IGA NEWS

Newsletter of the International Geothermal Association

Special Number on the Anniversary of the IGA

CONTENTS

INTRODUCTION

Message from the President

Since early hominids have inhabited the earth, there is evidence that they have used geothermal heat and the products of volcanic activity to enhance and enrich their lives. This special issue of the IGA News describes the history of geothermal energy from the beginning of the solar system to the first power plants, putting in context the geothermal energy that today continues to give us clean renewable heat and power. My thanks to Dr Raffaele Cataldi and Dr Mario Cesar Suárez for this article, which is based on presentation at the 2015 World Geothermal Congress 25th Anniversary celebration of the founding of the IGA. I hope you enjoy this special edition of the IGA News.

Best regards,

Juliet Newson, President
International Geothermal Association

Prologue from the Editor

At the 59th meeting of the IGA's BoD, held in Manila on March 2014, three of its members, i.e., Bruno Della Vedova, Luis C.A. Gutiérrez-Negrín and Paolo Romagnoli, proposed to celebrate the upcoming 25th anniversary of Association. It was created on 5 May 1989, when the first official meeting of the Board took place in Castelnuovo, Italy, after the IGA's inaugural meeting.

After discussing it with Raffaele Cataldi, one of the IGA founders, Bruno, Luis and Paolo proposed some ideas on how to celebrate the event and submitted them to the BoD. After several considerations, the Board approved motion 59-15 that said: "The Board of Directors appoints an ad hoc Organization Committee which shall ensure that the 25th anniversary celebrations are incorporated into the WGC (World Geothermal Congress) 2015. Eduardo Iglesias is appointed to be the Chairman of the ad-hoc 25th Anniversary Organization Committee and Raffaele Cataldi one of the members."

Due to the resignation of Eduardo Iglesias as chair of the ad-hoc Committee, during its 60th meeting held in Strasbourg, France, in October 2014, the Board appointed Luis C.A. Gutiérrez-Negrín as the new Chair of the Committee, and approved funds to cover the cost of a special session at the WGC2015. Also, it was decided that the other members of such committee were going to be Raffaele Cataldi, Bruno Della Vedova, Eduardo Iglesias, John Lund, Juliet Newson and Arni Ragnarsson.

The special session was developed as a side event of the WGC2015. It was held on April 23, 2015, from 5:20 to

8:00 pm in Room 218 of the Melbourne Convention Center and was chaired by Luis C.A. Gutiérrez-Negrín. The final program was as follows:

- Welcome and introduction - Luis C.A. Gutiérrez-Negrín

- Our geothermal legacy: A historic overview - Mario C. Suárez-Arriaga

- Origin, foundation and activities of the IGA in its first 25 years - Arni Rágnarsson

- Awarding diplomas of recognition to some promoters-founders and outstanding members of IGA during the first 25 years of IGA*, by Juliet Newson

- Towards the IGA's fifties, by Juliet Newson

- Reception

**The awarded promoters-founders were: Héctor Alonso-Espinosa (Mexico), Anthony Amor (UK), Raffaele Cataldi (Italy), James Combs (USA), Einar T. Elíasson (Iceland), Robert Greider (USA), James Koenig (USA), and William Anthony John (Tony) Mahon (New Zealand, in memoriam). The awarded outstanding IGA members were: Enrico Barbier (Italy), Derek Freeston (New Zealand, in memoriam), Ingvar B. Fridleiffson (Iceland), John Garnish (UK), Eduardo Iglesias (Mexico), and John W. Lund (USA).*

The special session was attended by approximately 150 persons. Given the interest in the historic presentations given by Mario César Suárez-Arriaga and Arni Rágnarsson, I asked the authors to prepare notes summarizing their talks for future publication. In this special issue of IGA News, you will find the first of those notes. It was written by Raffaele Cataldi and Mario César Suárez Arriaga, and proofread by Susan Hodgson. I included also the Cataldi's address in that event. I hope you will find it interesting and enjoyable.

Luis C.A. Gutiérrez-Negrín
Editor

OUR GEOTHERMAL LEGACY: A HISTORIC OVERVIEW

Raffaele Cataldi[1] and Mario César Suárez Arriaga[2]

[1]Italian Geothermal Union, [2]Mexican Geothermal Association
raf.cat04@libero.it, mcsa50@gmail.com

Preface

Not knowing what happened before us is like forever remaining children (CICERO)

To present ***A Legacy for All***, a volume published in 1980 by UNESCO (United Nations Education, Scientific and Cultural Organization) to illustrate some of the most significant historical, cultural and natural sites of the world, whose aim is to preserve their memory and foster their knowledge, the UNESCO Director General of the time, wrote:

"Contemporary society accentuates the break with the Past. There is even a tendency for a certain idea of progress to deny various fundamental human values, and to dissociate culture from people's material existence; and one of the consequences of this is to reduce the work of the Past to mere curiosity of little relevance to everyday reality.

"With the realization of this rift, people began to appreciate the real need they have for their artistic, literary and architectural heritage, and to perceive any encroachment on it as a drain on their own life-blood. Gradually, therefore, there grewup a compelling need for a cultural identity, hitherto accepted as a matter of course, but now seen as an imperilled achievement which each of us must at times fight to defend, safeguard and enrich." (Amadou-Mahtar M'bow, Unesco General Director, 1980).

In light of the above quoted aphorism by Cicero, as well as the thoughtful, warning remarks made by Dr. M'Bow regarding the 'cultural break' that is forming between modern society and its past, this paper aims to offer the geothermal community a summary review, addressing a number of the main aspects with no pretention to exhaustiveness, of the millennial non-technical but cultural history of geothermal energy, together with the impact that the Earth's heat and its products have had on the development of humankind over hundreds of centuries.

With this aim, we hope to provide a small but thorough contribution to prevent the above mentioned 'break' from also affecting our great geothermal heritage.

Keywords: History of geothermal energy, Earth's heat, thermal balneology, geothermal by-products, impact of terrestrial heat on the development of humankind.

Abstract

This is a short history of the long relationship between humankind and geothermal phenomena that aims to represent a general outline of the common points of contact between different human societies and the thermal Earth.

During millions of years, many areas in our planet were very rich in active geothermal manifestations:

earthquakes, volcanoes, thermal springs, fumaroles, hot water and mud pools, hydrothermal deposits and others. In these sectors, a tight and sometimes profound relationship emerged very early between humans and geothermal phenomena.

From their darkest past, prehistoric people used obsidian, basalt, volcanic and other igneous rocks, silex and flint to manufacture tools and weapons. Some of their descendants knew how to use igneous rocks to build homes, how to cook with steam at fumaroles or on naturally hot rocks, and also how to use thermal waters and mud in body hygiene, in curing wounds and in tempering arrows and lances for hunting, attack/defense actions, or war.

Washing and bathing from thermo mineral springs, irrigation and therapeutic or recreational applications occurred, too, at different times in many ancient cultures of all continents.

Bathing in geothermal waters was an essential custom of life in many ancient, advanced civilizations. There is a long line of bathing cultures, starting with prototypes in the 'old' world of Greeks, Etruscans, Romans, Turks, Chinese, Japanese, Arabs, North American, Mesoamerican and South American natives, Maoris, Koreans and Indonesians.

Spas (*Salus Per Aquis*, i.e. health through waters) that harnessed mineral-rich thermal waters were used to cure physical diseases relating to rheumatism, sciatica, gynecology, gout, psoriasis and other skin sicknesses, as well as psychiatric problems and for providing a means of relaxation.

Geothermal energy also played an important role in human occupancy of some territories, as volcanic activity often determined alternate emigration immigration fluctuations by the populations in the affected zones. At the same time, the economic, social, agricultural and artisan development of the people living in volcanic sites were influenced by volcanic eruptions.

Mythical, cosmogonical and religious interpretations of geothermal phenomena started also to form in very early times (probably Neolithic and definitely proto-historic times) in many geothermal areas of the world, reflecting a profound respect toward terrestrial heat and its external manifestations. Moreover, many ancient cultures throughout the world developed close by recent volcanic areas and interacted with geothermal events.

In recent times, the descendants of those cultures have been developing and using spas and widely implementing space heating/cooling and agricultural programs based on the uses of the Earth's heat, and others are commercializing its by-products or building geothermal greenhouses and power plants.

All of the above indicates the prehistoric antiquity of the human cognitive process regarding geothermal phenomena and the practical uses of the Earth's heat and its by-products. It is evidence of the substantial continuity in time of such process and use for at least thousands of centuries. Altogether they form Our Geothermal Heritage.

1. Stellar Origin of our Thermal Planet

In a still mysterious way, our Universe was born approximately 15 billion years ago from a great explosion. According to one of the theories on the formation of the Universe, which for logical and inductive reasons we are prone to consider more plausible than others, space dilated and countless galaxies formed, each containing billions of stars. The spiral form of many visible galaxies (Fig 1.) makes evident that their movements are controlled by rotational and centrifugal forces featured by angular velocities and accelerations, which likely explain why both the galaxies and the Universe are expanding. Rotation seems, in fact, to be the most important type of movement, perhaps the only real one, existing in our Universe.

In one of those galaxies the Sun and the Earth were born 5 billion years ago (Fig. 1). The same mechanism of centrifugal rotation seemingly explains the original cause of the expansion of our solar system. For example, the moon is moving away from the Earth some centimeters each year, and the orbits of all planets are not closed but open, with distances from the Sun increasing by a few centimeters per year.

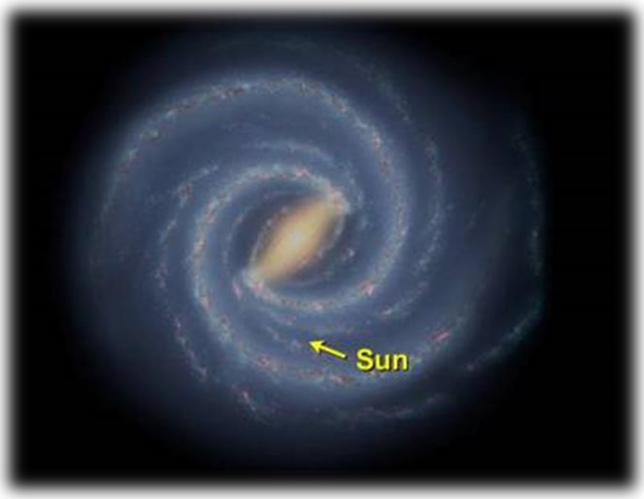


Fig. 1*. Milky Way Galaxy's Spiral Structure (Image credit: NASA/JPL-Caltech. Taken from: http://www.reasons.org/articles/no-ordinary-galaxy)*

The Sun's immense corona was the energy source that fueled our corner of Universe, but the Earth was also a gigantic furnace. Our planet was initially so hot that nothing could form and exist on it (Fig. 2). There was no water on the Earth's surface, which would form later as a result of continuous volcanic eruptions and fill in rock fractures. Dense clouds of methane, ammonia and carbon dioxide covered the Earth for millions of years.

Fig. 2*. Hot soil covered by lava after a volcanic eruption (Photo: Reuters. Taken from http://www.cbsnews.com/news/lava-flow-stalls-still-could-wipe-out-hawaii-town/).*

Slowly the Earth cooled, but it was a desert with no animals, no plants, no life and no blue sky. The Earth's atmosphere contained no oxygen. The original poisonous gas envelope was cooled down and a new atmosphere developed, dominated by hydrogen (H_2) and carbon dioxide (CO_2). These atoms and molecules eventually rearranged themselves and joined together to form water vapor, carbon and oxygen ($H_2O + C + O_2$). Some water drops then formed and the first rain occurred soon after. As the planet surface continued to cool with progressive intensity, the vapor turned to rain. For millions of years it rained and the boiling hot water that poured down started to form the oceans. Water was held to the Earth's surface as a solid, liquid and gas, and crept into each crack to fill up every empty space.

Almost four billion years ago life began in the water, as geologic conditions on the Earth's surface were very difficult; therefore, life more readily began in the dark depths of the primordial oceans where sulfurous fluids sprang up along preferential directions, fueled by the Earth's magma (Fig. 3). Bacteria were almost certainly the first living beings that drew their energy from a chemosynthetic reaction due to the conversion of CO_2 + nutrients into organic matter, while H_2S provided the energy source. Oxygen was still a rare gas and a danger to living beings; nonetheless, expelled into the air, it slowly altered the atmosphere's character and properties. As a consequence, the present process of life began, with all species evolving gradually thanks to the combined action of chemosynthetic bacteria, carbon, heat and water. For recent information about these aspects, the interested reader may wish to consult the paper on the website about eukaryotes cells, by Zimmer (2015).

The succession of geological Eras, with an example of the evolution in time of some animal species is shown in Figure 4. Evolution, however, did not proceed smoothly; in fact, several massive extinctions of species occurred at various geological times during the Phanerozoic Eon, from 540 million years (My) ago to present, mostly due to climate changes.

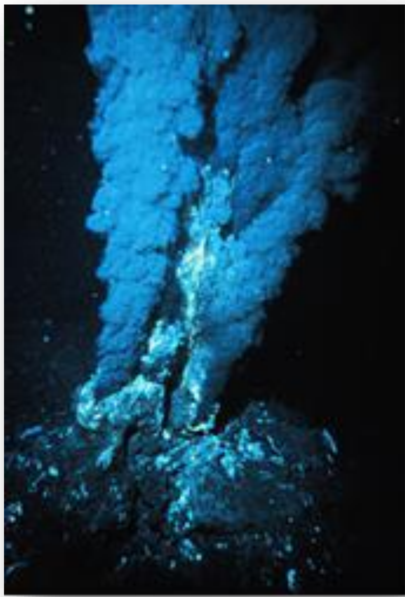
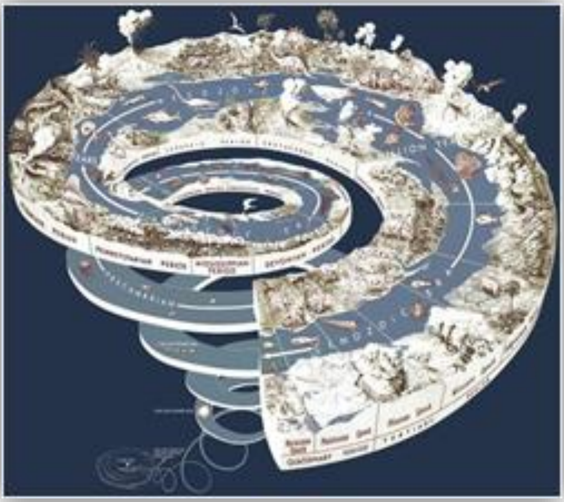


Fig. 3*. A submarine hydrothermal chimney with sulfurous springs (Image: Fuente hidrotermal, https://es.wikipedia.org/w/index.php?title=Fuente_hidrotermal&oldid=88971047, consultado por última vez agosto 2, 2016).*

Figure 5 shows eight extinction peaks above 50% of the then-living species: three peaks between 510 and 460 My, one peak some 400 My, two peaks around 250 My, one peak about 200 My, and the last peak some 60 My ago. In general, it is estimated that about 99% of all species that ever lived on Earth at different times disappeared because of changes in space, habitat and other reasons. In particular, it is thought that about 80% of the existing species died off between 540 and 250 million years ago.

Concerning our species, humanity has always lived on a geothermal planet. With their beauty and destructive powers, volcanoes have often inspired people's imaginations and influenced their beliefs and styles of life. Moreover, extraordinary civilizations emerged at the shores of big or important rivers (e.g. Nile, Euphrates, Tigris, Ganges, Yangtze, Yodo/Uji-gawa, Danube, Thames, Seine, Tiber and others) in whose hydrogeological basins one or more volcanic systems and high-temperature geothermal areas are found; however, this was not the case in the Americas, especially of the Amazon and Mississippi basins. There is evidence, in fact, that the development of civilizations in many areas of the world, especially in Mesoamerica, has been strongly conditioned by the occurrence of geothermal phenomena; in particular, volcanic activity determining alternate emigration immigration fluctuations by many old and recent populations in the affected zones.



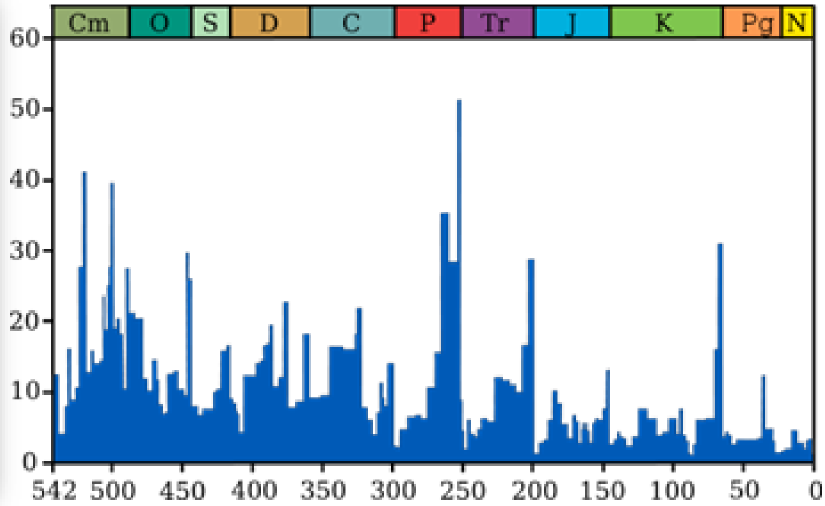


Fig. 4 *(left). Fig. 4: A creative representation of geological time [Image: Geologic time scale, https://en.wikipedia.org/w/index.php?title=Geologic_time_scale&oldid=731466156 (last visited Aug. 2, 2016)].*

Fig. 5 *(right). Marine extinction intensity during the Phanerozoic Eon (horizontal axis in million years) [Image: Extinction event, https://en.wikipedia.org/w/index.php?title=Extinction_event&oldid=729550848 (last visited Aug. 2, 2016)].*

2. Origin and Evolution of Humankind in Prehistory

Even though *Genus Homo* is one of the most recent living being that appeared on Earth, its origin dates back to some 5 million years ago. From that period onward, humankind's evolution progressed quickly with the appearance of the hominids first, followed by the humans proper, until reaching the present sub-species *Homo sapiens sapiens*. The evolutionary path is a complicated, still open and much debated scientific issue, with arguments that, on one hand are mostly ignored by us, and on the other hand fall beyond the scope of this paper. Schematically speaking, however, the succession of human species and sub-species, and their lapse of existence as known until a couple of years ago, are:

- 5 My ago: *Praeanthropus*;
- 4 - 2.5 My ago: *Australopithecus afarensis / anamensis / others*;
- 2.5 - 0.35 My ago: *Homo habilis / Homo ergaster / Homo erectus / Homo sapiens + Homo neanderthalensis / Homo sapiens sapiens*.

And *Homo naledi*, where? Discussions and determination of age on its find (discovered in 2013 in the Rising Star cave system near Johannesburg in South Africa) are still underway.

The evolution above seemingly developed during, and in association with, massive migrations of people along the routes: Eastern Africa, Mediterranean and other European areas, Middle East and nearby areas, India, China and SE Asia, Southern Pacific islands, Australia, NE Asia, Alaska, North America, Central and South America. Migrations occurred in different waves overland starting likely from 1.5-2 My ago and are documented by many archaeological finds for the last 200,000 years (Fig. 6); however, the scholars in this field do not exclude that, starting from the Upper Paleolithic, migration flows also may have occurred by sailing along the Northern Atlantic and Northern Pacific coasts. At any rate, the prehistoric migration flows continued in different waves until Neolithic times (*Encyclopaedia Britannica*, 1999).

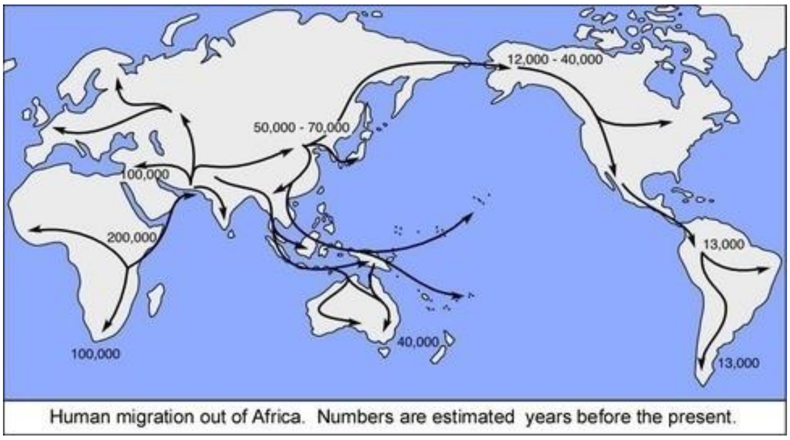


Fig. 6*. Migration flows of prehistoric and ancient people in the last 200,000 years (Image taken from: https://www.quora.com/Did-humans-kill-off-megafauna).*

It is widely thought that the initial area of departure corresponds to the Great Rift Valley in Africa, where our proto-human ancestors and the cradle of humanity proper are located. Here, in fact, hundreds of archaeological sites with buried proto-human and human remains, together with stone utensils and tools, have been found, dating from over 3.6 to 0.4 My ago. Such sites are mostly located on plains and on the shores of the lacustrine basins of the region, including Turkana, Tanganika, Malawi, Victoria, and others. However in relation to what we will discuss later, we deem that the most important archaeological find is represented by the footprints on fresh volcanic ashes left by a small family group of *Australopithecus afarensis* walking in an erect position (Fig. 7).

***Fig. 7**. Footprints left by hominids on volcanic ashes, found at Laetoli, Tanzania, and dated 3.6 My ago (After Hay and Leakey, 1982).*

The origin of humankind in the Americas does not introduce any epistemological problem. In fact, even though some have speculated recently (Perlman, 1998) that human arrival in the 'new' world may have occurred 250,000 years ago, no one has ever found in this continent bones from predecessors of *Homo sapiens*, as in Africa, Europe, Asia and the southeastern Pacific. It is, therefore, accepted that the proto Americans came from Asia between 50,000-23,000 years ago, and that they passed through the Bering Strait with initial immigrations likely to have departed from the shores of the river Amur in Siberia and from the southern zones of Central Russia (Ruiz, 1987; Sodi, 1992). The first passages probably occurred during the Wisconsinan glaciation (100,000-30,000 years ago): i.e. a period that agrees with the oldest human fossils discovered in America (Carmona, 1993). Nonetheless it cannot be excluded that some migratory flows may have happened since the Upper Paleolithic also along oceanic routes.

The Mongoloid immigration of the Olmecas and Mayan ancestors likely occurred after the second glacial period of the region, astride the Bering Strait, around the year 12,500 B.C. at the end of the Woodfordian interglacial period. The first contacts that these proto American Homo sapiens had with the Earth's heat probably happened soon after this migratory wave as the nomads passed through the northern portion of the Ring of Fire between the North American and Pacific plates.

While emigrating southward, the new populations reached the Cascade Range and found many active geothermal manifestations there; subsequently, in their slow expansion into the surrounding territories, they discovered first the imposing manifestations of what is today known as Yellowstone National Park and arrived later in the area of today's The Geysers geothermal field. In later times, some ancestral nomads arrived at the present-day Cerro Prieto geothermal field in northern Mexico and at other geothermal areas of the Colorado River lowlands, located near the Mexican-USA border. Later still, those archaic groups spread slowly towards central and southern Mexico, and then toward Mesoamerica and South America (Fig. 6), seeking fertile soils and mild climates (Suárez et al., 1999).

3. The 'Year Zero of Geothermics'

3.1. Initial Contacts of Humans with Terrestrial Heat

The first contacts that hominids made with the Earth's heat go back to prehistoric times, but the period and the locality in which such contacts happened is ignored. Several authors, including these writers, inferred that they probably occurred in one of the many active geothermal areas of the Great Rift Valley in Eastern Africa, and hypothesized that they might be traced back to the early Paleolithic, more than 1 My ago (Burgassi et al., 1992; Cataldi et al., 1999; Lund, 1999). However, based on present information, no one has been able to prove where and when the humankind-geothermal energy rapport started to form and take root in a systematic manner. Cataldi (1992, 1993, 1999) in particular, speculated that similar rapports may have formed (still in prehistoric times, but later compared to the period noted above) in different important geothermal areas on Earth, independently from each other, so that each rapport would likely be site-specific, characterized by peculiar connotations depending on local situations and the resulting experiences of the emigrant populations.

Regardless of the general consideration made above, however, the first observation by humans of a volcanic eruption may have happened in a locality of the African Rift Valley similar to that of Laetoli, a village in the Ngorongoro National Park of Tanzania. Remaining on volcanic ashes, here are the footprints left by a small family group of *Australopithecus afarensis* walking in an erect position (Fig. 7). They were found by Hay and Leakey in 1976 (Hay and Leakey, 1982; Salza, 1990). Those ashes were erupted about 3.6 My ago from the now quiescent Sadiman structure of the Ngorongoro volcanic system, where a lot of active manifestations formed in prehistoric times and still can be seen today.

On the other hand, many similar areas of recent volcanism and active geothermal manifestations exist in the East African Rift Valley. It is thus probable that other ancient forefathers of ours in that region had observed occasionally geothermal phenomena; therefore, they could have started to interact with those phenomena in epochs well before the Lower Paleolithic (2.5 My ago approximately).

At any rate, whatever the beginning of the interaction may have been, and regardless of the area in Eastern Africa where it first happened, a very long period of fertile contacts started from that moment onwards between our ancient ancestors and geothermal energy; a period which Cataldi (1992) defined as the 'Year Zero of Geothermics'. Since then, much has occurred and contributed to building humankind's rapport with the Earth's heat, starting from the probable area(s) of origin in the African Great Rift Valley.

Lund (1999) reports that human fossil remains of *Homo habilis* (2.5 My) were found on the shores of Lake Turkana in northern Kenya, Tanzania, and in other East African countries, together with many tools dated about 2 My made from volcanic rocks, like hammer stones, cobbles and choppers. Moreover, hundreds of human remains of *Homo erectus* (1.6 My) and *Homo sapiens* (0.6 My) were also found in the same areas as above, as well as in other areas with active volcanoes and hydrothermal manifestations in Tanzania, Kenya, Uganda, Ethiopia and Eritrea. This attests not only to the continental dissemination, but also to the continuity for at least three million years in Eastern Africa of the human-geothermal energy rapport.

Following the repeated migratory waves that began likely 1.5-2 My ago, as mentioned in the previous chapter, contacts of colonizing populations with geothermal phenomena in regions with active volcanism and other external manifestations of the Earth's heat led to the gradual formation, also in these new areas, of a tight rapport between local people and geothermal energy. This happened, in particular, during the whole of the Paleolithic and early Neolithic times in many places of the Mediterranean basin, Jordan Valley and other Middle East areas, the Carpathian region, India, Indonesia, New Zealand, the Philippines, China, Japan, northeastern Russia, western America, Mexico-Mesoamerica and the Andean region (Cataldi et al., 1999).

3.2. Early and prehistoric uses of the Earth's heat and its by-products

From the remote past, prehistoric people used intrusive and volcanic rocks, obsidian, basalt, flint, diabase, serpentine and other hard products of terrestrial heat to manufacture weapons and tools (Fig. 8).

***Fig. 8**. Weapons and tools made from volcanic rocks: silex, obsidian, flint and basalt (photo by R. Cataldi, from his collection)*

Moreover, archaeological finds, tales, legends and popular customs with deep roots in proto-historic epochs attest to the use of thermal waters and mud for body hygiene, curing wounds, and tempering arrows and lances for hunting and war (Suárez and Cataldi, 1993). In fact, much documented evidence (reported by Cataldi et al., 1999) show that in the territories of the African Rift Valley, Greece, Italy, France, Macedonia, Romania, Hungary, Poland, Turkey, Jordan Valley, Georgia, Armenia, Azerbaijan, Russia, India, the Philippines, Indonesia, New Zealand, China, Korea, Japan, North America, Mesoamerica and the Andean region, hot springs were known and used since prehistoric times for thermal bathing to cure different kinds of diseases and infirmities. Furthermore, some prehistoric and proto-historic people cooked food by using the Earth's heat directly, as did the Maori in ancient times in New Zealand (Severne, 1999) and the Mexican natives in the past (and still do, at present) in the geothermal zone of Ixtlán de los Hervores, among others (Suárez Arriaga, 1993).

However, it was only when nomadism ended and stable settlements were established for the cultivation of domesticated plants, that the systematic uses of natural heat and its by-products started to take root in active volcanic zones and in places with hot springs, fumaroles, hot water pools, kaolin, sulfur, iron oxide, boron and other hydrothermal deposits.

Volcanic eruptions and phreatic explosions, mentioned also in Greek mythology (Fytikas et al., 1999), took place on some Greek islands during prehistoric and proto-historic epochs. Furthermore, Eastern African, Indo-European, Asiatic and American natives, including Aztecs, Mayan, pre-Incas and Incas, often frequented thermal-spring sites and used volcanic rocks for tools, artifacts and buildings. Therefore, many old societies knew the healing properties of thermal waters and mud to alleviate stress, cure arthritis, rheumatism, leprosy, psoriasis, paralysis, skin ailments, dyspepsia, leucoderma and other diseases, treat wounds and embellish the body.

Prehistoric peoples developed many other uses for the Earth's heat, including washing clothes and other textiles, cooking food and recreation. Moreover, in certain sites with fumaroles, gas exhalations and boiling waters, rituals were conducted, with or without offerings of food and other objects, to chthonian entities; moreover, haruspices and divinations occurred in some places, and at other high-temperature sites suspected-people underwent ordeals, and guilty people got hard punishments (Cataldi and Chiellini, 1995 and 1999; Grifoni Cremonesi, 1999; Severne, 1999). Beside the above, some North American Indian tribes kept thermal springs as neutral areas where any person could enter safely (Lund, 1999).

In short, we may assume that in all colonized geothermal areas, therapeutic balneology, the use of by-products from the Earth's heat and other popular practices and customs related to the presence of hot manifestations, became consolidated traditions since prehistory.

3.3. Colonization in prehistory of geothermally-active areas

As said in Chapter 2, prehistoric migrations of people and their dissemination around the world developed by repeated waves from 1.5-2 My ago and continued almost uninterruptedly until the Late Neolithic. Therefore, many zones with geothermal manifestations, often located near active volcanoes, were colonized in prehistory and early historic epochs by nomadic populations; as a consequence, most of them could establish a tight rapport of coexistence with the Earth's heat and its phenomena and products.

Geographical research and archaeological discoveries verify the presence of resident communities in many of those zones (Cataldi et al. 1999). Their settlements are mostly related to the Neolithic revolution, represented by the beginning of the domestication and farming of a number of edible vegetables. Occurring approximately 8-10 to 4-5 thousand years ago depending on local situations (Fig. 9), the cultivation of vegetables then started to spread all over the world.

Due to the continuity of permanence in these native areas, the resident populations could establish a much tighter rapport with the terrestrial heat than that setup by the nomadic people. They could, therefore, undertake a kind of 'convivial' relationship with volcanoes and other surface manifestations of the Earth's energy.

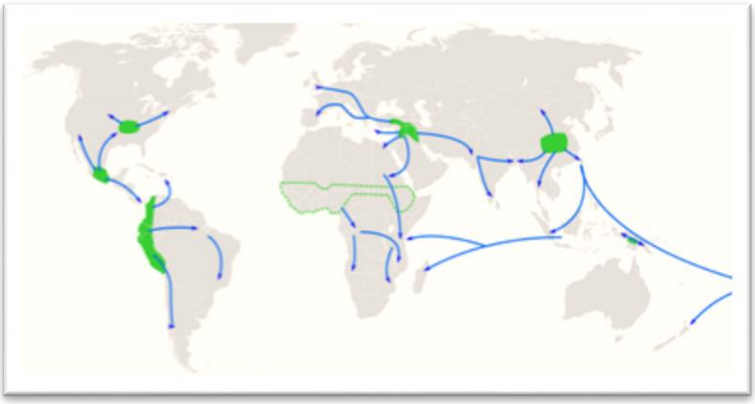


***Fig. 9**. Map of the world showing approximate centers of origin of agriculture and its spread in prehistory (Figure by Joey Roe - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=12176717).*

Two areas with the highest concentration of Neolithic non-migratory people in the Eastern Mediterranean are Jericho and Çatal Hüyük, dated back to the Upper Palaeolithic-Lower Neolithic (over 10 and 8 thousand years B.C., respectively). Çatal Hüyük, in particular, located at a relatively short distance from a then-active volcano (probably Hasan Dağ, according to Özgüler and Kasap, 1999), is thought to represent the spreading point of agriculture in Europe (Fig. 9).

Many Neolithic settlements were established in active geothermal areas due to the presence not only of fresh water and lush woods, but also of hot springs, steaming grounds and fumaroles, hydrothermal minerals, fertile volcanic soils and nearby hard rocks useful for making tools and building houses and monuments.

In Mexico, in particular, some 12,000 archaeological sites have been discovered (Bernal, 1979), the majority of which correspond to, or are near to, volcanic areas. The Mexican Volcanic Belt, located in south-central Mexico, has in fact an imposing series of 3,000 volcanic structures, with ten of them still active (Fig. 10).

The region is particularly rich in geothermal (active and fossil) manifestations. With an altitude of between 1500-3000 meters, a temperate climate, and an abundance of water and fertile soils, the Mexican Volcanic Belt was at the heart of all Mesoamerican civilizations up to Panama in the south.

At the same time, however, we must think that a number of Neolithic settlements in many places on Earth, located on the slopes, at the piedmont or nearby active volcanoes, were likely affected by destructive eruptions and volcanic earthquakes. That obliged the resident populations to flee from their native lands in search of safer cultivable grounds. The causes of such migratory phenomena (immigration to, and emigration from active geothermal areas) have been proven in countless cases of recorded history. When the populations had to relocate their villages or towns forced by volcanic eruptions, a year without summer often followed once the temperatures cooled; moreover, in several cases, eruptions or volcanic earthquakes completely wiped out most of their cultures. Examples from the last 2-3 thousand to a few hundred years include: Thera/Santorin in Greece; Vesuvius/Pompeii in Italy; Paricutin, Popocatépetl, Ixtaccíhuatl and Ceboruco in Mexico; Antigua, Ilopango, Santa María and Irazú/Cartago in Central America; Huaynaputina in Peru; Krakatoa in Java; Changbaishan in Korea; Tambora in Indonesia; Tarawera, Tongariro and Taupo in New Zealand; and Barðarbunga and Katla in Iceland.

***Fig. 10**. Eruption of the Popocatépetl volcano, central Mexico, in June 2013. Photo by Reuters, taken from http://www.enstarz.com/articles/21058/20130705/mexico-volcano-eruption-2013-videos-raw-footage-popocatepetl-cancels-flights.htm.*

Such displacement of entire communities as a result of volcanic eruptions and earthquakes is proven in many prehistoric cases, as for instance in the Phlegraean Fields in Italy, where several levels of Paleolithic and Neolithic finds have been discovered under volcanic products dated 40,000-2500 B.C. (Giacomelli and Scandone, 1992). Moreover, still in the Naples area, prehistoric human bones were found in the Somma-Vesuvius area by Lyell (the father of modern geology) in 1863, and footprints of fugitive people have been discovered recently on pyroclastic debris erupted by the Vesuvius from 1880-1660 B.C.

Apart from the above, bartering of a number of hydrothermal and other by-products of the Earth's heat was developed rather intensively among many Neolithic and proto-historic settlements of the 'old' and 'new' world, especially in the Mediterranean basin where it was facilitated by maritime traffic. Among those products, the most valuable was obsidian, considered as a kind of money during the Neolithic and early historic times (Grifoni Cremonesi, 1999; Fytikas et al., 1999).

3.4. Geothermally related cults, myths and legends in prehistory and proto-history

The presence of thermal sources and other manifestations of terrestrial heat led to the birth in prehistory of legends, traditions, myths, ritual practices and cults in Africa, Europe, Asia, Oceania and the Americas. Prehistoric tribes and ancient populations considered the 'fire of the Earth' to be a gift from the gods for the benefit of humans.

Since the early Neolithic, if not before, the people in the Mediterranean area (in Anatolia, Greece and southern Italy in particular) began forming a kind of religious relationship with geothermal manifestations. Initially, people likely believed in the existence of subterranean 'forces' and endogenous 'powers'; as a consequence, an identification started to form between human death and the afterlife, a world where those powers resided (Cataldi, 1999). Thus, cults were established for *chtonian* entities, and funerary rituals began that were related to the underground world. In this context are to be seen the numerous cults and rituals carried out in dark caverns with hypogeal waters in Italy and in other Mediterranean countries. Such cults and rituals formed in Neolithic times and lasted for at least three millennia before the Christian Era. In the same context are to be seen the many discoveries of vases, burnt remnants of food, lithic and bone objects found in Greece, Sicily and continental Italy in caves and natural tunnels, some with hot sulfurous exhalations (Grifoni Cremonesi, 1999).

Towards the end of the Neolithic, near the beginning of the Metal Age, the relationship in question evolved into more refined forms of religious feelings, resulting finally, during proto-historic times, into cults, myths and legends directly or indirectly related to the external manifestations of terrestrial heat, e.g. hot springs, volcanic eruptions and earthquakes, phreatic explosions and others. The cults should be seen in this light: for Mother Earth in Turkey, for the gods and semi-gods of Olympus in Thessaly (Greece), for the nymphs of the waters and for many other divinities mentioned by ancient Greek authors in their works on theogony and cosmogony (Fig. 11).

From the latter point of view, it is worth noting that (as happened in some important civilizations during their early stages of cultural formation) the proto-historic Greek thinkers were perhaps the first in the world to develop a complex cosmogony and to build a set of universal principles based on mythological and religious perspectives. On the other hand, tales handed down orally through many generations, and popular beliefs about some natural features contributed strongly to the formation of countless myths and legends related to the external phenomena of terrestrial heat. A number of these myths are reported by Cataldi and Chiellini (1995 and 1999) and by Fytikas et al. (1999). We will see in a following chapter that all these myths represented the background for the birth in Greek Antiquity of the first core of scientific thought on geothermal energy.

***Fig. 11**. Ancient divinities of geothermal manifestations in the Mediterranean region: Nymphs of the thermal waters (Photo from Fytikas et al., 1999).*

In light of the theogony and cosmogony mentioned above, the ancient Greeks believed that the thermal waters were special and thus sacred gifts of the gods, which led them to use their curative properties extensively. This is also why, especially in the last millennium B.C., the Greeks used to express their gratitude to the healing gods and other divinities of the hot waters (such as Asclepius, Hygeia and Hercules) by making generous offerings in money and by erecting temples near many hot springs all over Greece and in the territories then under Greek influence.

In the Hawaiian archipelago, a lovely legend has existed since remote times concerning Pele, a very beautiful and young Goddess of the Volcanoes and Fire within the Tahitian volcanic islands. After visiting the Hawaiian archipelago with her elder sister, the Goddess of the Sea and Water, both decided to establish in Kauai their new residence. Pele's task was to care for the formation of new lands with volcanoes and younger fire; whereas her sister's task was to destroy lands, to put out fires and create new water basins. Therefore, when Pele established her abode inside the old Kauaian volcano, her envious sister started to erode the new land and extinguish its internal fire. Thus, Pele was forced to flee from Kauai, and to create a new volcanic island, but her sister pursued her to destroy her new land and so forth —with progressively younger islands and active volcanoes formed, inside of which Pele could locate her always new and safer abode (Lund, 1999). This legend is still alive in the memories of many Hawaiians. Additionally, it is curious to note that, geologically speaking, the islands of the Hawaiian archipelago are actually younger from the northwest to the southeast (Fig. 12). The same author (Lund, 1999), reports that the Sioux Indians from the USA mainland considered the fumaroles and the thermal springs as Wakan Tanka (Great Mystery).

***Fig. 12**. Image of Pele, Goddess of Volcanoes and Fire in the Pacific area, and her last residence in the Hawaiian archipelago (after Cataldi, 2015).*

In Mexico and Mesoamerica, *Huehuetéotl*, the volcanic God of Terrestrial Fire, was the oldest deity in the region and deemed the father of all the other gods (Fig. 13). His representation as an old and wise man suggests the antiquity of mountains and volcanoes (Suárez et al., 1999).

In New Zealand, the Maoris called the hot springs Wahi Tapu (sacred).

In Japan, the God of the Fire was called Kagutsuchi. He was the youngest son of Izanami and Izanagi, central deities of Japan's traditional culture. The ancient Japanese people believed that volcanic eruptions were due to the fury of this god living inside the volcanoes (Sekioka, 1999).

Apart from the examples quoted above, we are prone to think that in different cultures of the world and in distinct epochs, perhaps ancestrally rooted in the human nature, each ethnic group may have had a unique and common set of religious certitudes. However, regardless of what we think about this subject, it is a matter of fact that the ancient religious beliefs originated by phenomena of the terrestrial heat, held much in common. In fact, several gods in proto-historic and ancient epochs in different areas of the world performed the same functions, even though they had different local names: Mother Earth, Jupiter Father, Hephaestus, Vulcan, Water, Sun, Rain, Moon, Fire, War, Heaven and others.

For example, the devotion toward the Sun and the volcanoes, considered sacred entities, was in ancient times intensely felt and almost universal. These beliefs, expressed in traditions and religious rites practiced by thousands of generations, were the origin of countless popular customs. That is why in many places and in different epochs on Earth, geothermal energy has had a preponderantly religious interpretation with a dual, ethical relationship: good/evil, helpful/malicious, beneficial/harmful and constructive/destructive (Suárez et al., 1993). Such ways of thinking deeply influenced the cosmic view of many people, proving that the mythical religious interpretation of geothermal phenomena occurred very early in prehistory, and reflected a deep respect for terrestrial heat in its manifold forms of external manifestation.

***Fig. 13**. Representation of* Huehuetéotl, *the old God of Fire, living in the Earth's center (Photo from Museo Nacional de Antropologia e Historia, Mexico City).*

3.5. Impact of geothermal energy on the development of mankind during the 'Year Zero'

All the above leads us to think that the external manifestations of the Earth's heat caused the following three effects on prehistoric societies and people:

a) An **attraction effect** in areas where the presence of benign and useful manifestations (e.g. hot springs, steaming grounds, hydrothermal minerals, etc.) encouraged people to settle in their vicinity, to cook food, take thermal baths, use by-products and farm the fertile soils;

b) An **expulsion effect** in areas where destructive eruptions and volcanic earthquakes forced people to run away from their native lands in search of safer places; and

c) A **propulsion effect** in areas where the presence of hot springs and useful by-products (e.g. obsidian, travertine, kaolin, smectite clays, sulfur and other hydrothermal minerals) fostered initially, during the Paleolithic, functional uses at a local level, and brought about, in Neolithic times, early forms of artisanship in making obsidian tools and pottery—with the consequent bartering of such goods with neighboring and far-away peoples.

However we must point out that the three effects in question were not a prerogative of prehistoric epochs, but also occurred in more systematic and evolved forms throughout historical periods in all inhabited geothermal areas on Earth.

3.6. Conclusions on the 'Year Zero of Geothermics'

During the long period called the 'Year Zero of Geothermics', started in Eastern Africa over 3.6 My ago, the human-geothermal energy rapport took root and developed in each area in a number of ways, including:

i) Functional development of the Earth's heat and its by-products (i.e. cooking food, thermal baths, processing hydrothermal minerals, and use of obsidian and other volcanic products);

ii) Empirical knowledge of the different types of manifestations and an ability to distinguish between those with beneficial effects and those with dangerous effects;

iii) Creation of new settlements in places with friendly manifestations and emigration from places with volcanic eruptions and earthquakes;

iv) Farming fertile volcanic soils;

v) Formulation of conjectures on connections between geothermal phenomena and *chtonian* entities; and

vi) Formation of the first cores of myths and legends related to the external manifestations of geothermal energy.

During proto-historic epochs, such myths and legends, in turn, represented fertile ground for the creation of beliefs, cults and rites on peculiar volcanic mountains, extrusive domes, steaming grounds and thermal waters. These gave rise later on to early explanations in etiological terms of volcanic eruptions, earthquakes and other geothermal manifestations.

Moreover, from the Late Paleolithic in the African Great Rift Valley and the Mediterranean area, and in the Neolithic in other geothermal areas, the people's rapport with the Earth's heat and its phenomena must have evolved and enriched in scope. That led to the formation of a transcendental sphere towards events and manifestations of terrestrial heat that began to seem like the expressions of endogenous entities dwelling underground: peaceful and benign entities in some places, irascible and malicious entities in others (Burgassi et al., 1992; Cataldi, 1993; Cataldi and Chiellini, 1995 and 1999; Grifoni Cremonesi, 1999; Suárez Arriaga, 1993).

In this light, we speculate that in prehistoric times, near the end of the 'Year Zero', the incubation and birth of spiritual feelings happened among people residing in active geothermal areas. There, cults and devotional rites arose towards benign *chtonian* entities and surface features related to geothermal energy, like hot springs, volcanoes, extrusive domes, round-shaped forms of hydrothermal encrustations and others.

Additionally, owing to the fact that the first contacts of humans with geothermal phenomena developed separately in each active and populated geothermal area of the world, the beginning of the 'Year Zero of Geothermics' differed from place to place depending on the period when settlements began in each area. However concerning the end of the 'Year Zero', we think that it coincides in each specific area with the conclusion of the respective Neolithic period and the beginning of the Metal Age, 7,000-8,000 years ago in Northern Africa and the Mediterranean area, and a few thousands of years later in the western Pacific and the Americas.

As a consequence, assuming that the first contacts between humans and geothermal energy happened around the age of the Laetoli footprints described earlier, the duration of the 'Year Zero of Geothermics' in the different populated geothermal regions of the world would range from almost four million years ago in Eastern Africa to a few tens of millennia in the Americas.

Concerning the Mediterranean area in particular, the end of the 'Year Zero' may be identified roughly with the time of the oldest artifact known so far reflecting human cultural interest in geothermal phenomena. It is a painting found in 1967 at Çatal Hüyük (Central Anatolia, Turkey) that depicts an erupting volcano (probably Hasan Dağ) visible from a highly evolved Neolithic settlement dated from 6,200 B.C. (Mellaart, 1967; Fig. 14). The painting illustrates not just the volcanic skyline but also many eruptive particulars, such as the explosion plume, main and lateral eruption cones, central depression (corresponding perhaps to a caldera), eruption bombs and volcanic ashes covering the mountain slopes. It is the first known geological sketch of the world, drawn over 8,000 years ago!

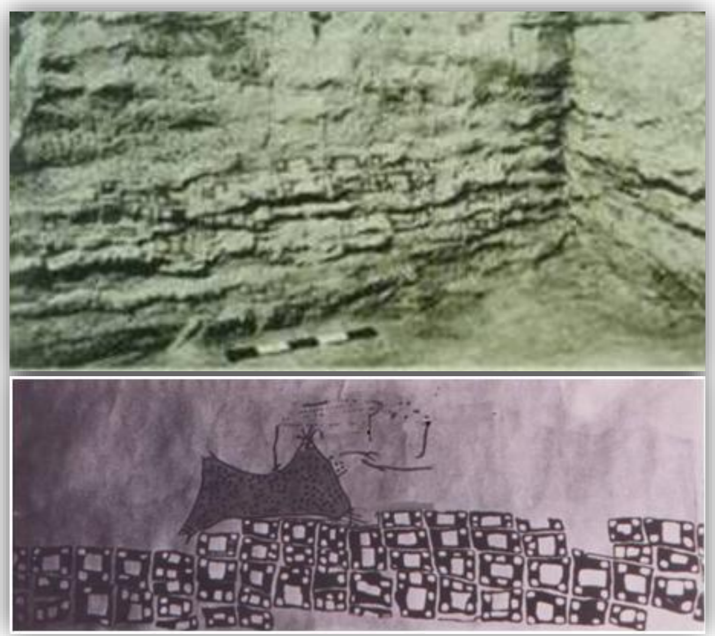


Fig. 14. *Excavation and painting found at Çatal Hüyük, Neolithic town in central Anatolia, Turkey. Up: Photo of the original wall painting found by Mellaart (1967) in 'level vii' of the settlement; Down: reconstruction by Mellaart of the wall painting (Taken from Mellart, 1967, available at: https://archive.org/details/Catal-huyuk.ANeolithicTownInAnatolia).*

The painting's details point to the fact that the author (and probably other Mediterranean people too, settled like him/her in geothermally active areas) had already acquired and developed by the Lower Neolithic a keen sense of observation of natural phenomena and an advanced ability to sketch them on rock and building walls.

Such a sense of observation, in turn, leads one to think that the Neolithic people living in geothermal areas had already acquired, since hundreds of thousands of years ago, much knowledge regarding the phenomena of external manifestations of the Earth's heat, including thermal springs, volcanic eruptions, fumaroles, hydrothermal encrustations and others; and this must have prepared them to adopt a rational approach in deciding on whether or not to settle in a given geothermal area.

To conclude, most likely originating in the African Rift Valley almost four million years ago, the initial rapport of humans with the Earth's heat and its manifestations expanded gradually to, or bloomed autonomously within, other geothermal regions, the most important of which are Eastern Africa, the Mediterranean area, the territories of the so-called 'Ring of Fire' and the islands of the Middle Atlantic Ridge. The length of the 'Year Zero of Geothermics' differs from case to case, from 3.5-4 My in Africa to a few tens of millennia in the Americas, depending on when people began settling in each area.

Though with specific forms in each region, in all populated geothermal areas of the world, the rapport in question took root and consolidated by including three similar processes:

a) Functional use of the Earth's heat and its by-products;

b) Intellectual approach in trying to understand the differences between various types of geothermal phenomena; and

c) Formation of a spiritual sphere towards peculiar visible features of terrestrial heat, like volcanic mountains, protrusion domes, thermal waters, steaming grounds, fumaroles and others.

Such a sphere initially included forms of respect and awe for those peculiar features, but later evolved, first into embryonic religious sentiments, and then in proto-historic times, into a number of cults and devotional rites. The cults of Hephaestus in the Mediterranean area, Izanami and Izanagi in Japan, Huehuetéotl in Mexico and Pele in the Pacific area, all divinities of active volcanoes, are just a few emblematic examples.

4. The Mesoamerican Cosmogony and its Relation with Geothermal Energy

4.1. General

Two stable, visible bodies in the heavens are the Sun during the day and the Milky Way during the night. Among the Aztecs, *Huitzilopochtli*, God of the War born from the Earth, represented the Sun, whereas his dismembered sister, Goddess *Coyolxauhqui* (Fig. 15), characterized the Milky Way (Aguilera, 1979). The Sun, dying at every sunset, undertook a daily trip through the underground to recharge himself with the energy from the womb of his mother, *Coatlicue*, Goddess of the Earth. Only in this way could the Sun be reborn at sunrise every day (Suárez et al., 1999).

For this culture, the divine energies were land, corn, volcanoes, wind, rain, lightning, sun and stars. Water was always related to the Mesoamerican people's origin (León Portilla, 1992) being the basic element in one of the first epochs of their existence. On the horizon, the waters of the Earth could be seen joining the water of the Heaven that enveloped the world. That world was called *Cemanahuac* ('that which is surrounded by water'). The cosmic meaning of water was so important that in the Náhuatl language, *atl* ('water') came to represent the phoneme 'a'. Due to such importance, *Tláloc* (Fig. 16), God of the Rain, was worshiped in all of Mesoamerica. The Mayan called him *Chac*; the Mixtecas, *Cocijo*; the Totonacas, *Tajín*.

Fig. 15. Coyolxauhqui, *the Aztec Goddess of the Milky Way and of the Moon (Photo by Museo del Templo Mayor, Mexico City).*

In Náhuatl, city is translated as 'in *atl* in *tepetl*', literally meaning water-mountain (León Portilla, 1992). Pilgrimages were made to the volcanoes in this region several times over the solar year, where the existence of lakes in various craters of old volcanoes reinforced the belief in the volcano-water relationship. This

Fig. 16. Tláloc, *the Aztec God of Rain, Lightning and Volcanic Eruptions (Photo by Museo Nacional de Antropología e Historia, Mexico City).*

equivalency implicitly contains the idea that mountains are big water reservoirs, preserved as reserves of rain by the gods. The Florentine Codex, in fact, says:

"All the high mounts, where the clouds join to make rain, are gods. To each one of them an image is made... Like the image of the volcano Popocatépetl *(the 'smoky mountain') or of her whose name is* Iztaccíhuatl *('white woman'), or the image of the mount* Poyauhtécatl *('that which is from the region of the fog')".*

The indirect references to the contacts between the population of Mesoamerica and geothermal energy and its external phenomena are quite varied. The majority consist of names of places, gods and narrations about religious myths (Suárez and Cataldi, 1993; Hodgson, 1995, Hernández Galán et al., 1995). There are also traditions and legends that are always transmitted orally, with some of them translated by Spanish monks. Many others, like most of the codices, were hopelessly lost, as for instance that of the indigenous informants of the Spanish historian Sahagún (1575), who narrated the arrival of travelers from remote regions coming through the Gulf of Mexico to settle in a mythical place named *Tamoanchán*, where the *Náhuatl* culture flourished for the first time. Concerning this account, here is the story that the old men used to tell:

"In a certain time that no one can any longer recount,
and which now nobody can remember...
Over the water, in their boats they came, in many groups,
and arrived at the edge of the water, on the north coast,
and where their boats were left, is called Panutla...
Off they went immediately following the water's edge,
searching for the white and smoking mountains ..."

We are not acquainted with the reasons that impelled those legendary nomads to seek out and settle near volcanoes because Sahagún's informants were not explicit in this regard. However, this story suggests a willful consciousness in the relationship between people and geothermal phenomena in America.

4.2. The Five Aztec Suns

In many chronicles and oral traditions, in Indigenous manuscripts and on the reliefs of several pre-Hispanic monuments, one perceives the idea that our time was preceded by four Eras named 'Suns' by the Aztecs (Fig. 17: the four squares in the central part of the disk). Each one of these epochs finished with the destruction of the world by different and terrible cataclysms generated by the energy of the Earth. Those past worlds were in cosmological order (León Portilla, 1961): *atl* (water), *ocelotl* (tiger), *quiahuitl* (rain) and *ehécatl* (wind).

Our present world is designated on the Aztec calendar by the date *nahui ollin* (4 Movement), which means earthquake (four sectors around the central part of the disk in Figure 17). The end of each age was governed by one of the four primal forces in nature: water, earth, fire and wind (León Portilla, 1983). Each age had great mythical importance; the meaning and the end of each of them follows:

1) *Atl Tonatiuh* (Water Sun). The first men were made from ashes. In this first catastrophe, humanity was destroyed by water in the form of floods and the inhabited land was invaded, converting people into fishes.

2) *Ocelotl Tonatiuh* (Tiger Sun). In this second age, the sun stopped at noon, interrupting its path; therefore, suddenly, the night appeared and heaven was oppressed. At this time giants lived who, in spite of their corpulence, were in fact weak beings. When they fell because of an accident, they fell forever.

3) *Quiahuitl Tonatiuh* (Rain of Fire Sun). In this third age, rock boiled, burning the people in a rain of fire coming down from volcanic eruptions (*Tlaequiahuitl*), which destroyed the world. The people underwent a tragic destiny because they were transformed into turkeys. The date 4-*Quiauitl*, which records the end of this time, is placed under the protection of *Tláloc*, God of Rain and Fire (Fig. 16), falling from the sky in the form of flashes of lightning and volcanic eruptions.

***Fig. 17**. The Aztec Calendar (Photo by Museo Nacional de Antropología e Historia, México City).*

4) *Ehécatl Tonatiuh* (Wind Sun). During this epoch, everything was destroyed by the wind in the form of terrible hurricanes, snowstorms and glaciation. Human

beings were converted into monkeys and were scattered to the mountains. At the end of this fourth era, the gods met in the sacred city of Teotihuacán to once again create the world. With the sacrifice of one of them, who flung himself into the fire of an active volcano, the Fifth Sun emerged.

5) The present 'Sun', *Ollin Tonatiuh* (Movement Sun), is the last of the cosmogonical Eras of Mesoamerica. The *Nahuas* lived in the Era of the Fifth Sun and we are now still in the midst of this Era, which will be devastated by earthquakes. Its divinity is *Xiuhtecutli*, God of Fire, who joins the heat of the Earth and Heaven (Fig. 17: face in the very central part of the disk).

We would like to quote at this point a Mesoamerican poem whose meaning is the equivalent of the ancient maxim 'Παντα ϱει' (pronounced 'panda raei, *all passes, everything flows*), by the Greek philosopher Heraclitus (5th Century B.C.), as is that of the Tibetan-Buddhist certitude that *nothing lasts forever*. The mythical essence of the text contains the *Náhuatl* explanation of the origin and evolution of the world. The oral tradition remains alive in the cadence of this poem, as in many other written transcriptions of native beliefs and customs. The readers of this paper may wish to read the poem aloud; only in this way will the reader be able to hear the *Nahuas* telling their story once again.

This poem is the most important original ancient source of *Nahuas* religious thought together with the associated vision of the world and the Mesoamerican cosmogony. In the mythical background, many references are made to tectonic and volcanic events, that is to say, to geothermics (free translation from the Spanish version, by Hodgson and Suárez, in Cataldi et al., 1999).

Ages or Suns that Have Existed

It was related so, it was said that four lives came before,
and that this is the Fifth Age.
Just as the old men knew it, in the Year 1-Rabbit
the Earth and the Heavens were founded.
And they knew it thus,
that when the Earth and Heavens were founded,
four kinds of men, had existed,
four kinds of lives.

They also knew that each one of them
had existed in a sun (in an age).
And they said that their God made the first men,
He forged them from ash.
This they attributed to Quetzalcóatl *(Fig. 18),*
whose sign is 7-Wind, he made them, he invented them.
The First Sun (Age) that was made,
its sign was 4-Water and it was called the Sun of Water.
In it happened that water carried away everything.
The people became fish.

Then the Second Sun was made.
Its sign was 4-Tiger; it was called the Sun of Tiger.
In it happened that the heavens were weighed down,
the sun did not follow its course.
When the sun arrived at noon,
it then became night, and when it was dark
the tigers ate people.
And giants lived in this sun.
The old men said that the giants greeted them thusly:
"Don't fall,
because he who fell, fell forever".

Then the Third Sun was made.
Its sign was 4-Rain.
It was called the Sun of Rain (of Fire).
It happened during it that fire rained,
those who lived in it were burned.
And during it sand also rained
and they said that in it
the little pebbles rained that we see
and that the tezontle *stone boiled*
and then that the rocks turned red.

Its sign was 4-Wind, then the Fourth Sun was made.
It was called the Sun of Wind.
During it everything was carried away by the wind.
Everyone became monkeys.
They spread themselves through the mountains,
the ape-men went away to live.

The Fifth Sun: 4-Movement its sign.
It is called the Sun of Movement,
because it moves, it follows its course.
And as the old men say,
and in it will be earthquakes,
there will be famine and so we will perish.

In the Year 13-Reed, it is said that it came to exist,
the sun was born that exists now.
Then was when it illuminated, when it dawned,
the sun of movement that exists now.
This is the Fifth Sun that was formed,
in it will be the movement of the Earth,
in it there will be famines.

This sun, its name 4-Movement,
this is our sun, in which we live now,
and here is its trace,
as the sun fell in the fire,
in the divine fire-box, there in Teotihuacán.
Equally this was the sun
of our prince in Tula,
that is to say, of Quetzalcóatl *(Fig. 18).*

In the poem above, the influence of the volcanic processes on the Mesoamerican cosmogony is clearly perceived. For the Aztec cosmogony, in four attempts the world is born and dies, destroyed by gigantic catastrophes. Similar beliefs, where the numeral 4 (four) prevails in the cosmogony, are found among the *Mayan Quiché* in the south of Mexico and among the Tarahumaras in the north (Soustelle, 1940).

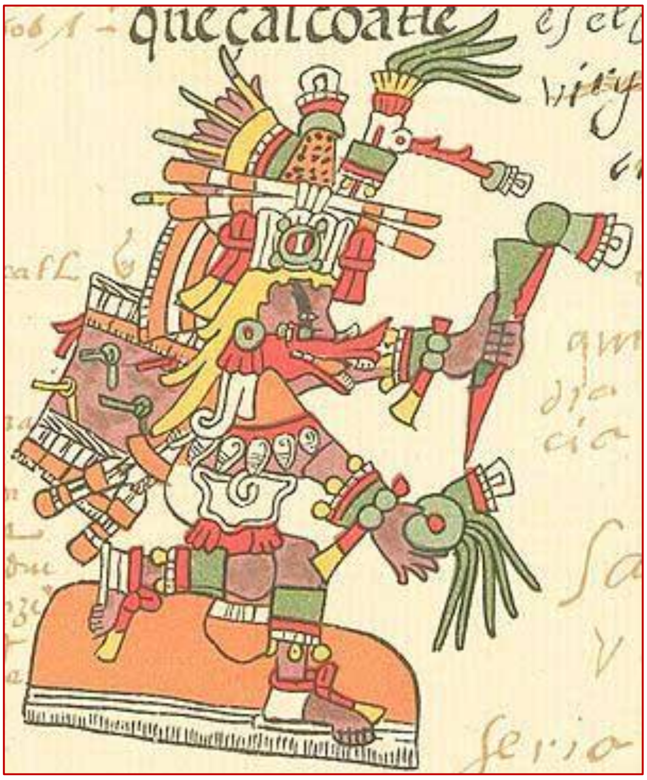


***Fig. 18**. Depiction of* Quetzalcóatl, *one of the main Aztec divinities (Image from* Codex Telleriano, *taken from: http://www.crystalinks.com/quetzalcoatl.html).*

During the aforementioned Eras, a spiral evolution took place: people appeared in upgraded forms, as did food and plants (León Portilla, 1961). The end of each Era was governed by one of the four primal forces in nature: water, earth, fire and wind. The order in which the 'Suns' are described is very important, because it reflects, in a poetically condensed way, the succession of geological processes that certainly took place, as witnessed by the predecessors of the *Nahuas*. The order of the version of the poem dated 1558 (León Portilla, 1961) is as follows:

i) Tiger Sun: the sun stopped;
ii) Wind Sun: hurricanes, glaciations;
iii) Rain of Fire Sun: volcanic eruptions;
iv) Water Sun: flooding;
v) Movement Sun: earthquakes, our present time.

This happened in the time in which the 'giants' (dinosaurs?) dominated the Earth. Afterwards, this first world, including the giants, was destroyed and the second Era came where everything was carried away by the wind in its wider meaning: hurricanes, snowfalls, blizzards and glaciations. Later, the third world was destroyed by lava, ash and burning rocks coming from volcanic eruptions. Finally in the fourth Era, terrible flooding happened and the water covered even the high mountains of the Earth for several years.

The present Era and world in which we are living, was created after one of the Gods (*Nanahuatzin*) flung himself into a volcano and gave birth to the Fifth Sun. This world will also disappear as a result of intense and frequent earthquakes.

Therefore, by following this order in the successive creations of the world according to the *Nahuas*, the ensuing chronology would establish that, after the appearance of people on Earth, the heaven was oppressed (i.e. obscured) and the Sun interrupted its path and no longer moved. A long night then came and the tigers (i.e. the other living beings of the ground), ate the people.

The *Náhuatl* description about the origin and evolution of the planet is surprising. In fact, in the poem many similarities can be found related to the geological events that have occurred on Earth. In particular, the destruction of the first world could be interpreted as a change in the duration of the planet's rotation (!), or to the collision of a giant meteorite with the Earth (!!). Moreover, apart from its religious implications and geological coincidences in the myth of suns, a deep way of thinking can be noted. The original text emphasizes a profound consciousness of the relativity of the world and of its existence. Furthermore, an implicit and resigned acceptance that everything passes on Earth, everything finishes, even the gods, is highlighted. In short, the poem above makes up an extraordinary synthesis of the group of cosmological certainties with which the latest heirs of Mesoamerica had to cope. In the whole of Mesoamerica, from Mexico to Panama (Fig. 19), the origin, existence and development of the Universe were the effects of divine beings and energies in action. Therefore, an understanding of reality was of a religious nature.

For the Aztecs, in particular, religion was the axis around which all of their existence turned, and this was accomplished even in the arts (Tibon, 1967). Gods, world and people formed a cosmos in equilibrium, interacting in a dynamic reality. Such a continuous motion occurred in an orderly way (De la Garza, 1990), giving stability to their existence. This was usually governed by the ethical duality of good/evil, inseparable from the intrinsic nature of all living beings: humans and animals on Earth, and even the gods. The Mesoamerican concept of geothermal manifestations also was permeated by fervent religious meaning, pregnant with duality into a positive / negative, beneficent / harmful, constructive / destructive relationship.

The characteristics of *Huehuetéotl*, divinity of geothermal energy (*see* Fig. 13), point out the paradox of the duality. He was one of the principal gods, the oldest one, the father of the other gods who lived in the 'navel of the world', at the center of the Earth from which he controlled fire. At the same time, he was the divinity nearest to the people, the *Tloque Nahuaque* (Lord of the Neighboring Vicinity), ruling in the immediate present and thus living in close contact with people, in the same abode of every human being. For the Aztecs, *Huehuetéotl* was the fire itself, coming from the volcanoes, the heat of terrestrial origin and the oldest principle generator of life, emerging from the center of the Earth to its surface.

The representation of *Huehuetéotl* as an old man suggests the oldness of the mountains and volcanoes. The antiquity of this god, seen in different forms at Teotihuacán (one of the most important archaeological sites located near Mexico City), underlines the importance given by the Mesoamericans to geothermal heat. His cult continued for many centuries and leads us to consider him the oldest Aztec god.

4.3. The calendar and the concept of time in the light of geothermal energy in ancient Mesoamerica

The Mesoamerican calendar has existed since the year 700 B.C. It is structured as a complex measuring system based on the idea that time flows as a kind of liquid. The Aztecs conceived time as a god called *Cáhuitl*, under the concept that he represents an entity that is leaving us (León Portilla, 1961). Therefore, being a fluid entity, time must come from a divine source. It was another and different "time", one beyond human understanding, which originated the time that people perceive. At the beginning of the universe, the vital activities of the gods created this world. The order in which the mythical actions occurred formed the conceptual base of the Aztec Calendar. Every new engendered being, person or animal, will take as a proper name that of the day when he was born (López, 1990).

Given the terrestrial nature of the oldest gods and the 'global' origins of the Sun and Earth, the symbols that formed part of the calendar to representing the days, months, years and centuries deeply reflected the influences of geothermal phenomena in the Aztec Calendar's final structure (Fig. 17). Each cycle expressed the eternal return of things and the recurrent regularity of natural phenomena. Thus, the calendar concept considers that the complex reality of the world originates in the intersections and simultaneous influences of cycles from different times. The historic repetition was inevitable; however, at the end there is only a gigantic cycle that will include all possible combinations of the previous cycles: "... *again it will be like this, again so will be the things, in some time, in some place.*" [Florentine Codex].

The outer ring holding the 20 days of the Aztec Calendar shows again the importance that the ancient Mexicans gave to the concepts related to geothermal processes: rain (water, fire or eruption), flint (production of knives and fire), movement (earthquakes) and serpents (related to the ground and underground things). The most surprising concept is the one related to water (*atl*), essential in all its forms, whose patron saint was *Xiuhtecutli*, the God of Fire (González, 1991). The Aztecs used the special name *atl tlachinolli* to say "water in fire", where the geothermal relation is immediately evident. Finally, it is worth stressing that on the central disk, a series of elements can be seen that, when combined, represent the planetary cycle, the lunar phases, the periods of comets and the eclipses.

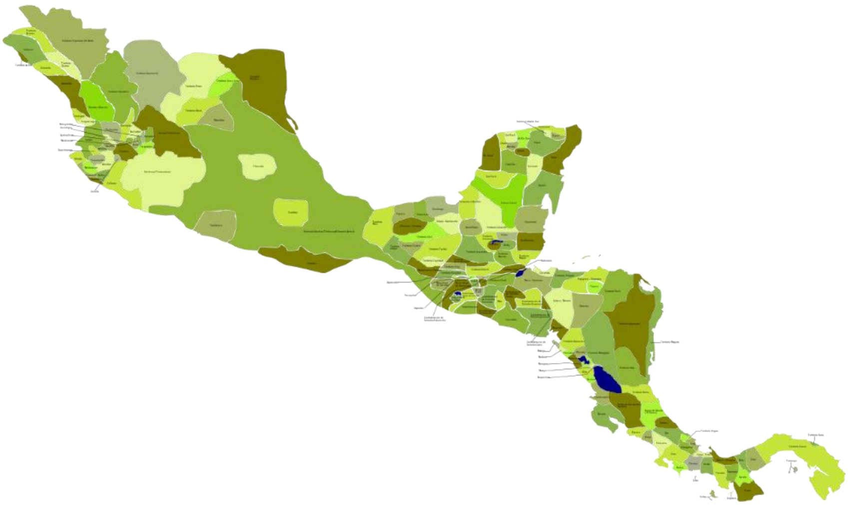


Fig. 19*. The Mesoamerican and Central America area: from northern Mexican territories to Panama (Image by Juan Miguel - Own work, CC0, https://commons.wikimedia.org/w/index.php?curid=30157365).*

Reading aloud the poem in paragraph 4.2, and knowing a little about the Mesoamerican cosmogony, helps to grasp the universal, ethical essence of the origin, evolution and caducity of our planet. It helps also to understand why one of us, in closing his metaphoric tale on the origin of geothermal energy, allusively wrote "…*Teotihuacán*, where the gods met to create the world and donate to mankind terrestrial heat, will be someday on another place, that nobody knows or can predict..." (Cataldi, 1992).

The above stresses again that everything changes and flows with time on Earth; all passes, dies and takes new forms of life until the Earth itself becomes a cold stone in the Universe. Παντα ϱει (*panda raei*), as Heraclitus said 2,500 years ago!

5. Social and Cultural Effects of Geothermal Energy in Selected Countries and Regions

Deeply rooted in the Lower Paleolithic, the human-geothermal energy rapport continued to develop and evolve in more refined forms during the Neolithic and Metal Ages, and in later times until recent historic epochs. In addition to what we have summarized in Chapter 3 for prehistoric and proto-historic times, and further to the description made in Chapter 4 for Mesoamerica, also in historical times the phenomena of terrestrial heat played an important role with notable socio-cultural effects in all populated geothermal regions on Earth. Though not exhaustive, some examples follow to highlight the importance of such effects in a number of countries or regions of the world.

5.1. Eastern Africa

In this region (the 'cradle of mankind', as said in a previous paragraph), due to favorable climatic conditions, harnessing hot springs for therapeutic purposes was in prehistory, and remained in historic times, a minor application of the Earth's heat. However, cooking food in areas with fumaroles, steaming grounds and boiling waters, and extracting and using by-products (hydrothermal minerals for a number of applications, and volcanic rocks for building purposes) were much developed.

One of the areas with the most intensive exploitation of sulfur, iron oxides and other hydrothermal minerals has been for centuries the Danakil depression, in the northern sector of the Afar Triangle between Eritrea, Ethiopia and Djibouti (Rosi, 2014). Another area of intensive exploitation of geothermal by-products has been (probably for over two thousand years) Lake Natron in northern Tanzania, where sizeable deposits exist of hydrothermal alkaline products, including sulfur, phosphorus chloride and soda (Lund, 1999). Moreover, important buildings and churches made with different volcanic materials, dated 1,000 years ago, are reported for Ethiopia by Lund (1999); and they are to be found also in other East African countries.

On the other hand, many legends, myths and beliefs related to volcanoes, protrusion domes, fumaroles and hot waters, sprang up and were consolidated in these countries from proto-historic times, and they are still alive in many cases today.

5.2. Mediterranean Region

As attested by archaeological finds, myths, legends and traditions reported by Greek historians and learned authors of the first millennium B.C., thermal bathing in continental and insular Greece was extensively practiced in proto-historic and historic times, with a peak reached in the Hellenistic period (3rd-1st B.C.). In this period, several hundreds of thermal spas were in operation in Greece and in the territories under Greek influence, i.e. in Western Anatolia to the east, in Macedonia to the north, in the peri-Adriatic area to the west, and in southern Italy and Sicily to the southwest (Cataldi-Burgassi, 1999/1; Fytikas et al., 1999; Özgüler-Kasap, 1999; Popovski-Dimitrov, 1999).

Such a wide and intensive development of spas had been prepared during the Late Neolithic and the Metal Age in some localities of Western Anatolia, Greece and southern Italy (Fig. 20); but they could bloom and boom quickly thanks to Asclepius, legendary personage of the 13th century B.C., trained in medical arts by Chiron, the most learned Centaur of the Greek mythology. This is why, by treating his patients successfully with medicinal herbs and thermal balneotherapy, Asclepius became the most famous physician of Greek Antiquity, who would create a medical school with thousands of followers, and was finally raised by the gods of Olympus to the rank of the God of Medicine. The cult of Asclepius spread over the entire Mediterranean area and lasted for almost 1,500 years, with hundreds thermal stations, temples and statues dedicated to him.

Fig. 20. Tholos *of St. Calogero (Lipari, Sicily), Bronze Age (1600 B.C.). Left: entrance to the* tholos, *used as a* sudatorium; *Right: pond of the* tholos, *probably used as an open-air thermal pool (photos taken from Grifoni Cremonesi, 1999).*

In short, the thermal practices in Greek-Roman Antiquity were relevant and important from social, cultural, religious and traditional viewpoints. The localities that reached prominent, international fame in that period were: Hierapolis/Pamukkale and Pergamon in Anatolia, Epidaurus and Aedipsos in Greece and Baiae in southern Italy.

In addition to thermal bathing, it must be mentioned the extensive in proto-historic and ancient times of many geothermal by-products, including any kind of hydrothermal minerals, travertine, pumice and other pyroclastic rocks, obsidian and volcanic rocks. The most important of them from a commercial viewpoint were obsidian, from the Neolithic to the end of Roman Antiquity (Fytikas et al., 1999; Grifoni Cremonesi, 1999), and silica, travertine, iron oxides and pumice from early historic to recent times (Cataldi-Burgassi, 1999/2).

For heating, we must recall that the first district heating system in the world was realized in the 14th century at Chaudes-Aigues (Cantal, France). By using the hot springs of Le Par (T = 45-82°C) and a circulation system like that shown in Figure 21, it served initially some 20 homes. The system was expanded gradually in the following centuries to over 100 homes; but in recent times the circulation layout has been improved and the dwellings heated at Chaudes-Aigues by the Le Par hot springs amount to 150 (Gibert and Jaudin, 1999).

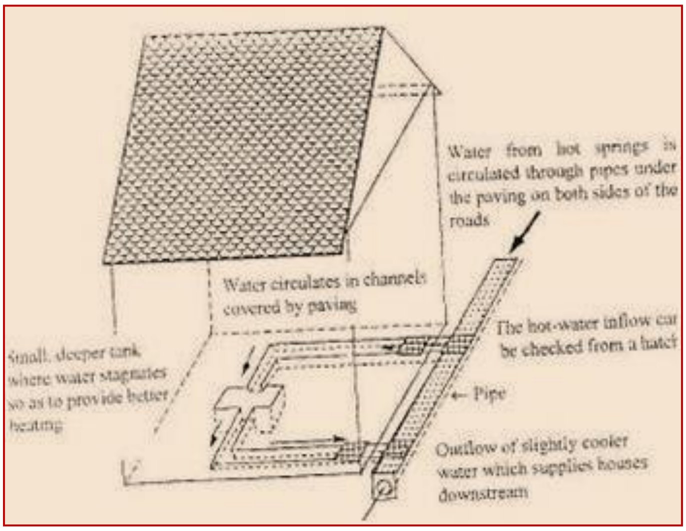


***Fig. 21.** Sketch of the domestic heating system used in past centuries at Chaudes-Aigues (Taken from Gibert and Jaudin, 1999).*

Finally, we must mention that the external manifestations of the Earth's heat in the southern sector of the Mediterranean area have been intensive during the Quaternary. Therefore, they gave impetus for the birth in this region, from proto-history to few hundreds years ago, of countless myths, legends, ritual practices and popular beliefs, producing in many places a notable impact on the formation of culture, traditions and style of life of the local people. Legends and myths, in particular, sprang up in most cases with an etiological content aimed at explaining why certain geothermal phenomena occurred or certain manifestations of the terrestrial heat had formed. The legend on the formation of the Phlagraean Fields issuing from the attempt by the Giants to throw Jupiter off from his throne on Olympus, or the battle by the Titans against the gods of Olympus (Fig. 22) aimed at explaining the explosive eruption that occurred in late prehistory in the Thermopylae area (Thessaly, Greece), are only two examples of the rich mythology originated in the Mediterranean area and inspired by geologically young geothermal events. These kinds of myths and legends prepared the cultural groundwork for the birth in the Mediterranean area, starting from the 6th century B.C., of the first core of scientific thought in geothermal energy (see Chapter 10).

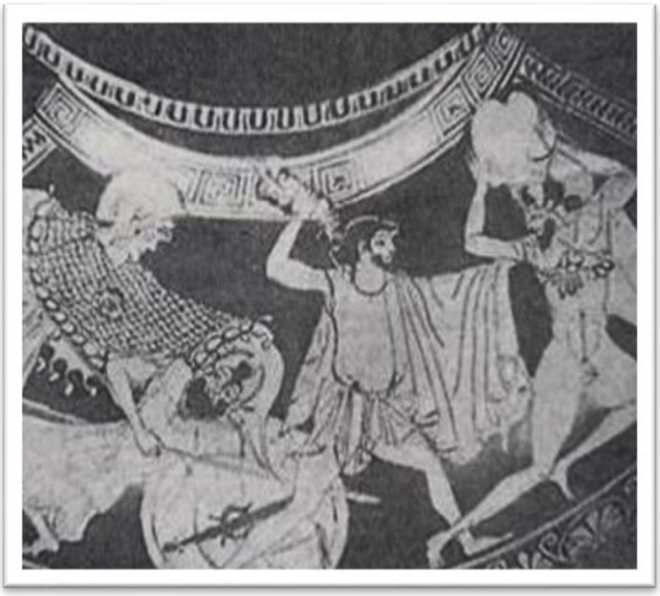


***Fig. 22**.Scene of the battle between gods of Olympus and the Titans. One of the Titans is about to launch a huge block of rock at the gods (Picture from a Greek ceramic vase of the 5th century BC, taken from Fytikas et al., 1999)*

5.3. Middle East

Due to their locations outside the East African region characterized by intensive, young igneous processes, most areas of present-day Lebanon, Syria, Israel, Palestine, Jordan, Iraq and Saudi Arabia are not endowed with important manifestations of the Earth's heat. One significant exception is a narrow belt between the Dead Sea and Lake Kinneret (Sea of Galilee) where four groups of thermal springs with superficial temperature of 25-65°C are found along the Jordan-Israel Rift Valley (Jaffé et al., 1999). This belt is part of the Dead Sea Transform Fault System that affects the northernmost sector of the Afro-Arabian Rift.

Those springs were probably known and frequented in Neolithic times; but at least one of them, *Hammei Tiberias*, was known to be in use at the time of King Solomon (1011-931 approximately, B.C.). In fact, a nice legend on its formation exists and is still recounted today, which says that King Solomon, before marrying the Queen of Sheba and wanting her to take a warm pre-nuptial bath, ordered one of his demons to heat the cold springs then existing near the shores of Lake Tiberias (Fig. 23). Since the Queen enjoyed so much the nuptial bath, the demon wanted to establish his abode there to keep the springs permanently warm for her.

Legend apart, those springs were systematically utilized during the last millennium B.C.; started to have international fame during the Hellenistic period (3rd-1st century B.C.) and reached their peak of splendor in Roman and Byzantine periods, until the 7th century A.D. The same Talmud (one of the Jewish sacred texts dating from 3rd-6th centuries A.D.) recommends the use of thermo-mineral springs for "… sufferers from skin diseases, leprosy, ailments of the urinary and digestive tracts, rheumatism, arthritis and nervous diseases…" (Jaffé et al., 1999).

After the 7th century, during the Islamic period and for the rest of the Middle Ages, when the Jordan Valley had lost its political importance, the springs in question remained in operation for local people only. All existing spas in the Jordan Valley were thus, as the quoted authors state "…far more important in Antiquity than in the last few centuries and at present…"

5.4. India

The holiness of springs, especially thermal springs, was a common belief of all old civilizations, formed probably at the dawn of history and has continued to exist in many places on Earth until relatively recent times. However, the belief that rain water in general, and some rivers in particular, were tamed and domesticated by a supreme god is a peculiar concept of the Hinduism, hardly found in other religions. The concept of taming is well depicted in Figure 24, where Ganga, the ruling female deity of thermal springs, is seen descending from the Heaven 'encapsulated' by a heavy shower, purportedly made by Shiva (the supreme Hindu God) to tame her arrogant temper (Chandrasekhram, 1999).

For the Hindus, the thermo-mineral springs of India (320, in total) are a gift from Shiva, and this is why they have all divine powers and special healing properties. As a consequence, attested to by archaeological excavations and old documents, since early historic epochs all those springs had been (and still are, at present) visited by lots of pilgrims for both devotional and therapeutic purposes. Starting from the 3rd century B.C., likely owing to their gas content, many of those springs were defined as rarified waters. The diseases treated in all Indian thermal springs are: leprosy, gout, paralysis, rheumatism, skin ailments and other diseases —plus goiter, dyspepsia and leucoderma (Chandrasekhram, 1999).

Moreover, it is worth recalling that Ganga is also the Hindu name for Ganges, the main Indian river, which is considered feminine in nature and represents the most sacred feature of Hinduism. Ganga is thought to be the unifying spirit of the nation: "The Ganges (locally called Ganga) above all is the river of India which has held India captive, and has drawn uncounted millions to her banks since the dawn of history. The story of the Ganges, from her source to the sea, from old times to new, is the story of India's civilization and

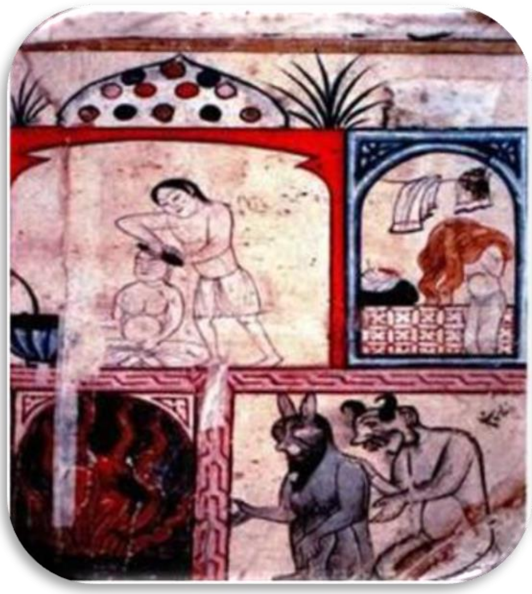


Fig. 23 (left)*. The Queen of Sheba taking a warm bath in the* Hammei Tiberias *thermal spring before her nuptial ceremony with King Solomon (from Jaffe et al., 1999).*

Fig. 24 (right)*. The Hindu goddess Ganga descending from Heaven inside a heavy shower. She was sent by Shiva to protect the thermal springs of India [Photo from Ganges in Hinduism, https://en.wikipedia.org/w/index.php?title=Ganges_in_Hinduism&oldid=730168747, (last visited Aug. 3, 2016)].*

culture, of the rise and fall of empires, of great and proud cities, of adventures of man…" This sentence, interrupted after man, and with no author specified, can be read in the Wikipedia's page referred in caption of Figure 24.

"…Ancient Indian civilization's valuable contribution to modern India is recognition of the medicinal powers of thermal spring waters… " stated Chandrasekhram in the abstract of his paper quoted above.

5.5. Indonesian archipelago

Almost all of the 17,000 islands of Indonesia have a recent volcanic origin; therefore, volcanoes and associated phenomena "… reverberate from the core of ancestral memory..." (Tjetiep et al., 1999). The influences that such volcanic activity and phenomena had in relatively recent times on the culture and social formation of the Indonesian people date from over 1,500 years ago, when Indian religious traditions first arrived in Indonesia, interacted with preexistent legends and beliefs formed probably since prehistory, and resulted finally in a combination of ancient and modern-day styles of life.

There was also a great influence of Indian culture from the penetration in Indonesia of Hinduism and Buddhism. According to the authors quoted above, the legendary Cosmic Mountain is important in many early Hindu creation epics and perhaps the imported Indian cosmology matched naturally with the Indonesian concept of 'sacred mountain'. These include Mount Semeru (the highest and one of the most active volcanoes of Java, also referred to as *Mahameru* or 'Great Mountain') and Mount Agung (or *Gunung Agung*), also an active volcano of over 3000 m (the highest in Bali), both deemed to be seats of the gods. The main Cosmic Mountain of Indonesia is the volcano Mt. Semeru, not far from where the *Borobudur* temple (Fig. 25) was built around 800 A.D. The latter has been for centuries the largest Buddhist monument in the world. It was and is considered by the Javanese people "…the center of our changing universe…" (Tjetiep et al., 1999).

Certainly, the theme of a Cosmic Mountain has influenced many religious and secular forms of expression in Indonesia, especially in Bali. Here, in fact, "…from the earliest times, the Balinese have believed in an ordered universe stretching from the heavens and the volcanic peaks, home of divine spirits who bring prosperity and good fortune down to the plunging depths of the sea, (…) All that is holy is associated with height, the mountains, and the direction upstream toward the majestic Mount Agung...", whereas "…all that is threatening or harmful belongs to the forces of the underworld, the fathomless ocean, and the direction downstream towards the sea…" (Tjetiep et al., 1999, quoted from Black et al., 1993).

In addition to *Borobudur*, there are many other famous and inspired Buddhist monuments and temples in Indonesia whose architecture, originating from Hindu culture, was influenced (since the arrival of Hinduism at Bali around the 5th century A.D.) by the dominant volcanic nature and stone materials of the country: mostly andesite and then basalt; therefore, almost all important buildings in the country are made of andesite and other volcanic rocks. The *Borobudur*, for instance, is entirely made of a yellowish-brown andesite, including its hundreds stupas of different dimensions. The sub-conical shape of such stupas, their high number, and their different dimensions are thought to represent symbolically the volcanic landscape of Java. The same happens in other important islands, in particular in Bali, where the most sacred place in every one of its many Hindu temples is the shrine for offerings dedicated to the volcano, *Gunung Agung*. All this attests to the sacredness of each and all volcanic structures in Indonesia, and still today all high, active volcanoes are regarded as living features, each with its own spirit, and are thus worshiped as living, divine creatures.

At the same time, many Indonesian hot springs and fumaroles, often located in recessed areas or in tropical jungles on volcanic slopes, were considered as sacred features, and religious rituals were held in each of those places. In certain remote areas, these types of rituals are held still today.

Fig. 25*.* Borobudur*, the main Buddhist temple of Java and Indonesia, dated 800 A.D. Its central structure and all its hundreds of stupas, all sub-conical in shape, symbolize the 'land of volcanoes, heart of fire' (taken from Tjetiep et al., 1999).*

Finally, it is worth mentioning that, in addition to the almost general use of volcanic rocks to build houses and any other edifice, obsidian was also used in ancient times to create knife blades, points and other tools. Moreover, thermal springs were often frequented for medical cures, and sometimes also for pure enjoyment.

5.6. New Zealand (*Aotearoa*)

All natural resources of the country, including geothermal manifestations, were considered by the Maori as valuable treasures of divine origin, donated by the gods to humankind for wise use and custody. To preserve the environment on Earth for the benefit of the present and future generations, Maori gods inspired people of each organized community to elect wise persons to the position of *kaitiaki* (guardians) who were endowed with full, indisputable authority (*rangatiratanga*) over all natural resources. In particular, the rapport of the Maori with their transcendental world (i.e. the *taha wairua*, or 'spiritual dimension') "… did not allow improper use of, or disrespect for, physical resources to go unpunished..." (Severne, 1999); and many Maori legends and songs also highlight this dimension.

This is why all thermal springs and pools were sacred features for the Maori, and were used in ancient times for a number of ceremonies, including childbirth events for good wishes, washing of the dead, and burial of special people; whereas some warm pools were used by menstruating women for health reasons. One of the most famous thermal localities of New Zealand is *Orakei Korako* in the Taupo Volcanic Zone, where a series of step-faulted terraces covered by sinter deposits, geysers and hot pools exist and have been used for different purposes since early historic times (Fig. 26). Moreover, hot waters were used to punish guilty persons by scalding, and the boiling pools even to execute criminals and felons (personal communication to Cataldi by New Zealander colleagues during his first mission to that country in 1965).

Fig. 26. Orakei Korako *geothermal manifestations, Taupo Volcanic Zone, New Zealand. Sinter terrace (one of a series of step-faulted terraces on the Waikato River banks). Photo by WJV&DB - Photo taken by Wilma Verburg 2006/04/01, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=2954257.*

In short, all active geothermal manifestations were for the Maori an integral part of their spiritual and material lives; and this resembles the feelings and behavior towards similar manifestations held by many ancient peoples on Earth.

The way of thinking, organization of social rules and style of life of the Maori benefitting the natural environment had been protracted and consolidated for many centuries, since their arrival from Polynesia some eight centuries ago until very recent times. Therefore, to take them into account, special provisions have been introduced since 1840 in New Zealand legislation that made possible in the last decades the development of geoelectric generation on the North Island. This has required, for each new project, coming to a specific agreement with the local populations, aimed at establishing appropriate preservation measures of the thermal manifestations that the Maori consider sacred and venerate still today.

Apart from the transcendental rapport with all natural beings and physical features, in all places with external manifestations, the Maori harnessed extensively in past epochs the Earth's heat and its by-products. For instance, in the Taupo Volcanic Zone, they used geothermal heat and products for cooking, heating, bathing, healing (skin diseases, eczema, rashes, leprosy, arthritis, rheumatism and others), agriculture, preparation of red ochre and black dye, and extraction of sulfur and other hydrothermal minerals and thermo-mineral clays (Severne, 1999). These uses have evolved into more advanced forms of application in the last two centuries, and many of them have been adopted by recently immigrated people and their descendants.

One such form (different from geoelectric generation, started in New Zealand some sixty years ago and worth of mention) is the desiccation and seasoning of wood at an industrial scale by using high-temperature heat from the Earth.

5.7. Philippine archipelago

The Philippine archipelago consists of about 7,100 islands spread over the western margin of the Pacific Ocean, with a total extension of 1.8 million km^2; but the land area (300,000 km^2) has approximately the size of Italy or one slightly smaller than Japan (Ote et al., 1999). According to these authors, there are many legends and more than one old theory about the formation of so many islands, stating that the Philippine archipelago formed as a result of "...gigantic battles between the sea and the sky, with the latter raining rocks on the former to become the islands…" (Ote et al., 1999, from Jocano, 1969).

Independently from legends and old theories, investigators have recently tried to learn what kind of rapport the early Filipinos (about 12 million out of the 100 million presently populating the country) had with the geothermal manifestations. The investigation established that, since those 12 million indigenous people are fragmented into 110 ethno-linguistic groups of different origins, each with its own language and culture, and owing to the fact that they have been pushed from their native lands to remote, often jungle-like places on the slopes of steep mountains, written information on the use of the terrestrial heat in ancient times in the country is not available. Nonetheless, it is has been ascertained that all reference made by the early Filipinos to the "...fire or heat is usually associated with volcanoes, which (…) they (…) revered as homes for their gods and symbols of fair maidens in myth and legends. Many of these stories have been passed orally from generation to generation and are now found in the few books of Philippine mythology" (Ote et al., 1999).

It has been also verified that the Filipinos used boiling spring waters to cook slaughtered poultry and pigs, and steaming ground or fumaroles for steam-cooking rice and root crops. Moreover, it seems that ancient people used a mixture of oil and sulfur encrustations for medicinal purpose.

Concerning cults and traditions, the two most important volcanic structures of the country (Mt. Apo, the tallest peak, 2954 m, and Mt. Mayon, 2463 m, *see* Fig. 27) have been worshiped since prehistoric times, with ceremonies and offerings made periodically to each of them. They have also been (and still are today) the objects of learned legends and popular traditions.

***Fig. 27**. One of the most important 'historic' geothermal features of the Philippines: Mt. Apo (called the grandfather of Philippine volcanoes). Photo by Bro. Jeffrey Pioquinto, SJ - Flickr, CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=4320938.*

In short, harnessing the Earth's heat for functional uses seemingly played a minor role in the lives of the early inhabitants of the Philippines. Nonetheless, legends, customs, tales handed down from generation to generation, popular traditions, cults and ritual practices, consolidated through many centuries (or perhaps millennia), prove that the transcendental rapport of the Filipino communities with active, external manifestations of the Earth's heat was, and still is, deeply rooted in their minds and souls. This is why all initiatives launched in the past three decades to develop the plentiful geothermal resources of the country for electric generation have had to cope with that rapport and, to gain social acceptance from the indigenous populations, all operators have had to negotiate with local representatives details of the executions of their projects.

5.8. China

With over 3,000 thousand years of proven tradition in the balneotherapeutic use of natural hot waters (Wang Ji-yang, 1999), China shares with Greece the record for written historical evidence of this practice. Many diseases were treated in China with thermal baths from proto-historic epochs onwards, especially in the past three millennia. Thermal waters were harnessed in some places for domestic and agricultural uses, and (in less ancient and recent times) for relaxation and pleasure by the rich and elite; therefore, many holiday residences, and even some royal or aristocratic palaces, were built in sites with important thermal springs.

From the medical viewpoint on thermal balneotherapy, the contribution of Li Shi-zhen must be recalled (Fig. 28). He is a Chinese polymath of the 16th century (medical doctor, scientist, pharmacologist, herbalist and acupuncturist) who wrote a voluminous medical work, *Bencao Gangmu* (*Compendium of Materia Medica*), which represents a benchmark in the history of medicine and can be read in five languages (according to http://www.itmonline.org/arts/lishizhen.htm, page written by S. Dharmananda). On the importance of the thermal baths in medicine, Li Shi-zhen would often say: "If you get ill, go to a hot spring area and take a bath." (Wang Ji-yang, 1999).

In addition to thermal bathing, in inland areas far from the sea and salt mines, the water of some thermo-mineral springs with high total dissolved solids (TDS) were vaporized to extract common salt for domestic use. This happened, in particular, at Zigong, Sichuan Province, during the Han Dynasty (206 B.C.-220 A.D.), when those waters became the main sources of salt for southwestern China. For this reason, Zigong was given the name of the 'salt capital' of the country (Wang Ji-yang, 1999). However, intensive salt production from hot brines continued at Zigong for many centuries, initially extracted from springs and shallow holes dug manually to a few tens of meters deep, and afterwards (starting "…400 years before the Europeans…"), drilled to progressively increasing depths. It has referred that that in 1835 the well depth "…was about 3,300 feet…" (little more than 1,000 meters). Should this value be verified, much information on the progression in time of drilling technology should be revised [Zigong, https://en.wikipedia.org/w/index.php?title=Zigong&oldid=732603562 (last visited Aug. 3, 2016)].

Another wide use of thermal waters in China was in past times the preparation of drinks for ceremonies, toasts and other joyful occasions, namely tea, wine, beer and liquor (Wang Ji-yang, 1999). This author presents several examples of these uses but does not mention the process followed to prepare those beverages. We can only argue that some of them, when prepared with thermal waters, acquire peculiar tastes or aftertastes, depending on the mineral(s) or gases dissolved therein, and in other cases because at higher temperature liquids tend to vaporize and their smells are more pleasingly perceived by the olfactory bulb.

There are also a lot of myths and legends related to geothermal manifestations in China, a few of which are to be found in the paper by Wang Ji-yang (1999). On the contrary, concerning popular devotion for volcanic mountains or active manifestations, the author states that "…there were no divinity cults…" Which is surprising if it referred to ancient times when most people on Earth had already matured the spiritual need to believe in powerful natural features or in transcendental entities, ruling over the creative forces of the world. It is true, however, there were no volcanic eruptions in recent geologic epochs in most of the Chinese mainland, excepting the very northern part of the country in the Changbai-shan massif, near the boundary with present-day North Korea. Here, Mt. Paektu (considered a sacred mountain, and known also as Mt. Baitou, over 2700 m high) last erupted in 1597, resulting in the formation of a large crater with Lake Paradise inside it.

***Fig. 28**. Depiction of Li Shi-zhen. Image by Unknown - http://www.itmonline.org/arts/lishizhen.htm, Public Domain, https://commons.wikimedia.org/w/index.php?curid=18500756*

Finally, as to the genesis of the thermal springs, Wang Ji-yang (1999) states that the early people in China tried to understand the origin of the heat in the waters, and quotes what two great Chinese poets said in this regard: The first, Li Bai (701-762 A.D.), wrote that "Where underground fire exists, there must be hot springs"; and the second, Su Shi (1037-1101), wrote that "Where a fire-mountain exists, there would be boiling springs".

5.9. Japan

Archaeological excavations and finds verify that prehistoric Japanese people knew and frequented hot springs and other manifestations of the Earth's heat since about 200,000 years ago and all through the Late Paleolithic, Neolithic and Metal Ages (Sekioka, 1999). Afterwards, the use of such springs during historic periods is attested to initially by legends and myths related to that practice, and subsequently by old illustrations, sketch maps, learned accounts, religious rituals and written documents. The latter include the so-called *Fudoki*, which are the descriptions of the natural features of each Province ordered in 713 by the then-Emperor, made by the respective provincial authorities (Sekioka, 1999). In particular, this author provides an account on the use of natural hot water during the almost 11-century period of the five historic Eras of the country: *Heian, Kamakura, Muromachi, Azuchi-Momoyama,* and *Edo*, lasting from 794 to 1868. Therefore, the balneological tradition and culture of the modern Nippon is deeply rooted in their ancestral behavior and style of life, "…independently from the many changes in average climatic conditions that occurred in the country in the last 200,000 years, from warm and humid to cold and dry, and vice versa", as the quoted author states.

Dogo (located in the Iyo Province, now Ehima Prefecture) is reputed to be the oldest spring in Japan used for therapeutic baths by legendary or early historic emperors (Olsen, 2002).

During the historic Eras mentioned above, a lot of diseases were treated in thermal spas of Japan, including neuralgia, liver, hypertension, edema, lumbago, glycosuria, hemiplegia, internal fistulas, paralysis, gonorrhea, menopause, beriberi (deficiency of vitamin B), gout and others. Moreover, in the *Edo* Era (1603-1868), one of the most important spas of the period (i.e. Kinosagi, Hyogo Province) was selected for experimental studies on the therapeutic effects of the thermal waters, as a result of which a four-volume treatise on this subject was published in 1734 by the famous medical doctor Goto Konzan –with the help of Shuan Kagawa, one of his followers. The prescriptions given in this work are considered valid still today (Sekioka, 1999; Olsen, 2002).

Furthermore, in several thermal stations with mineral-rich water, hydroponic treatments were practiced to cure stomach diseases. This is why a certain "…Kondai Utsugi, by heating pulverized sulfur, alunite and arsenious sulfide in salt water, …claiming that his artificial water held the same medical benefits as the

Arima hot spring…" sold his product to patients who could not receive the cures directly at one of the many hydroponic stations then existing in Japan. The business, however, collapsed (Sekioka, 1999).

Other typical uses of thermal waters in Japan are brewing sake and preparing miso (a soybean, rice or barley paste).

Apart from the above, for curiosity we recall that the thermal pools of *Jikogudani* ('Hell Valley') on the island of Honshu are frequented by a breed of macaques (*Macaque fuscata*) which, having developed a thick and hairy coat, have adapted themselves to life in a high-mountain habitat with a harsh climate. Despite their coats, however, during particularly cold periods, the macaques come down in full winter from their habitual area and settle temporarily around the thermal pools to take restoring warm baths (Fig. 29).

Fig. 29. *A couple of macaques enjoying a warm bath in a thermal pool of Joshin Etsu National Park, Honshu, Japan (Photo by Gavin Hellier, taken from http://www.allposters.com/-sp/Japanese-Macaque-Baby-Soaking-in-Hot-Thermal-Spring-Pool-Joshin-Etsu-National-Park-Honshu-Japan-Posters_i6059731_.htm).*

On the other hand, the presence of many active volcanoes in Japan resulted in the formation of a lot of myths and legends on their origins, natures and eruptive activities, some of which are reported by Sekioka (1999). One of the most important legends refers to Mt. Aso, on the island of Kyushu. It is an active stratovolcano with one of the largest calderas in the world (about 120 km diameter!), which has "… influenced not only the physical lives of the people but their imaginations, as well…" (Sekioka, 1999). In particular, since people were convinced that the volcano was the abode of the God of Fire, and that each of its eruptions was attributable to the God's anger for some wrong they had committed, the mountain was worshiped profoundly, with a Shinto shrine of the first class built in his honor in the 4th century A.D. Furthemore, over 400 additional shrines of a lower class exist in Kyushu to worship Mt. Aso and other volcanoes.

In general, the spiritual influence of volcanoes on Japanese people started to form likely in very early historic times, consolidated in tens of centuries and lasted until modern times in many areas. Mt. Fuji, the highest volcano and peak of the country (3776 m), has many worshiping sanctuaries; the most important of which (Fig. 31) is located nearby. Other symbolic images related to volcanoes in Japan are *Izanagi* and *Izanami*, creators of the Japanese archipelago, and the flying dragon. Mt. Fuji, in particular, a feature of the Earth's heat, "…has been for centuries, and is at present, the symbol of the Nippon nation …" (Bernstein, 2008).

5.10. Iceland (Ultima Thule?)

There are several learned accounts about the discovery of this geologically young volcanic island, which somebody in Antiquity referred to as the Ultima Thule, the legendary 'last' land located beyond any inhabited territory known to the north of Britannia.

The main accounts are: **i)** the sighting in 325 B.C. ("…after six navigation days from Britannic coasts…", Strabo states in his work *Geography*) of the cliffs of Ultima Thule by Pitea, the great Greek geographer and navigator who started from Massalia (Marseilles, southeastern France) to explore the northeastern coasts of the Atlantic Ocean and make observations on the length of the days at different latitudes. Based on the description by Pitea in his work The Ocean, Eratosthenes, the other great Greek geographer and astronomer who first calculated the circumference of the Earth and drew the first geographical map of the world, positioned Thule to the northeast of Britannia; **ii)** one of the interpretations given to the discovery made between 1905 and 1993 of six Roman coins of the 3rd century A.D. in different sites of the eastern and southern coasts of Iceland. On their base a lost Roman boat would have arrived in that period in Iceland; and **iii)** the sighting, in the late 5th or early 6th century A.D., of a "…land of fire and ice, where the sun never sets…, at the gates of hell…" by St. Brendan and a group of Irish monks (Fig. 30), who sailed that part of the North Sea in search of populated islands aimed at converting people to Christianity (see *Navigatio Sancti Brendani*, by an unknown Irish author of the 16th century).

However, according to Fridleifsson (1999), St. Brendan and his followers perhaps "…witnessed a volcanic island emerging out of the ocean, most likely during a submarine eruption of the Reykjanes ridge…"

Without entering into discussion on those above and other accounts on the possible discovery of Iceland before 800 A.D., the fact remains that the country was uninhabited until the landing of some Vikings in the last decades of the 9th century A.D. Therefore, no contact could have happened before the Viking colonization by local people with geothermal manifestations. Thus, the human-Earth's heat rapport in Iceland could only start to form in the 'Age of Settlement' (870-930).

***Fig. 30**. St. Brendan in his 7-year-long maritime journey in the North Sea (Taken from: http://www.history.com/news/did-an-irish-monk-discover-america).*

From that period onward, for a number of centuries, the use of geothermal resources in Iceland was probably limited to bathing in moderate-temperature waters, farming vegetables in warm soils, and "…. bending wood and bones, and softening materials in hot water…" (Fridleifsson, 1999). Subsequently, boiling waters were used to cook eggs, fish, meat, milk and vegetables, whereas steaming grounds and fumaroles were used to bake bread and for saunas. Furthermore, from a report by T. Thoroddsen (Icelandic geographer, 1855-1921), it seems that in certain places, beginning perhaps in the 16th century, "…people diverted hot water into fields where they grew potatoes and cabbage, significantly increasing the vegetable yield…" (Fridleifsson, 1999).

Two more important uses of geothermal resources should be recalled. Between 1350 and 1760, yellow sulfur was mined from the country's plentiful deposits and exported to southwestern Europe for pharmaceutical and gunpowder production. Salt was produced near Reykjanes (in northwestern Iceland) by using the boiling springs of the area to evaporate marine waters. For technical and commercial reasons, the salt project never had the importance of sulfur mining and lasted for only four decades, from 1753 to 1793.

Finally, for more recent epochs (until the end of the 2nd World War, the upper limit of time considered in this paper), and taken from Fridleifsson (1999), the following applications of the Earth's heat in Iceland are worthy of mention:

- 1930: First milk-pasteurization dairy for production of cheese;

- 1938: Experiments of drying hay by using geothermal steam;

- 1939-1941: Installation of a plant to dry seaweed with geothermal steam; and

- 1944: First pilot geo-power plant in Iceland.

5.11. North America

• General (Canada and USA)

As stated in Chapter 2, the colonization of the Americas began about 50,000 years ago by populations who arrived from Siberia through the iced Bering Strait, and who progressively moved southwards. Some of them may have had in their original land, and brought from the 'old' to the 'new' continent, experiences and memories on phenomena, manifestations and uses of geothermal energy; therefore, when they met similar manifestations and happened to observe comparable phenomena in the new land, their approach to the Earth's heat was facilitated in a number of cases. Most times, however, the first contact with such types of phenomena and manifestations happened very likely in the 'new' land, and the rapport between migratory populations and geothermal energy developed in an autonomous way.

Without excluding that some immigration waves to the 'new' world may have happened by sailing along the North Atlantic and North Pacific coastlines (see Chapter 2), with reference to the migration flows that occurred overland via Beringia, the specialists have verified that, once arrived in North America, the migratory groups followed different routes for their migration towards the south and southeast (Lund, 1999), and the main ones are shown below (Fig. 31). Lund (1999) gives many details on the succession of the different migratory waves from 40,000 to 5,000 years ago, when "…the ancestors of the present-day Eskimos arrived from Asia…" The so-called 'Old North Trail' has been probably the most important migratory path between 10,000 and 2,000 years ago; but it was also a trade route in the opposite direction for "…carrying obsidian and chert from quarries in Wyoming and Montana to Canada… and is now under consideration as an entry in the National Register of Historic Places…" (Lund, 1999).

All the above, jointly with archaeological finds dug up near hot springs and in other places with geothermal manifestations, as well as the aforementioned transport along thousands of kilometers of obsidian and chert, attest to the fact that the Native Americans knew already, and had began to deal with, phenomena and manifestations of the Earth's heat well before 10,000 years ago.

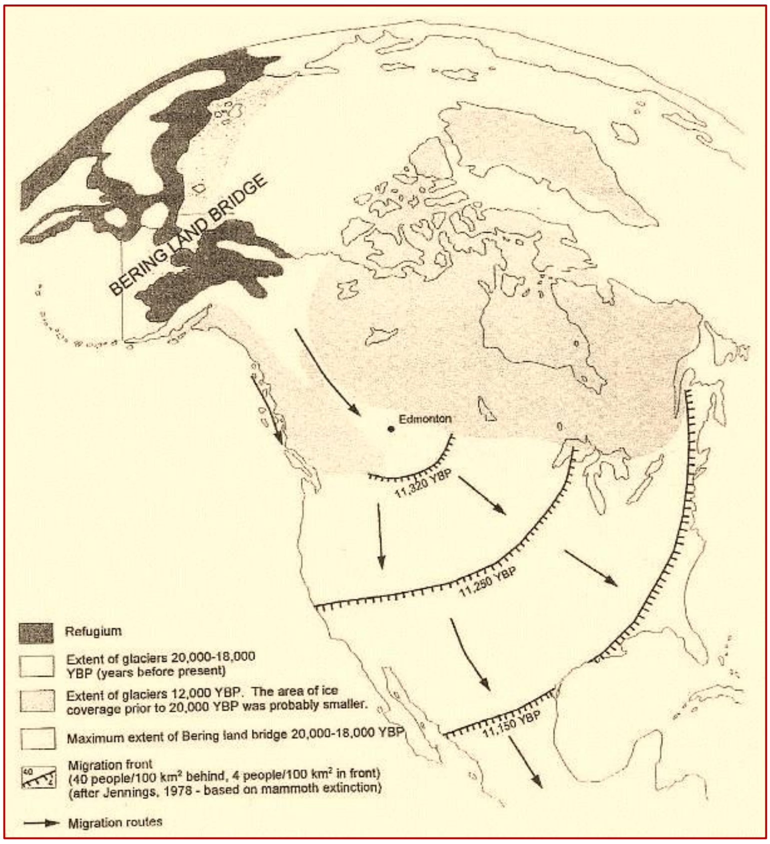


Fig. 31. *Main migration routes from NW Asia to America (after Jennings, 1978; in Lund, 1999).*

The places where such dealings occurred, and the rapport established between local people and geothermal energy, were mostly located in the western sector of North America, from Alaska-Canada in the north to California-northern Mexico in the south. The earliest documented sites frequented by Paleo-Indians of active geothermal manifestations (including hot springs, fumaroles, hydrothermal encrustations, etc.) are: Alvord Lake and Fort Rock Cave, Eastern Oregon; Tule Springs, Nevada; Lindenmeier, Colorado; Clovis and Folsom, New Mexico; and Borax Lake, California. All these places date back from 11,000 to 9,000 B.C. (Lund, 1999). Moreover, it has also been proven that the Paleo-Indians used also some isolated thermal springs found during their initial colonization of the middle and eastern sectors of North America (Lund, 1999).

After this period, Paleo-Indians were replaced by the Indians proper, represented by specialized hunter-gatherer cultures. Though split into hundreds of tribes with different names and languages (Apache, Cherokee, Cheyenne, Dakota, Mohicans, Sioux, etc.) these cultures dominated North America until the arrival of the European colonists, starting from the early 1700s in the east and around the mid-1800s in the west (Lund, 1999).

The rapport that all Indian cultures established with geothermal manifestations, especially hot springs and fumaroles, was based on the belief that, being 'different' from any other natural feature, each of them must have had a sacred nature.

Consequently, any site with a geothermal manifestation was in itself, by proper nature, a sacred place where no battle, conflict, dispute, fight or controversy could happen. Thus, any area with manifestations of the Earth's heat was a 'neutral' place for all Indians, where anybody could enter, renew energies and rest. This concept, in turn, represented one of the mysteries of the Indian transcendental universe, which they called *Wakan Tanka* (Great Mystery, Ultimate Mystery, Great Sacredness, The Unknowable, and the like) (Lund, 1999).

It is clear from the above why the American Indians were convinced that each thermal spring and natural hot manifestation was intrinsically endowed with peculiar healing properties. Therefore, all major hot springs of North America (both in Canada and the United States) have a record of being visited by native Indians, with specifications of the respective cures.

Moreover, from the transcendental concept on the nature of geothermal manifestations (including not only hot springs and fumaroles, but also volcanic structures and eruptions, hydrothermal encrustations, protrusion domes, earthquakes, etc.) one can grasp why a lot of legends were formed around them by the American Indians and were transmitted orally through hundreds of generations, probably in their original versions with no substantial modifications. Those legends were, in fact, likely perceived as essential components of their cultural identity (their own 'life-blood', we could say), and a number of them are still recounted today by indigenous people. Other legends, on the contrary, were probably distorted or modified by early European settlers according to their interpretations of the tales heard from native peoples in their original versions.

At any rate, in his extensive and well documented paper quoted above, Lund reports a number of geothermally related legends of North America. In addition to that of Pele, presented in a detailed and appealing fashion (see its summary in section 3.4, with Fig. 12), Lund summarizes six other beautiful legends concerning: i) the Battle of Llao and Skell (Oregon); ii) Mt. St. Helens (Washington); iii) Mt. Hood (Oregon); iv) Sleeping Child hot springs (Montana); v) Lolo hot springs (Montana); and vi) White Sulfur springs (West Virginia). They all describe the occurrence of geothermal phenomena and manifestations of the Earth's heat in an etiological way, and have become for this reason the objects of study in the new discipline called *geomythology* (Harris, 1990). This recent, investigatory branch has been taking root for a couple of decades with the purpose of analyzing the cultural backgrounds of ancient myths related to natural events, including (but not limited to) volcanic eruptions and earthquakes, hydrothermal explosions, geysers, fumaroles, hot springs and other geothermal manifestations.

As to the geothermal by-products, we should first recall the extensive use of obsidian to make arrow points, knives and several domestic tools. Rich deposits of this material exist in many present-day states of the western USA, including California, Colorado, Idaho, Montana, Nevada, Oregon, Texas, Utah and Wyoming, in a variety of compositions, structures and textures. However, the most important deposits of obsidian, harnessed for over 10,000 years by the American Indians, were those of the Basin and Range Province, outcropping in the many 'glass mountains' of California (Medicine Lake, Napa Valley, etc.), Oregon and Utah. Other rich deposits of obsidian harnessed by American natives are those of Yellowstone National Park (Wyoming-Montana).

For the definition of 'glass mountains', however, we must note that while most of them correspond to plentiful outcrops of obsidian (Fig. 32, left), in some other cases the name comes from the presence of different 'glassy' minerals of sedimentary origin; this is the case, for instance, of Oklahoma's Glass Mountain (Fig. 32, right) where Permian evaporitic gypsum layers outcrop with mirror-like selenite crystals.

Depending on its texture and color (black, green, pink, etc.), obsidian was highly priced and widely traded in the entire western and central USA and in southern Canada, in the present-day provinces of Alberta and British Columbia.

An extensive description on the uses and symbolic meanings of obsidian for California Indians is given by Hodgson (2007).

Other geothermal by-products widely used by the American Indians of Canada and USA were: cinnabar and yellow sulfur for dyeing; basalt and flint to make weapons and domestic tools; and flint and chert for various applications. In particular, among the cherts, the Arkansas stone was mined for centuries and used by certain indigenous tribes of Arizona and Texas for bartering with nearby populations. This rather infrequent geothermal product is novaculite, a microcrystalline form of quartz, grey-to-black in color, with an even and uniform texture owing to low-grade metamorphism, rather hard and very resistant to erosion. Therefore, the novaculite deposits (found in the form of masses, lenses, or contorted layers depending on their age and tectonic history) usually outcrop in relief compared to the embedding formations and can be easily seen. Novaculite was used in the past to obtain "…arrowheads, spearheads and tools. Europeans mined novaculite to make whetstones… it is still mined outside (the protected areas), and… is highly priced for its uniform sharpening characteristics" (Lund, 1999). In recent times, due to its supposed healing properties, this mineral is used to alleviate psychic and mental problems.

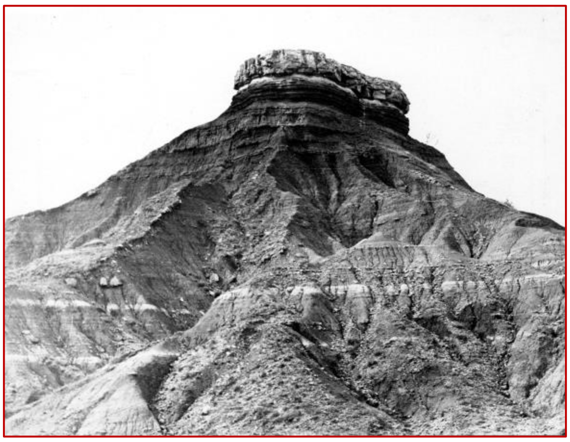


***Fig. 32**. Two types of 'glass mountains'. Left: vesiculated obsidian of the Obsidian Dome, Valles Caldera, New Mexico (Photo: Unknown USGS source. Taken from: https://volcanoes.usgs.gov/volcanoes/long_valley/long_valley_sub_page_19.html). Right: Permian sandstones with evaporitic gypsum layers and selenite at the top, Major County, Oklahoma [USGS photo by George Irving Adams, 1900. Taken from Glass Mountains, https://en.wikipedia.org/w/index.php?title=Glass_Mountains&oldid=732858699 (last visited Aug. 4, 2016)].*

Since 10,000 to 200-300 years ago, frequenting hot springs and steaming grounds was a habitual practice of all USA and Canadian Indian tribes south of the line of the permanent ice-shield. This practice was made not only for balneotherapy purposes but also (or perhaps mainly) for religious reasons.

In fact, all native populations of North America considered sacred all places with thermal manifestations, where they went alone or in groups to reflect and concentrate in profound absorption and personal communion with their transcendental spirits. "…In native traditions, Heaven, Earth and human consciousness were bound together in a rhythm of life, a sense of wholeness…" (Lund, 1999). This is also why areas with thermal manifestations and hot springs were considered neutral places, where one could recuperate from battle, rest, or regenerate physically, mentally, and spiritually. This special rapport between Indians and thermal springs or steaming grounds formed in all American places where such types of manifestations existed; and in fact they were "…guarded jealously, kept secret from the Europeans as long as possible; …sometimes battles were fought between Indians and (European) settlers to preserve these rights…" (Lund, 1999).

After the cited arrival of the European colonists, the rapport above continued on the Indian reservations only. Outside the reservations, to the contrary, some thermal and mineral springs were reorganized in the style of the European spas; therefore, a few of them had a good success until 1930 approximately. The most renowned of these spas were: Saratoga Springs (New York), White Sulfur Springs (West Virginia), Hot Springs (Virginia), Warm Springs (Georgia), Hot Springs (Arkansas), Calistoga (California), and Harrison Hot Springs in British Columbia, Canada (Lund, 1999).

• The Geysers

Though hidden in Prehistory by thick forests, the imposing manifestations (boiling springs, fumaroles, steaming grounds, and perhaps also geysers) of the present-day The Geysers area could not go unnoticed by the early immigrants arriving in Northern California some 12,000 years ago. This is, in fact, the age that, based on archaeological studies and local finds, has been estimated for the arrival of the Paleo-Indians in the region and their initial colonization of the area (Hodgson, 1999).

The names of the tribes that settled in the area permanently (perhaps starting from 10,000 years ago) are not known; but "…by the mid-1800s, when so many settlers came, six Indian tribes lived … around the 'The Geysers' area … (Fig. 35). All spoke different languages, had distinct cultures, and lived in well defined areas..." (Fredrikson, 1974). In common, however, they had the knowledge of the geothermal manifestations of the region and could frequent them at their pleasure. In fact, "…trails open to all the tribes crisscrossed The Geysers, some leading to the hot springs and fumaroles for healing purposes; but they may have had ceremonial significance, as well…" (Fredrikson et al., 1978; in Hodgson, 1999).

On the ancient use of the geothermal heat for therapeutic applications in 'The Geysers' area, we should mention the steam structure illustrated by the watercolor sketch shown in Figure 33, which "...was left standing by the Indians above some fumaroles at Geyser Canyon. The Indians placed hides across these structures and sat beneath them, basking in the trapped steam..." (Hodgson, 1999).

Fig. 33. *Watercolor sketch of a thermal structure built by the Indian natives above some fumaroles in The Geyser area (courtesy of S. Hodgson).*

Besides frequentation for balneotherapeutic and religious reasons, the hot geothermal manifestations were used for cooking and as sources of hydrothermal minerals, like soda and sulfur. By evaporating hot spring waters, the Wappo Indians (and probably other tribes) gathered a mineral-rich residue they called *te-ke* ('sulfur salt') and added it to one of their staple foods, called acorn bread (Hodgson, 1999).

All uses mentioned above date likely back to the period of stable settlement of the American Indians in Northern California (around 10,000 years ago, as said above); but they must have had a substantial continuity for millennia because they were fully alive around the mid-1800s when the Europeans arrived in the area.

With such arrival, all those uses began declining, but the number of tourists attracted by the natural features of the region started to increase. Thus, a hotel named 'The Geysers Resort' was built around 1855 just in front of the Geysers Canyon with a spectacular view of the geothermal manifestations (Fig. 36/b). For several reasons, however, the initiative had not the expected success.

Additional, stimulating details on the historic aspects of this important geothermal area are to be found in Hodgson 2010.

5.12. South America

There is a notable discrepancy among different sources about the period of the first appearance of *Homo sapiens sapiens* in South America. Most sources indicate 10,000-15,000 years ago, but others maintain that the beginning of the colonization by humans of the Andean Cordillera dates to 50,000 and perhaps 70,000 years ago (Rico Calderón, 1999, and some authors quoted therein: in particular Ibarra Grasso, 1956, and Ibarra Grasso-Querejazu, 1986). The archaeological finds discovered at Viscachani (Bolivia), Taltal (Chile) and Patagonia (Argentina) include scrapers, arrowheads, axes and other stone tools obtained from volcanic rocks, whose age is thought to be 30,000 years by those authors. Furthermore, "…radiocarbon dating of organic materials of human populations found in those places (indicate) about 37,000 years ago..." (Rico Calderón, 1999).

All sources, however, agree on the Asiatic origin of the South American colonizers; but the way followed to reach South America (if solely by land via Beringia-North America-Mesoamerica, or also by sailing along the North Pacific coast) is an open issue. For quick information in this regard, the interested reader may wish to consult Native American Origins/South America First People -Prehistoric Human Migrations in the Americas-; Permalink, Wikipedia free encyclopedia.

• Prehistoric times

In addition to the stone artifacts found in the localities of Bolivia, Chile and Argentina mentioned above, we must first recall that one of the most ancient quarries of hydrothermal minerals known in the world is that of red ochre at Taltal, located on the Pacific coast of Chile and dated 10,000 years B.C.

***Fig. 34**. 'Cave of the hands', Santa Cruz, Patagonia, Argentina, dating to over 10,000 years ago (Photo by Mariano - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=265811).*

Moreover, we should quote the presence in the Santa Cruz Province of Patagonia, Argentina, of one of the most beautiful sites on Earth with prehistoric pictograms indirectly related to geothermal energy; it is '*Cueva de las manos*' (Cave of the hands), included on the Unesco World Heritage List. The site consists of a large rock shelter forming a kind of amphitheatre before the entrance of the cave proper, with the walls and ceilings of shelter and cave 'printed' with hands of various sizes, thickly mixed with different types of figures: circles, ovals, stars and animals of distinct species. 'Printing' was achieved in the negative, by pressing on the rock wall hand palms (or other forms of figures) dipped in the color chosen for each case, with mostly left, not right, hands of young people (Fig. 34). This has suggested that the handprints might have had a ritual significance.

Looking at those prints carefully, one can distinguish "…five concentrations of rock art, figures and motifs, often superimposed upon those from earlier periods. The paintings were executed with natural mineral pigments, including iron oxides (red and purple ochre), kaolin (white), natrojarosite [$NaFe_3$•$(SO_4)_2$•$(OH)_6$, yellow], manganese (black), ground and mixed with other form of binders…" (Cueva de las Manos, https://en.wikipedia.org/w/index.php?title=Cueva_de_las_Manos&oldid=732238796, last visited Aug. 11, 2016). It can be seen that most of the pigments above could be derived solely from geothermal by-products. The age of these 'prints' ranges between 9,000 and 10,000 years ago approximately.

Concerning colonization of South America, it is worth recalling that at Los Toldos, not far from the Cave of the hands, another archaeological site has been discovered recently, whose finds indicate that a number of people were settled there about 13,000 years ago.

It should be mentioned also that petroglyphs depicting children's hands made 'in the negative' and by using the same pigments cited for the Cave of the hands have been found also in other volcanic areas of South America, as for instance at Tutakachi, Bolivia. This confirms that the practice of imprinting hands by young people in geothermal localities may have had a ritual meaning.

The aforesaid cultures, and many other regional cultures that grew in the western sector of South America over 10,000 years before the Inca Empire, probably developed a tight rapport of coexistence with active volcanoes and thermal manifestations of the Andean Cordillera. Spectacular Quaternary manifestations, like those of El Pilar-Casanay (Venezuela), Cerro Negro-Tufiño (Colombia-Ecuador), Laguna Colorada (Bolivia), El Tatio (Chile) and Domuyo (Argentina), could not pass unnoticed by the colonizing populations (Figs. 38); and in fact many prehistoric settlements with a lot of volcanic stone artifacts and other finds indicating the use of hydrothermal products have been discovered in these places and in many other Andean sites where geothermal manifestations exist.

Tools of volcanic rocks, settlements near thermal springs, bathing in hot waters, harnessing hydrothermal minerals for dyeing and other functions, presence of an uninterrupted series of active volcanoes, and occurrence of frequent earthquakes, lead us to think that the rapport formed between humans and geothermal energy in pre-Inca times in the western sector of South America must have been strong and continuous for at least 10,000 years. All the more so, if one considers that, besides the functional uses noted above, a number of legends arose in that period about many volcanic mountains, eruptions and tectonic earthquakes and other geothermal features.

At the same time, since volcanoes and all paroxysmal phenomena of the Earth's energy were thought to have divine origins, cults and devotion ceremonies for volcanic mountains could have arisen since early prehistory and consolidated in many millennia within all main cultures of the region.

Machu Picchu, meaning 'Old Mountain', 2430 m height (Fig. 39), is a faulted block of a Paleozoic batholith (not a volcano) near the Inca capital of Cuzco. It was founded around 1440 by the first Inca Emperor, *Pachacuti*, to establish there the royal summer residence; this is why it was promoted to become, and represented until the fall of the Inca Empire, the sacred mountain par excellence of the Andes. However, other sacred mountains existed in the Andean region for many thousands of years, one of which was Sajama, a now quiescent volcano (6542 m) in Western Bolivia, where the renowned 'Sajama lines' were etched into the earth during countless generations before the Inca period.

They are many thousands of nearly perfect straight paths, 1-3 m wide and up to 2 m deep, each from few to over 20 km long, etched into the ground by indigenous people living on the slopes of the Sajama Volcano. The significance and function of these lines (whose total area and length exceed 22,000 km^2 and 16,000 km, respectively) is still a debated issue; but most scholars are prone to think that they represent directional paths for devotional pilgrimages towards the sacred volcano of Sajama, with a number of convergence points for letting different groups of people gather and where, perhaps, small sanctuaries were located (for quick information, see: Machu Picchu, https://es.wikipedia.org/w/index.php?title=Machu_Picchu&oldid=92624301, last visited Aug. 11, 2016).

On the religious attitude of the prehistoric Andean populations, Rico Calderón (1999) writes: "…the first religious feelings in the Andean region probably developed after observing exceptional natural events. The tremendous force of volcanic eruptions and earthquakes contributed to the formation of popular beliefs in the existence of supernatural forces ruling over these phenomena. Early Andean populations probably believed in, and revered superhuman entities capable of triggering or stopping, at will, volcanic eruptions and earthquakes…"

Fig. 35. *Machu Picchu and its ruins (Photo by De icelight from Boston, MA, US - Before Machu Picchu, CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=420058).*

• Inca period

Before the Inca domination, many tens of cultures had flourished autonomously in western South America between 8,000 years B.C. and 1,200 A.D. (Rico Calderón, 1999; Fig. 36); but they had grown isolated from one another, with limited trade among them to barter goods not available locally. Such cultures, therefore, were independent but intrinsically weak.

This is why a small Inca tribe (a pastoral but ambitious community living around the ancient village of Cuzco, Peru) could strengthen easily and start its affirmation in the first decades of the 13th century, ruled by *Manco Capac*. However, the true strengthening and notable expansion of the Incas started in 1438, under the warrior king *Pachacuti*, who affirmed himself and took power as *Sapa Inca* (meaning 'paramount leader' and also 'earth shaker'). The allusive name, associated with the recurrent and strong geodynamic events of the region, are enough to let us imagine his determination in expanding the Inca rule over nearby territories during his 25-year reign between 1438 and 1463.

Afterwards by different means, including 'invitations' to the leaders of other tribes to join the Inca political system, progressive assimilation of appealing nearby cultures, but mostly through military conquest, the Inca domination quickly increased in most of the Andean Cordillera and adjoining lowlands until the Pacific Ocean –over 5,000,000 km²: a huge amount of territory.

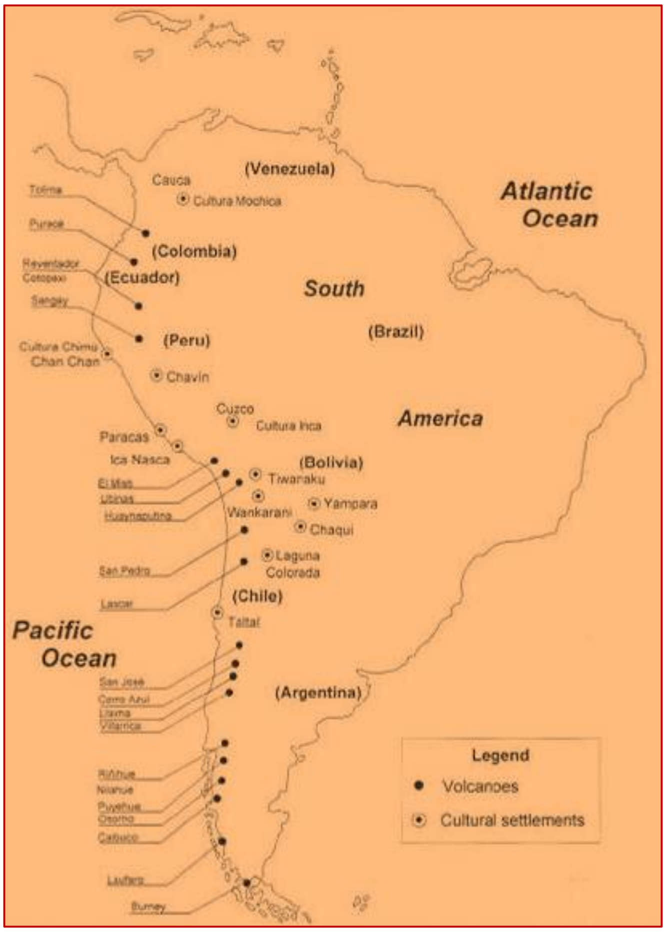


***Fig. 36**. Main volcanic complexes and principal prehistoric and Inca cultural settlements (after Rico Calderón, 1999).*

Money did not exist at that time in South America and trade was based only on an exchange of goods. Therefore, in the Inca system, the tributes to the Emperor had to be paid periodically in the form of precious stones or highly valued metals; but when some tribes could not pay the exorbitant tribute established by the Emperor, they had to provide an equivalent value of manpower for hard work in areas and for activities solely decided on by the central government. As a consequence, it is easy to imagine the social and cultural impacts of such a tributary system on all South American cultures other than Incas.

At any rate, many monuments, fortifications and hydraulic works, public buildings, residences for high-ranking dignitaries and a huge network of roads (over 30,000 km!) were built in the territories under Inca domination between 1440 and 1530. Such activities facilitated the temporary amalgamation of many languages, cultures and peoples. The new road network, in particular, enabled the connection of many regions along four main branches departing from Cuzco, each integrated by many local ramifications letting people and soldiers reach countless remote towns and villages. This resulted in an intensification of traffic, exchanges of experiences on various processing technologies and flows of information about different popular customs and traditions.

This is why the Inca network of roads (called the *Qhapac Ñan* Andean Road System), was registered in 2014 on the Unesco World Heritage List. It includes "…273 component sites spread over 6000 km (in Colombia, Ecuador, Peru, Bolivia, Chile and Argentina) … selected to highlight the social, political, architectural, and engineering achievements of the network, along with its associated infrastructures for trade, accommodation and storage, as well as sites of religious significance…" (Unesco, http://whc.unesco.org/en/activities/65/).

The road network linked all important areas with the geothermal manifestations of the Andean Cordillera; thus, all by-products of the Earth's heat took advantage during the period of the Inca rule in terms of increased exploitation, trade and utilization. This concerned in particular: many types of igneous rocks (andesite, basalt, diorite, etc.) for building purposes; obsidian to obtain knife blades, arrow points, scrapers, mirrors and other tools; metallic ores (gold, silver, copper, etc.); hydrothermal minerals, especially yellow sulfur and iron oxides; semi-precious stones (agate, amethyst, crystal rock, flint, onyx, opal, tiger-eye, etc.). All precious metals and stones were not harnessed for trade but to gather the tribute due by local tribes to the Emperor.

Thermal balneology was well developed during the period in question. This is verified by important Inca finds discovered in present-day Peru (Cuzco and Cajamarca), Bolivia (Tarapaya), Argentina (Huscarán and Puente del Inca) and other countries. In this regard Rico Calderón (1999) writes: "… these findings give direct proof of the care, knowledge, appreciation and value that the Incas granted the hot springs because of their healing properties…" We should observe, however, that the Inca social system was strongly centralized and vertically structured, with at least five governing levels; thus the people at large had almost no time or opportunity to enjoy thermal baths. Consequently, balneology with hot natural waters was solely a prerogative of the elite.

Many legends related to geothermal energy also existed during the Inca times, scattered over the entire territory of the Empire. Some of them (seemingly derived from older accounts locally emerged since prehistory) are briefly mentioned by Rico Calderón (1999), who gives several references on the issue: Emmerich (1966), Terán Erquicia (1966), Arguetas (1970), and Lara (1973).

For cults and religions related to volcanoes and other geothermal features of the Andean region, we should first recall that, since the start in 1438 of the systematic expansion of his dominion, *Pachacuti-Sapa Inca* immediately devised the idea to impose the adoption of the Inca language and religion in all conquered lands. Moreover, believing himself to have divine origin, he considered himself a descendant of *Inti* (the Sun), son of *Viracocha* (or *Pacha-Camac*), creator of the world and of all Inca gods. Therefore, probably taken from previous empires of Mesoamerica, *Pachacuti* legalized officially the divinization of his role and proclaimed the cult of the Emperor as one the most important Inca cults. Besides Inti, other main gods of the Inca cosmology were *Quilla* (the Moon), *Pacha Mama* (Mother Earth), *Mama Cocha* (Mother Sea), *Apu* (God of Mountains) and *Illapa* (God of Strikes). In Figure 37, *Inti* and *Quilla* (seen in the upper part), and *Pacha Mama* and *Mama Cocha* (visible in the lower part), are represented with round-shaped symbols to signify their special importance for the Inca religion.

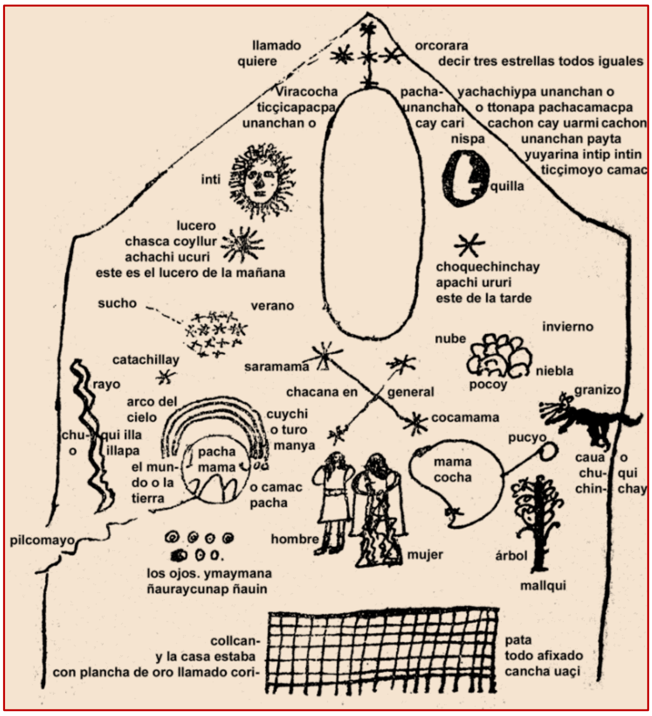


Fig. 37. *The Inca cosmology according to Santa Cruz. [Figure from: -Orig. Santa Cruz Pachacuti Yamqui Salcamayhua, Juan de (1613). Relación de las antigüedades deste Reyno del Piru. (Secund.) Marcos Jimenez de la Espada (ed., 1879). Tres relaciones de antiguedades peruanas. - Madrid, Imprenta y fundicion de M.Tello. p. 257, Dominio público, https://commons.wikimedia.org/w/index.php?curid=31765998].*

In addition to the cults of the gods, and of the living and dead emperors, many other divinities were worshiped by the Incas between 1438 and 1533, including the *huacas*. They were any peculiar natural features, such as high mountains with permanent snow caps, special rivers and lakes, strange beasts, old trees, and geothermal manifestations of any nature. Among the latters, volcanoes, fumaroles, steaming grounds, hot springs, and hydrothermal encrustations were special *huacas*, objects of devotional rites, with special offerings made, including many human sacrifices. The Payachata twin volcanoes of Chile-Bolivia, the Chimborazo and Cotopaxi volcanoes in Ecuador, and the so-called 'sacred tears' (*Wakai Willca*, now Mt. Verónica) in Peru are a few examples in this regard. Several other examples of cults and myths related to geothermal features in South America can be found in Rico Calderón (1999).

• Hispanic and recent times

After the *Sapa Inca* Huayna Capac died in 1527 from smallpox during an expedition in Ecuador, a dynastic dispute arose on his succession between his sons Huáscar and Atahualpa, step-brothers. Two opposite groups then formed inside the royal family and the ruling class, with two armies and two capitals: one in Cuzco, legitimately governed by Huáscar, and the second at Tumebamba (Inca city-state near modern Cuenca, Ecuador), led by Atahualpa. A series of struggles and harsh battles followed, together with a merciless civil war that lasted until mid-1532. Atahualpa was the winner; but the political integrity and the military strength of the Inca Empire were much weakened. This is the main reason why Francisco Pizarro, commander of the small battalion authorized by the Emperor Charles V of Spain to colonize that part of South America, could start the conflict with Atahualpa in late 1532 and win it in the autumn of 1533.

Four decades followed of guerrilla by Inca resisters retreated in a remote jungle area, where the new capital (Vilcabamba) was founded in 1539 by Manco Inca II, the top leader. He was succeeded by his son Túpac Amaru, with whose death in 1572, the Inca Empire ended.

An attempt of rebellion by Inca groups to the Spanish dominion, made in 1780-1781 and headed by Túpac Amaru II, last descendant of the *Sapa Incas*, could not have, and had no success. From him the name was taken in the 1960s by the insurrectional movement known as *Tupamaros* that operated in Uruguay until 1972-73 and finally was a part of the political coalition known as Frente Amplio in 1989. The popular former President of Uruguay, José Mujica, used to be a conspicuous leader of the movement [Tupamaros, https://en.wikipedia.org/w/index.php?title=Tupamaros&oldid=734750788 (last visited Aug. 25, 2016)].

Therefore, starting from 1533, in the framework of their rules, the Spanish conquistadors (through several missionaries who had followed the initial and the subsequent expeditions) developed an extensive evangelization campaign to convert to Christianity all ethnic groups of the region. As a consequence, most cults of the Inca and other local gods, and of the many sacred mountains of the Andes, volcanoes and other geothermal manifestations, including the *huacas* and any other natural worshiped features, were quickly replaced by the Catholic religion.

At the same time, with the radical change of governmental organization and the substitution of all Inca officers with Spanish officers, all buildings and structures equipped with spa facilities were seized and modified, resulting in a substantial decline of thermal balneotherapy and resort practices that had flourished in the previous three centuries, developed mostly for the elite.

The main myths and legends originated since pre-Inca times from geothermal manifestations and phenomena survived within the indigenous populations of each region. Thus, a number of such legends and myths were recounted to, and recorded by Spanish and Spanish-Inca chroniclers and religious missionaries; but some myths and legends underwent interpretations, modifications and (perhaps deliberate) distortions. Therefore, they probably lost with time their genuine spirit of popular culture.

The paper by Rico Calderón (1999) quotes several authors on this and other historical aspects of the period and region under review, among whom the most important are probably Cieza de León (1550), López de Gomára (1553) and Garcilaso de La Vega (1609).

After the final subjugation of the Inca Empire, the only significant activity related to geothermal energy in the western sector of South America was the exploitation of valuable metals (gold, silver, copper, zinc, lead, tin, etc.) for export to Europe; and hydrothermal minerals (native sulfur, iron oxides, cinnabar, lithium-sodium-potassium-magnesium chlorides and sulfates, etc.) and igneous rocks with related volcanic by-products for building in many South American localities.

Famous mines of metallic ores in pre-colonial and colonial times in the Andean Cordillera were located in the present-day countries of Bolivia (Potosí) for silver; Peru (Cuzco and Ica) for gold and zinc; Ecuador (Zaruma and Portovelo) for gold; and Chile (Chuquicamata and La Coipa) for copper and silver. Even more famous since prehistory for salt exploitation are the two endorheic, high-altitude, salt flats of Uyuni and Atacama, both surrounded by active volcanoes and geothermal manifestations (Fig. 38).

Finally, we must mention that one of the positive effects of the European colonization of South and Central America was the description of social and political organization, popular customs, myths and legends, religious beliefs and rituals of the indigenous populations, and of the geography, landscapes, flora, fauna, natural resources and geological phenomena and features of the 'new' continent. Many such features and phenomena concerned aspects of the Earth's heat never seen or experienced in Europe with the intensity and frequency found in Mesoamerica and the Andean Cordillera. The papers by Hernandez Galán et al. (1999), Rico Calderón (1999), and Suárez Arriaga et al. (1999) quote many authors of the 16th and 17th centuries who had participated in the Spanish colonization of the two macro-regions above and could thus describe, by direct experience, many observed geothermal manifestations and phenomena. Moreover, "…sometimes, the Spanish writers tried to provide an explanation of an event's origin, one in many cases of real scientific value, as happened with the description of a geothermal gradient offered by Gonzalo Fernández de Oviedo (1526). In other instances, they did not content themselves with theorizing about geothermal phenomena but sought to gain first-hand knowledge… of the actual situation." (Hernández Galán et al., 1999).

***Fig. 38**. One of the most famous 'salares' in the Andean Cordillera: Salar de Uyuni, Bolivia, covering a surface of 10,582 km^2, is the largest salt flat expanse in the world (Photo by Anouchka Unel - Own work, FAL, https://commons.wikimedia.org/w/index.php?curid=519745).*

For the readers of this paper who might wish to deepen their knowledge of the historic-scientific aspects of geothermal phenomena in the Andean Cordillera and Mesoamerica, the works of the following authors could help: Fernández de Oviedo (1526), Sahagún (1534), Muñoz Carmado (1540), Cieza de León (1550), López de Gomára (1553), Díaz del Castillo (1568), Suárez de Peralta (1589), Cárdenas (1591) and Garcilaso de La Vega (1609). These works provided fundamental information to later scientists in developing their research on natural phenomena in Meso- and South America.

Among them, Humboldt should be recalled for his attentive studies of the volcanoes in modern Colombia, Ecuador, Peru, Mexico and other Latin American countries, carried out between 1799 and 1804 to investigate their genesis in the framework of the geodynamic conditions of the region (Humboldt and Bonpland, 1825). These studies contributed substantially to ending the ideological dispute between the 'Neptunists' and 'Plutonists', which still divided the earth scientists of the world in the first decades of the 19th century (see also, in this regard, Chapter 9).

6. Other Aspects of Thermal Balneology in Ancient and Recent Times

6.1. General

There is a long list of cultures in the world that used water for functional and ritual purposes since Late Paleolithic, Neolithic or early historic times, depending on the period of colonization of the area concerned. For instance, the use of *lustral water* in religious rites, likely begun in proto-historic epochs for ancient rituals, is still alive today in the Christian and other religions.

Warm and hot waters, in particular, owing to their anomalous temperatures compared to fresh waters, were considered by our ancient ancestors a special gift with curative properties made by transcendental powers. Their balneological use, started with classical prototypes in the 'old' world, began probably in an occasional way over one million years ago in the southern Mediterranean area (Cataldi et al., 1992; Grifoni Cremonesi, 1999), and then spread out from there into the northern and eastern territories of the 'old' world, keeping pace with their colonization.

In proto-historic and ancient times, until the rise of Rome, thermal balneology was practiced in North Africa, South Europe and Asia Minor by Egyptians, Numidians, Sumerians, Babylonians, Assyrians, Anatolians, Phoenicians, Hittites, Cretans, Mycenaeans and other Greeks, Macedonians, Illyrians, Venetians, Etruscans and peoples of southern Italy. An example of this is the *tholos* of St. Calogero in Sicily (already seen in Fig. 20), dating back to over 3,600 years ago.

During this period, not only a lush blooming of myths and legends related to the Earth's heat, especially thermal balneology (as seen in Fig. 11) occurred in the Mediterranean area, but also refined forms of thermal cures were reached in certain places, as proven by the *tholos* above to differentiate high-temperature atmospheres for saunas from lower-temperature atmospheres for baths in an adjacent water pool. Another example of refined forms of bathing is shown below (Fig. 43) where men and women joyfully take a shower together in a (likely thermal) resort facility.

Fig. 39. *Men and women taking a shower together. Bathing scene painted on an Attic vase of the 6th century B.C. (after Cataldi, 2005/2).*

As to the meaning of 'spa', it is useful knowing that it probably represents the initials of *salus per aquis* (health through waters), a Latin expression used by the Romans to point out that thermal balneotherapy can help people maintain their bodies in good shape, prevent diseases and restore function to parts of the body. To stress the concept, the Romans used to complete that statement with another motto: *mens sana in corpore sano* (a sound mind in a sound body). The latter, however, is a motto borrowed from ancient Greeks, who used to say *noús hygies en somati hygie* (our abilities are in our able body) (Fytikas et al., 1999).

6.2. Greek Antiquity

All balneological stations of this period were located in sites with natural hot springs; therefore, their Greek name was *θερμή* (pronouncing *therme*), i.e. thermae, not balnea or spa, as they were named by the Romans to indicate any type of thermal station, with or without natural hot waters. There is also a nice legend in this regard concerning Hercules, the semi-god of the famous twelve labors, who was very fond of thermal baths and for that reason the patron of all thermal springs (Fig. 44). He advised young people to remain in good health by bathing in hot spring waters, at their source, because only there, where they spring from the rock, do waters have the healing properties given them by the gods (Fytikas et al., 1999).

Fig. 40*. Statue of Hercules, seen in the square before the Felix spa station near Oradea, Romania (after Cohut and Arpasi, 1999).*

Legends apart, in addition to the promotion of thermal bathing started by Asclepius in the late 13th century B.C. and continued by his followers for over a millennium in the whole Mediterranean area (see section 5.2), Hippocrates of Kos, the father of medicine, began popularizing in the 5th century B.C. balneotherapy by naturally hot waters as a way to cure many diseases and to recover physical energies after a period of weariness. The lectures held by Hippocrates in this regard, and the description of the thermal cures recommended for each specific illness given in his work *Air-Water-Land*, was for two millennia a recognized reference of hydrothermal medicine.

We should also mention here that the heating structure called a hypocaust, meaning 'heat from below', was a Greek invention dating back to the 3rd-4th century B.C. and applied in certain cases to natural hot springs only. The Romans, however, introduced notable technological improvements to this structure about two centuries later, thus enabling its adoption in both natural and artificially heated thermal stations (see following paragraph).

6.3. Roman Antiquity

From the 2nd century B.C. to the last decades of the 4th century A.D., thermal balneology underwent an intensive blooming, with spas modernized or newly built at practically all sites where natural hot springs and manifestations existed in the area under Roman rule. Moreover, artificial *balnea* were built by the Romans in all sites in which they stayed or passed through (e.g. towns, *castra*, villages and commercial bases) where no source with natural hot water was available. To stress the relevance of thermal baths in the first three centuries of the Christian Era, it is enough to recall that the sites with main spas in operation were highlighted by a special symbol in the geographical and road 'map' of the Empire, now known as the *Tabula Peutingeriana* (Fig. 41). It is a document on a parchment roll 7m long and 34cm high, compiled by a clever but unknown Roman cartographer around the mid-4th century A.D. It was found by chance in an Alsatian library in 1507 and given for study to the German Latinist Konrad Peutinger, from whom it took the name. Details on the way to read this 'map' and on the thermal stations shown therein can be found in Cataldi-Burgassi (1992). In total, over 2,000 spas (hundreds of them in private residences) existed in the Roman dominion towards the end of the 3rd century A.D. Out of that total, about half were located in Rome, where one million people lived in that period: one spa for every 1,000 inhabitants! (Montanelli, 1957).

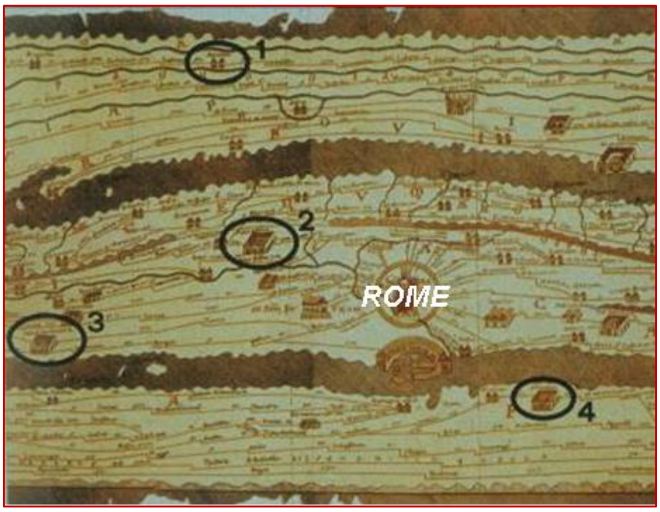


Fig. 41*. Portion of the* Tabula Peutingeriana *showing a few of the main natural spas in operation in the Roman Empire in the 3rd century A.D.: 1) Aquincum (Pest, Hungary); 2) Aquae Cutiliae (Palombara Sabina, Italy); 3) Aquae Apollinaris (Bracciano, Italy); and 4) Aquae Carpitanae (Hammam Lif, Tunis) (after Cataldi and Burgassi, 1992).*

The buildings of almost all spas supplied with natural hot fluids, and of all artificial balnea, were constructed above a new type of hypocaust designed by a rich entrepreneur born in Naples, Caius Sergius Orata (1st century B.C.). Starting from the idea of the hypocaust devised some two centuries before in Greece, Orata conceived a new structure suitable for installation in both natural and artificial spas (Fig. 42), with a general layout as that shown in Figure 43.

All thermal stations could provide the following services: balneotherapy (bathing, sauna and fangotherapy); esthetics (massage, shaving, combing, depilation, skin cure and toning, etc.); physical activities (wrestling, body-building, training exercises, etc.); restaurants (formal and fast food); information centers; public and private meetings (political, cultural, business, etc.); resort, social events and entertainments. In this way, most public spas were a kind of 'club' and "…represented not only institutions for hygiene and recreation but also (and perhaps more importantly), cultural centers where ideas could circulate, public opinion was formed, and basic political choices were made…" (Burgassi et al., 1992; Cataldi and Burgassi, 1999).

Moreover, the localities with spas supplied by natural hot water were in many cases sites of cult centers, athletic games and other large sporting events, popular festivals and regional or local markets (Cataldi and Chiellini, 1995 and 1999).

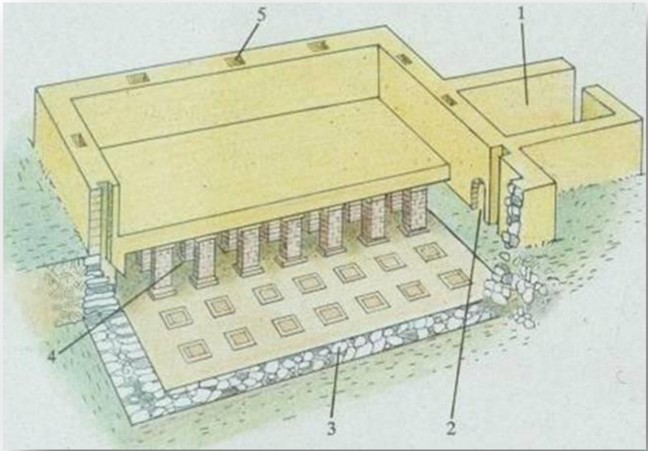


Fig. 42. *Orata's hypocaust system used in Roman spas. 1) Heating room (fed by natural hot source or boiler); 2) Opening in the wall to let the steam pass from the heating room into the spa; 3) basement; 4) hypocaust; 5) alveolated channels to let hot air pass through and warm the walls and the adjoining rooms (after Cataldi and Burgassi, 1992).*

The spas in private residences of rich or important persons, used by the elite, were equipped with every kind of then-modern facilities and were splendidly decorated with paintings and mosaics (Fig. 44). As a matter of amenity, we comment here that the 'bikini' was not invented after the end of the 2nd World War (as many people believe), but at least 2,000 years ago when it was already worn by beautiful women bathing in thermal spas as seen in the Figure 44.

The diffusion of thermal balneology in Roman times peaked in the late 3rd century A.D. at the same pace with the maximum extension and splendor of the Roman Empire. At that time, several tens of millions of people per year of every race, sex, class and age used the thermal stations: a phenomenon of relevant social

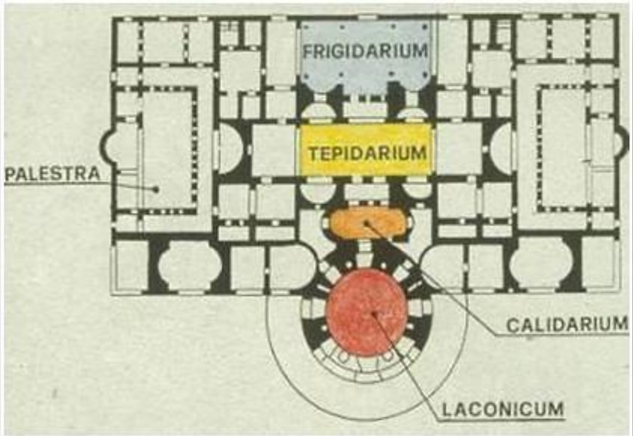


Fig. 43*. General layout of Roman thermal stations (after Cataldi and Burgassi, 1992).*

importance that contributed notably to foster the diffusion of Latin as a common language, and the cultural amalgamation of people from many countries, different ethnicities and diverse customs.

Thermal balneology in Roman territories continued to grow for a few more decades until the beginning of the 4th century A.D., when Rome was sacked by the Visigoths and Vandals in 408-410 and 455 A.D., respectively. Then started the decline of the balneological system in the old Empire; a system that lost quickly its connotation of general health, a socially wise custom that had been practiced for five centuries by many millions of people in the Mediterranean area.

Thus followed a deep crisis of the system, after the expulsion in 476 A.D. of the last Emperor of the Western Roman Empire. In that framework, the Baths of Caracalla, which had been for over two centuries the most important station of the whole Roman balneological system, started to fall into ruin. Afterwards, although remaining intermittently active for some cures until the end of the 6th century, the Caracalla Baths collapsed entirely in the Middle Ages. However, in relation to thermal spas, we too want to state: Quanta Roma fuit ipsae ruinae docent (Even ruins speak and tell us the greatness of Rome) (Cataldi and Burgassi, 1999).

6.4. Middle East and Turkish baths

The collapse of the Roman balneological system noted above had a lower effect in the Eastern Roman Empire (Constantinople was its capital), which ruled over the eastern sector of the old dominion of Rome for another millennium, until its defeat in 1453 by the Ottoman Empire. Therefore, thermal balneology in the Roman style, though at a reduced level, continued to function in that sector of the old Empire for the whole Middle Ages.

During that millennium, however, the Turkish style of thermal bathing in the *hammam* (equivalent to, but notably different from the Roman balnea) took root in the area of Ottoman influence. For the Turks, in fact, bathing in natural hot waters (or even artificially heated waters) was an essential component of their life. The Turkish baths are well known, and have been used for many centuries in countless places in the world, especially in the Middle East, the Balkan area, Central Europe, Northern Africa and certain sectors of southern Europe. In these regions, in fact, the Ottoman domination extended its rule until the second half of the 16th century in the Mediterranean basin, and until almost the end of 17th century in central Europe.

The Turkish baths were organized in a different way compared to the Greek and Roman spas; but their architectural style in the Middle Ages and in recent times was superb in many cases. Nonetheless, the separation by sex in any Turkish *hammam* was in the past, and still is at present, an imperative rule.

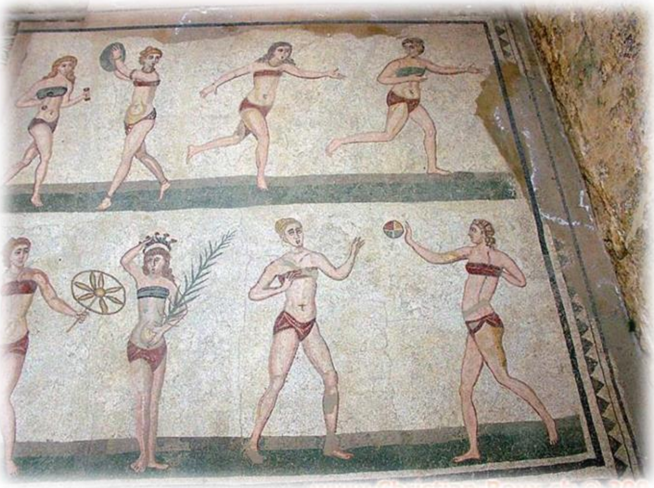


Fig. 44. *Example of mosaic decoration of Roman thermal pools: Villa del Casale, Agrigento, Sicily, 2nd century A.D. (Photo taken from http://www.huffingtonpost.com/paula-h-noe/ancient-folks-in-sicily_b_5458469.html).*

The treatments usually made in any Turkish *hammam* concerned the following diseases: rheumatism, sciatica, gynecological problems, kidney and psychiatric issues (Özgüler and Kasap, 1999).

From 1200 until 1700 approximately, a lush bloom occurred of Turkish baths in the Middle East and in the areas of Northern Africa and the southern Mediterranean basin under Muslim rule, with elegant establishments as, for instance, those in operation at Istanbul, Medina, Aleppo, Bagdad, Budapest, Palermo, Grenada, Girona and Seville.

6.5. Central Europe

Central Europe refers to the Balkans, Pannonian Basin, Czechia, Tatra ridge in Poland and Slovakia, Polish Lowlands, and to the Caucasus area in Georgia, Armenia and Azerbaijan. Here, the use of thermal springs for therapeutic relief has been known since Neolithic or proto-historic times, and was continued in ancient, mediaeval and recent epochs (Popovski and Dimitrov, 1999; Cohut and Arpasi, 1999; Fendek et al., 1999; Sokolowski et al., 1999; Buachidze et al., 1999). The culture, customs and experiences formed in the spas of these countries were strongly influenced by those formed in earlier times in thermal localities of the Mediterranean area.

Some of the most important spa sites in Central Europe, renowned since Antiquity or the Middle Ages, are: Skopje and Strumica in Macedonia; Vindobona in Austria (near the border with Slovakia); Sklene Teplice, Sliač and Dudince in Slovakia; Karlovy Vary (Carlsbad) in Czechia; Aquincum/Budapest and Heviz in Hungary; Felix Herculane, Bale and Aquas Herculi in Romania; Cieplice, Ladek, Duszniki and Zakopane in Poland; Tblisi and Borjomi in Georgia; Kelbadjari in Azerbaidjan; and Garrni, Arzni and Ararat in Armenia. The latter is located on the eastern foothills of Mt. Ararat, whose famed summit of 5137 m is where Noah took shelter during the universal flood related in the Bible. Having constructed his famous Ark, he was waiting for the waters to subside so he could start a 'new life' on Earth.

Many myths, legends and cults related to hot springs formed in Central Europe in proto-historic and ancient times; and here the thermal waters were also considered a divine gift for the people. Therefore, statues, columns, sanctuaries and temples to the divine protectors of geothermal manifestations were erected, with devotional rituals held nearby. One of those statues, located in the square before the Felix spa in Romania, is shown in Figure 40; whereas, one of the most beautiful and best preserved monuments of Roman Antiquity, erected in a thermal-spring area of the region in question, is the temple to the Sun's and Earth's energies (Fig. 45).

Fig. 45. *Temple of the Sun's and the Earth's energies, near the Garni thermal spring, Armenia (after Buachidze et al., 1999).*

6.6. Astride Europe and Asia

Early historical, ancient and relatively recent uses of thermal springs to cure various types of disease are to be found also in Russia and other countries of the former USSR (Svalova, 1999). However, except those of the Crimean peninsula and areas near the Black Sea, it seems that the culture, experience and traditions formed in Russia and those other countries regarding the presence and use of hot springs have not been influenced significantly by foreign experiences and cultures in the same field; they apparently experienced local and autonomous origins and development.

This is probably due to the fact that the external manifestations of the Earth's heat in Russia are located in four different and distant regions: the Crimea Peninsula, to the west and east of the Ural ridge, and the Kamchatka Peninsula. Moreover, the scattered distribution of people living in proto-historic and ancient times over the boundless expanses of the lowland and upland territories to the west and east of the Ural Mountains must have contributed to the isolated development of the experience and culture for using hot natural waters for therapeutic purposes.

Also legends and myths related to geothermal manifestations seem to have had an independent origin in each of the four areas mentioned above: one in Crimea, two on the opposite lowlands of the Urals and one in Kamchatka. With reference to the latter, however, Svalova (1999) maintains that the Siberian legends on geothermal phenomena probably influenced and were influenced by those existing in northwestern North America, as a result of the migratory flows of people between the two continents through the Bering Strait during the final stage of the Wisconsinan glaciation.

6.7. Pacific area

Though with alternating periods of 'ups' and 'downs', thermal bathing for cures were developed at a remarkable level in New Zealand, the Philippines, China (including Taiwan and Tibet), Japan and Korea, especially during the last part of the second millennium when balneotherapeutic practices were extended notably among the popular classes.

In China and Japan, in particular, starting from the Late Middle Ages, many thermal establishments were converted into public spas (Wang Ji-Yang, 1999; Sekioka, 1999). However, in some of those establishments, refined forms of treatments were introduced, with cures undertaken in old-fashioned environments and elegant atmospheres (Fig. 46).

In South Korea, high-temperature springs do not exist; therefore, relatively low-temperature springs had to be used for thermal bathing and therapy in past centuries. In recent times, however, higher-temperature waters extracted by drilling have been used for thermal bathing (Yum, 1999).

***Fig. 46**. Sketch of the entrance-hall of the* 'Liubeiting' *(Floating Cup Pavilion) in the Tangquan spa, Zunhua County, Hebei Province, China (after Waing Ji-Yang, 1999).*

6.8. Americas

From sections 5.11 and 5.12 it is clear that since prehistoric and early historic times, all through the period of the European colonization of the Americas (16^{th}-18^{th} centuries in Central and South America, and 17^{th}-19^{th} centuries in North America), hot springs and other manifestations of the Earth's heat had been frequently used by local people (especially the elite classes in certain areas and periods) for therapeutic cures, relaxation and ritual or religious purposes.

In Mesoamerica, in particular, some villages were accustomed to use the so-called *temazcal* (Fig. 47) for therapeutic and religious purposes (Krickeberg, 1956; González, 1991). The vapor bath was obtained by showering with cold water the piles of volcanic rocks naturally or artificially accumulated around the mouths of the hot manifestations. Pregnant women and babies also used *temazcales* for hygienic reasons.

It is worth recalling that the Náhuatl term *atotonilco* means literally place of hot boiling waters, and that there are many such places in Mexico that were used in pre-Columbian times for cures by people, in general, and by soldiers, in particular, during local conflicts. For instance, the Aztec Emperor Moctezuma-I used to send his soldiers to the Oaxtepec spa to let them recover from wounds and injuries suffered during the many wars he undertook to defend or expand his empire.

Concerning the number of thermal localities frequented by people in the Americas in pre-Columbian epochs, we estimate that before the Europeans began to settle in the 'new' continent, at least one hundred localities with thermal springs or steaming grounds were used altogether in North-, Meso- and South America.

Fig. 47. Temazcalli *Aztec steam bath from the Codex Magliabecchi (Folio 77r) [Photo taken from: https://commons.wikimedia.org/wiki/File:Codex_Magliabechiano_(folio_77r).jpg].*

However, with the beginning of colonization, for reasons that it would out of place discussing here, the use of natural heat for cures underwent a notable decline everywhere in the three macro-regions of America mentioned above. In fact, only a few of the previous thermal spas remained active at moderate levels starting from the 17th century in the areas of the former Inca, Mayan and Aztec empires, and the same occurred in North America starting from the late 18th century. In other cases, new spas were built for thermal cures according to the European style, but only a few of them had satisfactory success.

To sum up, out of the over one hundred active thermal localities mentioned above for pre-Columbian times, we estimate that only about fifty spas were in operation in the Americas between the middle 17th century and the first 3-4 decades of the 20th century. Among the spas that enjoyed good or moderate success in that period, we can list the following (taken from Hernández Galán et al., 1999; Lund, 1999; Rico Calderón, 1999; Suárez Arriaga, 1999):

• North America:

- Canada: Banff Hot Springs (Alberta), Harrison Hot Springs (British Columbia), and Takhini Hot Springs (Yukon);

- United States: Calistoga (California), Hot Lake (Oregon), Hot Springs (Arkansas), Hot Springs (Virginia), Saratoga Springs (for water cure, New York), Warm Springs (Georgia), and White Sulfur Springs (West Virginia);

• Meso America:

- Costa Rica: Rincón de la Vieja and Tabacón;

- Guatemala: Santa Teresita;

- Mexico: Aguas Calientes, La Cueva del Diablo, Los Azufres, Oaxtepec, Ojo de Dolores, and Tlacotlapilco;

• South America:

- Argentina: Rosario de la Frontera, Termas de Copahue, and Termas de Reyes;

- Bolivia: Chalviri, Oruro, Polques, and Utama;

- Chile: Corazón, Jahuel, Puritama, and Socos;

- Colombia: Santa Rosa de Cabal;

- Ecuador: Banõs de San Vicente, Chachimbiro, Nangulvi;

- Peru: Cajamarca, Cuzco, Monterrey, Termales Pachia.

Among the thermal localities above, the three (one in each group) deserving special attention for their historical importance are: Calistoga, Oaxtepec and Cajamarca, for North-, Meso- and South America, respectively. For each of them, the following few lines are worthy of interest.

• Calistoga (California, U.S.)

Calistoga is a composite name, formed by California (the state where the locality is found), and Saratoga Springs, an initially small village near Saratoga, some 300 km to the south of New York. The presence in this village of cold mineral springs with highly appreciated water for its diuretic properties, gave rise around 1820 to the creation of a mineral water cure station, which in a lapse of 15-20 years became the most famous spa and resort area in the United States. Many patients for cures and tourists for vacations started arriving there after 1840, so that the Grand Union Hotel was built around 1850. It seemingly was for many years the largest hotel in the world. Moreover, since the springs emerge from a carbonatic formation with peculiar stromatolitic concretions (Fig. 48), they were an additional attraction for tourism in the area.

The town and resort of Calistoga had not been founded yet at that time; but many thermal springs with temperature up to 100°C existed in the northern sector of the Napa Valley, 120 km to the north of San Francisco. The manifestations had been used by the Pomo, Wappo and Lake Miwok Indians for thousands of years, and they called the region *Tula-ha-lusi* ('beautiful land') (Lund, 1999). However, with the arrival of the Europeans in the early 1800s, the area was named 'Agua Caliente', and Catholic friars built a mission about 64 km away. The favorable climate of the zone allowed for the cultivation of several typical Mediterranean plants, the most important of which were the grape vines. Since then, the Napa Valley has become famous for the high quality of its wines.

***Fig. 48**. Stromatolites in the Cambrian Hoyt Limestone at Lester Park near Saratoga Springs, NY, USA [Photo by James St. John - Stromatolites (Hoyt Limestone, Upper Cambrian; Lester Park Road outcrop, W of Saratoga Springs, New York State, USA) 07, CC BY 2.0, https://commons.wikimedia.org/w/index.php?c*

Apart from the above, Samuel Brannan (prominent American journalist and businessman settled in San Francisco) had the good idea to establish there a European-style thermal spa and resort. He thus purchased over 2,000 acres of land (about 8 km^2) and started to develop in 1862 the initial core of the new settlement, with the necessary infrastructure, hotels, and spas. He then said "…I will make this place the Saratoga of California," from which Calistoga took the name.

Due to favorable circumstances (including the construction of the railway San Francisco-Portland, through the Napa Valley), the resort developed quickly and become in few decades the most renown thermal station of North America.

Many VIP customers started to arrive there. Robert L. Stevenson (the Scottish novelist) and his wife Fanny were among them in 1880. Since then, in addition to thermal cures, the visitors can enjoy at Calistoga cultural, art, sporting and social events.

• Oaxtepec (Morelos, Mexico)

In pre-Columbian times, Oaxtepec had been the main royal spa and botanical garden of the Emperor's family since 1440; therefore, Moctezuma-I ordered built here additional gardens, temples, apartments for aristocratic guests and relaxation rooms for soldiers. Later, the Emperor ordered built several pools and *temazcales* aside of the local hot springs for the use of everyday people; he also increased notably the uses of medicinal herbs and plants in the gardens to treat various diseases.

Subsequently, during the Spanish colonization (16th-17th centuries), a hospital was constructed at Oaxtepec by the religious order of the 'Hermanos Hipólitos'. Since then, though with periods of more or less intense activity, Oaxtepec always has remained in operation as a spa and curing center and is in use at present under the Mexican Institute for Social Security (IMSS).

• Cajamarca (Peru)

Located in a lush tropical area a few kilometers away from Cajamarca, a group of sulfurous springs with temperatures of about 70°C (now called *Baños de los Incas*, 'Baths of the Incas'), were known and used since the Chavin cultural period (9th-2nd century B.C.), if not before. Those springs, were believed by the Incas to have a divine origin, from one of the highest Inca gods: the Sun (Fig. 37); this is why they named them *Inti Puquio* (springs of the Sun) or *Choque Puquio* (golden springs). Between 1463 and 1533, when the Inca Empire was at its peak of extension and power, the area around the springs was utterly modified and embellished with a royal palace, many residences for high-ranking commanders and aristocrats, monuments and splendid gardens and orchards with all the fine and sweet-smelling herbs of the Inca territories.

According to Garcilaso de la Vega (1609), the royal palace and all residences built in that area were served by warm water gathered from the hot springs through gold and silver pipes, whereas the gardens themselves were decorated with many artifacts of animals (e.g. lizards, snakes, rabbits, wild-cats, foxes, butterflies and others) made of solid, or hollowed out gold and silver.

Moreover, "…in many palaces (the residents) had baths consisting of great tubs of gold and silver… And wherever there were natural hot springs (the Inca rulers) also made very rich and splendid baths. ...Other wonders included piles and heaps of firewood (made) of gold and silver, as if they were stocks for use in the (royal) palace…" (Garcilaso de la Vega, with English translation by H. Livermore; in Rico Calderón, 1999).

In short, *Inti Puquio* represented during the last part of the Inca Empire a luxury thermal station. It was a recreational place for the Inca royal family and government officers: the summer capital of the Empire. Atahualpa, the last *Sapa Inca*, was there before his capture by Francisco Pizarro in Cajamarca in November 1532.

After the fall of the Inca Empire in late 1533, all valuable objects of the complex were destroyed or stolen, mostly by the conquistadors. The wonderful spa and resort then fell into ruin for almost three centuries.

Subsequently, following the discovery of rich veins of metallic ores near Cajamarca in early 1800s, this town had a rebirth and a modern spa with many outdoor thermal pools was built aside the ruins of the old royal complex. However the name, *Baños de los Incas*, was preserved in memory of the ancient, glorious Inca period (Fig. 49).

Fig. 49. *Current view of spas in Cajamarca. This complex experienced three different moments in time: The golden age of* Inti Puquio *(1463-1533); Collapse of the Inca complex (1535-1830); and Relauching of new spas (1850 to present) (Photo taken from: http://juancloyola.blogspot.mx/2011/08/precedent-thermal-springs-in-cajamarca.html).*

6.9. From the Renaissance to the *Belle Epoque*

After the end of the Middle Ages, with the beginning of the Renaissance, though slowly and with intermittent periods of more or less intensive presence of patients depending on the political and socio-economic situation in each area, thermal balneology had a notable growth in many countries, most of all in Europe. As a consequence, the modernization and expansion of many old stations and the construction of new ones were made, resulting in a remarkable increase in the number of spas. We are unable to give the total number, but we estimate that the thermal spas in the world, during the over three-centuries-long Renaissance period, increased from a few hundred to many hundreds of units, out of which at least one hundred are in Europe. Also for the attendance by people at those spas, we cannot give quantitative data by country or continent; but we estimate that the overall visits could have been in the order of ten million persons per year. We must stress, however, that the frequenting of spas by people for therapeutic cures evolved during the Renaissance period from the prevailingly elite form it had taken in the whole of the Middle Ages into a more diffused form of popular use.

To the best of our knowledge, with no pretense of completeness or judgment on their rank, and regardless of the system or type of treatments made in each of them, among the most important thermal localities of the world in the period in question, starting from Western Europe, we recall: Gerona, Granada and Seville (Spain); Chaudes-Aigues and Vichy (France); Acqui Terme, Abano, Bagni di Lucca, Bagni di Romagna, Chianciano, Montecatini, Terme dei Papi, Tivoli, Agnano, Ischia and Sciacca (Italy); Baden (Austria); Aachen/Aquisgrana and Baden Baden (Germany); Carlsbad (Czechia); Budapest and Heviz (Hungary); Felix Spa (Romania); Therme Sulla and Loutraki (Greece), Istanbul (Turkey); Ganeshpuri and Rajgir (India); Fuzhou, Zhangzhou and Xiaotangshan (China); Arima, Hakone, Kinosaki, and Kusatsu (Japan); Saratoga and Calistoga (USA); Oaxtepec (Mexico), Santa Rosa de Cabal (Colombia), Cajamarca (Peru), and Termas de Reyes (Argentina).

All spas mentioned above were visited in that period by VIP patients, like emperors, kings and queens, princes and consorts, popes and cardinals, poets and writers, composers, high-level singers, noblemen and wives, entrepreneurs and the rich. All those patients shed luster and fame on the spa(s) attended; moreover, in some cases, they also gave notable cash contributions to a preferred spa, or became their sponsors in various forms. A few internationally renowned patients of thermal spas between the 13th and the 19th centuries are the Emperor Frederick II (1194-1250), Pope Pius II (1405-1458), Lawrence of Medici (1449-1492), M. D'Arquién Sobieska (Queen of Poland, 1641-1716), J.W. Goethe (1749-1832), J.Q. Adams (6th President of the United States, 1767-1848), and F. Chopin (1810 - 1846), among others.

After the end of the Renaissance, in full Industrial Age, as a result of the formation and consolidation of the social middle class (called the bourgeoisie), and as a follow-up also of the notable increase of the average person's welfare, from the smokes of the coal and the "smell" of the machines, the *Belle Epoque* joyfully emerged around 1870 and continued until 1914 approximately. It was a short but creative period that involved the cultural, artistic, architectural and social aspects of people's lives, in general, and of the middle- and upper-classes, in particular. The *Belle Epoque* took root between 1870 and 1880 in the whole of Western Europe and its fascination reverberated over large areas of the world, mostly in the Western Hemisphere.

During this epoch, thermal spas had a further spurt of growth, partly due to the actual need for cures by an increasing number of people, partly because the higher average welfare enabled some families to start taking vacations in attractive localities, and in part also (by noble and high-bourgeoisie people) for social contacts, business meetings… and gossip! The existing spa buildings thus underwent refurbishment, modernization and new decoration, and other establishments were built according to the most recent fashion of the time. Some examples of different architectural styles for spa stations of the period include Cağaloğlu *hammam* in Istanbul, Turkey, and Montecatini Terme (Fig. 50) and Abano Terme, both in Italy.

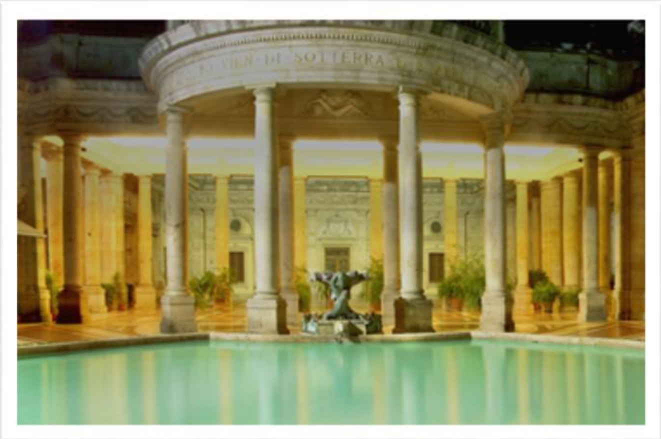


Fig. 50. *Montecatini Terme, Italy (Photo taken from: http://www.tuscanyfimba2017.com/es/montecatini-terme/).*

7. Use of By-products

7.1. General

Since the Paleolithic, much over 500,000 years ago, people observed volcanoes and other paroxysmal phenomena of geothermal energy with curiosity and fear; but they started also to use volcanic rocks and other products of the Earth's heat for functional purposes. Such uses continued for several hundred millennia in all localities of the world with active or fossil geothermal manifestations where our ancestors happened to arrive or stop temporarily. In later epochs, starting from the Neolithic, stable settlements were formed in many geothermal areas on Earth, and also there the immigrants began, or continued, to use for a number of applications the by-products of terrestrial heat available in each place: volcanic and metamorphic rocks to manufacture stone tools or build sheltering walls, and pyroclastic materials, travertine and hydrothermal minerals. Moreover, it is probable that the presence and abundance of geothermal by-products attracted migrating peoples to settle in areas with active manifestations. Consequently, the uses of geothermal by-products in those areas became habitual practices.

However, due to the possibility of bartering some geothermal by-products for other materials available in nearby zones, their use was not limited in the Neolithic and early historic times to areas with active manifestations, because a kind of manorial economy started to take root in those times in certain regions on Earth. In later times, when the bartering system of goods was replaced by exchanges of money and a systematic commerce was established, the most valuable by-products of the Earth's heat became an international business and their uses spread out in large areas, even those at great distance from the production zone.

This was the case, for instance, of obsidian, which had been since prehistory, and even more in early historic and ancient times, a kind of precious stone with the value of money. Moreover, flat pieces of obsidian were much sought in ancient civilizations for use as mirrors by the rich, women, in particular. Such use has been verified at Çatal Hüyük (Anatolia, Turkey) since 8,000 years ago, in Mesoamerica since 4,000 years ago and in several other localities for periods well before the present Era, until 1500 A.D. approximately (Enoch, 2006). An exceptionally beautiful example of an obsidian mirror is shown in Figure 51.

Fig. 51. *Aztec obsidian mirror (20 cm width, approximately) with a decorated wooden frame, reflecting a basalt sculpture of a Mexican female deity (after Hernandez Galán et al., 1999).*

7.2. Case study on the use of geothermal by-products: the Mediterranean region

Due to its geodynamic conditions, this region is characterized by young igneous processes that gave rise in the past (and still do at present) to the formation of shallow intrusions and volcanic eruptions with associated phenomena. As a result, the

Mediterranean area is richly endowed with many geothermal manifestations and by-products.

At the same time, several important civilizations began to rise in proto-history on coastal lands of the Mediterranean Sea, and marine traffic developed there over two millennia before the Christian Era. This is why most by-products of the Earth's heat were known and used in many areas of Europe since prehistoric and early historic times, and various applications have continued to occur since then for over three millennia. Some details follow on the by-products used and their applications in the regions in question until recent times.

- Several islands and places on the Eastern Mediterranean coast were important localities for mining and exportation of alum, bentonite, borates, iron oxides, kaolin, lapilli, obsidian, perlite, pozzolan, silica and sulfur (Cataldi and Chiellini, 1999). Neolithic artisans used these compounds to make pottery and pigments.

- The ancient Greeks exploited for many uses the following geothermal by-products: kaolin, pozzolan, perlite, iron oxides, sulfur and travertine; moreover, in some volcanic islands of the Aegean Sea, the Greeks gathered, used and widely commercialized obsidian (Fytikas et al., 1999).

- In Italy, geothermal by-products were numerous: kaolin and sulfur to prepare mortars for binding pebbles, slabs and other building materials; obsidian to obtain weapons and tools; pumice and fine-grained pyroclastics for tempering and grinding material for ceramic finishing; and sulfur for pigment and ointment mixtures. Moreover, thermo-mineral muds were gathered for balneo-therapeutic applications, and in particular to cure skin diseases (Cremonesi, 1999).

- Starting from the 12^{th} century B.C., in addition to thermal bathing, the Etruscans (Fig. 63) developed extensively the plentiful deposits of hydrothermal minerals (mostly borates) existing in the Boraciferous Region of Tuscany, one of their main development areas for nine centuries (Di Pasquale, 2005). By grinding and proportioning appropriately different types of hydrothermal minerals, Etruscans obtained special varnishing lacquers with which they finished their best pottery (Burgassi, 1987 and 2005). This is why the Etruscans have been named 'the fathers of industrial development of geothermal resources' (Cataldi and Burgassi, 1999).

- From about the beginning of the 2^{nd} century B.C., and until the end of the 4^{th} century A.D. approximately., the Romans developed a systematic use of geothermal by-products including: pyroclastic deposits and hydrothermal minerals to prepare cement slurries; travertine, lavas, tuffs, lapilli, intrusive and metamorphic rocks to build monuments and edifices; kaolin to make fine ceramics and bleaching solutions for the textile industry; boron compounds and iron oxides to prepare glazes and enamels for painting fine pottery; and soaps rich in hydrothermal minerals to cure skin diseases (Cataldi, 2005/2).

After the fall of the Roman Empire in the 5^{th} century A.D., the use and development of geothermal by-products in Italy declined quickly and remained at the minimum exploitation level in certain areas during the whole of the Lower Middle Ages. The same decline happened in all areas of the former Western Roman Empire (Cataldi, 2005/3).

The main areas of provenance for the by-products mentioned above are shown in Table 1.

MAINLANDS		**ISLANDS**	
Turkey + Greece	**Italy**	**Aegean Sea**	**Tyrrhenian Sea**
Western Anatolia	Phlegraean Fields	Lesbos	Northeastern Sicily
Thrace	Alban Hills	Yali	Vulcan
Macedonian area	Sabatinian Mts.	Nisyros	Lipari
Thessaly	Volsinian Mts.	Santorin (Thera)	Pantelleria
Peloponnesus	Southern Tuscany	Mylos	Ischia
		Aegina	Ponza
			Elba
			Western Sardinia

Table 1. *Areas of origin of geothermal by-products in the Mediterranean region from the Neolithic to Roman Antiquity.*

- From the second half of the 11^{th} century, all through the end of the 15^{th} century, systematic exploitation of a number of geothermal by-products gradually revived in Italy for pharmaceutical, industrial and craft purposes. In particular, the following hydrothermal compounds were exploited in the Late Middle Ages: yellow sulfur to prepare pharmaceuticals, bleaching solutions for the wool industry and as a component of gunpowder; alum for processing wool; green vitriol for preparing disinfectants; blue vitriol for making antiparasitics, disinfectants and coloring components; and boric acid for treating eye diseases and disinfecting sores (Cataldi and Burgassi, 1999; Cataldi, 2005/3).

- Finally, we should recall that, following the discovery in 1777-1779 by H. Hoefer and P. Mascagni of boric acid in the steam of the fumaroles and in the high-temperature waters of the Boraciferous Region of

Tuscany, after a number of attempts at using different harnessing techniques, a new technology of exploitation and processing hydrothermal minerals to produce boric acid and other boron compounds was developed at Larderello from 1810 to 1943 approximately (Burgassi, 1987; Cataldi and Burgassi, 1999 and 2005/3; Cerruti, 2005).

During this 130-year period, boric acid was the main chemical compound extracted from hydrothermal encrustations or steam produced in the Larderello area. Moreover, other chemicals were produced in that area from surface mineralization or geothermal fluid during the first three decades of the 20th century, including borax, sodium perborate, ammonium carbonate, carbonic acid and talcum powder. These products were largely used in pharmaceutical and in some industrial processes.

To give an idea of the importance that the use of geothermal by-products had in the Larderello region, in the over one century period from 1818 (when the industrial exploitation systematically began) to its peak in 1930, it is enough to recall that the total production of boric acid of geothermal origin (extracted from hydrothermal surface encrustations between 1818-1828, and from hot fluids yielded by wells from 1860 onwards) grew from 36 tons/year in 1818 up to 4,800 tons/year in 1930 (Table 2). It was a world record in the strongly competitive market of boric acid in that year (Cataldi, 2015), but it was also the start of the decline of the production of the boron compounds in the Boraciferous Region due to the progressive depletion of boric acid in the reservoir.

YEAR	PRODUCTION IN TONS/YEAR
1818	36
1827	50
1829	125
1850	1,000
1869	2,000
1900	2,550
1930	4,800

***Table 2**. Production of boric acid of geothermal origin in Larderello.*

7.3. Ten thousand years utilization of geothermal by-products

For the world as a whole the main by-products of the Earth's heat and their principal applications are shown in Table 3, regardless of the country where they have been used, and independent of the time in which their uses started. Many of them have been used by our ancestors for over 10,000 years and are still in use today.

This means that many by-products of the Earth's heat have contributed substantially to the development of human civilization in all geothermal areas of the world. Therefore, taken together, they represent one of the milestones of our geothermal legacy.

BY-PRODUCT	SPECIFICATIONS	PRINCIPAL USE(S)
Alum	Double sulfate of Aluminum & Potassium [$KAl(SO_4)_2 \cdot 12H_2O$]	Pharmaceutical compounds, wool industry and manufacturing processes
Ammonium carbonate	[$(NH_4)_2CO_3$]	Leavening agent and acidity regulator
Bentonite	Hydrated phyllosilicate of Sodium and Calcium	Absorbent, binding and cleaning agent in industry and masonry works, and purifier in the medical field. In modern times also a component of drilling muds
Borates	Various borates (Calcium, Sodium, Potassium, and others)	Glass industry, detergents and bleaching solutions for the wool and other industries
Borax	[$Na_2B_4O_7 \cdot 10H_2O$]	Detergents, disinfectants, insecticides, soap
Boric acid	Weak acid [H_3BO_3]	Antiseptic, antimycotic, disinfectant and insecticides
Boron compounds	Other than those above	Several types of industrial processes
Carbonatic solutions	$CaCo_3$-rich slurries	Plastering wall joints/fissures, and grouting brick channels
Carbonic acid	Weak acid [H_2CO_3]	Production of phosgene, urea and organic esters
Flint and Silex	SiO_2 veins and layers from hydrothermal circulation	Stone tools (arrows, axes, knives, etc.) and sparks to light fires

Hydrated silica	Quartz [SiO_2]	Glass & abrasives industries
Igneous rocks	Many types of intrusive and volcanic rocks (blocks and slabs)	Building works, monuments, statues, mill wheels, slabs for fireplaces, lining of floors, stair steps and others
Iron oxides	Ferrous and ferric oxides	Enamels and glazes for fine ceramics, pigments of paints, coloring agents for paintings and vases
Kaolin (China clay)	Hydrated silicate of Aluminum [$Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$]	Essential ingredient of fine old and modern porcelains. Used also in paper, rubber and paint industries, and in refractory and anticorrosive materials
Metamorphic rocks	Metamorphism of high temperature	Building works, monuments, statues, mill wheels, slabs for fireplaces, floors, stair steps and other stone items
'Nitro volterrano'	Boron compound of unknown formula, but probably borax	Pharmaceutical compounds, and probable other uses in manufacturing works
Obsidian	Usually black	Stone tools (arrows, axes, knives, etc.), necklaces for women and mirrors for the rich
'Peperino'	Pyroclastic rock with tight diagenesis, with black-white spots, like salt and pepper mixtures	Building works, monuments, statues and slabs for fireplaces, floors, stair steps and other stone items
Perlite	Volcanic vitreous rock of rhyolitic	Component of cement slurries,
	composition with very small ball structure	lightening agent for concrete and a light filling material for building works
Pozzolan	Siliceous-aluminous highly porous and loose pyroclastic, with cementing properties	Binding material for masonry, and component of cement slurries for building works
Pumice	Aluminum-silicate, very porous and light pyroclastic	Lightening and cementing material in building works
Pyroclastites (other)	Volcanic ashes, tuffs and lapilli	Components of cement slurries and other loose material for building works
Sodium perborate	Sodium borate, with a complex formula	Bleaching agent in textile and wool industries, component of detergent products and reagent in organic synthesis
Smectic clays	Clays deposited around hot manifestations, rich in hydrothermal minerals	Soap bars or balls, to cure human skin diseases (psoriasis, eczema and others) and domestic animals (scabies, itch, etc.)
Sulfur	Native (yellow) sulfur	Ointments and salves for medical treatments, bleaching solutions in industry and gunpowder from the 14th cent.
Talcum powder	Hydrated Magnesium Silicate [$Mg_3Si_4O_{10}(OH)_2$]	Dermatological treatments and hygienic uses
Thermo-mineral mud	Formed around thermal pools	Hot mud therapies in thermal stations
Travertine	Large blocks or slabs	Building works, monuments, statues, domestic

		items
Vitriol (blue)	Copper sulfate, pentahydrated [$CuSO_4 \cdot 5H_2O$]	Pharmaceutical compounds, and dye in several industry processes
Vitriol (green)	Ferrous sulfate, eptahydrated [$FeSO_4 \cdot 7H_2O$]	Pharmaceutical compounds, and dye in several industry processes

***Table 3**. . Main solid by-products of geothermal energy and their principal uses from prehistoric to recent times.*

8. Impact on History by Geothermal Phenomena and Resources

The notable importance that the phenomena and resources of the Earth's heat have had in past times in driving the course of the history in many parts of the world is verified by many recorded facts. A few of them are shortly mentioned here as examples.

8.1. Explosion of Thera and Geopolitical Influences in the Eastern Mediterranean

According to historians, the collapse of the Minoan civilization happened around 1450 B.C.; but it is likely that the first shock that prepared the conditions of the collapse happened from 1628 B.C. onwards after the huge explosion that eviscerated the island of Thera, present day Santorini: a cone-shaped volcano (Fig. 52) with a small caldera on the top, located 170 km to the north of Crete, Greece. Imaginably, Thera had been a woody island, fully integrated in the Minoan dominion over the entire southern Aegean. The volcanologists call a Minoan eruption the sudden explosion that occurred in Thera in 1628 B.C., and have estimated that 32 cubic kilometers of rocks (4 x 8 x 1 km) were thrown away in a single blow, as a result of which a tremendous tsunami was triggered, with sea waves up to 200 m high. Therefore, not only the earthquake but also those waves affected dramatically all islands and coastal areas of the southern Aegean Sea (Luce, 1969).

Concerning the end of the Minoan civilization, nobody could prove or disprove that it started to collapse in the final part of the 17th century B.C. as result of the Minoan eruption; but the fact remains (as the historians maintain) that the collapse of Crete happened around the middle of the 15th century B.C. suddenly, and that several new Mediterranean peoples came to the fore soon after that eruption: Phoenicians, Achaeans, Dorics, Aeolians and Ionians. We should recall also that, in the learned literature, the disappearance of Atlantis (the famous 'lost continent') has been associated with the huge explosion that annihilated the central portion of ancient Thera (Marinatos, 1939; Luce, 1969).

In short, so huge phenomenon of the Earth's heat for sure had an enormous impact on the geopolitical and economic order of the ancient Mediteranean civilizations. A synthesis from the geothermal viewpoint of the subject in question can be found in Fytikas et al. (1999), Cataldi and Burgassi (1999/1), and in the papers quoted therein on the same subject.

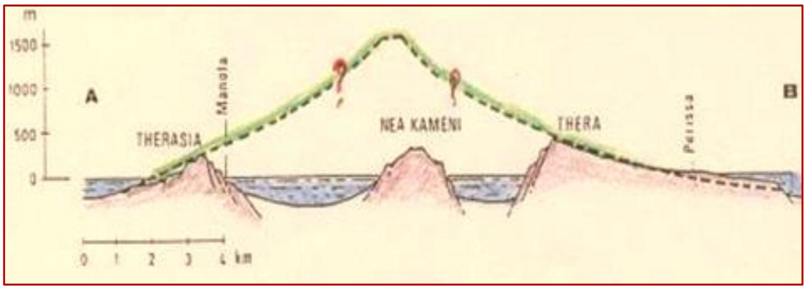


***Fig. 52**. Cross section NW-SE, from Therasia to Perissa. As a result of following eruptions, two intracalderic islands (Palea and Nea Kameni) formed astride the pre-Christian and Christian Eras (after Cataldi and Burgassi, 1999/1).*

8.2. Romans vs. Etruscans

From the foundation of Rome in 753 B.C, for over two centuries, the Romans had no interest in the emancipated style of life of the Etruscans, especially in their customs of thermal bathing; but they knew that in some areas of Etruria, and in particular in the now-called 'Metalliferous Hills' of Tuscany, in addition to hot springs, there existed rich metal-bearing ores (iron, copper, zinc, lead, manganese, silver and others), alabaster and hydrothermal minerals: all resources lacking in their own initially small territory, but very important economically (Cataldi and Burgassi, 1999/2; Cataldi and Chiellini, 1995).

Beginning from the late 6th century B.C., concomitantly with its improved socio-political organization and increased power, Rome devised an expansion policy over surrounding regions, and Etruria could not but become one of its objectives. A series of conflicts then started between the Romans and Etruscans (Fig. 53), which continued all through the 4th century and concluded in the early 3rd century B.C. with the total subjugation of Etruria.

The main reasons of the conflicts above were, of course, supremacy over larger territories, an expansion strategy, control of traffic and economic reasons, in general; but there is no doubt, in our opinion, that the commercial relevance of both the metallic ores of the Metalliferous Hills and of the rich hydrothermal deposits of the Boraficerous Region of Tuscany (all products of notable importance in the Mediterranean market of the time) played also a remarkable role.

8.3. Iconoclastic controversy

During the 8th century A.D., an enraged dispute arose in the Byzantine Empire on whether or not religious images or icons could be worshiped by the Christians as an expression of devotion towards God, Jesus Christ, the Virgin Mary and the Saints (Fig. 64). The opposers (i.e. the Iconoclasts: a Greek-derived term meaning 'icon-breakers') thought that the veneration was a pagan-like idolatry of man-made objects; whereas the supporters maintained that the religious images and icons represented visible symbols of Divine Beings and that the veneration act had a transcendental value, independent from any natural object.

***Fig. 53**. Etruscan warrior dated c. 500 BC, found near Viterbo, Italy. [Photo by PHGCOM - Own work, photographed at Le Louvre, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=9735779].*

The dispute was so vividly felt that for decades it shook violently the Byzantine Empire, bringing with it the risk of anarchy and secessions; even physical persecution of people occurred in certain periods during the 8th and 9th centuries. According to the historical account on the subject made by Teophanes the Confessor (1975, reprint), probably in the first decade of the 8th century, the dispute stopped temporarily after a series of destructive earthquakes and volcanic explosions occurred at Thera, starting from 726 A.D., which were taken as signs of the wrath of God for the prolonged dispute in question (Fitykas et al., 1999).

8.4. Tuscan struggles and 'War of the *Allumiere*'

From the 12th all through the 15th centuries, bitter struggles occurred in Tuscany between the Communes of Florence, Pisa, and Siena on one side, and the powerful Archbishopric of Volterra on the other side, and among the same Communes for the ownership of the rich hydrothermal deposits of the Boraciferous Region mentioned in the previous section 8.2.

After the consolidation of Florence as the main Commune of Tuscany, the above-said struggles evolved into a conflict between the towns of Florence and Volterra, historically known as *Guerra delle Allumiere* (War of the Allumiere).

Allumiere originates from alum (see first line of Table 3) and means alum-rich minerals. The term designates collectively the hydrothermal deposits then existing in the Boraciferous Region of Tuscany, formed mostly of boron, calcium, potassium and sodium sulfates, with subordinate amounts of yellow sulfur. All these minerals had in the late Middle Ages a fundamental importance for a number of manufacturing processes —most of all those of wool and other textiles, which were an emerging export market for the Commune of Florence, then ruled by the powerful Medici family.

A bloody war started finally in 1470 between Florence and the Archbishopric of Volterra, owner of those deposits, for the possession of the *Allumiere* area. The war lasted two years and was won by Florence, which could so be waived from paying import taxes on all those products. This greatly facilitated its growing wool and textile industry; and, in fact, from that moment onwards Florence became the leader of the textile industry in Europe.

8.5. Fall of the Aztec Empire

Previously announced by a number of roars and earthquakes, a strong eruption of Popocatépetl, the sacred and most revered volcano of Mexico (*see* Fig. 10), happened in 1519 while the Spanish army was preparing for its attack on Tenochtitlán, the Aztec capital (Hernández Galán et al., 1999). Moreover, an unusual geothermal phenomenon (probably a phreatic explosion, according to Suárez and Cataldi, 1992) had happened in a lake near Tenochtitlán a few weeks before that eruption.

However, based on premonitions by his augurers, these two phenomena, occurring as they did one after the other in a short lapse of time, were interpreted by the Aztec Emperor Moctezuma II (*Xocoyotzin*) as a sign of the next arrival of a powerful benefactor. For these reasons, rather than ordering his fierce warriors to fight in defense of the Empire, Moctezuma II decided to welcome Cortés with honors and an enormous amount of offerings: many tons of gold and precious stones, as reported by the chroniclers of the time (Hernández Galán et al., 1999).

Some historians of that epoch believed that, in seeing Hernán Cortés, a tall white man elegantly dressed (Fig. 54), Moctezuma II considered him the returned Aztec god called *Quetzalcóatl* ('feathered serpent'; *see* Fig. 18). But this historical fact could also be interpreted as common diplomatic politeness in the Aztec culture. Other historians speculate that the Aztecs were particularly susceptible to ideas of doom and disaster because the particular year in which the Spanish arrived (1519) coincided with a 'tying of years' ceremony at the end of a 52-year cycle in the Aztec Calendar, linked to changes, rebirth and dangerous events. The belief of the Aztecs being rendered passive by their own superstition is part of the post-conquest rationalization by the Aztecs of their defeat, and serves to show Moctezuma as indecisive, vain, superstitious and ultimately the cause of the fall of the Aztec Empire (Restall, 2003). Ethnohistorian Susan Gillespie (1993) has argued that "the Nahua understanding of history as repeating itself in cycles also led to a subsequent rationalization of the events of the conquests. In this interpretation, the description of Moctezuma, the final ruler of the Aztec Empire prior to the Spanish conquest, was tailored to fit the role of earlier rulers of ending dynasties, for example *Quetzalcóatl*..." (or *Kukulkán*, the last emperor of the Toltecs).

Fig. 54. *Depiction of Hernán Cortés (Photo taken from http://quotesgram.com/img/quotes-about-hernan-cortes-aztecs/11315005/).*

Besides the smallpox plague that struck the Aztecs in September 1520, another very important historical reference that explains, more realistically, the tragic end of the Aztec Empire (13 August 1521), is precisely the fact that the Aztecs had formed an empire. They established their rule by force and war over hundreds of thousands of indigenous natives of Mesoamerica. As normally happened in other historical empires, many people hated and disliked the Aztecs before the Spanish arrived. Therefore, it is not surprising to understand why Cortés and his 600 soldiers (he had never commanded men in battle before this date), when they approached Tenochtitlan made easily an alliance with many of the Aztec's enemies and rivals, building a powerful army of several thousands of ferocious fighters.

At any rate, the decision by Moctezuma II to welcome Cortes was also influenced by the interpretation by his augurs of the two geothermal phenomena noted above. It was a tragic interpretation that had an enormous impact on the history of the world!

8.6. Exploitation of sulfur in Iceland

From the 'Age of Settlement' (870-930 A.D.) and for over 350 years, Iceland was an independent country, "…but lost its independence to the King of Norway in 1262, and together with Norway to the Queen of Denmark in 1388. Apparently, the Archbishop of Niðarós, now Throndheim, Norway, acquired some kind of exclusive right to buy or transport sulfur from Iceland during the latter part of the 13th century…" (Fridleifsson, 1999). Therefore, as this author leads readers to understand, the exceptionally bountiful deposits of hydrothermal sulfur on the island had remained untouched until the end of the 15th century. Meanwhile, however, the exclusive right to export sulfur from Iceland had been taken over by the Kingdom of Denmark.

The exploitation of this hydrothermal mineral started intensively in Iceland at the beginning of the 16th century, and the raw material was sold to merchants from Hamburg. Transported there, the sulfur was sold in Germany and nearby countries at "extremely high prices", the author above states. Thus, sulfur had become in the middle 16th century a very lucrative business for the merchants, with no additional return for the producers, and the same King of Denmark had to buy it at high prices for gunpowder production in his territory.

This is why that King, in virtue of his exclusive right of export, "…in 1561 forbade the Icelanders to sell sulfur to foreigners, or to anyone except merchants appointed by him…" (Fridleifsson, 1999). In this way, the Danish Crown could control an important portion of the sulfur market in northwestern Europe. Since then, the relevant earnings coming from exporting Icelandic sulfur represented for about 70 years the main income source of the Danish Kingdom from Iceland.

From the first decades of the 17th century, however, following the sudden decline of the sulfur market in Europe, the intensive exploitation of sulfur in Iceland was reduced until finally, in 1760, the King of Denmark gave the Icelanders the right to mine the deposits of that mineral as a part of a development plan of the island.

It is clear from the above that, as a by-product of the Earth's heat, sulfur has played an important role in the economy and history of some countries in Northern Europe for at least two centuries.

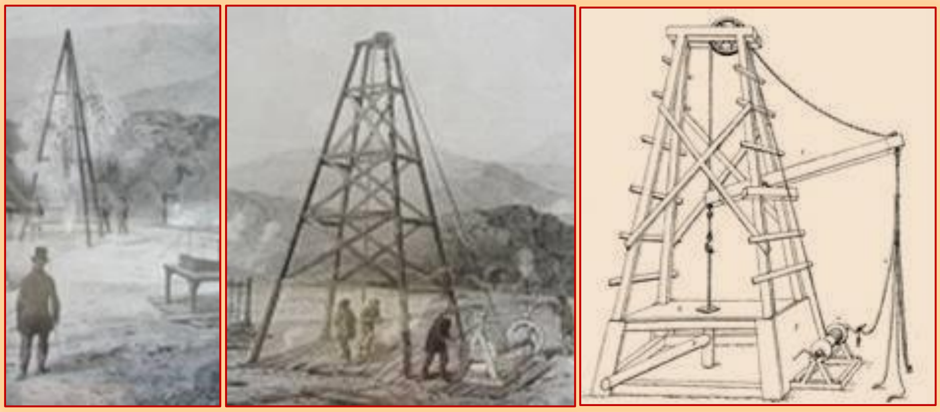


Fig. 55. *Evolution of drilling equipment used in the Larderello area from 1828 to 1855 to produce boron-rich hot fluids. Left: 3-legged* 'verga artesiana' *(1820-1834); Center: 4-legged drilling rig on a wooden platform (1834-1845); Right:* 'Ballanzino' *(1845-1866) (after Cataldi, 2016).*

9. Initial Development of the Geothermal Electric Technology

9.1. Background

Geothermal resources in the Larderello area had a notable impact on the local population from prehistoric times to the 20th century. Here, in fact, fumaroles, steam and gas jets, boiling pools (*lagoni*), hot springs and hydrothermal deposits were known and used since the Neolithic all through historic and recent times. Here, too, after the discovery in 1777-1779 of boric acid in the thermal manifestations and fumaroles of the region, from 1818 onwards, many scientists, engineers and technicians, entrusted by Francesco Larderel (founder of the Larderello chemical industry), developed exploitation and drilling technologies, and industrial processes to produce boric acid and other boron compounds. For the first ten years, until 1828, the boric acid was produced from surface mineralizations only; afterwards, it was extracted until 1850 in part from outcropping encrustations and in part from geothermal fluids produced by wells. From 1850 onwards, to the contrary, the boric acid was extracted solely from steam or water-steam mixtures produced by wells (Burgassi, 1987 and 1999).

Drilling started in 1828, with depths of 6-8 m and diameters of 10-12 cm; they were the first geothermal wells in the world. With passing time, improved techniques (mostly developed in situ by engineers of the Larderello Company) led to drilling wells at progressively increasing depths: 20 m in 1834, with ø = 12 cm, and 50 m in 1850 with ø = 15 cm (Fig. 55). Notable improvements in drilling were made afterwards between 1860-1900, reaching well depths up to 300 m, with ø = 15-18 cm in 1900.

Between 1828 and 1900, in addition to the impulse given to geothermal drilling technology, many other technological innovations were introduced in the extraction and processing of boron brines, including those illustrated in Figure 56 (Burgassi, 1987, 1999 and 2005).

As a combined result of deeper wells, drilling made in progressively larger areas, innovations introduced and other measures, the production of boric acid increased from the initial 36 tons in 1818 to 50 tons in 1827, 125 tons in 1829, over 1,000 tons in 1850, 2,000 tons in 1869, and 2,250 tons in 1900. For the period after 1900, *see* Table 2.

In the framework of the activities above, the idea arose around 1880 of harnessing the kinetic energy of powerful steam wells to obtain motive power. A number of experiments were thus carried out between 1885 and 1895 with pilot reciprocating motors to produce mechanical energy, aimed at driving pumps and presses to transport and process boron-rich fluids, grinding minerals, shaking fluid mixtures, driving pulleys and gears, and other mechanical works needed in the chemical plants. Moreover, those motors were used extensively to drive winches and other drilling equipment, resulting in a notable increase of the daily-drilled meterage (Burgassi, 1999; Parri-Lorenzi, in press 2016).

Nonetheless, though effective in principle, the experiments above evidenced that direct flushing of hot, wet and saline-rich fluid on the blades of rotating machinery caused rapid corrosion of the blades and other parts of the equipment. Therefore, the idea of

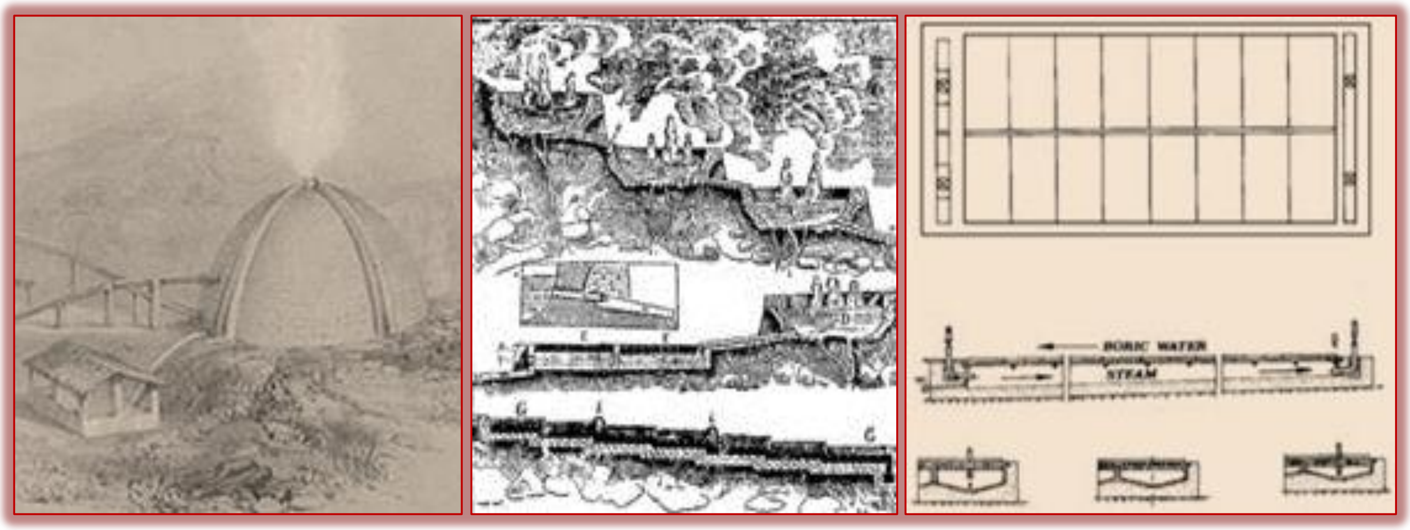


***Fig. 56.** Some technological innovations introduced at Larderello between 1828-1900 to produce and process boric acid. Left: 'Lagone coperto' (covered lagoon), 1828; Center: Cascading lagoons, A-B-C-D, with decantation tanks, E-F, and stepped evaporation tanks G-G, 1841; and Right: 'Caldaia Adriana' (Adrian boiler), top view above, longitudinal section in the middle, and cross section below, 1855 (after Cataldi, 2016).*

producing mechanical energy directly from the wells was temporarily abandoned; but it gave the cue for a different approach to the possibility of harnessing thermodynamically the heat of the Earth.

Subsequently, after Prince Piero Ginori Conti (son in law of Count Florestano De Larderel) was appointed general director of the Larderello Company in 1903, many other technological innovations were introduced aimed at opening new horizons to harness the geothermal resources of the area. The most important of them was the generation of electric power, which will be dealt with in the next section.

However, to complete the framework of activities from which the idea to generate electric power arose, it is worth recalling that to consolidate and increase the core business of the family's industry, P. Ginori Conti had three main lines of action in mind: i) integrate the production of boric acid with other boron compounds; ii) increase the amount of boron-rich fluid by drilling wells at higher depths and in larger areas; and iii) carry out intensive campaigns of scientific studies and applied research in all fields related to the knowledge of, and the most efficient use possible for, the geothermal resources of the region.

In the light of the above, while referring the readers to the last lines of section 7.2 for the new chemicals added to boric acid in the period 1903-1939, it suffices here to recall that boric acid production had passed from 2,250 tons in 1900 to 4,800 tons in 1930. After that year, a decline of the boron content in the reservoir started to occur, which increased continuously over the following two decades and finally obliged a stop in subsequent years of chemical production from the geothermal fluid.

For the increased drilling activity carried out, and the scientific results obtained by P. Ginori Conti in the period 1903-1939, we can refer the reader to Burgassi (2005) and Cataldi-Burgassi (2005), respectively. However, we cannot omit to mention in this paper that the advancements obtained in this period are attributable mainly to two persons: Bernardino Lotti in the geological field, and Raffaello Nasini in the technological sector. The latter, in particular, a physical chemist and professor at the University of Pisa, represented between 1905 and 1930 the main reference scientist and technologist of the whole production chain of the Larderello Company, including the adoption of different power cycles for the simultaneous production of electricity and boron chemicals. One of his works (Nasini, 1930) is a benchmark in the world technical literature of the 20th century; it also contains a long chapter on the history of geothermal energy, which all people interested in this matter may wish to consult.

Figure 57 shows some results of the extremely creative initiatives taken by P. Ginori Conti between 1903 and 1939. Among them, we must mention the first international congress dedicated to geothermal energy, which was promoted and sponsored by P. Ginori Conti and held at Larderello in the summer of 1928. That congress represented the turning point from the important scientific advancements achieved since Antiquity and through the Mid Ages, the Renaissance and the early Modern Age, towards the more advanced knowledge on geothermal energy we have at present.

To conclude: on the exploitation of the hydrothermal manifestations of the Boraciferous Region, and especially on the chemical industry developed at Larderello from 1818 to 1940 approximately, many hundreds of papers and books can be found in the literature dealing with technical, historical, socio-economic, scientific, political and cultural aspects of that region of Tuscany. Nonetheless, for readers wishing to deepen their geothermal background, summarized in this section, the following papers may help: Burgassi, 1987, 1999 and 2005; Bianchi, 2005; Cataldi, 1993 and 2016; Cataldi and Burgassi, 2005; Cataldi and Chiellini, 1995 and 1999; Cerruti, 2005; Ciardi, 2005; Papini, 2005; Buonasorte et al., 2011; and Parri and Lazzeri (2016, in press).

***Fig. 57**. Left: First mobile geothermal laboratory in the world, on a horse-driven cab, 1903 (after Cataldi and Burgassi, 2005); Right: Well 'Soffionissimo 1' (1931). Depth 267 m; flow rate 230 tons/h at 4.5 atm; T =205 °C (after Burgassi, 1999).*

9.2. Geothermal light at Larderello: from five bulbs in 1905 to 127 MWe in summer 1944

When appointed in 1903 general director of the Larderello chemical industry, P. Ginori Conti was not a newcomer in geothermal matters. In fact, having married in 1894 Adriana, daughter of Count Florestano De Larderel (last male descendant of Francesco, founder of the industry), P. Ginori Conti was well aware of the family's business in the chemical market and was informed also about all the technologies enabling extraction, processing and production of boric acid. In particular, since he had started already to conceive of the idea of converting into electric energy the motive force of the fluid produced by geothermal wells, he knew about the experiments carried out to this purpose in the family's industry from 1885-1895; moreover, he himself had conducted a similar experiment in 1897 by using the kinetic energy of the wet steam yielded by a well near Larderello (Parri and Lazzeri, 2016 in press).

Therefore, as mentioned in the previous section, one of the first actions made by P. Ginori Conti after taking power in the top position of the industry, was to contact high-level scientists in fields related to the activity of his company, in order to establish and implement an R&D program in all these fields, including the possible utilization of the Earth's heat to produce electric power. On this issue, after a series of studies and lab tests carried out at the Department of Industrial Chemistry of the University of Pisa, and following a number of tests made on steam wells located near Larderello (Fig. 58), the first experiment of geopower production was carried out on 4 July 1904 under his coordination. The well chosen (named '*Forte*', meaning strong, to indicate that it was one of the most powerful wells then existing in the area) was connected to a piston engine coupled with a 10 kW dynamo that enabled lighting five small bulbs. It was the first geothermal light ever seen in the world.

We must recall at this point that the photo shown in Figure 58 has been often referred to wrongly by many authors as taken on the proper date of the experiment, which was on 4th July 1904; but it was actually taken more than two months before the experiment, during one of the field tests carried out to determine the production characteristics of the wells worthy of supplying the steam for the experiment. Moreover, after the experiment made on 4th July, in order to check the behavior over time of the geothermal reservoir and of the surface equipment, other similar experiments were conducted under different conditions until October 1904, and also in those occasions other photos were taken (Cataldi, 2016 in press; Parri and Lazzeri, 2016 in press).

As a follow-up of the successful experiment above, the first prototype geothermal power unit was ordered from Cail, a well-known mechanical industry of the time. The unit was built in few months and installed in early 1905 near the palace of the De Larderel-Ginori Conti family at Larderello. It was a reciprocating piston engine connected to a 20 kW dynamo, by which the family palace and some civil residences near it were illuminated. Subsequently, in 1908, a second prototype piston engine, different from that above but still coupled with a 20 kW dynamo, enabled electrification of other residential buildings and of the most important chemical plants then existing at Larderello and nearby production areas. Both prototypes remained in operation regularly, the first for over ten years, and the second for seven, until they were stopped in 1915 as a follow-up of the installation in 1913 of the first commercial power plant.

After 1910, in fact, owing to the satisfactory operation of the prototypes above and, more importantly, due to the very good performance of the steam wells supplying them, the construction of the first true power plant was ordered from Tosi, the most advanced electro-mechanical firm of Italy in the field. Since then, the geothermal-electric gross capacity in the Boraciferous Region increased as follows.

1913: Turbo-alternator of 250 kWe, driven by 'pure' steam (indirect or binary cycle, with heat-exchanger) installed in a purpose-built power plant that P. Ginori

Conti (as a sign of good fortune) named Larderello 1: the first commercial power unit in the world (Fig. 59). It enabled electrification of all chemical plants of the Boraciferous Region, and of the towns of Saline, Pomarance and Volterra to the north of Larderello, by means of a 16 km-long electric line purposely built. After three years of regular generation, this unit was moved to another steam production locality (Lago) and replaced by the following larger units.

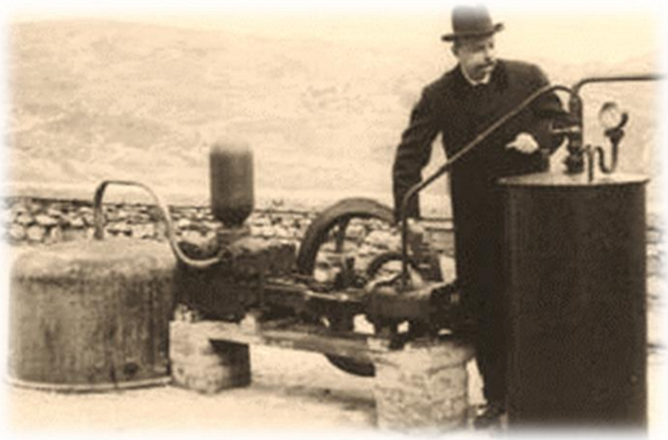


***Fig. 58**. Equipment used for field tests made in preparation of the experiment carried out on July 4, 1904. P. Ginori Conti is looking at the shut-in pressure of the well chosen for the experiment: the manometer shows almost 5 atm (Photo taken on 24 April 1904) (after Burgassi, 1999).*

0**1916-1917:** Two turbo-alternators of 3.5 MWe each, again of indirect-cycle type, installed in the Larderello 1 power plant. It is worth recalling here that the size of these two new units was comparable to that of the main hydroelectric and thermal power plants then existing in Europe. Therefore, in relation to the times, they had a notable size.

1923: Pilot unit of direct-cycle type (23 kWe), installed at Serrazzano to test the behavior of turbines fed directly by natural steam (Fig. 60). In two years of successful operation under different conditions, it proved that dry steam with high temperatures and pressures can directly feed the turbine. Afterwards, the unit was moved to the technical school of the company at Larderello and used to train personnel for the power plants. This small unit had a fundamental importance towards the end of the 2nd World War, for the reasons explained below for the summer of 1944.

1926-1927: Two exhausting-to-atmosphere (back-pressure) units of direct cycle, of 600 and 800 kWe, respectively, installed at Castelnuovo V.C.

1930: Installation at the Larderello 1 power plant of an exhausting-to-atmosphere, 3.5 MWe turbo-alternator next to the two units of indirect-cycle type installed in 1916-1917.

In short, by December 1930, a total of 11.9 MWe was installed in the Boraciferous Region, of which 7 MWe were of indirect-cycle type to produce both electrical energy and boron compounds, and 4.9 MWe were of direct cycle, exhausting-to-atmosphere (back-pressure) type to generate almost solely electricity, with only a small amount of boric acid extracted from the exhausted steam of the turbines.

The electricity aggregately produced by these plants in 1930 was about 80 million kWh: a notable amount in economic terms, but a modest fraction in cash terms of the total sales of the Larderello industry. In fact, the core business of the company in that year was still the production of boric acid and other boron compounds obtained from geothermal fluids.

After 1930, the gross geothermal-electric capacity in the region grew as follows.

1935-1939: A new power station, Larderello 2, was constructed aside the first station. It hosted six standard units of 11 MWe each, all of indirect-cycle type for simultaneous production of electric power and boric acid plus other boron compounds.

1940-1943: Four standard units of the same size and type of the six units above were installed at Castelnuovo V.C. to produce power, boric acid and boron compounds.

Moreover, three exhausting-to-atmosphere units were installed for power generation only: one of 3.5 MWe at Sasso Pisano (southern Boraciferous Region), and two of 3.5 MWe at Serrazzano.

Consequently, considering the replacements or modernization of some previous units, the installed capacity in the Boraciferous Region by June 1944 totalled 126.75 MWe, out of which 116.25 MWe were of indirect-cycle type and 10.5 MWe of direct type, exhausting-to atmosphere.

Summer 1944: Complete destruction, due to events of

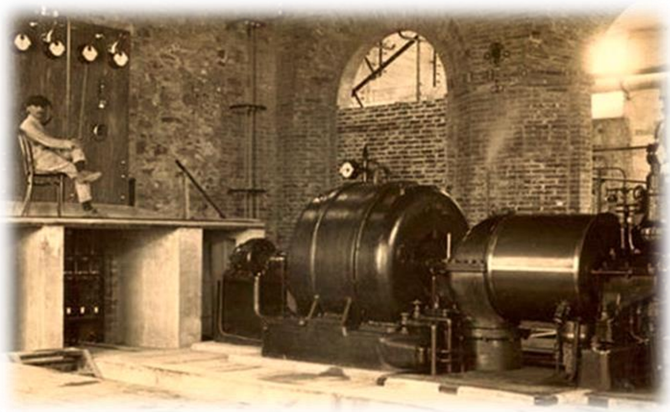


***Fig. 59**. First commercial power plant fed by geothermal heat (after Parri and Lazzeri, 2016, in press).*

the 2nd World War, of all production wells and power plants of the over 120 year-old chemical and geothermal-electric industry grown at Larderello up to June 1944. Among the ruins of the technical school of Larderello –miraculously intact— was found the 23 kWe pilot unit which had been installed at Serrazzano in 1923 to test the behavior of turbines supplied directly by natural steam (Fig. 60).

With the small amount of electricity produced by that minuscule unit, the reconstruction of the chemical and electric plants previously existing in the area could start a few months later in that same year. From that reconstruction began the second important step (not dealt with in this paper) of geothermal-electric development in Italy.

9.3. Remarks on the geothermal power plants installed at Larderello until summer 1944

Apart from the two dynamos used before the construction of the first commercial turbo-alternator, from the description above it can be drawn that the power plants installed in the Boraciferous Region in the 30-year period of 1913-1943, are of two types: i) indirect-cycle units, fed by 'pure' steam, i.e. steam obtained from fresh water by means of heat-exchangers supplied with hot natural fluid; and ii) direct-cycle, exhausting-to-atmosphere, units, i.e. turbo-generators fed directly by dry steam, with free discharge of exhausted steam into the atmosphere.

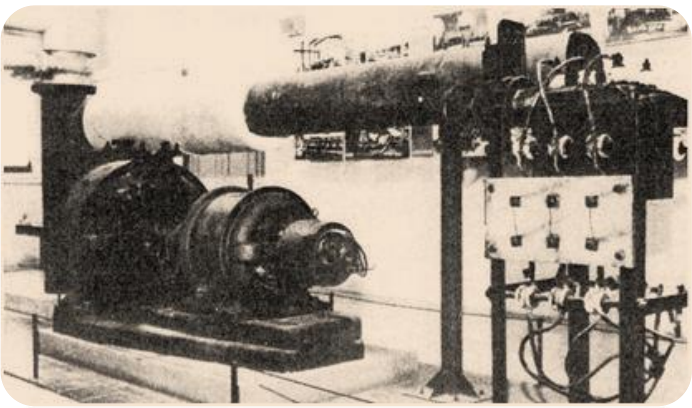


***Fig. 60**. Exhausting-to-atmosphere pilot unit (23 kWe, 1923) (after Burgassi, 1987).*

The first type of plant enabled production of both electric power and boric acid plus other boron chemicals, and in June 1944 represented about 91% of the total geothermal-electric units then installed; whereas, the second type of plant (9% of the total) in exceptional cases, and by few of them only, could be used for the production of chemicals from the exhausted steam by applying adequate equipment downstream of the turbine. All the above was because, as already mentioned, the core business of the De Larderel-Ginori Conti family was the production of boric acid and boron compounds, and not power generation. In other words, from the business viewpoint, power generation was a kind of by-product of chemical production.

The situation of the power plants between 1913-1943, however, was actually more complex than schematized above because many parameters had to be considered when each plant was designed, including temperature and pressure of the fluid, gas content, efficiency and others —in addition to the main economic interest of the De Larderel-Ginori Conti family.

All these technical aspects are discussed widely in the literature, but many quotations here on this subject would be out of the scope of this paper. Nonetheless, two very recent papers deserve special attention in this regard: one by DiPippo (2015) on the evolution and performance of the geothermal power plants; and the other by Parri and Lazzeri (2016, in press). Moreover, regarding geothermal power plants during their initial period of development (1915-1960), two recent books are worthy of mention: one compiled entirely by DiPippo (2016) and the second edited by the same DiPippo with 26 chapters by different authors (2016, in press).

As regards in particular the efficiency of the geothermal plants, in opening the abstract of his aforequoted paper of 2015, DiPippo states, "The study of the evolution of the efficiency of geothermal power plants is complicated by the fact that all plants built for more than a half century following the first plant (Larderello 1) have been designed to accommodate chemical facilities along with power generation. From 1904 until 1959, the plants in Italy and New Zealand were built to allow the simultaneous recovery of valuable minerals and the production of heavy water, respectively…" In the case of Italy, this statement applies to all plants installed in the period 1913-1943.

9.4. Other areas with early geothermal light

In addition to Larderello, following the successful experience in the Boraciferous Region, other areas of the world 'saw' geothermal light in the first half of the past century.

Taken mostly from DiPippo (2015), but integrated in few cases by information obtained from more recent or different papers, these areas, their countries and the essential, most significant data of the plants installed in each area until 1946 are given below.

a) Geysers (Grant), USA, 1923. Effective capacity 18.6 kW, fed by dry steam.

b) Geysers (Resort), USA, 1925. Effective capacity 250 kW, supplied by dry steam.

c) Beppu, Japan, 1925. Effective capacity 1.12 kW, using wet steam. The data on this plant are taken from DiPippo (2015); but additional information on this area is provided by Hernández Galán (2013), who writes (page 83 of his book): "… In 1918, the Vice-Admiral Masuji Yamauchi drilled a well in Beppu, Kyushu, which produced steam. In 1925, Dr. Heizi Tachikawa installed there a 1 kW generator, which was replaced in 1948 by a 30 kW unit" (translation from Spanish into English by the authors of this paper) (Fig. 61).

d) Ischia 1, Italy, 1939-1942. The experiment made at Ischia (a volcanic island offshore of Naples in southern Italy) consisted of two steps. The first was to test a prototype 11 kW unit installed near some wells (100-150 m deep, small diameter, and bottom temperature of 110-130°C) drilled on the beach of a locality called Citara. The working fluid of the unit was ethyl chloride (C2H5Cl) let to vaporize by a water-steam mixture at temperatures slightly above 100°C. Subsequently (1941-1942), "…the excellent results obtained paved the way for the design of a 300 kW plant based on the same principles, which used 60 liters (~360 tons/h) of thermal water per second…" (Parri and Lazzeri, 2016 in press). However, due to difficulties in obtaining a sufficient quantity of ethyl chloride during the 2nd World War in 1942 and also during the following three years, this unit could not enter into commercial operation. DiPippo (2015) indicates for it an effective capacity of 250 kW and specifies that it was "…binary, (C2H5Cl)…" Both prototype units (11 kW and 300 kW, respectively) were designed by Luigi D'Amelio, an outstanding Engineer and Professor of Mechanical Engineering at the University of Naples, who is the precursor of the binary technology applied to geothermal and solar plants (*see* references in Parri and Lazzeri, 2016 in press).

e) Ischia 2, Italy, 1942-1943. An attempt was made in the same island, but in a different locality (St. Angelo), to put in operation another geothermal electric power plant at Ischia. To this end, "…Two 300 m-deep wells were drilled, the first of which in 1942 produced 7,000 kg/h (~250 tons/h) of fluid at a pressure of 1.2 atm. The positive results of this well pushed SAFEN (*Società Anonima Forze Endogene Napoletana*) to experiment with machines using directly low- pressure steam as the motive fluid… and the construction of a power plant utilizing a steam turbine …with a maximum output of 200 kW …was begun…" (Parri and Lazzeri, 2016 in press). However, also in this case, the entry into operation of the plant could not be made owing to events of the 2nd World War, which in that period reached in the Mediterranean area the maximum intensity. Additional information on the two power units installed at Ischia, and references for the papers by D'Amelio dealing with early geothermal power technology with a binary cycle, can be found in Parri and Lazzeri (2016, in press).

f) Hveragerði, Iceland, 1944. Fridleifsson (1999) reports that "experimental electrical production" was made in Iceland in 1944, in the framework of "…pioneering work for multipurpose uses of geothermal energy, started in the Hveragerði hot spring village (Thorhallsson, 1988)." No technical data on the generation equipment used there are provided by Fridleifsson, but perhaps they are found in the paper by Thorhallsson quoted by him (*see* References at the end of this paper).

g) Onuma 1, Japan, 1946. Effective capacity 3 kW, supplied by wet steam.

h) Onuma 2, Japan, 1946. As above, but with an effective capacity of 8 kW.

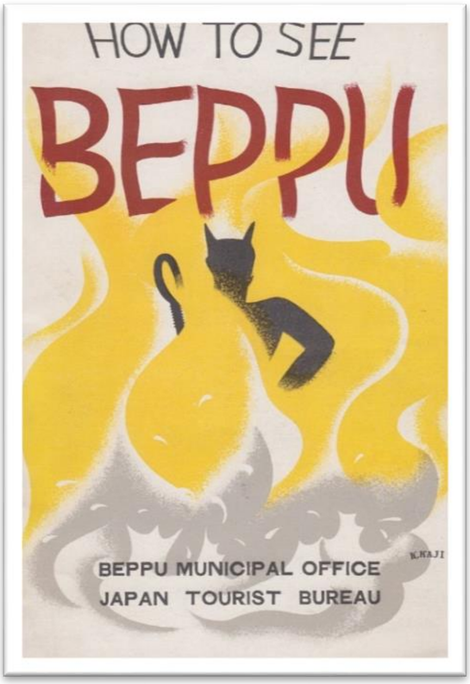


***Fig. 61**. A 1937 travel poster promoting the hot springs of Beppu [By Beppu Municipal Office Japan Tourist Bureau - Unknown, Public Domain, https://commons.wikimedia.org/w/index.php?curid=48681373].*

10. Birth and Evolution of Scientific Thought on Geothermal Energy until 1928, an Attempt of Synthesis

10.1. Cultural background

• When did geothermal culture start to form?

We ignore it. We can only presume that the acculturation of mankind to phenomena of the Earth's heat began in the night of the human times, perhaps one million years ago, much after the beginning of the 'Year Zero of Geothermics', as a result of observations of volcanic eruptions and other geothermal manifestations, accrued ancestrally in the people's memories over many hundreds of millennia.

However, the ability of our ancestors to discern different types of manifestations and the curiosity to compare their beneficial or dangerous effects, date probably back to the Middle-Upper Paleolithic, over 30,000 years ago, well before the end of the 'Year Zero of Geothermics'. Such ability must have taken root, consolidated and evolved during many millennia until the need to depict on rocks certain phenomena of terrestrial heat arose in ancient people. Probably, this need was felt in different geothermal areas of the world, at different times and independently from each other; but we are unable to say where and when it may have happened. Nonetheless, should someone ask us to guess the period and site where that need might have formed first in the world, we would be prone to say Western Anatolia, Turkey, where a wall sketch depicting a volcanic eruption was drawn over 8,000 years ago and was found by Mellart in 1967 (*see* Fig. 14). This means that the spirit of observation of geothermal phenomena, and the curiosity of the people to observe volcanic events, had already matured much over 10,000 years ago.

• Myths and legends: Prometheus, symbol of Science for his gift of volcanic fire to humankind

We think that myths and legends in prehistory did not spring from nothing or from pure imagination only. Peculiar landscape features, natural phenomena and resources (hurricanes, floods and rivers, lakes, vegetation, lightning strikes and rain, celestial bodies, sunrise and clouds, high mountains, caverns and dark nights, eclipses and many others), circumstances and facts of daily life, animals and persons, real or fictitious, must have been in proto-history and ancient times a cue for the formation of myths and legends. This involved also geothermal phenomena and physical features formed as a result of the Earth's heat. Furthermore, unlike any other visible events (celestial bodies, strikes, eclipses, fires, etc.), owing to the hidden origins of their subterranean formation, all geothermal manifestations were, for pre- , proto- and early-historic people, mysterious and exceptional phenomena, causing in their mind a mixed sense of respect, fear and love, coupled with a strong mental appeal (Burgassi et al., 1992; Cataldi, 1993). This was, in our opinion, a further goad for our oldest forefathers to try to grasp the intimate 'spirit' of the geothermal phenomena.

However, the etiological elaboration of such phenomena goes probably back to 7,000-8,000 years ago, when the cultural level of people was ripe enough to create legends and myths directly or indirectly linking those phenomena to endogenous powers ruled by supernatural entities dwelling underground or above the Earth's surface (Burgassi et al., 1992; Cataldi and Chiellini, 1995; Cataldi, 2005/1).

In general, myths and legends were handed down from parents to children for millennia or many centuries. As a consequence, in passing from generation to generation and from site to site, most myths and legends underwent modifications, adaptations, enrichments and distortions, which gave rise to different versions of the same account in the same place.

In particular, concerning geothermal energy, exist in the world hundreds (or perhaps thousands) of myths and legends related to phenomena of the Earth's heat, some of which have been mentioned in previous pages of this paper. Nonetheless, in the framework of this chapter, a special meaning has the myth of Prometheus (Fig. 62), legendary Titan of Greek and other mythologies of ancient civilizations in the 'old' world, whose fame in proto-history and early historic epochs spread over the Mediterranean area, the Middle East, and the Caucasus and Trans-Caucasus regions (Buachidze et al., 1999; Fytikas et al. 1999).

***Fig. 62**. Prometheus, benefactor of humankind and symbol of Science. Prometheus depicted in a sculpture by Nicolas-Sébastien Adam, 1762 (Louvre) [Photo by No machine-readable author provided. Own work assumed (based on copyright claims), Public Domain, https://commons.wikimedia.org/w/index.php?curid=1520906].*

Prometheus owes his fame for having been the benefactor par excellence of humans, especially during harsh periods on Earth when humans had not been endowed yet with fire by the gods, and were therefore about to extinguish from cold. Then, moved to pity, Prometheus took away a spark of fire from Hephaestus' workshop in the bowels of Mt. Etna in Sicily and donated it to mankind. The fire that saved human life would have had, therefore, a geothermal origin. The legend might have sprung in Neolithic times as a result of old memories of the final part of the so-called global glaciation that affected the northern hemisphere from 100,000 to 10,000 years ago approximately, and that is known with various names: Wisconsinan in North America, Weichselian and Vistulian in North and Central Europe, and Wurm in the Alpine area.

Besides its geothermal origin, the legend goes on to specify that, as a consequence of his theft of the fire in alleviation of the life conditions of people on Earth, Prometheus was condemned to be permanently chained to a rock at the top of Mt. Elbrus in the Caucasus, where an eagle, under the orders by the most powerful of the gods, fed on his liver every day and where the liver itself regenerated continuously during the night.

Due to the gift of the fire to mortals, for his determination in favoring the development of humankind, and for the metaphorical consumption and regeneration of his liver during the night, Prometheus is taken as model of courage and freedom, symbols of Science: "…How deep should have been his love for the humans, to donate them a so precious gift…" (excerpted from Prometheus, by Simone Veil).

10.2. From myths to science

Even though we are unable to document when and where the first cue occurred for scientific thought to start blooming, the fact remains that many proto-historic legends and myths related to the external manifestations of the Earth's heat are presented as an etiological key aimed at explaining the occurrence of observed events; in our case, volcanic eruptions and earthquakes, fumaroles, steaming grounds, geysers, hot springs and others.

Were those myths and legends 'science' in the modern sense of the term, i.e. inductive or deductive reasoning on certain phenomena according to a holistic vision of cause-effect-interactions of factors and their consequences, as an 'unbroken whole' of the same phenomena? Not at all, for sure!

Nonetheless, those myths and legends reveal, in our opinion, the mature need of knowledge, and the mental attitude of proto-historic people wishing to understand nature and imagining the causes of geothermal events. This means that myths and legends had prepared effectively a fertile ground for the birth of the proper scientific thought on geothermal energy.

Such ground formed presumably in several areas of the world, at different times and in various forms; but also on this point we are unable to document where and when it happened. We can say, however, that the description in scientific terms of geothermal phenomena began (perhaps for the first time in the world) in the Mediterranean area around the 6th century B.C., and bloomed then in Greek and Roman Antiquity with a lot of philosophers, historians and geographers, many of whom visited intentionally the sites of the geothermal manifestations and endeavored to interpret their nature and genesis in the light of the cosmogonical, philosophical and naturalistic theories of their epoch. Furthermore, some poets (as for instance Homer and Virgil in Greek and Roman Antiquity, and probably other poets, too, of ancient civilizations around the world) identified certain manifestations with the 'gates of the hell'.

Incidentally, it may be of interest knowing that 'history' and 'historian' are Greek-derived terms (*ιστορία* and *ιστορός*, pronounced "*historía*" and "*historós*", respectively), whose meanings are: on-site inspection, visual investigation, research and direct observation in the first case; and inspector, explorer, investigator, visitor of the sites of interest to investigate personally local facts and events, in the second case. This clarification enables us to understand why many ancient historians undertook long journeys to observe directly phenomena, manifestations and effects of events related to the Earth's heat before describing and interpreting them to the best of their knowledge.

One of the famous ancient authors who wanted to reach a very risky area and observe at close range a paroxismal phenomenon of geothermal heat was Pliny the Elder (Fig. 63), who lost his life during the initial phase of the Vesuvius eruption that annihilated Pompeii

***Fig. 63.** Pliny the Elder, as imagined by a 19th-century artist. [Photo by http://www.nlm.nih.gov/archive/20120918/hmd/breath/Faces_asthma/VIIA29.html. This file was derived from Plinyelder.jpg, Public Domain, https://commons.wikimedia.org/w/index.php?curid=30423233]*

in 79 A.D. In his honor, and in honor also of his nephew Pliny the Younger (who was ordered by his uncle to remain at a safe distance so he could, therefore, report the details of that catastrophic event), modern volcanologists have defined as Plinian the type of eruption that killed Pliny the Elder and many tens of thousands of people in that occasion.

Referring the readers to the volumes by Burgassi et al. (1992) and Cataldi et al. (1992), and to the papers by Burgassi et al., 1999, Cataldi and Chiellini (1999), and Cataldi and Burgassi (2005), for details on the subject(s) dealt with by each of them, the principal authors who described various scientific aspects of geothermal energy in the Mediterranean area, and their respective main work(s) from Greek Antiquity to the start of the Middle Ages are listed below in Table 4.

Century	Author(s)	Main work(s)
6th B.C.	Anaximenes	In *Meteorology,* by Aristotle
5th B.C.	Herodotus	*The Nine Books of History*
5th B.C.	Hippocrates	*Air, Water, Land*
5th B.C.	Democritus	In *Meteorology,* by Aristotle
4th B.C.	Aristotle	*Meteorology*
3rd B.C.	Lycophron	*Alexandra* (or *Cassandra*)
2nd B.C.	Poseidonius	In *Geography*, by Strabo
1st B.C.	Strabo	*Geography*
1st B.C.	Pompeius Trogus	In *Epitome of Philosophy and History by Pompeius Trogus,* by Justin
1st B.C.	Tibullus	*Elegies*
1st B.C.	Ovid	*Metamorphoses*
1st B.C.	Vitruvius	*Architecture*
1st B.C.-4th A.D.	Various Greek and Latin Authors	In *Baia,* by A. Correnti
1st A.D.	Pliny the Elder	*Natural History*
2nd A.D.	Pliny the Younger	*Letters (Letter to Tacitus)*
2nd A.D.	Pausanias	*Description of Greece*
2nd A.D.	Galen	*Vita medica*
1st-4th A.D.	Apuleius and others	In *Hierapolis. Excavations and Research*, by T. Ritti
4th A.D.	Oribasius	*Medical Collections*
5th A.D.	Macrobius	*Saturnalia*

Table 4*. Main authors who dealt with geothermal phenomena in the Mediterranean area, from 6th century B.C. to 5th century A.D.*

From the list above one can argue that, in relation to the times concerned, the scientific interest for the Earth's heat was rather much developed during Greek and Roman Antiquity in the Mediterranean area. Presumably, the same happened also in other important geothermal regions of the world, as for instance southern Asia and the Pacific areas; but we are unable to document it.

10.3. From the 6th century A.D. to the First International Geothermal Congress (1928)

Based on the notable advancements reached in the previous 10-12 centuries, scientific interest for geothermal energy grew slowly in the Lower Middle Ages, but started to revive again in the Upper Middle Ages, and bloomed lushly from the Renaissance onwards. The principal authors and their main work(s), from the Mediterranean area and other regions of the world are listed in Table 5.

Century	Author(s)	Main work(s) (Original in italics, with English translation when necessary)
6th A.D.	Cassiodorus	*Variae (Miscellanea)*
6th A.D.	Gregorius Magnus	*Registrum Gregori* (The Gregorius collection)
10th A.D.	Avicenna	- *Liber canonis medicinae* (Book of medical standards) - The book of healing
10th-19th	Salernum Medical School	*Regimen sanitatis salernitatis* (The Salernum health regime)
12th	Benjamin de Tudela	The travels of Benjamin de Tudela
13th	Ristoro d'Arezzo	*Della composizione del mondo* (On the composition of the world)
13th	Pietro Az.no da Eboli	*De balneis terrae laboris* (Thermal stations of southern Italy)
13th	Dante Alighieri	*Vita Nova* (The new life)
14th	Fazio degli Uberti	*Il Dittamondo* (Accounts on a journey around the world)
15th	Ugolino da Montecatini	*De natura et virtute balnearum Comitatus Volterrae* (Nature and characteristics of the thermal stations in the Municipality of Volterra)
15th	Michele Savonarola	*De balneis Volterrae* (On the baths of Volterra)
15th	Mengo B.	*De balneo de morba volterrano*

	Faentino	(On the healing baths of Volterra)
15th	Bartolomeo Taurinensis	*De balneis* (On thermal baths)
15th - 16th	Benuccio Capacci	*Scoperta dell'allume di rocca nella Regione boracifera* (Discovery of alum in the Boraciferous Region)
16th	Gonzalo Fernández de Oviedo	*Sumario de la natural historia de las Indias* (Summary of the Natural History of the Indies (Indies refers to the American continent), 1526
16th	Georg Bauer (better known as Agricola)	- *De veteribus et novis metallis* (Old and new minerals), 1546 - *De natura eorum quae effluent ex terra* (On the nature of the fluids outflowing from underground), 1546 - *De re metallica* (Minerals), 1556
16th	Tommaso Giunta	*De Balneis omnia quae extant apud graecos, latinos et arabos* (Therma1 stations in all territories of Greek, Latin and Arabian languages), 1553
16th	Gabriele Falloppio	*Opera de thermis* (Treatise of thermal baths), 1560
16th	Andrea Baccio	*Opera de thermis* (Treatise of thermal baths. It includes a dissertation on the origin of the heat source), 1571
16th	Ugo Aldrovandi	*Musaeum Metallicum* (Treatise of minerals, 4 volumes), ~1575
16th	Li Shi-zhen	Compendium of Materia Medica (53 volumes), 1578-1560?
16th	Michele Mercati	*Metallotheca Vaticana* (Description of minerals in the Vatican museum of minerals, founded by him). Work published by G.M. Lancisi in 1717
17th	Philippe Clüver (better known as Cluverius)	*Italia Antiqua*, Vol. I (Ancient Italy, including geology), 1624
17th	Athanasius Kircher	*Mundi subterranei prodromus* (Prodrome to subterranean world), 1657
17th	Niels Steensen (better	*De solido intra solidum naturaliter contento dissertationis prodromus*

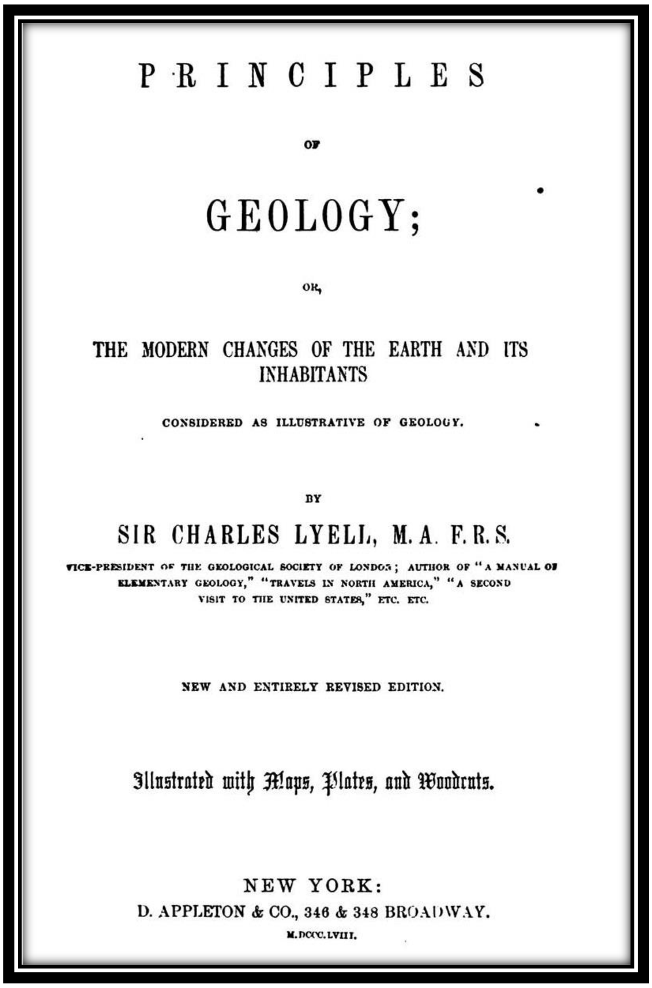
	known as Steno)	(Prodrome to a treatise on formation of minerals inside the rocks), 1669
18th	Goto Konzan and Shuan Kagawa	Medical benefits of hot springs, 1734. Original name of the work is unknown (see references for this paper in Sekioka 1999; pag. 404)
18th	Giovanni Targioni Tozzetti	*Relazione d'alcuni viaggi fatti in diverse parti della Toscana* (Report on geological, geothermal and other investigations made in Tuscany), 1769
18th	Hubert Hoefer	*Memoria sopra il sale sedativo di Homberg* (Discovery of the boric acid - then known as Homberg's sedative salt –in the geothermal steam), 1777
18th	Paolo Mascagni	*Dei lagoni del Senese e del Volterrano* (On the geothermal pools –then called lagoni— in the territories of Siena and Volterra), 1779
18th	James Hutton	Theory of the Earth, 1788
19th	Jean Baptiste Dumás	*Traité de Chemie appliquée aux Arts* (Treatise of Chemistry, applied to the Arts), 1828
19th	Francesco Larderel	*Memoria sull'acido borico scoperto in Toscana e sulla sua applicazione* (Discovery of boric acid and its application in Tuscany), 1831
19th	Paolo Savi	*Memorie per servire allo studio della costituzione fisica della Toscana* (Studies on the physical constitution of Tuscany), 1833
19th	Giuseppe Gazzeri	*Induzione ora verificata di ottenere nuovi soffioni di acido borico per mezzo della trivellazione del terreno* (Creation of steam jets by drilling), 1841
19th	Leopoldo Pilla	*Breve cenno sopra la ricchezza minerale della Toscana* (Short account on the mineral resources of Tuscany), 1845
19th	Anselme Payen	*Acide borique des soffioni de la Toscane* (Boric acid from natural steam vents in Tuscany), 1847

19th	Charles Lyell	- Principles of Geology, 1850 (8th edition) - The Geological Evidence of the Antiquity of Man, 1863
19th	Roderick Impey Murchison	On the Geological Structure of the Alps, Apennines and Carpathians, 1848.
19th	Paolo Savi - Giovanni Meneghini	*Considerazioni sulla geologia della Toscana* (Remarks on the geology of Tuscany), in relation to the paper above by Murchison, 1851
19th	Charles Saint-Claire Deville	*Recherches nouvelle sur le bore et ses affinités, et en particulier son afinité pour l'azote* (New research on boron and its affinities), 1857
19th	Emilio Bechi	- *Studi sulla formazione dei soffioni boraciferi* (Studies on the formation of the boron-bearing steam vents), 1858 - *Teoria sui soffioni boraciferi della Toscana* (Theory on the formation of the steam vents in Tuscany), 1878
19th	Giovanni Meneghini	*Sulla produzione dell'acido borico dei Conti De Larderel* (Production of boric acid at Larderello), 1867
19th	Oracle Popp	Annals of Pharmaceutical Chemistry, 1872
19th	Antonio Stoppani	*Il Bel Paese. Conversazioni sulle bellezze naturali, la geologia e la geografia fisica dell'Italia* (The beautiful country. Accounts on natural beauties, geology and physical geography of Italy), 1874
19th	Johann Rudolf Wagner	Handbook of Chemical Technology, 1875
19th	Luis Dieulafait	*Acide borique: methodes de recherche, origine et mode de formation* (Boric acid: Research methods, origin and formation factors), 1877
19th	Antonio D'Achiardi	*Sull'origine dell'acido borico e dei borati* (Origin of boric acid and of the borates), 1878
19th	Carlo De Stefani	*I soffioni boraciferi della Toscana* (The boron-bearing steam vents of Tuscany), 1897
20th (until 1930)	Bernardino Lotti	- *I soffioni boraciferi della Toscana* (Steam vents of Tuscany), 1900 - *Sulla provenienza dell'acido borico nei soffioni della Toscana* (Origin of the boric acid contained in the steam vents of Tuscany), 1907 - *I soffioni boraciferi della Toscana* (The boraciferous steam vents of Tuscany, Revised edition of the first paper, with geological map), 1928
20th (until 1930	Enrico Perrone	*Carta idrografica d'Italia: Fiora, Cecina, Cornia* (Hydrogeology of Italy: Rivers Fiora, Cecina and Cornia), 1904
20th (until 1930)	Piero Ginori Conti	*L'impianto di Larderello* (Chemical and Power plants of Larderello), 1917
20th (until 1930)	Giovanni D'Achiardi	*Il ritrovamento dell'anidrite nella Regione dei soffioni boraciferi a Castelnuovo Val di Cecina* (Discovery of the anhydrite at Castelnuovo V.C., in the steam-vents region), 1926
20th (until 1930)	Raffaello Nasini	- *I soffioni boraciferi e l'industria dell'acido borico in Toscana* (The boraciferous steam vents and the industry of boric acid in Tuscany), 1906 - *I soffioni ed i lagoni della Toscana e l'industria boracifera* (Steam vents and boiling pools of Tuscany, and its chemical industry), 1930

Table 5. *Main authors who dealt with geothermal phenomena in the world from the 6th century A.D. to 1930.*

From Table 5, we can note that during the Middle Ages the scientific interest on terrestrial heat was mostly focused on hot springs and thermal balneology, with minor consideration given to geothermal phenomena and hydrothermal minerals. On the contrary, starting from the Modern Age, a wide range of issues was considered for R&D activities, especially during the 19th century when a notable increase occurred in scientific interest about the Earth's heat. This is attested to by numerous papers on geoscientific investigations carried out in geothermal areas, publications of geological maps, discovery and chemical characterizations of many hydrothermal minerals, formulation of genetic hypotheses on various geothermal phenomena, and enunciation of theories on how and where the geothermal fields can form.

Polite discussions and lively debates also started in some cases on the origin of certain phenomena of the Earth's heat, as for instance on the genesis of boric acid carried by natural steam vents, or on the formation of the geothermal fields. This was in certain cases the result of the bitter disputes that in the 5-6 decades astride the 18th-19th centuries animated the earth science world: the contrast between the 'Neptunism' and 'Plutonism' theories, the main supporters of which had been Abraham Gottlob Werner and James Hutton, respectively. These disputes ended in the second half of the 19th century after the affirmation of Lyell's Principles of Geology (Fig. 64) and the general acceptance of the theory of 'Actualism' as a methodological approach to the earth sciences.



PRINCIPLES

OF

GEOLOGY;

OR,

THE MODERN CHANGES OF THE EARTH AND ITS INHABITANTS

CONSIDERED AS ILLUSTRATIVE OF GEOLOGY.

BY

SIR CHARLES LYELL, M. A. F. R. S.

VICE-PRESIDENT OF THE GEOLOGICAL SOCIETY OF LONDON; AUTHOR OF "A MANUAL OF ELEMENTARY GEOLOGY," "TRAVELS IN NORTH AMERICA," "A SECOND VISIT TO THE UNITED STATES," ETC. ETC.

NEW AND ENTIRELY REVISED EDITION.

Illustrated with Maps, Plates, and Woodcuts.

NEW YORK:
D. APPLETON & CO., 346 & 348 BROADWAY.
M.DCCC.LVIII.

Fig. 64. *Cover of the Lyell's book published in 1850 (Photo taken from http://servicios.educarm.es/paleontologia/tectonica.htm).*

The notable increase of scientific interest in geothermal energy from the 18th century onwards occurred mostly in southern Europe due to the many active volcanoes, fumaroles and thermal manifestations existing in this part of the world, especially in the Boraciferous Region of Tuscany and in the Phlegrean Fields in Italy. The interest, however, involved not only Italian scientists but also scientists from many European countries and other continents. For Asia and the Americas, in particular, we feel that the scientific interest on the phenomena of the Earth's heat may have been much wider than that the readers of this paper may infer from the few non-European authors we were able to quote in Table 5.

10.4. Synopsis of the most significant scientific advancements from Antiquity to 1930

The scientific progress made in geothermal science through investigations and research carried out by thousands of people in the 2,500 years considered in Tables 4 and 5 can be broken down schematically into two main conceptual periods: i) the first, from Antiquity to the end of the Middle Ages, almost solely based on field observations and conjectural hypotheses; and ii) the second, from the Renaissance to 1930, based on systematic field surveys of geothermal phenomena, supported by measuring devices, lab analyses, drilling data, quick flows of information among the interested scientists, and the possibility to compare results and integrate data much more widely and quicker than that possible in previous centuries.

The main results on scientific progress obtained during the two aforesaid periods are as follows.

• From Antiquity to the end of the Middle Ages

- Qualitative classifications of thermal and mineral waters;

- Early theories on the genesis of earthquakes;

- Description of volcanic eruptions and accounts on different forms in which they occur;

- Hypotheses on the formation of geothermal manifestations:

- Discovery that temperature increases with depth and formulation of explanatory theories. One of them, attributable to Vitruvius, proposed that in some places on Earth thermal anomalies form as result of 'interactions' between masses of different minerals. It may have been an intuition of the phenomenon that we call today exothermal reactions;

- Initial hypotheses first, and consolidation afterwards, of the idea that in many places on Earth exists a subterranean fire and drives the igneous process. It was probably a precocious idea of what we call nowadays magmatic intrusions and magma chambers.

Taken as a whole, those points represent indisputable fundamentals of modern geothermal science.

• From the Renaissance to 1930

The interest in geothermal phenomena increased considerably after the end of the Middle Ages when the hydrothermal minerals of some zones (mostly those of the Boraciferous Region of Tuscany) underwent a period of intensive exploitation for pharmaceutical and industrial uses. The exploitation had a strong acceleration in the first half of the 19th century following the discovery by Hoefer and Mascagni in 1777-1779 of the boric acid in the Boraciferous Region, and a further acceleration in the first decades of the 20th century after the start of the industrial production of geothermal-electric power at Larderello.

The scientific advancements obtained from 1500 to 1930 can be grouped into the following issues:

- Mineralogic determination of all products associated with the manifestations of the Earth's heat;

- Recognition of the fact that most manifestations are located along preferential tectonic trends (Fig. 65);

- Identification of anticlines and fractures created by intrusions and eruptions of recent igneous bodies;

- Recognition of regional thermal anomalies controlled by magmatic processes of young geological age (Plio-Pleistocene);

- Location of the main hydrogeologic circuits of the geothermal systems (percolation of meteoric waters in correspondence to outcropping permeable formations and along fractures);

- Identification of interactions between percolating meteoric waters and deep rocks and minerals;

- Recognition of the role played by permeable formations (reservoir) overlain by impermeable complexes (cap-rock);

- Recognition of self-sealing processes (scaling) at the surface and underground, caused by mineralized hot fluids and resulting in shifting in time of the natural steam-jets (*soffioni*) along preferential tectonic trends (NW alignments in the case of Italy);

- Determination of the nature of all incondensable gas associated with geothermal steam and hot water;

- Recognition of the possible formation, at shallow depths and in certain conditions, of over-pressurized steam caps, capable of giving rise to new steam-jets or phreatic eruptions;

- Formulation of the first organic theory on the formation of the geothermal fields. This theory was known as the theory of the *juvenile origin of the endogenous steam*.

Based on the groundwork laid in Antiquity and the Middle Ages, and in conceptual continuity with it, the advancements above represent the solid columns of the present geothermal science. They form together our common scientific heritage: the cognitive foundation upon which the advancements have grown in the last 70-80 years of the much wider knowledge we have today of geothermal energy.

Fig. 65. *Print from 1818 showing the alignment of steam jets along a fault scarp in the Boraciferous Region (after Cataldi and Burgassi, 2005).*

10.5. Highlights on selected subjects and authors

The advancements achieved in the three main sectors of geothermal research, obtained in the world from Antiquity to 1930, can be summarized as follows. For the main work(s) of the authors indicated below see Tables 4 and 5.

• Geodynamics, igneous processes and genesis of geothermal fields

The most outstanding scientists by their their contributions to foster the knowledge of geothermal energy in the subject and the period in question are in our opinion: Aristotle (384-322, B.C.), Vitruvius (90-15 B.C.), Strabo (60 B.C.-23 A.D.), Pliny the Elder (23-79 A.D.), Pausanias (110-180 A.D.), A. Kircher (1602-1680), C. Lyell (197-1875) and B. Lotti (1847-1938). A symbolic detail of the scientific input given by Kirker is to be seen in Figure 66.

• Characteristics of hot water and thermal balneology

The most outstanding scientists who fostered this sector of the Earth's heat from Greek Antiquity onward are in our opinion: Hippocrates (460-377 B.C.), Oribasius (320-403 A.D.), Avicenna (980-1037 A.D.), G. Falloppio (1523-1562). Li Shi-zhen (1518-1593) and Goto Konzan (1659-1593). All of them were medical doctors who dealt with thermal balneology from Antiquity to the 18th century.

The *Scuola Medica Salernitana* (Salernum Medical School), founded astride the 9th-10th centuries A.D., is considered the forerunner of the modern universities (Fig. 81) and operated intensively for about 1,000 years. Medical matters only were taught in that school, and the most renowned medical doctors of the time were called to give lectures there. Sanitary and practical aspects of thermal balneology were also dealt with in that institution. Federick II, Emperor of the Holy Roman Empire, was its high patron between 1220 and 1250, and Constantine XI, the last Emperor of the Eastern Roman Empire, was cured there around 1450.

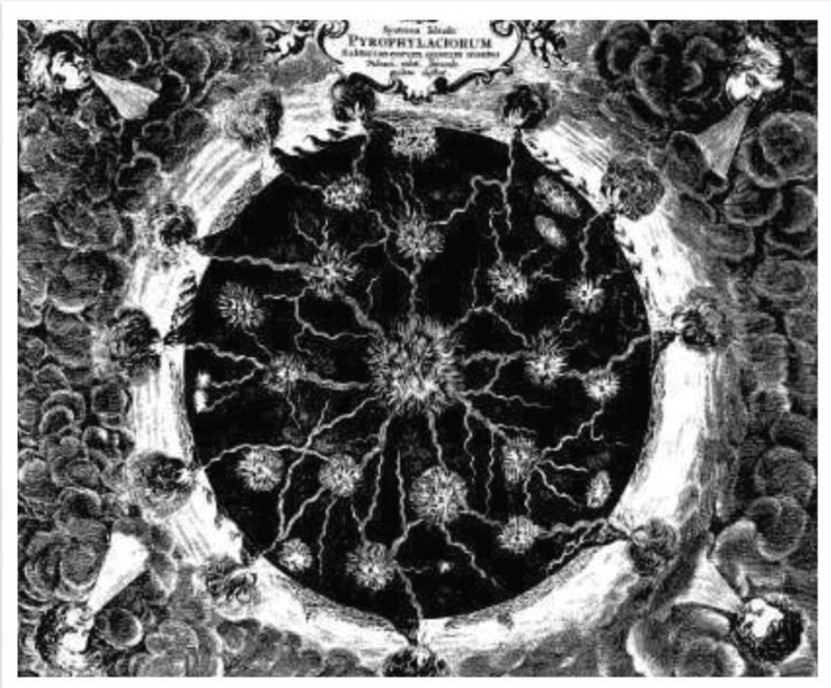


***Fig. 66**. Kircher's model of the Earth's interior and formation of volcanoes, 1657 (after Cataldi et al., 1999).*

• Applications of the Earth's heat (space heating, by-products and geoelectric generation)

The most important, scientifically minded, pioneers in the utilization of geothermal resources between the first century B.C. and 1930 are in our opinion: C.S. Orata (140-91 B.C.), which was the Roman engineer designing and developing the hypocaust system to heat bathing and other rooms in thermal Roman spas from the 1st century B.C. onwards; G. Bauer (Agricola, 1494-1555), F. Larderel (1789-1858), R. Nasini (1854-1931) and P.G. Conti (1865-1931). Two emblematic images depicting peculiar uses of the Earth's heat for direct applications, ascribable to C.S. Orata and to F. Larderel, respectively, can be seen in Figures 67 and 68.

10.6. Concluding remarks on scientific aspects

We have decided to stop at 1928 approximately our review of the scientific aspects of geothermal energy, not for a mere recognition of the first international geothermal congress held at Larderello in that year, but because that event represents the most important turning point ever in geothermal science, one that enabled taking in the following decades notable steps ahead in the methodological approach to its cognitive and developmental issues.

To prove the different modus operandi arising from that congress (though halted temporarily between 1939 and 1945 by the events of the 2nd World War), it is enough to mention the following facts and advancements that happened from 1930 approximately onward.

The 'theory of the juvenile origin of the endogenous fluids' (which had been almost generally been accepted in the previous decades) was overcome around 1930. The affirmation started to establish since then of the theory of 'meteoric origin of the water supplying the geothermal fields'. This was the cue to devise a totally new methodological approach in the research and exploitation of high-temperature geothermal fields, the results of which were:

- New prospecting methodologies to characterize high-temperature areas and discover hidden reservoirs by means of many advanced techniques including: magnetotelluric, induction, dipole-dipole, tri-dimensional seismic and other refined geophysic surveys; analysis of gas escaping from deep layers; temperature gradient measurements, thermal conductivities and heat flow determinations; airborne and satellite surveys of geothermal regions;

- Possibility to carry out isotopic and spectrographic analyses on rocks, fluids and gases;

- Reinjection of spent hot waters for environmental reasons, and injection of fresh water to resupply the geothermal reservoirs;

- Well-logging in most exploration wells, and adoption of highly resistant materials for equipment, drilling and power plants;

- Drilling deviated and directional wells;

- Harnessing not only steam-dominated, but also water-dominated geothermal reservoirs;

- Use of electronic devices in most field surveys and laboratory determinations, together with many new computer programs for interpreting any kind of data;

- In addition to traditional power units, electricity generation started also to be made by binary, ORC and hybrid plants;

- Diffusion of direct applications and multi-purpose, cascading utilization of geothermal resources, heat pumps and others.

Many such new investigation methods, harnessing and processing technologies, and uses of geothermal resources were not yet born in the 1940s and 1950s of the past century, or were barely infants; whereas others were still in the mind of God.

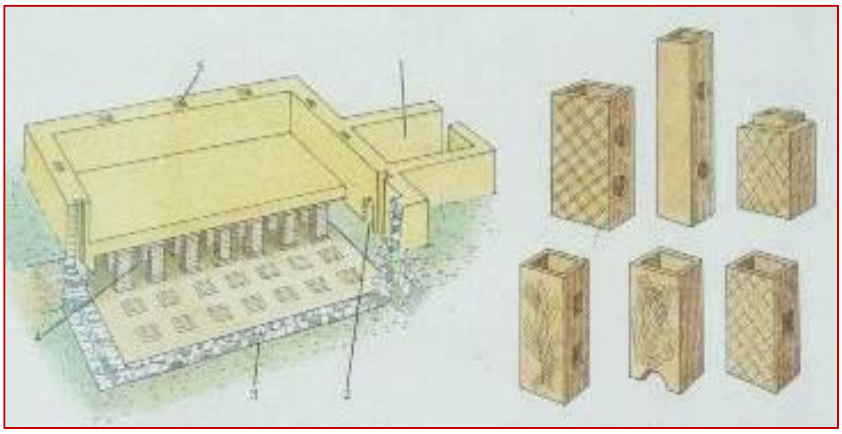
As a consequence, and in consideration also of the fact that many members of the present geothermal family have been or are directly involved in the implementation of the aforesaid advancements, and are therefore aware of their input to scientific progress made in the geothermal sector in the last decades, it would have been rather difficult for us to depict those aspects objectively as required from the History of Science and Technology point of view.

On the other hand, dealing appropriately with all advancements listed above would have required much more time, and would have fallen outside the scope and limits of this paper.

The rapport in question probably started to form some two million years ago in Africa; it then 'migrated' sequentially with people in prehistoric times during the long time lapse called the 'Year Zero of Geothermics': a few hundreds of thousands of years in the Mediterranean area and Far East, and a few dozen thousands of years in North-, Meso- and South-America. The rapport matured slowly in distinct sites and at different times, but was always a close relationship that was initially limited to functional applications: cooking, bathing and washing, and the use of volcanic rocks to manufacture weapons and tools, of thermo-mineral waters and muds for therapeutic applications, and of hydrothermal compounds (cinnabar, iron oxides, sulfur and others) to prepare pigments.

With passing time, starting probably in Late Paleolithic in Africa, the Mediterranean area, the Middle East and the East Pacific, and in Neolithic times in the Americas, the functional relationship was accompanied by a more refined rapport of coexistence with special physical features and manifestations of the Earth's heat: volcanoes, fumaroles, steaming grounds, hot pools and thermal springs.

The rapport involved afterwards the spiritual sphere of



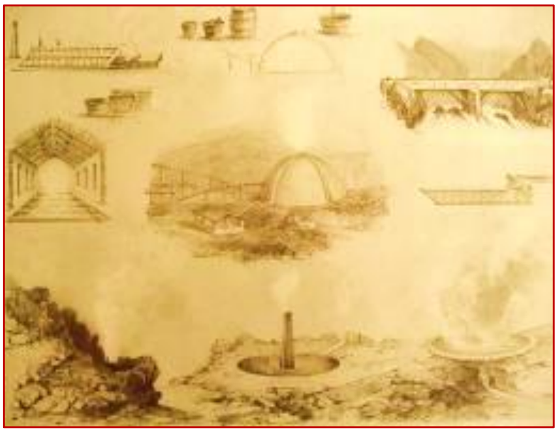


Fig. 67 *(Left). Thermal building heated by hypocausts and the alveolated walls on the right part,* 1^{st} *century B.C. (after Cataldi and Burgassi, 1992).*

Fig. 68 *(Right). Main equipment used at Larderello to extract and process boric acid, 1820-1860 (after Ciardi and Cataldi, 2005).*

11. Final Thoughts

In analyzing the history of the rapport of humankind with the external manifestations of the Earth's heat, we note that exist surprising similarities in the use of geothermal energy in different epochs, in places very far from one another, and by totally different cultures. We also note that the rapport is always deeply rooted in prehistory or early historic times of each geothermal locality where people happened to reach and settle.

people, and evolved later into forms of religious feelings towards those features and manifestations and, through them, towards *chtonian* or surface beings dwelling inside each of them.

A lot of active volcanoes, in particular, in many countries of all inhabited continents, were believed to be in prehistory, and continued to be considered in historic and recent times, living creatures endowed with human feelings of grace and hot temper, that they used in different ways, depending on the behavior of the people on Earth. Kilimanjaro in Tanzania with its much-photographed snow cap (Fig. 69), Etna in Italy, Ararat in Turkey-Armenia, Paektou in China-North Korea, Semeru and Agung in Indonesia, Aso and Fuji in Japan, St. Helens in the USA, Popocatéptl in Mexico, Miravalles and Irazú in Costa Rica, Cotopaxi and Chimborrazo in Ecuador, are a few examples only of volcanoes profoundly worshiped by our ancient ancestors. All such volcanoes, and many others, were considered 'sacred mountains'; therefore, local people had to give offerings to them periodically, and in some other special occasions, offerings of a different nature: even human sacrifices, in many cases. Moreover, each of them was believed to have a peculiar character with its own spirit or soul.

As a result of the above, the relationship of humans with volcanoes was everywhere on Earth, for many millennia or centuries, a tight rapport, whose core was made by a mix of love, faith, awe and fear. Furthermore, fresh water and heat, with their cosmic meaning, have always been recognized universally as signs of life since the dawn of human time.

In addition to reverence felt and rituals made to gain their benevolence, volcanoes and other manifestations of the Earth's heat gave the cue for the formation, in proto-historic and ancient times, of countless myths and legends related to them, which played an important role in disseminating information about their physical features and 'good' or 'bad' tempers, depending on the behavior of the people on Earth.

All those legends and myths represent the first core of knowledge on the external manifestations of terrestrial heat.

From the functional viewpoint, other common denominators of the ancient rapport between humankind and Earth's heat in all inhabited geothermal areas of the world were: cultivation of soils around thermal manifestations and use of warm waters to irrigate cultivated grounds in relatively cold regions; barter in prehistoric times, and commerce from ancient to recent times of almost all geothermal by-products; and visits by people of every social class, ethnic group and gender to thermal spring sites. These were organized not only for healing cures but also for special events, such as cults, ritual ceremonies, sporting contests, popular festivals and others.

All these functions helped increase the knowledge of the Earth's heat and its external phenomena; the second and third of them, in particular, contributed to starting in proto-historic times the 'internationalization' of geothermal energy.

To conclude, the terrestrial heat and its by-products have been in many areas on Earth, and in substantial continuity through countless millennia, an important factor for human development, and for the birth and growth of many civilizations, from the dawn of the prehistory to recent times. They also have had, in certain periods and areas, a notable impact on the course of history.

***Fig. 69**. First aerial view of the Kibo volcanic cone of Mount Kilimanjaro taken in 1929 [Photo by Walter Mittelholzer - E-Pics Bildarchiv online http://doi.org/10.3932/ethz-a-000254045ETH-BIBLIOTHEK. Public Domain, https://commons.wikimedia.org/w/index.php?curid=49617129].*

In our opinion, the three main effects of the Earth's heat on society through time have been:

a) An **attraction effect** in areas where the presence of benign manifestations encouraged people to settle and develop nearby;

b) An **expulsion effect** in areas where volcanic eruptions and earthquakes impelled people to flee from their native lands in search of safer places; and

c) A **propulsion effect** in areas where the presence of thermal manifestations and by-products, or the possibility to use the terrestrial heat for direct applications and energy purposes, fostered the growth of important developmental initiatives with social and economic benefits on a local and regional scale.

Notable scientific advancements were made in the geothermal sector from Antiquity to 1930 that concerned practically all aspects of the nature, characteristics and phenomena of the Earth's heat. They enabled the formulation, at the beginning of the 20th century, of an organic explanation on the formation of all vapor-dominated fields in the world, known as the 'theory on the juvenile origin of the endogenous steam'. On this base the exploration of high-temperature areas and the location of the steam-production wells were carried out during the first three decades of the past century.

In the second half of that century, prepared by the previous scientific advancements, but halted for some 15 years by the tragic events of 2nd World War, began the present 'era' of the development of the Earth's heat worldwide.

For the reasons explained in a previous chapter, we have not wanted to enter in the most recent aspects of the history of the geothermal energy; but somebody else may wish to do so in the future, to compile another important chapter of our great millennial legacy.

Acknowledgment

Authors wish to thank Susan F. Hodson for her patient and careful review and proofreading of the original manuscript.

References

General Reference Works

BURGASSI, P.D., CATALDI, R., HERNÁNDEZ GALÁN, J.L. MOGGI, M., RUBINO VICH, R., Y SALDAÑA, J.J., 1992. Primera Contribución al Conocimiento Historiográfico de la Energía Geotérmica en el área mediterránea y en la América Latina. Volume of vii + 129 pages, with Presentation and Summary in Spanish and English, prepared as contribution to the *Simposio de Historia de la Geotermia*, Ciudad de Mexico, 12-16 Enero de 1992. Edición Especial, México, D.F.

R. CATALDI, P.D. BURGASSI, AND SUÁREZ-ARRIAGA, M.C. (Editors), 1992. La Geotermia en el Periodo Pre-Colombino en las Áreas Mediterránea y Mesoamericana. *Geotermia*, Vol. 8, No. 2 (pp. 145-175); Vol. 8, No. 3 (pp. 251-303); and Vol. 9, No.1 (pp. 5-58).

CATALDI, R., HODGSON, S., AND LUND, J. (Editors), 1999. *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., 580 pp.

CIARDI, M, AND CATALDI, R. (Editors), 2005. *Il Calore della Terra: Contributo alla Storia della Geotermia in Italia*. Edizione ETS, Pisa, Italy, xvi + 345 pp.

Specific Reference Works and Papers

AGUILERA, C., 1979. Coyolxauhqui y la Vía Láctea. *Ciencia y Desarrollo* No. 24, pp. 6-10.

ARGUEDAS, G.M., 1970. *Mitos, leyendas y cuentos peruanos*. Casa de La Cultura del Perú, Lima.

BERNSTEIN, A., 2008. Whose Fuji? Religion, Region and State in the Fight for a National Symbol. *Monumenta Nipponica*, Vol. 67, n. 1, pp. 51-99.

BIANCHI, M.C., 2005. Francesco De Larderel, Uomo ed Imprenditore. *In* M. Ciardi and R. Cataldi (Editors), *Il Calore della Terra: Contributo alla Storia della Geotermia in Italia*. Edizione ETS, Pisa, Italy, pp. 209-224.

BLACK, S., HANNA, W.A., BALLINGER, R., DARLING, J., EISEMA, F., HARNISH, D., WIJAIA, M., AND ZURBUCHEN, M., 1993. *Insight Guides Bali*. Apa Publications (H.K.) Ltd. Singapore.

BUACHIDZE, G., ALIEV, S., AND ANANYAN, S., 1999. Trans-Caucasus: One of the Most Ancient Regions Using the Earth's Heat. *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 321-336.

BURGASSI, P.D., 1987. Historical Outline of Geothermal Technology in the Larderello Region. *Geothermal Resources Council Bulletin* 16, n. 3, pp. 3-18.

BURGASSI, P.D., 1999. Historical Outline of Geothermal Technology in the Larderello Region to the Middle of the 20th Century. *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 195-200.

BURGASSI, P.D., 2005. Sulla presenza di acido borico nei Vasi Sigillati della Toscana. *Il Calore della Terra: Contributo alla Storia della Geotermia in Italia*. Edizione ETS, Pisa, Italy, pp. 74-79.

BURGASSI, P.D., CATALDI, R., AND DONATI, C., 1999. Four Centuries of Scientific Investigation at Larderello, from the 16th Century to the 1st International Geothermal Congress in 1928. *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 221-238.

CÁRDENAS, J. 1591. Primera parte de los problemas y secretos maravillosos de las Indias. *In* E. Trebulse, *Historia de la Ciencia en México*, Siglo XVI, Reprint 1983. Fondo de Cultura Econòmica, Mexico City.

CATALDI, R., 1992. El año cero de la geotermia. *Geotermia*, Vol. 8, n.2, pp. 155-175.

CATALDI, R., 1993. Review of historiographic aspects of geothermal energy in the Mediterranean and Mesoamerican areas prior to the Modern Age. *Geo-heat Center Quarterly Bulletin*, Vol. 15, n. 1, pp. 13-16.

CATALDI, R., 1999. The Year zero of Geothermics. *In* R. Cataldi, S.Hodgson and J.Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the

IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 7-17.

CATALDI, R., 2005/1. L'Uomo e la Geotermia nell'Anno Zero. *In* M. Ciardi and R. Cataldi (Editors), *Il Calore della Terra: Contributo alla Storia della Geotermia in Italia*. Edizione ETS, Pisa, Italy, pp. 3-9.

CATALDI, R., 2005/2. La Geotermia nelle antiche civiltá mediterranee. *In* M. Ciardi and R. Cataldi (Editors), *Il Calore della Terra: Contributo alla Storia della Geotermia in Italia*. Edizione ETS, Pisa, Italy, pp. 27-41.

CATALDI, R., 2005/3. Applicazioni della Geotermia in Italia dal VI al XV secolo. *In* M. Ciardi and R. Cataldi (Editors), *Il Calore della Terra: Contributo alla Storia della Geotermia in Italia*. Edizione ETS, Pisa, Italy, pp. 116-125.

CATALDI, R., 2015. Hawaii / Big Island: dall'indifferenza all'ostilità e da questa all'impulso della geotermia. *Notiziario UGI*, n. 41, pp. 16-17.

CATALDI, R., 2016. Historical Outline on Geothermal Development in Italy up to 1960, with Particular Reference to the Boraciferous Region. Prologue of Chapter 19: 100 Years of Geothermal Power Plant Evolution in Italy, by Parri, R. and Lazzeri, F. *In* R. DiPippo (Editor), *Geothermal Power Generation: Developments and Innovation*, Woodhead Publishing/Elsevier, Duxford, UK, pp. 539-551.

CATALDI, R. AND BURGASSI, P.D., 1992. Florecimiento y decadencia del termalismo y de los otros usos directos del calor de la Tierra en el área mediterránea, desde el nacimiento de Roma hasta el fin del primer milenio. *Geotermia*, Vol. 8, No. 3 pp. 265-288.

CATALDI, R. AND BURGASSI, P.D., 1999/1. From the Mystery of Atlantis to the first Integrated Uses of Geothermal Energy. *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 137-144.

CATALDI, R. AND BURGASSI, P.D.; 1999/2. Flowering and Decline of Thermal Bathing and Other Uses of Natural Heat in the Mediterranean Area, from the Birth of Rome to the End of the first Millennium. *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 147-164.

CATALDI, R. AND BURGASSI, P.D.; 1999/3. Utilization of Geothermal Resources in Italy, from the 11th through 16th Centuries. *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 185-194.

CATALDI, R. AND BURGASSI, P.D., 2005. Le ricerche scientifiche a Larderello dal XVI secolo al 1928. *In* M. Ciardi and R. Cataldi (Editors), *Il Calore della Terra: Contributo alla Storia della Geotermia in Italia*. Edizione ETS, Pisa, Italy, pp. 316-330.

CATALDI, R. AND CHIELLINI, P., 1995. Geothermal Energy in the Mediterranean area before the Middle Ages. *Proceedings of the World Geothermal Congress 1995*, Vol. I, pp. 373-380.

CATALDI, R. AND CHIELLINI, P., 1999. Geothermal Energy in the Mediterranean area before the Middle Ages. A Review. *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 165-181.

CERRUTI, L., 2005. Scienza, industria, estetica. Raffaello Nasini ed I soffioni boraciferi. *In* M. Ciardi and R. Cataldi (Editors), *Il Calore della Terra: Contributo alla Storia della Geotermia in Italia*. Edizione ETS, Pisa, Italy, pp. 276-293.

CHANDRASEKHARAM, D. 1999. A Prehistoric View of the Thermal Springs of India. *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 357-366.

CHANDRASEKHARAM, D. AND BUNDSCHUH, J., 2008. *Low enthalpy geothermal systems for power generation*. CRC Press / Taylor & Francis / Balkema Editors, Boca Raton, FL, U.S.

CIARDI, M., 2005. Da Florestano De Larderel a Piero Ginori Conti: Ferdinando Raynaut ed il primo esperimento di produzione geotermoelettrica. *In* M. Ciardi and R. Cataldi (Editors), *Il Calore della Terra: Contributo alla Storia della Geotermia in Italia*. Edizione ETS, Pisa, Italy, pp. 247-275.

CIEZA DE LEÓN, P., 1550. La crónica del Perú. Reprint 1973, Editorial Zig Zag, Santiago de Chile.

COHUT, I. AND ARPASI, M., 1999. Ancient Uses of Geothermal Waters in the Pre-Carpathian Area of Romania and the Pannonia Basin in Hungary. *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 239-250.

DE LA GARZA, M., 1990. Cosmovisión de los Mayas Antiguos. Revista Ciencias, UNAM, n. 18, pp. 33-35.

DIAZ DEL CASTILLO, B., 1568. Historia verdadera de la Conquista de la Nueva España. Reprint 1999. Fernández Editores S.A., México, D.F.

DI PASQUALE, G., 2005. Risorse geotermiche in Etruria. *In* M. Ciardi and R. Cataldi (Editors), *Il Calore della Terra: Contributo alla Storia della Geotermia in Italia*. Edizione ETS, Pisa, Italy, pp. 42-52.

DIPIPPO, R., 2015. Evolution of Geothermal Power Plants: Performance Assessments. *Geothermics*, n. 53, pp. 291-307.

DIPIPPO, R., 2016. *Geothermal Power Plants: Principle, Application, Case Studies and Environmental Impact*, 4th Edition. Butterworth-Heinemann / Elsevier, Oxford, UK, 780 pp.

EMMERICH, F., 1966. *Leyendas chilenas*. Programa Andrés Bello, Santiago de Chile.

ENCYCLOPAEDIA BRITANNICA, 1999. Multimedia Edition in CD.

ENOCH, J.M., 2006. History of mirrors, dating back to 8000 years. *Optometry and Vision Science*; Vol. 83, n. 10.

FENDEK, M., REBRO, A., AND FENDEKOVA, M., 1999. A Spell Cast: Historical Aspects of Thermal Spring Use in Western Carpathian Region. *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 251-266.

FERNÁNDEZ DE OVIEDO, G., 1526. *Sumario de la natural historia de las Indias*. Reprint 1995. Fondo de Cultura Económica, México, D.F.

FREDRIKSON, D.A., 1974. An archaeological survey of ten small land parcels, in The Geysers Geothermal Field, Lake and Sonoma Counties, California. Manuscript filed at the Nortwest Information Center, Sonoma State University. Unpblished.

FRIDLEIFSSON, I.B., 1999. Historical aspects of Geothermal Utilization in Iceland. *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 307-320.

FYTIKAS, M., LEONIDOPOULOU, G.M., AND CATALDI, R., 1999. Geothermal Energy in Ancient Greece: From Mythology to Late Antiquity. *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 69-102.

GIACOMELLI, L. AND SCANDONE R., 1992. *Campi Flegrei, Campania Felix*. Liguori Edit. Naples, Italy.

GARCILASO DE LA VEGA, 1609. Crónica de la conquista. Reprint 1973. Buenos Aires, Argentina.

GIBERT, J.P. AND JAUDIN, F., 1999. Using Geothermal Waters in France: The District Heating System of Chaudes-Aigues from the Middle Ages. *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 287-305.

GILLESPIE, S.D., 1989. *The Aztec kings, the construction of rulership in Mexica history*. The University of Arizone Press, Tucson, U.S., 315 pp.

GONZÁLEZ, Y., 1991. Diccionario de Mitología y Religión de Mesoamérica. Ed. Larousse, México, D.F.

GRIFONI CREMONESI, R., 1999. Human Rapport with Hypogeal Waters and Geothermal Manifestations in Italian Prehistory. *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 115-136.

HARRIS, S.L., 1990. *Agents of Chaos*. Mountain Press Publishing Company, Missoula, Montana, U.S.

HAY, R.L. AND LEAKEY. M.D., 1982. Fossil footprints of Laetoli. *Scientific American*, Feb. 1982, pp. 50-57.

HERNÁNDEZ GALÁN, J.L., GUIZA LÁMBARRI J., AND SUÁREZ ARRIAGA, M.C., 1999. An Overview of the Historical Aspects of Geothermal Influences in Mesoamerica. *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 519-534.

HERNÁNDEZ GALÁN, J.L., 2013. El aprovechamiento de la Energía de la Tierra. Publication of the Author, 434 pp. + 4 Appendices.

HODGSON, S.F., 1999. Hot Springs and Fumaroles, Early Days at The Geysers. *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 479-497.

HODGSON, S.F., 2007. Obsidian: Sacred Glass from the California Sky. *In* L. Piccardi and W.B. Mass

(Editors), *Myth and Geology*, The Geological Society, London, UK, 350 pp.

HODGSON, S.F., 2010. *A Geysers Album: Five Eras of Geothermal History*, 2nd Edition. California Division of Oil, Gas and Geothermal Resources, Sacramento, CA, U.S.

HUMBOLDT, A.V. AND BONPLAND, A., 1825. *Voyage aux Régions Equinoxiales du Nouveau Continent en 1799, 1800, 1801, 1803, 1804*. Smith Edit., Paris.

IBARRA GRASSO, D.E., 1956. Descubrimiento de puntas paleolíticas en el altiplano de Bolivia. *Revista de Cultura*, n. 2, pp. 186-221.

IBARRA GRASSO, D.E. AND QUEREJAZU, L., 1986. *30,000 Años de Prehistoria en Bolivia*. Ed. Los amigos del Libro, Cochabamba, Bolivia.

JAFFE, F., DVORJETSKI, E., MASSARWIEH R., AND SWARIEH, A., 1999. Geothermal Utilization in the Jordan Valley between Lake Kinneret and the Dead Sea: A View from Antiquity. *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 35-50.

JENNINGS, J.D., 1978. Origins. *In* J.D. Jennings (Editor), *Ancient Native Americans*, W.H. Freeman and Co., San Francisco, U.S.

JOCANO, F.L., 1969. *Outline of the Philippine Mythology*. Centro Escolar, University Research and Development Center, Manila, Philippines.

KRICKEBERG, W., 1956. *Altmexikanische Kulturen*. Springer Verlag, Berlin, Germany.

LARA, J., 1973. *Mitos, leyendas y cuentos de los Quechuas*. Ed. Los Amigos del Libro, Cochabamba, Bolivia.

LEÓN-PORTILLA, M., 1961. *Los antiguos mexicanos a través de sus crónicas y cantares*. Colección Popular No. 88, Fondo de Cultura Económica, México, D.F.

LEÓN-PORTILLA, M., 1983. Origen del Nuevo Sol en Teotihuacán. Informantes de Sahagún: Códice Matritense del Real Palacio. *In Antología: De Teotihuacán a los Aztecas. Fuentes e Interpretaciones Históricas*. UNAM. México, D.F., pp. 57-58.

LEÓN-PORTILLA, M., 1992. El Agua: Universo de significaciones y realidades *Revista CIENCIAS-UNAM*, No. 28, pp. 7-14.

LÓPEZ AUSTIN, A., 1990. El Tiempo en Mesoamérica. *Revista CIENCIAS-UNAM*, No. 18, pp. 28-32.

LÓPEZ DE GOMÁRA, F., 1552. Hispania victrix. *In Primera y Segunda Parte de la Historia general de Las Indias*. Ediciones Orbis, S.A., Barcelona, Spain.

LUCE, J.V., 1969. *The end of Atlantis*. Thames and Hudson, Ltd., London, UK.

LUND, J.W., 1999. Historical Impacts of Geothermal Resources on the People of North America *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 451-478.

LYELL, C., 1850. *Principles of Geology*, 8th Edition). Athenaeum, U.S.

LYELL, C., 1863. *The Geological Evidence of the Antiquity of Man, with remarks on Theory of the origin of Species by Variation*. J. Murray Ed., London, UK.

MARINATOS, S., 1939. The volcanic destruction of Minoan Crete. *Antiquity*, n. 13, pp. 425-439.

MELLAART, J., 1967. Çatal Hüyük. A Neolithic Town in Anatolia. *In* Mortimer Wheeler (Editor), New Aspects of Antiquity. London-Southampton, Thames & Hudson Ltd. and Camelot Press.

MONTANELLI, I., 1957. Storia di Roma. Milanostampa, Farigliano (CN), Italy.

MUÑOZ CARMAGO, D., 1540. Historia de Tlaxcala. Reprint 1963. *In* M. León Portillo and A.M. Garibay (Editors). *Visión de los Vencidos*. Fondo de Cultura Económica, México, D.F.

NASINI, R., 1930. I soffioni ed i lagoni della Toscana e l'industria boracifera. Storia, studi, ricerche chimiche e chimico-fisiche eseguite principalmente nell'ultimo ventennio. Tipografia Editrice Italia, Roma, Italy.

OLSEN, J.K., 2002. Introduction to Japanese hot springs. Website: http://www2.gol.com/users/jolsen/onsen/intro.html

OTE, L.M., ALCARAZ, A.P., AND DE JESUS, A., 1999. Geothermal Legacy from the Early Filipinos and Later Migrants. *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 407-418.

ÖZGÜLER, M.E. AND KASAP, A., 1999. The Geothermal history of Anatolia, Turkey. *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 69-102.

PAPINI, P., 2005. Larderello: il villaggio e la comunità. *In* M. Ciardi and R. Cataldi (Editors), *Il Calore della Terra: Contributo alla Storia della Geotermia in Italia*. Edizione ETS, Pisa, Italy, pp. 293-305.

PARRI, R., AND LAZZERI, F., 2016. 100 Years of Geothermal Power Plant Evolution in Italy. *In* R. DiPippo (Editor), *Geothermal Power Generation: Developments and Innovation*, Woodhead Publishing/Elsevier, Duxford, UK, pp. 552-589.

PERLMAN, D., 1998. Scientists push back date man arrived in the new world. *Chronicle*, 17 February 1998, San Francisco, U.S.

POPOVSKI, K. AND DIMITROV, K., 1999. The Rolling Ball of History: Geothermal Resources in Macedonia. *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 103-114.

RESTALL*, M., 2003. Seven Myths of the Spanish Conquest*. Oxford University Press, Inc. New York, USA, 295 pp.

ROSI, M., 2014. Dancalia, Terra di conquista. *In Afar and Dancalia*. Centro di documentazione e studi sulla Dancalia Italiana c/o University of Pisa, Italy.

RUIZ, F., 1987. *Los Antiguos Michoacanos: Visión de la Prehistoria a la Conquista Hispana*. Editorial Morelia, Morelia, Mich., Mexico.

SAHAGÚN, B., 1534. Historia general de las cosas de Nueva España. Reprint 1963. *In* M. León Portillo and A.M. Garibay (Editors). *Visión de los Vencidos*. Fondo de Cultura Económica, México, D.F.

SALZA, A., 1990. *Ominide*. Written with the collaboration of Leakey, R.E., Tobias, P.V. and Masali, M. Cartiere del Garda Edit., Italy.

SODI, D.M., 1992. *Las Grandes Culturas de Mesoamérica*. Editorial Panorama, México, D.F.

SOKOLOWSKI, J, SOKOLOWSKA, J. AND KEPINSKA, B., 1999. Using Geothermal Energy in Poland in the second Millennium. *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 267-286.

STARK, P., 1997. The Old North Trail. *Smithsonian* 28, n. 4, pp. 54-69.

SUÁREZ, M.C. AND CATALDI, R.; 1993. La Geotermia en Mesoamérica y Regiones Colindantes. *Geotermia*, Vol. 9, No. 1, pp.5-58.

SUÁREZ ARRIAGA, M.C., CATALDI, R., AND HODGSON S.F., 1999. Cosmogony and Uses of Geothermal Resources in Mesoamerica. *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 499-518.

SUÁREZ DE PERALTA, J., 1589. Tratado del descubrimiento de las Indias. Edición del Consejo Nacional para la Cultura y las Artes, México, D.F.

SVALOVA, V.B., 1999. Geothermal legends through history in Russia and the Former USRR: A Bridge to the Past. *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 337-356.

TERÁN ERQUICIA, V., 1966. Chiwanwayus Achankaras: Flores de leyendas Queswas. Renovación Editorial, La Paz, Bolivia.

THEOPHANES THE CONFESSOR, 790-810 (?), The Chronicles. *In* J.P. Migne (Editor), Theophanis Chronographia, Tome 108. Reprint 1975. Belgium.

TIBÓN, G., AND MARTINEZ NEGRETE, M., 1967. *Mujeres y Diosas de México*. Parviescultura Prehispánica en Barro. Instituto Nacional de Antropología e Historia, México D.F.

TJETIEP, W.S., NASUTION, A. AND HODGSON, S.F., 1999. Indonesia, Land of Volcanoes, Heart of Fire. *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 421-432.

THORHALLSSON, S., 1988. Experience in developing and utilizing geothermal resources in Iceland. *Geothermics*, n. 17, pp. 205-223.

YUM, B.W., 1999. Historical Review of Hot Spring Waters in the Republic of Korea. *In* R. Cataldi, S. Hodgson and J. Lund (Editors), *Stories from a Heated Earth: Our Geothermal Heritage*. Published by the GRC/Geothermal Resources Council and the IGA/International Geothermal Association, Sacramento, CA, U.S., pp. 431-442.

ZIMMER, C. 2015. Under the Sea, a Missing Link in the Evolution of Complex Cells. http://www.nytimes.com/2015/05/07/science/under-the-sea-a-missing-link-in-the-evolution-of-complex-cells.html?_r=1

THE FOUNDING SPIRIT OF IGA

Thanking address by Raffaele Cataldi in Melbourne on 23 April 2015 during the celebration session of the 25th anniversary of IGA, after the delivery of the recognitions.

We must also recall some past scientists and technologists with whom we discussed, in the period 1970-1985, the idea of forming an organized international geothermal group. They are:

- John Banwell, Dick Bolton, Jim Ellis and James Healy (New Zealand)
- Masami Hayakawa (Japan)
- Elena Lubímova (Russia)
- Baldur Lindal and Gudmundur Palmason (Iceland)
- Christofer Armstead (United Kingdom)
- Oskar Kappelmeyer (Germany)
- Jean Goguel (France)
- Carlo Facca, Teo Leardini, Giorgio Marinelli, and Ezio Tongiorgi (Italy)
- Joe Aidlin, Frank Miller, Henry Ramey, Don White and Paul Whitherspoon (U.S.)
- Luis F. de Anda (Mexico)

These outstanding scientists and technologists are giants in thought and pioneers of the present advancements of geothermal energy.

We cannot either miss to mention a number of colleagues who, though not chosen for this recognition, nonetheless contributed notably to the creation, or the consolidation, or the conduction of IGA in the period 1986-2010. They are:

- Manfred Hochstein and Ian Thain (New Zealand)
- Nazario Vasquez (The Philippines)
- Ji-Yang Wang (China)
- Yuri Esaki (Japan)
- Julian Sokolowski (Poland)
- Valgardur Stefansson (Iceland)
- Ladsi Rybach (Switzerland)
- Kiril Popovski (Macedonia)
- Guido Cappetti and Giancarlo Passaleva (Italy)
- Lucien Bronicki (Israel/U.S.)
- Gordon Bloomquist, Ron DiPippo, Wilfred Elders, Robert Fournier, George Frye, Marcelo
- Lippmann, Patrick Muffler, John Rowley and Alfred Truesdell (U.S.)
- José Luis Hernández Galán (Mexico)
- Alfredo Mainieri (Costa Rica)

For the women, we should recall many of those who acted as IGA Directors in the period 1989-2010; but a special mention, in our opinion, deserve (in alphabetical order):

- Rosa María Barragán-Reyes (Mexico)
- Florence Jaudin (France)

- Franciska Karman (Hungary)
- Beata Kepinska (Poland)
- Ender Okandán (Turkey)
- Valentina Svalova (Russia)
- Meseret Teklemariam (Ethiopia)

Finally, we must stress that behind nearly all people mentioned above existed a public organization or an institution that backstopped him or her, and supported IGA in economic way and other forms. They are:

- United Nations
- Unesco
- European Union
- The five International Geothermal Schools: in Italy (which was the first, created in 1970 and operated actively for over 25 years), in Iceland, in Japan, in Mexico and in New Zealand;
- Orkustofnun (Iceland)
- Enel and National Research Council (Italy)
- CFE and IIE (Mexico)
- DoE, USGS and other institutions (U.S.)

Sorry if we have missed to mention other persons or institutions of a special relevance for IGA.

But it is important to stress that without the effort by tens of people, and without the support by many organizations, the IGA could not have been created over 25 years ago, and this session would not have been held today.

To all those dead and living outstanding colleagues, and to all those farsighted organizations we all, the present members of IGA, should be indebted.

With all of them, mentioned and not mentioned people and organizations, we think that it should be shared the recognition made by the IGA BoD to the promoters and some other members in the occasion of the celebration of the 25th anniversary of our Association.

The collaboration, friendly and disinterested spirit that vivified and backstopped the promotion and the foundation of IGA over 25 years ago has been evoked, brought again to live and cheered up by this celebration today, and has been heartily felt by all participants at this session.

Therefore, we wish that the same spirit that animated its foundation, may represent always the gnomon for IGA to envision its future development and life.

To all people and organizations mentioned above, and to those also that we have missed to mention, dead or living, present at this celebration ceremony or not, to all those who/which contributed to the creation and conduction of our Association, and not to me and Tony, distinguished colleagues and dear friends, you may wish to address a warm ovation.

Thank you.

IGA News

IGA News is published quarterly by the International Geothermal Association. The function of IGA News is to disseminate timely information about geothermal activities throughout the world. To this end, a group of correspondents has agreed to supply news for each issue. The core of this group consists of the IGA Information Committee:
Luis C.A. Gutiérrez-Negrín, Mexico (Chairman)
Rolf Bracke, Germany
Paul Brophy, USA
Varun Chandrasekharam, India
Surya Darma, Indonesia
Lúdvík S. Georgsson, Iceland
José Luis Henríquez, El Salvador
Susan F. Hodgson, USA
Eduardo Iglesias, Mexico
Marcelo J. Lippmann, USA
Alfredo Mañón-Mercado, Mexico
Fernando (Ronnie) Peñarroyo, Philippines
Paul Quinlivan, New Zealand
Alexander Richter, Iceland
Horst Rueter, Germany
Benedikt Steingrímsson, Iceland
Koichi Tagomori, Japan
Shigeto Yamada, Japan
The members of this group submit geothermal news from their parts of the world, or relevant to their areas of specialization. If you have some news, a report, or an article for IGA News, you can send it to any of the above individuals, or directly to the IGA Secretariat. Please help us to become essential reading for anyone seeking the latest information on geothermal worldwide.
While the editorial team makes every effort to ensure accuracy, the opinions expressed in contributed articles remain those of the authors and are not necessarily those of the IGA. The editorial team does not assume any liability for external content taken from public sources and websites, or endorse the products or services mentioned.
Send IGA News contributions to the editor (l.g.negrin@gmail.com) and/or:
International Geothermal Association (IGA)
c/o Bochum University of Applied Sciences
Lennershofstr. 140, 44801 Bochum, Germany
Tel.: +49 (0)234 32 10712, Fax: +49 (0)234 3214809
E-mail: iga@hs-bochum.de
This issue of IGA News was edited by Luis C.A. Gutiérrez-Negrín. Marcelo J. Lippmann & Susan Hodgson proofread the texts. Distributed by Marietta Sander for the IGA Secretariat. Design layout by François Vuataz.

Application for membership

Please complete the following form and return it with payment to:
International Geothermal Association (IGA)
c/o Bochum University of Applied Sciences
Lennershofstr. 140, 44801 Bochum, Germany
Tel.: +49 (0)234 32 10712; Fax: +49 (0)234 3214809
E-mail: iga@hs-bochum.de
IGA Home Page: www.geothermal-energy.org

Membership

❐ Enrol me as a new member of IGA

❐ Renew my membership to IGA

Dr Mr Mrs Ms (circle)
Family name ________________________________
First name ________________________________
Profession ________________________________
Organization ________________________________
Address ❐ Work ❐ Home

____

____

Phone (area code) ____________________________
Fax (area code) ____________________________
E-mail ____

Note: The information you provide will be held on the IGA database. It will be used to update you on the activities of the Association, and may be changed or cancelled at any time upon your request. It will be included in the IGA Directory, which may be circulated in printed or electronic form to IGA members only. If you do not wish your details to be used for this purpose, please tick the box (in which case your name will not be printed in the IGA Directory) ❐

Membership category

❐ Individual – USD 40

❐ Student – USD 10

❐ Corporate – USD 500

❐ Institutional – USD 500

❐ Sustaining: individual – USD 100

❐ Sustaining: corporate – USD 1000

Representatives of Corporate and Institutional members:
Contact person ______________________________
Second person ______________________________
Third person ______________________________

Payment

There are three ways to make payment to IGA:

1. Credit card

❐ Master Card

❐ American Express

❐ Visa

Card # ____
Expiration date ________________________________
Signature ______________________________________

Date of signature ______________________________

2. Bank draft.

3. International Wire Transfer in USD to the International Geothermal Association

Please notify the Secretariat by fax or e-mail when you wire funds.
Bank: Helaba
Address: Friedrichstr. 74
40217 Duesseldorf, Germany
Account # 1007100413
SWIFT: WELADEDD
IBAN: DE77 3005 0000 1007 1004 13

2016 dues USD ______________________________
2017 dues USD ______________________________
2018 dues USD ______________________________
Contribution USD ____________________________
TOTAL USD __________________________________

These financial data will not be stored on a database, and will not be recorded in any electronic form.

Rates for advertising in IGA News

Space/Format	Size mm	Number of Issues	
		1	4 (per issue)
Full Page	185 x 245	USD 450	USD 350
Half Page (horizontal)	185 x 120	USD 310	USD 215
Half Page (vertical)	90 x 245	USD 310	USD 215
Quarter Page (horizontal)	120 x 90	USD 195	USD 155
Quarter Page (vertical)	90 x 120	USD 195	USD 155

REDUCED SUBSCRIPTION RATES FOR ***Geothermics***

Elsvier is pleased to offer members of the IGA a preferential subscription rate to the journal *Geothermics*. It is published six times a year, with a normal institutional suscription rate of USD 2,085 per year (printed version), or USD 1,042.80 per year (eJournal) (2016 prices).

IGA members, are eligible for a special yearly rate of USD 285. If you want the special rate, please contact JournalsCustomerServiceEMEA@elsevier.com. Upon request, they will send a proforma invoice to your e-mail ID. You can make your payment via bank transfer, fax your card details or call them with the information provided in your invoice.

Elsevier (https://www.elsevier.com/) provides web-based, digital solutions —among them *ScienceDirect, Scopus, Elsevier Research Intelligence and ClinicalKey*— and publishes over 2,000 journals, including *The Lancet* and *Cell*, and more than 33,000 book titles. Elsevier is part of RELX Group, a world-leading provider of information and analytics for professional and business customers across industries.