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Plate Tectonic Model for the Evolution of the Central Andes: Discussion

D. E. James (1971) presented a synthesis of the development of the Andean mountain belt which requires discussion in terms of the evidence presented and his approach. The evidence contains errors and inconsistencies. James's plate tectonic model may be partly correct, but the orogenic history of the Andes is different and more complex than his model. In particular, Paleozoic history is of greater importance in Andean evolution (Cecioni, 1970) than James implies. His approach seems to slight the possibility that pre-Mesozoic plate motions may be of significance in building the Andes.

PALEOZOIC HISTORY OF THE ALTIPLANO AND EASTERN CORDILLERA

James (the term "eastern cordillera" is used after James's usage and incorporates all of the ranges east of the altiplano, rather than the Cordillera Oriental alone, see Ahlfeld and Braniša, 1960, p. 13) implies that folding and faulting first occurred in Cretaceous through Miocene time and that the only tectonic or igneous activity during the Paleozoic "appears to have been gentle epeirogenic movements" (p. 3335). However, Newell and others (1953, p. 13) described block faulting in late Carboniferous time as evidenced by local absence of otherwise thick Carboniferous sections beneath Permian rocks. Audebaud and Laubacher (1969) described an intra-Hercynian angular unconformity in the Cordillera Oriental of Peru. Late Paleozoic igneous activity also took place. In southern Peru, tuff (Newell and others, 1953) and rhyolite (Braun, 1967) are found in upper Paleozoic rocks, and a thick Permian-Triassic volcanic unit, the Mitu Group (McLaughlin, 1924), is well known.

Lohmann (1970) presented evidence for the existence of an emergent tectonic land in the altiplano region of Bolivia during much of the Paleozoic era. Silurian granite unconformably overlain by mid-Silurian conglomerate is known from the extension of the altiplano in northwest Argentina (Turner, 1970). Harrington (1962) described Paleozoic orogenesis throughout the Andean belt. Therefore, during the Paleozoic era, igneous and deformational events occurred as far east as the altiplano and deformational events extended even farther east.

It should also be noted that Carboniferous marine deposits are not "rare or absent" in the central Andes as stated by James (1971). Newell and others (1953) described thick marine Carboniferous sections in Peru.

MESOZOIC HISTORY OF THE ALTIPLANO AND EASTERN CORDILLERA

James states that "no rocks of mid-Permian to mid-Cretaceous age are reported in the eastern cordillera" (p. 3336) and that "marine deposition in the eastern cordillera ended in mid-Permian time." In the altiplano and eastern cordillera of Bolivia, poorly dated (Lohmann, 1970) sedimentary rocks of Triassic and Jurassic age are locally present. Marine carbonate rocks of Aptian-Albian-Cenomanian ages ("a few thin marine limestone beds," James, p. 3337) are hundreds of meters thick in Bolivia (Lohmann, 1970).

Whether "no large-scale plutonism" has occurred in the eastern cordillera (James, 1971, p. 3326) is a matter of opinion concerning the structural level exposed to erosion. Outcrops of plutonic rocks in this region of Bolivia cover more than 1,000 km² (Servicio Geológico Bolivia, 1968).

Although James (p. 3341–3342) considered pre-Cretaceous Mesozoic deformation to be limited to the western cordillera, there is a regional angular unconformity at the base of the Cretaceous rocks in the eastern cordillera (Schlatter and Nederlof, 1969).

PALEOZOIC HISTORY OF THE WESTERN CORDILLERA

The Paleozoic history of the western cordillera (the term "western cordillera" is used

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after James's usage and incorporates all of the ranges between the altiplano and the Pacific Ocean), particularly the coastal cordillera, is a key to understanding the evolution of the Andean orogen. James noted the presence of pre-Mesozoic metamorphic rocks in this region and the difficulty of interpreting their significance (p. 3335, 3340), but he does not recognize their importance to crustal evolution in the Andes. A real question exists as to whether the earth's crust in the Andes consists largely of Mesozoic-Cenozoic igneous and sedimentary rocks or if it comprises mostly pre-Mesozoic rocks.

Much information is available on the pre-Mesozoic rocks, and evidence suggests skepticism regarding James's interpretation of Andean development. From Peru to southern Chile, igneous and metamorphic basement rocks crop out extensively the length of the coastal cordillera (Bellido and Narváez, 1960; Zeil, 1965; Miller, 1970). Many Paleozoic radiometric ages have been obtained from the basement rocks in central and southern Chile (Gonzáles-Bonorino and Aguirre, 1970). The basement rocks comprise a pre-Carboniferous and possibly Precambrian older igneous-metasedimentary complex (Miller, 1970), and an overlying sequence with a basal unconformity succeeded by Carboniferous and Permian sedimentary and acidic volcanic rocks (Guizado and Landa, 1964; Galli, 1968). These sequences are, in turn, unconformably overlain by Late Triassic to Jurassic and younger rocks, which are considerably less deformed and metamorphosed than the pre-Mesozoic rocks. Therefore, the geology of the western cordillera suggests that pre-Mesozoic history is of equal if not greater importance than Mesozoic-Cenozoic history in the formation of the Andes.

To interpret the above evidence, the western cordillera must have undergone orogenesis during medial Paleozoic or earlier time and become emergent prior to the Carboniferous. In late Paleozoic time, this orogen was transgressed, received marine sediments, and volcanism began. Climactic orogenesis followed in Permian-Triassic time. The present Andean orogen was developed upon this complex older tectonic edifice from Late Triassic time onward.

Thus, it is not true that "during Late-Triassic–Early Jurassic time an incipient volcanic arc developed in the *ocean* [my emphasis] west of the Paleozoic continental shelf" (James, p. 3336, 3342) because (1) there already was an arc by Permian time, (2) the arc developed on sialic crust which was in part emergent, and (3) the continental shelf may not have been a simple continental shelf in the tectonic sense. Moreover, the deformation of the western cordillera in pre-Jurassic time was more important than subsequent events (Zeil, 1965), and although strong post-Cretaceous thrusting and folding of the western cordillera are evident, there is some question that basement is involved (Szekely, 1969; Coney, 1971). It would therefore appear that an interpretation of Andean geology and crustal structure, largely in terms of Mesozoic-Cenozoic history (James, p. 3340–3343), may not be easily realized. The Andean belt is not one orogen, but several, which are superposed in time and space (Aubouin and Borrello, 1970).

"MODELS" OF ANDEAN OROGENIC BELT

It is misleading to look upon plate tectonics as a theory which has undergone "verification" (James, p. 3325) because the theory must be considered incomplete regarding orogenesis. The Andean orogenic belt as presented by James is no more a model of cordilleran mountain belts than are other models based essentially on speculative inference (for example, Dewey and Bird, 1970). Any orogenic belt that is marginal to a continent and has some volcanoes can simplistically be interpreted within a "plate tectonic model." The question is whether it is worthwhile to do so when unique and important aspects of geological history are omitted or de-emphasized. It would seem more fruitful to use geological evidence to test and improve the model.

Is the segment of the Andes under consideration a good "modern active analogue" (James, p. 3326) of cordilleran mountain belts? As James mentions (p. 3326), the central Andes are unusual; they display their maximum width in this segment and are split by the altiplano; and, they do not contain the typical facies assemblages of "normal cordilleran arcs" (James, p. 3343), including flysch. Another anomaly, in his view, is the widespread occurrence of basement rocks along the Pacific coast as already discussed. If there is a model cordilleran orogen, perhaps it is not or should not be a real mountain belt; rather, it is probably a simplified conceptual model. This model might be used to obscure as well as elucidate the history of mountain chains given the label. If the model and the geology of the mountain chain are opposed, the model should be modified or discarded.

James briefly considers (p. 3342–3344) such opposition of data and model for the Andes which he says poses questions, and this discussion has attempted to bring out these questions by considering the geological evidence. James's model does not appear to reflect this evidence. On the other hand, Miller (1971) proposed five models for Andean orogenesis, some of them involving plate tectonics, and all of which are tenable hypotheses incorporating the more problematical aspects of Andean geology.

James also consider the geosynclinal "model" and states, "it is clear that no depositional eugeosynclinal basin has ever existed" (p. 3343); yet he also states that "in northern Chile, volcanic and intercalated sedimentary rocks of Jurassic and Cretaceous age are as much as 15 km thick." A 7-km thickness of Cretaceous sediments in the altiplano is given (p. 3342). Great thicknesses of Tertiary sediments in the Chaco-Beni plains (eastern Andean foredeep) and in the Central Valley of Chile are well known. Therefore, various geosynclinal troughs have existed at different times and places in the Andes. The geosynclinal concept (Kay, 1951) is as applicable to the Andes as plate tectonic concepts.

CONCLUSIONS

James's plate tectonic model of the Andes appears to be an a priori conceptual model rather than a model developed or modified by critical synthesis of evidence. This approach is unsound because a good model survives hard testing. Geologists have traditionally employed the scientific method in an approach using multiple models, that is, multiple working hypotheses. I find it disturbing that James discards this approach, in particular by refusing to incorporate into his model a pre-Mesozoic component of Andean evolution which, in reviewing data of many workers, has been demonstrated to be exceedingly important.

Many geologists enthusiastically endorse plate tectonics and currently are applying this hypothesis to solving problems. This path of research has yielded great returns because of the strength of the plate tectonic hypothesis in the face of many strong geological and geophysical tests. However, it is neither a complete theory, nor one proposed primarily as an orogenic theory. The plate tectonic hypothesis must be expanded and developed to explain the accumulated observations of the major features of orogenic belts. In my opinion, an insightful approach to problems of orogenesis will involve bastardized model-building, by combining the best features of deductive plate tectonic models with the soundest inductive hypotheses derived from geological data in mountain belts.

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