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ENVIRONMENTAL IMPACTS DURING GEOTHERMAL DEVELOPMENT: SOME EXAMPLES FROM CENTRAL AMERICA

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ABSTRACT

The impacts of geothermal development projects are usually positive. However, without appropriate monitoring plans and mitigation actions firmly incorporated into the project planning process, there exists the potential for significant negative environmental impacts. We present five examples from Central America of environmental impacts associated with geothermal development activities. These brief case studies describe landslide hazards, waste brine disposal, hydrothermal explosions, and air quality issues. Improved Environmental Impact Assessments are needed to assist the developing nations of the region to judiciously address the environmental consequences associated with geothermal development.

INTRODUCTION

Geothermal power is a relatively benign source of energy compared to many other energy alternatives. There are, however, certain negative impacts that geothermal development can have if appropriate mitigation actions and monitoring efforts are not established. Many countries with excellent geothermal potential do not have laws, strong governmental agencies, financial resources, or trained personnel that can evaluate and regulate environmental issues, although guidelines are available (OLADE, 1993). As examples, we describe five abbreviated case studies of environmental impacts from geothermal fields or power plants in Central America. Two of the examples discussed resulted in loss of life. The three other cases presented are capable of negatively affecting the health and safety of the public.

It is worth noting that up to now, geothermal production impacts on natural phenomena, such as reduced flow or temperature of hot springs, are not important issues in most Central American countries. This is because ambient temperatures are high and because no large, influential industry depends on hot spring waters for resort or medicinal use. However, along with the resurgence of economic growth and social progress in the region, there is an increasing awareness and interest by the general public in the restoration of natural resources, and the improvement of the environment.

CATASTROPHIC LANDSLIDE AT ZUNIL I FIELD, GUATEMALA

On January 5, 1991, at 2230 hrs local time, a catastrophic landslide occurred in the Zunil I geothermal field in western Guatemala. The area, characterized by high relief and steep terrain, is located on the flanks of Cerro Quemado Volcano. Active faults permeate the geothermal field, which is well known for its abundant fumaroles and hydrothermally altered volcanic rocks. The slide engulfed an area that contained active fumaroles as well as the access road and drill pad for the production well ZCQ-4, one of six production wells already existing in the field (Fig. 1). At one time, the fumarole area ("*la calera*" or "lime-like") was the site of mercury prospecting (Flynn et al., 1991).

The landslide was multi-lobate in form and was nearly 800 m long, varying from 200 to 300 m in width. Thickness was estimated at three to ten meters. Twenty-three people who lived and farmed on the slopes below *la calera* were buried alive by this landslide.

Initial reports by the Associated Press and local newspapers attributed the slide to an explosion at geothermal well ZCQ-4, which was heavily damaged and buried by the slide. Statements issued by the Guatemalan government agency responsible for the Zunil geothermal project (INDE) and spokesmen for the geothermal industry refuted early press reports and blamed the cause of the landslide on natural causes.

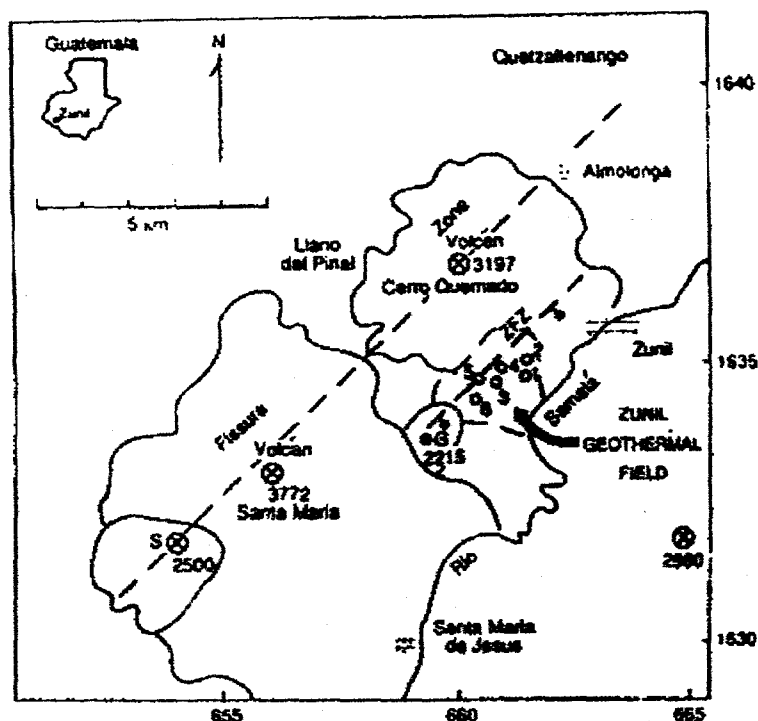


Fig. 1: Map of Zunil geothermal region, Guatemala showing major volcanoes and tectonic features; ZFZ=Zunil fault zone; S=Santiaguito Volcano; G=Cerro Galapago. Numbers by small circles are geothermal production wells ZCQ-1 to ZCQ-6. Elevations at volcano summits are in meters. Ball and bar on downthrown side of ZFZ. Landslide headwall occurs just west of well ZCQ-4 and ZFZ. Slide traveled SE toward the Río Samala (from Flynn et al., 1991).

Soon after the slide, the Guatemalan electric utility (INDE) conducted an investigation to determine the cause of the slide, to evaluate the damaged well, and to provide security measures for workers and residents in the Zunil geothermal field (INDE, 1991). INDE reported that the landslide was an unfortunate catastrophe caused by natural events. This evaluation was supported by several other published and unpublished reports (Barberi et al., 1991; Cordon y Merida, 1991a, 1991b; Schafer and Williams, 1991).

Although relatively heavy vegetation and colluvium masks much of the bedrock, the landslide exposed a major trace of the Zunil fault zone (ZFZ, Figs. 1 and 2) on either side of the headwall area. The fault juxtaposes weathered to slightly altered andesite/dacite flow and flow breccia on the NW (upthrown side) against severely altered and brecciated volcanic rocks on the SE. The main fault plane is sharply defined by gouge, breccia, open cracks, and color contrast. Weak fumarolic emissions, smelling of H_2S and visible from steam, discharge from open cracks along isolated locations on the main fault trace. Alteration consists mainly of kaolinite with minor Fe-oxides, silica minerals, and various sulfates formed by oxidation of acidic gases rising from the underlying geothermal system (reservoir temperature $\leq 300^\circ C$) and by oxidation of disseminated pyrite in the host rocks. Oxidation of sulfur forms natural sulfuric acid.

The landslide displayed a classic circular failure mode and had an estimated volume of $800,000 m^3$ (Flynn et al., 1991). The slide consisted of one main lobe of white- to green-colored, highly fluidized volcanic breccia that moved downslope rapidly as a mudflow. Two to four smaller subsidiary lobes, less fluidized than the first, followed the initial lobe. These landslide lobes damaged and buried the well ZCQ-4. A small crater roughly 15 m in diameter soon developed a few meters downslope of the well. The crater apparently formed when debris that had buried the damaged well were forcibly ejected by a mixture of hot water and

steam that escaped from the well. As the crater formed, a radial blanket of fine-grained mud up to several centimeters thick was deposited around the crater. It is likely that a post-slide blast was interpreted as an exploding geothermal well by some of the early observers.

A previous map portrayed the geology of the geothermal production area as a zone of down-faulted bedrock blocks SE of the ZFZ (Cordon y Merida, 1988). However, as early as 1989, the Geothermal Advisory Panel to INDE realized that the geothermal area was a potential zone of nested slide blocks with several coalescing arcuate headwall scarps and recommended that INDE re-evaluate the geology of the area with landslide hazards in mind. After, the slide occurred, the Zunil I geothermal field was re-evaluated by geoscientists experienced with landslide geology and it was found that large landslide masses occurred throughout the area, hiding bedrock and covering fault traces. The new hazard map was used to reassess placement of roads, well pads, and a future power plant. Within a year of the landslide failure, INDE successfully uncovered ZCQ-4 and rebuilt the wellhead so that it again became one of the production wells of the field. Fig. 2 is a photograph taken in January 1991 of the Zunil I landslide.

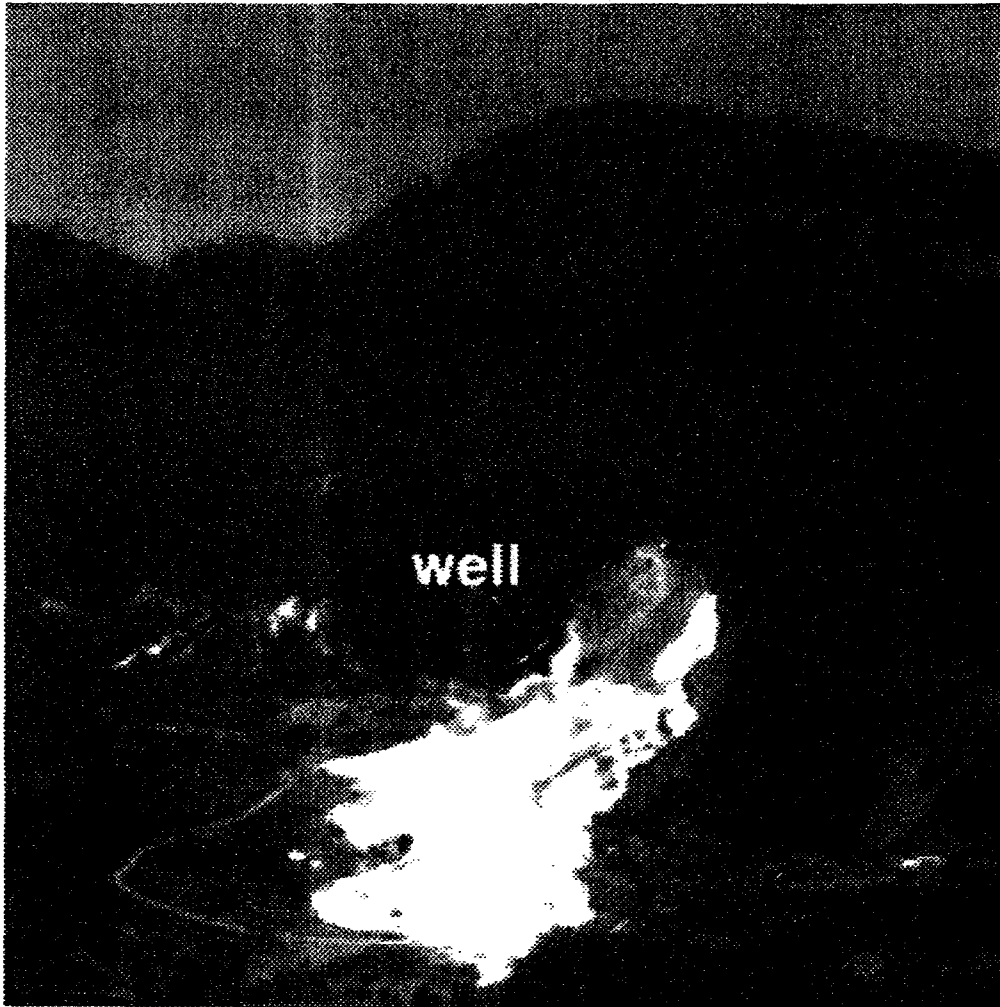


Fig. 2: Photo looking west at the catastrophic landslide that killed 23 people on January 5, 1991 at the Zunil I geothermal field, Guatemala. The area is heavily cultivated from terraced fields. Because of its fluidized character, many local inhabitants mistakenly thought the slide was a white lava flow. Note steam near headwall of slide from damaged well ZCQ-4.

SLIDE COMPLEX, BERLIN GEOTHERMAL FIELD, EL SALVADOR

El Salvador is a small country with impressive geothermal resources (Fig. 3). One of the most noticeable characteristics of the Berlin geothermal field is the steep topography and presence of a large landslide complex. Local zones of fumarolic activity and hydrothermal alteration occur in the complex. Several areas within the complex displaying past or present creep were shown to the authors during a visit in 1994. Of major concern, the most productive well in the field at that time (TR-2) was located at the base of an obvious headwall scarp near the top of the slide complex (Fig. 4). The ground surrounding the TR-2 was riddled with cracks (which grouting could not stabilize), the paved road just above the headwall scarp displayed arcuate subsidence cracks, and the casing of the well was leaking steam due to damage caused by creeping ground. Access roads, project headquarters, and the small binary power plant of the field were all located in the slide complex several hundred meters below TR-2.

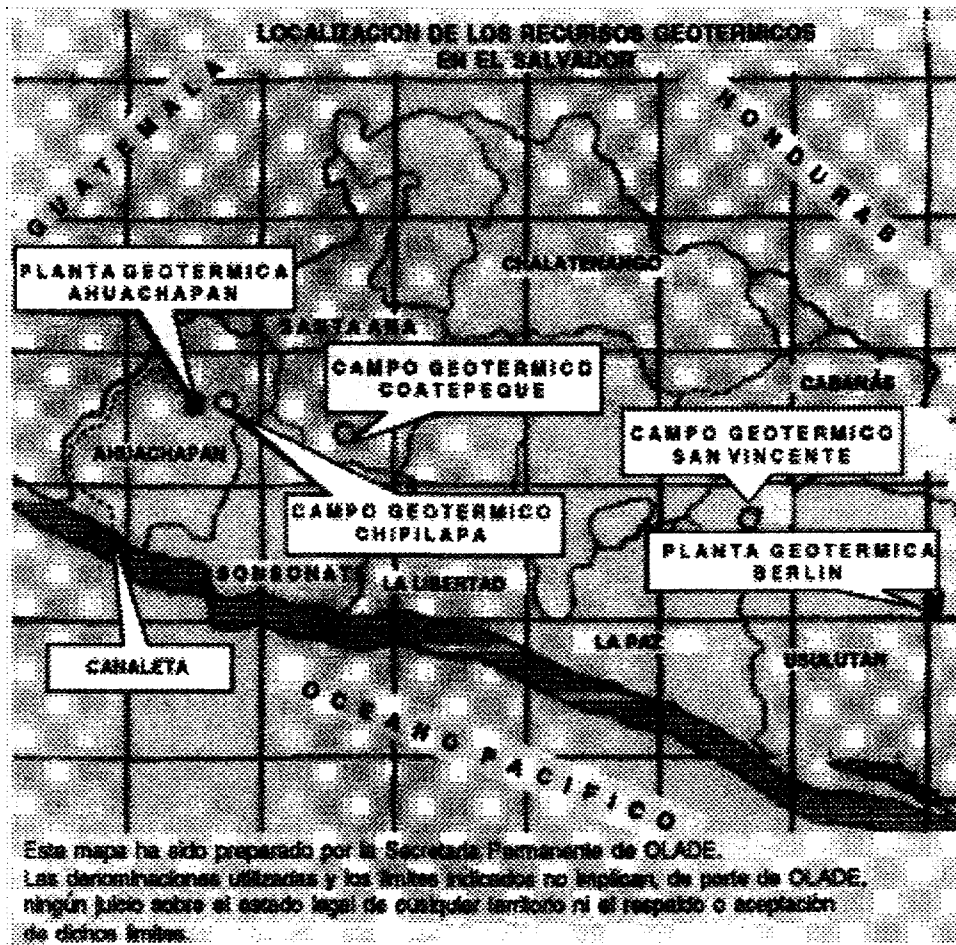


Fig. 3: Map of El Salvador showing locations of Berlin and Ahuachapán geothermal fields and the path of the "canaleta" from Ahuachapán to the ocean. (From OLADE, 1993)

The Zunil I catastrophe shows that it is not immediately obvious where and when slope failures will occur. A recommendation was given to El Salvadoran Electric Utility (CEL) that summarized the parallels between Zunil and Berlin and suggested that the CEL implement work to monitor the slides, re-evaluate the landslide hazard with respect to infrastructure, and to possibly abandon well TR-2 after redrilling of a replacement well(s) from stable ground (Goff, 1994).



Fig. 4: Photo of well TR-2 showing grouted slope, Berlin geothermal field, El Salvador. The grout did not prevent continued ground cracking and other "creep" phenomena in the landslide encompassing the well.

THE CANALETA, AHUACHAPÁN GEOTHERMAL FIELD, EL SALVADOR

The Ahuachapán geothermal field is one of the world's first liquid-dominated geothermal reservoirs to produce electric power and is a geothermal success story of the 1960's and 1970's. Because initial efforts to drill and manage reinjection wells were unsuccessful, an 82-km-long canal ("canaleta") was constructed to remove geothermal brine from the power plant and dump it in the ocean. The canal traverses many kilometers of rugged terrain along its journey to the ocean and has been used since 1978. It generally carries 0.35 m³/s of waste brine. When examined in summer 1994, no waste brine was reaching the ocean because of major leaks along the canal. The largest leak occurred only 2 to 3 km from the Ahuachapán power plant (Fig. 5) and allowed geothermal brine to cascade down a steep slope into the Río San Rafael, which drains into the Río Paz (the local boarder between Guatemala and El Salvador). Analysis of the fluid cascading into the Río San Rafael (45°C) showed that it far exceeded U.S. Environmental Protection Agency (EPA) limits for As, B, and Cl (about 9, 110, and 7620 ppm, respectively). For example, As levels in the waste brine were about 175 times higher than EPA limits and the waste would need to be diluted with about 225,000 tons/hr of essentially pure water to bring concentration levels down to EPA limits (Goff, 1994).

Since local residents wash their clothes and domestic animals drink in the Río San Rafael, the leaking canaleta is a rather toxic example of an environmental hazard. In addition, the canal is so long that it is impossible to patrol; thus, many sections of the canal roof have been removed by nearby inhabitants to construct buildings. Animals and people have fallen into the hot waste brine and have died by drowning or from burns. Future drilling and wise use of reinjection wells is the only solution that will permanently remove this hazard from the local scene.

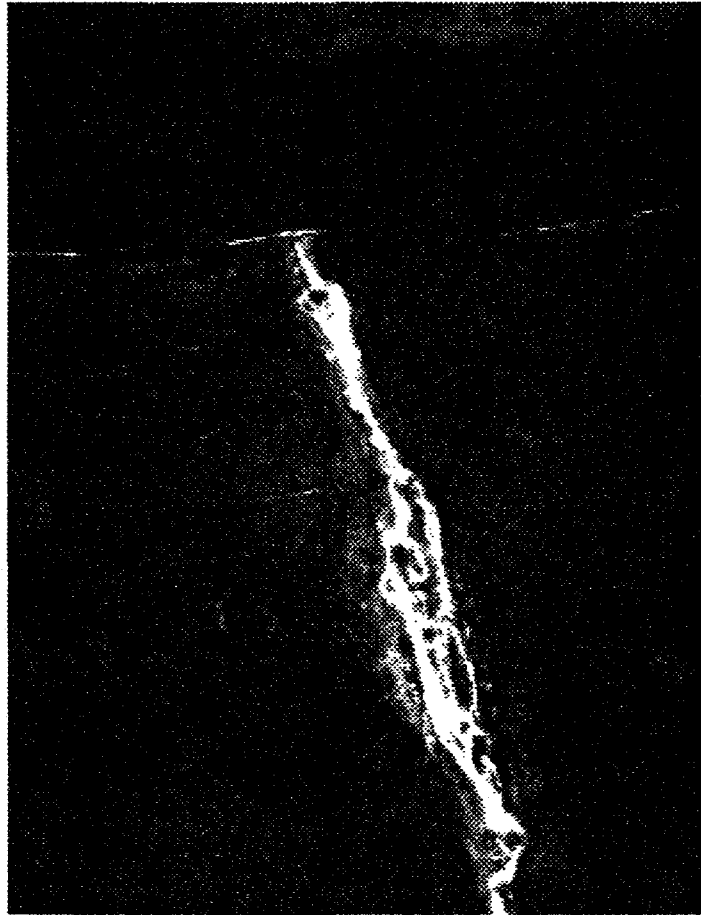


Fig. 5: Photo of waste geothermal fluid leaking from the canaletta near Ahuachapán geothermal field, summer 1994. This fluid contained 9 ppm As as well as high concentrations of other constituents.

PHREATIC EXPLOSIONS IN THE AHUACHAPÁN AREA

Hydrothermal (phreatic) explosions are relatively common phenomena in and near fumarole areas of high-temperature geothermal systems. At 0300 hrs on October 13, 1990, a tragic hydrothermal explosion occurred at the fumarole area named Agua Shuca which killed 25 people who lived in a small village near the margin of the boiling mud pools (Bruno et al., 1992). The site (Fig. 6) is located on the SW side of the Ahuachapán geothermal field. A similar explosion had occurred at Agua Shuca probably in 1868 and at an earlier but unknown time at La Labor fumarole in the NW part of the geothermal field. The latter explosion is inferred by the presence of a 200-m-diameter crater that is 20 to 25 m deep. The Agua Shuca eruption of 1990 enlarged the pre-existing 25-m-diameter crater to one that was over 40 m in diameter and over 5 m deep. The volume of ejected material was 1600 m³. People in the surrounding houses died or suffered injuries in their sleep from a "violent rainfall of boiling water, mud, altered soil, and rocks . . ." (Bruno et al., 1992).

Although several explanations for the explosion are evaluated by Bruno et al. (1992), no firm conclusions were reached. All inhabitants were removed from the immediate margins of the fumarole areas and the existing buildings were destroyed. A monitoring program that incorporates chemical, temperature, heat flow, shallow seismic, and survey measurements of the fumarole areas might forecast future explosions.



Fig. 6: Photo of the Agua Shuca explosion crater, Ahuachapán area. The explosion of this feature about four years earlier killed and injured many people who lived on its edge. In the summer of 1994, the crater was a muddy, boiling cauldron.

AIR QUALITY AT THE AHUACHAPÁN POWER PLANT

Evaluation of noncondensable gas data from the Ahuachapán geothermal field shows that H_2S is the only gas constituent in recovery operations that seriously impacts air quality (Dennis et al., 1990). During a tour of the Ahuachapán site on June 28, 1994, the odor of H_2S was strong both inside and outside the power plant. At that time, a small ejector pipe discharged noncondensable gases 1 to 2 m above the roof of the power plant and roughly 15 m above ground level (Fig. 7). The power plant has a small chemistry laboratory used to monitor water quality in different areas of plant operations, but in 1994 there was no in-house capability to measure gas compositions nor was there on-site portable H_2S measuring equipment.

An evaluation of the H_2S problem at the power plant by ELC (1994) used fluid production and composition data and a meteorological code to calculate probable air quality without heed to real air quality measurements. Among other conclusions, ELC stated that in the worst case situation, H_2S concentrations in air will exceed "strict" American air quality limits but will never exceed Italian limits. The U.S. Occupational Safety and Health (OSHA) ceiling level for H_2S is 14 mg/m^3 but an ambient air quality standard of 0.042 mg/m^3 is used in California (Goff, 1994).

Because H_2S is an insidious poisonous gas, a credible accident scenario should be developed for the power plant. Several kinds of reliable monitoring equipment are available that have reasonable cost ($\leq \$10,000$ depending on type of device). When appropriate data are collected, a suitable abatement scheme can be planned. Occupational health standards of H_2S levels in air vary from country to country but to prevent adverse health problems, levels should be low enough to protect the very young, the very old, and the infirm.

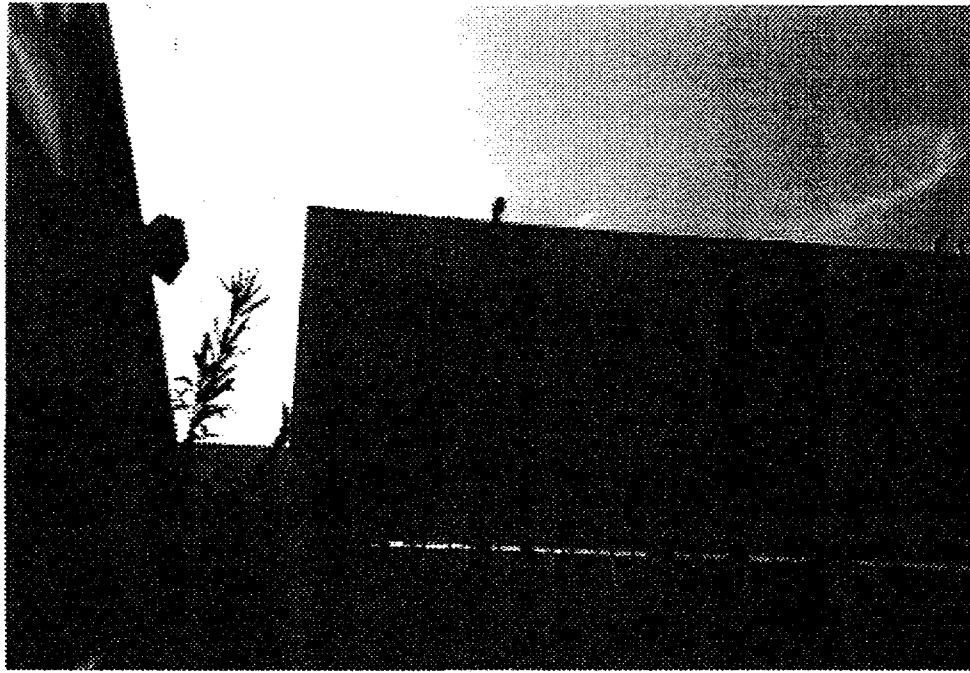


Fig. 7: Stack at Ahuachapán power plant emitting non-condensable gases including lethal H_2S , summer 1994.

RECOMMENDATIONS AND CONCLUSIONS

For the most part, the impacts of geothermal development projects are positive. There are however, certain negative impacts that these undertakings could have if there are not appropriate mitigation actions and monitoring plans in place. The developing nations of Central America need to be equipped to address environmental issues in a systematic manner. This will require significant improvement to the Environmental Impact Assessments (EIAs) prepared as part of development project packages. Analytic, not encyclopedic EIAs must be the norm. The purpose of the EIA should not be to generate paperwork, but to foster excellent response. The process should be intended to help public officials make decisions that are based on an understanding of environmental consequences and take proper actions. Often the EIA is carried out fairly late in the project planning and the EIA process mostly ends after the decision to proceed with the project has been taken. The EIA process can only be effective if there is regular monitoring during project implementation and operation so that appropriate environmental impacts can be identified and measured. The EIAs need to concentrate on impacts most closely associated with energy sector development. Air quality, water resources and quality, geologic factors, and socioeconomic issues will consistently be the most important factors. In addition, the positive impacts that energy development projects could have on ecological issues should also be stressed. This could include a reforestation, revegetation program, for example. Not necessarily costly, such a plan will add to the overall improvement of environmental quality in the region. And, with the increasing awareness and interest by the general public in environmental issues, meaningful public participation should also be a part of a geothermal development program.

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