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ORIGINAL ARTICLE

Geosites and Geotouristic Attractions Proposed for the Project Geopark Colca and Volcanoes of Andagua, Peru

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Abstract

The Colca Canyon (Central Andes, Southern Peru), about 100 km long and 1–3 km deep, forms a magnificent cross section of the Earth's crust giving insight into mutual relations between lithostratigraphical units, and allowing relatively easy interpretation of the fascinating geological history written in the rocky beds and relief. Current activity of tectonic processes related to the subduction of the Nazca plate beneath the South American Plate exposed the geological heritage within study area. Well-developed tectonic structures present high scientific values. The volcanic landforms in the Valley of the Volcanoes and around the Colca Canyon include lava flows, scoria cones and small lava domes. They represent natural phenomena which gained recognition among tourists, scientists and local people. Studies performed by the Polish Scientific Expedition to Peru since 2003 recognized in area of Colca Canyon and Valley of the Volcanoes high geodiversity, potential for geoturism but also requirements for protectection. The idea of creating geopark gained recently the approval of regional and local authorities with support from the local National Geological Survey (INGEMMET). The Geopark Colca and Volcanoes of Andagua would strengthen the relatively poor system of the protected areas in the Arequipa department, increasing the touristic attractiveness and determine constraints for sustained regional development.

Keywords Geopark · Geosites · Geodiversity · Colca Canyon · Valley of the volcanoes · Peru

Introduction

Worldwide, the idea of geodiversity protection has developed a century later than that of planet's animal and plant life preservation. In 2001, UNESCO invited member states to promote areas with special geological characteristics by converting them into national geoparks. On the 17th of November 2015, the General Assembly of UNESCO adopted the "International Geoscience and Geoparks Programme". This program allows to seek new territories to be considered as UNESCO Global Geoparks (UGG) (UNESCO 2016). Geoparks aim to protect geodiversity, to promote geological heritage to the general public as well as to support sustainable economic development of geopark territories primarily through the development of geotourism (Alexandrowicz and Wimbledon 1999; Dingwall 2000; Alexandrowicz 2006a; Newsome and Dowling 2005; Farsani et al. 2014). Too date, only two geoparks (1) Araripe (Brasil 2005) and Grutas del Palacio (Uruguay 2013) were established in the South America. Nevertheless, the introduction of geoparks initiative in Latin America and the Caribbean allowed to expect that further projects from Chile, Ecuador, Colombia, and others will be launched soon. UNESCO co-organized a workshop on "Geoparks and geological heritage: promoting geological heritage in Latin America", held in Mexico (May 2015), that allowed to present progress of several proposals by aspiring countries. During the "First National Symposium of

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Geoparks: geological heritage and geo-tourism" (Arequipa, 2015), the idea of creating South America and Caribbean Geoparks Network was presented (Goso and Irazabal 2015; Arequipa Declaration 2015).

The mountain desert of south Peru and Altiplano has scant vegetation. The animals tend to be grouped near lakes and mountain wetlands. The lack of vegetation cover exposes rock formations and makes it easy to perform observation of geological structures. Extremely deep, almost 100 km long, hardly accessible and practically uninhabited canyons of south Peru, especially the Colca Canyon with adjoined Valley of the Volcanoes appear to be the ideal for creation of a Global Geopark (Fig. 1). The investigations carried out by the Polish Scientific Expedition to Peru (Paulo and Gałaś 2008a), INGEMMET and other institutions allow to recognize, evaluate and popularize the unique geological features of this area, to identify threats and conflicts between protection and alternative developments, to delimit the area for the aspiring Geopark and its sectors of special protection, to find proper measures for tourist access, and develop educational programs for of local people as future guardians and guides (Paulo et al. 2014). Examples of the educative routes in the Muskau Arch UGG (transborder geopark between Germany and Poland) and other protected areas worldwide are provided, as well as manuals for local school teachers illustrating educational programs describing the geological structure of local outcrops on local outcrops (Koźma and Kupetz 2008). Necessary activities to be undertaken in scientific and socio-organizational milieus were signalized.

At this point, it is worth mentioning that several canyons in the world have already been declared protected areas, e.g. the Colorado Canyon (USA) or the Canyon of Tara (Montenegro). Several geoparks have been proclaimed in volcanic areas e.g. Vulkaneifel (Germany), Unzen (Japan), Katla (Iceland), Azores (Portugal) and Monts d'Ardèche (France).

The main objective of this work is to demonstrate that area of the Colca Canyon and the Valley of the Volcanoes have a significant number of geosites and geotouristic attractions (Radwanek-Bąk 2014; Gałaś et al. 2014b; Zavala and Churata 2016), which can be applied within the future Global Geopark. The settlement pressure caused by the strong development of tourism and services, threaten natural wonders of described area, and therefore the protection of its advantages is proposed. There are also conflicts of interest with mining activities, transmission of high voltage electricity, water management and construction of road network. Determination of the direction and limits of development will guarantee the preservation of individual geoforms and the whole geodiversity of the area.

The Area of the Investigation

Research was carried out in southern Peru, NW part of the Arequipa department. These include the provinces of Caylloma, Castilla and a small part of Condesuyos. The area is relatively difficult to access to this area due to its location in the high and jagged mountains dissected by the deep canyon of the Colca River. Driving distance from Arequipa town, (ca. 970,000 inhabitants) to the investigated areas of Caylloma is about 250 km, and Castilla up to 410 km. Due to ongoing highway improvement projects, the Regional Government of Arequipa is paving the way for Castilla (entering the Valley of the Volcanoes) and Huambo-Canco-Ayo connecting the Colca Canyon and volcanoes as well as other tourist sites placed northwestern of Arequipa like the Valley of Cotahuasi.

In terms of physiography, the study area is located in the Western Cordillera, close to the Altiplano plateau. The absolute height ranges from about 800 m a.s.l. at the confluence between the Colca River and the Andamayo River to more than 6000 m a.s.l. at Hualca Hualca volcano. The Coropuna, Ampato, Sabancaya, Hualca Hualca and Mismi volcanos (Figs. 1 and 2) stands as towers over peneplenized surface of the cordillera. Their peaks above 5500 m a.s.l. are at most covered with eternal snow and glaciers (Gałaś et al. 2014a). The Colca River bed falls from some 3056 to 900 m a.s.l. along the river section. It has its springs Altiplano near Lagunillas Lake where the altitude is surpassingly 4500 m a.s.l. The river follows a system of grabens bordering the Cordillera Chila, which breaches through the folds of Cordillera Occidental then incises into alluvial covers of the Intermediate Depression and even into the Proterozoic Arequipa Massif, reaching the Pacific Ocean at Camaná city.

Dry climate is characteristic this part of Peru territory. Among eight ecological regions distinguished in the whole of the Peru territory by Pulgar (1981) as much as five regions: *Yunga, Quechua, Suni, Puna* and *Janca* are present in the investigated area (Table 1).

Deep erosion incision in the Colca Canyon, tributary streams and topping of the Western Cordillera by volcanic edifices resulted, both in landscape richness and occurrence of numerous climatic-ecological zones (Parodi 1987; Tumialan 2004).

The most favourable conditions for farming occur in the river valleys up to 3600–3700 m a.s.l., where most region population and communication routes are settled. Farmlands are concentrated in the irrigated and the terraced Colca Valley (between Madrigal and Chivay), and on the local terraces above Colca Canyon in Cabanaconde and Huambo districts, and also in the Valley of Volcanoes (Andagua, Chachas, Ayo). Huambo is world famous for its plantations of oregano grow.

Since 1973, a huge hydrotechnical project Majes-Siguas was implemented. Irrigation of the desertified areas of Pampa Majes and Pampa Siguas was achieved by diverting waters of Colca River (Fig. 1). The project was aimed and improving aimed at crops and livestock development. Water is supplied through channels and tunnels above the Colca

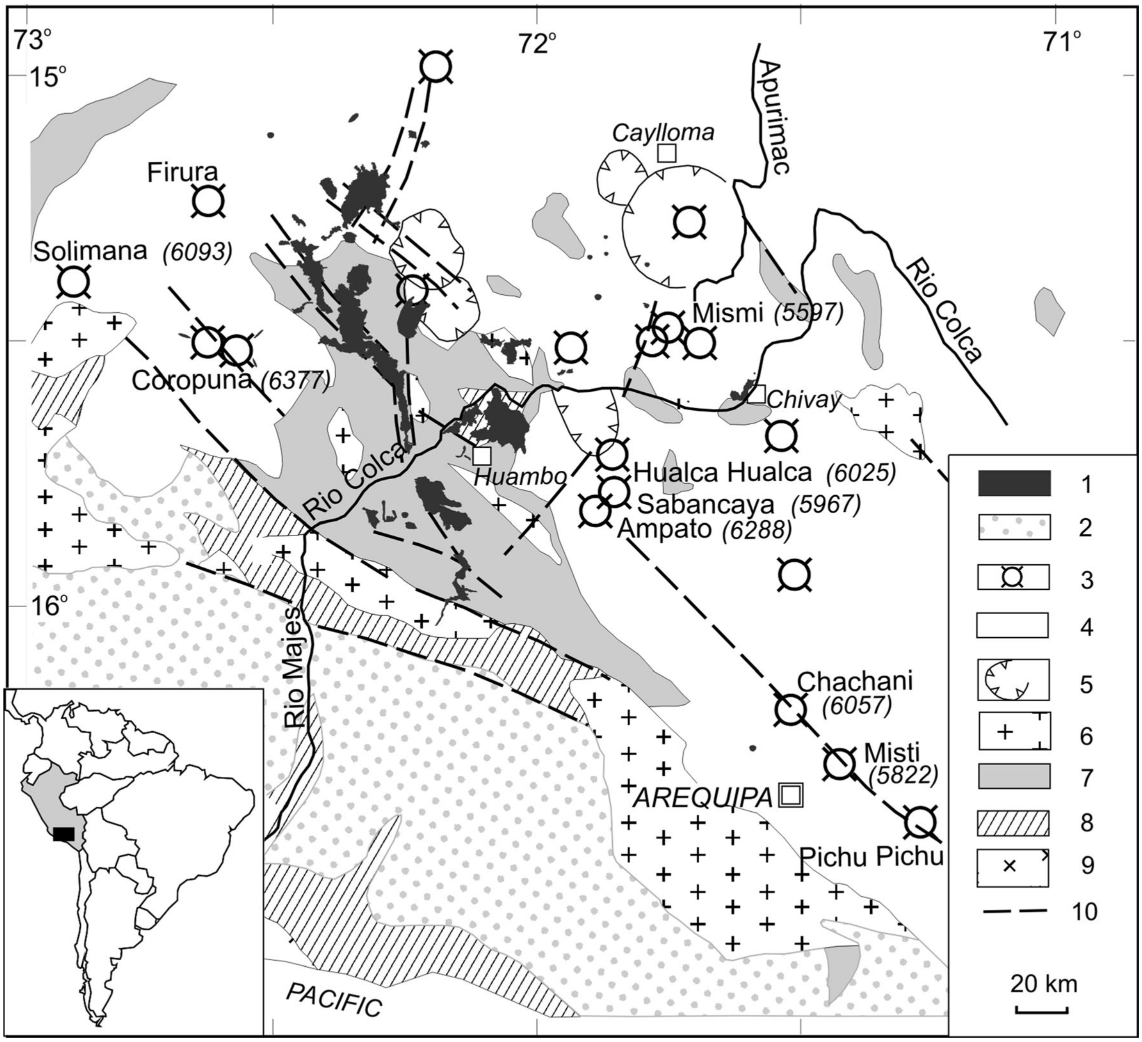

Fig. 1 Geological map of study area (based on Salcedo 2007 and Paulo 2009). 1—Quaternary: Andahua Group, 2—Pleistocene: alluvial gravels, 3—Pliocene-Quaternary: stratovolcanoes of Barroso Group, 4—Neogene-Quaternary: pyroclastic and lacustrine deposits, 5—Neogene: caldera complexes, 6—Jurassic-Paleogene: plutons, 7—Jurassic-Cretaceous: sedimentary formations, 8—Proterozoic-Paleozoic: magmatic intrusions, 9—Proterozoic: Arequipa massif gneisses, 10—major faults

Valley and Canyon to the Huasamayo broken in the Siguas River basin (Acción Popular 2004).

The Chila and Huanzo cordilleras, which borders the Colca Canyon from the north, have been an area of mining activity since colonial time. Important, modern gold and silver ore mines are active in Orcopampa, Poracota, Caylloma and Paula (Fig. 2) (Paulo and Gałaś 2005, 2008b; Echavarria et al. 2006). They employ, including the infrastructure, 2000 people, being the main local source of income. Illegal, small and primitive gold mines exist between Choco and Soro. Near Huambo rock salt and travertine (a source of lime) are exploited. Gold exploration is carried out north of Lari and Madrigal. In the past income form polymetallic-silver mines in Madrigal (Tumialan 1991), Shila (Chauvet et al. 2006), and Caylloma had a great impact on the economy. Madrigal polymetallic-silver ore mine in the NW corner of the Colca Valley was active since ancient times until the end of the twentieth century. The excavation left relicts in the form of discarded, not reclaimed dumps of poor ore and a basin of sludge. Their existence brought the local population to protests (DESCO 2005).

Tourism services and local products have become an important source of livelihood of the population of Colca Valley and the city of Arequipa, where dozens of agencies offer daily excursions to Chivay, Cruz del Condor, and Cabanaconde, claiming that they will show the deepest canyon of the world. In fact, they show the Colca Valley and, best case scenario, an initial part of the canyon, 1000–1200 m deep. The Colca Valley is about 2 km wide and 50 km long intramontane depression between Sibayo and Chivay on the east and Madrigal on the west, inhabited by 15,000 people living in more than a dozen villages. It is interspersed with numerous artificial picturesque agricultural terraces abundantly supplied with water (Gutiérrez et al. 1986). About 100 hotels have been built in Chivay, Cabanaconde and in a few other villages, markets

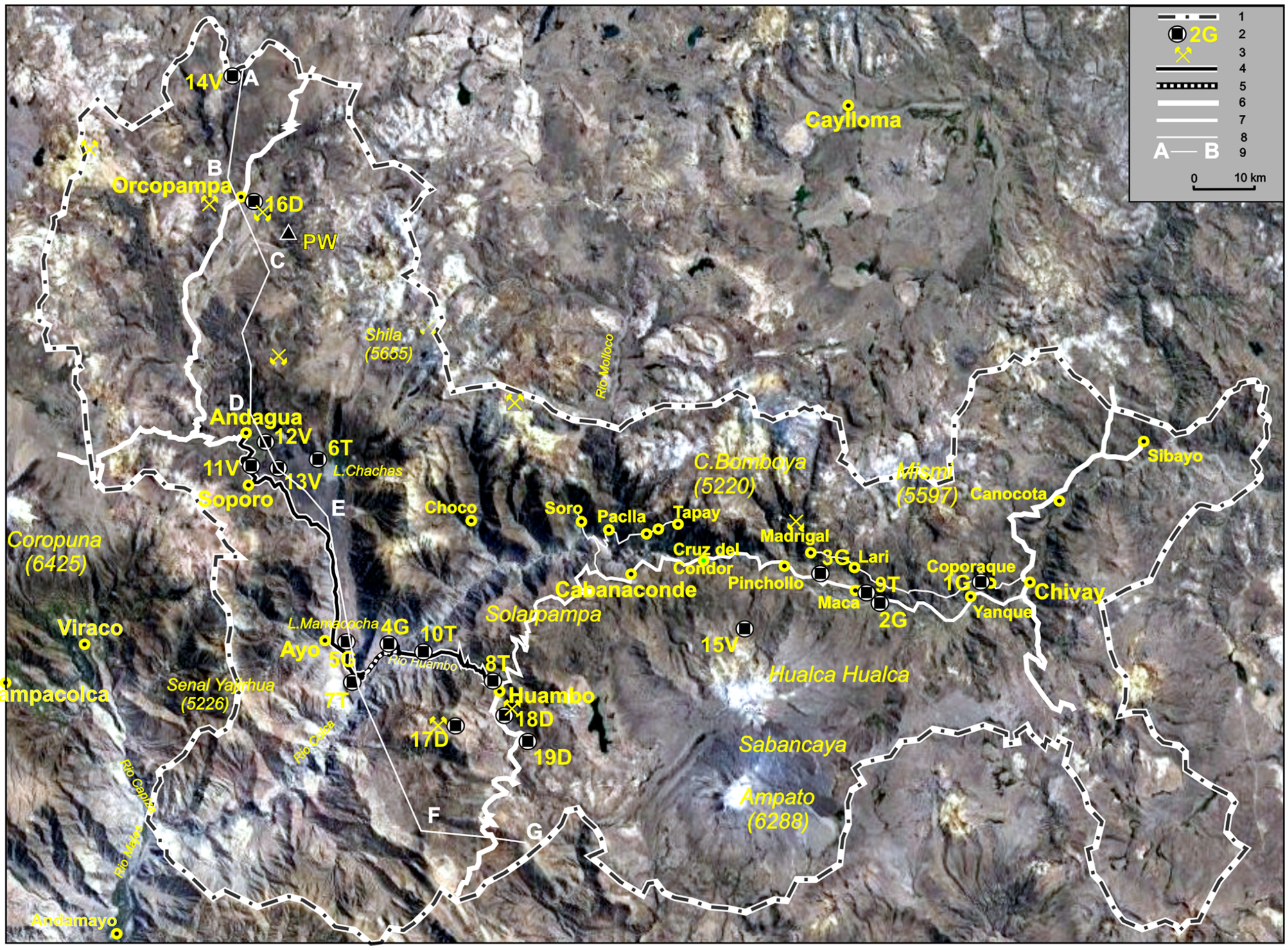

Fig. 2 Map of Project Geopark Colca and Volcanoes the Andagua (Landsat 7) (Gałaś et al. 2016 modified). 1—borders of territory of the Project Geopark, 2—geosities (Tables 4 and 5), 3—mines, 4—Andagua–Huambo road ready, 5—Andagua–Huambo road in construction, 6—regional roads, 7—local roads, 8—small local roads, 9—cross-section line (Fig. 3)

have flourished with local products, thermal baths have been enlarged and local communication developed. Unfortunately the sewage systems have been disregarded. Local governments of the districts located along Colca River established an autonomous union, AutoColca, which has introduced fees for entrance of tourists into both the Colca Valley and Canyon. AutoColca authority has defined its mission to provide restoration, protection, development, use and promotion of natural, archaeological, historical heritage and economic resources into the specially erected Tourist Circuit (www.autocolca.gob.pe). This area was visited by about 185,000 tourists in 2014 and 250,000 in 2016 (more than 144,000 foreign tourists; management report of AutoColca, 2017). Experiential rural tourism has been strengthened in recent years. In 2010 it has been prioritized into four zones for the development of rural tourism in this region (Rural Community Tourism - program nationwide): Sibayo, Yanque, Tapay and Coporaque. Sibayo Rumillacta in the Colca Valley and more recently in Andagua, Chachas, Ayo and Orcopampa in the Valley of Volcanoes. Local families trained by NGOs offer tourist services (Zavala et al. 2016). The development of tourism is highly unstable and relies on wet to dry season changes. Two periods in a year with low tourist visits occur due to heavy rain. That creates problems with acquiring proper personnel due to not being able to withhold constant levels of employability.

Geological and Morphological Setting

The catchment of Colca River developed within an active edge of the South American Plate overriding the Nazca Plate. Neotectonic activity has led to restructuring of primary Peruvian fold system and laying fundaments of contemporary relief—highly elevated horsts, separating grabbens as well as Cenozoic calderas, ash sheets and stratovolcanoes (Palacios et al. 1993).

The Colca Canyon and the Valley of the Volcanoes are deeply incised into the Western Cordillera of the Central Andes. The Western Cordillera is bordered by the Intermediate Depression from the southwest, and a passage

Table 1 Functional-landscape valorization of the Valley of the Volcanoes (Gałaś and Gałaś 2011, modified)

Ecological units (vide Pulgar, 1987)	Economic potential	Proposed protection areas	Evaluation of environment, landscape, education	Character of potential geosities	Conflicts
Yunga (500–2300 m a.s.l.) South part of Valley has a desert character, surface of lavas is water and plants less, same species of cacti and sec bushes.	a) productive area d) nature and culture protection	Strict conservation for mainly area	High: lavas and faults (Holocene), active morphological processes, few types of landscape, otter habitat	Natural landscape, volcanic and tectonic structures, lakes,	Power line, planed changing of location and high of the transmission tower, road in planed
Quechua (2300–3500 m a.s.l.) Central and south part of Valley, were temperate to sec conditions of climate are dominate, good predispositions for agriculture. Are observed same trees (eucalyptus).	a) productive area b) settlements, d) nature and culture protection	Strict and partial conservation for mainly area, buffer zone with cultivated areas	High: volcanoes (Holocene), lavas and faults, active morphological processes, diversity of landscape	Natural and culture landscape, volcanic and tectonic structures, cataracts, lakes, high difference	Power line, planed changing of location and high of the transmission tower,
Suni (3500–4000 m a.s.l.) North part of Valley. The temperate cold climate are dominate, is the border of extent of agriculture. Are observed tuft of grass *ichu* and *chudo*.	a) productive area b) settlements, c) mineral deposits	Partial conservation, buffer zone and communal reserve	Middle: volcanoes and lavas (Pleistocene-Holocene) few types of landscape	volcanic structures, cataracts, lakes, bofedales	Planed changing of high of the transmission tower,
Puna (4000–4800 m a.s.l.), Surroundings area of Valley. Typical in vegetation cover are species of strong grass, herbs and pastures.	c) mineral deposits	Partial conservation for small area,	Small	Natural landscape, cataracts, lakes, high difference	No exists

from the Inter-Andean Depression into the Altiplano from the northeast. In this transitional area, the Colca Valley was formed.

Deep section of the Earth's crust exposes its internal structure which provides important arguments in the debate on the geology of the edge of South America continent and tectonic evolution of the lithospheric plates in general. Several structural storeys are easy to distinguish. They differ in age, tectonics, lithology, facies and other geological features (Fig. 3).

Scarce vegetation barely covers the landscape allowing characteristic colours of specific formations to pierce thru, facilitating professional studies and ease the explanation of the geological landscape for tourists.

The area of the proposed Geopark can be divided into three main parts: the Colca Valley, Colca Canyon and Valley of the Volcanoes (Fig. 2). This division arises from their distinct morphology and geological structure as well as significant differences in access. The features of each part are described below.

Colca Valley Covers the area between Sibayo and Madrigal. It follows a complex of Pleistocene grabens, running NNE-SSW and SEE-NWW, filled with glacial, fluvial and lacustrine sediments (Kalicki and Kukulak 2009b; Kukulak et al. 2016) and locally with Andahua volcanic rocks (Galas 2011). Grabens are limited by a Neogene volcanic complex of Tacaza Group and local outcrops of Mesozoic formations surmounted with pyroclastic cover and several stratovolcano structures of Barroso Group (Ampato, Sabancaya, Hualca-Hualca, Mismi and other volcanos). The Barroso volcanic arc was formed in the Pliocene (Mamani et al. 2010). Sabancaya volcano is currently active (Samaniego et al. 2016), others from this group became extinct during the Pleistocene (Fig. 4).

Upper part of the valley up to Coporaque is filled with Andahua type lava flows of middle and late Pleistocene. Rio Colca incises between the steep slopes of Andahua lavas and Barroso volcanoclastics (Gałaś 2011).

Contemporary Colca Valley results from overlap of two independent subsystems and captive action of backward erosion. The first subsystem was represented by endorheic intermontane tectonic grabens founded probably in the early Pliocene. The highest erosion and then accumulation levels related to the developing depression, preserved at the slopes and at the mouths of tributary valleys. Along with the rising Andean range, the transversal transport of sediments diminished and evapotranspiration increased. Therefore, at the end of the Pliocene and in early Pleistocene such depression might be occupied by a long lasting endorheic lake. The second subsystem was created by a river draining steeply to the Pacific. Its backward erosion intercepted/captured the lake catchment into the Pacific.

Remnant lacustrine sediments of three major Pleistocene lakes are beautifully exposed in the Colca Valley.

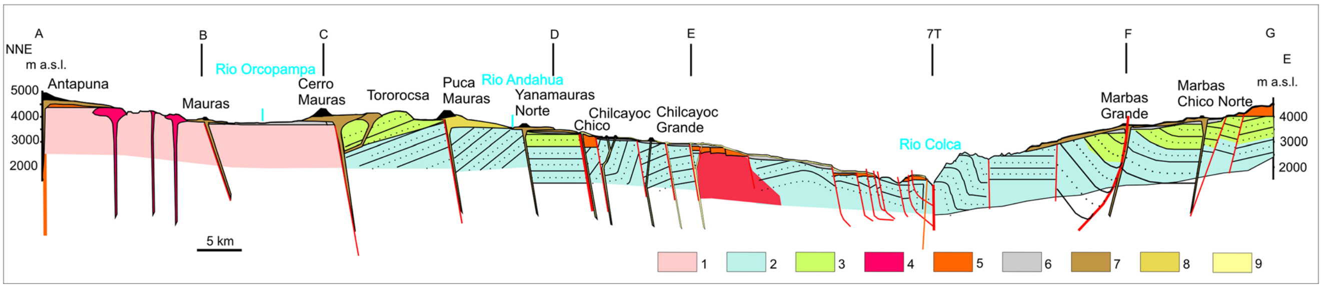

Fig. 3 Geological cross-section of the Valley of the Volcanoes and Colca Canyon (Gałaś 2013), 1—volcanic formation Sarpane, 2—Jurassic sedimentary formation, 3—Cretaceous sedimentary formation, 4—magmatic intrusions, 5—Barroso Group, 6—alluvia, 7–9 Andahua Group (7—Pleistocene, 8—Pleistocene-Holocene, 9—Holocene)

Approximate age of the lacustrine deposits found under lavas has been dated at near Achoma at 0.61 Ma (Klinck et al. 1986). Oldest lake, extended between Pinchollo and Coporaque when the Colca River was dammed by huge debris avalanche from Hualca Hualca volcano. Much later lava flows blocked the river near Chivay and Canocota resulting in less extensive, shallower lakes and a variety of their sediments. The river cut through the sediments to a depth of approximately 300 m between Chivay and Pinchollo, over a distance of 30 km and formed several terraces in the lacustrine deposits. Outcrops of lacustrine sediments lie now at elevation of 3100–3600 m a.s.l. in the lower lake and 3700–3800 m a.s.l. in the upper one. Spatially dominant are regularly layered and laminated fine-grained sediments: silt, sand, and locally diatomaceous ooze (Kukulak et al. 2016).

Landslides, caused by undercutting the slope by the river and faults, have great importance to the development of the lower and also the wider part of the valley. The biggest landslide has developed between the Maca, Lari and Madrigal. Its niches have a radius of more than 2 km. SW niche overlaps in part with the course of an active normal fault (Żaba et al. 2012). Within the tongues of those landslides sets of rejuvenated slopes, secondary crevices and ox-bow lakes occur (Kalicki and Kukulak 2009a). In the area of niche two systems of faults differing in age were recognized, which form numerous grabens and escarpments in Quaternary colluvia (Żaba and Małolepszy 2009; Żaba et al. 2012).

Fig. 4 Active Sabancaya volcano from the Colca Valley (July, 2017)

In the section Sibayo-Madrigal there are 86 springs of water suitable for irrigation (Robles 2010). Several sources of thermal waters with a temperature of 40–80 °C can be also observed. They are recognized for Balneotherapy in several places. The main baths are located near Chivay and Yanque. On the slopes of the volcano Hualca Hualca above Pinchollo a geyser is permanently active and in the vicinity a solfatara, mineral efflorescences, also boiling mud can be observed (Ciesielczuk et al. 2012; Zavala et al. 2014). The ascent of thermal waters in Southern Peru is connected with neotectonic movements which are the result of subduction of the Nazca Plate under the South American lithospheric plate.

Colca Canyon Developed between Pinchollo and Andamayo where the river enters the Majes Valley. It follows 98 km long course of the Colca River. The river flows across complex structures of the Cordillera Occidental exposing an extraordinary section of the Earth's crust 1000–4000 m deep. Between Madrigal and Pinchollo outflow of Colca River from the Colca Valley is obstacled by ridges falling away from Hualca Hualca (6025 m a.s.l.) and Cerro Bomboya (5220 m a.s.l.). The river breaks a barrier of Pliocene/Pleistocene volcanic debris, follows and deepens river valley and its bed incises between 3050 to 900 m a.s.l. along whole stretch up to Andamayo River. Colourful, precipices excavated in rock formations passing into mountain desert cover both sides of the Colca Canyon except for scarce springs and tributary streams with abundant of vegetation. There are few villages near streams with the total number of inhabitants there reaching approximately 4000 people. Hardly any travellers reach that place.

The Canyon exposes Proterozoic amphibolites and gneisses of Arequipa and Paracas massifs (Mamani et al. 2010), Mesozoic sedimentary formations of former West Peruvian Shelf and coastal zone. It was strongly folded during the Mochica and Peruvian orogenic phases and injected with granitoide intrusions. Slightly folded Upper Cretaceous marine to continental red beds contain evaporites, almost flat lying, thick and differentiated series of Tertiary continental volcanic and epiclastic deposits, as well as huge Pliocene-Quaternary stratovolcanoes, dwarf scoria cones and lava flows of the Andahua Group (Delacour et al. 2007; Gałaś 2011), intercalating with river gravels, lacustrine deposits (Caldas 1993; Klinck and Palacios 1985; Kalicki and Kukulak 2009b) and travertines (Fig. 2).

Stratigraphically all the rock formations that appear in the studied territory include a vast time period from the Proterozoic (1.8–1.95 Ga) to the Quaternary (Fig. 3). This allows to observe high lithological and genetic diversity of rocks—from sedimentary clastic and carbonate of marine and continental environments, through igneous plutonic and volcanic rocks of differentiated chemistry, crystallinity and emplacement mode into those transformed by deuteric, metamorphic, thermal-metasomatic and weathering processes.

The different formations revealed complex folds, gentle troughs and domes, inverse and normal faults, grabens, large magmato-tectonic structures (explosive calderas, intrusive stocks), dykes, chevron and duplex structures and many others. A plethora of tectonic structures was described in a detailed study by Żaba et al. (2009) along Huambo River. Magnificent sets of lava columns are exposed nearby Cabanaconde. Structural unconformities can be observed in many outcrops. Even Holocene sediments are regularly fractured (Żaba et al. 2012) what allows to study the current stress field. The active faults El Trigal-Solarpampa, exposed between Cabanaconde and Huambo, can be traced along 30 km and find clear morphological expression and volcanic overprint. Since 2015 experimental morphometric and seismological monitoring has been established there (Benavente et al. 2015).

The Colca Canyon and its surrounding are an ideal area for the study of landforms, landscape and geomorphic processes. In a relatively short time of a few million years the river incised one of the deepest gorges in the world. Colca belongs to the category of mountain canyons, which are distinguished from plateau canyons. However, on its periphery it is possible to encounter the relics of the planation surface and inside fragments of river and lacustrine terraces (Kalicki and Kukulak 2009b). Among other denudational landforms are easy to distinguish ridges, ravines, sinkholes, hillslopes, and cliffs, while among constructional landforms—orogenic range, morraines, travertine precipitates, peat-bogs, subvolcanic intrusions and volcanoes of different size and structure. Thermal alterations along a porphyry stock near Huambo are visible leading to characteristic mineral assemblages as described by Paulo et al. (2013).

Valley of the Volcanoes The name the Valley of the Volcanoes comes from scoria cones and lava flows damming great part of the valley floor. The surroundings of Andagua village can be regarded as *locus typicus* of the Andahua Group. Moderately eroded volcanic centers and lava flows of the same group occur also in the Colca Valley and to the south of the Colca Canyon (Gałaś 2011). The elevation of the Valley of the Volcanoes floor at Orcopampa exceeds 3800 m a.s.l. and the mouth of the valley entering the Colca Canyon is at 1360 m a.s.l. The valley is approximately 60 km long and its course follows three tectonic grabens. They are bounded by Mesozoic sedimentary and Neogene volcanic-subvolcanic formations, locally with tuffs and conglomerates of Barroso (Gałaś 2013). Mesozoic sedimentary substrate is unconformable overlain by Pleistocene-Holocene volcanism on and can be observed at the base of several monogenetic cones (Fig. 3). The Valley floor is covered with extensive lava fields and some high slopes surmounted with pyroclastic cones and minor lava flows. Based on morphology it is possible to distinguish twelve volcanic fields in the whole Colca region. The Valley of the Volcanoes by itself concentrates 82 eruption centres, that includes 58 small lava domes and 24 scoria cones (Gałaś 2011, 2013).

The distribution of the eruption centers follows different extensional structures. For example, several domes culminating in Puca Mauras cone are bound by the eastern limit of the middle graben while the latest eruptions (Jenchaña, Niñamama) followed a normal NE-SW fault, diagonal to this graben (Gałaś 2011, 2013).

The morphology of the Valley of the Volcanoes was transformed entirely by volcanic and fluvial processes. Lava flows have temporarily blocked water outflow resulting in barrage lakes like contemporary Laguna de Chachas y Mamacocha (Fig. 2). Traces of older limnic sediments are preserved near Canco. Also an epigenetic fracture at the mouth of Mamacocha River cuts through a young volcanic dam.

The Goal and History of the Project

Brave canoeing carried out in the Colca River by Polish team Canoandes in 1981 and the proclamation of the Colca Canyon as the deepest worldwide by the National Geographic Magazine and the Guinness Book of Records (1984) made the region of Colca one of the most popular tourist destinations in Peru. This led to the rapid growth of regional income and the development of infrastructure. In 2003 a research project to create a national park was put forward by members of the Polish Section of the Explorers Club and geologists from AGH University of Science and Technology in Krakow (Poland).

After reconnaissance studies in 2006, a Polish Scientific Expedition to Peru (PSEP) was organized. Studies performed by PSEP are aimed at projection of the Colca Canyon and Valley of the Volcanoes National Park initiative. Until now 36 scientists participated in this project. Their scope of interest included structural geology, geomorphology, volcanology, environmental protection and management, geotourism, botany and parasitology. The results of these investigations confirmed the high geodiversity and unique landscape of the area. The boundaries of the future park were proposed as covering the entire area of the Colca Canyon and the Southern part of the Valley of the Volcanoes (Gałaś and Paulo 2008; Paulo and Gałaś 2008a, 2012).

In parallel with the detailed research a spatial framework efforts for the formal adoption of the draft project was defined. The authorities of the Department of Arequipa, local governments as well as research centers and the media have been informed of the progress of research and the idea of the creation of the National Park Colca Canyon and Valley of the Volcanoes (Gałaś and Paulo 2009; Paulo et al. 2014).

In the meantime, in 2006 INGEMMET opened the "Heritage and Geotourism" programme. Geological Survey of Peru began work on documenting resources of the geological heritage and identifying areas of high value for promotion and protection. In 2011 the geotouristic guide to the Valley of the Volcanoes was published and presented as a project of the National Geopark Valley of the Volcanoes. In 2014 a valuable monograph of the Colca River basin was published (Zavala et al.). In early 2015 the planned geopark range was extended into the Colca Valley and the Colca Canyon and in May 2015, at a symposium in Mexico City (Zavala 2015b), the implementation of the Geopark Colca Canyon and Valley of the Volcanoes was first time announced. In the same year the 1st International Symposium on Geoparks, organized by INGEMMET, was held in Arequipa. This gave impetus to undertake projecting the geopark project towards a future application to the UNESCO Global Geoparks (Zavala 2015a).

Methods

Colca Valley has countless morphological forms, that allow for better understanding of its development. Its majority corresponds to geomorphosites (sensu Reynard 2009). It is easy to identify the sections of the river-bed with different flow regime, and geoforms like alluvial fans, erosional and accumulation terraces, soils, erosional cuts of various size (canyons, gullies, potholes), colluvia, debris flow deposits, different factions of lake sediments, surface and hypabyssal forms of volcanism.

The attractiveness of the area for geotourism depends on the number of valuable and accessible geosites that need to be properly described and evaluated. For this purpose an inventory of volcanology, tectonics, stratigraphy, geomorphology, hydrology, paleontology, mining and culture geosides was made. A wide range of scientists could have been involved due to the connection between geology and other field of technique, science and industry. Each of them submitted a list of items which, in their opinion, could be used as geosites. These geosites have been characterized by dataset, prepared as expected in relevant forms (Table 2) (Radwanek-Bąk 2008). The forms used in Poland and Europe were supplemented with the data necessary to fill up the geosite cards used in Peru (INGEMMET 2014).

The concept of geological and cultural heritage preservation in the contemporary world is evolving. Keeping this in mind, newly defined standards gave an international character of previously chaotic survey due to the aegis of the UN. Developing a common procedure of geosites assessment is a difficult task because of their diversity and local unique value. Worth to note are pioneer publications of Panizza and Piacente (1993), guidelines of UNESCO (2004, 2014) and articles of Reynard (2005), Alexandrowicz (2006b), Dowling and Newsome (2006), Garofano (2014). A point grading method was applied for evaluation of the geosites by scientific and touristic criteria. The following six elements were evaluated (Table 3), most of which were proposed earlier by Radwanek-Bąk (2008):

1) scientific and educational-cognitive values,
2) landscape and scenic-aesthetic values,
3) architectural and cultural values,
4) recreational values,
5) accessibility,
6) rarity.

All geosites in the area of the newly projected Geopark were valorised. The assessment took into account the state of preservation of architectural objects and threat to the sustainability values of a geosite resulting from natural causes and human activity. The impact of mining, hotels, holiday destinations, and communication infrastructure was of particular importance. At the same time were highlighted were both the short-term pressure of individual mines due to the depletion of their ore resources and the advantage of using the infrastructure of closed mines for tourism.

Geotouristic Attractions

The lower part of the Colca Valley is rich in water, relatively accessible (since the end of the twentieth century) and more developed than the rest of the area of proposed geopark. It was an important area of agricultural production (Gutiérrez et al. 1986) at the time of the Inca empire. Much of the ongoing cultivation takes place on the terraces ingeniously constructed before the Spanish colonial era. The cultivated terraces create a wonderful mosaic, which diversifies relief of slopes and adds the most characteristic, emblematic feature to the Colca Valley landscape near Tuti (Gobierno Regional Arequipa 2012). The most spectacular is an amphitheatre set of terraces in Oscolle near Coporaque (Fig. 5) (Zavala 2015b). These

Table 2 Geotourism attraction inventory form (Radwanek Bąk 2008, modified)

Geotourism attraction type: o – object, p – phenomenon

Object/phenomenon type

object:
Natural: geomorphological form, fossil accumulation, minerological-petrographical attraction, hydrogeological object, rock formation, geological profile, cave.
Anthropogenic: excavation, constructional and decorative materials etc.

Geological phenomenon (active symptom of geological process):
volcanic, geodynamic, hydrologic, eolian, sedimentative,

database number

localization:
administrative unit
coordinates GPS
high above see level
topographic map sheet 1:100 000
object/phenomenon number on the map
Occurrence site (on/under land's surface, under the water)

External characteristics (in case of phenomenon – observatory site description):
Object's geometry (single punctual, punctual group, linear, superficial, large – areal):
preservation degree:
"readability" of geological content:

Geological characteristics:
geologic-environmental description
structural unit:
formation, member:
age:

assessment:

values				
(educational – cognitive	landscape – scenic	architectonical – cultural	recreational	accessibility

Skala ocen: 0 – brak, 1 – małe, 2 – średnie, 3 – duże, 4 – wybitne
Scoring system: 0 – none, 1 – small, 2 – mean, 3 - high, 4 – extreme

availability of geotourism attraction:
travel:
difficulty level:

works needed to improve accessibility:

remarks:

scenic man-made terraces have been recognized by Archaeological Cultural Landscape of worldwide importance and since 1998 aspire to become a part of the list of UNESCO-ICOMOS World Heritage Cultural Landscapes.

Considering the architectural heritage the National Institute of Culture declared about 20 religious (Gutiérrez et al. 1986) and 32 public and civil domestic monuments (Maldonado 2012). Most of them arose in the Spanish colonial era. However, survival of two pre-Incaic populations: Collaguas and Cabanas that survived in this long-time remote intraandean valley are credited for their unique cultural value.

Building arrangements of Sibayo are worth a special mention. A well preserved traditional village which retains 12 stone houses covered with grass, archaeological remnants Uyo Uyo near Yankee with stone (tuffs of Tacaza Group) constructions designated for ceremonies, housing, roads and aqueducts (Zavala 2015a).

Among the archaeological sites Qolqas de Shininia and Choquetico are also noteworthy. Originally the word Qolquas came from Qeczua, transformed later into Colcas. Its current meaning is similar to warehouses built to store food or other objects. They consist of stone buildings, usually

Table 3 Alternatively evaluation of the geosites by scientific and touristic criteria

Evaluated elements	Values				
	0	1	2	3	4
1) Scientific and educational-cognitive values, 2) Landscape and scenic-esthetic values, 3) Architectural and cultural values, 4) Recreational values,	No	Low	Medium	Large	Unique
5) Accessibility, 6) Rarity.	No	Low	Medium	Good	Very good

erected in the hillsides on fresh, high and ventilated areas. Turrets were built in rows and separated in order to prevent fires (Zavala 2015a). The great importance, which had for a long time this cultivated valley to Andean tribes, was reflected in its name—the Colca Valley. Only five places with the construction of this kind are preserved in Peru. Choquetico landscape is inserted with graves curved into natural cavities of shear rock wall and nearby hanging Colcas. They, most likely served as offerings for the dead (Zavala 2015c). In the uppermost section of the valley above Callali, the caves of Mollepunko were discovered. This is where rock art depicts the domestication of the alpaca.

Chivay, the capital of the Caylloma province, is a convenient center for the organization of cognitive or adventure tourism (Krzak 2005). One can get qualified help, local guides and prepare riding, biking or rafting expeditions as well as high volcanoes trekking.

Some sections of the Colca Canyon or high shelves above it are accessible. The main point of access: Cabanaconde and Huambo are connected by bus with Chivay and Pedregal. New roads are joining both sides of the Canyon Cabanaconde-Paclla-Tapay. At the same time other are under construction, namely Cabanaconde-Soro-Choco and Huambo-Canco-Ayo, producing high negative impacts in the landscape (Fig. 6) (Gałaś et al. 2016). A network of breathtaking and cognitive interesting pedestrian routes is developed near Cabanaconde and some tourists reach Canco and Choco on foot or with the support of mules and llamas. Few try rafting. Cabanaconde offers relatively good hotels and restaurants, with basic tourist services, while Huambo, Tapay and some minor villages may receive backpackers. However, the rapid growth of Cabanaconde disregards rules of the regional management and new constructions threatens to damage the cultural landscape (Maldonado 2012; Gobierno Regional Arequipa 2012).

A few hot springs are present near the Colca River bed in Paclla and downstream of Soro (Majcherczyk 2000), some emanating pressured vapour like geysers or depositing minerals. Due to difficult access they have only scientific value.

The most popular touristic place is a Cruz del Condor viewpoint, where almost every day one can observe the ascent of numerous condors from the depths of the Canyon. This place ensures the close observation of these huge birds in the majestic surrounding. Nevertheless, studies of local biodiversity indicate that condors are not the only advantage in this area. It is also possible to observe a rich habitat of pioneering plants like bryophytes and lichens, *yareta* and numerous other small shrubs, variety of succulents, relics of queñua (*Polylepis tomentella*) (Cykowska and Flakus 2009; Sobiech-Matura and Węgrzyn 2009).

To the west of the rich in water Huambo valley and Canco the Colca Canyon and its outskirts arises a rocky mountain desert. As far as the merger with Capiza River in the wide and green valley of the Majes River there are no major contemporary living human settlements. Dry springs are the reason for the abandonment of small farms.

The discussed section of the canyon is also the deepest and presents the most beautiful landscapes. The stream of Colca River has numerous rapids and waterfalls, and some sides of the Canyon walls are overhanging. Especially spectacular are the John Paul II and Condor waterfalls. In the outcrops the tectonic deformations of layers may be observed. High Canyon walls allow an insight into tectonic structures (Cerro Canco). Volcanic landforms identified in the outcrops of Tacaza and Barroso groups are numerous. However, due to the erosional process, only those in the youngest Andahua group deserve tourists' attention. Volcanic centers located near

Fig. 5 The cultivated terraces, amphitheatre set in Oscolle near Coporaque

Fig. 6 Colca Canyon and merger of Mamacocha River. The place of the planned construction of a bridge and road

Fig. 7 Landscape in the Valley of the Volcanoes. Lava flows and scoria cones from south of Andagua

Huambo and at the mouth of Mamacocha River are probably of the Pleistocene in age (Gałaś 2013). Interesting are artificial outcrops unveiling metamorphic series and contacts of igneous and sedimentary rocks, easily accessible along a new Soro-Choco road.

The middle and southern part of the Valley of the Volcanoes is coated with the youngest generation Quaternary volcanoes and lavas of the Andahua Group. There are represented by lava fields of Accopampa, Soporo, Chilcayoc and Sucna (Gałaś 2013). Those include the attractive pyroclastic cones, lava domes and lava flows, which are the basis of geodiversity of the intended Geopark (Bębenek 2006). The pyroclastic cones are rather small—about 250 m high (Fig. 7). Some cones have craters broken by lava, which allows to enter there and to see their interior. The surface flows are built of sharp-edged lava of *aá* type and deeper by lava blocks (Gałaś and Paulo 2005; Gałaś 2011). Research works carried out showed that the last volcanic activity took place in the Valley about 300 years ago (Cabrera and Thouret 2000).

In the Valley of the Volcanoes only the districts of Andagua and Orcopampa have water pipeline systems, sewage systems and electricity supply (Andagua has got a local hydroelectric plant). There are also a few hotels offering a low standard services. The road network consists of one main dirt road that runs along the bottom of the valley. Some sections are practically available only for 4WD vehicles. There are also numerous paths for llamas and mules. Construction of a bridge over the Colca River is an important initiative of the local authorities. It would connect the Valley of the Volcanoes to Huambo and shortened the distance to the capital of the Arequipa Department in half (Gałaś et al. 2016).

The Proposed Geosites

Colca Valley and Canyon present with abundantly impressive morphological forms, which allow for understanding of its development. Overall, they satisfy the conditions to be classified as geomorphosites in accordance with Reynard (2005). River-bed sections with different flow regime, as well as other geoforms like alluvial fans can be easily observed (Table 3, geosities 1-5G).

The study area is characterized by the immense variety of tectonic structures, from old and deeply exhumed ductile shear zones to evidences of tectonic deformation of the Precambrian metamorphic rocks, through the results of Mesozoic and Cenozoic orogenic phases, to recently deformed lymnic deposits in the Colca Valley and travertines in the Huambo Graben as well as the manifestations of currently active tectonic processes, represented mainly by fault scarps and tensile fractures. Furthermore, very clearly noticeable, even for non-geoscientists, is the relationship between tectonic structures, modern tectonic processes, and the morphology of the area. The chosen examples mainly from the Huambo River valley provide significant opportunity to explain to non-geoscientists the dependence of the landscape features, particularly the drainage network on to geology. Therefore, to cover the mentioned diversity in age, origin and activity of tectonic structures, we propose five geosites that are examples of one or more of listed aspects: inherited/exhumed tectonic structures, recently created structures or the manifestations of the ongoing deformation, features presenting the passive or active tectonic control of the on the morphology, particularly the drainage network (Table 3, 6T–10T).

In the Valley of the Volcanoes the most interesting morphology is presented by quadrilateral formed by Andagua-Soporo-Sucna-Chachas, where there are youngest and varied forms of eruption centers and lava flows, which, among others, blocked Andagua River surface runoff thus creating the Laguna de Chachas and hiding the river underground. The river emerges to the surface alter 12 km in the form of distant karst spring in Laguna de Mamacocha (Table 4, 11V–15V).

At the surrounding of the Geopark Project territory, the exploitation of gold ore in the Chipmo, Poracota and Paula

49 mines are carried out and until recent similar mines operated in Orcopampa and Shila. Polymetallic ores were mined in Madrigal and Sta Rosa. In the Huambo region a small scale mining of porphyry, rock salt and travertine left behind a set of mining heritage (Table 3, 16D–19D).

Geomorphosites (1G–5G)

In Colca Valley, between Chivay and Yanque, a powerful alluvial fan from the region Coporaque (Fig. 8) has intercalated with lavas of Andahua Group (Coporaque position 1G). Forms of fluvial and fluvial-denudation can be easily seen in the Achoma-Maca section. At valley outlets of tributaries high, accumulative (gravels and sands) terraces occur ("valley levels"), whereas in the valley bottom stair system of erosional (headward erosion) terraces cut in a limnic series is visible (Achoma Maca - 2G). Near Achoma lacustrine series are covered with lava. Between Maca and Pinchollo, on the both sides of the Colca Valley there is a wide range of landslide forms. They are of different ages, have secondary edges, cracks, terraces, small lakes. The biggest landslide, situated on south side of the valley at Maca was developed on the background rocks and also lacustrine sediments (3G).

In Colca Canyon, in its broader sections and preserved at different levels, narrow strip of fine grained lacustrine series, sediments of debris and weathering cover and coarse-grained alluvia were preserved. Lava flows periodically dammed river outflow producing a lake, and the traces of these like. Lacustrine sediments are best seen is near Canco (4G). These lacustrine sediments are up to 40 m thick and occur 200 m above the river bed.

Evidences of changes in the intensity of flows and in the hydrographic network occurred also near Ayo and at the confluence of the Colca River with the Ayo River and the Mamacocha River (geosite Ayo). It is possible to observe the interfingering of fluvial (cones, terraces) and volcanic forms (5G). This reality implied changes in the settlement of the area, as evidenced by abandoned agricultural terraces.

Structural Geosities (6T–10T)

A geosite with high educational value can be found in the exposures close to the town of Chachas (6T) further north of the Valley of the Volcanoes. There, even though the outcrop is smaller than the one in Ayo (7T), but the relationship between folds and thrusts is even clearer and easier to explain to non-geoscientists (Table 5). Despite the big dimensions of the first outcrop, both mentioned geosites present structures in meso-scale, i.e. thus those that can be observed in the scale of a single exposure. Very interesting and worth mentioning is the structure of higher rank in this area, apart from the Valley of the Volcanoes itself, the N-S Huambo Graben (8T) located to the south of the Colca Canyon. In the central part of the valley is the village of Huambo that and developed in the axis of this structure (Fig. 9). The graben is best seen from the road leading to the Huambo in a place located about 5 km south of the village (8T). A geosite is defined as allowing a spectacular view towards the Huambo Valley and the Huambo River, currently forming travertine deposits with very interesting carst features and evidences of recent tectonic deformations (Żaba et al. 2012). All the above-mentioned geosites are characterized by significant scientific values, meaningful geoeducational potential and high aesthetic values related to the gorgeous landscapes.

Evidences of the fault activity related with the underthrust of the Nazca Plate beneath the South American Plate can be seen almost everywhere in the proposed area of Geopark. Nevertheless, one of the best places to observe this phenomenon is the Colca Valley, particularly in the areas of Maca, Lari and Madrigal (9 T). Here crops out recently formed fault scarps of normal and strike-slip faults. To smaller extent tensile fractures in the morphology of the area are also clearly visible (Żaba et al. 2012). The activity of these faults triggers the formation of landslides, or at least control the extent and size of the observed landslides, highly increasing of the geohazard potential of this area. Visitors can observe evidence of recent activity along normal and strike-slip crustal faults in the form of a network of fault scarps and associated tensional fractures. Moreover, they can see landscape features related to landslides triggered by the crustal faults (e.g. landslide niche, landslide tongue, secondary landslide scarp, etc.). This geosite provides arguments and evidences into debate on catastrophic events, related directly with tectonic activity (effects of earthquakes) and also some indirect events, i.e. land movements triggered by tectonic activity of faults or just passively controlled by the exhumed old structures. It could serve as an example of the relationship between tectonic processes that happen deep in the earth and resulting from them processes that occur on the surface.

The passive tectonic control as well as the dependence of the river network development and directions of the main river valleys on the tectonic structures is particularly well developed and easy to observe in the Huambo River valley (10T). This especially applies to downstream of the Huambo village. On many sections the Huambo River does not follow the general slope direction, i.e. does not follow the gravitational slope, but changes its direction (often very rapidly, producing clear bends) using different geological structures, e.g. fold axis, brecciated fault zones, fracture zones and bedding surfaces, among others. A very spectacular example is the place located between Huambo and Canco villages, where the river flows in the axis of a syncline (Żaba et al. 2009, 2012). The view from the bridge above the Huambo River is a textbook example of the use of a folded structure to excavate a river valley. Besides obvious scientific and geoeducational reasons, the mentioned site can be also characterized by a high aesthetic value (Table 4), presenting a beautiful view of the deep V-shaped Huambo River valley.

Volcanic Geosities (11V–15V)

The youngest volcanic forms of the Andahua Group, which have the highest scientific and landscape attractiveness are concentrated in the Valley of the Volcanoes, in its central and southern parts. 12 lava fields, 24 pyroclastic cones and 58 lava domes in the Valley (Gałaś 2011) have been documented. Almost the entire width of the valley is located in the sections that extends from the Kanalla Mauras (11 V) – Niñamama (12 V) fault (Figs. 10 and 11) to the place where the valley joins the Colca Canyon is filled with flows of black and reddish lava bristled with blocks, ridges and needles. This part of the Valley of the Volcanoes, which is full of young and distinct geoforms, is proposed to become an important part of the planned national park (Gałaś and Paulo 2008; Gałaś and Gałaś 2011). The pyroclastic cones Kanalla Mauras and Chilcayoc Chico (13V) and the lava domes Niñamama and Antaymarca (Table 4) were identified as most interesting volcanic geosites. Massive lavas are mainly dark grey and reddish on weathered surfaces. Tephra from pyroclastic cones is mostly black or red, volcanic ashes are black. In petrographic classification they represent mainly trachyandesites and basaltic trachyandesites (Gałaś 2014).

Erosive spires, buttes and shear tuff walls of Alpabamba Formation (Neogene period) create a fascinating volcanic landscape (14V) on the western slopes of Antapuna. Especially worth mentioning are geoforms over Umachulco River. Numerous finds of obsidian tools indicate that this area was inhabited during the Stone Age.

Currently, all the Andahua volcanoes are dormant. The last eruption occurred about 300 years ago. Basing on the study of former eruption styles, the most probable is Hawaiian and Strombolian-type activities. Such activity would be a big threat to the local population but at the same time a fascinating attraction for tourists.

In the niche of the Lower Pleistocene Hualca Hualca volcano landslide, there is the active geyser Pinchollo (15V), and gurgling volcanic mud, and smoking solfataras occur nearby. The geyser in Pinchollo is associated with an active W-E fault clearly visible in both satellite images and area morphology. Alunogen and several other sulphates are deposited around the site (Ciesielczuk et al. 2012). Above it, up to the vicinity of the crater, vast fields of hydrothermal-solfatara alterations can be observed.

Mineral Deposit and Mining Geosites (16D–19D)

Orcopampa is a mining district with a long history dating back to the rule of the Incas. In the extension of the Valley of the Volcanoes tens of epithermal Ag-Au ore veins were exploited in the Manto mine until 1999. Total resources of the Manto-Chipmo system are comparable to the world's largest epithermal deposits (Paulo and Gałaś 2008b). They reach 92 ton of contained gold (Au) and 2200 ton of silver while famous Comstock and Goldfield had initial resources of about 312 ton and 136 ton of Au plus 7300 t and below 49 ton of Ag respectively (Vikre 1989). Conservation of a small portion of the deposit as a museum (not necessarily rich, or shallow part of the gallery) would preserve the geological and mining heritage. Leaching pond that remains even after closing the mine due to exhausted resources, creates an opportunity for education on environmental threats created by mine industry (Fig. 12) (Geosite Orcopampa 16D). Present-day managers of CM Buenaventura take care of nature, preserving local peat-bogs as an ecosystem for trout fish migration and sufficient waterfowl. Apart from this, the eco-park offers visit to nearby garden where various crops are being breed before planting on reclaimed mining dumps.

Geosite "Rodriguez mine" (17D) (Fig. 12) is a small scale underground mine exploiting a 2 m thick lens of halite in a Late Cretaceous continental red-bed of the Ashua Formation. Salt deposit covers an area of about 1 ha. Outcrops of white halite and karstified gypsum surface among mudstone-gypsum sequence and can be traced traced for about 5 km. They point to the dissolution of former halite lenses when exposed to meteoric water but also allow to find preserved deposits. Gypsum and halite as well as some accompanying clay minerals precipitated into a series of shallow lakes, termed playa, surrounded by a mud plain, occasionally flooded and supplied with sand by streams. Local salt is, probably, traded in Cuzco, crossing some 300 km of mountain ranges. Traditional transport means are mules and llamas. The access route with precipices connects Huambo to the mine (2 h) along a ravine and gives opportunity to observe a variety of geological phenomena. The route needs restoration.

Geosite Huambo (18D) represents one of the largest deposits of spring and stream sourced limestone worldwide. It fills the Huambo Valley with 30–80 m thick terraced cap at the altitudes 3950–2950 m a.s.l. The cap is 10 km long, 0.8–2.5 km wide, well stratified and exposing many internal unconformities. Both fibrous compact crusts as highly porous layers occur. The latter, called tufa, results from the activity of aquatic and marsh plants, algae, cyanobacteria and other organisms colonizing the surface of precipitating calcite and enhancing the process. A quarry (Fig. 12) in the Pedregal-Huambo road exposes middle part of the travertine cap and 1–5 thick carbon rich intercalations dated radiometrically

Table 4 Characteristics of selected geosities

Geosities	Location	Type	Character of phenomena	Form/shape	Availability of information	References	Note
1G Coporaque	Colca Valley	Geology, relief	Large alluvial fan, lacustrine sediments intercalated with delta sediments (coarse gravels), lava flow with Prehistoric archeological sites	alluvial fan, outcrops	visible in the field	Kalicki and Kukulak 2009b	General view from the road on opposite site of the valley + Several sites along a didactic route suggested
2G Achoma-Maca	Colca Valley	Geology, relief	, High morphological "valley" levels. Stairway of erosion-accumulative terraces and flood plain cut in the lacustrine sediments	Fluvial relief	visible in the field	Kalicki and Kukulak 2009a	General view from the road on opposite site of the valley
3G Pinchollo-Madrigal	Colca Valley	Geology, relief	Two huge lanslides of different age. Macro-, mezzo- and macroforms of landslide	Landslides	General view from the road on opposite site of the valley		Several sites along a didactic route suggested
4G Canco	Colca Canyon	Geology, relief	Interaction between endo- and egzo- processes. Gap section, waterfalls, accumulative terraces, rockfalls tallus cones, lacustrine sediments of dammed lake by volcanic flow	Valley	visible in the field	Kukulak et al. 2016	Several sites along a didactic route suggested
5G Ayo	Colca Valley and Canyon	Geology, relief	Changes of the river pattern and human activity by volcanic processes. Alluvial fans of Ayo river interfinger with lava flows of Andahua formation	Outcrops, alluvial fan	visible in the field		Several sites along a didactic route suggested
6T Chachas	Valley of the Volcanoes	Geology, tectonics	Fault-related folds represented by detachment, fault-propagation and fault-bend folds	natural outcrops	visible in the field	Żaba et al. 2009	Several sites along a didactic route suggested
7T Ayo	Valley of the Volcanoes; Colca Canyon	Geology, tectonics, relief	Highly deformed Mesozoic sedimentary formation: folds of various geometry and shape, mostly detachment-, fault-bend- and fault-propagation folds strictly related with thrust faults	Wall of the Cerro Aquehuina ridge presenting a unique cross-section	visible in the field, perfectly seen also from village	Żaba et al. 2012	5 km long and 1 km height cross-section visible from far away
8T Huambo	Colca Canyon,	Geology, tectonics, relief	Palaeogene-Neogene tectonic graben clearly marked in morphology of the area, filled with currently formed	Tectonic graben forming wide river valley	visible in the field	Żaba et al. 2012	Point view

Table 4 (continued)

Geosities	Location	Type	Character of phenomena	Form/shape	Availability of information	References	Note
			travertine deposits deformed by active tectonic processes				
9T Colca Valley	Colca Valley	Geology, tectonics, relief	Evidences of current tectonic activity well-developed in the Colca Valley between Maca, Lari and Madrigal, represented mainly by: fault scarps, secondary fractures and landslide features triggered by earthquakes and/or controlled by traces of active faults.	Wide valley with numerous evidences of current tectonic activity	visible in the field	Żaba and Małolepszy 2008; Żaba et al. 2009, 2012	General view from the road on opposite site of the valley
10T Huambo	Colca Canyon,	Geology, tectonics, relief	Huambo River valley strongly controlled by tectonic structure, e.g. synclinal valley, valley direction determined by faults and fractures, and differences in erodability of sedimentary beds, etc.	Deep valley	visible in the field	Żaba et al. 2009, 2012	Several sites along a didactic route suggested
11V Kanalla Mauras Jenchana	Valley of the Volcanoes	Geology, Relief	Volcanic structure,, volcanic rocks (scoria, lavas), volcanic landscape, eruptive centre surrounded by external lava flows	Scoria cone	visible in the field	Gałaś 2011, 2014	Volcano active in historical time
12V Niñamama	Valley of the Volcanoes	Geology, Relief	Volcanic structure,, volcanic rocks (scoria, lavas), volcanic landscape, eruptive centre	Small lava dome	visible in the field	Gałaś 2011, 2014	Volcano active in historical time
13V Chilcayoc Chico	Valley of the Volcanoes	Geology, Relief	Volcanic structure,, volcanic rocks (scoria, lavas), volcanic landscape, eruptive centre breached by lava flow	Scoria cone	visible in the field	Gałaś 2011	Volcano active in historical time
14V Collunas	Antapuna Massif	Geology, Relief, Archeology	Volcanic structure,, volcanic rocks (welded tuffs, lavas, obsidians), volcanic landscape,	Outcrops	visible in the field	Paulo 2009	
15V Pinchollo	Hualca Hualca Massif	Geology, Hydrogeology	Postvolcanic processes, mineralogy,	geyser	Partly visible in the field	Ciesielczuk et al. 2012	
16D Orcopampa	Valley of the Volcanoes	Reclaimed ore mine	Reclaimed tailing&leching pond, eco-park at dressing plant (preserved bog with fish and bird wildlife), fragment of ore vein (outcropping or exposed underground – historical ore mine)	Original preserved surface, mine gallery	Mayor of Orcopampa district	Paulo and Gałaś 2006, 2008b	Cooperation with CM Buenaventura necessary
17D Rodriguez mine	Margin of Canyon Colca	Mine of rock salt	Artesanial underground mine of salt. Geoindices of paleoenvironment. Transport	Near surface salt lense in red beds	Mayor of Huambo district	(in press)	Rute of access needs repair

Table 4 (continued)

Geosities	Location	Type	Character of phenomena	Form/shape	Availability of information	References	Note
			of crude salt by mule and lama caravans.				
18D Huambo	Margin of Canyon Colca	Travertine quarry	Artificial outcrop of large exploited travertine body dated early Holocene by carbonaceous intercalations; nearby sinkholes and waterbearing karst system	Cavernous beds, encrustations	In future Mayor of Huambo district	Under study	Several sites along a didactic route suggested
19D Ashua	Road Huambo - Pedregal	Hydrotechnical constructions	Water channel, desilter, entrance to the shaft and water tunnel.	Concrete channel and entrance to the tunnel	Visible in the field	Florez 2013, Paulo and Gałaś 2008b	

from early Holocene. Precipitation of calcium carbonate continues today, covering pebbles and plastic rubbish in the Huambo river. Travertine is an important aquifer. Strong karst springs burst 0.8 km north of the quarry and a dozen of sinkholes can be observed in the upper part of the Huambo Valley.

Geosite Ashua (19D) is the place where the terminal tunnel carries the Colca River water for the irrigation of the Pampas de Majes y Siguas. It is a suitable site to explain environmental and technical base of this huge project and its socio-economic consequences. The tunnel with more than 15 km long is executed in relatively soft mudstones, reinforced with concrete. The construction of the entrance shaft, the channels, desilter and aqueduct are easy to observe in place. Supplementary observation point to the Ashua geosite may be the abandoned Torre Torre quarry located 300 m above the entrance shaft but at a distance of 6.5–7 km of the road. This quarry reveals dacite intrusion into the Ashua Formation, accompanying mylonitization and alteration under the influence of hot solutions. At the contact with the intrusion several minerals from the zeolite group can be found. Ashua, Torre Torre and the road between them are perfect view points to the fertile Huambo Valley and craggy Cordillera Chila at the background.

Geodiversity Protection and Sustainable Development

Beautifully developed and well exposed, the tectonic structures, with high educational potential—textbook examples—are related mainly from the Late Cretaceous to Miocene compressional orogenic phases. During that time a number of NW-SE thrusts were formed, folds related to them ware represented mainly by -detachment-, fault-bend- and fault-propagation folds that trend NW-SE, with axes mostly plunging gently to SE. One of the most beautiful examples of these structures can be found in the Valley of Volcanoes in the vicinity of the Ayo village (7T) (Table 4). Here numerous folds within the Mesozoic sedimentary formations are exposed on over 1 km high and about 5 km long, at the North-West wall of the Cerro Aquehuina ridge. The undoubted value both geological and aesthetic of that place has also been confirmed by the use of a photo of this exposure as *the photograph of the month* in the Journal of Structural Geology (2014. vol.65).

Pyroclastic cones and lava flows of the Andahua Group create a spectacular landscape of the Valley of the Volcanoes. Especially the central and southern part of the valley abounds in the youngest forms, which remains notable both for tourists and scientists. The individual forms are located at relatively low altitudes (2500–3500 m a.s.l.) in the Andean scale and in short distance from the dirt roads.

Designed geopark borders must compromise conflicting tasks of protection of natural, educational and touristic values on the one hand with the possibility of doing business on the

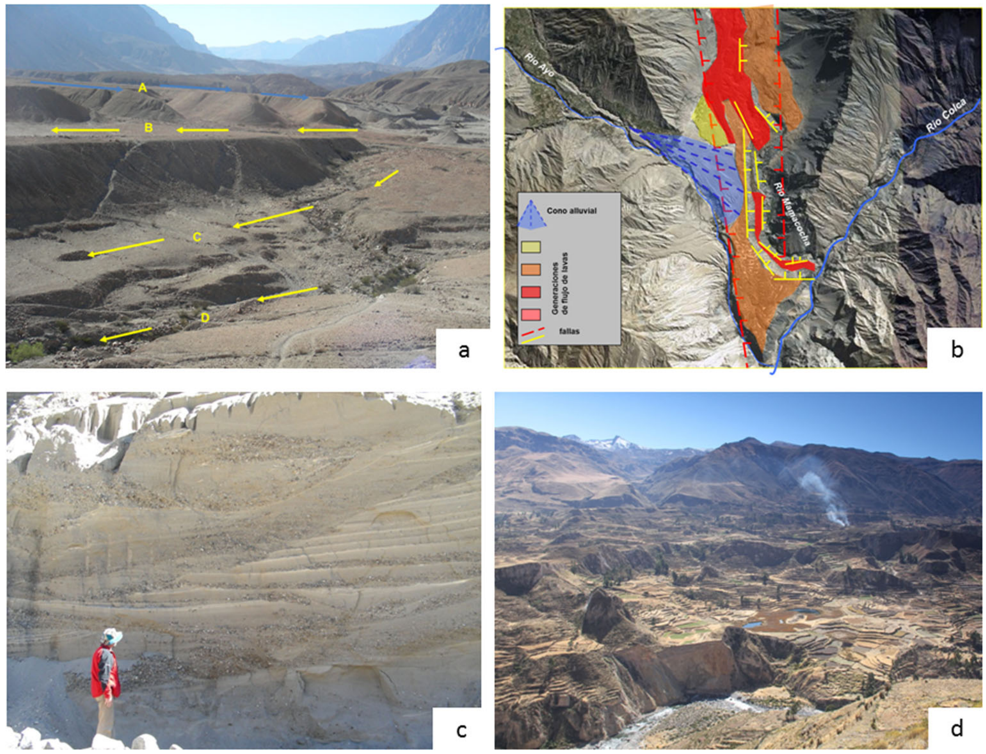

Fig. 8 Geomorphosites. **a**, **b** The interfingering of fluvial cone and lava flow near Ayo (5G). **c** Intercalation of lacustrine sediments and grained alluvia near Yanque (1G) (photos **a**, **c** by Kalicki). **d** Landslide at Madrigal (3G), photo by Gałaś)

other. The ore deposits are best exposed in the mines, but due to the difficult access and safety requirements these are not convenient places to create geosites. Geological-mining lease area is managed by its owner. In contrast, abandoned mining

Table 5 Evaluation of selected geosities

Geosite	Values					
	Educational–cognitive	Landscape–scenic	Architectural–cultural	Recreational	Accessibility	Rarity
1G Coporaque	3	3	2	0	4	2
2G Achoma-Maca	4	4	0	0	4	3
3G Pinchollo-Madrigal	4	4	1	0	4	3
4G Canco	4	4	1	2	4	4
5G Ayo	4	4	2	0	4	3
6T Ayo	3	4	0	3	3	3
7T Chachas	3	3	0	3	3	3
8T Huambo	4	4	0	3	2	4
9T Huambo	3	4	3	4	3	3
10T Colca Valley	4	4	2	3	4	4
11V Kanalla Mauras Jenchana	4	4	1	1	4	2
12V Niñamama	4	4	1	0	3	2
13V Chilcayoc Chico	4	4	1	0	4	2
14V Collunas	4	4	3	0	3	3
15V Pinchollo	4	4	1	0	3	3
16D Orcopampa	4	2	3	1	4	3
17D Rodriguez mine	3	4	1	0	1	2
18D Huambo	3	3	1	1	4	3
19D Ashua	4	2	3	0	4	4

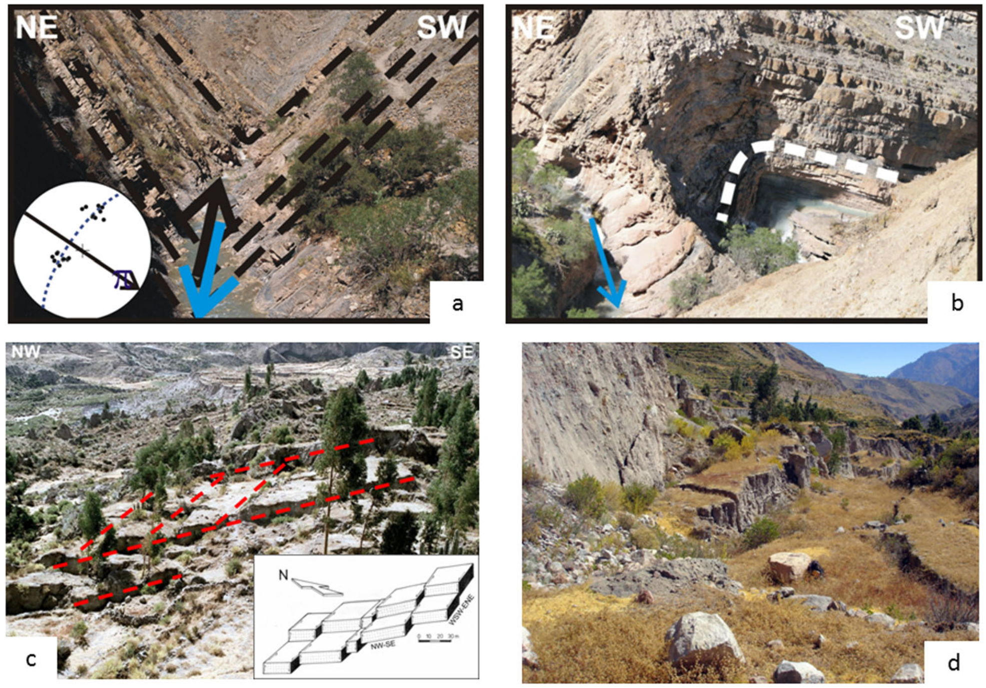

Fig. 9 Structural geosites. **a** The river flows in the axis of a syncline between Huambo and Canco (10T). **b** Fold structures usage by the Huambo river (10T). **c** Superposition of two fault sets in Quaternary colluvial deposits in Maca area (9T). **d** Tectonic graben in Maca area (9T). (photos by Żaba J)

areas may become attractive places to establish geosites since no private interests would be involved.

To sum up, the suggested area has numerous and diversified geosites (Tables 4 and 5) (Gałaś and Gałaś 2017). These have different scientific and cognitive values and uneven access facilities. Some geosites require a substantial qualification for visitors or some special inputs, like the use of all-terrain vehicle, the assistance of a guide, or the organization of mule or llama caravan. All this can provide a rich experience of communing with exotic wildlife and enjoy breathtaking landscapes. Hotels and geothermal baths provide relaxation while contact with surrounding folklore and traditional culture enriches the palette of spiritual and aesthetic impressions. Geosites can support economic development for local communities which can serve as a resource for geotourist activities (for example service guide, transport, marked paths etc.) (Kubalíková and Kirchner 2016).

The major task for any geopark is the promotion of sustainable development of the area. This can be realized through tree steps: conservation, education and tourism (McKeever et al. 2010; Sá 2015). The following actions should be taken in to consideration to ensure the short term the sustainable development of the area:

- the establishment of the territorial area to apply in the near-middle future to UNESCO Global Geoparks;
- geoeducation of the inhabitants of the area, especially those employed in the service of tourists;
- monitoring the behaviour of tourists and the level of their satisfaction of recorded trips;
- implementation of appropriate forms of environmental protection (sewage treatment plants, maintenance of cleanliness and good condition of touring trails, waste segregation);
- reclamation and post-mining land use directed for the tourism infrastructure;
- providing access to information about the geological heritage, the state of the environment and development of initiatives to protect and promote the territory.

Conclusions

Investigation presented in this paper is unveiling the genesis of natural phenomena occurring in the vicinity of Colca Canyon and The Valley of the Volcanoes. It clearly shows the interdependency of the living world and the surrounding rocks. This knowledge supports education and protection of characteristic profiles and sites for scientific research. Understanding the importance that protection of described area has to the region and in some instances to the world would help to build pride in local inhabitants and straighten cooperation between scientists and local society. Creation of the UNESCO Global Geopark would allow to ensure protection of unique geological heritage. UNESCO guidance would not allow to over exploit areas richness by changing political situation and short-term interests of social-economic groups in.

The carried investigations show geosites, with a clear record of structures and sedimentation environments, tectonic deformations, evolution of the area in time, transformation on the surface and deeper in the crust, hot springs and geysers, conditions of development of soil, lacustrine and river network, and various

Fig. 10 Volcanic geosites. **a** Scoria cone Kanalla Mauras (11V). **b** Small lava dome Niñamama (12 V). **c** Some cleft feature on the lava flow in the Valley of the Volcanoes (11-12V). **d** Tent rocks formed by erosion of welded tuffs Alpabamba Formation near Antapuna Massif (14V) (photos by first author)

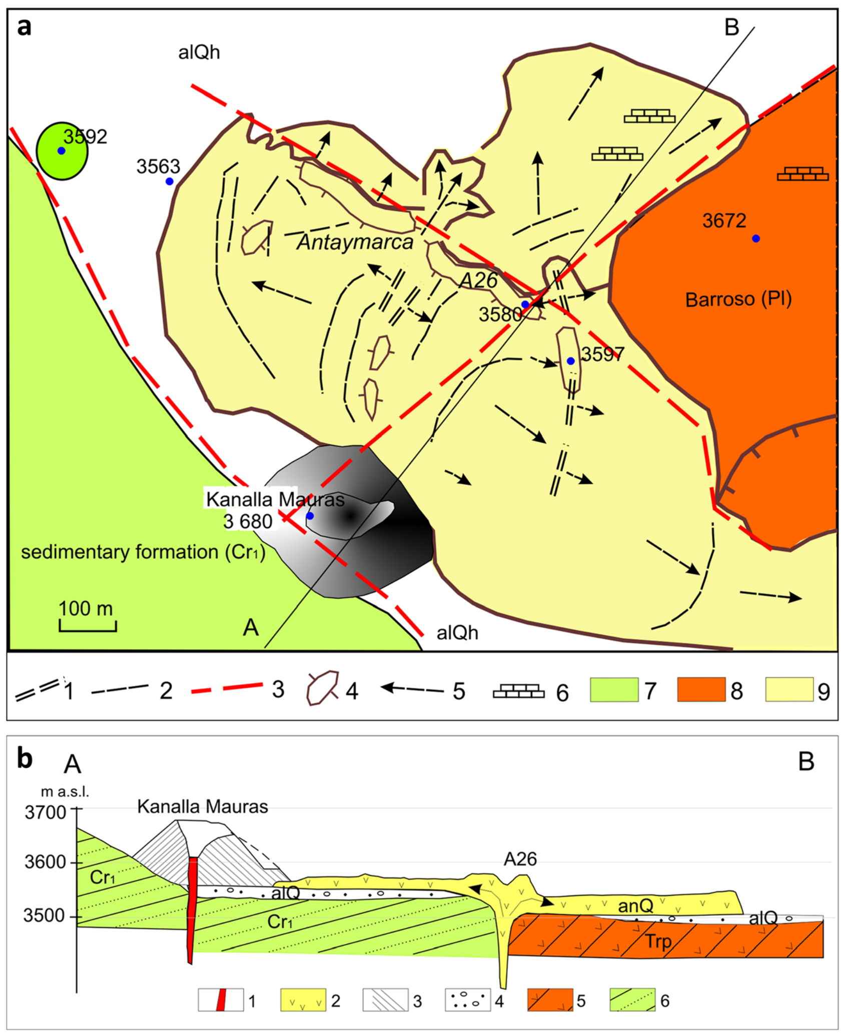

Fig. 11 **a** Geological draw of Kanalla Mauras (11V) and Antayamarca volcanoes (Gałaś and Paulo 2005, modified), 1—squeezing out fissure, 2—fissure in lava, 3—faults, 4—lava pile, 5—lava flow direction, 6—ancient settlement ruins, 7—Cretaceous sedimentary formation 8—Barroso Group, 9—Andahua Group. **b** Cross-section of Kanalla Mauras (11V) and lava dome A26 (Gałaś and Paulo 2005, modified), 1—neck, 2—block and scoriaceous lavas, 3—scoria, 4—gravels, 5—tuffs of Barroso Group, 6—quartzites of Cretaceous

Fig. 12 Mineral deposit and mining geosites. **a** Orcopampa mine, tailing pond and eco-park, in the background settlement (16D). **b** Huambo travertine quarry (18D). **c** Rodriguez mine (17D). **d** Mules with rock salt from Rodriguez mine (photos by second author)

forms of the relief. Given the landscape, active geological processes, unique ecosystems, cultural heritage and opportunities for recreation or sports, the authors estimate that this territory could apply to become a Geopark Colca and Volcanoes of the Andagua. This is due to its unique natural and cultural attractions that also hold high science, education and tourism values. The display of geodiversity and other natural values of the area must be combined with educational activities among the population. There is a clear need to raise awareness and to take proper measures to protect geological heritage, the remaining natural heritage and the cultural heritage (tangible and intangible).

The main attraction is the Colca Canyon, which, if made properly accessible, is a uniquely sufficient place to explain the geological processes that take place currently and are evidence of the past. Its record depth draws many tourists. The previous European experiences of functioning geoparks in volcanic areas (Germany, Portugal, Iceland, a.o.) show their popularity and increased interest in the Earth sciences. The creation of Geopark Colca and Volcanoes of Andagua would popularize also the immediate vicinity of the Canyon. The result would also be the dispersion of tourists throughout and thus reducing the pressure on the places visited currently.

Tourism in the proposed geopark will be organized according to the rules ensuring preservation of the landscape diversity, documentation, exhibition and explanation of unique rock outcrops and geological processes. Economic activities should also be directed towards sustainable development, which will increase the environmental awareness of citizens and create new jobs in the professional service of tourism.

The consolidation of this geopark project will allow the development of the people living in this area. It would provide more money for proper basic education as well as providing understanding of the uniqueness and real value of the area they inhabit. Knowledge of geological environment would bring more involvement into proper conservation and enhancement of the geological resources, and would also allow to potentiate the regions' cultural, natural and social resources.

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