XVIII Peruvian Geological Congress

Timing of Incaic Deformation And Subsequent Erosion, Middle Eocene Volcanism, And Plutonism in Central Southern Peru with Implications for Mineralization

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1. Introduction

• Two new $^{40}Ar/^{39}Ar$ ages from the Huancavelica area of central Perú show that Incaic II phase of deformation had ceased and resulting topography eroded, producing a regional surface, by 45 Ma.
• A new accurate U-Pb age of 35.45±0.48 Ma (2σ) has been obtained on rock from the same part of the Limatambo pluton of the Andahuaylas-Yauri batholith earlier dated by K-Ar as 43.3±1.9 Ma.
• We know of no evidence that any portion of the batholith is older than about 43 Ma, and therefore conclude that the batholith in its entirety postdates Incaic II compressive deformation.
• It is very unlikely that the formation of the porphyry, skarn, and other deposits hosted by the Andahuaylas-Yauri batholith were in any way influenced by the Incaic II orogenic event.
• Two new $^{40}Ar/^{39}Ar$ ages on the Anta volcanics confirm that eruption of the unit also followed Incaic II tectonism and was contemporaneous with plutonism of the Andahuaylas-Yauri batholith.
• Volcanic and plutonic rocks of the Andahuaylas-Yauri batholith and the Anta volcanics to the north of Cerro de Pasco define a middle Eocene magmatic belt in Perú extending for at least 1,000 km.
• The thick middle Eocene sequences of volcanic rocks of the Anta volcanics and in the region of Huancavelica in central Perú demonstrate an extensive and voluminous early mafic volcanism followed by eruption of pyroclastic rocks and lavas of intermediate to silicic composition.
• The lower part of the Anta volcanics consists of hundreds of meters of basalt and basaltic andesite 100± ppm of Cu. The upper part is a volcanic complex hosting Au porphyry deposits. Phenocrysts (hornblende, magnetite, no plagioclase) formed under high P, fH_2O and fO_2.
• The large amounts of mafic magma erupted to the surface show that appreciable amounts of Cu were transported directly to medium and high levels in the crust; similar magmas may have provided some or all of the copper within the porphyry and skarn deposits hosted by the batholith.
• Pyroclastic flows within the Anta volcanics contain lithic fragments of a variety of rock types of intermediate composition, some with the chemical properties of "adakites" (e.g., high Sr/Y).
• Intermediate rocks of markedly different composition, reflecting different sources and histories of generation and evolution, were erupted in the same area in Permian, Eocene and Quaternary times.

2. Age of Incaic compressive deformation and subsequent erosion

The Mesozoic sedimentary platform, including the Late Cretaceous-Paleocene Casapalca Formation of the central Peruvian highlands were deformed during the Incaic phase of Steinmann (1929; see also McLaughlin, 1929). An upper limit on the Incaic II compressional event of 40-41 Ma was provided by K-Ar ages on volcanic rocks overlying the surface of erosion developed after the deformational event (Noble et al., 1979), from which Benavides-Cáceres (1999) inferred an age for the Incaic II event of ca. 43 Ma. New $^{40}Ar/^{39}Ar$ ages for two specimens from the Huancavelica region show that deformation and erosion had effectively ceased by 45 Ma (Fig. 1); the Incaic II phase must be significantly older. These specimens are biotite from a rhyolite clast (AC-BX; 13.080ºS, 75.050ºW) from the Chonta member (Wise and Noble, 2001) that yielded a plateau age incorporating more than 90% of the released ^{40}Ar of 44.81±0.29 Ma (2σ) and plagioclase from a fresh specimen of aphyric diktytaxitic basalt (HUAN-BAS; 12.757ºS, 74.909W) that yielded a plateau age incorporating 56.4% of the released ^{40}Ar from the last eight of eleven heating steps of 45.51±0.19 Ma. This upper limit is supported by published $^{40}Ar/^{39}Ar$ ages of 45.78±0.31 Ma from south of Yauricocha (Noble et al., 2005), 44.4 Ma near Caravelí (Roperch et al. 2006) and several from northern Perú on rocks unconformably overlying strata deformed by Incaic II tectonism. Our analysis of this major orogenic event, which extends from at least northernmost Perú to possibly south of Santiago, Chile, marks the coincidence of deformation with the ca. 50-45 Ma change in the plate vectors tracked by the Hawaiian-Emperor chain. Tectonic models and histories as well as exhumation and other studies should utilize this revision in timing.

3. Age of the Andahuaylas-Yuari Batholith

The Andahuaylas-Yauri batholith (AYB) intrudes the Anta volcanics (AV) and rocks affected by Incaic II phase. A U-Pb age on magmatic zircon (N=15; specimen AY14-2) of 35.45±0.48 Ma (2σ) on the 15 by 35 km Limatambo pluton (Fig. 1) is much younger than a previous K-Ar age of 43.3±1.9 Ma from the same location. There is no evidence that the batholith contains rocks older than about 43 Ma; the old K-Ar ages of Carlotto (2002) are problematic. An approximate age of 40.2 Ma has been inferred from zircon data for a precursor gabbro for the Coroccohuayco porphyry-skarn deposit by Chelle-Michou et al. (2015). The batholith was emplaced in its entirety after the Incaic II compressive pulse, rather than both before and after the pulse, as has been proposed (e.g., Perelló et al., 2003). The Incaic II pulse had no influence on the formation of the porphyry/skarn deposits hosted by the AYB.

4. The Anta Volcanics: Geology, Age, and Composition

The Anta volcanics (AV) (Fig. 1), centered about 25 km west of Cuzco, are the remnants of a much larger volcanic field. Thickness exceeds two km. The unit is tilted and slightly folded; deformation is much less than in the sedimentary rocks filling the Cusco basin to the east (Wise and Noble, this meeting). It is composed mainly lava and pyroclastic material ranging in composition from basalt to dacite and is intruded by plutons, including gold porphyries, of the AYB. Lava flows of basalt and basaltic andesitic dominate the lower portion of the unit (Table 1). These lavas are succeeded by pyroclastic flows, typically rich in large lithic fragments. These in turn are overlain by pyroclastic and lava flows of andesitic to dacitic composition and at the top one or more flows of basalt. Lenses of breccia, including laharic breccia, composed of blocks lithologically similar to the lavas are present within the upper part of the Anta volcanics. These lavas, pyroclastic rocks, and breccias are strongly suggestive of a volcanic complex that includes stratovolcanos. The Anta volcanics therefore is the best preserved high-level example of host of the porphyry and skarn deposits hosted by the AYB.

A similar, but not identical, relationship is seen in central Perú. A 2.5 km thick sequence of middle Eocene volcanic rocks, well-exposed at Chonta Pass, extends for about 100 km in a SSE-NNW direction. About 1 km of basalt with a minimum lateral extension of 90 km is overlain conformably by silicic ash-flow tuff, andesite lava flows and volcaniclastic sedimentary rocks. At both areas basalt is an important part of the volcanic package and was erupted early in the history of the volcanic field.

Carlotto (2002) presented K-Ar ages of 38.4±1.5 and 37.9±1.4 Ma on hornblende from the middle portion of the AV and a whole-rock K-Ar age of 29.9±1.1 Ma on basalt from the uppermost part of the formation. We have obtained $^{40}Ar/^{39}Ar$ ages of 37.33±0.12 Ma and 34.48±0.18 Ma, respectively, on hornblende from the lower and middle portions of the formation (Fig. 1); these ages corroborate those presented by Carlotto. A pluton at Contaño (Fig. 1) has been dated at 38.7±1.0 Ma (K-Ar). These ages show that eruption of the AV was contemporaneous with emplacement of the AYB. Both volcanism and pluton eruption took place after termination of the Incaic II tectonic event. A $^{40}Ar/^{39}Ar$ age of 33.77±0.07 Ma (adularia) from an Au-Ag epithermal vein (Fig. 1) is within the range of porphyry ages.

The Anta rocks contain abundant phenocrysts of magnetite; in places accumulations of Fe-Ti oxide grains weathered from rocks can be seen. Hornblende is abundant and plagioclase phenocrysts are not present in the rocks examined. Phenocrysts formed under high P, fH_2O and fO_2. In some rocks low to medium contents of Ni, Co, Cr and MgO (Table 1) reflect the separation of variable amounts of mafic silicates. Pyroclastic deposits contain blocks and fragments of a variety of more silicic rocks.

Specimens D4 and Anta-4 are from the lower Anta. Clast Anta-5, from breccia, has the characteristics (high Sr/Y, Ca, Al) of "adakites", which have been suggested as being associated with porphyry mineralization. Some of the more mafic rocks contain ca. 100 ppm copper. They provide prima facie evidence that significant amounts of copper can be transferred directly to medium and high levels of the Earth's crust by subcrustally-derived magmas; this copper can be called upon to form the Cu porphyry/skarn deposits. The volumetric importance of basalt and basaltic andesite in both areas cannot be overemphasized.

5. Quaternary Potassic Andesite

A remnant of potassic andesite (S-1) is preserved near Pantipata (Fig. 1). The unit yields a $^{40}Ar/^{39}Ar$ whole-rock age of 1.89±0.02 (2σ) Ma. The flow belongs to the suite of highly alkaline "high-K calc-alkaline and shoshonitic" rocks erupted along the major active Cuzco-Vilcanota fault system (e.g., Carlier et al., 2005). The rock is profoundly different in chemistry and mineralogy from the andesites of the Anta volcanics (Table l). The several parent magmas were generated from different source materials and evolved under different P-T-X conditions during Permian, Eocene and Quaternary times.

6 Middle Eocene Magmatic Belt in Southern and Central Peru

The 2.5 km thick middle Eocene section exposed at Chonta Pass southwest of Huancavelica consists of rock of mafic (1 km) to silicic composition and can be traced in a NNW-SSE direction for 100 km. Igneous rocks of middle Eocene age have been recognized between Huancavelica and Cerro de Pasco (Benavides-Cáceres, 1999; Bissig et al., 2003; D.C. Noble, unpub. data). Quicay, a middle Eocene gold deposit (Noble & McKee, 1999) is located east of Cerro de Pasco. Together with the AV and the AYB these occurrences define a belt of middle Eocene magmatic activity at least 1,000 km long. This belt extends southward into Chile (e.g. Perelló et al. 2003) and rocks of middle Eocene age in the Bambamarca-Llama region of northern Perú mark a continuation into Ecuador.

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% wt	D4	Anta-4	Anta-5	S-1		D4	Anta-4	Anta-5	S-1
SiO_2	55.90	51.75	61.65	57.32	Ni	63	9	0	68
TiO_2	1.05	1.17	0.60	1.32	Co	30	0	0	11
Al_2O_3	15.86	21.04	18.30	18.12	Cr	210	15	4	118
FeO*	8.16	8.61	4.08	5.49	Cu	95	126	11	2
MnO	0.19	0.11	0.10	0.06	Zn	58	76	45	73
MgO	5.71	3.32	1.34	2.17	Pb	0	<2	<2	15
CaO	6.25	9.67	8.91	5.95	Rb	15	6	29	69
Na_2O	5.66	3.27	3.45	4.58	Sr	331	409	1964	2373
K_2O	0.74	0.58	0.91	3.33	Ba	346	230	894	2923
P_2O_5	0.28	0.21	0.26	0.86	Y	19	21	20	19
Minor Ox.	0.20	0.27	0.40	0.80	Sr/Y	18	19	96	125

Table 1. Major- and minor-element data, recalculated to 100 percent minus LOI, for specimens from the Anta volcanics and of Quaternary lava (S-1) from near Pantipata.

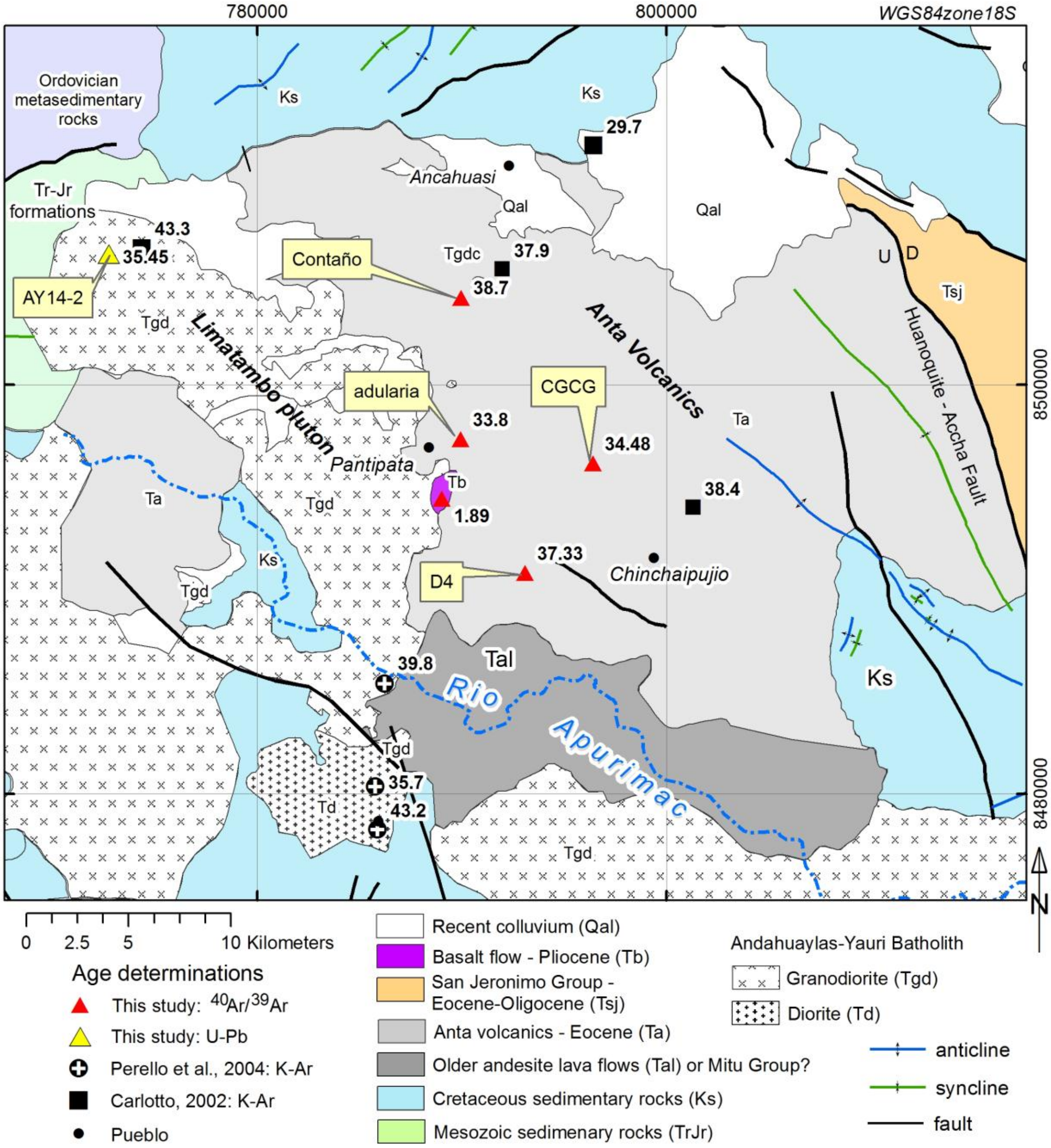

Figure 1. Map showing Anta volcanics, other units, and isotopic ages and analyses referred to in text.