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GEOLOGICAL PROCESSES AND ORCHID BIOGEOGRAPHY WITH APPLICATIONS TO SOUTHEAST CENTRAL AMERICA

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Introduction

This contribution owes its origins to a paper and presentation by Dr. Calloway H. Dodson at the Second International Conference on Neotropical Orchidology held in San José, Costa Rica in May of 2003 (Dodson 2003). Dr. Dodson outlined some of the reasons to suspect that regional geological factors may play important roles in orchid speciation and biogeography and gave examples from the northwestern South America. He also suggested that evolutionary change in orchid might occur over fairly short time periods, perhaps even as short as decades, centuries or millennia (Dodson 2003, SHK lecture notes).

These ideas stimulated the author, a professional earth scientist, to begin thinking about how these exciting ideas could begin to be tested in Costa Rica neighboring and Central American countries, an area that has drawn him to return frequently over the last decade. The present contribution is a proposal for integrating geological observations, such as the chronology of arc volcanic activity in Nicaragua, Costa Rica, and Panama, in hypothesis forming and testing of the geographic distribution of orchids (and possibly other biota). I initially focus on comparisons between orchid inventories on the windward slopes of mountainous regions (elevation > 1000 m) with high rainfall (> 1-2 m) in tropical regions, the so-called tropical cloud forests. These regions represent the *tropical pre-montane rain forest* to *lower montane tropical rain forest* life zones of Holdridge (1967) and the *montane* vegetation zone applied to Costa Rica and Panama by Dressler (1993). An important message of this paper is that such tropical mountainous regions are not necessarily static, but may change in elevation over geologic time due to active tectonic deformation and uplift and that the presence of active volcanism in a mountain range may also introduce additional chemical factors, such as volcanic gases, acid rain, and volcanic soils, and also physical factors, such as interruption of gene flow by explosive eruptions and coverage by their air fall products such as ash (tephra), lava flows, and lahars (volcanic mudflows). Thus over a given geological time interval, forests may be slowly increasing in elevation by tectonic uplift or by the accumulation of volcanic products such as steep-sided stratovolcanoes (built from both lavas and tephra), or by down-slope accumulations of lava flows or lahars. Mountains may also lose elevation by erosion or by tectonic subsidence. As we shall see, tropical Central America shows an extraordinarily high level of tectonic and volcanic history that has changed its geography and, by implication, climate, life zones, and likely orchid distribution. My working hypothesis put forward for testing is that orchid adaptations to these changes may have led to the development of new species and endemism in this region.

Geological Background

The region of southeast Central America (Nicaragua, Costa Rica and Panama) and NW Colombia is a center of profound geological changes during the late Cenozoic (Pliocene to present, 0-5 million years ago) (see excellent summaries in Denyer and Kussmaul 2000, Denyer *et al.* 2003). It is one of the most active tectonic regions of the world, being at the nexus of four major moving tectonic plates, the Cocos, Nazca, Caribbean, and South America, and three smaller microplates: the Coiba, Panama, and North Andean. As such, it abounds in geologically young mountain belts from Nicaragua to the northern Andes, active volcanic chains, and earthquakes and earthquake belts related to the motions of these plates.

Subduction of the Cocos plate under Central America is marked by the Middle America Trench off the Pacific coast that results from the down bending of the Cocos plate that subsequently descends at various angles under Central America from Mexico to western Panama. This descent produces an inclined zone of earthquakes that represent earthquake slip between the sinking Cocos Plate and the plates above (the North American and Caribbean plates) as well as internal seismic deformation in the Cocos plate. Subduction has also built a nearly continuous chain of active arc volcanoes from Mexico to SE Costa Rica that is thought to represent the effects of water released from the Cocos plate as it heats up during descent into hot mantle and induces melting in the hot mantle above the sinking plate (often termed a "slab").

In addition to the first-order deformation pattern associated with subduction, SE Central America displays clear evidence for internal deformation in the plates above the Cocos slab (Caribbean and Panama), deformation that builds tectonic mountains and has affected the history of seaways that segmented Central America in the recent geologic past. Finally, the Cocos plate is decorated by volcanic islands, seamounts, and the Cocos Volcanic Ridge that have been produced by the Galapagos Volcanic Hot Spot that also built the Galopagos Islands. The hot-spot islands, ridges, and plateaus built on the Cocos plate have been moving toward the Middle America Trench with time. These have collided or are colliding with the Central American Isthmus in Costa Rica and western Panama and some of these structures have accreted to the Isthmus (e.g., the Nicoya and Osa Peninsulas). Thus the geographic positions and elevation ranges of mountain belts have rapidly changed in this region over the last 5-10 million years and these changes undoubtedly have led to important changes in rainfall distributions and temperature and in the continuity of life zones. I now discuss the following potential implications of these regional plate-tectonic processes for the biogeography of SE Central America.

Geological Events Possibly Relevant to Orchid Science in the Region

Chief among important geological events that have accompanied these processes are:

1. The well known early Pliocene closing of the Panama Seaway and the subsequent rise of the Panamanian Cordillera from the seafloor and their effects on ocean circulation, weather, and faunal exchange across the Isthmus.
2. Less well known is the Holocene (since 10,000 years ago) opening and partial closing of the Nicaraguan Seaway, represented presently by the lowland from the Gulf of Fonseca, to Lakes Managua and Nicaragua and the San Juan River Valley. This lowland is thought by Costa Rican consulting geologist Roberto Protti (personal communication 2007) to have represented subsidence in a graben (a valley created by a fault-bounded down-dropped block) that was flooded by the sea.
3. The geologically recent migration toward the Middle American Trench of offshore volcanic islands (e.g., Cocos Island), flat-topped seamounts (former islands, such as the Fisher Seamount), and the Cocos volcanic ridge associated with volcanic processes at the Galapagos Hot Spot. Island speciation from continental forebears like that which has occurred the Galapagos Islands could possibly lead to reverse gene flow to continents as plate motion brings oceanic island crust close to the Middle America Trench. Subsequent collision of such terrains with Costa Rica (Caribbean plate) probably produced stresses and deformation in Costa Rica that raised tectonic mountain belts, such as the Talamanca cordillera.
4. The late Cenozoic rise of the Central Volcanic Range (CVR) in Costa Rica, one of the youngest arc volcanic mountain ranges in the world (largely in the Pleistocene to the present, 1.64 million years to the present) and hence its geologically recent effects on topography, rainfall distribution, air quality (from volcanic gases), and soil chemistries.
5. The late Tertiary (about 5 million years ago) cessation of volcanism in older, presently non-volcanic cordillera, such as the Talamanca, SW of the CVR and the Tilaran Cordillera, SE of the CVR.
6. The ongoing uplift of the Coast Ranges south of

the Talamanca and the non-volcanic Matama cordillera east of the CVR.

The above changes not only are potentially important in orchid gene flow, but also may influence through volcanic chemistry such processes as orchid mutagenesis, pollination, and germination. As such, their understanding may lead to useful hypotheses concerning orchid biogeography and to purposeful orchid surveys to test them.

The majority of the pristine forests of Costa Rica and Nicaragua have disappeared largely through deforestation. Conservation of the remaining orchid ecosystems is a critical requirement in order for such investigations of the origins of orchid biogeography to be successful. Orchid surveys directed to this particular end therefore should be purposeful. The ongoing multi-year survey of orchids at the Bosque de Paz Biological Reserve began in June of 2004 (See Kirby 2003, Muñoz and Kirby this volume). It is believed to be the first attempt at conducting a comprehensive survey of orchid species in the active Central Volcanic Range in Costa Rica above 1500 m elevation. I compare the identified species in the genera from this Survey that I feel are likely nearly complete after 2.6 years of monthly collection, description, and identification with those from Carpentera, Tapanti, San Ramón, and Monte Verde, all pre-montane to montane rain forest environments in Costa Rica.

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LITERATURE CITED

Denyer, P. & S. Kussmaul (eds). 2000. Geología de Costa Rica. ISBN 9977-66-118-9. Editorial Technologica de Costa Rica. 515 p.

Denyer, P., W. Montero & G.E. Alvarado. 2003. Atlas Tectónico de Costa Rica. Universidad de Costa Rica, San José, CR. Serie Reportes técnicos. 81 p.

Dodson, C.H. 2003. Why are there so many orchid species?. I^{er} Congreso International de Orquideología Neotropical, 20-25 Mayo, 2003, Proceedings Issue in Lankesteriana 7: 99-103.

Dressler, R.L. 1993. Field Guide to the Orchids of Costa Rica and Panama. Cornell University. New York. 374 p.

Holdridge, L. 1967. Life Zone Ecology. Tropical Science Center, Costa Rica. 89 p.

Kirby, S.H. 2003. Neotropical orchid ecotourism: Educational experience of an orchid neophyte at the Bosque de Paz Biological Reserve, Central Volcanic Range, Costa Rica, I^{er} Congreso International de Orquideología Neotropical, 20-25 Mayo, 2003, Proceedings Issue *in* Lankesteriana 7: 121-124.

Muñoz, M. & S. H. Kirby. 2007. An orchid inventory and conservation project at Bosque de Paz Biological Reserve, Upper Rio Toro Valley, Alajuela, Costa Rica, Proceedings of the 3rd International Orchid Conservation Conference *in* Lankesteriana (this issue)

Ossenbach, C., F. Pupulin & R.L. Dressler. 2007. Orchids of the Central American Isthmus: Checklist and conservation status. Unpublished.

Protti, R. 2007. Posible interrupción parcial del paso terrestre en Centroamérica durante la transgresión Flandriense (Holoceno medio). Personal communication.

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