones and mantle-crust connections," *Tectonophysics* 280 (1997) p. 15-29. It is via the interaction of the mantle and crust, as impacted by planetary tidal forces caused primarily by the sun and secondarily by the moon, that the creation of H_2O within our planet and its movement along deep fractures is best understood. As clearly defined on the *Carte Tectonique de Madagascar* of Besairie (1954) below, the crust is divided into multiple blocks which are acting against each other as they are affected by Earth's tectonic forces.



Pili et al. demonstrate this same effect, on a smaller scaler, within the major and minor shear zones that predominate in the south of Madagascar:



The study uses specialized vocabulary to describe how gases such as CO_2 and H_2O are formed within the crust where they act as a volatile fluid moving through the fissures of the fractured crust:

METAMORPHISM AND TECTONICS, SOUTHERN MADAGASCAR 359

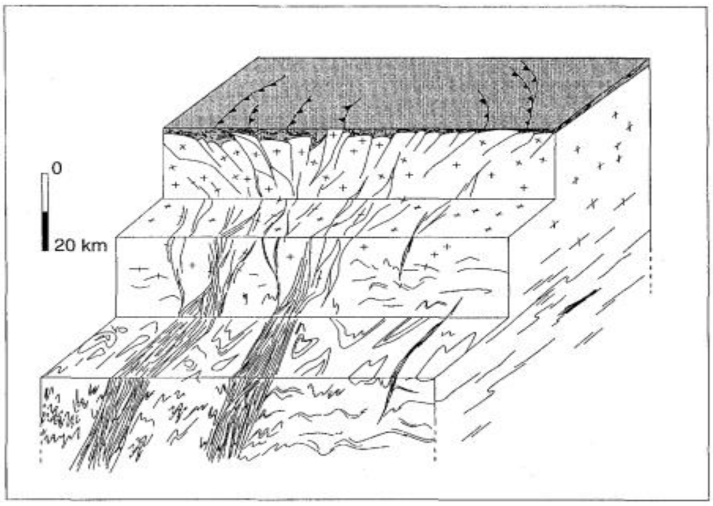


Fig.4. Schematic block diagram of a flower -like structure showing the possible relationships between the main crustal levels now exposed in Madagascar. Under transpression the thrusts developed in the upper crust are connected with vertical ductile shear zones in the lowermost structural levels. In the deepest part of the thickened crust strain is partitioned between shear zones and folded domains.

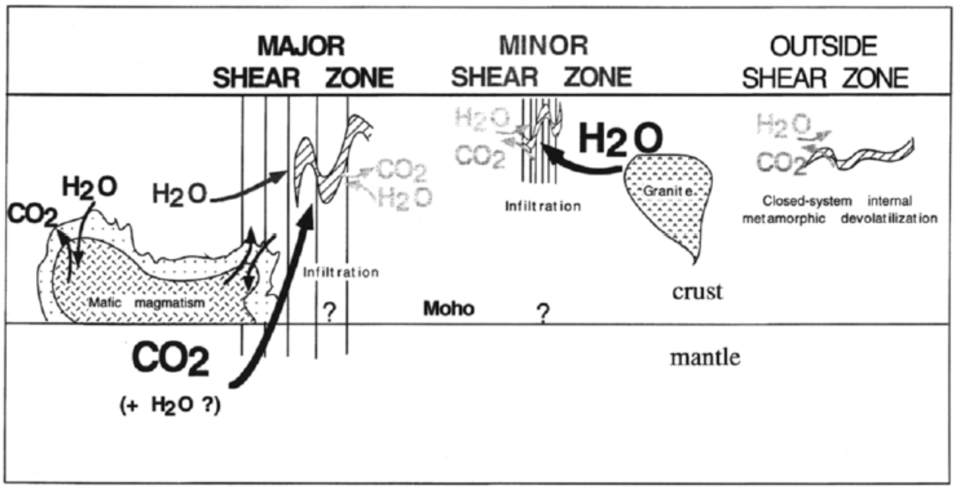
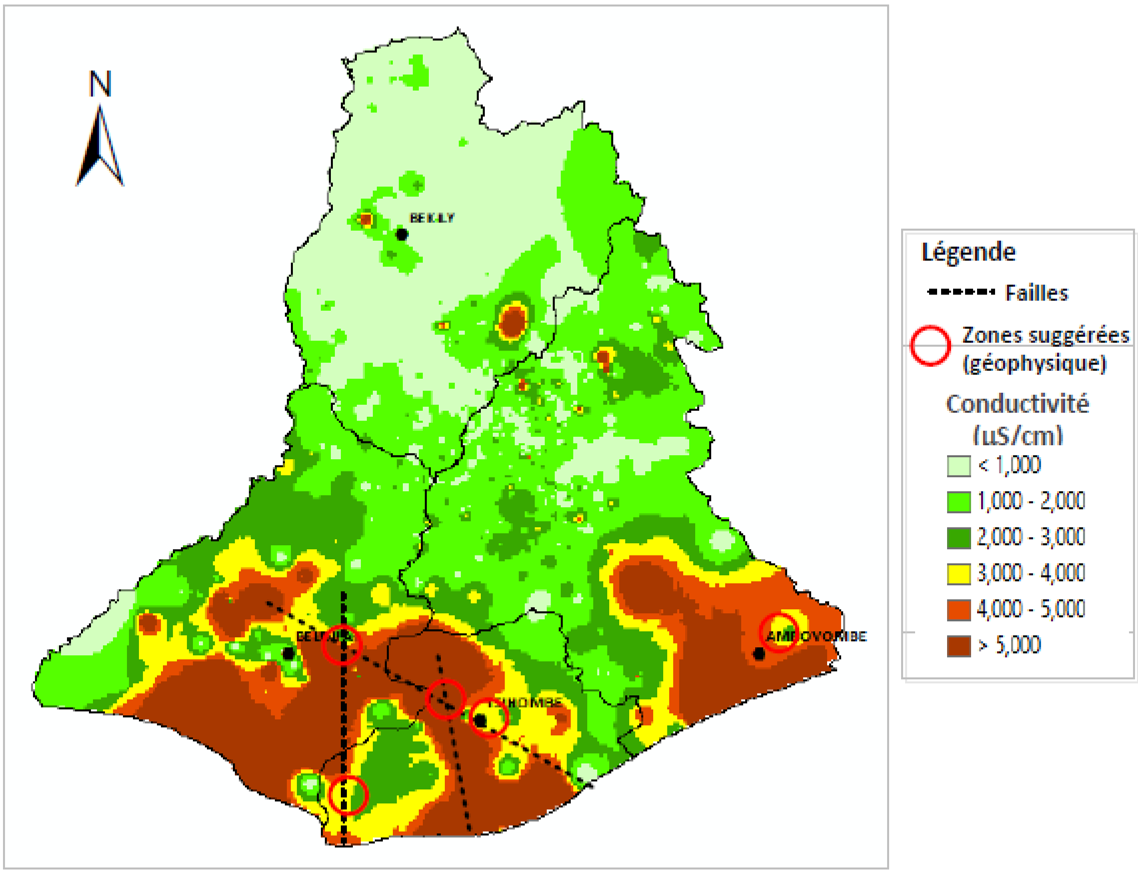


Fig. 2. Geochemical outline of the shear zones of Madagascar, after Pili et al. (1997). The wavy hatched structures represent a marble layer. Outside shear zones, marbles only record internal metamorphic devolatilization, which depends on the initial silicate-content of the limestone and hardly modifies their isotopic compositions. The minor shear zones only focus H_2O-rich and CO_2 fluids drained from the crust, from crystallizing synmetamorphic granites or internally produced by metamorphic reactions. Water infiltration enhances devolatilization of the marbles. In addition to crustal fluids, dominated by H_2O, the major shear zones focus $CO_2(\pm H_2O?)$ from the mantle. Mafic magmatism released CO_2 only locally and developed a corona of metasomatized rocks (clinopyroxenites) both outside and inside shear zones, and have been infiltrated by crustal H_2O. Metabasites are much more metasomatized inside than outside shear zones.

As a result, these fluids then move up, down and through the many passage ways created by these tectonic forces within the crust. Lardeaux et al. in "Metamorphism and Tectonics in Southern Madagascar: An Overview" *Gondwana Research* Vol. 2, Issue 3 (July 1999) p. 355-362, provide a schematic that depicts a flower-like structure whereby crustal fluids flow:

Pili and Lardeaux provide the best depictions of the tectono-physics related to the creation of primary water (and primary minerals) in the primary rocks of the crystalline basement of Southern Madagascar (and globally). Tsiombe sits on the southern edge of the major Berakata shear zone—indeed, we located the large "Stone Mountain" formation exposed to a height of some 30 meters north of town. This is where we first explored and collected data that confirmed our belief that this area is highly prospective for "fractured rock aquifer" sources that until now do not appear to have been exploited. Below is the salinity map of Androy provided by Unicef :



Tsiombe sits in the transition zone between the high salinity depression / littoral formation and the shear zone from the north. Drilling into Stone Mountain to release high quality primary water in high volume would be a dramatic example of our methodology and the Primary Water paradigm.

Beloha also sits between the high salinity depression / littoral formation to the south and a region of decreasing salinity to the north. In this case, however, the dramatic discovery of alternative volcanic features—the maar "crater lakes" field—allowing for near-surface exploitation of deeper groundwater sources provides another opportunity to demonstrate our alternative to traditional deep drilling programs.

The area around Ambovombe provides a third unique opportunity—albeit related to the discovery of the maar field of Beloha—to locate high quality primary water in a zone classified variously as sedimentary, argilaceous, and calcareous. The many maars located at the boundary between the Ampamoloro

Depression and the sedimentary formations provide an excellent example of contact points between formations causing zones of tectonic weakness—and their correlation with deep water sources.
Lastly, the very large crater of Ambondro offers a similar proof of concept similar to Beloha and Ambovombe, while sitting on a sedimentary plateau of mostly *sable blanc* and *sable roux* formations. For this reason we have recommended launching the drilling phase at Ambondro "Crater Lake" (see information further).

3 METHODOLOGY

As water resource scarcity increases globally, it is imperative that modern water exploration and production (Water E&P) methodology and related geophysical technologies be applied in the locating and sustainable exploitation of high quality, higher volume groundwater for both urban and rural populations. Most professional borehole drillers worldwide will attest that science and technology is leveraged in only a very small percent of their projects--almost always for government, military or large multinational clients. It is time for the advancements in the oil/gas and mining extractive sectors to be applied to groundwater resource management globally.

The science of Primary Water is based on the now proven theory that planet Earth creates water deep within the mantle. Hydrogen and oxygen combine under the electromechanical forces of our planet to produce H_2O in all its phases. This is a renewable, sustainable additional water resource to the traditional atmospheric/meteoric water cycle. Deep observation wells on multiple continents are proving this deeper recharge source. This water moves through the cracks of the crust and can be located in any geological environment, but typically in or above near-surface hard rock formations. This water will have a distinct chemical profile, easily differentiated from runoff and perched aquifers in the same zone.

The methodology of Primary Water E&P involves using GIS and geophysical survey techniques more common to oil/gas and especially mining sectors. Specifically, we will combine fracture trace analysis mapping (to locate broad and detailed fissures and fracture zones in the project area), ground radiometric surveying (a well-developed science in the USA and Germany), and deployment of passive seismic data collection that provides an inexpensive 2-D and 3-D investigation of the specific target to pinpoint well location and allowing for precision drilling via relative complex fractures to the deeper Primary Water source. In many cases, a driller can miss a Primary Water source by drilling just a few meters off the pinpoint location or by not adjusting drilling techniques during the borehole engineering. This is a dramatically disruptive approach that can be applied to all types of well drilling programs to minimize cost and maximize success.

3.1 Phase : Exploration

As the UNICEF solicitation outlines, the process of exploration generally has three sub-phases: data gathering and mapping; geophysical surveys; final site selection and drilling supervision. It is critical that exploration and production are joined together since this untraditional method requires a somewhat different approach to drilling into conventional aquifers in unconsolidated formations: once fissures and fracture zones are located, drilling normally starts with small bore to depth with constant monitoring of tailings, more frequent flow tests and water quality analysis. We start by carrying out a fracture trace analysis (FTA) of the target areas (Tsiombe, Beloha and Ambovombe) to locate prominent features such as faults, fissures and fracture zones in relation to the underlying geological formations and their potential for primary water. Such wide area mapping allows us to narrow our focus in advance of deployment. This will be followed by field geophysical surveys using two technologies, radiometrics and passive seismics. Radiometrics, specifically advanced gamma ray scintillation counting equipment, allows us to conduct target zone surveys via vehicle or ATV and then on foot to narrow down prospective zones of interest in relation to the FTA maps and with respect to project objectives, rig accessibility and local infrastructure. The portable passive seismics system can then be used for smaller area surveys to allow same-day processing of 2-D and even 3-D profiles as deep as 2000 meters. We will focus on data collection at 250 meters and 100 meters, generally starting with 10 meter line and point spacing, narrowing to 2m x 2m and ultimately ‘hot spot’ data collection over the final selection site for reference during the borehole drilling. Other forms of passive geophysical data collection include magnetics, gravity and radiometrics—all of which assist in determining depth to hard rock, lithology, dykes etc. All our geophysical systems have been in use for many years, mostly in other extractive sectors, but also in projects on all continents and geologic formations to locate groundwater.

3.2 Fracture Trace Analysis – Androy Region of Madagascar

The following is a proposal to conduct a fracture trace/lineament analysis for Unicef - Madagascar of a predefined study area in the Androy region of Madagascar.

Proposed Scope of Services :

Level I – Fracture Trace / Lineament Analysis
Project description - Produce a lineament map for four specified target areas in the Androy region of southern Madagascar. The areas of interest were marked by four red circles on the map in Annex 3. The circles delineate areas roughly 7-8 kilometers in diameter.

To be most useful, lineament analysis should be done in regional context. Therefore, the lineament map will include a wide margin around each circle, resulting in mapped circles of about 15 kilometers in diameter. This means coverage of an area totaling about 1000 square miles. Our analysis will be limited to use of readily available public domain data. This analysis is to be completed within one week after authorization to proceed.

1. Obtain DEM and satellite imagery – We will conduct a rapid search for available public domain Digital Elevation Model (DEM) data. The default assumption is that the best readily available data will be ASTER data. Limitations of the ASTER data set are the relatively low resolution (30 meters) and "noisiness" of the data. The noise level is variable by location; we will assess the suitability, and consider alternatives if any others exist in the public domain. Access to the ASTER data would be immediate, with the data downloadable.
2. Given the rapid turnaround required and the cost limit, we would use satellite imagery from Google Earth. This would involve making screenprints from Google Earth, assembling them into screenprint "quilts" of each circled area, and then rectifying them with GIS software.

3. Assemble GIS file set – Create a GIS file set including the DEM and satellite imagery, based on UTM Zone 38. Produce hillshaded relief images from the DEM using a range of lighting directions in Global Mapper. Use those images as mapping backdrops in the GIS database.
4. Map lineaments – Map DEM-based lineaments using GIS. Map satellite imagery based lineaments in either the GIS or Google Earth, as appropriate for the situation.
5. Deliverables – Produce area-specific maps in PDF format, using the satellite image as a backdrop. Also provide digital lineament GIS shape files that may be integrated and/or superimposed onto geologic and hydrologic maps of the region. Write a roughly three-page letter report. The letter will document what was done, discuss any patterns noticed, and identify areas that appear of interest based purely on lineament mapping. Integration of the lineament results with geological and geophysical data will be carried out in the field given the integrated phases of the project. Note that the work product will not be a single map of the entire region defined by the red circles on the map Unicef provided. Instead, it will be separate maps, each of them showing lineaments in roughly a 8-kilometer radius around the center of each circle. This is based on the limited time and budget of the pilot project.

Provisos

- Before undertaking the project, it is difficult to predict how well lineaments will be manifested in the study area. Portions of the area appear to be underlain by coastal plain sediments. The Precambrian gneisses just to the north show very well-defined structure, but the degree to which this structure will be expressed through the sediments of the study area is uncertain. Nevertheless, the limited reference to the JICA lineament study of 2007 indicates that a full scale Level II+ study should be considered for a larger program.
- The public domain ASTER DEM data is best suited for delineation of grand-scale features. Higher-resolution data such as 5-meter digital terrain models that may be available from various vendors would undoubtedly be more effective in revealing smaller-scale and more-subtle features, but the cost may be on the order of $5-10K for the data sets alone (see Level II below).

3.3 Phase : Production

Given the variables related to drilling operations, in particular borehole depth and water flow, it is recommended that production be scheduled along the following lines, allowing for stakeholders to make decisions before moving to the next site. First, drilling should commence with small bore (~150 mm) to the source, allowing for open bore in hard rock formations. Then, an initial flow test will be conducted to estimate volume along with field water quality checks. If success is deemed achieved, then the borehole would be capped and the rig mobilized to the next site. Recommendations will be made as to whether the well should be bored out to 200mm/250mm and potentially deeper drilling to release even higher volume. This will affect well completion decisions, pump acquisition and installation, infrastructure etc. Passive seismic data will be taken at that point of production to detect any change in the structure. Same process will be repeated for site 2. After the Tsiombe and/or Beloha boreholes are drilled, estimates of well completion will be provided to Unicef. The team will then move to Ambovombe where the more challenging geologic formations require more time for drilling, clean out, flow testing and more expensive well completion. Depending on initial flow tests and water quality--and the remaining production budget--decision can then be made to return to the capped wells for temporary installation of a mechanical pump or full well completion and infrastructure. It remains the intention of the Consortium to seek matching funds upon contract award which would be directed to extending the drilling program to more sites.

3.4 Important note

IT HAS BEEN STATED SINCE THE UNSOLICITED PROPOSAL THAT PRIMARY WATER EXPLORATION AND PRODUCTION (WATER E&P) AND THE METHODOLOGY DEVELOPED BY PRIMARY WATER TECHNOLOGIES IS A COMPREHENSIVE APPROACH TO SUCCESSFUL GROUNDWATER EXPLORATION. THE BUSHPROOF CONSORTIUM ABSOLVES ITSELF FROM ALL IMPLICATIONS SHOULD THE DRILLING PHASE BE SEPARATED FROM THE EXPLORATION PHASE AND CONTRACTED TO A THIRD PARTY.

4 GEOPHYSICAL REPORT

4.1 Site 1 : Ambondro Maar 2 - "Crater Lake"

4.1.1 Summary

Location: Ambondro, Androy, Madagascar

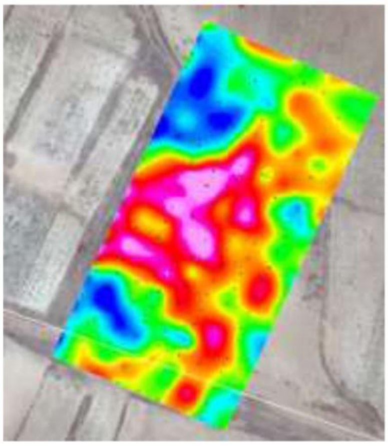
Grid Coord: 25° 13' 06.64"S 45° 50' 06.83"E

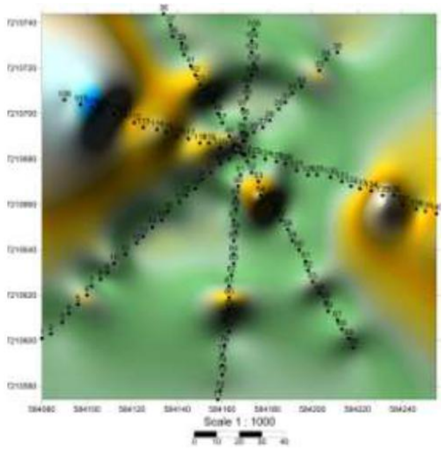
Formation: Sedimentary (*Sable Blanc* and *Sable Roux*)

The area around Ambondro was not covered by the lineament studies. However, as documented thoroughly in the Restitution presentation, it was the discovery of the maar field north of Beloha town that led us to survey a dry lake outside Ambondro which we quickly determined was also a maar. As this area was also without a high quality groundwater well, we returned to survey a much larger and more dramatic crater nearby that we believed to be highly prospective for primary water sources. We undertook extensive radiometric and passive seismic surveys of this nearly 200 meter in diameter maar to allow for extensive 2D and 3D processing of the data. (Photo below.)

4.1.2 Radiometric Survey

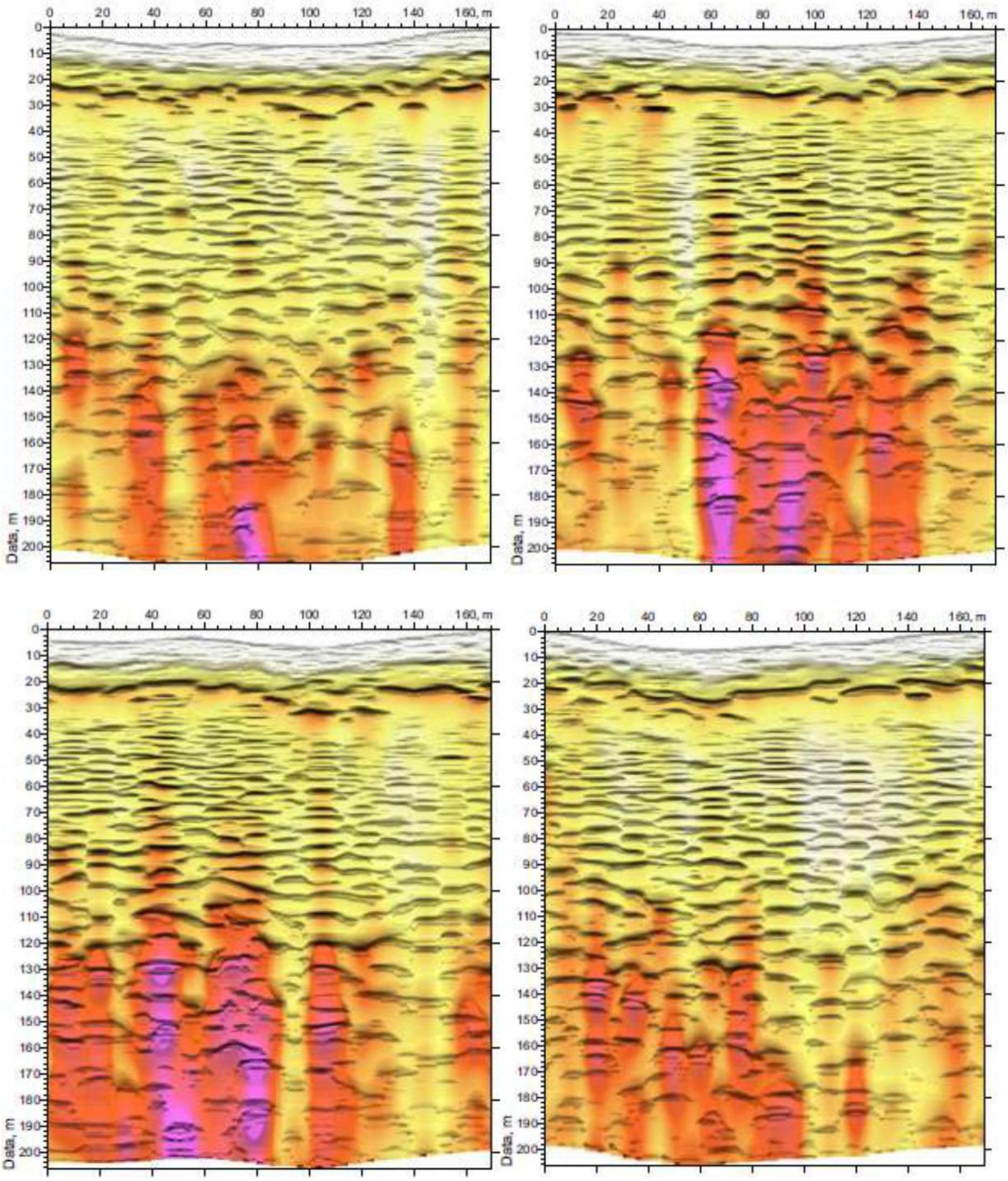
Upon arrival at the site and noting the quite large and deep nature of the crater (nicknamed —Crater Lake) and proximity to the town just one kilometer away, we proceeded to conduct radiometric grid surveys using an advanced gamma ray scintillation counter customized over many decades for use in ground-water exploration. The original crater structure was easily determined:





4.1.3 Passive Seismics

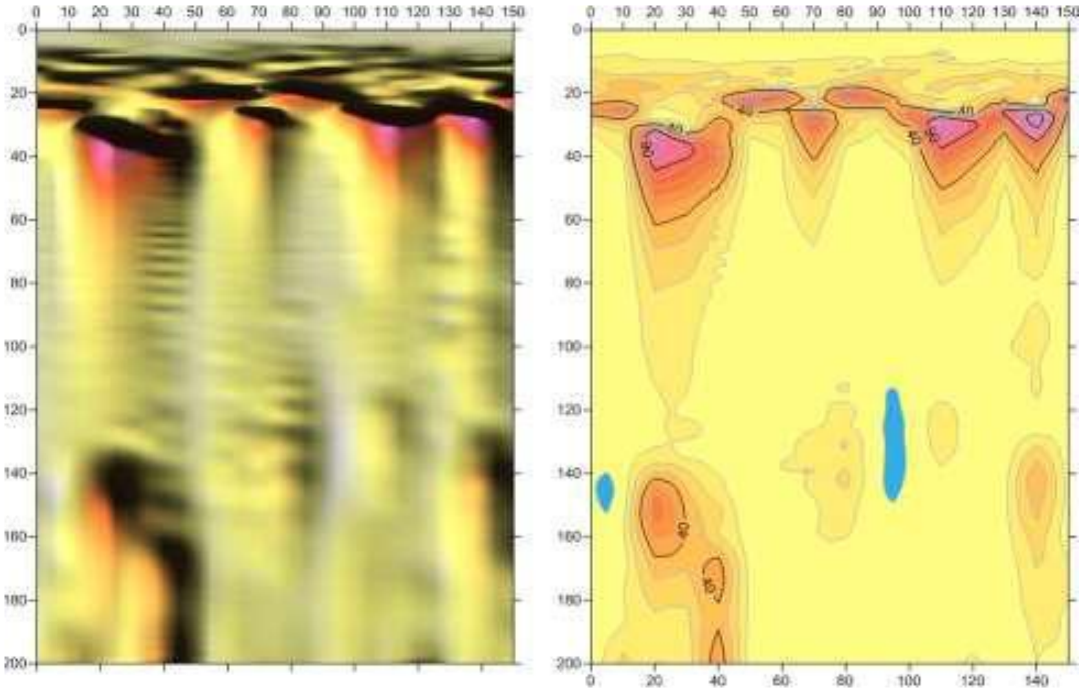
Four lines of passive seismic acoustic profiling crossing the center were collected as depicted in the previous diagram (on right). Each profile presents a high degree of fractured rock highly prospective for primary water (Line 1 top left collected SW to NE; Line 2 top right collected NW to SE; Line 3 bottom left collected S to N; Line 4 bottom right collected W to E) with white/yellow being the hardest zones and green/red the weakest zones:



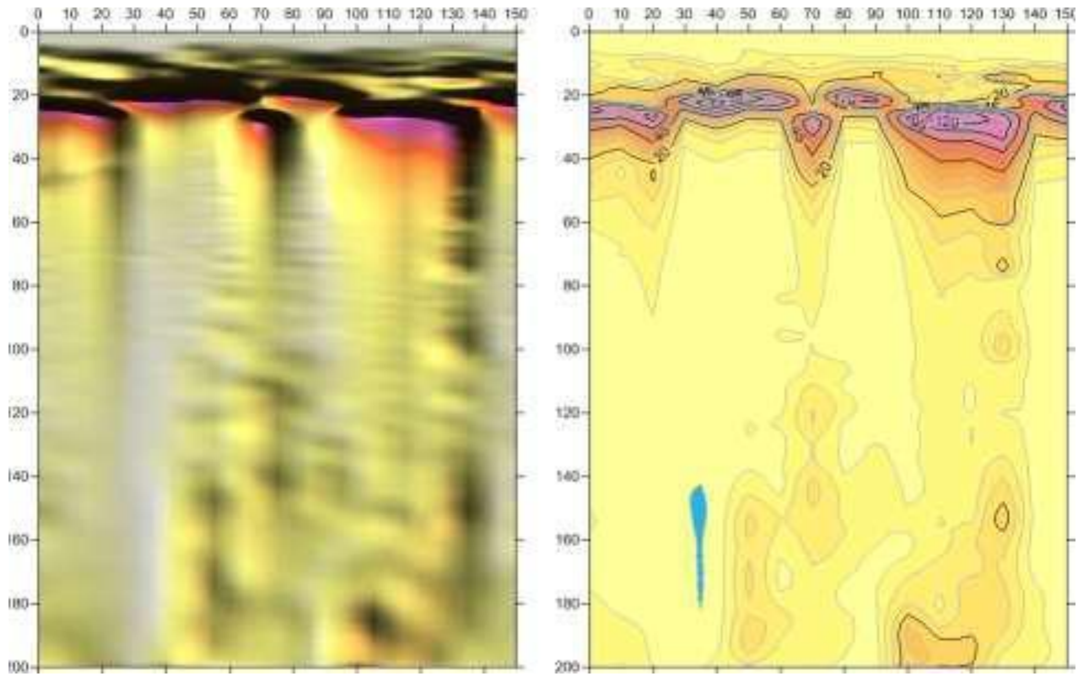
As discussed in the Restitution presentation, maars are geological formations formed by phreato-volcanoes, similar to what we call today geysers (or hydrothermal vents at the bottom of the oceans), when deep groundwater comes in contact with tectonically super-heated rock. These are almost always over diatremes, which are nothing more than zones of weakness where escaping gas and vapour would natural seek to escape and rise toward the surface. Translation of the Russian term for diatreme is “blow out” which is perfectly descriptive of what occurred to create this crater!

15 lines of passive seismic were collected in grid pattern to present a comprehensive 2D and 3D analysis of this highly prospective crater (the first 10 lines were 150 meters and the last 5 were 100 meters in length):

Line 1

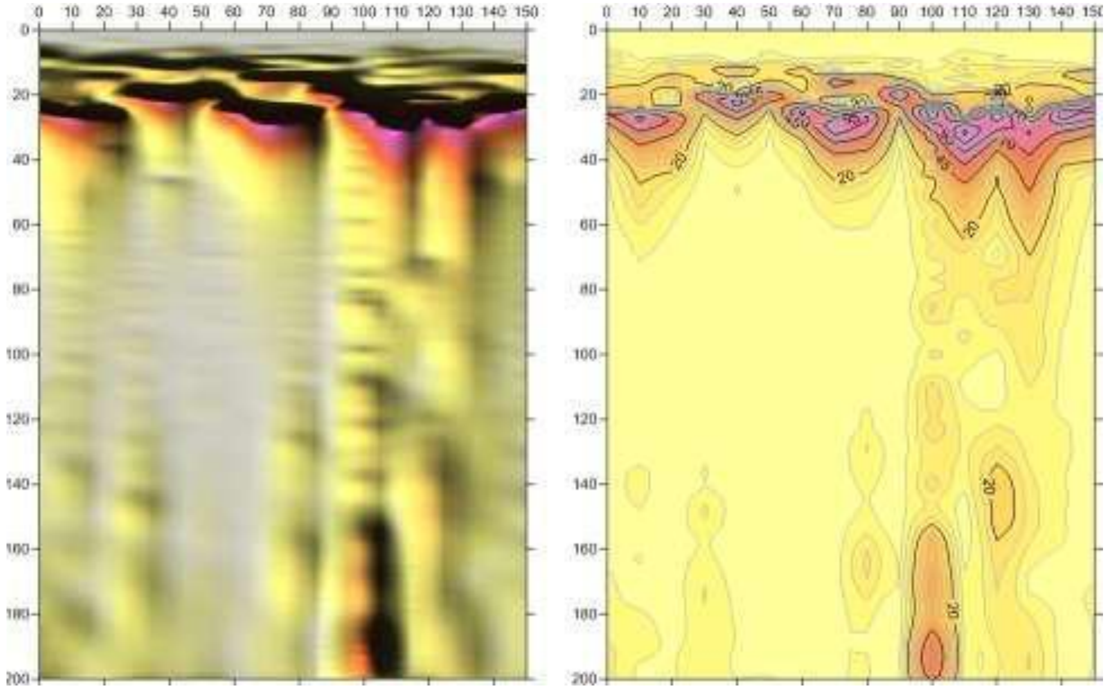


Line 2

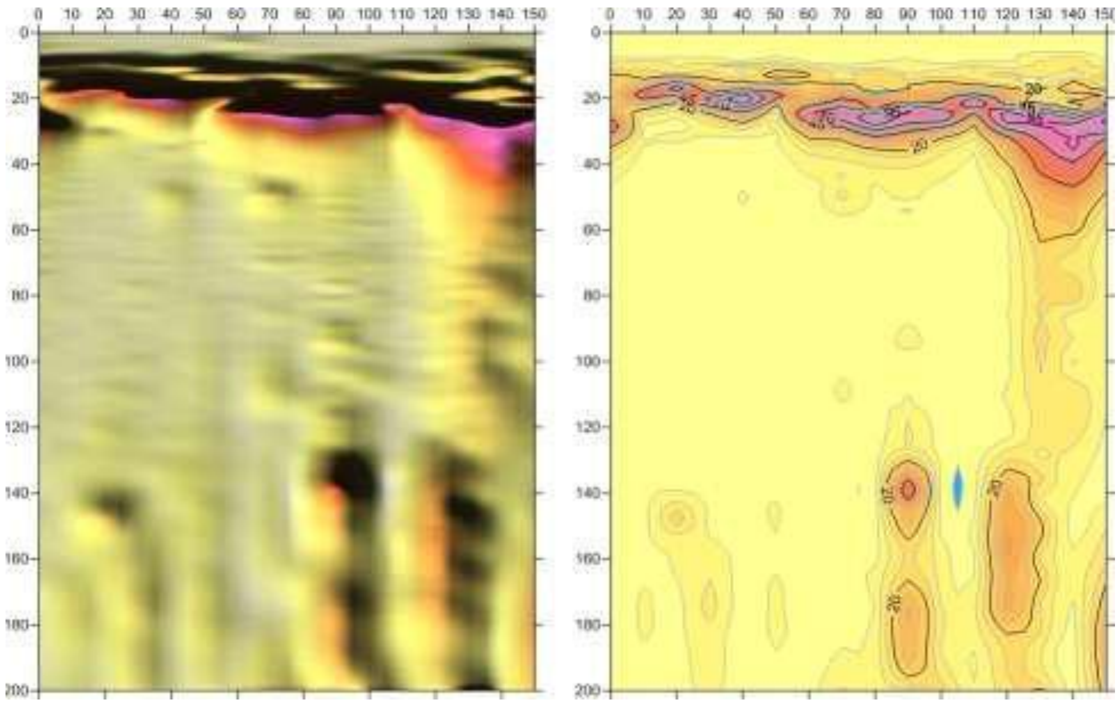


Data processed using Surfer: color relief on the left and contour format on the right.

Line 3

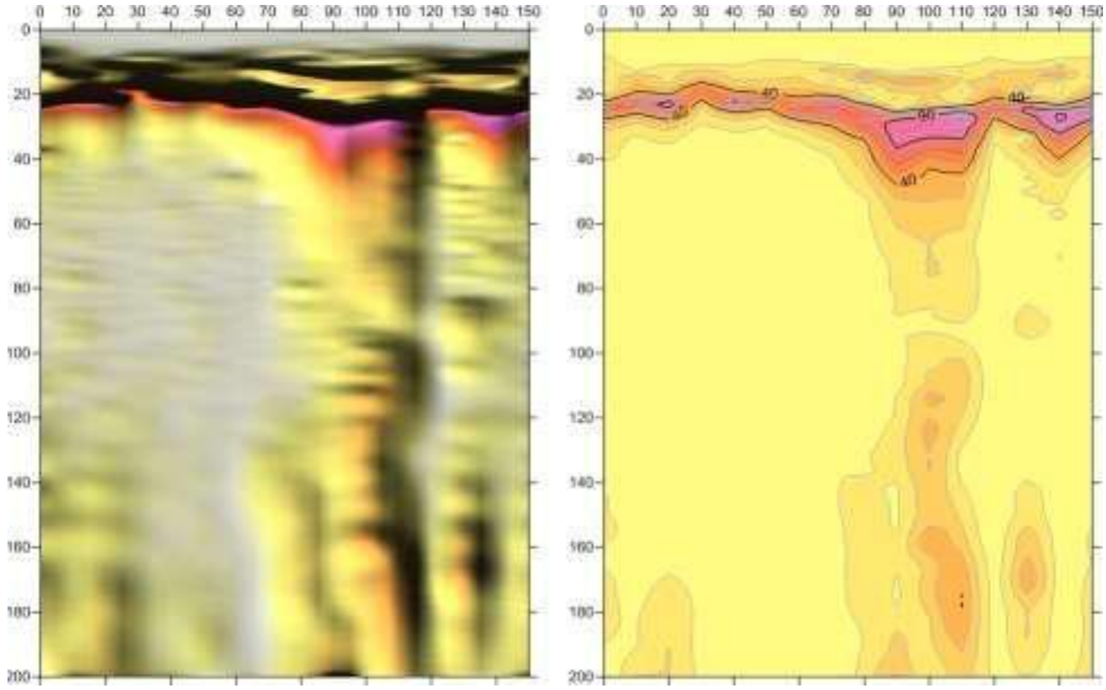


Line 4

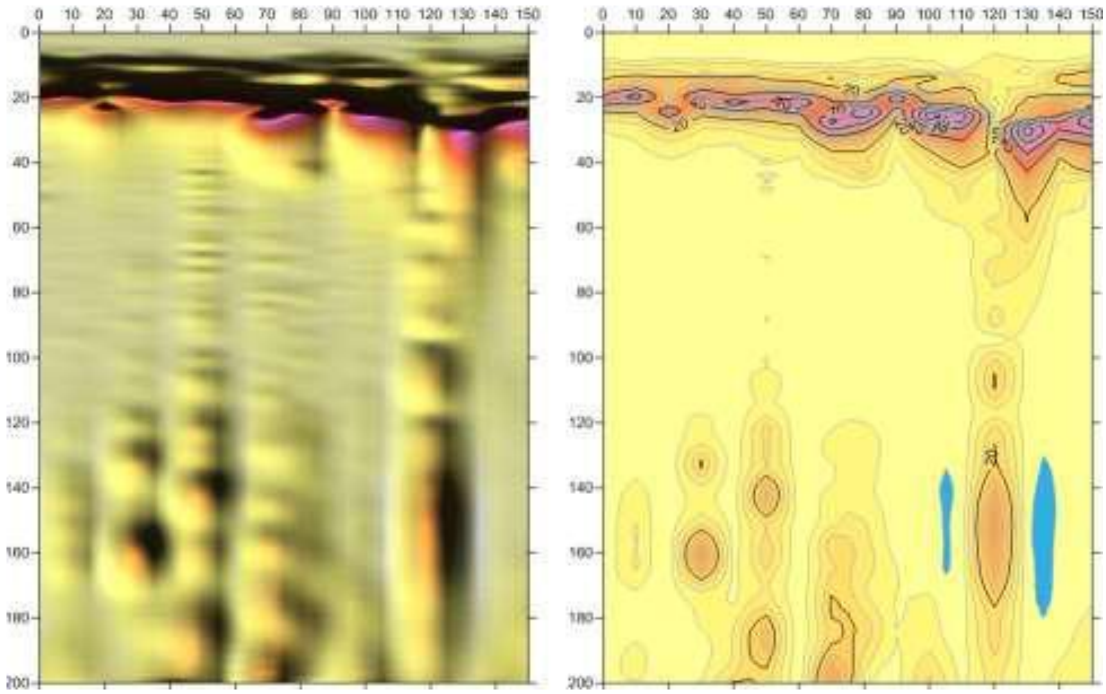


Data processed using Surfer: color relief on the left and contour format on the right.

Line 5

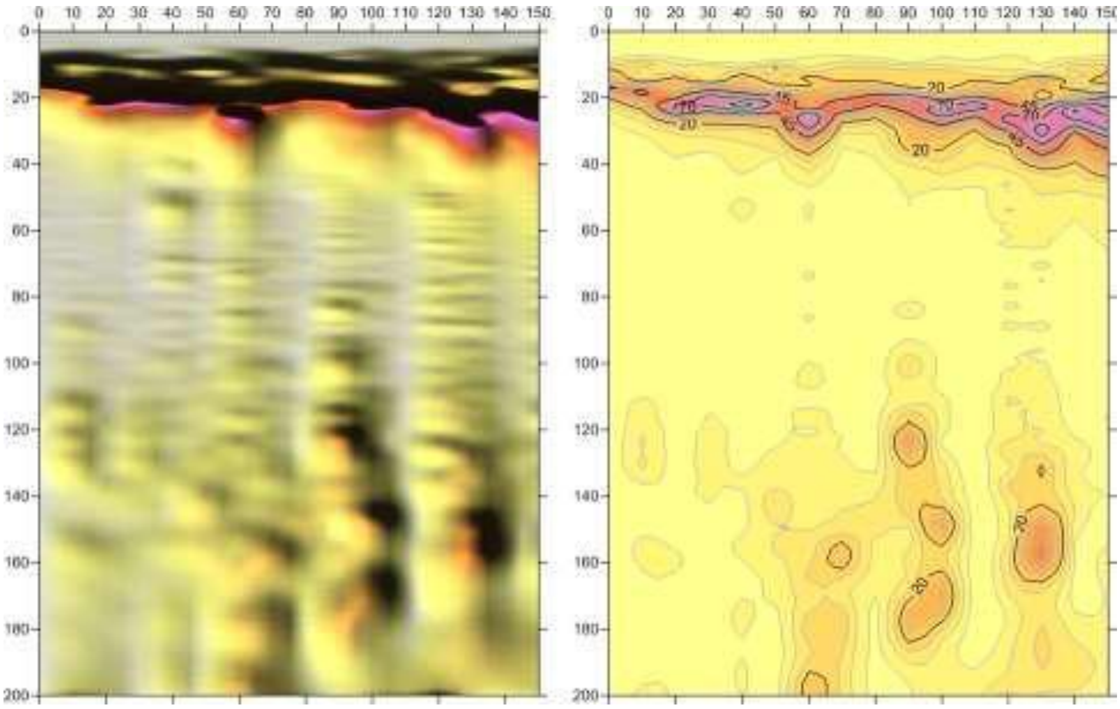


Line 6

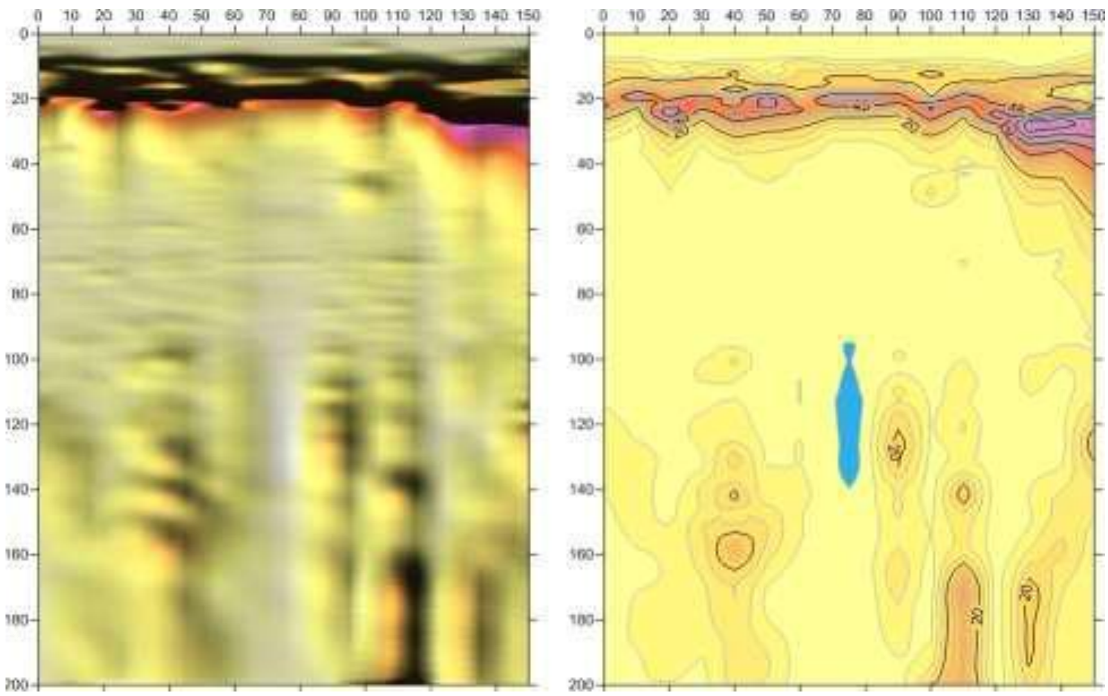


Data processed using Surfer: color relief on the left and contour format on the right.

Line 7

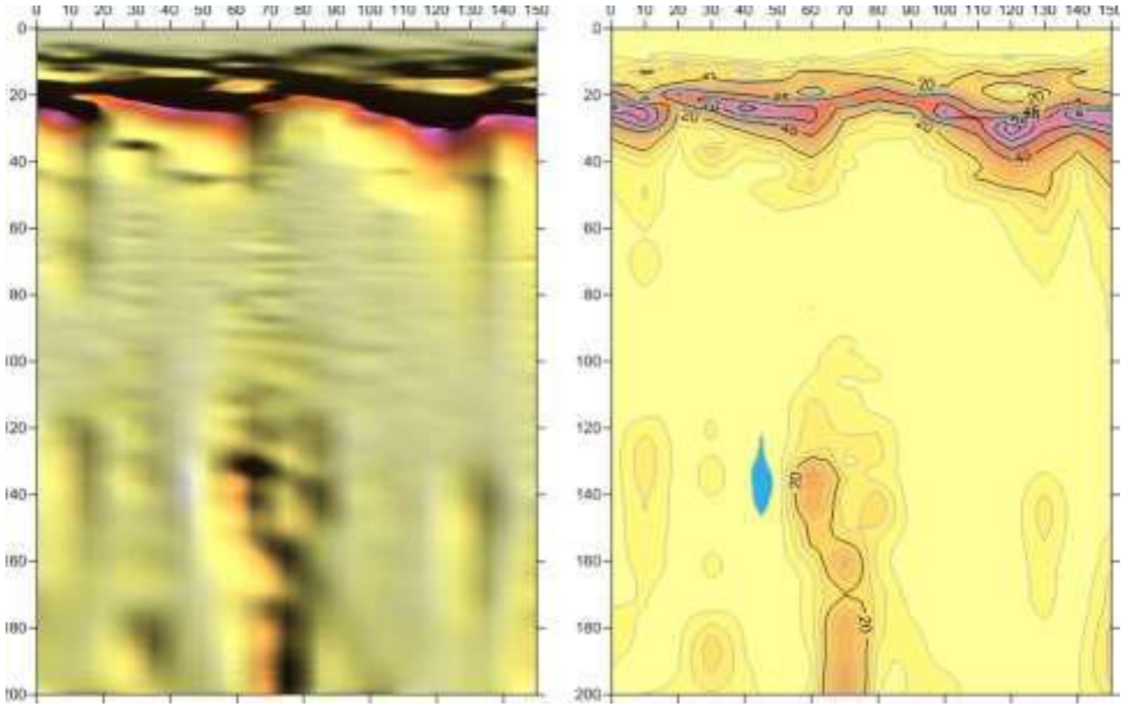


Line 8

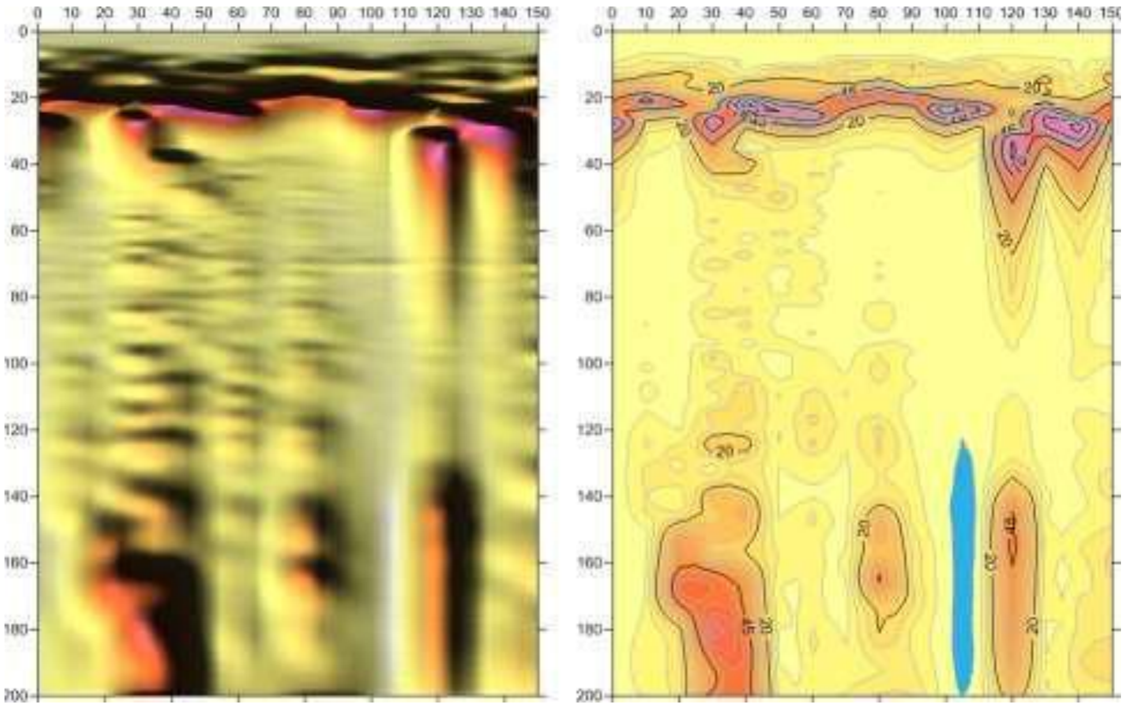


Data processed using Surfer: color relief on the left and contour format on the right.

Line 9

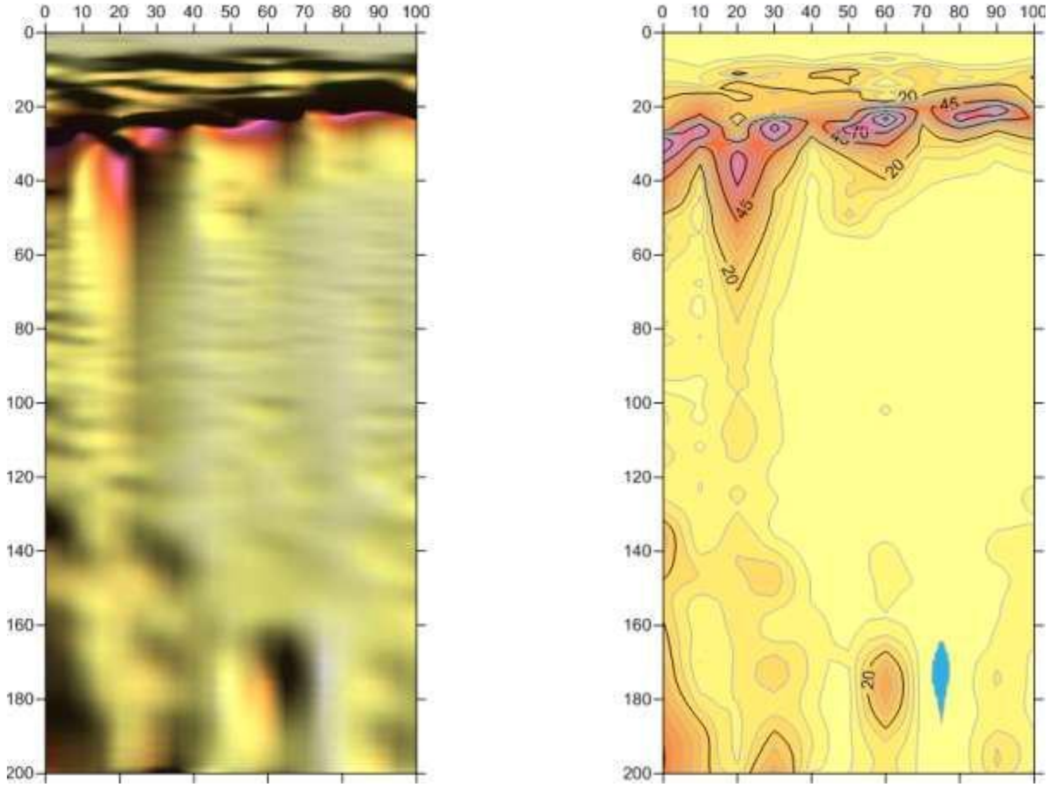


Line 10

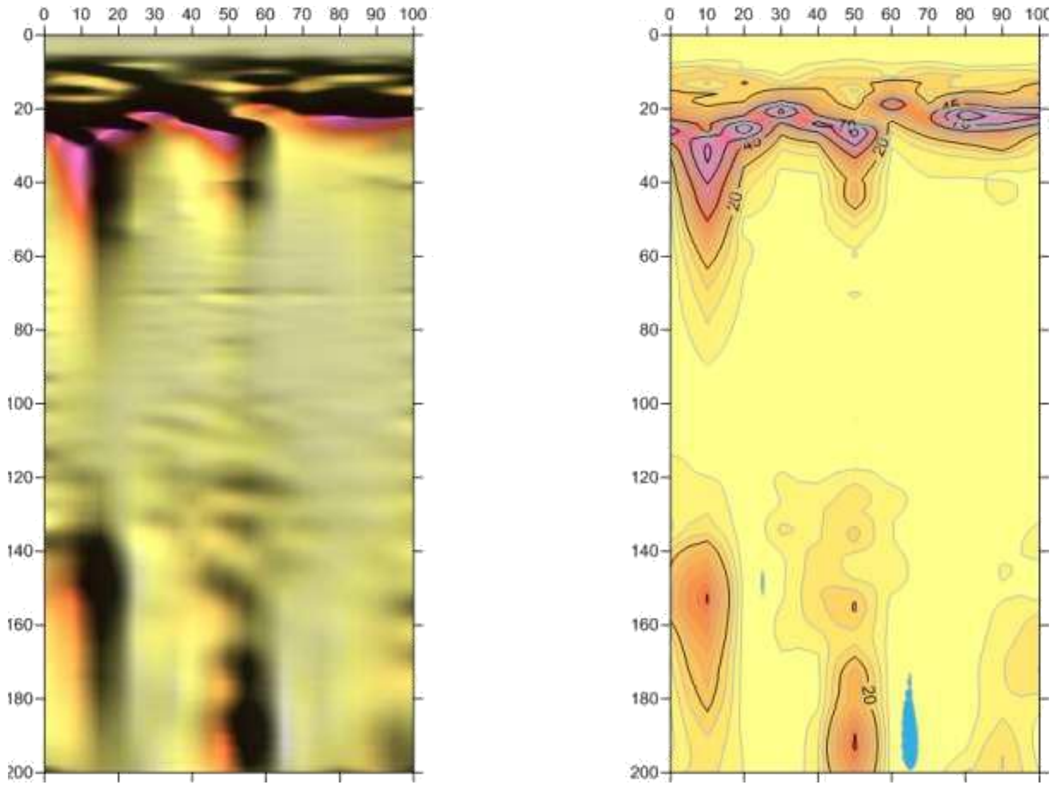


The following six profiles are 100 meters in length, instead of the previous 150 meters because of limitations of the survey field and the adjacent farm.

Line 1

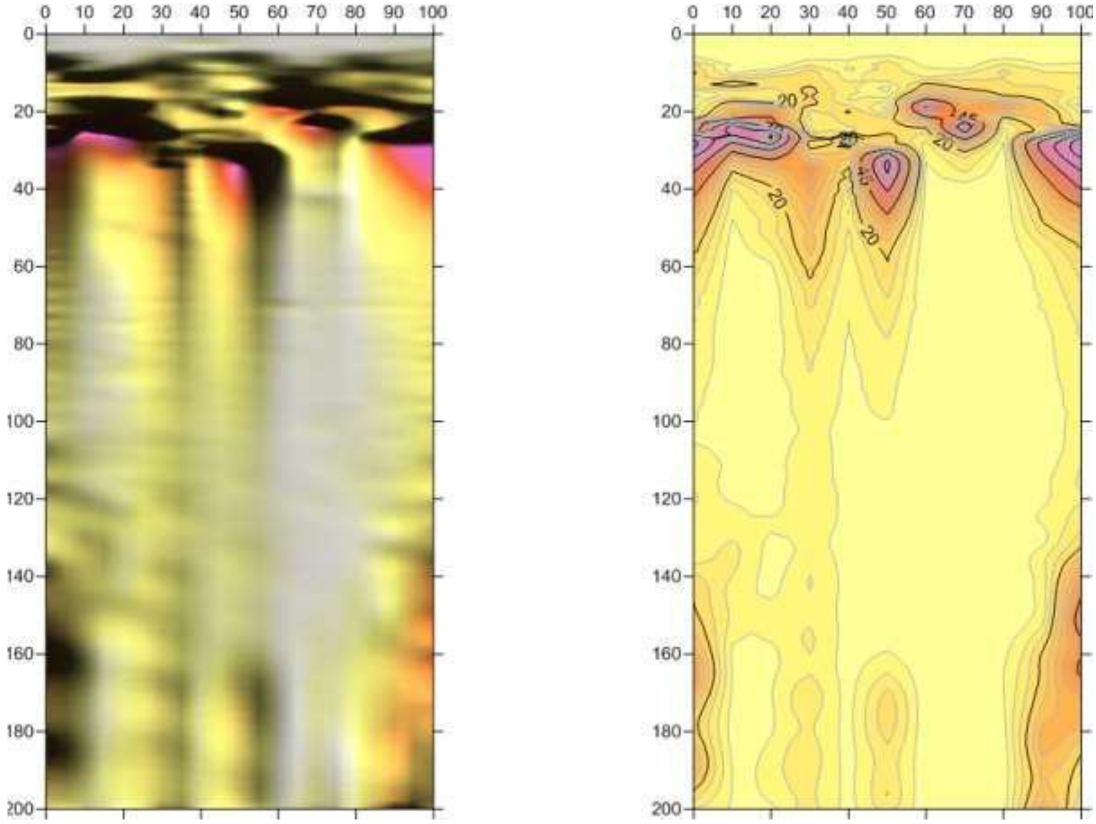


Line 12

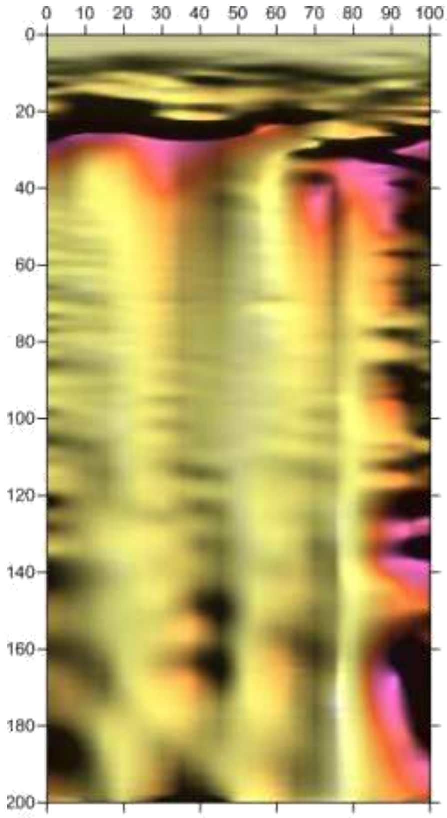


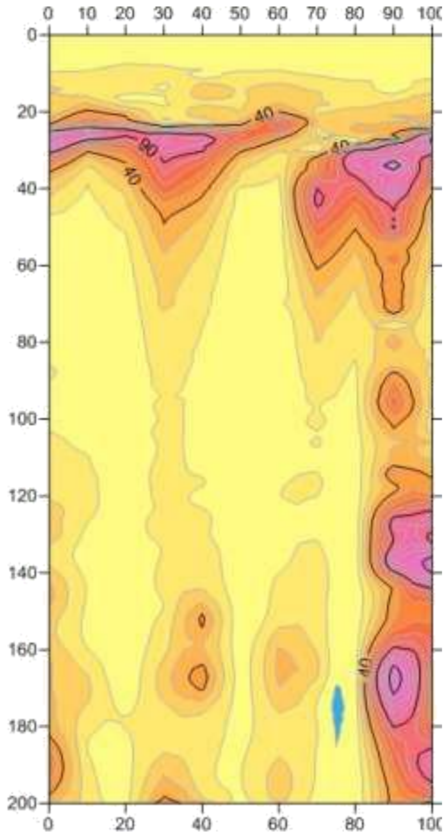
Data processed using Surfer: color relief on the left and contour format on the right.

Line 13


0 10 20 30 40 50 60 70 80 90 100
0 20 40 60 80 100 120 140 160 180 200
0 10 20 30 40 50 60 70 80 90 100
0 20 40 60 80 100 120 140 160 180 200
20

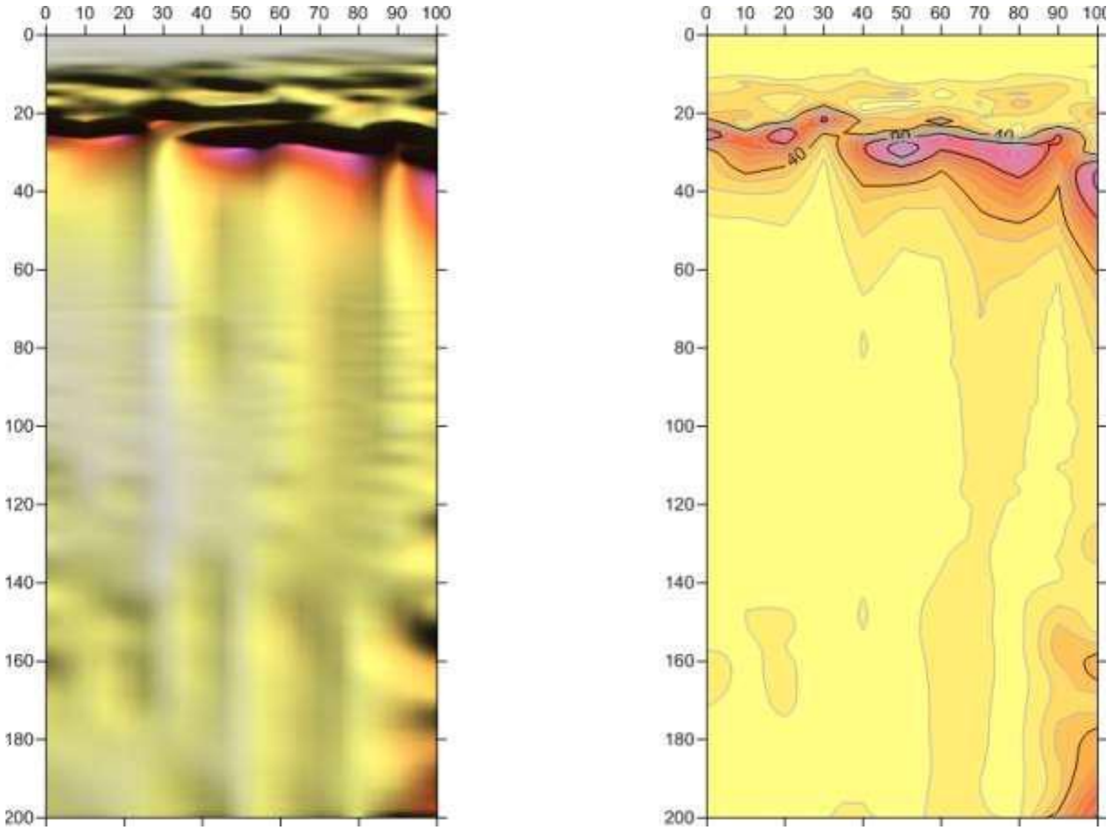
Line 14





Data processed using Surfer: color relief on the left and contour format on the right.

Line 15

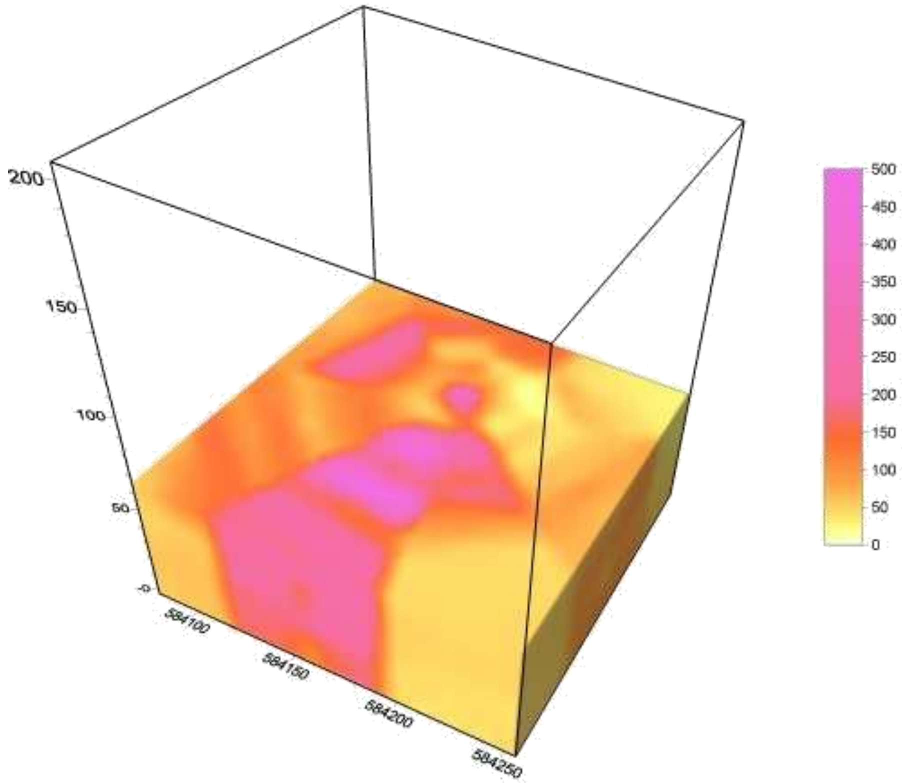


Below is a map of the 15 passive seismic lines, collected from W -E and S-N:

4.1.4 Observations

The Unicef – BushProof Consortium Expedition has made a significant contribution to the geological maps and understanding of the Androy Region. The dry lakes that were theorized to be volcanic craters, or maars, have been proven to be in each case (Beloha x 2, Ambondro x 2, Ambovombe x 6) to be the result of ancient phreato-volcanic eruptions. —Phreato- comes from the Greek word for spring and is a perfect description of the results of the tremendous heating of deep groundwater by tectonic forces leading to volcanic eruptions at points of greatest weakness in the crust—in this case diatremes representing cross-fracture zones of crustal weakness.

Many “crater lakes” are fed perennially from deep water sources, such as Crater Lake in Oregon USA and Lake Tritriva in Madagascar. Primary Water pioneers have drilled highly productive boreholes in these structures. The key is to properly select a site at the outer edge of typically the widest crater where there has been a secondary explosion, near the diatreme wall. Final prospection sites would be in the NE and W/NW sectors as depicted below in 3D (North pointing WNW in this rendering with the z-axis showing elevation).



4.1.5 Recommendations

We recommend using the Ambondro “Crater Lake” maar as the pilot for drilling into craters throughout the region. Pal Pauer, Primary Water pioneer and founder of the Primary Water Institute, who has over 50-years experience locating and drilling high volume Primary Water wells in all formations and five continents, will select the final site and supervise the driller closely. PWT will return to collect small area passive surveys at all drill sites for use in final pinpoint borehole locating and profiling.

4.2 Site 2 : Ambovombe "Maar Brittany"

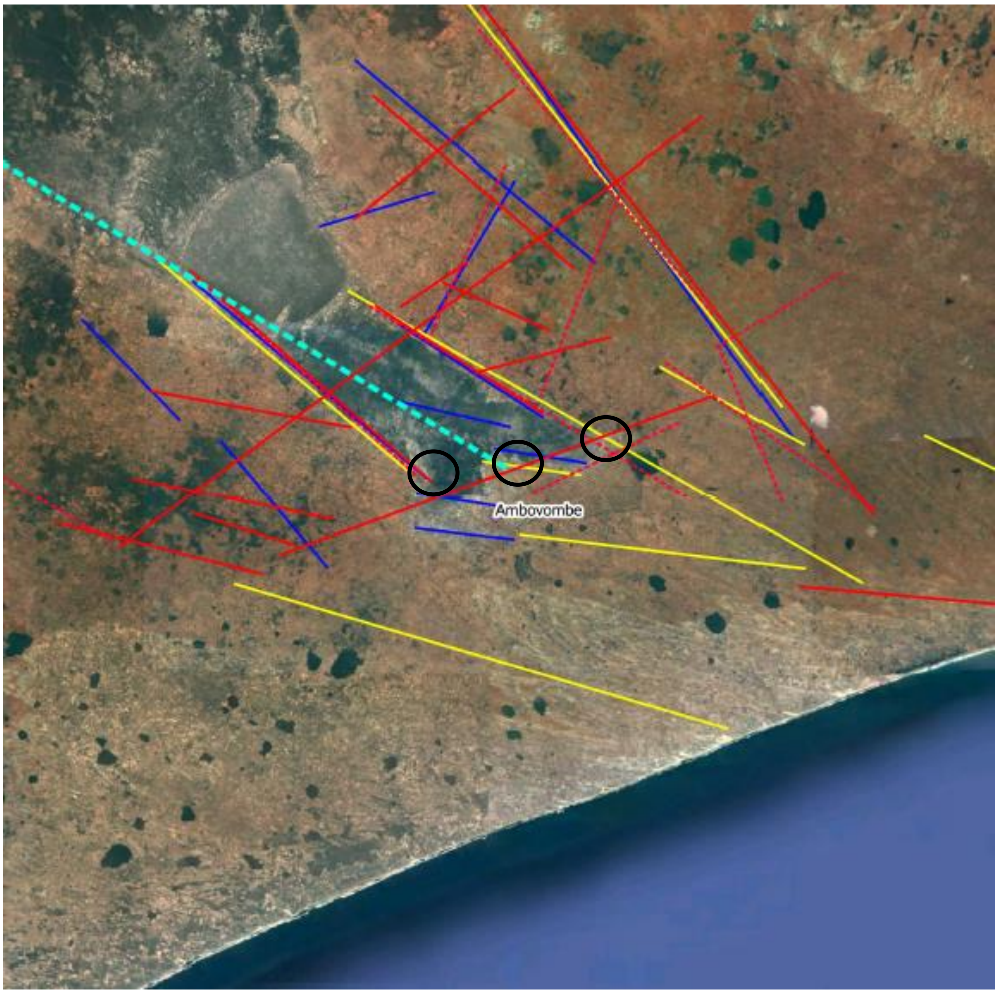
4.2.1 Summary

Location: Ambovombe, Androy, Madagascar

Grid Coord: 25° 09' 24.73"S 46° 05' 58.12"E

Formation: Sedimentary (*Sable Blanc/Roux*) and Volcanic Depression

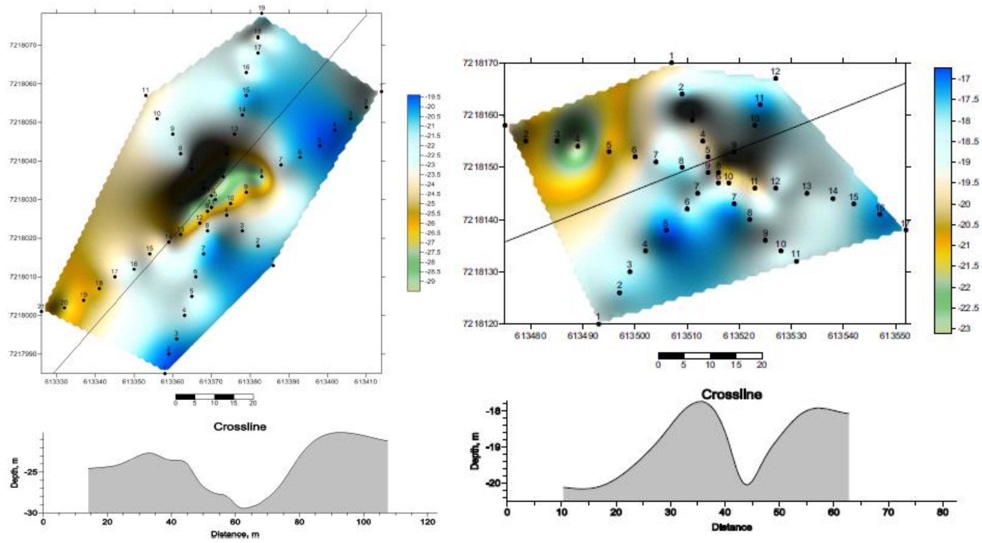
The area around Ambovombe was included in the lineament studies (below). As documented thoroughly in the Restitution presentation, and in the Geophysical Report: Ambondro "Crater Lake", it was the discovery of the maar field north of Beloha town that led us to discover the maars of Ambondro. Then, based only on the lineament study, BushProof selected three sites to survey to the NW, North and East of Ambovombe city (circled in black below). All three sites were on the border of the predominant sedimentary formation and the Ambovombe Depression. In each case we noted the coincidence of maars at or very near the target sites!



As we guided Unicef personnel from the Ambovombe East maar field to the north field, we passed more dry lakes that we did not survey. Once north of the city and only two kilometers away, we agreed to do a rapid survey of an interesting location (photo below) and to process the data and demonstrate the real time capability of our methodology.

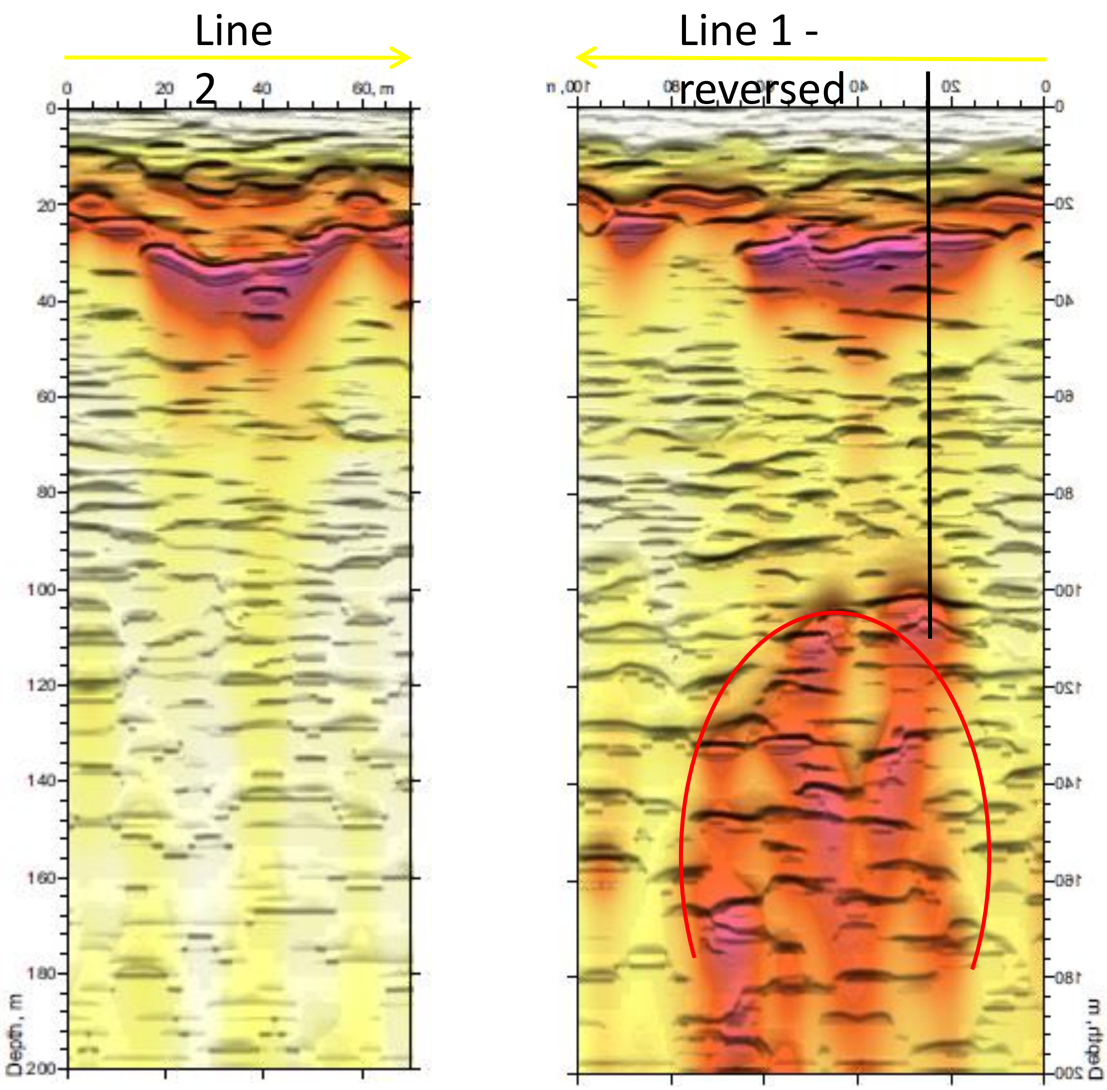
4.2.2 Radiometric Survey

We did not conduct a full gamma collection survey of the last maar, however previous radiometric surveys once again proved the now familiar structure of these craters as presented below (Ambovombe East – Maar 1 on the left and Ambovombe East – Maar 3 on the right, with crossline below each showing the sharp nature of the inner diatreme):



4.2.3 Passive Seismics

Two lines of passive seismic acoustic profiling crossing the center were collected as depicted in the previous diagram (on right). Each profile presents a high degree of fractured rock highly prospective for primary water (Line 1 top left collected SW to NE; Line 2 top right collected NW to SE; Line 3 bottom left collected S to N; Line 4 bottom right collected W to E) with white/yellow being the hardest zones and green/red the weakest zones:



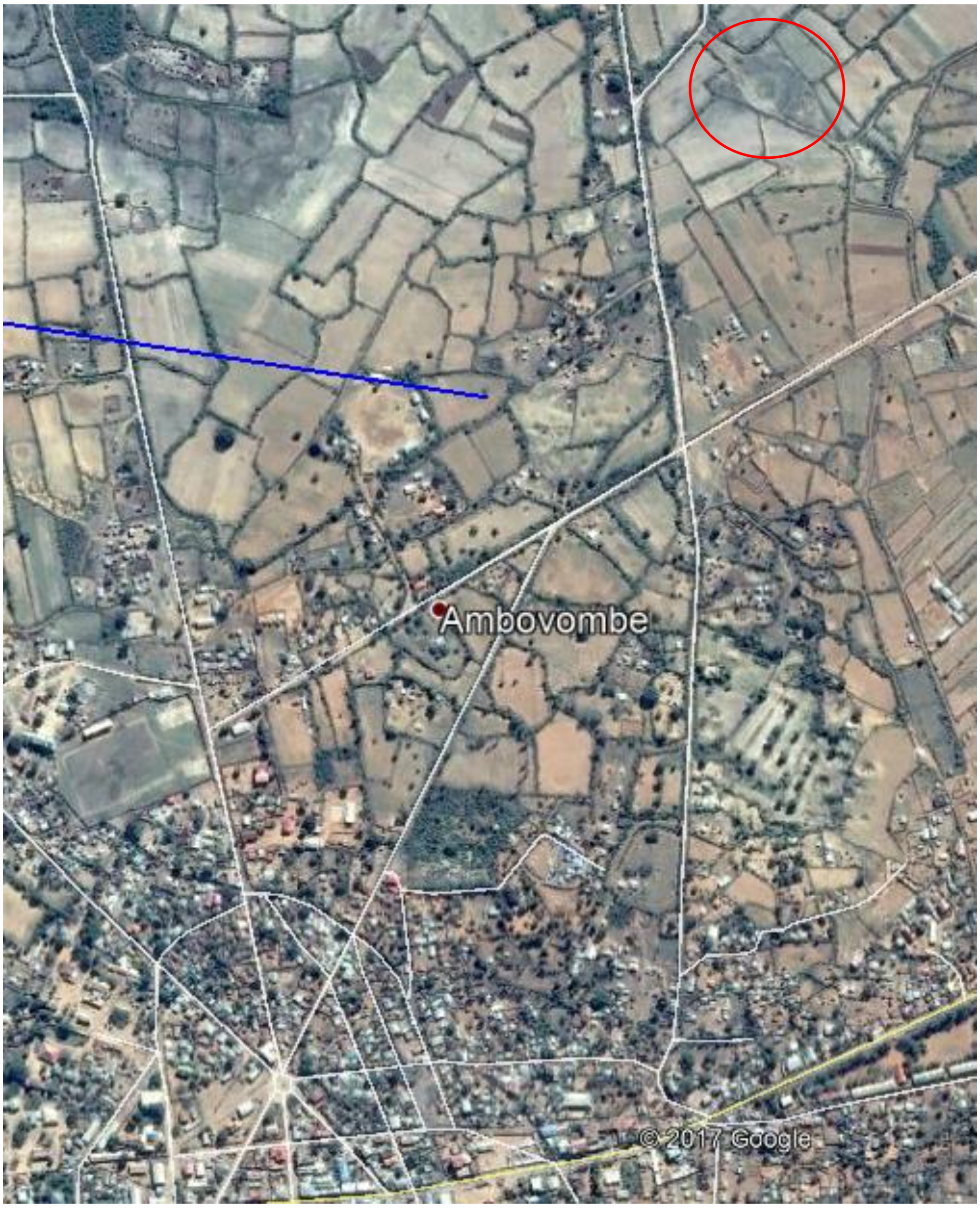
The Line 1 profile was the most dramatic of those we had surveyed north of Ambovombe. A large dome of primary water appears trapped along one of the two cross-factures of the maar, exploitable at the 100 meter depth. For this reason we recommend drilling this as Site 3 after proving out the maar structure in Ambondro as Site 1.

4.2.4 Observations

As always, drilling in the center of the maar is not recommended! But there are clear targets on the edges of the crater, such as at the 70 meter mark of Line 1. A complete survey of this maar can be carried out, while Ambondro is being drilling, to provide a more comprehensive 3D analysis.

4.2.5 Recommendations

We recommend drilling this maar first for Ambovombre, although further surveys could be made while the Ambondro drilling is underway. We may prefer the maar that is just on the outskirts of the city and only one kilometre from the city center (circle in red below).



4.3 Site 3 : Tsiombe North "Stone Mountain"

4.3.1 Summary

Location: Tsiombe, Androy, Madagascar

Grid Coord: 25° 17' 41.29"S 45° 28' 17.45"E

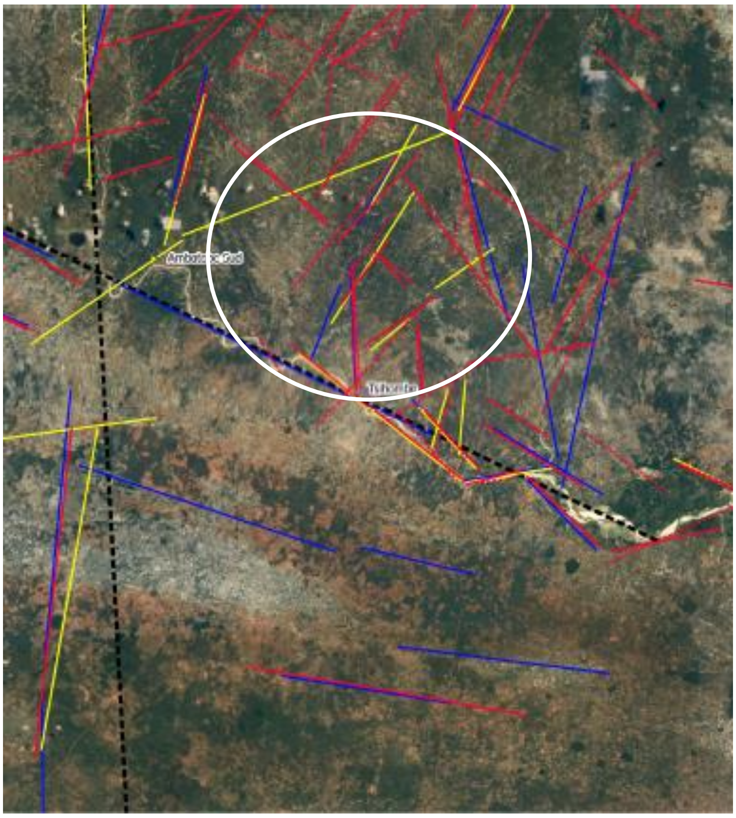
Formation: Basement Complex (Berakata SZ at surface)

During pre-mobilization mapping and data collection phase, this formation was easily seen via Google Earth and noted to HydroSource who conducted the broad scale lineament analysis. It was stated in the proposal to the solicitation that the zone north of Tsiombe would be highly prospective for Primary Water extracted from hard rock formations at or near the surface. During the team's stay in Tsiombe town it was experienced that the municipal water is river off-take and thus subject to rainfall and of low quality. Just one properly sited and drilled groundwater well would supply more high quality water than any borehole in the area—and thus provide an important alternative and redundancy to the current source.

4.3.2 Lineament Analysis

The mapping and lineament analysis revealed highly fractured Pre-Cambrian rock sweeping from the N & NW via the Berakata Shear Zone and ending at or just across the Manambovo River bordering the south side of town where the strong E-W littoral zone forms a barrier to natural N-S tectonic flow, most likely forcing groundwater deeper and under the coastal zone to the sea. (See geo-hydrological analysis for further context.)

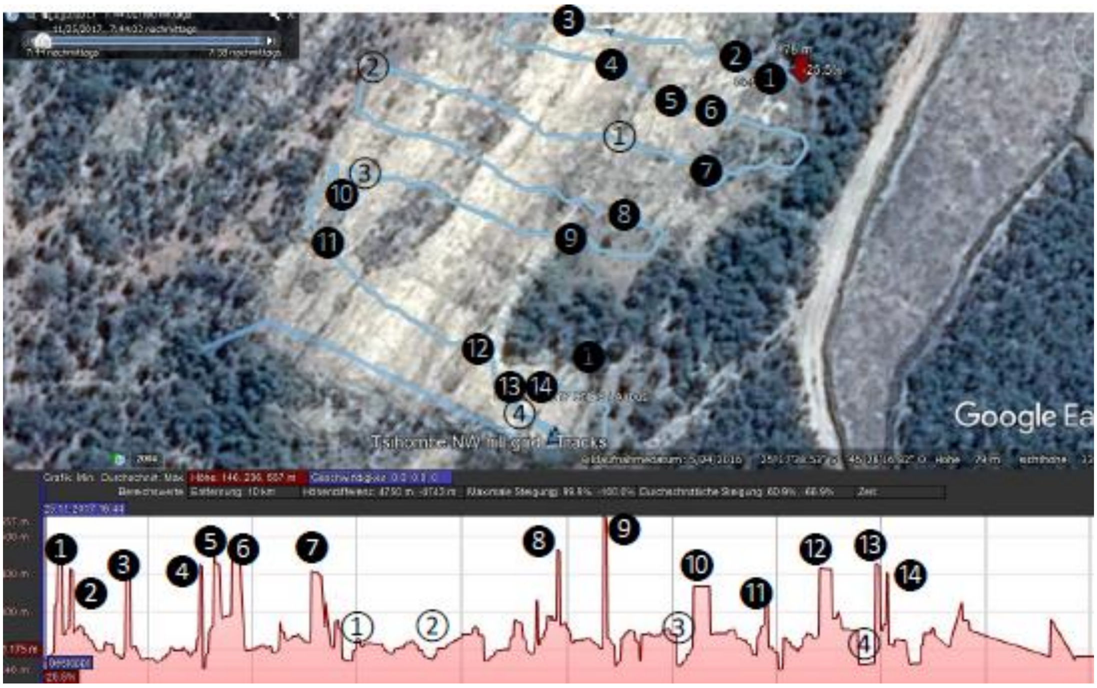
The lineament study reveals strong NW-SE & NE-SW fracturing to the north:



The area of interest reflected this same cross-fracturing and was thus chosen as a target site for exploration in Tsiombe, given easy access by road for drilling rig and end users alike :

4.3.3 Radiometric Survey

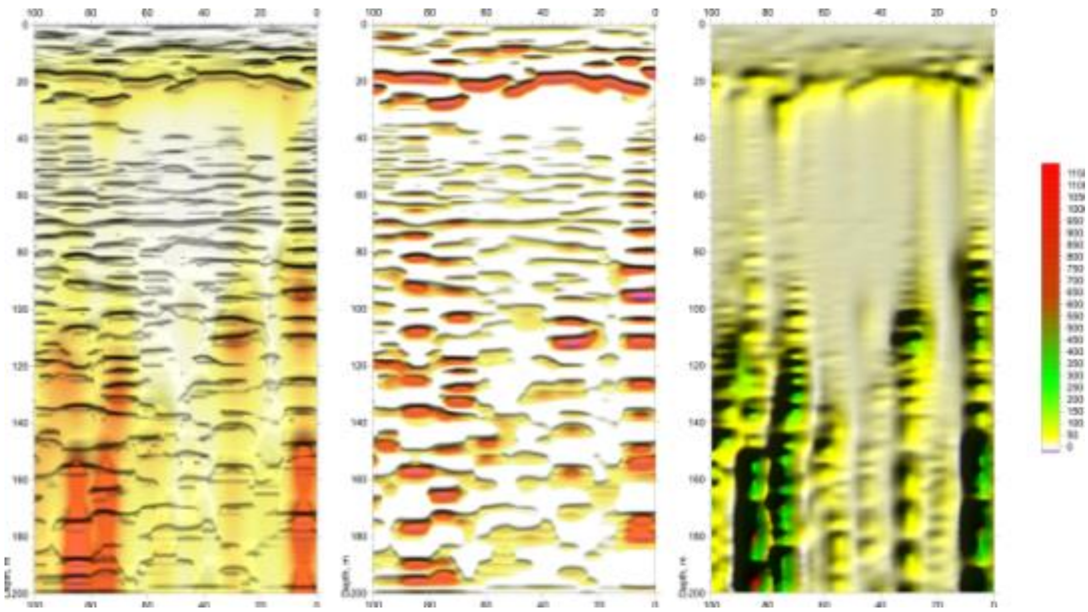
Upon arriving at the site and confirming the large nature of the formation (nicknamed “Stone Mountain”), ease of access to the perimeter and clear evidence of fractured rock tectonics at the surface—we proceeded to conduct a radiometric grid survey using an advanced gamma ray scintillation counter customized over many decades for use in groundwater exploration. A grid survey of the area revealed numerous trends and hot spots:



The spikes show high impulses per second (IPS) count while troughs show a decrease; down spikes are evidence of groundwater deflecting the emissions.

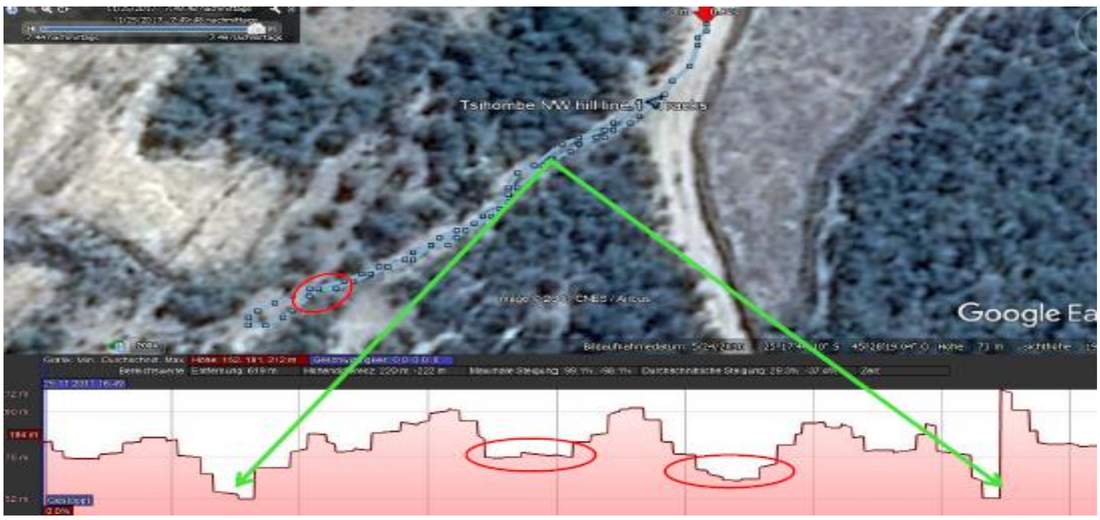
4.3.4 Passive Seismics

A line of passive seismics acoustic profiling was collected on the east side of Stone Mountain from the road to the SE corner where the rock formation ended at a NW-SE fracture indicated by the lineament study. The only question was on which side of the structure would primary water most likely be trapped. The seismic profile provided clear indication of fractured rock with multiple channels exploitable for primary groundwater:



The scale indicates the relative mechanical strength of the subsurface, with white/yellow being hardest and green/red weakest. The continental crusts are highly fractured near surface and deep into the crust as proven by all deep borehole projects. Surveys over fractured rock zones like Tsiombe "Stone Mountain" provide dramatic examples of this alternative to thinking only about aquifers sitting in basins like tubs of water to stick a straw into and drink from!

A gamma survey was conducted over the acoustic profile line and confirmed the location of the two zones of interest at 25 meters and the much larger and highly prospective structure at 70-90 meters (red circle).



4.3.5 Observations

Formations like Stone Mountain north of Tsiombe town have been developed into major city and town well fields throughout the fractured rock of the Appalachian Mountain range in the United States from Maine to Tennessee. The same goes for similar formations throughout Europe where groundwater is understood much differently, and categorized more precisely, than in the United States. This why many of the Primary Water pioneers in America—such as Stephan Riess, Armin Bickel and Pal Pauer—were immigrants from Europe! Often these formations are either overlooked (for, after all, why drill into impermeable rock for rainwater?) or the local residents lack access to advanced drilling equipment and the necessary capital required for such critical infrastructure projects that we in the West take for granted.

4.3.6 Recommendations

We recommend drilling the first test borehole along the east side of the mountain, choosing between either fissure; depending on rig access, stakeholder issues and any planned infrastructure. This whole structure, **some 500 meters long and over 100 meters wide**, should be considered for multiple municipal wells, water trucking operations and local irrigation or livestock water points. (View of survey line below; and view from top!)

4.4 Site 4 : Ambazoa Town Square

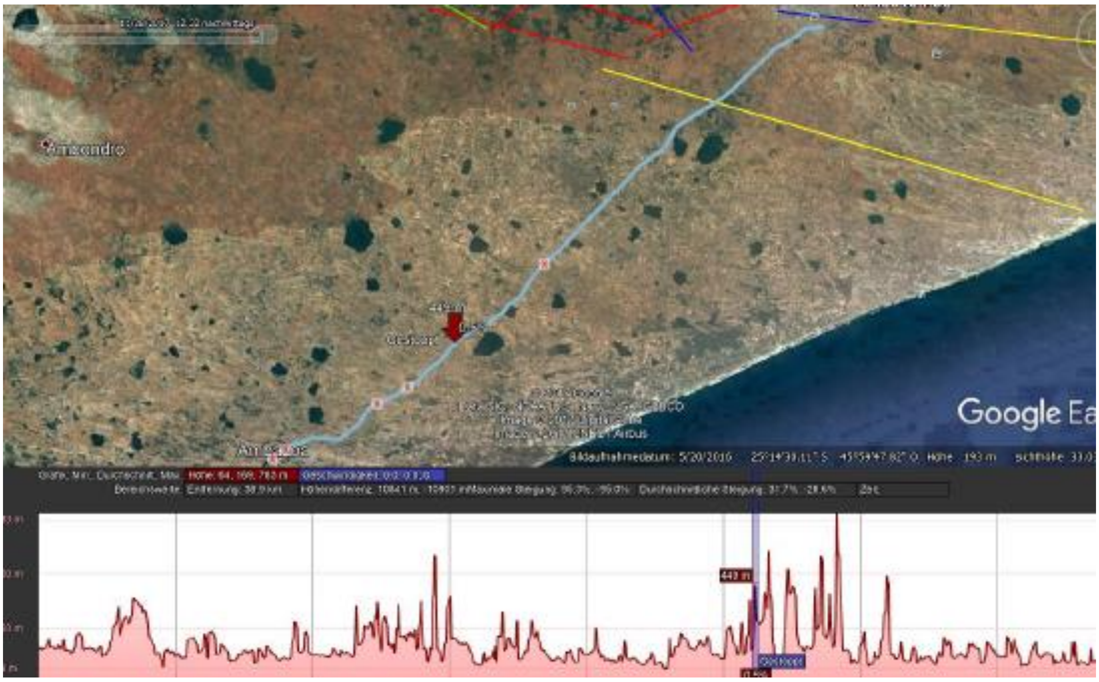
3.3.1. Summary

Location: Ambazoa, Androy, Madagascar

Grid Coord: 25° 18' 47.681"S 45° 53' 48.45"E

Formation: Sedimentary (*Sable Blanc and Sable Roux*)

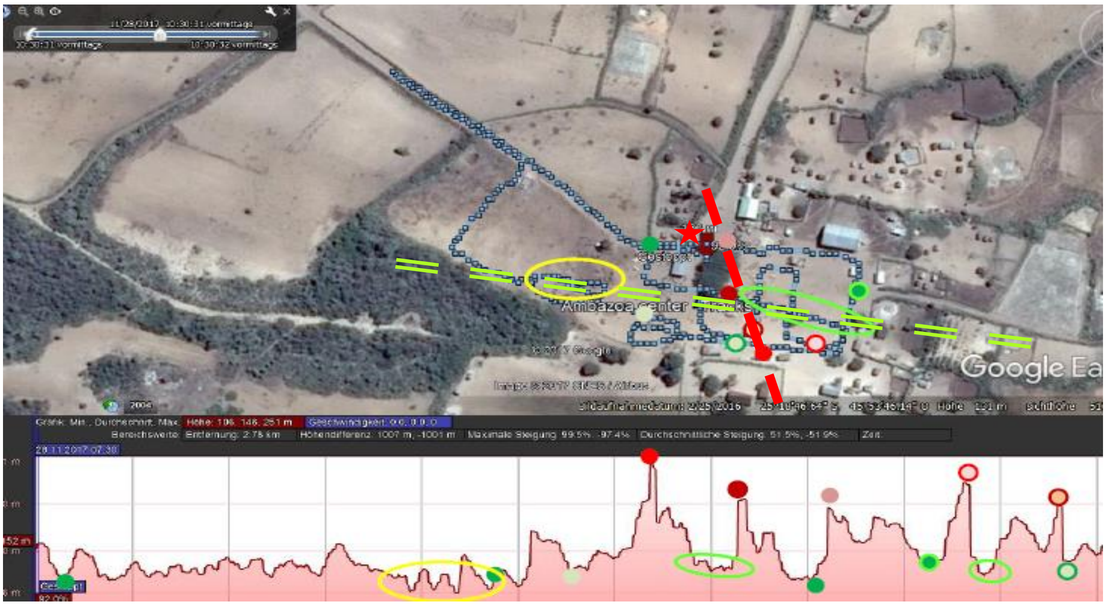
The area around Ambazoa was not covered by the lineament studies. However, it remains in the heart of the littoral zone which clearly demonstrates long E-W structures which, from ground inspection, appear to be hardened limestone structures, likely almost marble in many places in the crust, as reported in various reports. We drove from Ambovombe to Ambazoa, collecting radiometric data from the vehicle (below.)



A number of spikes with troughs on each side reflected these long structures, one of which is quite visible to the west of Ambazoa and ending at the town.

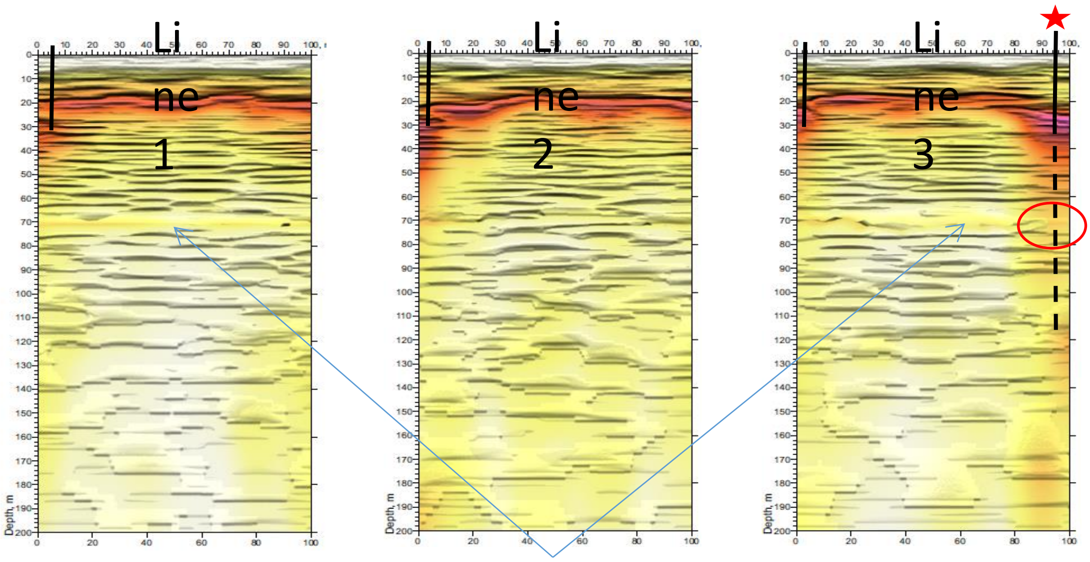
4.4.2 Radiometric Survey

Gamma surveys were conducted on foot, revealing a cross structure indicated by the red and green lines in the graphic below. There also were areas of interest in the field to the west but it seemd this may be used as a septic field, so focus was directed to what we nickname the “Town Square”.



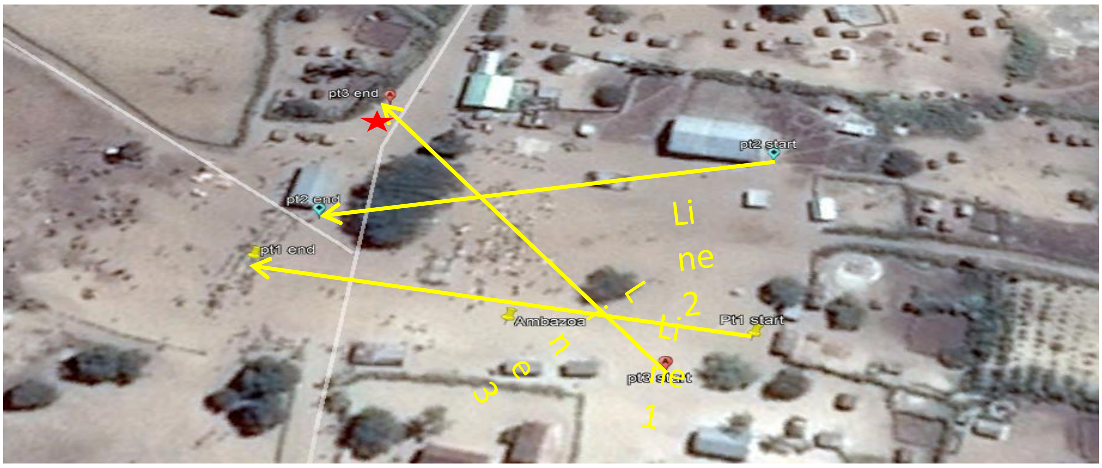
4.4.3 Passive Seismics

Three lines of passive seismic acoustic profiling were collected criss-crossing the Town Center. While not as dramatic as other surveys, a line of hard limestone is visible at 70 meters—but appearing fractured at the 95 meter mark of Line 3, clearly being fed from much deeper primary water sources:



Note very thick hard rock layer (probably marble) transition at 70 meters.

Below is a map of the 3 passive seismic lines collected at Ambazoa "Town Center":



4.4.4 *Observations*

While this site is not as dramatic as Crater Lake or Stone Mountain it nevertheless demonstrates the ability to rapidly survey a remote location and locate best prospect areas for so called perched aquifers. More intensive survey of the east side of Town Square and the two other zones of interest may reveal an even better prospect.

4.4.5 Recommendations

Drilling only 30-40 meters into the fracture zone at the 95 meter mark of Line 3 would provide an excellent test bore for this region. We could also make a wider survey following the structure to the east of the village.

5 CONCLUSION

The two exploration phases carried out allowed to highlight four sites presenting a potential for exploitable primary water upwelling. For this, the detailed study of the environmental context of the area, and particularly its geology, was the key to guide the mission and to pre-select the areas of interest, which then showed sites with the expected structures.

On some sites, the observation of volcanic morphologies never discussed until now constitutes a major discovery of this exploration. These deep structures induce the presence of deep fracked zones, interesting for the researched flow of primary water.

Four drill points are submitted in this report to UNICEF, of which a choice should be made (three points) before deciding on the continuation of the pilot project and starting the production phase. The implementation of three wells on three of the four proposed sites should represent a total of 350 linear meters drilled, but this may evolve in progress.

Note that other sites, not presented in this report and requiring some additional work, may also be selected.

The consortium formed by The Primary Water Technologies (PWT, USA), The Primary Water Institute (PWI, USA), Lanoé Forages (Madagascar), and BushProof (Madagascar) stays available to UNICEF for any assistance in site the selection of sites and preparation of the next phase of the pilot project.

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