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The Segmented Coastal Batholith of Peru: Its Relationship to Volcanicity and Metallogenesis

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ABSTRACT

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The Coastal Batholith consists of about 1000 interlocking plutons and is organized in a systematic way. Its constituent components may be defined as the pluton, the super-unit, and the batholithic segment.

The primary level is that of the pluton which may itself be internally zoned by pulses and surges of related magma. Chains of plutons of identical lithology and which have consistent intrusive relationships to other members of the batholith may be traced for hundreds of kilometres. These are referred to as the super-units. The batholithic segment consists of a very large area of the batholith which is comprised of a specific number of super-units. Five segments have been recognised but only two have been mapped in detail: the Lima segment 400 km long and the Arequipa segment 1000 km long.

The Lima segment is comprised of eleven units and super-units which are:

Pativilca	monzogranite	34 m.y.
Canas-Sayan	monzogranite	60 m.y.
Puscao	granodiorite–monzogranite	60 m.y.
San Jeronimo	monzogranite	60 m.y.
La Mina	tonalite	60 m.y.
Dyke Swarm	andesite	70 m.y.
Humaya	granodiorite	70 m.y.
Santa Rosa	tonalite–granodiorite	80–90 m.y.
Paccho	diorite–tonalite	95 m.y.
Jecuan	granodiorite	102 m.y
Patap	gabbro	102 m.y.

The Arequipa segment is comprised of five super-units as follows:

Tiabaya	tonalite–granodiorite	80 m.y.
Incahuasi	monzodiorite	95–80 m.y.
Pampahuasi	tonalite	95–80 m.y.
Linga	monzodiorite–granodiorite	97 m.y.
Patap	gabbro	102 m.y.

Magmatism lasted longer in the Lima segment than it did in the Arequipa segment. The

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younger members of the Lima segment are more acid and these also build the ring complexes which are confined to that segment.

The plutons of the Coastal Batholith are spatially associated with marine volcanics of Cretaceous and Jurassic age and a metallogenic belt of copper, molybdenum and gold is developed in the same zone.

A belt of scattered plutons of Tertiary age lies to the east of the batholith and is associated with post-orogenic plateau volcanics and also with the polymetallic metallogenic belt which produces copper, lead, zinc, silver and other metals.

INTRODUCTION

During the past 12 years a programme of systematic mapping has been undertaken in Peru by British geologists from the Institute of Geological Sciences and from the Liverpool University who were funded by the Overseas Development Administration and the Natural Environment Research Council, and Peruvian geologists of the Instituto Nacional de Geologia y Mineria of Peru. The objective was to delineate the Coastal Batholith in all its phases and to establish the relationship of the batholith to the volcanic and sedimentary belts which form the Western Cordillera of Peru. It was considered that the Peruvian Andes provided a type example of an orogenic belt which had developed at the plate boundary between a continent and a subducting ocean, and that if large scale patterns could be discerned from the apparently simple belt, they could serve as a guide to plate tectonic processes elsewhere.

GEOLOGICAL HISTORY

The Western Cordillera of Peru lies immediately to the west of a fold belt of Palaeozoic age which is known as the Eastern Cordillera. It is also flanked to the west in southern Peru by a terrain of basement gneiss of cratonic aspect for which an age of 2000 m.y. has been obtained (Lancelot et al., 1976; Cobbing et al., 1977; Shackleton et al., 1979). The orogenic belt has therefore developed in an ensialic environment at a continental margin.

The Western Cordillera itself is comprised of a belt of marine volcanic rocks which outcrop along the coast and which are of mainly andesitic composition though the compositional range is from basalt to rhyolite. These rocks, which comprise pillow lavas, lava flows and volcaniclastic sediments, were deposited in fault-bounded troughs which developed in a fractured basement, and their source was a chain of island volcanoes which developed on the outer edge of the continental margin, mainly in Cretaceous time. This volcanic belt or eugeosyncline (Cobbing, 1978) was flanked to the east by a sedimentary belt which also accumulated in interconnected fault-bounded troughs (Cobbing, 1978) and which was comprised principally of well-sorted clastics in the lower part of the sequence, and carbonates in the upper part. The volcanic and the sedimentary belt together form an eu-miogeosynclinal couple (Cobbing, 1976).

At the close of the Albian, open folding occurred in the eugeosynclinal belt, and early intrusives were emplaced along a well-defined batholith lineament. Subsequent intrusives continued to be emplaced along this lineament until the beginning of the Tertiary but while plutons were emplaced in the eugeosynclinal zone sedimentation continued in the miogeosynclinal zone (Cobbing, 1978).

During the early Tertiary a tectonic revolution took place, the Incaic orogeny of Steinmann (1929) which affected the whole of the Western Cordillera. The crust was thickened, the orogenic belt emerged and an erosion surface was formed upon which was deposited a thick sequence (2000–3000 m) of terrestrial volcanics between Eocene and Late Miocene times. Final uplift of the Andes followed and volcanicity continues in southern Peru to the present time.

These volcanics are of generally more acid composition than the marine Cretaceous volcanics and they are apparently associated with innumerable small stocks of granodioritic composition which are emplaced into the Tertiary volcanics and also into the folded Cretaceous sediments. It is with these small stocks that the polymetallic mineralisation of Peru is associated (Bellido and De Montreuil, 1972).

Composition of the Coastal Batholith: plutons, super-units, and batholithic segments

In the course of the systematic mapping it quickly became apparent that the Coastal Batholith is comprised of many separate plutons of varying size. As the interrelationships of these various plutons was gradually established it became clear that certain plutons were related in lithology and texture and that these plutons always displayed regular cross-cutting relationships to other groups of plutons which in their turn were also lithologically and texturally distinct. In this way it became possible to consider the rock types of related plutons as if they were lithostratigraphic units, and to map them on this basis. These lithostratigraphic units have been called super-units (Cobbing et al., 1977b).

As the work progressed a map was produced which displayed the outcrops of the superunits as overlapping and interlocking to form a heterogeneous batholith. With further work, however, it was found that each super-unit occupied a finite length of the batholith and that a particular segment of the latter would be comprised of a certain assemblage of super-units, while an

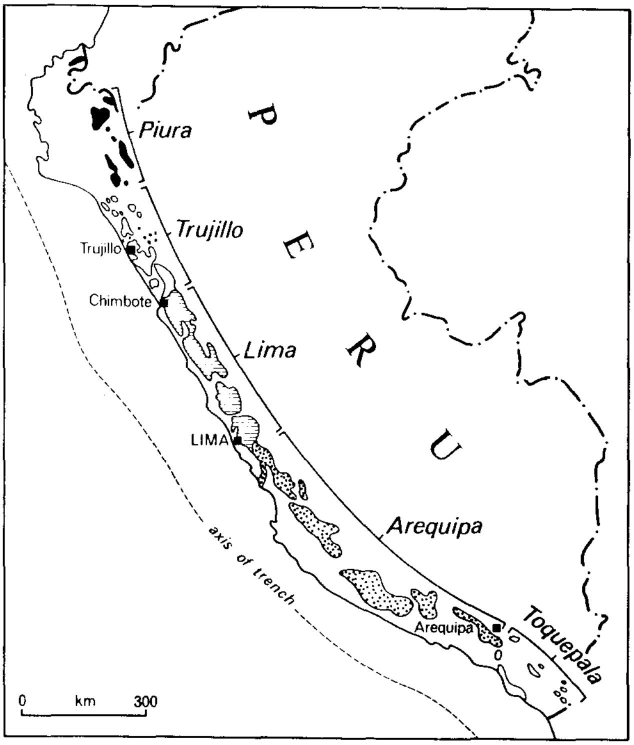

Fig. 1. The major segments of the Coastal Batholith of Peru.

adjacent segment would be characterised by another. This led to the concept of the Batholithic Segment (Cobbing et al., 1977b), in which separate segments of the Coastal Batholith are comprised of varying numbers of super-units which are specific to those parts of the batholith and nowhere else. Five batholithic segments have been recognised so far: the Piura segment of 250 km, the Trujillo segment of 250 km, the Lima segment of 400 km, the Arequipa of 1000 km, and the Toquepala segment of 200 km in length (Fig. 1). The Lima and the Arequipa segments are the best known and are comprised of seven and five super-units respectively.

It is now clear that the Coastal Batholith of Peru is organised in a systematic way and the component units may be considered as the pluton which is a primary structural element, the super-unit which is a lithological-magmatic element, and the batholithic segment which is a structural assemblage of super-units.

In this contribution the pluton and the super-unit will not be discussed in detail since they have been described elsewhere (Pitcher, 1978), but an attempt will be made to compare two of the main batholithic segments, and to discuss their development, as revealed by geochronology, in the context of the volcanic arc and the continental margin.

The geochronological study was undertaken at a time when the concept of super-units had been established but before the recognition of the batholithic segment. Moreover, the area of intrusives mapped is so large that the radiometric information available can only be of a preliminary nature in relationship to the batholith as a whole. However, the field mapping programme which established the super-unit concept also clearly distinguished individual plutons and their relative emplacement sequence, which served as a rigorous control for the collection of geochronological samples.

Up to the present the Lima segment has been investigated chiefly in the area of the Rio Huaura by Wilson (1975) who collected and analysed about 100 samples.

The Arequipa segment has not been so fully investigated, only the traverse of Rio Pisco has been studied in any detail by Moore (in preparation). Nevertheless, this data, together with that provided by Stewart et al. (1974) has corroborated the field classification of the intrusives. The ages assigned to the super-units in the following sections are preferred ages based on the work of Wilson (1975) and Moore (in preparation).

Two batholithic segments compared

As stated above, five batholithic segments have been recognised in the Coastal Batholith of Peru which are those of Piura Trujillo, Lima, Arequipa and Toquepala. Only the segments of Lima and Arequipa have been mapped for their entire length, and information on the other three segments is at present only of a rudimentary character. Nevertheless it is of interest to note that the porphyry copper deposits of Cerro Verde, Quellaveco, Cuajones and Toquepala are all associated with intrusives in the Toquepala segment.

The Lima segment. This batholithic segment is the best known and extends from Chimbote to Lima, a distance of 400 km. It is comprised of seven super-units which were emplaced over a time span of 70 m.y.

The Patap Gabbro was emplaced as a series of large plutons about 50 km long and 10 km broad along the west side of the batholith. Smaller remnants of early gabbros are also preserved over the entire width of the batholith. It is difficult to know the original extent of these remnants but they were probably much smaller than the main line of large gabbro plutons. The age of emplacement of these gabbros was probably about 100 m.y.

Following the gabbros and closely associated with them, the Jecuan granodiorite was emplaced as a chain of disconnected small plutons each of about 10 km in length down the west side of the batholith. A representative of this group the Atocongo monzogranite, has been dated by Stewart et al. (1974) at 102 m.y.

The next oldest member of the batholith in this segment is the Paccho super-unit which outcrops on the east side of the batholith and which is comprised chiefly of quartz-diorite and tonalite. It is emplaced as a discontinuous chain of plutons which may be up to 50 km in length but are generally rather smaller. These plutons are now preserved generally as remnants and they are in a somewhat altered condition. The age of this super-unit is about 95 m.y.

The Santa Rosa super-unit is the most important constituent of the segment and outcrops mainly along the western side of the batholith lineament. The age of the super-unit is 85–90 m.y.

Following the emplacement of the Santa Rosa a major dyke swarm was intruded with an age of 70 m.y. The dyke swarm, which also cuts the Humaya granodiorite of similar age, marks a clear break in the plutonic sequence: super-units which postdate the swarm are of more restricted importance and of generally more acid composition.

There is in fact a group of three super-units which were all emplaced at about the same time of 60 m.y. Although the radiometric ages are all similar, the field relationships are such that a relative order of emplacement can be established. It is also of interest that these three super-units all contribute to form three major ring complexes which are equidistant at 35 km down the centre line of the batholith.

The first of these super-units, La Mina, is comprised of tonalite and is presented as well-defined but rather widely separated, small plutons of 7–10 km diameter.

The Puscao super-unit which follows, ranges from tonalite to monzogranite in composition and is present as large, tabular plutons up to 15 km in length and 7 km broad which show good evidence of having differentiated in situ (Taylor, 1976).

The last of this series, the San Jeronimo super-unit is comprised of plutons of similar size which are composed almost entirely of monzogranite. Examples of all these super-units are to be found in the ring dykes of the ring complexes. It would appear that the ring complexes of the Lima segment are associated specifically with this group of 60 m.y. super-units for they do not occur in batholithic segments either to the north or to the south where super-units of this age are not present.

The last phase of intrusive activity within the Lima segment is provided by the coarse porphyritic monzogranites of Sayan and Pativilca. The Sayan pluton of 15 by 5 km occupies a large irregular area in the centre of the batholith around the Huaura ring complex. The Pativilca pluton on the other hand forms a large isolated pluton on the east side of the batholith which is 25 by 10 km in size. Whereas the Sayan pluton gives ages of 60 m.y. the Pativilca pluton gives ages of 34 m.y. This apparent discrepancy in age

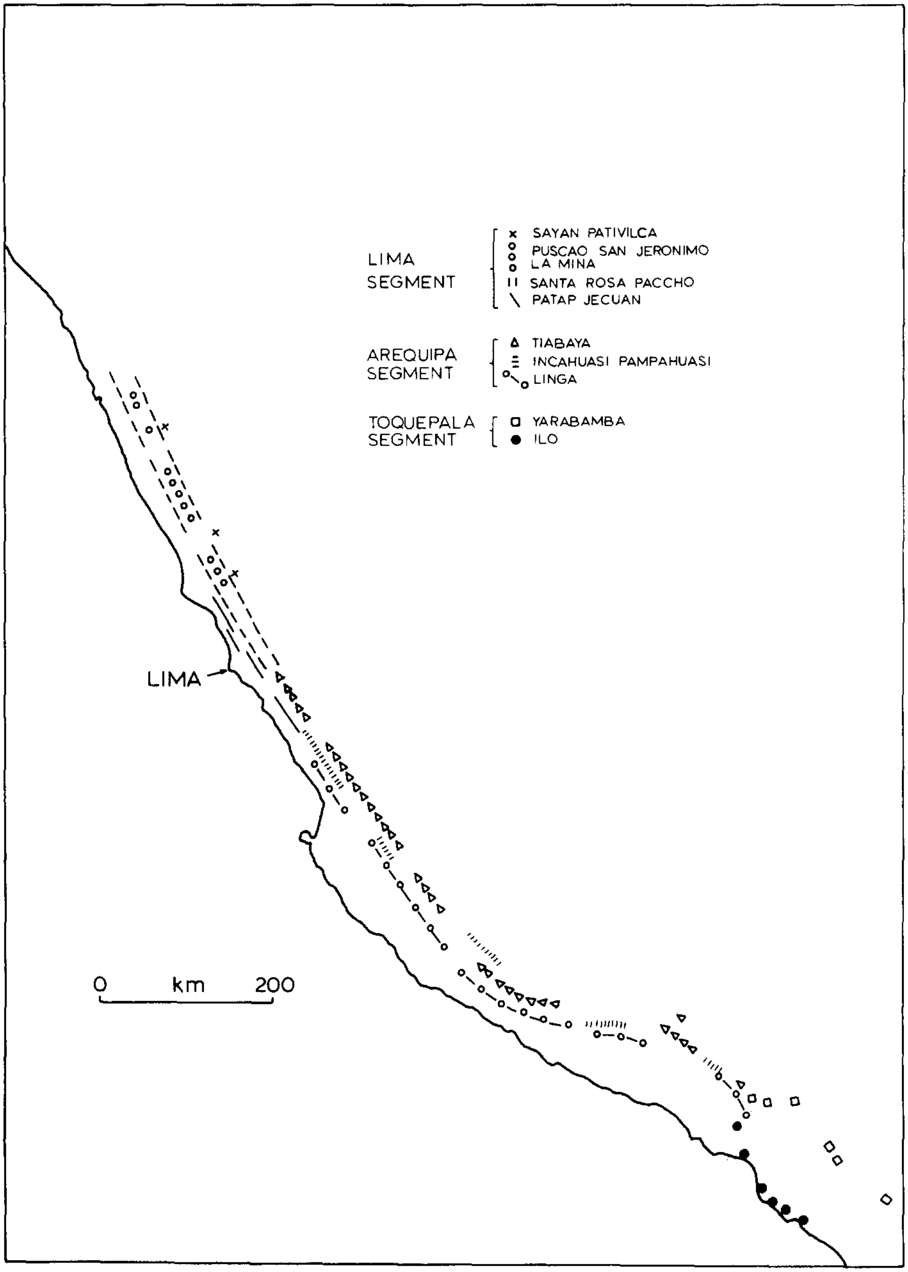

Fig. 2. The distribution of the super-units within the Lima, Arequipa and Toquepala segments.

between these two bodies leads to very serious problems which at present are being investigated by means of radioisotopes.

In summarising the Lima segment (Fig. 2) it may be said to be comprised of two main phases separated by a dyke swarm. The first phase of the Patap, Jecuan, Paccho and Santa Rosa, is comprised mainly of diorites and tonalites which occupy the full length of the segment. The second phase of La Mina, Puscao, San Jeronimo and Sayan-Pativilca is comprised principally of monzogranite which occupy only a restricted portion of the segment and which form the ring complexes which are peculiar to the Lima segment.

The Arequipa segment. This segment extends from Lima to Arequipa, is about 1000 km in length and is comprised of five super-units. The Patap gabbro is of similar age and lithology to the gabbros of the Lima segment but is emplaced as widely dispersed small plutons of which only small relics now remain.

The Linga super-unit is present as large complex plutons which outcrop all down the western side of the Arequipa segment. The compositional range is from monzodiorite to monzogranite. The Linga super-unit is actually very complex but can be divided into two broad groups, an early phase of large plutons comprised principally of monzodiorites which are cut by equally large plutons of more acid composition which range from monzotonalite to monzogranite. The age of two members of the Linga super-unit has been determined as 97 m.y. by Moore (personal communication).

The Pampahuasi super-unit consists of tonalites of rather distinctive aspect which are emplaced in medium sized plutons in restricted areas.

The Incahuasi super-unit which follows is of similar age but is comprised of large plutons which in some areas form the greater bulk of the batholith. The plutons tend to be very large, complex assemblages of pulses perhaps 100 km in length by 50 km broad, and within the plutons variation in lithology tends to be gradational rather than sharp. Potassium-argon ages for the Incahuasi and Pampahuasi super-units have been found to be between 95 and 80 m.y. (A. Moore, personal communication).

The most important member of the Arequipa segment is the Tiabaya super-unit, which outcrops over the entire length of the segment and displays cross-cutting relationships to all the preceding intrusives. It is a distinctive rock with well-developed prismatic hornblende and ranges in composition from diorite to monzogranite but is most commonly a granodiorite. Plutons are of all sizes and tend to be rather homogeneous, but zoned plutons are also present. They occur down the entire length of the segment and may occupy the full width of the batholithic lineament. Units of the Tiabaya super-unit have been dated at 81 m.y. by A. Moore (personal communication) who considers that the emplacement of this super-unit has been responsible for a wholesale resetting of potassium/argon ages in the Arequipa segment.

In comparing the Arequipa to the Lima segment it is clear that in both segments the bulk of the plutonism occurred between 104 and 80 m.y. but whereas in the Arequipa segment there was no further activity after this, in the Lima segment activity continued until 33 m.y. and was expressed in the form of (a) a major dyke swarm at 70 m.y., (b) monzogranitic super-units and ring structures at 60 m.y. and (c) porphyritic monzogranites at 33 m.y.

DISCUSSION

The work of Wilson (1975) also clearly distinguished plutonism of mainly Cretaceous to Lower Tertiary age, which occurred entirely within the batholithic lineament, from a phase of Tertiary plutonism of between 30 and 10 m.y. which was manifested as a spread of small, dispersed plutons of porphyritic dacite along the crest of the Western Cordillera. The plutonism of the batholith is spatially associated with marine volcanics of Jurassic and Cretaceous age whereas the Tertiary plutonism is associated with plateau volcanics of terrestrial origin, which were laid down upon an erosion surface produced by orogenic deformation, uplift, and erosion in Early Tertiary times. These two distinct pulses of plutonism with related volcanism are also related to the metallogenic belts. The belt of copper and gold mineralisation (Bellido and De Montreuil, 1972) corresponds to that of the mainly Cretaceous Coastal Batholith and its related marine volcanics, whereas the polymetallic belt of lead, zinc, silver, copper and other metals (Bellido and De Montreuil, 1972) corresponds spatially with the Tertiary plutonism and related terrestrial volcanics.

It is evident that the recognition of these two separated episodes of plutonism, volcanicity and metallogenesis has considerable implications for the development of a plate-tectonic model for the evolution of the Andean orogen in this sector of the Central Andes.

These two completely separate episodes are tectonically distinct even though they were produced in relation to the same process of subduction of oceanic crust at a continental plate edge.

The mainly Cretaceous Coastal Batholith and its associated marine volcanics may be regarded as the products of an essentially pre-orogenic volcanic arc constructed on thinned continental crust at the outer edge of the continent, whereas the Tertiary magmatism is entirely post-orogenic and was emplaced into thickened crust further inland. It is of interest to consider whether a similar pattern may be detected in other circum-Pacific regions. It may well be that different kinds of calc-alkaline magmatism and metallogenesis are related to different stages of the geotectonic cycle.

In the context of plate tectonics it is natural to look for the generation of the magmas in the subduction of oceanic crust beneath the continent, or in some process related to that subduction. Pitcher (1978) has suggested that initial Sr87/86 ratios for the rocks of Coastal Batholith as a whole are near to 0.704 which suggests a primitive origin for all of its magmas. Moreover, James et al. (1974) have found that initial ratios for Jurassic and Cretaceous volcanics are also of the order of 0.704.

At present no systematic isotopic work has been done on the Tertiary intrusives and only a little on the volcanics. Yet James et al. (1974) report that for the Late Tertiary volcanics of southern Peru initial ratios ranged from 0.706 to 0.7085. There would seem to be little doubt that these rocks were produced in a continental-margin situation related to the subduction of oceanic crust, yet the difference in isotopic composition may suggest that the source areas for the pre-Incaic orogenic magmas were different to those for the post-Incaic orogenic magmas. This is a problem which could well be investigated by isotopic methods and the results could also be of widespread application.

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