Geotourism 2 (37) 2014: 61–68
http://dx.doi.org/10.7494/geotour.2014.37.61

Stratovolcanoes in the Western Cordillera – Polish Scientific Expedition to Peru 2003–2012 reconnaissance research

Andrzej Gałaś[1], Paweł Panajew[2], Piotr Cuber[3]

[1] *AGH University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, al. Mickiewicza 30, 30-059 Kraków;*
e-mail: pollux@geol.agh.edu.pl

[2] *KGHM Polska Miedź S.A., Polkowice-Sieroszowice Mine, Kaźmierzów 100, 59-101 Polkowice;*
e-mail: p.panajew@kghm.pl

[3] *Medical University of Silesia in Katowice, School of Pharmacy with the Division of Laboratory Medicine, ul. Jedności 8, 41-218 Sosnowiec;*
e-mail: piotrc10@op.pl

Abstract: *The Polish Scientific Expedition has been carrying out research in the Colca Canyon and the Valley of the Volcanoes (South Peru) since 2003. The National Park project, covering the mentioned areas, is the main purpose of the research. The extent and genesis of the Quaternary volcanic Andahua group is the leading theme of the investigation. The study area is surrounded with numerous Pliocene and Pleistocene stratovolcanoes: Ampato (6,288 m a.s.l.), Chachani (6,057 m a.s.l.), multi-cone Coropuna (6,425 m a.s.l.) and others. Some of them are still active, such as Misti (5,822 m a.s.l.) or Sabancaya (5,967 m a.s.l.) and pose a real hazard to the local population. In 2003–2012, the participants of the Polish Scientific Expedition climbed several times on volcanic peaks, gaining new experience and comparative samples for study.*
Key words: *reconnaissance, stratovolcanoes, Central Volcanic Zone, Western Cordillera, Peru*

Introduction

The Andes is the longest mountain range on Earth (9 thousand km) extending from Venezuela to Tierra del Fuego along the coast of the Pacific Ocean. It consists of four main, parallel to each other, ranges of Cordilleras: Eastern, Central, Western and Coastal, of a total width of 150–700 km. There are 102 peaks in the Andes, with heights of more than six thousand meters. Since the nineteenth century, it has attracted mountaineers, scientists and travelers (Biggar, 2005). Some of the peaks were climbed much earlier by the Incas, leaving at the tops votive offerings and sacrifices for their Gods, e.g. on Llullaillaco (6,739 m a.s.l.), Ampato (6,288 m a.s.l.) and Nevado Quehuar (6,130 m a.s.l.) (Reinhard, 1999).

The Western Cordillera in the area of Colca Canyon has been under investigation by the Polish Scientific Expedition to Peru (PSEP) since 2003 (Fig. 1). The aim of the research is the Canyon itself and the lower part of the Rio Colca Valley together with the nearby Valley of the Volcanoes (Bębenek, 2005; Krzak, 2005). The obtained research material is going to be used as a base for the establishment of a National Park in this area (Gałaś, Paulo, 2008; Paulo, Gałaś, 2011; Paulo *et al.,* 2014). Colca Canyon has been considered the deepest canyon on Earth since 1984 (The Guinness Book of Records). It was discovered in 1981 by the Polish academic expedition "Canoandes-79", organized by the SKK "Bystrze" (Majcherczyk *et al.,* 1981; Piętowski, 2013). Rapid economic growth that followed the discovery of the Canyon caused the most valuable qualities of the environment to be seriously threatened. The main reasons are: development of transport infrastructure, touristic services (hotels), hydraulic and energy engineering investments and, to a smaller extent, mining (Macedo, 2012; Paulo *et al.,* 2014; Zavala *et al.,* 2014). In 2003–2012, participants of the Polish Scientific Expedition to Peru entered several stratovolcanoes in the direct vicinity of the Colca Valley and Canyon. Among those peaks were (Fig. 1): Mismi (5,597 m a.s.l.), Misti (5,822 m a.s.l.), Nevado Sabancaya (5,967 m a.s.l.), Nevado Chachani (6,057 m a.s.l.), Nevado Ampato (6,288 m a.s.l.) and Coropuna (6,377 m a.s.l.).

Study area

The study area is located in the Central Andes, southern Peru, within the department of Arequipa. Central Andes are divided into parallel to the edge of the continent ranges: Coastal Cordillera, Intermediate Depression, Western Cordillera, Mid-Andean Depression, Altiplano and Eastern Cordillera (Fig. 1). The Polish Scientific Expedition to Peru conducts research in the area of Western Cordillera, and partly at the edge of Altiplano. The ridges of the Cordillera rise up to a height of 4–5 thousand m a.s.l. They are topped by stratovolcanoes, with a height exceeding 6 thousand m a.s.l.: Coropuna (6,425 m a.s.l.), Ampato (6,288 m a.s.l.), and Chachani (6,057 m a.s.l.). The massif of Mismi volcano (5,395; 5,597; 5,515 m a.s.l.) is the watershed between the Atlantic and Pacific oceans.

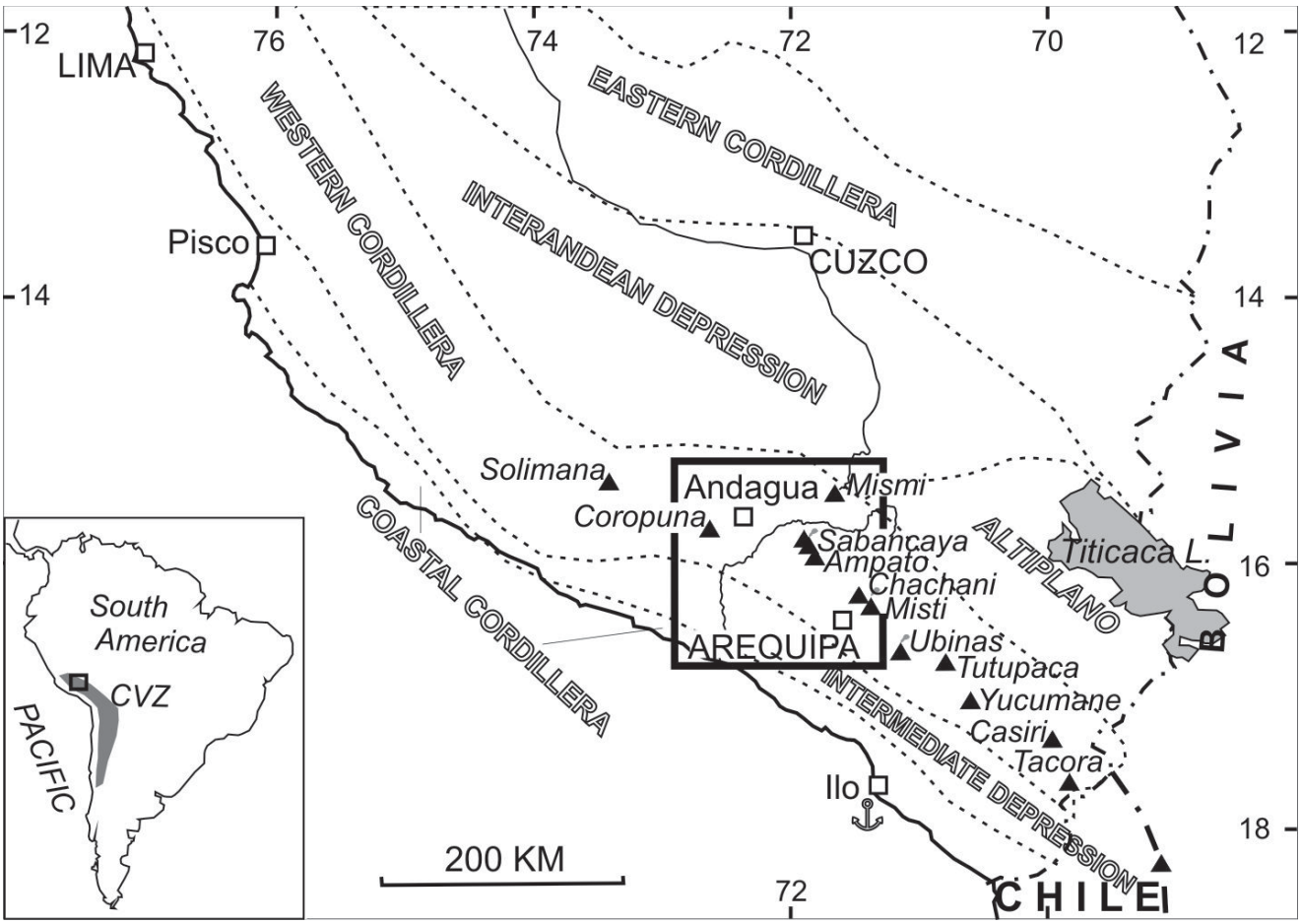

Fig. 1. Location of the study area within tectonic units of the Andes in southern Peru (Paulo, 2008, modified). CVZ – Central Volcanic Zone

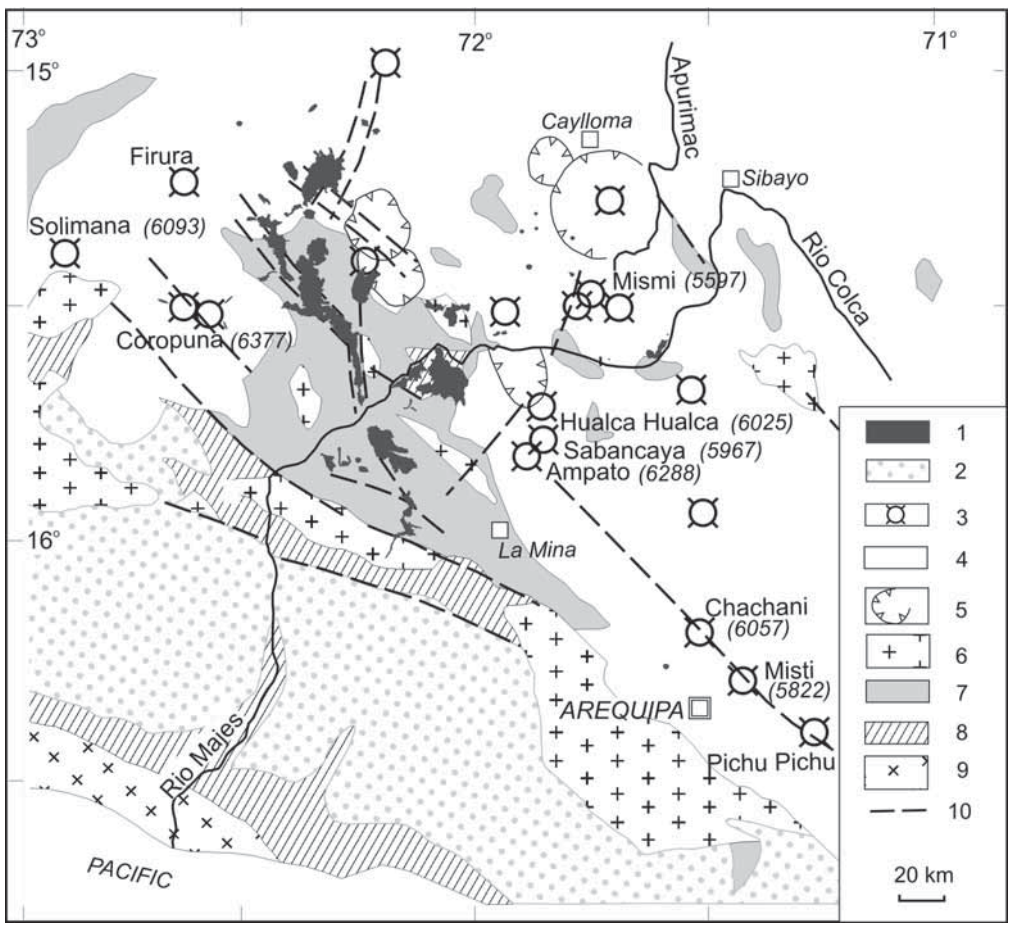

Fig. 2. Geological map of study area (based on Salcedo, 2007 and Paulo, 2008)

1 – Quaternary: Andahua Group, 2 – Pleistocene: alluvial gravels, 3 – Pliocene-Quaternary: stratovolcanoes of Barroso Group, 4 – Neogene-Quaternary: pyroclastic and lacustrine deposits, deluvia, 5 – Neogene: caldera complexes, 6 – Jurassic, Cretaceous, Paleogene: plutons, 7 – Jurassic, Cretaceous: sedimentary formations, 8 – Proterozoic, Paleozoic: magmatic intrusions, 9 – Proterozoic: Arequipa massif gneisses, 10 – major faults

Apurimacu springs are located northward from the ridge, in the McIntyre Lake. It is the longest tributary of the Amazon River (Piętowski, 2013). Rio Colca River, on the other hand, flows next to Mismi Volcano massif from the east and south. Here, the river flow has formed the deepest canyon in the world (The Guinness Book of Records).

The base of the Central Andes in this area is composed of igneous and metamorphic rocks, divided into two massifs. The Arequipa massif is located in the south. Due north, more or less on the line of the Colca Canyon, it merges with the Paracas massif. The massifs are built of gneisses and much younger granitoids. Western Cordillera ranges are composed mainly of Mesozoic sedimentary formations and Cenozoic volcanic rocks. Volcanic products are primarily tuff covers and subvolcanic agglomerates and intrusions with significantly smaller lava spreading (Fig. 2; Paulo, 2008). Epi-continental Jurassic and Cretaceous formations represent thickness of several thousand meters. These are mainly clastic sediments (sandstones and shales) and limestones. On the western slope of the Cordillera, the formations are greatly folded and, in some places, there are steep overthrusts present. Further towards the east, the Western Cordillera is dominated by horst tectonics. There are numerous mountain rifts and synorogenic depressions, such as the Ashua and Huanca basins or the Valley of the Volcanoes, connected in the north with the Colca Canyon. Pull-apart type structures formed in the investigated area, as a result of transtensional forces, which caused the opening of deep fissures in the crust and raising magma to the surface. This type of origin was proposed in the case of Sabancaya volcanic activity (Mering *et al.,* 1996).

Since the Jurassic Period, the area of Andes has formed the active edge of the continent over the subduction zone. The Mesozoic magmatic arc in the Coastal Cordillera is partially eroded. Paleogene sub-volcanic intrusions of the Toquepala group as well as the diversified volcanic Oligocene-Miocene formations of the Tacaza group are in better condition. The Neogene-Quaternary volcanic arc Barroso (10–1 Ma) was initially 100 km wide. However, over time, its range and activity decreased (Wörner *et al.,* 2000). Contemporary volcanoes from southern Peru belong to the Central Volcanic Zone (CVZ), which spreads along the edge of the continent to central Chile. There are 44 stratovolcanoes located within the CVZ (de Silva, Francis, 1991).

Stratovolcanoes

The Firura (5,498 m a.s.l.) and Solimana volcanoes (6,093 m a.s.l.) are situated the most northwards. These are old stratovolcanoes with distinct traces of glacial erosion. However there is no data available about their activity.

The Coropuna volcano massif is located due south-east from them. It consists of six domed tops, situated along the W-E direction and covered with an ice cap (Fig. 3). This is the highest volcano in Peru (6,425 m a.s.l.) and the 22nd highest peak in the Andes. It covers an area of 20 ×12 km, with a relative height of about two thousand meters. Both streams of lava (andesites and dacites) and pyroclastic covers are heavily damaged by glacial erosion. The activity of the volcano was dated at the turn of the Miocene-Pliocene (Weibel, Fejér, 1977). However, isolated lava streams can still be observed at the foot of the massif. Their effusive centers are hidden under the ice cap, which descends to the height of 5,300 m a. s. l. (Fig. 4). These forms are well-preserved covered by the deposits of glacial moraines (Gałaś, 2013). On the basis of their position in relation to glacial moraines, it was concluded that they must be about 10 thousand or less years old.

The complex of volcanoes: Hualca Hualca (6,025 m a.s.l.) – Sabancaya (5,967 m a.s.l.) – Ampato (6,288 m a.s.l.) (Fig. 5) is separated from the Coropuna massif by the polygenic Cordillera and the Colca Canyon. The Hualca Hualca (Pliocene) is the oldest in the complex. The walls of the Colca Canyon are formed by streams of andesite lavas and basaltic andesites, with a total thickness of over 100 m. A significant part of the cone slid towards the Colca Canyon, forming a huge niche on the northern slope of the volcano. Colluvium is hundreds of meters thick. Its area consists of solfatara patches and an active geyser. The geyser is the subject of the PSEP research (Ciesielczuk *et al.,* 2012). The landslide progress caused the emergence of a ridge, with ragged, circular in their course and extremely steep walls. The ridge is covered with a slightly thick ice cap. Ignimbrite covers located on the slopes indicate explosive activity of the volcano, of which the last manifestations occurred during the Pleistocene.

Fig. 3. Pallacocha Lake on the foothills of the Coropuna volcano, photo P. Panajew

Fig. 4. A blocky lava outcropping under ice cap near the peak of Coropuna, photo A. Gałaś

Fig. 5. Volcano complex, from the left: Ampato, Sabancaya and Hualca Hualca. View from the ridge of Chachani, photo P. Panajew

The much younger volcano located southernmost is Ampato (6,288 m a.s.l.), the 35th highest peak of the Andes. In this area, Rivera *et al.* (2012) have identified five stages (I-V) of stratovolcano activity. The oldest andesite lavas (I stage) were dated at 217 ± 5 ka. Their activity manifested in the subsequent stages mainly in the form of lava effusions accompanied by pyroclastic eruptions (Mariño *et al.*, 2011). In the final stage five V, which took place at the end of the Pleistocene, the top part of the main cone partially collapsed and the lava dome formed on its northern flank after the explosion occurred (Rivera *et al.,* 2012). The ash from the eruptive column of a nearby Sabancaya volcano melted part of the ice cap, revealing a large part of the top of Ampato. An archaeologist J. Reinhard, together with an Andean mountaineer M. Zarate found in 1995, on the north-western slope, a place of offering and a teenage girl frozen in ice, commonly known as Juanita, that was sacrificed by the Incas in the fifteenth century (Reinhard, 1999).

Sabancaya (5,967 m a.s.l.) is located between Hualca-Hualca (6,025 m a.s.l.) and Ampato (6,288 m a.s.l.) volcanoes and has a relative height exceeding 1.5 thousand meters. An insulated lava dome is situated in the immediate vicinity of the main crater. Ash covers on the crater itself and around it come from the activity that took place in the Holocene. The Sabancaya volcano cone covers an area of approx. 70 $km^{2,}$ and, lava surrounding its structure, a further 40 km^2. The volume of the whole structure is approximately 25 km^3. Lavas and ashes are composed of potassium-rich andesites and dacites, 61–65% SiO_2. Pyroclastic streams have been identified (pumice stone, block-ashes and *scoria*) with a length of up to 7 km. The volcano erupted twice in the eighteenth century. Since 1986, it has been activating more often (Simkin, Siebert, 1994), most recently in 2003. Eruption in 1990 was classified as the Volcano type with an eruptive column ranging up to 0.5–3 km. The result of the eruption was dust fall covering a radius of 20 km. Sub-plinian activity is typical for this volcano, although in the past one eruption was classified as plinian (Mariño *et al.*, 2011; Thouret *et al.,* 1995). Currently, volcanic activity took the form of fumaroles. The temperature of the rocks is about 42°C. Older volcanic deposits indicate a typical for stratovolcanoes activity: lava effusions, pyroclastic streams, dust fall, which may happen again in the future. So far, due to its remote location, the victims were only animals.

Mismi (5,597 m a.s.l.) is a multi-top stratovolcano (Neogene), which is located on the watershed between the Atlantic and Pacific Ocean (Fig. 6). A glacier covering Mismi disappeared completely in 2010. Mismi is the oldest volcano described in this work. Most likely, the entire structure formed during the Pliocene. There is no evidence of its subsequent activity. The exposed and heavily eroded tuffs take amazing forms. The ground reveals the parched ignimbrites of the Alpabamba formation. Morevoer, an abandoned settlement Ran-Ran is situated on the slopes of the volcano, at an altitude of 4,500 m a.s.l.

Further south, the Chachani, Misti and Pichu Pichu volcanoes are located along a NW-SE line. The city of Arequipa is situated to the south of this line, at their foothills.

Fig. 6. The deglaciation effect – outcrop of summit ridge of Mismi, photo P. Panajew

Fig. 7. Chachani volcano. Opposite, the edged summit of Cerro Nocorane, probably the oldest center in this complex, photo P. Panajew

Fig. 8. Ignimbrite wall in *sillar Arequipa* mine, photo P. Panajew

Chachani (6,057 m a.s.l.) is 84th highest top of the Andes. Similarly to Coropuna, it forms a massif consisting of several eroded cones and domes. In addition to the main top, the following structures can be easily distinguished from the north: Cerro Peñones, La Horqueta and Pampa de Palacios lava domes and the ragged ridge of Cerro Nocorane (5,750 m a.s.l.) (Fig. 7). Its morphology is distinguished by numerous lava streams. The factor that triggered pyroclastic flows in the past was the extrusion of acidic lavas, which are the building stones of the La Horqueta dome. At the foot of the volcano, *sillar* is being exploited. This Sillar is a pyroclastic stream sediment (Fig. 8) covering an area of about 800 km^2. Pyroclastic streams were moving during eruption time at speeds exceeding 300 km/h, while the temperature in their interior could have exceeded 500°C. The volume of the cover that formed during only one cycle, and there are usually 3–4

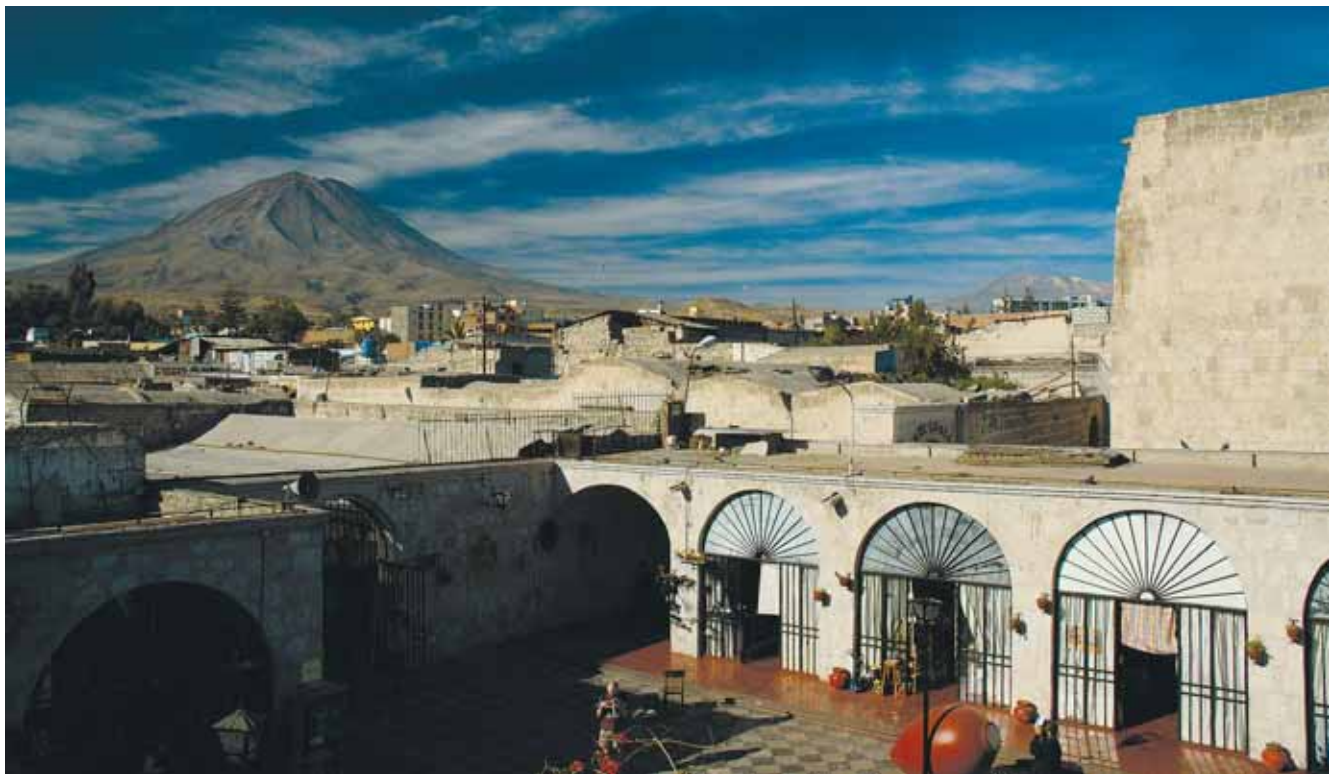

Fig. 9. Misti volcano seen from Arequipa, photo P. Panajew

distinguished, is estimated at 16–24 km^3 (Paquereau *et al.,* 2005). This rock was used to build the Arequipa old city center, also known as the "the white city". The participants of the PSEP observed active solfatars, near the main tip of the Chachani, in September 2012.

Misti volcano is located closer to Arequipa (Fig. 9). It had strong eruptions in prehistoric times (Thouret *et al.,* 1999). In 17th, 18th and 20th Century, a plume of water vapor used to appear over the volcano (Fig. 10). This phenomenon, of course, aroused the fear of future eruption, and this was recorded in historical chronicles. Even today, the volcanic activity is manifested in the form of fumaroles, in the restored crater. The threat posed to the city is very real. In the event of an eruption, rain of ash, pyroclastic streams, lahars and avalanches of rubble are expected (Thouret *et al.,* 1999). It is predicted that the possible eruption will be of the sub-plinian type, although it is not completely excluded, that it might be a plinian explosion.

Fig. 10. Renewed crater of Misti. At the horizon Pichu Pichu volcano, photo A. Gałaś

The Pichu Pichu volcano, the oldest in the complex, is heavily eroded. There are no data on its activity.

Andahua group

Volcanoes and lavas of the Andahua group are a separate stratigraphic unit, regarded as the youngest unit in this area. They group within 7 regions on both sides of the Colca Canyon, at a height of 3–5 thousand meters a.s.l. (Gałaś, Paulo, 2005). In total, 167 eruption centers were recorded (Gałaś, 2011). Volcanoes of this group have a much simpler structure than the stratovolcanoes discussed above. The Andahua group volcanoes are mainly lava domes and *scoria* cones, mostly of the monogenetic type. Lava domes are more numerous, and lavas represent approximately 97% of the volume of the products of this group. Domes are 20 to 150 m high. Lavas that flow out of them form single or ramifying in several directions streams. Either block-type or *aa* lavas are present on the surface of the fresh lava streams (Fig. 11). The Cerro Coropuna dome (the coincidence of the name with the described stratovolcano is accidental) occurred by the squeezing (extrusion) of a very viscous lava, forming an extremely steep hill, up to 250 m b.g.l. The height of the dome was measured in 2006, reaching 5,180 m a.s.l. (Gałaś, 2008, 2011, 2013).

The most commonly observed centers, in the case of the Andahua group, are *scoria* or slag (*spater*) cones. These structures occur after a volcanic eruption of small energy. Their height ranges from 50 to 170 m b.g.l. Some of the cones are torn by the stream of lava flowing from the crater.

Fig. 11. The youngest lava flows and scoria cones in the Valley of the Volcanoes, near Andagua, photo A. Paulo

The PSEP additionally assessed the landscape and educational and touristic values of the discussed volcanic group. The most interesting records included lava domes, pyroclastic cones and streams of lava located southward of the Andagua village, in the Valley of the Volcanoes. It was acknowledged that their classic formation, negligible erosion and easy accessibility make them attractions, on the scale of the South America continent at the least. This area is postulated as a part of the proposed Colca Canyon and the Valley of the Volcanoes National Park (Gałaś, Paulo, 2008; Paulo *et al*., 2014).

Climate, vegetation and fauna in higher parts of the Andes:

The Western Cordillera range, at the height of 4–5 thousand m a.s.l., is marked by a surface alignment called *puna*. Enormous, majestic cones of stratovolcanoes stick out from it. The highest of them exceeds 6,200 m a.s.l. At this latitude, the zone of perpetual snow starts at 5,800 m a.s.l., although just a few years ago, it was recorded at approx. 5,500 m a.s.l. The PSEP's field work was carried out mainly at the height of 3,500–3,900 m a.s.l., in *quechua* and *suni* ecological zones (Pulgar, 1981). Mainly pioneer plants, such as lichens and mosses (Cykowska, Flakus, 2008) grow in this area, accompanied by flowering plants: dwarf shrubs *Yareta* (*Azorella compacta*) of the carrot family, Peruvian feather grass (*Jarava ichu*), herbs and cacti (Fig. 12). Above 4,000 m a.s.l., vegetation gets poorer, displaced by rocks and patches of snow and glaciers. However, on the mountain marshes (*bofedales*), the biodiversity is exceptionally high (Coronel *et al.,* 2009).

Fig. 12. Succulent plant from this area of study – *Opunia*, photo P. Panajew

Fig. 13. *El condor* flying above Colca Canyon, photo P. Cuber

Fig. 14. Penitents and blocky lava on the Sabancaya slope, photo P. Panajew

Despite harsh conditions, animal life, even if less noticeable, represents a variety of forms and wide range of species. These are mostly insects, such as hymenopterans and beetles. Among the vertebrates, birds can be spotted, with the, threatened by habitat loss, species of the Andean condor (*Vultur gryphus*) present (Fig. 13) (Stotz *et al.,* 2007). Some of the naturally occurring animals are widely used by man. For example, the cochineal (*Dactylopius coccus*) is often cultivated for its carminic acid that it produces, used as coloring agent in carmine (Reyes-Salas *et al.,* 2011). Another very interesting and most-known among Peruvian wild mammals species is the vicugna (*Vicugna vicugna*), a camelid which is now regarded as the wild ancestor of the alpacas (*Vicugna pacos*), raised for their coats (Kadwell *et al.,* 2001).

The climate of the coast of Peru and the Western Cordillera is dry. Here, volcanic rock formations are usually very porous and fissured, preventing the retention of scarce rainfall close to the surface. The main form of precipitation at this high altitude is snow. Interesting forms of snow-ice cover encountered, among others in the Andes, are the penitents (Spanish *penitentes*), also called repentants, or snow monks, forming fields of penitents (Spanish *campo de penitentes*) or repentant snow (Spanish *nieves penitentes*) (Ostrowski, 1959). Their shape resembles the ranks of kneeling, hooded monks. These forms are the result of slow melting of snow and ice under the influence of wind erosion, rain and sunlight on the surface of the glacier. Penitents we had to face on the slopes of Coropuna, Ampato and Sabancaya volcanoes were of 0.2–2.0 m high, at an inclination of 70–80 degrees (Fig. 14). The entire south-eastern slope of Sabancaya volcano was covered with penitents, leaning from east to west. They were much smaller on the Coropuna and Ampato volcanoes and grouped into single isolated fields of several hundred square meters. The morphology of the area seems to have no major impact on the formation of these snow-ice forms, as we observed them both on sub-peak flattenings and on slopes steeper than forty degrees.

Volcanic eruptions hazard

Stratovolcano eruption hazard is monitored primarily for large cities, including the capital of the department – Arequipa. The second largest city in Peru is located at the foot of the Misti volcano, only 15–18 km from the crater, which dominates over the city 2,500 m (Fig. 3). Only Quito, the capital of Ecuador, is located closer to the Guagua Pichincha volcano (4,784 m a.s.l.).

Huaynaputina, Tutupaca, Yucumane, Sabancaya, Misti and Ubinas volcanoes were active in historic times in the investigated area (Simkin, Siebert, 1994). The largest, described in the chronicles, volcanic eruption was at Huainaputina, in February, 1600. It is estimated, that it was a plinian type eruption of the 7th VEI degree (Volcanic Explosivity Index scale ranging from 0 to 8) (de Silva, Francis, 1990). Paroxysm lasted continuously for 16 days, while during this time; the about 80 km distant Arequipa was flooded with a rain of ashes. According to the chronicles, roofs of the houses collapsed under the weight of ashes within a radius of 30 km from the volcano. Traces of this eruption were recorded in wetland sediments even in the area of the hundreds of kilometers distant Coropuna volcano (Jara *et al.,* 2000; Buda *et al.,* 2010).

Currently, Misti volcano activity would be far more dangerous to Arequipa. The volcanic activity is manifested in the form of fumaroles in the restored crater. Even with only a small force of eruption, the short distance from the city centre makes the lava and in particular the pyroclastic streams,

a potential cause of significant damages and losses. Additionally, gorges are carved in front of the city in the cone of the volcano (Quebrada Guarangal and Quebrada San Lazaro). These can act as concentration channels for speeding pyroclastic streams. The following forms of activity are predicted on the basis of the events recorded in the sediments: rains of ash, pyroclastic streams, lahars and avalanches of rubble (Thouret *et al.,* 1999). It is assumed that the possible eruption will be of a sub-plinian type, although it is not completely excluded, that it might be an explosion one degree stronger.

The authors would like to thank the participants of the Polish Scientific Expedition to Peru for their help and for creating great atmosphere. The work was completed within the framework of statutory research of AGH, No. 11.11.140.175.

References

Bębenek S., 2005. Wyprawa naukowa Peru'2004. *Geoturystyka*, 1: 63–64.

Biggar J., 2005. *The Andes. A Guide for Climbers.* 3rd Edition, Andes, Scotland.

Buda P., Sobczyk M., Wołoszyn J., Ziółkowski M., 2010. Maucallacta – an Inca administrative and ceremonial center in Condesuyos. Results of 2006 and 2007 field seasons. In: Mirek Z., Flakus A., Krzanowski A., Paulo A., Wojtusiak J. (eds.), *The Nature and Culture of Latin America. Reviev of Polish Studies.* W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków: 339–353.

Ciesielczuk J., Żaba J., Bzowska G., Gaidzik K., Głogowska M., 2012. Sulphate efflorescences at the geyser near Pinchollo, southern Peru. *Journal of South American Earth Sciences*, 42: 186–193.

Coronel J.S., de la Barra N., Aguilera X., 2009. Bofedales altoandinos de Bolivia: Vegetación acuática y factores ambientales. *Revista Boliviana de Ecología y Conservación Ambiental*, 26: 23–24.

Cykowska B., Flakus A., 2008. Flora mszaków i porostów Kanionu Colca (Peru) – badania rekonesansowe. *Geologia*, 34, 2/1: 193–203.

De Silva S.L., Francis P.W., 1990. Potentially active volcanoes of southern Peru – observations using Landsat Thematic Mapper and Space Shuttle imagery. *Bulletin of Volcanology*, 52: 286–301.

De Silva S. L., Francis P. W., 1991. *Volcanoes of the Central Andes.* Springer Verlag, Berlin-Heidelberg.

Gałaś A., 2008. Zasięg i budowle wulkaniczne grupy Andahua. *Geologia*, 34, 2/1: 107–135.

Gałaś A., 2011. The extent and volcanic structures of the Quaternary Andahua Group, Andes, southern Peru. *Annales Societatis Geologorum Poloniae*, 81,1: 1–19.

Gałaś A., 2013. *Charakterystyka grupy wulkanicznej Andahua w południowym Peru.* Rozprawy, Monografie, 281.

Gałaś A., Paulo A., 2005. Karłowate wulkany formacji Andahua w południowym Peru. *Przegląd Geologiczny,* 53: 320–326.

Gałaś A., Paulo A., 2008. Idea ochrony Kanionu Colca i Doliny Wulkanów. *Geologia*, 34, 2/1: 17–33.

Jara L.A., Thouret J.-C., Davila J., 2000. The AD 1600 eruption of Huaynaputina as described in early Spanish chronicles. *Boletin Sociedad Geológica del Perú*, 90: 121–132.

Kadwell M., Fernandez M., Stanley H.F., Baldi R., Wheeler J.C., Rosadio R., Bruford M.W., 2001. Genetic analysis reveals the wild ancestors the llama and alpaca. *Proceedings of the Royal Society B: Biological Sciences*, 268, 1485: 2575–2584.

Krzak M. 2005. Ruch turystyczny w rejonie Arequipy i możliwości jego rozwoju w Dolinie Wulkanów (prowincja Castilla) w południowym Peru. *Geoturystyka*, 2: 3–22.

Macedo L., 2012. Aportes del INGEMMET en la gestión del riesgo volcánico en la Región Arequipa. INGEMMET, www.slideshare.net/ingemmet.

Majcherczyk J., Piętowski A., Chmieliński P., 1981. *In kayak trough Peru. Whitewater guide. Polish expedition Canoandes-79 & Embajada de Viajero*, Lima.

Mariño J., Samaniego P., Rivera M., Bellot N., Delgado R., Macedo L., Manrique N., 2011. *Mapa de peligros del complejo volcánico Ampato-Sabancaya, 1 : 50.000.* INGEMMET & IRD.

Mering C., Huaman-Rodrigo D., Chorowicz J., Deffontaines B., Guillande R., 1996. New data on the geodynamics of southern Peru from computerized analysis of SPOT and SAR ERS-1 images. *Tectonophysics,* 259: 153–169.

Ostrowski W., 1959. *Wyżej niż kondory.* Wydawnictwo Sport i Turystyka, Warszawa.

Paquereau P., Thouret J.-C., Wôrner G., Fornari M., 2005. Neogene and Quaternary ignimbrites in the Arequipa area, southern Peru: Stratigraphical and petrological Correlations. 6th International Symposium on Andean Geodynamics (ISAG 2005, Barcelona), Extended Abstracts: 563–566.

Paulo A., 2008. Zarys budowy geologicznej Kordyliery Zachodniej południowego Peru. *Geologia*, 34, 2/1: 35–53.

Paulo A., Gałaś A., 2011. Polska Wyprawa Naukowa do Peru. *Przegląd Geologiczny,* 59: 58–68.

Paulo A., Gałaś A., Gałaś S., 2014. Planning the Colca Canyon and Valley of the Volcanoes National Park in South Peru. *Environmental Earth Sciences*, 71, 3: 1021–1032.

Piętowski A., 2013. *Canoandes. Na podbój kanionu Colca i górskich rzek obu Ameryk.* Bezdroża, Gliwice.

Pulgar Vidal J., 1981. *Geografia del Perú: las ocho regions naturales del Perú.* Editorial Universo, Lima.

Reinhard J., 1999. Zaklęte w lodzie. *National Geographic* (Polska), 2,2: 56–75.

Reyes-Salas O., Juárez-Espino M., Manzanilla-Cano J., Barceló-Quintal M., Reyes-Salas A., Rendón-Osorio R., 2011. Titrimetric and polarographic determination of carminic acid and its quantification in chochineal (*Dactylopius coccus*) extracts. *Journal of the Mexican Chemical Society,* 55: 89–93.

Rivera M., Samaniego P., Delgado R., Mariño J., Liorzou C., Nauret F., 2012. Evolución petrológica y geoquímica del complejo volcánico Ampato-Sabancaya (Arequipa). 16th Peruvian Geological Congress & SEG 2012 Conference, Lima 23–26 September, USB key.

Simkin T., Siebert L., 1994. *Volcanoes of the World – A regional directory, gazetter and chronology of volcanism during the last 10,000 years.* 2nd ed. Smithsonian Inst. Geosciences Press Inc., Washington.

Stotz D.F., Schulenberg T.S., O'Neill J.P., Parker T.A., Dyer D., Lane D.F., Schmitt J., Mcqueen L.B., 2007. *Helm Field Guides. Birds of Peru.* Christopher Helm Publishers Ltd.

Thouret J.-C., Gourgaud A., Uribe M., Rodriguez A., Guillande R., Salas G., 1995. Geomorphological and geological survey, and spot remote sensing of the current activity of Nevado Sabancaya stratovolcano (South Peru): assessment for hazard-zone mapping. *Zeitschrift für Geomorphologie, N.F.,* 39: 515–535.

Thouret J.-C., Suni J., Eissen J.-P., Navarro P., 1999. Assessment of volcanic hazards in the area of Arequipa City, based on the eruptive history of the Misti Volcano, Southern Peru. *Zeitschrift für Geomorphologie. N.F.*, 114: 89–112.

Weibel M., Fejér Z., 1977. El Nevado Coropuna, departamento de Arequipa. *Boletin Sociedad Geológica del Perú*, 57–58: 87–98.

Wörner G., Hammerschmidt K., Henjes-Kunst F., Lezaun J., Wilke H., 2000. Geochronology (40Ar-39Ar-, K-Ar-, and He-exposure-) ages of Cenozoic magmatic rocks from northern Chile (18°–22°S). Implications for magmatism and tectonic evolution of the Central Andes. *Revista Geologica Chile,* 27: 205–240.

Zavala B., Vilchez M., Rosado M., Pari W., Peña F., 2014. Estudio Geoambiental en la Cuenca del Rio Colca. *Boletin Serie C: Geodynámica a Ingeniería Geológica,* IGEMMET, Lima, Peru.